



11th INTERNATIONAL CONFERENCE
ON HIGH-POWER ELECTROMAGNETICS:

EUROEM'98

TEL AVIV, ISRAEL, JUNE 14 - 19, 1998

Program and Abstracts

Home Page: <http://physics.technion.ac.il/~peter/euroem98.html>

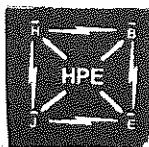


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Dear Colleague,

We welcome you to the 11th International Conference on High-Power Electromagnetics: Euroem'98. It is a great pleasure for us to host the Euroem'98 Conference in Tel Aviv during the 50th anniversary of the State of Israel.

The scientific program follows the tradition of the previous Euroem and Amerem meetings, encompassing the subjects of EMP, High Power Microwave (HPM), Ultra Wide Band (UWB) and Unexploded Ordnance Detection and Range Remediation (UXO). We have more than 250 abstracts and we expect worldwide participation from more than 15 countries.

Israel provides many tourist attractions, ancient and modern. On Tuesday afternoon we plan to participate in a tour of Jerusalem and the Israel Museum, followed by an outdoor reception in the mountains of Jerusalem.

The farewell banquet on Thursday will take place in the ancient city of Jaffa and our guest speaker will be Major General Matan Vilnai. In addition we will have the new EMP fellows award ceremony, a tradition of the Euroem/Amerem Conferences.

We wish all of you a rewarding scientific meeting and an exciting time during your stay in Israel.

Sincerely

Joseph Shiloh
Conference Chairman

Benjamin Mandelbaum
Conference Co-Chairman

CONFERENCE CHAIRMAN

Joseph Shiloh Rafael, Israel

CONFERENCE CO-CHAIRMAN

Benjamin Mandelbaum Rafael, Israel

USP COORDINATOR

Ehud Heyman Tel Aviv University, Israel

UXO COORDINATOR

Andrew Hooper US Army Yuma Proving Ground, USA

TECHNICAL / PROGRAM COMMITTEE**HPEM/NEM - High Power Electromagnetics/Nuclear EMP:**

C. Baum USAF Phillips Laboratory, USA
J. Benford Microwave Sciences, USA
J.P. Castillo Logicon RDA, USA
V. Fortov Academy of Sciences, Russia
R.L. Gardner USAF, USA
J.C. Giles Los Alamos National Laboratory, USA
D. Giri Protech, USA
S.H. Gurbaxani University of New Mexico, USA
M. Ianoz Federal Institute of Technology, Switzerland
E. Joffe KTM Project Eng., Israel
C.W. Jones Metatech Corp., USA
A.W. Kaelin AC-Zentrum, Switzerland
T. Karlsson Emicon, Sweden
S. Kashyap Defense Research Establishment, Canada
K. D. Leuthauser Fraunhofer Institut INT, Germany
L. Libelo Army Research Laboratory, USA
V.M. Loborev Central Institute of Physics & Technology, Russia
K.G. Lovstrand FMV, Sweden
J. Ma Pierre Defense Special Weapons Agency, USA
G. Mesyats Academy of Sciences, Russia
J. Nitsch Otto-Von-Guericke University, Germany
W. D. Prather USAF Phillips Laboratory, USA
D. Price Maxwell Physics International, USA
W.A. Radasky Metatech Corp., USA
D. Serafin Centre d'Etudes de Gramat, France
L. Shachter Technion - I.T.T., Israel
J. Shiloh Rafael, Israel
R. White Maxwell Technologies Inc., USA
M. Wik FMV, Sweden

UWB,SP4 - Ultra Wide Band, Short Pulse:

A. Boag Israel Aircraft Industries, Israel
W. Boerner University of Illinois, USA
L. Carin Duke University, USA
S.R. Cloude Applied Electromagnetics, UK
E. Heyman Tel Aviv University, Israel
R. Kastner Tel Aviv University, Israel
R. Kleinman University of Delaware, USA
P. Smith University of Dundee, UK
A.P. Stone University of New Mexico, USA
A. Tijhuis Eindhoven University of Technology, The Netherlands
A.P.M. Zwamborn TNO-FEL, The Netherlands

UXO - Unexploded Ordnance Detection and Range Remediations:

T.W. Altshuler	Institute for Defense Analyses, USA
K. Casey	Stanford Research Institute, USA
R. Dugan	Defense Advanced Research Projects Agency, USA
J. Foley	Sanford Cohen & Associates, USA
C. E. Garcia	Los Alamos National Laboratory, USA
V. George	Walcoff and Associates, USA
A. Hooper	U.S. Army Yuma Proving Ground, USA
Z. Hovav	Soreq Nuclear Research Center, Israel
Y. Kanayama	Naval Postgraduate School, USA
I. Kohlberg	Kohlberg Associates Inc., USA
M. Kolodny	Army Research Laboratory, USA
R. Lewis	U.S. Army Corps of Engineers, WES, USA
X. Maruyama	Naval Postgraduate School, USA
G. Olhoeft	Colorado School of Mines, USA
L. Smith	U.S. Army Yuma Proving Ground, USA

LOCAL STEERING COMMITTEE

S. Diamant	Applied Materials (Israel) Ltd.
S. Eckhouse	ESC Medical Systems, Israel
J. Felsteiner	Technion - I.T.T., Israel
C. Goldstein	Rafael, Israel
D. Gordon	Ministry of Defense, Israel
A. Gover	Tel Aviv University, Israel
O. Hartal	Rafael, Israel
D. Havazelet	NNRC, Israel
Y. Krasik	Technion - I.T.T., Israel
B. Mandelbaum	Rafael, Israel
M. Markovits	Rafael, Israel
E. Milstein	Rafael, Israel
D. Parkes	Defense Research Agency, UK
W. Peter	FM Technologies, USA
A. Sternlieb	Ministry of Defense, Israel
A. Zigler	The Hebrew University of Jerusalem, Israel
D. Zimra	Ministry of Defense, Israel

SOCIAL EVENTS

SUNDAY, JUNE 14, 1998

20:00 GET TOGETHER RECEPTION

At the Dan Panorama Tel Aviv Hotel and Convention Center.

TUESDAY, JUNE 16, 1998

19:30 VISIT OF THE ISRAEL MUSEUM, Jerusalem

Depart Tel Aviv for a short guided tour of Jerusalem and a tour of the Israel Museum followed by an outdoor reception.

Buses will Depart the Dan Panorama Tel Aviv Hotel and Convention Center at 16:00.

THURSDAY, JUNE 18, 1998

20:00 FAREWELL BANQUET

At "The Loft" - formerly used as the main warehouse for Jaffa oranges awaiting export. During the 1956 Sinai Campaign, Sherman Tanks were stored in the building.

Master of Ceremony: J. Shiloh

Guest Speaker: Major General Matan Vilnai

Conference Greetings and Summary

- on behalf of UWB,SP: E. Heyman

- on behalf of UXO: A. Hooper

Invitation to EUROEM 2000 in England: D. Parkes

Best Paper Award: W. Radasky

New EMP Fellows Award Ceremony: J.L. Gilbert and K.D. Lenthauser

Buses will Depart the Dan Panorama Tel Aviv Hotel and Convention Center at 19:30, the Metropolitan Hotel at 19:15.

GENERAL INFORMATION

LOCATION

Conference sessions will take place at the Dan Panorama Tel Aviv Hotel and Convention Center.
10 Kaufman Street, PO Box 50252, Tel Aviv, 68012
Tel +972 3 519 0190; Fax: +972 3 517 1777

REGISTRATION / INFORMATION / HOSPITALITY / SECRETARIAT

A registration and information desk will operate at the Conference venue as follows:
Sunday, June 14, 1998, from 17:00 - 20:30
Monday, June 15, 1998 - Friday, June 19, 1998, from 08:00 throughout session hours

BADGES

Upon registering you received your Conference kit, which includes your name badge. You are requested to wear your name badge during all Conference sessions and events.

MAIL / MESSAGES / LOST AND FOUND / MEDICAL ASSISTANCE

Please apply to the Information Desk for assistance.

PROJECTION

Speakers are requested to notify the Information Desk of their audio-visual requirements, other than standard viewgraph projector, 24 hours prior to their presentation.

POSTER DISPLAY

Presenters should be available alongside their posters during the poster session, Tuesday, June 16, 1998. Posters should be mounted by 08:30 and should be removed at the end of the sessions.

SHOPPING HOURS

Department stores are usually open from 08:00 to 19:30. Small stores close for lunch from 13:00 to 16:00. Stores close on Friday at 14:00 and remain closed on Saturday.

TRAVEL AND ACCOMMODATION

Kenes Tours will operate a desk during the Conference. Participants requiring additional hotel accommodation in Israel, tours by motor coach or by chauffeured limousine, domestic flights, car rental, etc., should apply to this desk at their earliest convenience. Payment for any of these services can be made in travelers cheques, Eurocheques, foreign currency or major credit cards. Payment in local currency is subject to 17% VAT.

WORKING LUNCHEONS

UWB-SP Committee - Monday, June 15, 1998
UXO Committee - Wednesday, June 17, 1998
HPEM Committee - Thursday, June 18, 1998

Luncheons will be held at the "Alon" room during the lunch breaks as indicated in the scientific program.

PROCEEDINGS FOR UWB,SP4

Authors are requested to submit their manuscripts for inclusion in the Proceedings, at the Registration Desk from Monday, June 15, 1998 at 11:00 and prior to the conclusion of the Conference on Friday, June 19, 1998.

FLIGHT RECONFIRMATION

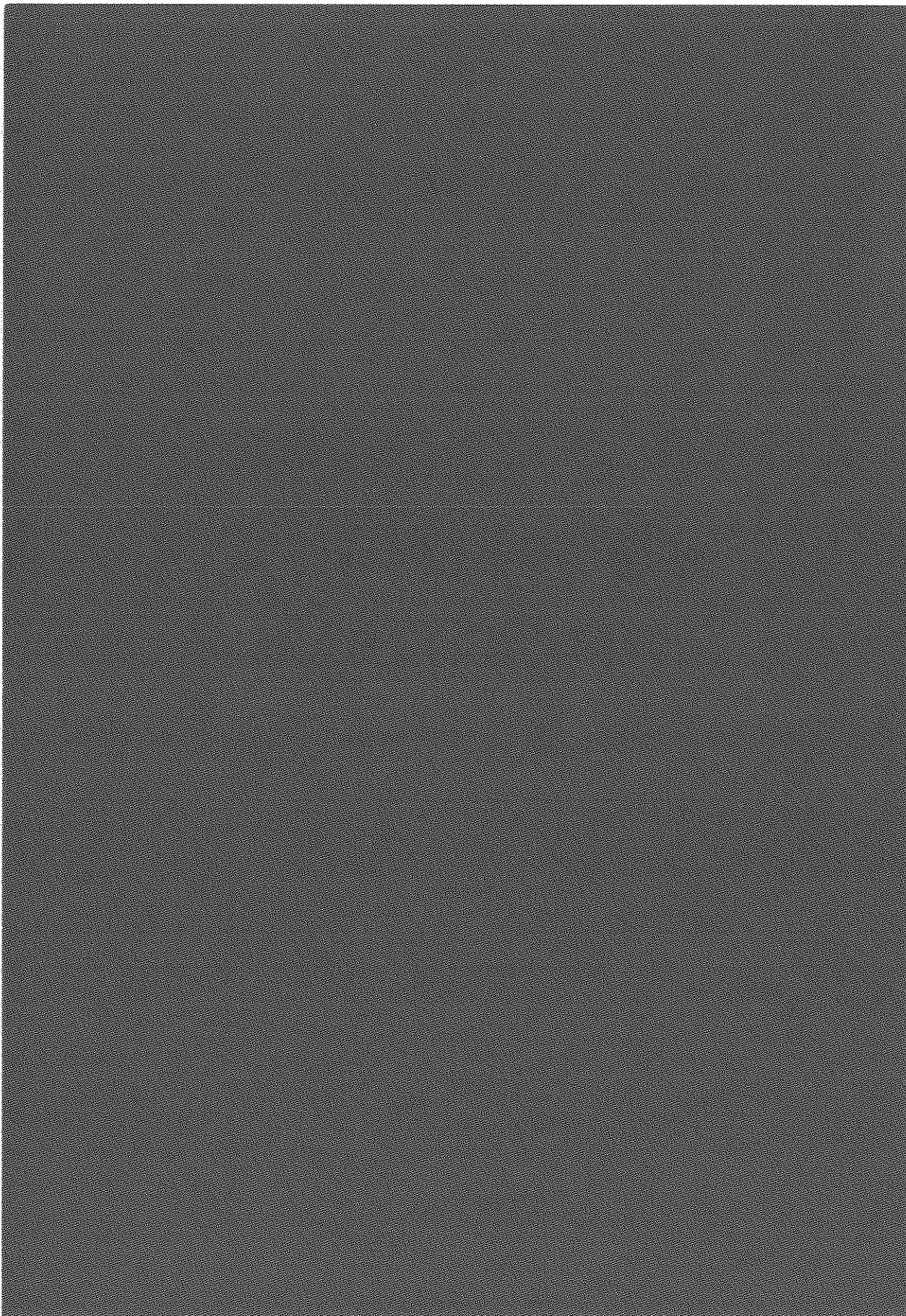
Participants flying EL AL Israel Airlines are requested to reconfirm their return flight at the Kenes Hospitality Desk no later than Wednesday, June 17, 1998.
Participants flying other airlines are requested to reconfirm their return flight directly with the respective Airline.

PROGRAM AT A GLANCE

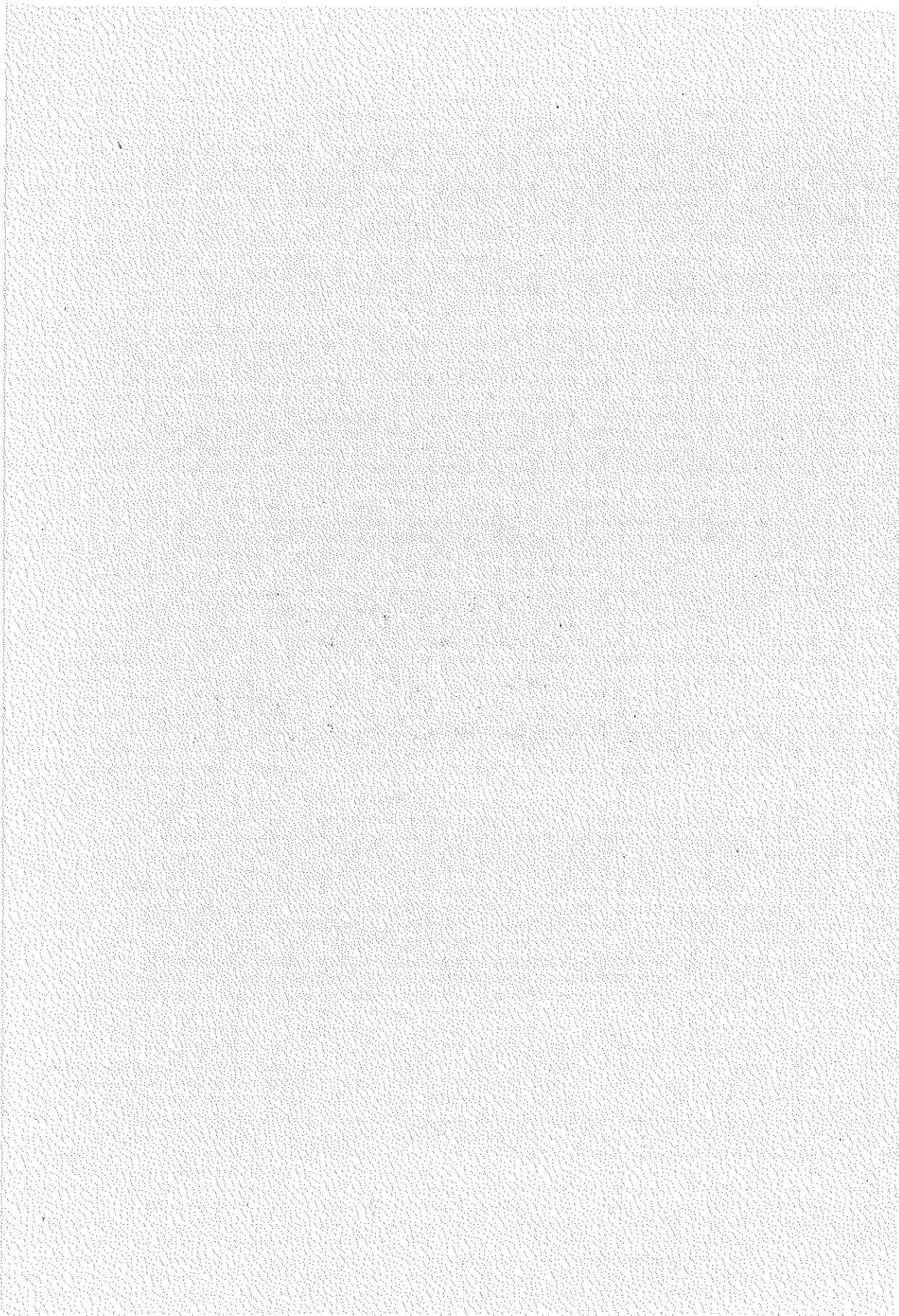
SUNDAY June 14, 1998	MONDAY June 15, 1998				TUESDAY June 16, 1998			
	HALL A 08:30-10:10 HPEM-2: LIGHTNING	HALL B 08:30 - 10:10 HPEM-3: HPM SOURCES-1	HALL D 08:30 - 10:10 HPEM-4: INTERACTION II	HALL C 08:30 - 10:10 USP-2: ANTENNAS 2: SYSTEMS	HALL D 08:30 - 10:10 HPEM-7: SYSTEM TESTING	HALL A 08:30 - 10:10 HPEM-8&9: SIMULATORS & ANTENNAS	HALL B 08:30 - 10:10 USP-3: TARGET IDENTIFICATION	HALL C 08:30 - 10:10 USP-4: ULTRA FAST SWITCHING
	10:10 - 10:40 COFFEE BREAK				10:10 - 10:40 COFFEE BREAK			
	HALL A 10:40-12:40 HPEM-2: LIGHTNING (Cont'd)	HALL B 10:40 - 13:00 HPEM-3: HPM SOURCES-1 (Cont'd)		HALL C 10:40 - 12:20 USP-2: ANTENNAS 2: SYSTEMS (Cont'd)		HALL A 10:40 - 12:00 HPEM-8&9: SIMULATORS & ANTENNAS (Cont'd)	HALL B 10:40 - 12:40 USP-3: TARGET IDENTIFICATION (Cont'd)	HALL C 10:40 - 11:20 USP-4: ULTRA FAST SWITCHING (Cont'd)
	13:00-14:00 LUNCH BREAK				12:40-14:00 LUNCH BREAK		12:00 - 15:30	
	HALL A 14:00-15:40 HPEM-1: HPEM INERACTION -1	HALL B 14:00 - 15:40 HPEM-5: HPM SOURCES-2 & 3	HALL D 14:00 - 15:40 HPEM-6: APPLICATIONS	HALL C 14:00 -15:40 USP-1: ANTENNAS-1: BASICS	HALL A 14:00-15:30 PANEL DISCUSSION-1: UWB/SP	HALL B 14:00 - 15:30 PANEL DISCUSSION-2: HPM - SOURCES	FOYER POSTER SESSION	
	15:40 - 16:10 COFFEE BREAK							
17:00 REGISTRATION	HALL A 16:10-17:50 HPEM-1: HPEM INERACTION -1 (Cont'd)	HALL B 16:10 - 17:50 HPEM-5: HPM SOURCES-2 & 3 (Cont'd)	HALL D 16:10 - 17:10 HPEM-6: APPLICATIONS (Cont'd)	HALL C 16:10 - 17:10 USP-1: ANTENNAS-1: BASICS (Cont'd)				
20:00 GET TOGETHER RECEPTION					16:00 VISIT OF THE ISRAEL MUSEUM			

WEDNESDAY June 17, 1998				THURSDAY June 18, 1998				FRIDAY June 19, 1998	
HALL A 08:30-10:30 PLENARY SESSION				HALL C 08:30-10:10 HPEM-14: MULTI- CONDUCTOR CABLES & EM TOPOLOGY	HALL A 08:30 - 10:10 HPEM-18: GENERATION & PROPAGATION OF EM FIELDS	HALL D 08:30 - 10:10 USP-6 & UXO-2: PROPAGATION IN MEDIA	HALL B 08:30 - 10:10 UXO-3: MAGNETIC DETECTION AND IDENTIFICATION	HALL A 08:30-10:00 PANEL DISCUSSION-3: EM TERRORISM	HALL B 08:30 - 10:00 PANEL DISCUSSION-4: EM INTERACTION
10:30 - 11:00 COFFEE BREAK				10:10 - 10:40 COFFEE BREAK				10:00 - 10:30 COFFEE BREAK	
HALL A 11:00-12:30 PLENARY SESSION (Cont'd)				HALL C 10:40-11:40 HPEM-14: MULTI- CONDUCTOR CABLES & EM TOPOLOGY (Cont'd)	HALL A 10:40 - 12:00 HPEM-18: GENERATION & PROPAGATION OF EM FIELDS (Cont'd)	HALL D 10:40 - 11:40 USP-6 & UXO-2: PROPAGATION IN MEDIA (Cont'd)	HALL B 10:40 - 12:00 UXO-3: MAGNETIC DETECTION AND IDENTIFICATION (Cont'd)	HALL A 10:30-12:00 PANEL DISCUSSION-5: UXO- UNEXPLODED ORDNANCE	HALL B 10:30 - 12:00 PANEL DISCUSSION-6: HPE ENVIRON- MENTS & STANDARDS
12:30-14:00 LUNCH BREAK				12:00-14:00 LUNCH BREAK					
HALL A 14:00-15:40 HPEM-10: HPE ENVIRONMENTS & STANDARDS	HALL C 14:00 - 15:40 HPEM-11: SENSORS & DIAGNOSTICS	HALL D 14:00 - 15:40 HPEM-13: PULSED POWER	HALL B 14:00 - 15:40 USP-5 & UXO-1: SCATTERING THEORY OF BURIED TARGETS	HALL A 14:00-15:40 HPEM-17: EFFECT ON AIRCRAFTS	HALL B 14:00 - 15:40 HPEM-20: BIOLOGICAL EFFECTS	HALL C 14:00 - 15:40 HPEM-21: EFFECTS ON COMPONENTS	HALL D 14:00 - 15:40 UXO-4: REQUIREMENTS & TECHNOLOGY		
15:40-16:10 COFFEE BREAK				15:40 - 16:10 COFFEE BREAK					
HALL A 16:10-17:10 HPEM-10: HPE ENVIRONMENTS & STANDARDS	HALL C 16:10 - 17:30 HPEM-11: SENSORS & DIAGNOSTICS (Cont'd)		HALL B 16:10 - 17:30 USP-5 & UXO-1: SCATTERING THEORY OF BURIED TARGETS	HALL A 16:10-16:50 HPEM-17: EFFECT ON AIRCRAFTS (Cont'd)	HALL B 16:10 - 17:50 HPEM-19: EM COMPUT- ATION	HALL C 16:10 - 17:30 HPEM-21: EFFECTS ON COMPONENTS (Cont'd)	HALL D 16:10 - 17:50 UXO-5: CHARAC- TERIZATION OF SOILS		
				20:00 FARWELL BANQUET					

SCIENTIFIC PROGRAM



**MONDAY,
JUNE 15, 1998**



MONDAY, JUNE 15, 1998

08:30 - 12:40

HALL A

HPEM-2: LIGHTNING

Chairpersons: M. Ianoz, Switzerland
F.M. Tesche, USA

Abstract page

08:30	A NONLINEAR TRANSMISSION LINE MODEL FOR LIGHTNING R.L. Gardner, Envisioneering Inc., Fairfax VA, USA	1
08:50	EXPERIMENTAL MEASUREMENTS AND CALCULATIONS OF LIGHTNING-INDUCED CURRENTS ON SHORT OVERHEAD LINES F. Rachidi, Swiss Federal Institute of Technology, Lausanne, Switzerland, & University of Toronto, Toronto, Canada, P. Zwejacker, M. Ianoz, Swiss Federal Institute of Technology, Lausanne, M. Rubinstein, Swisscom, Bern, Switzerland, B. Braendli, A.W. Kaelin, DPA, Swiss NEMP Laboratory, Spiez, Switzerland	2
09:10	LIGHTNING EFFECTS ON A METALLIC BURIED CONNECTION BETWEEN TWO SHIELDED BUILDINGS F.M. Tesche, EMC Consultant, Dallas TX, USA, A.W. Kaelin, B. Braendli, B. Reusser, DPA, Swiss NEMP Laboratory, Spiez, Switzerland, M. Ianoz, D. Tabara, P. Zwejacker, Swiss Federal Institute of Technology, Lausanne, Switzerland	3
09:30	HIGH FREQUENCY RADIATION FROM A ZIGZAG LIGHTNING DISCHARGE CHANNEL V.M. Fedorov, V.P. Tarakanov, High Energy Density Research Centre of RAS, IVTAN, Moscow, Russia	4
09:50	TRANSIENTS ON OVERHEAD TRANSMISSION LINES PRODUCED BY INDIRECT LIGHTNING STROKES F. Schlagenhauer, EMCSI Pty. Ltd., North Melbourne, Victoria, Australia	5
10:10	Coffee Break	
10:40	CHARACTERIZATION AND SIMULATION OF LIGHTNING M.V. Kostenko, St. Petersburg State Technical University, St. Petersburg, Russia	6
11:00	BRANCHING MODELING AND EFFECTS ON RETURN-STROKE FIELDS R.E. Zich, G. Vecchi, F.C. Canavero, Politecnico, Torino, Italy	7
11:20	MCG-BASED SYSTEM FOR SIMULATION OF LIGHTNING E.V. Chernykh, V.E. Fortov, K.V. Gorbachev, I.P. Kouzhekin, E.V. Nesterov, V.A. Stroganov, I.O. Zolotikh, Russian Academy of Sciences, Moscow, Russia	8
11:40	OPTIMIZATION OF COMPONENTS OF MCG-BASED LIGHTNING SIMULATOR E.V. Chernykh, V.E. Fortov, K.V. Gorbachev, Y.V. Karpushin, I.P. Kouzhekin, E.F. Lebedev, E.V. Nesterov, A.V. Shurupov, V.A. Stroganov, Russian Academy of Sciences, Moscow, Russia	9
12:00	SPACE-TIME BEHAVIOUR OF THE ELECTRIC FIELD INTENSITY CREATED BY "LIGHTNING" DISCHARGE N.I. Petrov, High-Voltage Research Center of All-Russian Electrotechnical Institute, Istra Moscow Region, Russia	10
12:20	DETERMINATION OF LIGHTNING PARAMETERS FROM THE MEASUREMENTS OF STATISTICAL CHARACTERISTICS OF ELECTROMAGNETIC FIELD N.I. Petrov, High-Voltage Research Center of All-Russian Electrotechnical Institute, Istra Moscow Region, Russia	11
13:00	Lunch Break	

MONDAY, JUNE 15, 1998

08:30 - 13:00

HALL B

HPEM-3: HPM SOURCES-1

Chairpersons: D.J. Serafin, France
D. Price, USA

Abstract page

08:30	RELATIVISTIC MICROWAVE ELECTRONICS IN RUSSIAN FEDERAL NUCLEAR CENTER - VNIIEF. RESEARCHES, ACHIEVEMENTS, PERSPECTIVES V.D. Selemir, A.E. Dubinov, S.L. Voronov, N.V. Stepanov, I.V. Kononov, V.G. Kornilov, B.G. Ptitsin, RFNC-VNIIEF, Sarov, Russia	12
08:50	A REVIEW OF RECENT PROGRESS IN RELTRON TUBE DESIGN R.B. Miller, Titan Advanced Innovative Technologies, Albuquerque NM, USA	13
09:10	EXPLOSIVELY DRIVEN HIGH CURRENT ELECTRON ACCELERATORS AND HIGH-POWER MICROWAVES SOURCES A.N. Didenko, V.E. Fortov, Russia Academy of Sciences, Moscow, Russia, V.B. Mintsev, Institute of Chemical Physics in Chernogolovka, Chernogolovka, Russia	14
09:30	GENERAL SCALING OF PULSE SHORTENING IN EXPLOSIVE-EMISSION-DRIVEN MICROWAVE SOURCES D. Price, PRIMEX Physics International, San Leandro CA, J. Benford, Microwave Sciences, Lafayette CA, USA	15
09:50	PLASMA FILLED RADIAL ACCELERON M.J. Arman, Air Force Research Laboratory, Kirtland AFB NM, USA	16
10:10	Coffee Break	
10:40	HPM-RESEARCH PROGRAM-GERMAN FORCE K. Ruffing, WTD 81-Competence Center, Greeding, Germany	17
11:00	RELATIVISTIC MAGNETRON WITH DIFFRACTION OUTPUT M.I. Fuchs, N.F. Kovalev, Russian Academy of Science, Nizhny Novgorod, Russia	18
11:20	HIGH-TO-LOW FREQUENCY CONVERSION IN NONLINEAR CIRCUITS - SOME EXACT RESULTS W. Ochs, Fraunhofer INT, Euskirchen, Germany	19
11:40	NUMERICAL SIMULATION AND EXPERIMENTAL INVESTIGATIONS OF BEAM-PLASMA PROCESSES IN VARIOUS GAS-FILLED ELECTRODYNAMICAL STRUCTURES OF MICROWAVE TUBES V.I. Perevodchikov, M.A. Zavjalov, All-Russian Electrotechnical Institute, Moscow, A.N. Didenko, A.S. Roshal, Moscow Engineering Physics Institute, Moscow, Russia	20
12:00	POWERFUL WIDEBAND AMPLIFIERS AND GENERATORS ON THE BASIS OF PLASMA-BEAM INTERACTION V.I. Perevodchikov, M.A. Zavjalov, L.A. Mitin, A. Chapiro, All-Russian Electrotechnical Institute (VEI), Moscow, Russia	21
12:20	LOWERED PLASMA VELOCITY WITH CESIUM IODIDE/CARBON FIBER CATHODES AT HIGH ELECTRIC FIELDS J. Benford, Microwave Sciences Inc, Lafayette CA, USA, D. Price, W. DeHope, Primex Physics International, San Leandro CA, USA	22
12:40	PHASE AND FREQUENCY CONTROL OF OUTPUT RADIATION IN SOURCES OF POWERFUL MICROWAVES E. Abubakirov, M. Fuchs, N. Kolganov, N.F. Kovalev, A. Savelyev, Institute of Applied Physics, Nizhny Novgorod, Russia	23
13:00	Lunch Break	

MONDAY, JUNE 15, 1998

08:30 - 10:10

HALL D

HPEM-4: INTERACTION II

Chairpersons: V. Demidov, Russia

Abstract page

08:30	HPM PENETRATION TO CIRCUIT WIRES M. Merzer, RAFAEL, Haifa, Israel	24
08:50	MICROWAVE COUPLING TO EQUIPMENT: THE DIRECTIONAL DEPENDENCE AND ITS IMPACT ON SUSCEPTIBILITY TESTING M. Backstrom, J. Loren, O. Lunden, L. Jansson, FOA Defence Research Establishment, Linkoping, Sweden	25
09:10	RISK OF INTERFERENCE TO AIRCRAFT FROM VSAT AND SNG TERMINALS R.J. Zielinski, Wroclaw University of Technology, Wroclaw, Poland	26
09:30	PENETRATION OF MICROWAVES INTO A METALLIC CYLINDER WITH A SLIT C. Steukers, E. Schweicher, Royal Military Academy, OMRA, Brussels, Belgium	27
10:10	Coffee Break	

MONDAY, JUNE 15, 1998

08:30 - 12:20

HALL C

USP-2: ANTENNAS 2: SYSTEMS

Chairpersons: E.L. Mokole, USA
A.P.M. Zwamborn, The Netherlands

Abstract page

08:30	DESIGN OF AN ULTRA-WIDEBAND GROUND-PENETRATING RADAR SYSTEM USING IMPULSE RADIATING ANTENNAS J.B. Rhebergen, F.T.C. Koenis, W. Pont, A.P.M. Zwamborn, TNO Physics and Electronics Laboratory (TNO-FEL), The Hague, The Netherlands, D.V. Giri, Pro-Tech, Lafayette CA, USA	28
08:50	NUMERICAL EVALUATION OF AN IMPULSE RADIATING ANTENNA USED IN AN ULTRA-WIDEBAND GROUND-PENETRATING RADAR SYSTEM M.H.C. Van Eeuwijk, A.P.M. Zwamborn, F.T.C. Koenis, TNO Physics and Electronics Laboratory (TNO-FEL), The Hague, A.G. Tijhuis, Eindhoven University of Technology, Eindhoven, The Netherlands	29
09:10	FABRICATION AND MEASUREMENT OF A ONE-METER DIAMETER HALF REFLECTOR IRA L.H. Bowen, E.G. Farr, Farr Research, Inc., Albuquerque NM, USA	30
09:30	DESIGN, FABRICATION AND TESTING OF A PROTOTYPE IMPULSE RADIATING ANTENNA (IRA) A.W. Kaelin, B. Reusser, DPA, NEMP Laboratory, Spiez, Switzerland, D.V. Giri, Pro-Tech, Lafayette CA, USA	31
09:50	SUPPRESSION OF OFF-BORESIGHT RADIATION FROM WIDE BAND ANTENNAS R.J. Torres, H. Del Aguila, Air Force Research Laboratory, Kirtland AFB NM, USA, J. Lawrence, G. Hoffer, D.P. Byrne, ITT Systems & Sciences Corporation, Albuquerque NM, USA	32
10:10	Coffee Break	
10:40	ELECTROMAGNETIC LENS DESIGN C.E. Baum, A.P. Stone, Air Force Research Laboratory, Albuquerque NM, USA	33
11:00	MINIMIZING DISPERSION IN A TEM WAVEGUIDE BEND BY A LAYERED APPROXIMATION OF A GRADED DIELECTRIC LENS W.S. Bigelow, E.G. Farr, Farr Research, Inc., Albuquerque NM, USA	34
11:20	A LINEAR ARRAY OF ULTRA-WIDEBAND RADIATORS DRIVEN BY PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHED BLUMLEINS J.S.H. Schoenberg, J.S. Tyo, J.W. Burger, Air Force Research Laboratory, AFRL/DEHP, Kirtland AFB NM, M.D. Abdalla, M.C. Skipper, Maxwell Technologies Inc., Albuquerque NM, USA	35
11:40	ULTRA-WIDE BAND DUPLEXERS FOR LOW AND HIGH PEAK POWER APPLICATIONS M. Piette, Royal Military Academy, Brussels, Belgium	36
12:00	LARGE CURRENT RADIATOR FOR THE SHORT ELECTROMAGNETIC PULSES RADIATION G.P. Pochanin, Institute for Radiophysics and Electronics of National Academy of Sciences of Ukraine, Kharkov, Ukraine	37
13:00	Lunch Break	

MONDAY, JUNE 15, 1998

14:00 - 17:50

HALL A

HPEM-1: HPEM INTERACTION 1

Chairpersons: G.K. Deb, India
A. Tehori, Israel

		Abstract page
14:00	ATTENUATION OF EMP FIELDS AND EMP INDUCED CURRENTS BY A WIRE MESH AND WIRE GRID STRUCTURE C. Goldstein, A. Tehori, J. Leopold, RAFAEL, Haifa, Israel	38
14:20	BOUNDING OF VOLTAGE RESPONSE K.S.H. Lee, ITT Systems and Sciences Corporation, Los Angeles CA, L.K. Warne, Sandia National Laboratories, Albuquerque NM, USA	39
14:40	NEMP INDUCED TRANSIENTS ON TRANSMISSION LINES WITH NON-LINEAR LOADS F. Schlagenhauser, EMCSI Pty Ltd., North Melbourne, Victoria, Australia	40
15:00	ELECTROMAGNETIC FIELD COUPLING TO AN ELECTRICALLY SMALL SCATTERER IN A RECTANGULAR CAVITY S. Tkatchenko, G. Vodopianov, Radio Research & Development Institute, Moscow, Russia	41
15:20	EXPERIMENTAL IMPACTS OF QUASI-DC CURRENTS ON TRANSFORMERS B.W. McConnell, P.R. Barnes, F.M. Tesche, Oak Ridge National Laboratory, Oak Ridge Tennessee, USA	42
15:40	Coffee Break	
16:10	THE USE OF TEM COAXIAL CELLS FOR DETERMINING SHIELDING EFFECTIVENESS IN THE PLANE WAVES REGION-THEORETICAL AND PRACTICAL LIMITATIONS M. Badic, M.J. Marinescu, Research Institute for Electrical Engineering-ICPE, Bucharest, Romania	43
16:30	FAILURES ON TRANSMISSION-DATA INTERFACES DUE TO TRANSIENTS ON THE EARTH PROTECTION WIRE E. Mino Diaz, J. Vila Areste, Telefonica Investigacion y Desarrollo, Madrid, Spain	44
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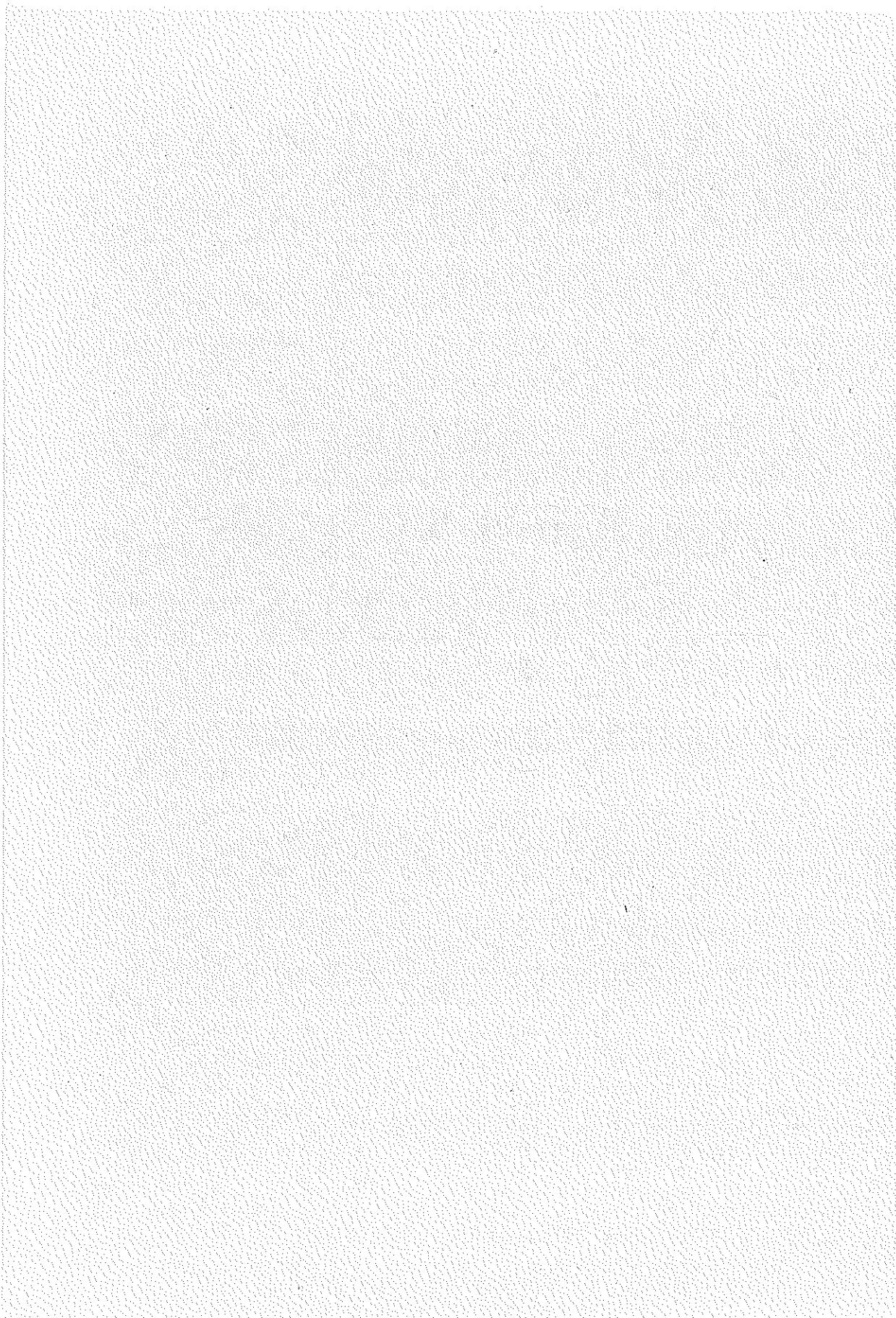
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Chairpersons: A.P. Stone, USA
A.D. Yaghjian, USA

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J. Giles, USA

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A. Boag, Israel

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Chairpersons: J.M. Arnold, UK
J.S.H. Schoenberg, USA

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ULTRA WIDE BAND, SHORT PULSE

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HALL B

Panel Discussion-2
HPM - Sources

Moderator: J. Benford, USA

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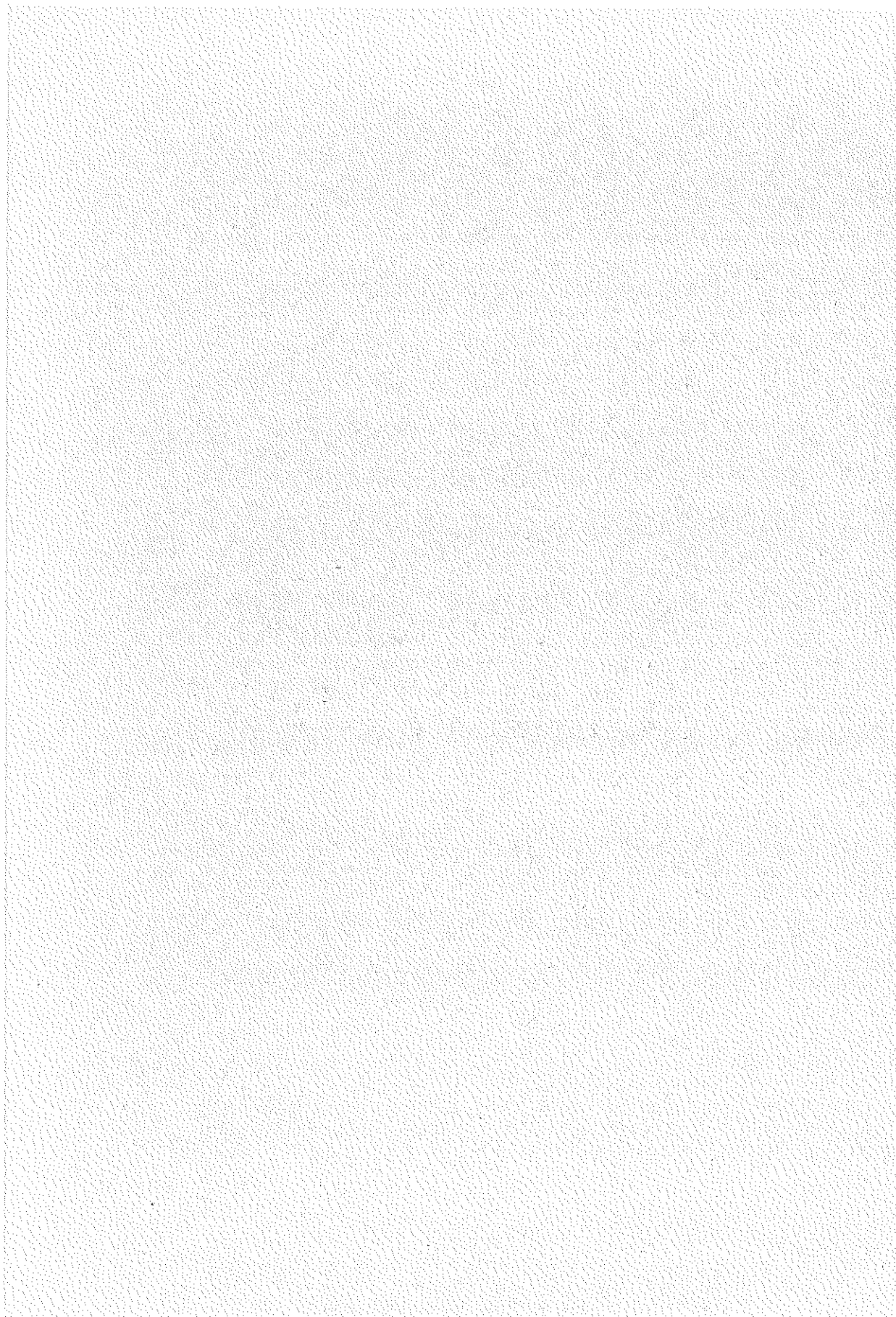
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FOYER

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WEDNESDAY, JUNE 17, 1998

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HALL A

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D.M. Parkes, UK

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Y.V. Parfenov, Russia

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Chairpersons: C. Goldstein, Israel
A.W. Kaelin, Switzerland

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* "microwave heating with time-varying material properties." L. Libelo Abst. p.61

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Chairperson: M. Kristiansen, USA

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HALL B

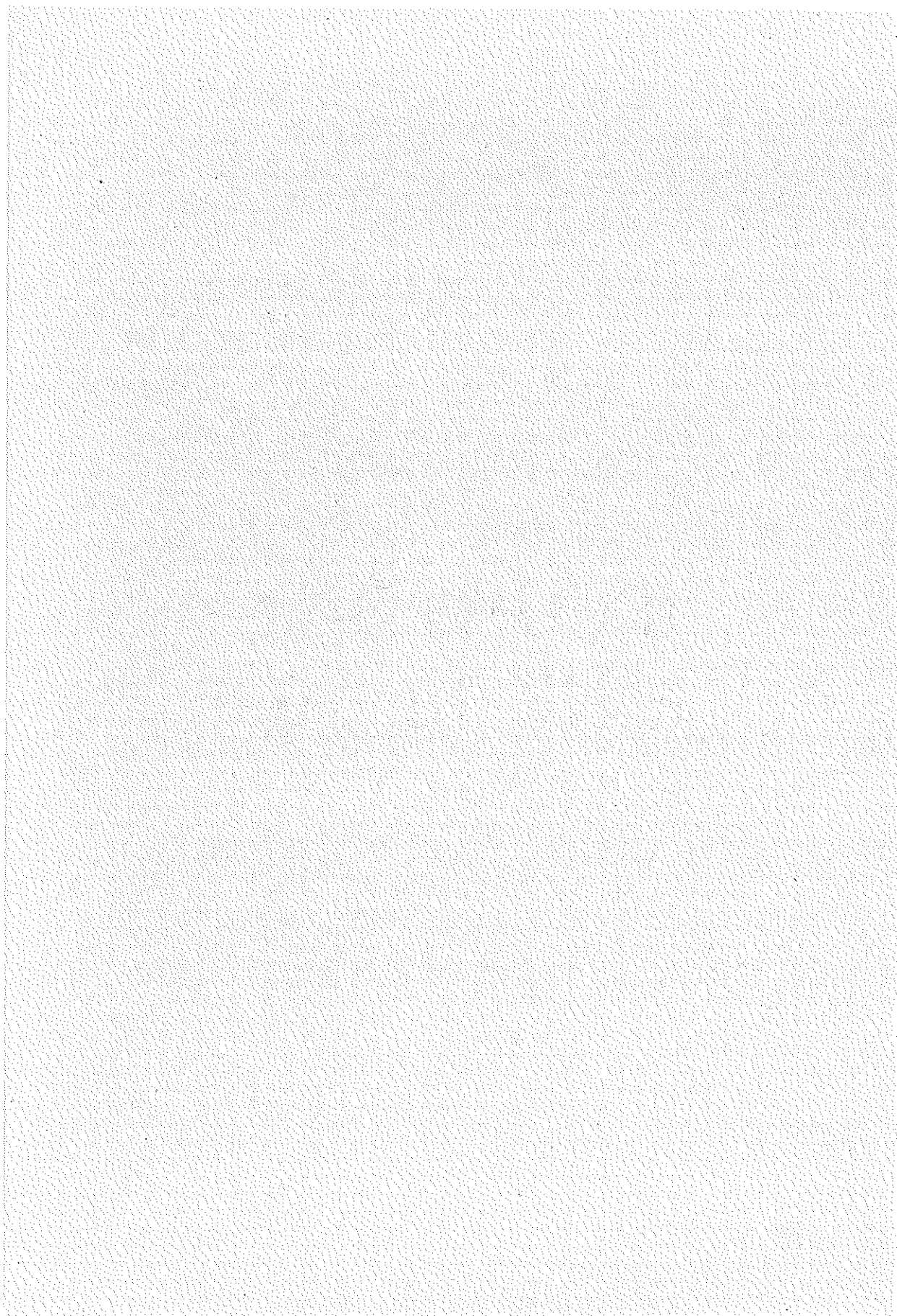
**USP-5 & UXO-1: SCATTERING THEORY OF BURIED TARGETS
(R. KLEINMAN MEMORIAL SESSION)**

Chairpersons: T. Angell, USA
V. George, USA

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JUNE 18, 1998**



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08:30 - 11:40

HALL C

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Chairpersons: J.B. Nitsch, Germany
J.L. Ter Haseborg, Germany

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09:30	USING EM TOPOLOGY FOR CABLE COUPLING PREDICTION: APPLICATION TO EMPTAC AIRCRAFT J.P. Parmantier, V. Gobin, F. Issac, L. Paletta, ONERA, Meudon, France, I. Junqua, J.M. Daudy, J.M. Lagarde, Centre d'Etudes de Gramat, Gramat, France	148
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HALL A

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Chairperson: K.S.H. Lee, USA

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08:50	NONLINEAR AND KINETIC EFFECTS IN PROPAGATION OF INTENSE ELECTROMAGNETIC PULSE THROUGH THE ATMOSPHERE A.I. Golubev, M.D. Kamchibekov, A.V. Soldatov, T.G. Sysoeva, V.A. Terekhin, Russian Federal Nuclear Center (VNIIEF), Sarov, V.T. Tikhonchuk, Russian Academy of Science, Moscow, Russia	154
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HALL D

USP-6 & UXO-2: PROPAGATION IN MEDIA

Chairpersons: K.E. Oughstun, USA
R. Kastner, Israel

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09:30	SPECTRAL ALTERNATIVES FOR THE SYNTHESIS OF SHORT-PULSE WAVEFIELDS IN WAVEGUIDES B.P. de Hon, Eindhoven University of Technology, Eindhoven, The Netherlands, E. Heyman, Tel Aviv University, Tel Aviv, Israel, L.B. Felsen, Boston University, Boston MA, USA	165
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Chairpersons: A.A. Riggs, USA
T. Altshuler, USA

Abstract page

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HALL A

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B. Fomel, Israel

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HALL C

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R.J. Torres, USA

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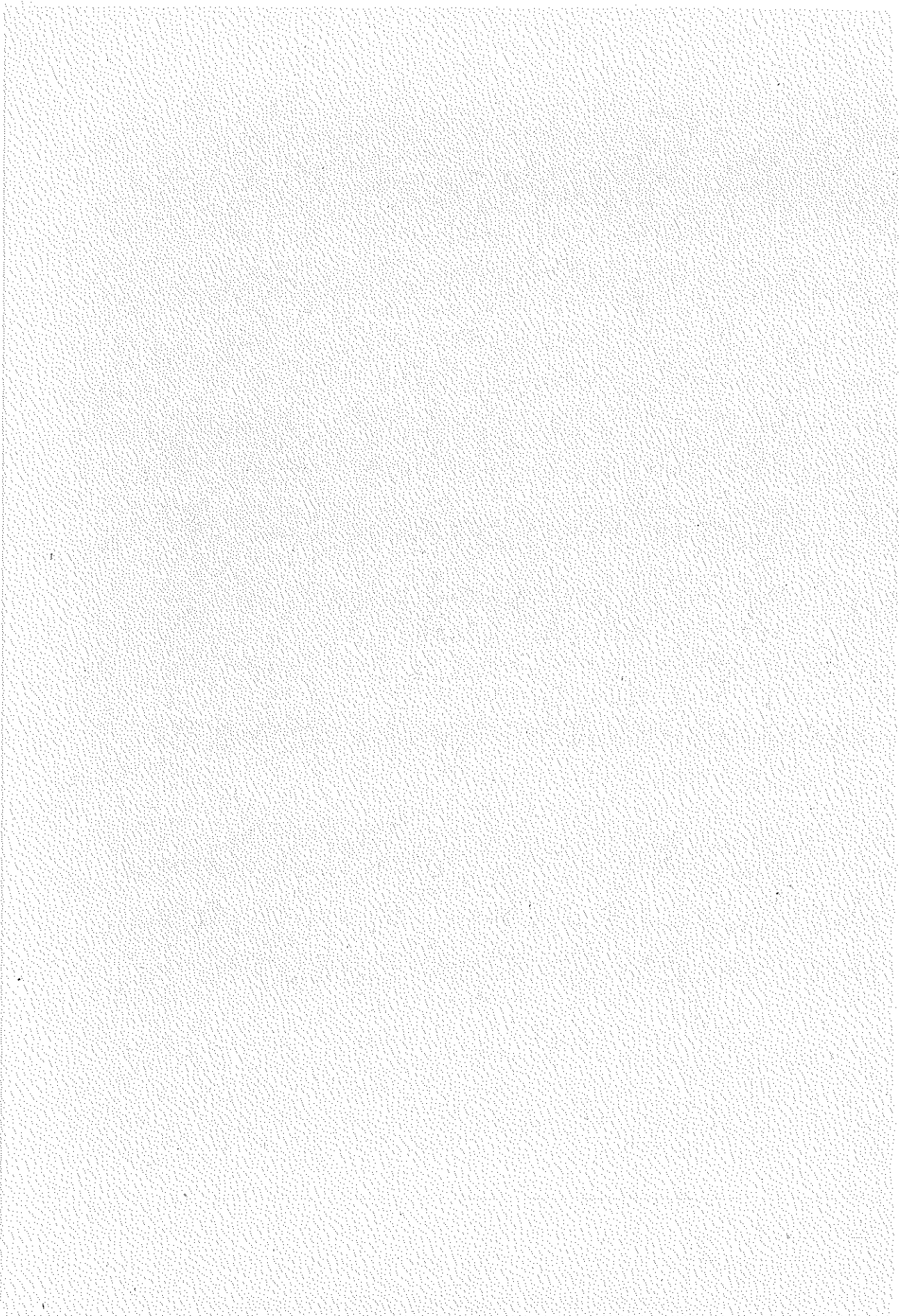
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Chairperson: J.L. Gilbert, USA

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**FRIDAY,
JUNE 19, 1998**



FRIDAY, JUNE 19, 1998

08:30 - 10:00

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Moderator: R.L. Gardner, USA

10:00 Coffee Break

08:30 - 10:00

HALL B

Panel Discussion-4
ELECTROMAGNETIC INTERACTION

Moderator: J.P. Parmantier, France

10:00 Coffee Break

10:30 - 12:00

HALL A

Panel Discussion-5
UXO - UNEXPLODED ORDNANCE

Moderator: A. Hooper, USA

10:30 - 12:00

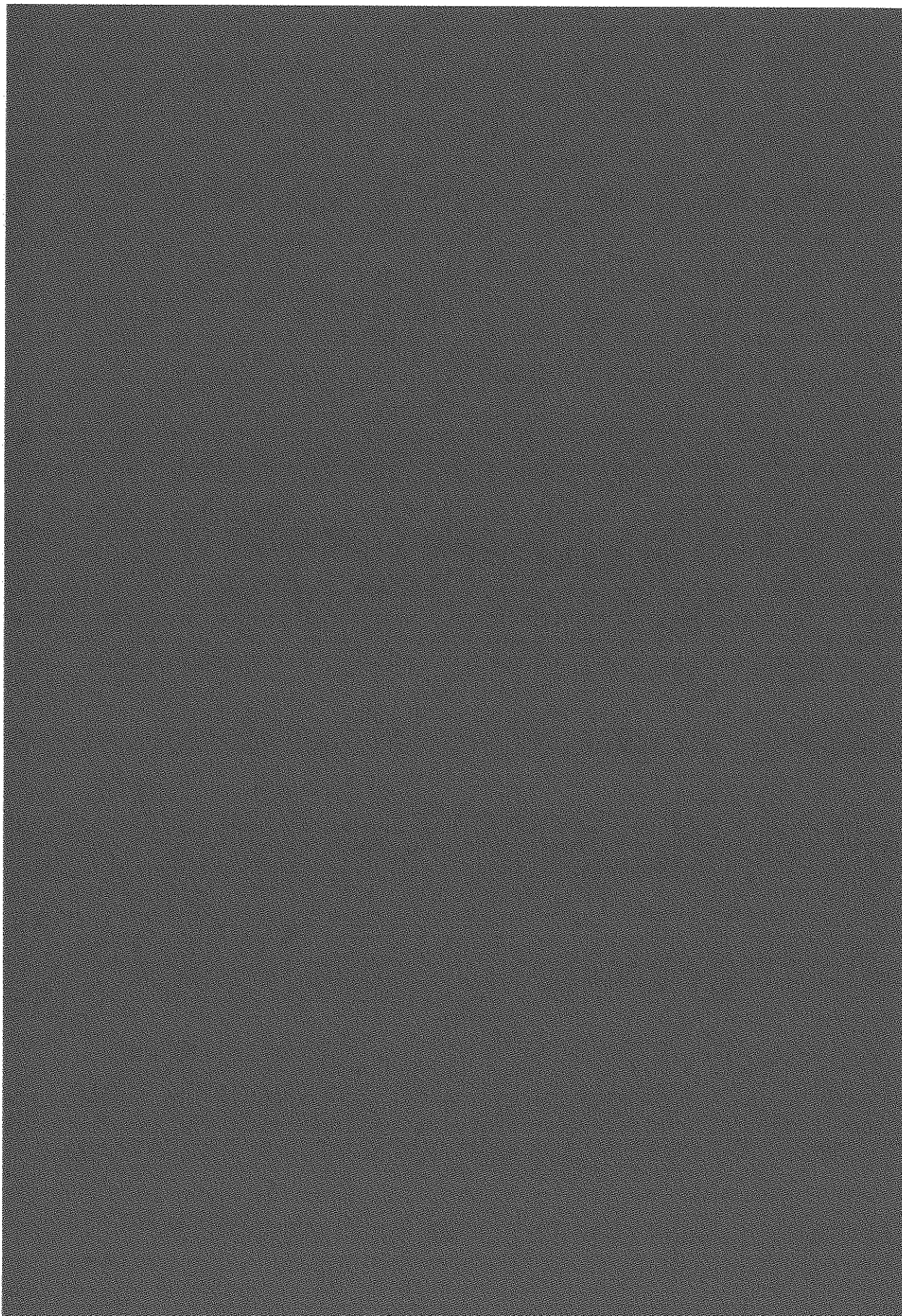
HALL B

Panel Discussion-6
HPE ENVIRONMENTS AND STANDARDS

Moderator: W.A. Radasky, USA



ABSTRACTS



**MONDAY,
JUNE 15, 1998**

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A NONLINEAR TRANSMISSION LINE MODEL FOR LIGHTNING

Robert L. Gardner

Envisioneering, Inc.
5267 Pumphrey Dr.
Fairfax, VA 22032-2630

High Power Electromagnetics combines normal electromagnetic coupling with various nonlinear effects, such as air breakdown. The lightning return stroke is a phenomenon where these interactions are very strong and very important. A lightning return stroke is formed by the emptying of charge built up in a channel by a stepped leader. The return stroke initiates when the channel forms a complete circuit, e. g., from cloud to ground. As the current builds from the discharge, the channel changes its electrical and physical characteristics through joule heating and consequent interactions.

Modeling such a discharge channel is difficult because the radial interactions occur over a small dimensions. Important changes in variables occur on submillimeter length scales. Since the channels are often kilometers long the same techniques cannot be used while calculating the longitudinal evolution as the transverse.

In this paper we will model the longitudinal evolution of the channel with a nonlinear transmission line and use a more complex rad-hydro model for the transverse dimensions. We use a simple equation of state for the air and a simple radiation model. The evolution of air as it is exposed to large electric fields is very complex, involving hundreds of species and thousands of reactions. A complete model is beyond ability of current computers to calculate in a timely way. The choice of the best approximations are key to a good model.

Models of this sort are used to link pairs of observables. Here, a known current is linked to emitted electromagnetic, optical and acoustic energy. Predictions are made for the energy balance of the channel as well as for the electrical evolution so that they can be used for comparison with experiments.

EXPERIMENTAL MEASUREMENTS AND CALCULATIONS OF LIGHTNING-INDUCED CURRENTS ON SHORT OVERHEAD LINES

F. Rachidi^{1,2}, M. Rubinstein³, P. Zwiacki¹, M. Ianoz¹, B. Braendli⁴, A. Kaelin⁴

1 - Swiss Federal Institute of Technology, Power Systems Laboratory, EPFL-DE-LRE, CH-1015 Lausanne; 2 - University of Toronto, Department of Electrical and Computer Engineering, Toronto M5S 3G4, Canada, 3 - Swisscom, EMC Department, CH-3000 Bern 4 - Defence Procurement Agency, NEMP Labor, AC Zentrum, CH-3700 Spiez, Switzerland

In many cases electrically short lines along which propagation can be neglected are subject to electromagnetic disturbances such as those produced by a nearby lightning strike. This can be the case for circuits in power network substations, or telephonic aerial connections, for instance from an underground cable to a building, or a telephonic line installed temporarily on the ground. Persons or installations in contact or connected to the line extremities can possibly be subject to dangerous voltages induced by lightning.

In order to quantify the order of magnitude of this danger, measurements of induced currents using a rocket-triggered lightning were performed at Camp Blanding, Florida, on an experimental telephonic line consisting of two twisted pairs connected together at both ends and grounded using 30-cm earthing rods (Fig. 1). Measurements of common mode induced currents by nearby triggered lightning (70 m) were performed on the line extremities, simultaneously with the measurement of lightning channel-base current and radiated electric and magnetic fields.

As the aerial part was a very short line, the remaining running on the soil, it was possible to use a quasi-static approximation for the calculations. An example of comparison between calculated and measured induced current is shown in Fig. 2.

In the High Voltage Laboratory of the Swiss Federal Institute of Technology of Lausanne, currents from a surge generator were injected in the same kind of wires used for the telephonic line and the efficiency of protection measures was checked (Fig. 3).

The results of this study, have permitted to obtain useful conclusions for the protection. Another conclusion is that a quasi-static approach for the estimation of indirect-lightning effects for short lines nearby the strike can be used. Such a compromise solution is very useful also for complicated circuits, with a large number of branches, for which the usual high frequency coupling models can hardly be applied.

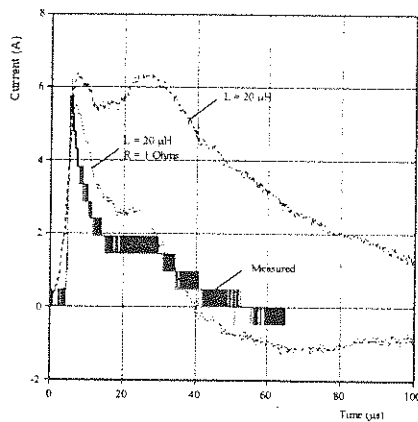


Fig. 2 - Comparison between measurements and calculations using a low frequency quasi-static approximation for the coupling between lightning magnetic field and an electrically small circuit

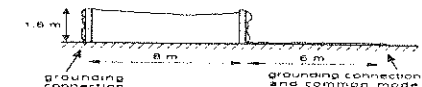


Fig. 1 - Experimental arrangement at Camp Blanding, Florida

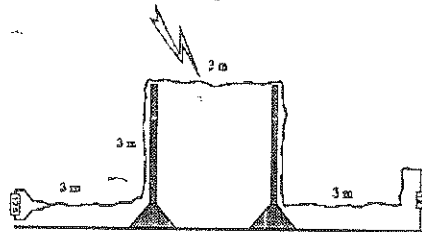


Fig. 3 - Simulation of the lightning-induced current by injection with a surge generator

LIGHTNING EFFECTS ON A METALLIC BURIED CONNECTION BETWEEN TWO SHIELDED BUILDINGS[†]

F. M. Tesche¹, A.W. Kälin², B. Brändli², B. Reusser², M. Ianoz³, D. Tabara³, P. Zweiacker³

1 - EMC Consultant, Dallas, TX, USA, 2 - Swiss NEMP Laboratory, 3700 Spiez, Switzerland, 3 - Swiss Federal Institute of Technology, 1015 Lausanne, Switzerland

The responses of four different types of metallic tubes connecting two shielded buildings (see fig. 1) to a direct lightning strike on one of the buildings are estimated using a calculation model validated by measurements. The lightning current flows (at least partially) into the conduit and this induces a voltage on the inner conductors within the shield. Using several different models, this voltage is estimated and the effectiveness of the various shields is determined. A key element in the calculations are the transfer impedances of the shields, and a measurement arrangement for determining these quantities is described (fig. 2). Four types of metallic tubes have been considered : a steel tube, a corrugated copper tube, a corrugated Cr-Ni steel tube and a manufactured cable for power or signal transmission with a double shield. The response can be calculated from a knowledge of the external current on the cable shield $I(x)$, together with the shield transfer impedance $Z_t(\cdot)$. The lightning current varies so slowly compared to the length of propagation along the shield, that the voltage sources in the distributed circuit can be lumped together as a single source, and a simple lumped circuit may be used to represent the internal signal wires excited by the lightning current. The results of the study are summarized in table 1.

Table 1 – Summary of the 50 kA lightning-induced voltages for 1 km of buried line

Cable shield type	Peak voltage (kV)	Rate of rise (kV/ s)	Fall time (half value)
Steel tube	0.23	9.4	7.8 ms
Copper tube	2.0	1.0	61.0 s
Cr-Ni-steel tube	70.0	35.0	61.0 s
Double-shielded	0.29	30.5	5.1 ms

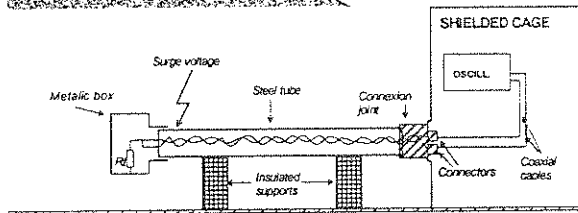
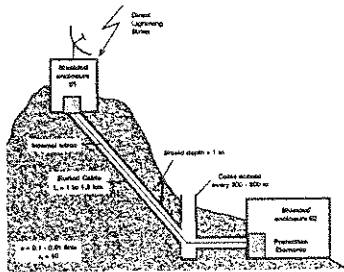


Fig. 1 - Two shielded enclosures connected by a buried shielded cable and excited by a direct lightning strike

Fig. 2 - Experimental set up for the shielded tubes transfer impedance measurements

HIGH FREQUENCY RADIATION FROM A ZIGZAG LIGHTNING DISCHARGE CHANNEL*

V.M. Fedorov, V. Tarakanov

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Electromagnetic radiation from a return stroke of propagated current wave in the case of the zigzag lightning channel has been calculated using the fully electromagnetic 2&3D KARAT code. A model of the return stroke zigzag channel is used. It includes non-uniform distributions along the channel as regards value and a spatial direction of the propagated current wave velocity. As is known, the lightning discharge of the return stroke has a fantastic zigzag form. This was produced by a stepped leader process during electrical breakdown of the cloud-to-earth air gap. Typical length of the single stepped leader is few tens of meters. The current wave velocity of the return stroke is about one third of the light velocity on the leader channel. According to that, the time period of modulation of the current spatial component is in the range 0.1 - 3 μ s. As a result, additional high power HF -radiation from the zigzag lightning discharge channel is in the 0.1 -3 MHz band.

* Work was supported by RFFI under grant 97-02-17390.

TRANSIENTS ON OVERHEAD TRANSMISSION LINES PRODUCED BY INDIRECT LIGHTNING STROKES

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EMCSI Pty Ltd, 59-61 Curzon St., North Melbourne, Victoria, 3051, Australia

Direct and indirect lightning strokes can produce high overvoltages on overhead transmission lines. For an effective protection of the devices connected to the illuminated transmission lines computer programs can be used for a prediction of the expected voltages and currents. The simulation process for indirect lightning strokes consists of three major parts:

1. Consideration of the Lightning Electromagnetic Pulse (LEMP) given in accordance with a suitable lightning model;
2. Coupling process into the transmission lines taking into account the propagation times from the lightning source to the transmission line and along the transmission line;
3. Calculation of voltages and currents at the line terminals including detailed modelling of non-linear protective elements.

The LEMP in the proposed paper is based on Heidler's Travelling Current Source (TCS) model. For the coupling process Bergeron's method has been extended so it can be applied to field excited multiconductor lines. The computation is performed in the time domain and, thus, allows the treatment of non-linear loads.

Some principal arrangements are investigated varying:

- The distance between the excited transmission line and the point of the lightning stroke;
- The location of the lightning stroke in respect to the transmission line;
- The type, location and number of protective elements.

The presentation will give a short introduction in the theoretical background used for the simulation. It will show the importance of a precise modelling of protective elements including stray capacitances and parasitic inductances. Another interesting outcome is that the voltages at the far end of a transmission line, away from the lightning stroke, may even be higher than its near end.

Based on the examples to be presented a general relationship will be developed between LEMP parameters, the location of the lightning stroke and the pulses induced in overhead transmission lines. These pulses that are originally induced in the transmission line are then modified due to reflections at the line terminals. Because of the non-linear nature of the line terminals these reflections will be, in most cases, voltage dependent.

CHARACTERIZATION AND SIMULATION OF LIGHTNING

M.V. Kostenko

St.Petersburg State Technical University, Russia.

Electrodynamics model of the Lightning stroke in the overhead line has to take into account the current waves in the Leader and in the Return Stroke. The Leader has high impedance, comparatively thin and cold channel surrounded by volume charge owing to Corona discharge. The channel of the Return Stroke expands and warms up very quickly with the increasing of current and its impedance decreases.

The system of the partial differential equations of the Lightning is of hyperbolic type with nonlinear coefficients, depending on the summary current in channel (in return stroke and in leader). The solution of them by the method of characteristics [1] gives the different phase velocities and impedances of the Leader and of the Return Stroke. The lack of the lightning electro-physical characteristics according to field measurements forces to take the volt-ampere characteristic of the lightning channel, volt-coulomb characteristic of the corona discharge and the radius of the channel according to the laboratory investigations [2].

The Voltage U_s in the Node S struck with the Lightning is equal to:

$$U_s \approx \frac{i_0 + \sum_{j=1}^K 2U_{js} / Z_j}{\sum_{j=1}^K Z_j^{-1} + Z_{gr} + Z_L}; Z_L \approx 140 * (1 + \frac{240}{i}); i = i_0 - \frac{U_s}{Z_{L1}} \quad (1)$$

where i_0 is the «calculated Lightning current» (i.e. the current of the same lightning, that strikes in the object with zero impedance to ground $Z_{gr}=0$); U_{js} and Z_j are the voltages of the waves going to the node S from the neighboring nodes in lines ($j=1,2...K$) and their impedances; Z_L is the equivalent impedance of the Lightning return stroke; i is the total current (of the leader and of the return stroke) in the lightning channel.

In the first approximation U_s/Z_L can be ignored compared with i_0 . To get more precise result it is necessary to make 1-2 iteration with the formulas (1).

The phase velocity of the return stroke at the first moment is the same as in leader $v_{rs} \ll c$. But with increasing of current v_{rs} increases very quickly from $10^{-2} * c$ to $0.3 * c$. The next portions of the current wave overtake the proceedings. The steepness of the front and luminosity of the channel does not decrease or even increases with height leaving out of account the high losses in the stroke losses and neutralization of the surrounding volume charges.

References.

- [1]. Christianovich S.A. About ultra-sound streams of gas. Trans. of TsAGI, v.543, pp.1-43, 1941 (in Russian).
- [2]. Kostenko M.V. Electrodynamics characteristics of lightning and their influence on disturbances of high voltage line. Journ. Geophys. Res., v.100, D2, pp. 2739-2747, 1995.

BRANCHING MODELING AND EFFECTS ON RETURN-STROKE FIELDS

R.E. Zich, G.Vecchi, F.C.Canavero

Dipartimento di Elettronica, Politecnico, Torino, I-10129 Italy

The temporal waveforms observed in experimental measurements of the electromagnetic field radiated by lightning discharge often show a "fine structure" that deviates from the smooth shape obtained with the assumption of radiation from a straight (filamentary) channel. This "fine structure" entails both "macroscopic", almost-isolated irregularities, as well as noise-like jagged high-frequency components. The "macroscopic" part in some cases may be attributed to reflections, from branches, ground, or other grounding structures while the high-frequency irregularities have been in the past years recognized to be related to the irregularities of the discharge channel.

We analyze the effect of lightning channel branching on the temporal waveform of the radiated fields of the return stroke. To model the far-field radiation, we consider the modified transmission line (MTL) model for pulse propagation on the channel, and some recent results by the authors on the discharge of a transmission line that simulates the channel discharge.

The effect of branches on the upward traveling return stroke pulse is modeled as a pulse-driven release of charge from the branch into the main channel. The radiated field are then computed using this current-triggering model.

The effect of branching is also isolated, and compared to the effect of tortuosity of an unbranched channel.

MCG-BASED SYSTEM FOR SIMULATION OF LIGHTNING

Chernykh E.V., Fortov V.E., Gorbachev K.V., Kouzhekin I.P.,
Nesterov E.V., Stroganov V.A., Zolotikh I.O.

*High Energy Density Research Centre, Russian Academy of Sciences,
IVTAN, Izhorskaja St. 13/19, Moscow, 127412, Russia*

For simulation of lightning discharges into industrial objects and arrangements, the current pulses with MegaJoules energies are necessary. For such applications, the utilization of magnetic-cumulative generators having the highest energy content per unit of mass is reasonable. The units put into practice at present have the effectiveness of conversion of HE chemical energy into electrical energy delivered to the load not higher than 1%.

At present report, the circuit of MCG-based simulator is represented, results of calculations of output parameters are given, and the possible ways to increase the efficiency of such devices are suggested.

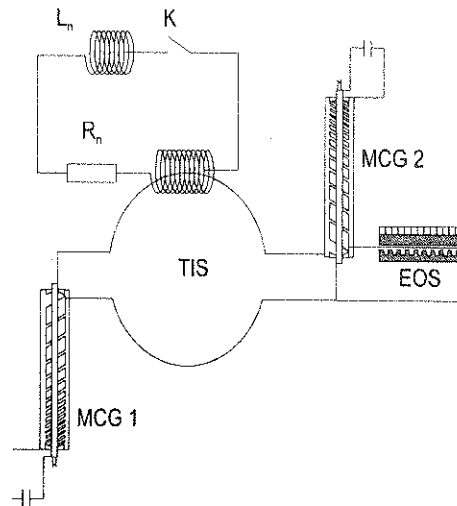
It is shown, that the most effective is the modules system. Each module consists of two generators: one MCG 1 - the fast-run, for shaping the current leading edge, and another MCG 2 for maintaining the given shape for trailing edge at the expense of proper choice of inductance variation law. Explosive opening switch is used to provide the given rate of current growth in the load as well as to switch the generators.

Addition of one more EOS allows the simulation of secondary lightning shock also.

For matching the low-impedance MCG to the high-impedance load (L_n hundreds of microHenries and R_n tens of Ohms) the transformer inductive store (TIS) is used.

Depending on the problem and type of the load the number of modules and way of their connection could be varied, while each module could be placed into separate protective altitude chamber.

Numerical simulations showed that the effectiveness of such system could be considerably increased.



OPTIMIZATION OF COMPONENTS OF MCG-BASED LIGHTNING SIMULATOR

Chernykh E.V., Fortov V.E., Gorbachev K.V., Karpushin Y.V., Kouzhekin I.P., Lebedev E.F., Nesterov E.V., Shurupov A.V., Stroganov V.A.

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The system for lightning simulation consisting of capacitor storage for initial current supply, magnetic-cumulative generator, pulsed transformer, inductive store, electro-explosive opening switch, discharger and the load is considered. For creation of mobile system the calculation are fulfilled to optimize it for mass. The main elements determining the mass of the system are capacitor storage and protective altitude chamber, which is necessary for reasons of industrial and ecological safety. The results are: The optimum mass-to-mass ratio takes place $M_{pc}/M_{cs}(1)$, where M_{pc} $\frac{1}{4}$ the mass of protective altitude chamber and M_{cs} $\frac{1}{4}$ the mass of capacitor storage. The MCG energy amplification factor $k_a=10$ allows to achieve the high MCG effectiveness.

The energy consumption of electro-explosive opening switch strongly depends on the effective time of MCG operation. To reduce these losses it is supposed to use the bank of fast-run MCG of small diameter, for example, the spiral-coaxial transformer generators MK-40, when secondary windings are connected in series. It is found by experiment, that in this case one can use transformer units many times. To verify the simulation model of electro-explosive opening switch the experimental researches were carried out. The generalized characteristics of maximum electrical strength, increment of wires resistance, maximum value of relative growth of resistance showed, that among the three variants, namely, the free surface of wires, the presence of hard insulators, the presence of wires in capillary, the last variant suits our purposes the best way.

SPACE -TIME BEHAVIOUR OF THE ELECTRIC FIELD INTENSITY CREATED BY "LIGHTNING" DISCHARGE

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Usually the measurements of the electric field, created by Lightning are carried out far from breakdown channel. However, it is necessary to know the space-time behavior of field in the vicinity of discharge area (near zone) in order to create physical model of lightning.

In this paper method is developed and measurements of the electric field created by leader discharge in long air gaps using Pockel's device are carried out. Measurements were carried out in rod-plane gap under application of voltage impulses positive and negative polarity. Impulses were forming on an outlet of high-voltage generator of an outdoor installation with total charging voltage 9 MV and energy capacity 1.35 MJ. Generator allows to obtain spark discharges in atmosphere with length up to 150 m.

The sensor is a primary transducer optically connected by optical fibers with a light source and a photodetector. A sensing element as a cylinder form is fulfilled of bismuth silicate crystal.

Space-time dynamics of volume charge of streamer corona and streamer zone of leader in long air gaps at different forms of applied voltage is investigated. Two stages corresponding to different physical processes are observed in oscillograms. First stage corresponds to leader propagation stage, second - to neutralization of space charge or return stroke stage. It is shown, that the electric field intensity in streamer zone of positive leader composes 5 kV/cm and this value is kept along full length of streamer zone. Characteristic peculiarity of electric field behavior in the vicinity of leader channel is the change of field polarity at final jump phase. Neutralization time of space charge increases with growth of gap length. It is shown that the vector of electric field is directed perpendicularly to the channel but not along the channel. The velocity of propagation of streamer corona front and leader in rod-plane gap is measured. It is shown that the streamer corona front velocity growths with increase of steepness of applied voltage. It is established that sharp changes of electric field in sub-microsecond area are caused by stepwise propagation of a leader or final jumping.

Results obtained show that space-time behavior of electric field intensity in discharge gap is determined by dynamics of volume charge of a streamer zone and leader channel. Oscillograms of electric field contain the information about amplitude, temporal changes of field, velocity of propagation of streamer corona and leader, neutralization time of volume charge.

DETERMINATION OF LIGHTNING PARAMETERS FROM THE MEASUREMENTS OF STATISTICAL CHARACTERISTICS OF ELECTROMAGNETIC FIELD

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The average characteristics of the field $\langle E(r, t) \rangle$ and their fluctuations (variations) are usually considered in the studying of Lightning electromagnetic fields. However, it is also necessary to consider the correlation functions of the field $\langle E^*(r, t) \cdot E(r', t') \rangle$ in order to analyze the statistics of the field more deeply. The correlation function contains the information about the statistical characteristics of the source and may be experimentally determined. The knowledge of the correlation functions is also important for elucidation of the nature of oscillations of Lightning electromagnetic field.

In this paper the methods for determination of Lightning parameters from the measurements of spatial and temporal correlation functions of electromagnetic field are proposed. It is shown that the measurements of the correlation radius (coherency radius) of radiation allow to determine also the distance from Lightning stroke. New quantitative characteristics for analyzing of experimental data are introduced.

There are two main factors leading to the random oscillations of Lightning electromagnetic field: oscillations of the return stroke current in a Lightning channel and the random bending and branching of breakdown channel. Recent experiments (Le Vine D.M., Willett J.C. 25th GA URSI, Lille, France, 1996. Abstracts. P.218) have showed that the oscillations of electromagnetic field of triggered Lightning are caused by the geometry of discharge channel.

The analysis of the correlation function of field shows, that for distances $z_0 \gg Lr_0/\lambda$ (L is the characteristic length of discharge channel, r_0 is the correlation radius of the source, λ is the wavelength of radiation) the correlation radius of electromagnetic field r_c is determined as $r_c \approx \lambda z_0/L$, i.e. it is possible to determine the discharge channel length from the measured correlation radius. For distances $z_0 \ll Lr_0/\lambda$ the correlation radius r_c is determined by the correlation radius of source r_0 and allows to determine the characteristic scale of the channel inhomogeneities $r_c \approx r_0$. On the other hand, the average sizes of channel tortuousities of Lightning is determined by the length of streamer zone of leader l_{str} , and the streamer zone length determines the charge per unit length of Lightning channel $q_l \approx 2\pi\epsilon_0 E_s l_{str}$ (E_s is the electric field in the streamer zone). Therefore it is possible to determine the charges distribution along the channel from the measurement of correlation radius. In its turn the charge per unit length of Lightning channel is connected with the amplitude of the return stroke current i_0 (Petrov N.I., Waters R.T. Proc.Roy.Soc.A, 1995, v.450, p.589): $q_l \sim i_0^{2/3}$, i.e. it is possible to determine the Lightning current amplitude i_0 from the measurement of the correlation radius r_c .

RELATIVISTIC MICROWAVE ELECTRONICS IN RUSSIAN FEDERAL NUCLEAR CENTER - VNIIEF. RESEARCHES, ACHIEVEMENTS, PERSPECTIVES

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Since 1987 the experimental and theoretical developments and investigations in the field of high-power relativistic microwave electronics are performed in RFNC-VNIIEF. It is developed the whole park of the unique electro-physical devices, such as:

- linear inductive electrons accelerators I-3000 and "Korvet";
- electrons accelerator of the direct operation on the basis of inductive storage capacitors and open switches of different types: electric-discharge, plasma-erosion, semiconductor;
- high-voltage generators of nanosecond pulses GIIR-4;
- magnetocumulative energy generators.

On the basis of these devices we realized different types of microwave generators: relativistic TWT, plasma-beam generator, vircator, reflecting triode.

Currently active investigations on joint operation of meshes of such microwave generators have been performed. Modern state and perspectives of the further researches are presented in the paper.

A REVIEW OF RECENT PROGRESS IN RELTRON TUBE DESIGN

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We have continued to make improvements to our Reltron high power microwave tubes. In particular, in this presentation experimental data and analysis will be reported on the following topics:

- (1) A new modulating cavity design now permits a useful tuning range of approximately +/- 10% about the nominal center frequency. Moreover, this change has also resulted in a flatter tuning curve of power versus frequency;
- (2) An investigation of explosive emission cathodes has shed additional light on the behavior of dielectric cathode materials such as velvet cloth, and has identified alternate materials capable of higher repetition rate operation with significant pulse durations;
- (3) An analysis of pulse shortening mechanisms has identified the dominant mechanisms in Reltron tubes, resulting in significant improvements in the energy per pulse (to almost 500 joules per pulse for our L-band tubes).

EXPLOSIVELY DRIVEN HIGH CURRENT ELECTRON ACCELERATORS AND HIGH-POWER MICROWAVES SOURCES

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Review of the pulsed power explosively driven sources for the high current accelerators and powerful relativistic generators of the coherent microwave radiation is presented. Among the generators of single pulses the explosively driven systems seems to be the most attractive, because they look like rather simple, compact and cheap constructions, which have very high specific characteristics and sufficient reliability. To convert chemical energy of high explosives into the energy of electromagnetic pulse special devices, so called Magnetic Flux Compressors (MFC), were designed. MFC action is based on the effect of "magnetic accumulation" during compression of magnetic flux by metal conductor pushing by detonation products of HE. In most experiments carried out MFC were switched on the low-inductive loads (1-100 nH), resulting in great efficiency of chemical high explosive energy transformation up to 20%. Last years with the advances in pulsed power technology the great interest is appeared in investigations of possibilities of MFC employment as energy source for unusual high impedance loads such as high current accelerators and powerful microwave generators. To realize considerable powers in such loads MFC must have large values of inductance derivative of >1 ohm and has to produce large values of voltages of 0.1-1 MV. In the present report we will look on MFC from the point of view of their integration with high power microwave sources. The typical constructions and principals of their operations will be considered. Requirements to the explosively driven pulsed power system for feeding relativistic microwave generators will be described. Experiments to realize voltages up to 500 kV and microwaves powers of several hundreds MW on a vircator systems will be discussed.

GENERAL SCALING OF PULSE SHORTENING IN EXPLOSIVE-EMISSION-DRIVEN MICROWAVE SOURCES

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Microwave generation in devices that depend on synchronization between an electron beam and a resonant cavity or slow wave structure can be disrupted by changes in either. Explosive-emission-driven microwave sources use plasma as the electron source in the diode. This plasma is conductive enough to act as the boundary for both the applied diode voltage and the microwave electric field. The motion of this plasma can effectively change the dimensions of either the electron beam diode or the cavity and will thereby cause resonance destruction. This shortens the microwave pulse length τ_p . A general model of the process predicts that, for a Child-Langmuir diode, microwave power will fall as $P \propto \tau_p^{-5/3}$ and that pulse energy will fall as $E \propto \tau_p^{-2/3}$. Therefore, energy efficiency declines as the pulse length is extended. We compare with data from magnetrons, MILOs and BWOs, with good agreement. Explosive-emission-driven microwave sources are fundamentally limited by the speed of the diode plasma and can be improved by finding cathode materials that generate slower plasmas.

PLASMA FILLED RADIAL ACCELETRON

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The advantages of the radial acceletron over conventional sources has been reported by Arman(1). Briefly, the radial structure of this design allows for much smaller impedances and thus higher powers, the growth rate is large because of the transit-time nature of the interaction, and the source is compact because there is no need for external magnetic fields. Adding plasma to the interaction region of certain high power microwave sources has had beneficial effect on the growth rate and efficiency. We believe the radial acceletron will also be enhanced by the presence of positively charged plasma in the main cavity. Here I report on the results of adding plasma to the radial acceletron. The research is carried out numerically by simulation, using the PIC codes MAGIC and SOS. The plasma enhanced radial acceletron can possibly generate gigawatts of coherent rf power in a wide rage of frequencies.

(1) "Radial Acceletron, a New Low Impedance HPM Source", IEEE Transactions on Plasma Science, Vol. 24, No. 3, June 1996, Special Issue on High Power Microwave Generation

HPM-RESEARCH PROGRAM - GERMAN FORCE

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In 1992, the MOD of Germany installed a research HPM-Program to get more information about the condition from foreign Weapon systems. But up to now, the research activities are growing up to large different objects, like, missiles, smart ammunition, aircraft equipment, Stealth etc.

The way ahead is to get more information about the behavior of electrical equipment and modelling combined with experiments in test facilities.

This presentation will describe about HPM-areas in Germany (in general) and special procedures to get more information about resonance transfer function, etc. Further important research work is to develop or improve Software for modeling and EME-predictions.

To find out the thresholds in regard of power, voltage, current, energy or burn out values of components is a second area of business.

I will present an overview of still on going activities, handled from several German companies and to demonstrate some results about bilateral experiments with FR and SW. The prospect for the future will be that we will arrange some work in regard of HPM sources up to a demonstration device.

RELATIVISTIC MAGNETRON WITH DIFFRACTION OUTPUT

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The relativistic magnetron is the highest-power source of coherent microwave radiation in the long centimeter range. The resource of increase of the power in magnetrons is associated with making the cross section of the interaction space larger, thus operating on higher modes or their spatial (azimuth) harmonics. However, here the problem how to provide the single-mode operation appears, to preserve coherence of radiation.

In traditional design versions of magnetrons, the problem of mode selection is complicated by a presence of the output of radiation from a single resonator cavity. Such non-symmetrical load leads to removal of polarization degeneracy and to splitting of the spectrum of free oscillations. Non-symmetrical output fixes azimuth positions of nodes and antinodes of oscillations. This results in lower quality of the radiated wave having an antinode at the coupling slot than the quality of a locked-up parasitic mode having a node on the coupling slot. Change of Q-factors leads to excitation of the competition wave.

This problem can be solved with the use of the diffraction output of radiation in relativistic magnetrons. Such an output is made as an axial symmetric horn with a smooth decrease of transverse dimensions of resonators from the interaction space to the regular circular waveguide which has diameter more than the critical one for the radiated wave.

The use of the diffraction output makes it possible:

1. to evenly load all types of oscillations;
2. to provide maximum quality $Q \approx (8\pi/n)(L/\lambda)^2$ for lowest longitudinal mode $n = 1$ (n is a number of longitudinal variations of high frequency field for the mode, L is the length of the resonator system, λ is operating wavelength). It permits to choose the length basing only on the required amplitude of the microwave field without taking into account the condition of providing mode selection;
3. to get a higher breakdown strength of the microwave output;
4. to decrease of the useless electron flow injected by the cathode edge.

Let us note that the pattern of electromagnetic field radiated by the diffraction output is rather complicated. However, it can be transformed using special means to any desired field structure if necessary. Transformation of the operating mode to a mode with lesser azimuth index can be realized in the diffraction output directly by choice of the resonator profile on the horn.

The advantages of diffraction output were demonstrated experimentally in X-band relativistic magnetrons with multi-gigawatt output power.

HIGH-TO-LOW FREQUENCY CONVERSION IN NONLINEAR CIRCUITS - SOME EXACT RESULTS

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As has been demonstrated in many cases, modulated microwave signals of sufficient length and intensity can affect the functioning of an irradiated system. This interference is due to nonlinear circuits/components in the system's electronics which convert purely high-frequency signals (coupled into the system) into signals with effective low-frequency parts which interact with the low-frequency control and steering cycles of the system in their own frequency regime.

To explore this high-to-low frequency conversion we consider the class of input signals of the form $y(t) = m(t) \cos(2\pi f_c t)$ for $|t| \leq T/2$ and $y(t) = 0$ for $|t| > T/2$. Here f_c and T denote the carrier frequency and signal duration, respectively, and the periodic non-negative function m describes the amplitude modulation of the input signal. In addition, we assume some relevant (if somewhat idealized) non-linear transformations $y \rightarrow y^\#$ of the input signal (as e.g. rectification) by specifying the corresponding characteristic of the non-linear circuit or component.

On these assumptions we derive the Fourier transform of $y^\#$ and provide an exact closed expression for the low-frequency part of the distorted signal. From this one can calculate various stress parameters (as energy, maximum or average power,) specifically for the low-frequency part of the distorted signal which is a potential threat to the operation of critical subsystems with control cycles in the same frequency regime.

NUMERICAL SIMULATION AND EXPERIMENTAL INVESTIGATIONS OF BEAM-PLASMA PROCESSES IN VARIOUS GAS-FILLED ELECTRODYNAMICAL STRUCTURES OF MICROWAVE TUBES

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An effective method of numerical simulation of strongly nonlinear beam-plasma interactions in gas-filled electrodynamic structures is described. The self-consistent system of model equations consists of two Boltzmann-type kinetic equations for beam and plasma electrons and Maxwell curl equations. The kinetic equations are solved at each time-step by sequential modeling of different physical processes, the Maxwell equations are solved by a finite-difference method. The ions are supposed being in rest, beam electrons are represented by particles and for plasma electrons a hybrid model 'gas-particles' is used. The results of simulation of some beam-plasma systems are presented.

Theoretical estimations are used in developments of some new beam-plasma devices having different hybrid slow-wave structures. The results of experimental investigations of beam-plasma processes in a high-power plasma TWT are given. The slow-wave structure of the tube is filled by rare working gas, its pressure is held constant by incorporated sources and pumps. Ionizing collisions of beam electrons with gas molecules results in the fast accumulation of plasma in the structure. The pressure-dependencies of microwave processes are analyzed, the optimal pressure is found that maximizes the gain, frequency bandwidth and efficiency of the tube. The advantages of various types of plasma-filled microwave devices are discussed.

POWERFUL WIDEBAND AMPLIFIERS AND GENERATORS ON THE BASIS OF PLASMA-BEAM INTERACTION

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The basic physical preconditions of creation and characteristics of a new type of electronic devices - plasma-filled TWT are considered. The electrodynamic processes in these devices proceed with interaction of electron beams with plasma. It allows to receive set of parameters: power in a continuous operation mode, electronic efficiency and width of the working frequency band essentially exceeding achieved in vacuum devices. The results of theoretical investigations and experimental characteristics, confirming them, are given.

Plasma-filled TWT are intended for application in the various radioelectronic devices and as amplifiers for communication. Therefore special attention is given to study of noise and other parameters determining qualitative amplification of signals. The application of plasma filled TWT in technological and plasmachemistry processes determines an opportunity generation of stochastic fluctuations. The characteristics of generators are given depending on a feedback circuitry.

Alongside with plasma filled TWT the high-voltage power supply systems are developed. In power supply systems the converters of the increased frequency, transformers on amorphous steel with solid cast isolation, electronic switching tubes are used. It has allowed to create powerful amplifiers on plasma filled TWT with lowered in weight and sizes.

LOWERED PLASMA VELOCITY WITH CESIUM IODIDE/CARBON FIBER CATHODES AT HIGH ELECTRIC FIELDS

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When explosive emission cathodes are used in higher power (>100 MW) devices, microwave pulse shortening occurs because of motion of the cathode plasma at speeds 1 to 5×10^6 cm/sec, which can limit present-day high power microwave (HPM) sources to a few hundred joules. The introduction of cathodes made from Cesium Iodide-coated (CsI) carbon fiber has shown plasma speeds reduced by factors of a few from uncoated carbon fiber, but previous work was at low diode fields of a few 10's of kV/cm. We have demonstrated reduced CsI plasma speed for macroscopic electric fields of up to 285 kV/cm, sufficient for the diodes of GW microwave sources. Carbon fiber coated with CsI in saturated solution gives plasma speeds at these high electric fields of 0.7×10^6 cm/sec, three times less than the bare carbon fiber. The apparatus had oil-free high vacuum conditions (metal seals and glass insulator) and the cathode was baked both before assembly at atmospheric pressure and in vacuum after assembly, to temperatures of >600 °C. A residual gas analyzer showed burnout of the water; base pressure was $\sim 10^{-6}$ Torr. An unexpected benefit of the CsI coating is that diode current and voltage traces are substantially more reproducible than with bare carbon fiber. This may be because CsI emits copious UV, lighting up the surface much more uniformly. This increased reproducibility in voltage and current magnitude, density, and distribution as well as far more reproducible diode closure conditions permits an associated HPM device to be operated closer to its true optimum conditions for increased power and efficiency. With this reduced plasma velocity, CsI cathodes should produce an extension of the HPM pulse length and an increase in pulse energy by a factor of three in sources now limited by low-Z contaminant, cathode plasma motion.

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PHASE AND FREQUENCY CONTROL OF OUTPUT RADIATION IN SOURCES OF POWERFUL MICROWAVES

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One of the most prospective directions of development in microwave relativistic electronics is connected with a creation of powerful devices with controlled output radiation. Such sources can be applied for coherent radars, for microwave feeding of particle accelerators and for other technical and scientific areas. To control frequency spectrum of output radiation two main operation modes can be used: an amplification of input signal or lock of auto oscillations.

These regimes have some peculiarities in short-pulse devices. If transient time in oscillator is comparable with pulse duration τ or operation frequency bandwidth in amplifiers is comparable with effective width of radiation spectrum $\Delta f \sim 1/\tau$ the difference between these two regimes is rather conditional and hardly can be determined. Powerful microwave devices operate as a rule in nanosecond pulse range so the peculiarities of these regimes are of special importance.

Possibilities of control of output radiation parameters were studied experimentally with the X-band high power Cherenkov type sectioned amplifier consisted of BWO preamplifier, drift channel combined with microwave input and output TWT section pierced with a common electron beam. Electrodynamical systems of parts of the amplifier were made as corrugated circular waveguides. The cross sections of the elements were oversized to provide transportation of the gigawatt level microwave radiation. The presence of the BWO section operating near its excitation threshold allowed to realize in the same design either amplification or oscillation regimes with change of the beam diameter.

In experiments 1 MeV 6 kA hollow electron beam produced with the field emission cathode was used. Duration of accelerating voltage was about 150 ns. The parameters of output microwave were measured with heterodyne method. For phase measurements the master oscillator of the amplifier (100 kW magnetron) served simultaneously as the local oscillator. In the series of frequency measurements output radiation was mixed with a signal of additional magnetron oscillator. The heterodyne method gives possibility to resolve reliably areas of amplification and phase or frequency lock for the device. In amplification regime about 500 MW of output power with pulse duration about 30 ns was achieved. Maximum amplification reached 40 dB with frequency bandwidth about 1%. Microwave pulse duration in this experiments seemed to be limited by the self-excitation of the system (namely, of the BWO-section) due to enlargement of the electron beam during the accelerating pulse.

The work is supported with Civilian Research and Development Foundation, grant #RP1-243 and Russian Interdisciplinary Program "Physics of Microwaves", project # 1.4.

HPM PENETRATION TO CIRCUIT WIRES

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An essential estimation of HPM effects is their influence on circuit wires.

In the paper, we present experimental and comparative computational data of the penetrative effects of waves at HPM frequencies in a wire, which represents part of electrical/electronic circuitry.

Initially the measurements for reception on an unshielded wire are presented and compared with similar measurements made at Lawrence Livermore National Laboratories.

The effects of penetration through slits are then considered. Initially measurements up to 4GHz to a wire lying behind a slit in an infinite wall are compared to relatively simple method-of-moment computations based on a method of Naiheng and Harrington. Afterwards a similar comparison is made for perefraction to a wire in a missile-like cylinder with a slit in the wall.

The comparisons indicate that using relatively simple programs with small computational times (< 5 min) good approximate estimations of HPM penetration to circuit wires can be obtained.

MICROWAVE COUPLING TO EQUIPMENT: THE DIRECTIONAL DEPENDENCE AND ITS IMPACT ON SUSCEPTIBILITY TESTING

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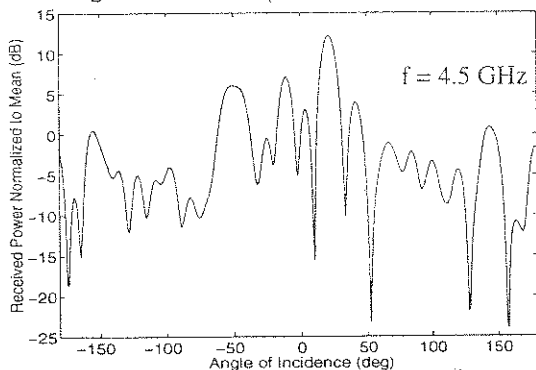
In RS (radiated susceptibility) testing as well as in shielding effectiveness determination of electronic equipment the dependence of direction and polarization of the incident field has to be considered. This holds for MSC (mode-stirred chamber) testing as well as for testing in an AC (anechoic chamber). In AC testing an obvious problem is the uncertainty whether the most critical directions and polarizations have been used in the test. On the other hand, when performing a test in an MSC its isotropic environment means that only a fraction of the radiation exposing the EUT (equipment under test) will hit it in the most critical directions, which makes it difficult to relate the outcome of this kind of test to worst case plane wave conditions.

The directivity problem in susceptibility testing has been discussed earlier but it seems that the magnitude of the variations due to directivity has been assumed to be much lower than what is reported below.

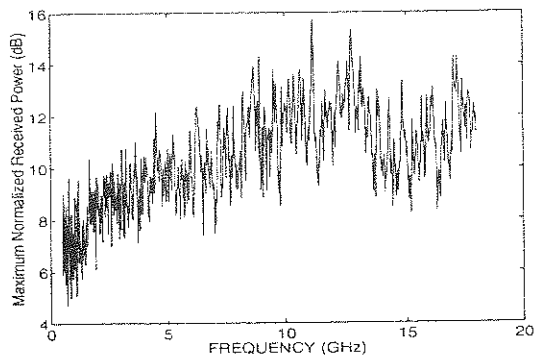
This paper presents an overview of measured results of coupling to various equipment for frequencies between 0.5 and 18 GHz. The measurements were performed in FOA's large AC, and in our MSC facility. In the former case measurements were carried out in three perpendicular planes between 0 and 360 degrees, with an angular resolution of one degree. For each angle of incidence the coupling was measured for two orthogonal polarizations.

The coupling, i.e. the field level inside the equipment, was measured using short "monopole" probes of length 4 or 20 mm. Such a probe consist of a semi-rigid cable with the inner conductor exposed at the end. The probes are regarded as representative for coupling to typical cables and components inside the object. The coupling is expressed as a receiving cross section, σ_p , i.e. as the power received by the probe normalized to the power density of the external incident field. Some results, for an avionics box, are shown below:

From the measurements we conclude that RS testing in an AC may typically lead to stress levels that are more than 15 dB higher than what is achieved in an MSC, given the same magnitude of the exciting field. The difference is due to a combined effect of directivity and polarization. This fact has to be taken into account in RS testing. In MSC testing of an equipment that in real life may become exposed to a plane wave, e.g. a missile, it is necessary to put a margin on the test level, equal to the EUT's maximum normalized. For AC testing, since the direction and polarization causing the worst stress on the EUT is generally not known, the large variation in σ_p calls for a test methodology based on a statistical approach.



Normalized σ_p vs. angle of incidence



Maximum normalized σ_p at each frequency

RISK OF INTERFERENCE TO AIRCRAFT FROM VSAT AND SNG TERMINALS

Ryszard J. Zielinski

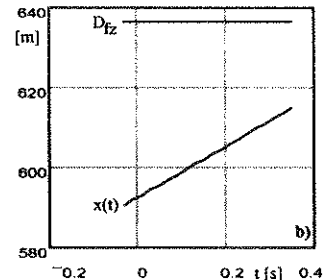
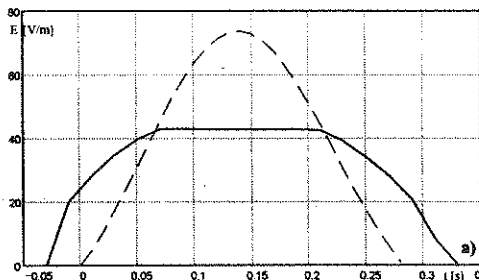
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With the ever increasing use of Very Small Aperture Terminals (VSAT) and Satellite News Gathering Transportable Earth Stations (SNG TES) there is an urgent need to define the potential risk of interference to aircraft passing through the main beams of such stations. This problem was raised in ERC during October 1996 meeting and administrations were encouraged to contact their national Civil Aviation Authority to get information on this subject. Except for Denmark no other Administrations have taken measures as to limit the use of SNG and VSAT terminals in close proximity to airports and glide paths.

This paper provides a detailed analysis of the risk of interference resulting from aircraft exposure to the main beam of a Satellite Earth Station (SES). Since the worst case conditions considered in the study for SNG terminal pertained to the near-field zone of the antenna, use is made of the near-field radiation model [1]. Presented analysis aimed at determining the levels of electromagnetic exposure experienced by an aircraft during landing approach. The typical scheme of landing approach has been considered.

Taking into account the difference in field strength determination between the near zone and the far zone of the antenna radiation, the calculations will involve models for both the zones. If we use the far zone model, initial dissipation of energy in the antenna aperture becomes negligible. But if use is made of the near zone model, the physical dimensions of the antenna aperture must be considered.

Making use of the models described in [1], calculations were carried out for several types of SES including typical VSATs and SNGs. Two antenna elevation angles ε were adopted, 30° and 10° . The speed with which the aircraft travels during landing approach was assumed to be 77 m/s (about 280 km/h) in every instance. The picture a) presents only one example of the results obtained by simulation of the electromagnetic field strength amplitude as a function of time during aircraft flight through the main beam radiated by typical SNG TES (type Dornier VMA-26/73/25) at antenna elevation angle $\varepsilon=30^\circ$. In the picture b) you can see distance $x(t)$ to the analysed points and distance D_{fz} to the far zone which shows us the need of use near field model (continues line) rather than far field model (dotted line).



The results of analysis present the risk of interference to aircraft from high power VSAT and SNG terminals especially to older aircrafts types certified before 1989.

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PENETRATION OF MICROWAVES INTO A METALLIC CYLINDER WITH A SLIT

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In the frame of mine neutralisation with High Power Microwaves, we are interested in the penetration of microwaves into a completely closed metallic box with slits and slots. For this purpose, we constructed a metallic cylindrical box with a lid. The complete cylinder is about 100 mm high and has a diameter of also 100 mm and between the core and the lid a dielectric joint of 1.5 mm is inserted.

First calculations have been made based on the Finite Difference Time Domain method. A Transverse Electromagnetic impuls of the form of a \sin^2 of 1.5 ns FWHM is impinging on the cylinder with a parallel polarisation. The incident angles vary from 0 to 90° with a 5° step and for each angle the electric field is measured at different spots in the cavity : in the middle near the bottom, on the side near the bottom, in the middle and in the middle near the top. The results of the calculation give us the amplitude of the electric field as a function of time. Depending on the incident angle and the place of measurement, we try to find out the most interesting angle which couples the most energy into the cavity. By applying the inverse Fourier transform to the measured signals we can find the resonance frequencies in the cavity and compare them to the frequencies found theoretically for this size of cylindrical cavity. Also, depending on the angles of incidence, the energy coupled at these frequencies is more or less important.

Corresponding, experiments can be made on the same cylinder by irradiating the cylinder within a TEM cell or on a ground plane. A broadband detector is placed inside the cylinder which will measure the part of the electromagnetic pulse penetrated in the cylinder and send it to a broadband oscilloscope (DC up to 40 GHz). From here on the same inverse Fourier Transform can be applied and the results can be compared to the ones obtained by calculation.

In this way, knowing the amplitudes and the frequencies of the electromagnetic wave harmful to the electronic components, an optimal angle of incidence can be calculated for attacking the electronic mine with High Power Microwaves.

DESIGN OF AN ULTRA-WIDEBAND GROUND-PENETRATING RADAR SYSTEM USING IMPULSE RADIATING ANTENNAS

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At TNO-FEL, one of the research programs is to explore the use of ultra-wideband (UWB) electromagnetic fields in a bi-static ground-penetrating radar system for the detection, location and identification of buried items of unexploded ordnance (e.g. land mines). In the present paper we describe the current status of the development of this system. The UWB ground-penetrating radar system is designed to operate in the frequency band from 200 MHz to 3 GHz and uses impulse radiating antennas (IRAs) as transponders to radiate and receive very short electromagnetic pulses from a short distance above the soil. Both IRAs have been characterized in an anechoic chamber. The radiation IRA is driven by a pulse generator with a double exponential voltage waveform with a pulse rise time of 90 ps, a pulse width (FWHM) of 3 ns and a peak positive amplitude of 9 kV. The receiving IRA is similar to the radiation IRA and is connected to a receiving unit. The IRAs operate from suitable antenna stands.

The measurement system consists of a sampling oscilloscope appropriate to cope with the signal processing. The signal processing part employs techniques for the identification of the electromagnetic singularities (the *singularity expansion method* or SEM) in the received signals. With the SEM the locations of the poles (singularities) of the dominant resonances can be found. These poles can be compared to poles of known land mines in a library and an identification can be made.

In order to perform controlled radar experiments, a full-size testing facility has been designed and constructed on the premises of TNO-FEL. The testing facility consists of a buried wooden box. The dimensions of this box are 10 m x 10 m wide and 3 m deep. The box has been fully digged in into the ground. Special care has been taken to avoid the use any metal parts in the construction of the box or in the vicinity thereof. The sandbox is filled with clean (homogeneous) river sand. In order to maintain the condition of the sand in the box constant and to prevent pollutions (for example ground water) into the embedding of the box, a drainage system was installed and the inside of the box was covered with a watertight plastic lining. To prevent the weather from influencing the test conditions and to protect the entire measuring equipment, a large tent covers the testing facility.

Data will be presented which show the first results of our UWB ground-penetrating radar system. The radar will be employed in the summer of 1998 within the Dutch research project dealing with humanitarian demining.

NUMERICAL EVALUATION OF AN IMPULSE RADIATING ANTENNA USED IN AN ULTRA-WIDEBAND GROUND-PENETRATING RADAR SYSTEM

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At TNO-FEL, several aspects are being explored of using of ultra-wideband (UWB) electromagnetic fields in a bi-static ground-penetrating-radar (GPR) system for the detection, location and identification of buried items of unexploded ordnance (e.g. land mines). In this context, a dedicated UWB GPR system is under development (Figure 1). This system is equipped with identical receiving and transmitting IRA's, designed to operate in the frequency band from 200 MHz to 3 GHz. The transmitting IRA is driven by a pulse generator with a double exponential voltage waveform with a pulse rise time of 90 ps, a pulse width (FWHM) of 3 ns and a peak positive amplitude of 9 kV. This system will be tested in the summer of 1998 within the Dutch research project dealing with humanitarian demining.

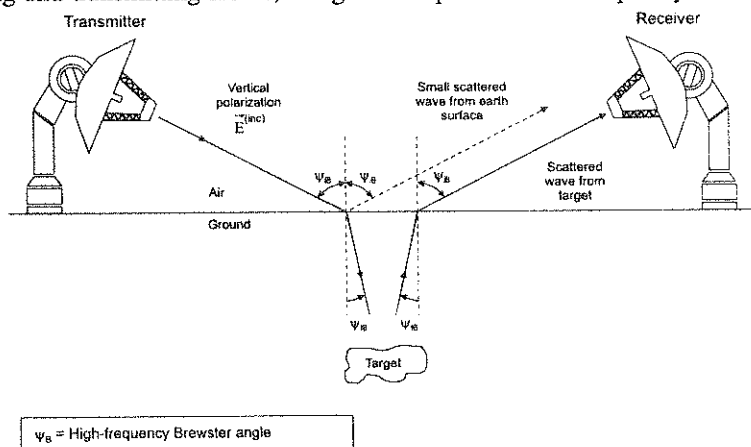


Figure 1 The TNO-FEL GPR system

Within this project, more insight into the performance and behavior of the IRA is needed. In particular it should be possible to evaluate

changes in the design of the antenna. To this end, a numerical method is being implemented for modeling the electromagnetic properties of both the antennas. The current on the IRA is described by the Electric Field Integral Equation (EFIE). Interaction with the ground interface is neglected. In the discretization, Rao, Wilton and Glisson triangular patch basis and expansion functions are employed [1]. The IRA is driven by a point voltage source and the generated field is computed in the frequency domain, using a frequency-independent mesh [2]. Subsequently the generated time-domain field is obtained by applying an inverse discrete Fourier transformation. Representative numerical results will be presented and the performance of the antenna will be discussed.

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FABRICATION AND MEASUREMENT OF A ONE-METER DIAMETER HALF REFLECTOR IRA

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A Half Impulse Radiating Antenna (HIRA) designed by Farr Research, Inc. was constructed from one half of an aluminum 1 m diameter parabolic dish with a focal length of 0.383 m. The half parabola was mounted on an aluminum ground plane through the axis of the parabola. The HIRA design allows for a simple coaxial feed through the ground plane at the focal point of the parabolic dish. The HIRA has two feed arms with a combined impedance in air of 100Ω .

The step response of the HIRA was measured in the time domain using a source with a 4 volt output and a rise time of 18 ps. The radiated field was measured using a TEM horn sensor designed by Farr Research and a Tektronix 11801B digitizing oscilloscope. The radiated field in V/m was computed from the raw voltage by deconvolution with the impulse response of the TEM sensor. A modified Butterworth filter was used to reduce high frequency noise and the minimum value of the denominator term was limited to prevent division by very small numbers. The effective height of the TEM sensor was approximately 17 mm.

The raw voltage in the time domain was measured at 3, 10, and 20 meters. At each distance, the field was scanned in both the H and E planes at 0° , 2° , 5° , 7.5° , and 15° . The corrected measurements converted to V/m were compared with predictions for the HIRA and were used to calculate the half power and half voltage spot size at 20 m.

The HIRA was further characterized by recording the TDR of the antenna and by computing the impulse response of the antenna in both the time and frequency domains. The effective height of the HIRA was approximately 0.13 m which was very close to the maximum expected value of 0.14 m. The FWHM of the impulse response was 30 ps.

DESIGN, FABRICATION AND TESTING OF A PROTOTYPE IMPULSE RADIATING ANTENNA (IRA)

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The objective of this study has been to design, fabricate and test an antenna system that radiates an impulse like-waveform [1]. This has been accomplished in the past, using a paraboloidal reflector [2,3,4]. Such an IRA has many applications in the military and civilian areas.

The prototype Swiss IRA (SwIRA) uses a reflector of diameter $D = 1.8\text{m}$ and a focal length $F = 0.42\text{m}$, resulting in a (F/D) of 0.27. The pulse generator is a double exponential type with a peak amplitude of 2.8 kV, (10-90)% risetime of 100ps, a FWHM of 2 ns and a prf of 1 to 800Hz. The design consisted of feed point considerations, impedance matching, near and far field calculations on boresight. A critical component was to introduce a balun between the single-ended (50Ω) source and a differential input to the antenna with an impedance of 200Ω . The conical transmission lines that illuminate the reflector have a net impedance of 200Ω . This is made up of two lines, each with a characteristic TEM mode impedance of 400Ω , connected in parallel. On axis, near and far fields are estimated and only the near field measurements are presently available. Calculated and representative measured results will be presented. The clear-time between the central ray and the edge rays of the antenna is about 27 ps at an axial distance of 50m. Given the pulse risetime of 100ps, the far field is expected to start at a distance of 50m. The near field is of the order of 1 kV/m and the calculated far field is about 600 V/m at 50 m, resulting in $V_{far} = 30\text{ kV}$, starting from a pulser amplitude of 3 kV.

Additional experimental characterizations of the antenna performance in time domain, as well as with CW sources are being planned.

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- [2] D. V. Giri and C. E. Baum, **Temporal and Spectral Radiation on Boresight of a Reflector Type of Impulse Radiating Antenna (IRA)**, *Ultra-Wideband Short Pulse Electromagnetics 3*, Plenum Publishing Corporation, New York, 1997.
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SUPPRESSION OF OFF-BORESIGHT RADIATION FROM WIDE BAND ANTENNAS

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Communications and radar antennas are often a common source of electromagnetic interference (EMI) for on-board aircraft electronics systems. To reduce this type of interference with sensitive aircraft electronics, the Air Force Research Laboratory (AFRL) has been investigating techniques to suppress the side- and back-lobes of the radiation patterns of directive antennas, while maintaining the main-beam intensity.[§] Though a variety of antenna back-lobe suppression techniques have been developed for narrow-band radiated signals, work at AFRL is presently focused on developing useful suppression schemes across a broader (3-to-4 octave) frequency bandwidth.

Off-boresight radiation from an antenna can be reduced, for a given power density at range R, by increasing the directivity of the antenna or by reducing the external currents on the supporting structures of the antenna aperture. When beamwidth considerations restrict the gain of the antenna, back-lobe suppression can best be accomplished by selective placement of electric or magnetic absorbing materials on or about the antenna structure to suppress external currents or their radiated fields. This approach can yield up to 20-30 dB of back-lobe reduction, without significantly affecting the main beam, for narrow frequency ranges.

In the investigation described in this paper, we sought to increase the bandwidth of conventional narrow-band suppression schemes, and also to identify suppression schemes that were as generic as possible, providing adequate suppression and broad applicability regardless of the antenna topology or the number of apertures. For practical reasons, we restricted the study to horn antenna shapes (with linear polarization), and we limited the possible number of apertures for arrays to 4. To achieve increased bandwidth and generic applicability while conserving limited experimental resources, we first reviewed the narrow-band antenna back-lobe suppression literature and carried out a variety of FDTD computer simulations to identify the most promising approaches. Once identified, test suppression structures were then fabricated and their effects on the beam patterns of single- and multiple-aperture antennas were characterized over a 4-octave frequency range in the laboratory.

This paper first presents the suppression schemes selected for experimental testing from earlier narrow-band investigations and from computer simulations, and then presents the experimental time- and frequency-domain results obtained from the suppression structures fabricated. The results include quantitative comparisons of antenna beam patterns, both with and without suppression treatment, for the E- and the H-plane, and for co- and cross-polarization. Both generic and antenna-specific treatments were addressed in the experiments. Finally, we show that with care, antenna treatments can be formulated to produce wide band side- and back-lobe suppression of up to 20 dB for specific antenna designs, and up to 10 dB for generic horn and horn-array configurations.

[§] see, e.g., D. Robert Smith, Carl E. Baum, Robert J. Torres, K.S.H. Lee, and F.C. Yang, "Suppression of Radiation in Unwanted Directions for a Conical Horn (The Microwave Shade)," USAF Phillips Laboratory Sensor and Simulation Note 404, Kirtland AFB, NM, USA, 30 Oct 96.

ELECTROMAGNETIC LENS DESIGN

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This paper considers the exact design of transient dielectric lenses. The general purpose of such a lens is to propagate transient EM waves with minimal pulse distortion while changing the direction of propagation. Exact dielectric lenses are essentially transition regions which support the propagation of dispersionless TEM waves which satisfy Maxwell's equations for all frequencies in the lens region. The differential geometry scaling method has been used to develop synthesis procedures for lenses, generally with variable permittivity but constant permeability.

Earlier work discussed a special case of a uniform isotropic dielectric lens which can bend a transient TEM wave between two parallel perfectly conducting sheets without distortion, reflection, and dispersion.

Alternatively one can also design an anisotropic lens in which a set of parallel conducting sheets, with small spacing, can be used to bend the direction of propagation of a TEM wave. A very practical case is that of a purely dielectric, but inhomogeneous, bending lens as a portion of a body of revolution (BOR) with propagation in the azimuthal direction. Examples of exact dielectric lenses of this type have been given for bending the propagation direction along the azimuthal coordinates of a BOR. All of these lenses have the same dependence of the permittivity as proportional to the reciprocal of the square of the cylindrical radius from the axis of revolution (the z axis). The cases studied involve planar, circular cylindrical, circular conical, and spherical conducting boundaries. This includes the H-plane bend (planar conducting boundaries). This problem may be approached from the general point of view of a "jacket" in which the conductor spacing, perpendicular to the electric field, is electrically small, and small compared to the dimensions in the direction of the magnetic field.

Further steps in the synthesis of dielectric lenses include a consideration of unipolarized generalized inhomogeneous TEM plane waves in inhomogeneous media. In this case, the formal fields each depend on a single coordinate and the formal media parameters have specialized forms, as products of single variables. The introduction of differential geometric scaling and the condition that the permeability be that of free space gives an extra degree of freedom in transient lens design using differential-geometric scaling.

MINIMIZING DISPERSION IN A TEM WAVEGUIDE BEND BY A LAYERED APPROXIMATION OF A GRADED DIELECTRIC LENS

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Waveguide bends pose a problem for high-voltage UWB systems or for any transmission-line system with low-loss/fast-risetime requirements. The difficulty arises because only a straight section of conventional waveguide can support the pure TEM mode necessary to preserve the risetime of a transmitted pulse. When there is a bend in the waveguide, especially when the cross-section of the waveguide is large, as it typically must be for high-voltage or low-loss systems, the risetime of the transmitted signal is lengthened. This can severely limit the system bandwidth.

Conventional waveguide is filled with a *homogeneous* dielectric material, sometimes air, or is evacuated. Here we consider compensation of a waveguide bend by a purely dielectric lens, characterized by an *inhomogeneous*, frequency-independent, isotropic permittivity. If the relative index of refraction of the lens varies inversely as the radius of curvature, then the optical path length through the bend will be independent of the radius, and the bend will support pure TEM waves.

Although waveguide structures employing lens materials having the required inhomogeneous permittivity profile are easily conceptualized, constructing them is more problematic. In this paper, we describe an approximation employing coarsely graded layers of dielectric materials of various uniform permittivities. We used this approach to compensate a 90-degree H-plane bend in a strip transmission line.

Here, we first summarize the relevant theory. Then, we describe our hardware implementation of the graded dielectric strip line bend. We analyzed the structure numerically, and we determined its performance experimentally. The measured pulse risetime was 70 ps for a straight air section of strip line. For a 90-degree air bend, it was 250 ps. With our layered compensating lens installed, the risetime of the transmitted pulse was reduced to 180 ps. By thus reducing the dispersion of a transmitted pulse, the strip line bend provided a proof-of-principle demonstration of compensation of a waveguide bend by a graded dielectric lens.

Further work in this area is on-going. For example, we are preparing to build coaxial waveguide bends. In one approach, these bends will seek improved performance through the use of very finely or continuously graded lenses, in order to more accurately produce the required permittivity profile. This will address the pulse risetime limitation posed by differences in signal transit times for the lens material layers. In another approach, a single, sculptured dielectric material will partially fill the cross-section of the waveguide. Although a design based on this approach would have an anisotropic effective permittivity, its performance should be adequate for some applications.

Dielectric compensating lenses will permit even electrically large waveguide bends to be implemented with minimal dispersion. Use of such bends would permit more compact and convenient designs of high-voltage UWB or low-loss systems.

A LINEAR ARRAY OF ULTRA-WIDEBAND RADIATORS DRIVEN BY PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHED BLUMLEINS

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An array of ultra-wideband (UWB) pulse radiators is presented. Each array element consists of a parallel-plate blumlein driving a matched, low impedance impulse radiating antenna (IRA). Each blumlein is charged with the same pulse power conditioner and each is independently commuted with a lateral photoconductive semiconductor switch (PCSS). Switching is achieved by illuminating each lateral PCSS gap with a compact, low power solid-state laser diode array and driver module. Low timing jitter of all devices used in the switching process enabling precise timing of each element for array beam forming and beam steering control. Each of the array IRAs is a tapered flat-plate rectangular TEM horn with 4:1 width-to-height aspect ratio, resulting in a 70- aperture impedance. Four elements are inter-connected and stacked in the electric field plane (*E*-plane) so that their fields constructively add in the far field. The size of the entire array aperture is 30.5 cm on a side. For the purpose of performance comparison, the field and spectral content of the array is compared to a single element source with the same aperture size as the array. The comparison shows that peak radiated field of the array is greater than N^2 than for the elemental source, all other conditions being equal. In addition, the array shows a 10-fold improvement in the efficiency of radiating low frequency components of the drive waveform. Analysis and numerical calculations indicate that these performance improvements are due to greater aperture efficiency and greater directivity of the lower-impedance elements used in the linear array. The figure shows the measured radiated field profile on bore sight in the far field. The rise time is 300 ps and the peak field-range product is 20 kV.

ULTRA-WIDE BAND DUPLEXERS FOR LOW AND HIGH PEAK POWER APPLICATIONS

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In the frame of a six years research project called Hued (Humanitarian DEMining) the Royal Military Academy (RMA) is developing a lightweight and compact Ultra-WideBand Impulse Radar (400 MHz - 4 GHz) with the purpose of detecting and locating abandoned antipersonnel landmines.

In contrast with the conventional GPR (Ground Penetrating Radar) that uses two separate antennas to transmit and receive the signal, the UWB Impulse Radar in development at the RMA will need only one antenna. This is possible when a broadband duplexer is available. Conventional duplexers like circulators, directive or hybrid couplers exhibit a bandwidth that is too limited (a few percents) to be able to transmit and receive without distortion the ultra-wideband signal waveform. They are therefore useless for short pulse radar applications. Hence special broadband duplexers have been designed at the RMA to be able to transmit and receive the short pulse signals used by the UWB impulse radar without significant distortion.

The first duplexer, designed for low power radars, is an active switch based on a fast AsGa SPDT (Single Pole Double Throw/3 ns switching time) combined with a power splitter, a coaxial matched termination and a broadband amplifier. The duplexer is triggered by the radar transmitter so that the power signal is routed to the antenna and that the echo signal received by the same antenna from the target can be routed to the receiver.

The second duplexer can be used by high peak power radars (up to 50 kW peak power). It is based on the use of power splitters and a pulse inverter mounted in a suicide transmission line. If necessary a broadband amplifier can be integrated in the duplexer to compensate for the loss in the power splitters.

The paper will describe the design of the two ultra-wideband duplexers and will outline their performances in terms of power rating, speed, isolation, insertion loss, size, weight and cost. Such duplexers can offer many advantages for low or high power UWB radars where monostatic configuration is preferred. They contribute to a gain of space, weight and money, three important factors in the design of portable detection systems for humanitarian operations

LARGE CURRENT RADIATOR FOR THE SHORT ELECTROMAGNETIC PULSES RADIATION *

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The report discusses the design of a large current radiator (LCR) [1] and its observed performance. The metallic plates of complicated shape used as the radiating element. Two TEM-horns for impedance matching reduce distortions and increase the amplitude of the current pulses driving the radiator. The shield and the TEM-horns make it possible to achieve dipole rather than quadrupole radiation. The use of a relaxation pulse generator with an S-diode provides good energy efficiency. This made it possible to use a battery as the power supply. The use of a battery and the ability to trigger the S-diode via infrared radiation removes many sources of distortion from the vicinity of the radiator. Using a battery also permits a reduction of size and weight of the LCR. A three-layer metal-ferrite-ferrite shield suppresses radiation from the return loop significantly. The independent power supply and the triggering of the radiation via infrared radiation make this LCR usable as element of an antenna array.

The designed LCR has the following features:

- peak current driven through the LCR is 12A;
 - time variation of the radiated electric and magnetic field strength resembles one period of a sinusoidal oscillation with the following characteristics:
 - rise time of the electric field strength from 0 to $|E_{\max}|$ is 0.5ns;
 - duration of the first half period of the electric field strength measured at $0.5E_{\max}$ is 1ns;
 - total duration of first and second half period is 3.5ns;
 - pulse repetition rate can be varied from 150Hz to 1000Hz;
 - peak amplitude of the electric field strength is about 56V/m at a distance of 3m from the radiator;
 - beam width of the peak amplitude pattern of the LCR for the electric and magnetic field strength are:
 - electric field strength in the E-plane measured at the level of $0.5 E_{\max}$. 70° ;
 - magnetic field strength in the H-plane 360°
- (The magnetic field strength varies between 0.57 and 1 for a rotation of 360°).
- a power supply for nominally 5V, or 4.5 to 6V, and a current of 0.15A is required;
 - size of the LCR is $0.4 \times 0.3 \times 0.15 \text{ m}^3$;
 - weight is 1 kg.

The results obtained show that the LCR is a very promising radiator for non-sinusoidal carrier-free signals.

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ATTENUATION OF EMP FIELDS AND EMP INDUCED CURRENTS BY A WIRE MESH AND A WIRE GRID STRUCTURE.

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A 6x4x2.5 m wooden structure has been located in the working volume of a 1MV parallel plate EMP simulator at RAFAEL. The structure was covered either by a thin aluminum mesh (18 mesh) or by a 20x20 cm rebar grid. The internal E and H fields have been measured and compared to the values measured before the shielding cover was constructed. Currents on wires which form loops around the main cross sections of the structure, have also been measured.

Measurements have been performed while the shielding envelope of the structure had no openings and also while different openings existed in the shielding envelope. The following attenuations have been calculated from a comparison of the measured amplitudes:

1. Mesh shielding: E_z -63dB, H_y -56dB, Loop current-52 dB.
2. Wire grid: E_z -10dB, H_y -21dB, Loop current-12dB.

Where E_z and H_y are the main components of the E and H fields respectively.

From the Fourier analysis of the measured values, the attenuation in frequency domain was calculated.

BOUNDING OF VOLTAGE RESPONSE

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Past efforts have met with some success in bounding the energy absorbed by a resistive load in a transient field [1-5]. The reason for the success is the availability of an integral bound on the absorption area over all wavelengths. Very often the load voltage is a more important quantity than either energy or power, as in the discussion of system upset. A voltage can be induced across an inductance, a capacitance, or a resistor. The real power or energy absorbed by an inductance or a capacitance is of course zero. Thus, in bounding the load voltage in general, one is not helped by the conservation law of energy or power which, together with the causality principle, leads to the integral bound on the absorption area. In the particular case where the load is a resistor and the field is time varying, one can invoke the integral bound on the absorption area to bound the peak load voltage.

This paper deal with bounding the voltage response at an antenna's terminal with or without a transmission line attached to it, first in a time-harmonic field and then in a time-varying field. The same attempt is made for the terminals of a multiconductor transmission line, but much work remains to be done.

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NEMP INDUCED TRANSIENTS ON TRANSMISSION LINES WITH NON-LINEAR LOADS

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The high electric field strength of Nuclear Electromagnetic Pulses (NEMP) can produce transient overvoltages and currents of considerable magnitude on transmission lines. Devices connected to these lines will therefore, in many cases, be equipped with non-linear protective elements such as spark gaps, varistors, diodes or with combinations of these elements. The non-linear nature of protective elements must be considered for a reliable prediction of the voltages and currents that occur when a transmission is illuminated by a NEMP.

The shape of the exciting pulse and its main parameters: rise time, pulse length and peak value, can vary significantly dependent on the characteristics of the nuclear explosion. The proposed presentation will investigate the influence that the basic pulse parameters have on the resulting overvoltages and currents when different types of non-linear elements are used to protect sensitive devices.

Pulses of the following shapes will be considered:

- 1) Double exponential:
$$e(t) = E_0 \cdot (e^{-t/T_1} - e^{-t/T_2})$$
- 2) Reciprocal-exponential:
$$e(t) = \frac{E_0}{e^{-t/T_1} + e^{+t/T_2}}$$
- 3) Trapezoidal shaped:
$$e(t) = \begin{cases} E_0 \cdot \frac{t}{T_1} \\ E_0 \cdot \left(1 - \frac{t - T_1}{T_2}\right) \end{cases}$$

Especially in the case of spark gaps as protective elements or where parasitic inductances have to be taken into account the resulting overvoltages are dependent not only on the peak value of the exciting field, but also on the rise time and the pulse shape. The paper will compare maximum voltages and currents generated by the different pulse shapes for several typical non-linear elements and will help to choose worst case configurations for detailed analyses.

Another important aspect not to be neglected is that reflections will occur at the locations where protective elements are placed. These reflections may lead to an increase in voltage or current at other locations along the transmission line. This will also be addressed in the presentation.

The calculations will generally be made in the time domain to allow treatment of the non-linear elements but in some instances frequency spectra will be presented as well.

ELECTROMAGNETIC FIELD COUPLING TO AN ELECTRICALLY SMALL SCATTERER IN A RECTANGULAR CAVITY

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The necessity to study the electromagnetic radiation coupling to electrically small scatterers (which may however have a complex internal structure and own resonances) inside a rectangular metallic enclosure is connected to a number of electromagnetic compatibility problems like the evaluation of strong electromagnetic field effects on printed circuits inside racks and enclosures with slots and apertures, the mutual coupling between them, and the estimation of scatterer effects on resonant properties of reverberation chambers.

In this paper we propose a method to estimate analytically currents induced in these scatterers. This method is similar to the small range potential method in quantum mechanics [1]. It is known [2], that the current induced by an external electrical field E_z^0 in a wire scatterer located in the free space (for instance, the loaded vibrator can be considered), which generally is determined by an integral equation with a free-space tensor Green's function $\hat{G}^0(k, \vec{R}_1 - \vec{R}_2)$, can be represented for the electrically small scatterer as $J^0(l) = E_z^0 \cdot K_E(\omega) \cdot f(l)$. Here $K_E(\omega)$ is a frequency domain response function, $f(l)$ a dimensionless frequency independent function equal about to one (for simplicity we assume that the vibrator is directed along the axis z). On the other hand the current induced by an external field \vec{E}^{RES} in the scatterer located in the resonator is determined by the solution of an integral equation with the resonator tensor Green's function $\hat{G}^{RES}(k, \vec{R}_1, \vec{R}_2)$ [3]. The method consists in dividing the resonator Green's function on small distances $kR \ll 1$ ($R \equiv |\vec{R}_1 - \vec{R}_2|$) into two parts. The first part is a Green's function in the free space which is singular at small distances. The second part is a renormalized resonator Green's function $\tilde{G}^{RES}(k, \vec{R}_1, \vec{R}_2)$ which interval of significant space variation is about the wavelength λ . The function can be considered as a constant within the limits of the characteristic size of the vibrator L ($L \ll \lambda$). In this case it is possible to look for a solution for the induced current in the scatterer inside the resonator as a current induced in the same scatterer in the free space multiplied by a constant

$$J(l) = E_z^{RES} \cdot K_E(\omega) \cdot f(l) / \left(1 - \tilde{G}_{zz}^{RES}(k, \vec{R}_1, \vec{R}_1) \cdot K_E(\omega) \cdot L \right)$$

The obtained result gives the possibility to estimate analytically the frequency dependence of the induced current, including the case of close resonance frequencies of the scatterer and the cavity, mutual coupling of the scatterers, and the influence of the scatterers on the resonant properties of the cavity.

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EXPERIMENTAL IMPACTS OF QUASI-DC CURRENTS ON TRANSFORMERS

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It is a well-established fact that geomagnetic storms influence electrical power transmission and distribution systems. In the northern latitudes, these storms have resulted in occasional power disruptions and, in some cases, damage to power transformers. The effects are caused by a time variation of the earth's magnetic field creating an induced electric field along the surface of the earth. The electric field acts as a voltage source along long power transmission or distribution lines, and if the lines are connected to earth at both ends, a quasi-dc current can flow. This current can cause unwanted saturation in the magnetic cores of transformers in the power system, which produces harmonic distortion and transformer heating. Saturated transformers also consume reactive power, which places higher reactive power demands on the power system. The power frequency harmonics, transformer heating, and additional reactive power demand can lead to power system disruptions and possibly damages to transformers.

A high-altitude nuclear explosion is also known to affect the magnetosphere, producing variations of the earth's magnetic field for several hundreds of seconds. This magnetic field distortion, known as the magnetohydrodynamic electromagnetic pulse or late-time high-altitude electromagnetic pulse, is of particular concern to electrical power systems since its effects will be similar to very severe solar storms. Although the induced currents can be significantly larger in magnitude than those resulting from solar storms, they have much shorter time durations.

An important issue in assessing the effects of relatively short duration quasi-dc currents on transformers is the response time of transformers to these transient currents. Electrical and thermal response times are both important for transformer and power system assessments. If the required response times are longer than the quasi-dc current duration, then there will be little or no impact on transformers. This paper presents the results of experiments designed to increase the understanding of the behavior of distribution-class power transformers subjected to quasi-dc current excitation. It was found that significant harmonic distortion and increased reactive power demand occurs within a fraction of a second for quasi-dc levels of a few amperes for a 75 kVA three phase distribution transformer. The transformer response time was found to be highly depended on the injected current.

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THE USE OF TEM COAXIAL CELLS FOR DETERMINING SHIELDING EFFECTIVENESS IN THE PLANE WAVES REGION- -THEORETICAL AND PRACTICAL LIMITATIONS

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Based on previous results (M.Badic, M.J.Marinescu & C.Paun - Proceedings of EUROEM 94 Bordeaux, France and M.Badic & M.J.Marinescu - AMEREM 96, Albuquerque, NM, USA), we are now able to show when and how to use TEM circular coaxial cells in order to determine, as precise as possible, shielding effectiveness (SE_{dB}) of different materials.

In theory, the modelling of the ideal case of infinite plane shield in the Fraunhofer zone by means of TEM coaxial holder is accepted. That is why the method was applied on large scale, but results were not as accurate as expected, so generally it is said that this method is good "only for ranking".

In fact, based on the wave impedance concept, introduced by S.A. Schelkunoff, there is a mathematical isomorphism between the ideal and TEM cell cases, which allows us to replace a shielding effectiveness measurement with an insertion attenuation (IA_{dB}) measurement. A detailed analysis of theoretical problems implied by this isomorphism indicates that two different cases should be considered (thin and thick samples from electrical point of view), each with two sub-cases (TEM cell with propagation and TEM cell considered as lumped constants circuit). This was the starting point of our demonstration in order to specify how to use TEM cells with good results. In addition, an original way of presenting the conditions imposed to TEM cells allowed us to demonstrate why certain results do not fit to isomorphism theory at all.

We present, in this paper, both theoretical and practical limitations for the TEM cells measurements and the conclusion that there are cases when these measurements offer quite accurate results (certain corrections must be considered) and other cases when these measurements are not able to offer not even approximate results.

We performed experiments on different materials (Iron, Bismuth, Ferrite, Conductive Rubber, a.s.o.) that support our assertions. Experimental results are included in the paper together with the theoretical demonstration.

FAILURES ON TRANSMISSION DATA INTERFACES DUES TO TRANSIENTS ON THE EARTH PROTECTION WIRE

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This paper treats about failures on data transmission interfaces induced by voltage transients on the earth protection wire. It is based on a study of modems failures connected to remotes data terminals through RS-232 interfaces. Other data interface could also be damaged by this mechanism of failure (RS-422, Ethernet, Token Ring, etc.).

On this type of failure the failed circuits (drivers and receivers RS-232) are not located nearby the transient entry gate (telephone line and VAC inputs). They are in an interface between two equipments and usually the only failed components are the drivers and receivers.

Figure 1 shows the connections between a modem and a remote data terminal.

Figure 2 shows the equivalent circuit of the RS-232 connection between a data terminal (a PC) and a modem, when a transient go through the earth protection wire. The common wire of the RS-232 interface connects the two ground wires of the DC powers supplies (COM1 and COM2). Internally the PC power supply joined the earth wire (T1) with COM1. The modem has power supply decoupling capacitor (C4) between earth wire (T2) and COM2.

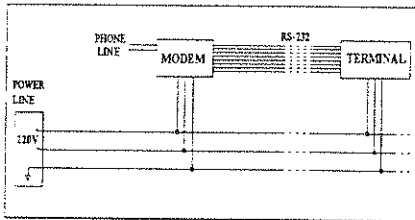


Figure 1

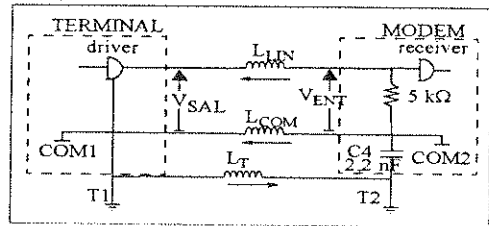


Figure 2

When a fast transient go through T1 and T2, some voltage is induced on L_{COM} by C4. As L_{LIN} have a series resistance of 5 kΩ (the typical RS-232 driver input resistance) a despicable voltage drop on it. Then the voltage induced on L_{LIN} is divided between the driver and receiver impedances:

$$V_{COM} = V_{ENT} + V_{SAL}$$

It was applied a discharge of 1000 V, with a waveform 1.2/50 μs, between T1 and T2. The discharge induced a damped sinewave with a peak value of 70 V and a frequency of 333 kHz. It has been simulated a simplified model of the previous circuit using SPICE obtaining a similar waveform.

ON THE POSSIBILITY TO MEASURE THE INTERNAL INDUCTANCE OF CONDUCTORS VERSUS FREQUENCY

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The paper deals with the theoretical basis referring to experimental checking of dependence of internal inductance of the cylindrical circular straight conductor versus frequency. As known, total inductance of such a conductor is the sum of two component parts:

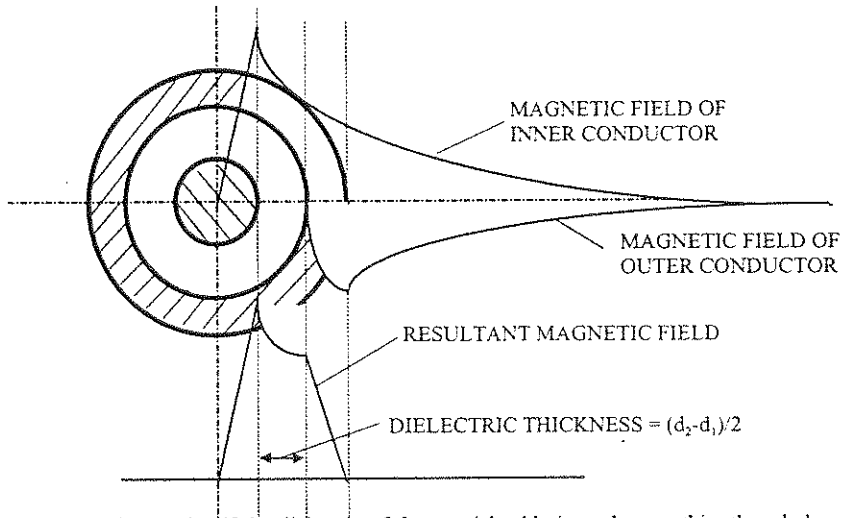
$$L_{TOT} = L_{ext} + L_{int}; \quad L_{ext} = F(\mu_0, l, r); \quad L_{int} = F(\mu_0, \mu_r, l, f, \sigma, r)$$

where L_{ext} is external inductance and depends on magnetic (μ) and geometric (l, r) factors, and L_{int} is internal inductance and depends also on electric conductivity (σ) and frequency (f).

The formula of internal inductance (expressed by means of Bessel Functions) shows that it decreases from the maximum value ($L_{int\ max} = \mu_0 \mu_r l / 8\pi$) to 0 versus frequency in the area of medium skin effect. But, because of the extremely low magnitude of $L_{int\ max}$ (approx. 50nH/m for $\mu_r \cong 1$) it is very difficult to measure L_{int} value versus frequency, L_{ext} having a very large value.

Authors suggest a new method in order to determine this variation, starting from the expression of inductance, respectively the configuration of magnetic field, that characterize the coaxial cable:

$$L_{TOT} = \frac{\mu_0}{2\pi} \left[\ln \frac{d_2}{d_1} + \frac{1}{\sqrt{\pi\mu_0\sigma f}} \left(\frac{1}{d_1} + \frac{1}{d_2} \right) \right] [H / m]$$



One can observe that if the dielectric of the coaxial cable is made very thin, the whole magnetic field is virtually made up by the internal magnetic fields of the two conductors that build the cable. This principle led the authors to the elaboration of an experimental method in order to measure internal inductance versus frequency.

ON THE CALCULATION OF GEOMAGNETICALLY INDUCED CURRENTS IN ELECTRIC POWER SYSTEMS

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The combination of large geomagnetic disturbances of solar cycle 22 and the construction of electrical power systems with longer lines and more efficient transformers has resulted in widescale damage to components of these power systems, particularly from the March 1989 storm. The geomagnetic disturbances often have a "sudden onset" phase with large time derivatives of the geomagnetic field, and relatively uniform perturbed magnetic fields over large regions. This later develops into an electrojet characterized by a line of current typically at 100 km altitude with magnitudes up to a megampere. Early calculations of the geomagnetically induced currents (GICs) on power systems used a technique based on earth surface potential gradients (ESPG) that is only valid when the surface electric field can be represented by the gradient of a scalar potential, that is when the horizontal electric field is irrotational. This technique can provide a good representation for the sudden onset phase if the horizontal variations in the earth conductivity profile are small, but it is necessary to use a procedure where the horizontal electric fields resulting from the geomagnetic disturbances are integrated along the power lines to calculate system currents associated with the electrojet, as the rotational parts of the horizontal electric field are substantially greater than the part that can be derived from a potential. Physically, this is due to the fact that the coupling between the electrojet and the power system is inductive. (The sudden onset phase also couples inductively, but a uniform electric field can be represented either as the gradient of a scalar potential or as the curl of a vector potential.)

Fortunately, when the admittance matrix technique is used to solve for quasistatic currents in resistive models of electrical power systems, there is a transformation between the ESPG technique and the line integrated electric field (LIEF) technique that allows models developed for ESPG to be easily modified to calculate the system currents resulting from electrojets. In this paper we will show the limitations of ESPG calculations for electric power systems of different sizes and show how the GICs resulting from the electrojet fall off at distances away from the jet location. We will also show the effect of horizontal variations in the earth conductivity profile.

ON THE CALCULATION OF ELECTRO-MAGNETIC FIELDS IN CONDUCTORS

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New approach to solve Maxwell equations in the finite conductive area is presented. Unlike the most existing methods this one does not require the calculation of the field in the surrounding nonconductive infinite area and the consequential conjugation with the solution in the conductor on its surface. The boundary integral equation is derived from the Maxwell equation using the physical boundary condition - zero field in infinity. This equation connects the magnetic vector potential on the surface with its normal derivative and the potential of the field produced by the given external source. This approach permits us to create efficient numerical solvers for low-frequency Maxwell equations and easily take into consideration the interaction between the conductive area and external sources of electric and magnetic fields.

RECENT EXPERIMENTAL RESULTS AND PLANNED HIGH POWER APPLICATIONS OF THE ISRAELI TANDEM FREE ELECTRON LASER (FEL)

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The Tandem - FEL is an Electrostatic Accelerator Free Electron Laser (FEL) operating presently at the mm wavelength regime. It was constructed by the Israeli FEL consortium (including Tel-Aviv University, Rafael, NRCN), who converted the old tandem van-der-Graaff ion accelerator of the Weizman Institute into a high current electron accelerator and modified it to include an internal wiggler and a mm wave cavity. This Electrostatic-FEL configuration is the only one that can operate at high average power (potentially MWatts). The Tandem FEL group demonstrated pulsed lasing using it for the first time at a power level of 1.2 kW and at frequency 100.5GHz.

The FEL is presently being upgraded to operate at a record long pulse duration (1mSec), and subsequently in a repetitively pulsed mode at an average power of 1 kWatt. At this power level a number of material processing applications will be tested including sintering of Ceramic layers and H.T. S. C. materials and surface treatment of metals.

A quasi-optical radiation transport system is presently under construction, to be used for bringing the radiation power from the internal resonator output to the work.

Details of the FEL design and recent experimental results will be presented. Development options of the FEL facility (pulsed operation with a photocathode injector, extension to the THz frequency regime) will be discussed. Future scientific, industrial and energy applications of this FEL technology will be delineated.

INVESTIGATIONS ON MICROWAVE FEL DRIVEN BY MICROSECOND SHEET BEAM

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Investigations on generation of microwave radiation on the scheme of Free Electron Laser driven by high-current sheet electron beam are carried out at BINP[1]. Three main problems are solved: to generate a sheet beam with required parameters, to achieve the highest efficiency in energy transfer from E-beam to microwave radiation and to provide a spatial coherence for the electromagnetic waves with a large cross section of a flow. Results of investigations on solving these problems are presented in the paper.

The first stage of experiments was performed at the U-2 accelerator with the sheet beam at the following parameters: $E_e \sim 1\text{MeV}$, $I_b \sim 3\text{kA}$, $\tau_b \sim 5\mu\text{s}$, $S_b = 0.2 \times 12\text{cm}$. The beam was passing through a slit vacuum channel with the cross section $1 \times 20\text{cm}$ and the length about 1m . In the channel a guiding magnetic field had a longitudinal component varied from 3 up to 13 kG. A transverse undulating component of the field had spatial period 4cm and unchangeable amplitude on the level 1kG. For the pointed parameters of the experiments the FEL driven by the sheet beam, produced 4 mm wavelength radiation with 200J total energy content at pulse duration of a few microsecond (See [1]).

The further development of the FEL studies is performed on the U-3 accelerator [2] specially modified for the sheet beam experiments. In differ from the first stage experiments the plane undulator has been replaced by a new one with varying amplitude of the transverse component that is necessary for optimization of the generator. For reaching single mode operation of the generator one-dimension Bragg gratings in the FEL resonator are also replaced by two dimensional ones [1]. In addition, during the experiments we can control a longitudinal velocity spread of the electrons and can measure this spread by CO_2 -laser scattering on the beam electrons. In order to eliminate the effect of RF-break down, the slit channel is added by a big size vacuum chamber that the microwave measuring equipment is put in.

Perspectives to increase the energy content of the radiation pulse up to ten kJ are based on using microsecond sheet beam with the cross section $\sim 1 \times 140\text{cm}$ and the current $\sim 30\text{kA}$. Such kind beam with the energy content of 0.4 MJ has been already produced at the U-2 accelerator [3]. Good coherence of the generated radiation can be provided by using the resonator with 2-D Bragg gratings.

The work is supported under ISTC grant # 531.

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SPONTANEOUS AND SUPER-RADIANT EMISSIONS IN FREE-ELECTRON LASERS

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Electrons passing through a magnetic undulator of a free-electron laser (FEL) emit a partially coherent radiation which is called *undulator synchrotron radiation*. In a classical analysis each wiggling electron is a point source, which can be treated as a moving radiating dipole. Since the radiation process takes place in the absence of applied electromagnetic radiation, it is termed *spontaneous emission*.

An individual electron moving in an undulator emits a wave-packet of electromagnetic radiation which is in synchronism with the electron. When a continuous (unmodulated and unbunched) electron beam advances through a periodic field of a wiggler, the radiation from different electrons, which enter the undulator at random, adds up incoherently. This radiation is essentially *shot noise*, resulting from the charge fluctuations in the e-beam due to its corpuscular nature and the random electron distribution. Coherent summation of the radiation from individual particles occurs if the electrons are injected into the undulator in a single short bunch (shorter than the oscillation period of the emitted radiation) or enter as a periodic train of bunches at the frequency of the emitted radiation. Only in these cases do the electrons radiate in phase with each other (*super-radiant emission*) and the radiation is coherent.

A generalized formulation of spontaneous emission and super-radiance effects in a free-electron laser is presented. We consider a stream of electrons of arbitrary temporal current distribution propagating through the undulator. Using the waveguide excitation equations formulated in the frequency domain, an analytical expression for the power spectral density of the electromagnetic radiation is derived. It is shown that the spectrum of the excited radiation is composed of two terms which are the spontaneous and super-radiant emissions.

NOVEL SOURCE OF POWERFUL SUBNANOSECOND MICROWAVE PULSES BASED ON THE SUPERRADIANCE

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In recent years much attention has been given to theoretical considerations of superradiance (SR) from space-localized non-equilibrium ensembles of electrons. This phenomena includes features which are presented in both as stimulated (self-bunching and coherence) as spontaneous processes (absence of threshold). It is reasonable to consider SR in a specific situation when the electron pulse duration essentially exceeds the operating wavelength (otherwise traditional spontaneous emission is effective) while at the same time is less or comparable with the interaction length (in contrast with traditional mechanisms of stimulated emission of quasi-continuous electron beams which are used extensively in microwave electronics).

Different types of superradiance associated with different mechanisms of stimulated emission (bremstrahlung, cyclotron, Cherenkov) have been observed experimentally in Ka band based on RADAN 303 accelerator as a source of intense subnanosecond electron bunches. The maximal power and SR pulse stability and reproducibility have been achieved for Cherenkov emission of electron bunches moving in periodical slow-wave structure.

Observation of RF breakdown of ambient air as well as the illumination of a panel of neon bulbs with a finely structured pattern corresponding to the excitation of the TM₀₁ mode leads to an estimate of the absolute peak power of 25-30 MW. The realized repetition rate 25 pps mode of operation give reason to consider that novel a table-top source of powerful subnanosecond Ka band pulses has been developed. It is promising to consider the application of a source in areas such as novel diagnostics and the study of nonlinear phenomena in plasmas and solids. It is also interesting to test the influence of such pulses on biological objects.

NUMERICAL RESEARCH ON DYNAMICS OF A RADIATING LAYER FORMATION IN AN ELEMENTARY SUPERLIGHT SOURCE

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The use of microwave generators based on a superlight source makes possible to increase the power of electromagnetic radiation sources of microwave band in orders, reduce pulse duration to picoseconds and to left restrictions on the size of the energy- accumulation region which are not overcome by existent pulse technologies. The power of microwave generator based on a superlight source increases as the characteristic wave length of radiation decreases and can be increased by straightforward increasing of its sizes. A large-scale source with high radiated energy can be constructed of little "elementary" sources in which the dipole radiating layer propagating at the superlight velocity is formed.

The results of numerical research on a dipole layer formation in an elementary superlight source are presented in the report.

The radiating element (see Fig.1) constitutes the diode with the cathode of photoemission material and the anode in a net form. Electrons emanated by luminous radiation are accelerated in interelectrode electric field and having passed through the net they form the radiating dipole layer in above-net space. In general, the acceleration process produces changes in spatial-temporal distribution of the current density and the form of time-dependence current function on the anode and the cathode may be different. If the interelectrode gap is much less than the characteristic electrode size then at the occurrence of a superlight pulse on the cathode the pulse of accelerated electrons on the anode will be superlight also. Hence, a phased radiating dipole layer is formed over the net. The diode with discharge of this type will be a superlight source of electromagnetic radiation and thus possesses all properties of such sources [1]. Varying the parameters of radiating element (diode), choosing various sources of luminous radiation and various supply sources for the diode we can obtain rather wide spectrum of devices generating an electromagnetic pulse of microwave band.

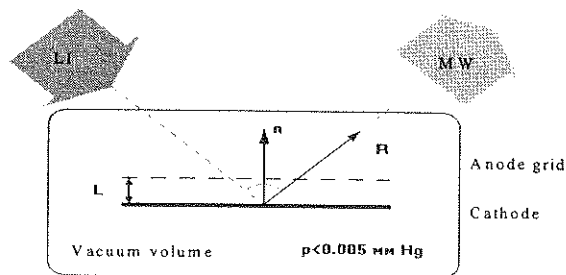


Fig.1. Principle of electromagnetic pulse generation by superlight current pulse.

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HIGH POWER MICROWAVE SOURCES WITH 200 P.P.S. REPETITION RATE

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Results of two experiments are presented aimed on creation of efficient repetitively-pulsed BWO's with no application of superconductive magnets.

In the first experiment, one-second batches of 0.7 GW, 20 ns X-band microwave pulses were obtained from a traditional relativistic BWO utilizing strong magnetic field (~3 T). The one-second pulses of magnetic field used have been produced in a solenoid fed from a bank of molecular capacitors. The energy stored in the bank was about 1 MJ. The solenoid has been cooled for few minutes after each cycle.

Another scheme of relativistic X-band BWO with low magnetic field (~0.6 T) allowed to realize a continuous repetitively-pulsed regime with 0.5 GW power and 10 ns pulse duration. A principal feature of the novel BWO concept was the application of resonant reflector instead of beyond cutoff-neck. This made it possible to use a slow wave structure with extended (by the factor of two) cross-size and the cathode of respectively increased diameter. The reflector serves simultaneously as a modulating gap for the electron beam. The latter effect is of big importance for mode selection in the moderately oversized BWO. The power consumption of DC solenoid was about 25 kW.

USING DYNAMIC CHAOS FOR GENERATION OF POWERFUL MICROWAVE NOISE SIGNALS IN POWERFUL BACKWARD WAVE OSCILLATORS

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The nonlinear dynamics of backward wave oscillators investigated earlier demonstrates that as electron current increases a steady state generation regime becomes unstable and changes on self-modulation regime [1]. Moreover under large exceeding of electron current over threshold chaotic self-modulation should occur. For the low power (milliwatt) sub-relativistic BWO the consequence of bifurcation of generation regimes described above have been observed in [2].

In present work, the first results of theoretical and experimental investigations of self-modulation in powerful BWO are presented. The aim of these studies is to create a powerful X-band noise source based on the dynamic chaos. Experiments have been carried out using the microsecond accelerator <Saturn> with magnetron-injector gun. As an operating mode, the lowest π mode was chosen to avoid competitions of different waveguide modes. The operation frequency was 7.5 GHz. According to the numerical simulations for the observation of the self-modulation, the length of interaction space of BWO was increased up to 10 wavelengths. Under operating voltage 70 kV bifurcation of oscillations regimes occurred when electron current had been increased from 4á to 30á. In he self-modulation regimes the amplitude of output signal had sinusoidal modulation, then with increasing of the current the radiation presented the periodical set of spikes. A typical period of the self-modulation was 13 ns and it corresponded to the time of perturbation propagation over feedback circle. Under large currents, the chaotic self-modulation regimes have been observed. The mean power in chaotic regime was about 100 kW. The further increasing of power was limited by RF breakdown.

At the next stage of the work using special technology, we intend to improve an electrical strength of inner surfaces of waveguide and increase the operating current as well as output power.

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DEVELOPMENT OF HIGH POWER GYRO-AMPLIFIERS AT Ka-BAND AND W-BAND FOR RADAR APPLICATIONS *

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Recent advances in the development of high power Ka-band and W-band gyro-amplifiers for millimeter wave radar systems will be presented. Potential applications for such systems include high resolution imaging, precision tracking and cloud physics studies. For most of the applications in the millimeter wave band the relatively high atmospheric absorption necessitates the use of high power sources. In addition, many of the applications call for extended instantaneous bandwidth. Recent investigations at Naval Research Laboratory have been focused on enhancement of the power-bandwidth product in millimeter wave gyro-amplifiers. Both gyro-klystron and gyro-twystron type circuits have been investigated to achieve this goal. The two cavity gyro-klystron circuit at Ka-band produced 210 kW output power at 37% efficiency with a 125 MHz FWHM bandwidth¹. Three cavity experiment produced 190 kW output power at 28% efficiency with 210 MHz bandwidth. Four cavity gyro-klystron results will be also presented. At W-band four cavity gyro-klystron circuit produced 60 kW peak output power at 25% efficiency with a 640 MHz FWHM bandwidth². The gyro-twystron circuit achieved 50 kW peak output power at 17% efficiency with 925 MHz bandwidth. This represent a record power-bandwidth product at W-band. The experimental results are in excellent agreement with theoretical predictions. Transition of the gyro-amplifier technology into millimeter wave radar systems will offer significant improvements in radar detection, imaging and tracking.

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GYROTRONS AND GYROKLYSTRONS: DEVELOPMENTS AND APPLICATIONS

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Gyrotrons and gyroklystrons are based on the induced electron-cyclotron resonance (ECR) radiation of electrons gyrating in constant magnetic field. This mechanism provides effective interaction of intense electron beams with RF fields of oversized resonant cavities allowing to shift various power limitations at shortest microwaves to values inaccessible for traditional devices (TWT's klystrons, magnetrons etc.). Now the gyrotrons, oscillators, and gyroklystrons, amplifiers dominate over the total millimeter wavelength range in the output power in CW and long-pulsed regimes of operation. Owing to this, new high power and high-energy applications are being developed basing on specific features of propagation and interaction of the shortest microwaves in various media (atmosphere, plasmas and solid materials).

The oscillators, gyrotrons, are developed and produced at frequencies from 8 GHz to near 300 GHz with stationary magnetic fields and over 600GHz with pulsed ones. The frequency range output power and type of a magnetic system of gyrotrons depend on their destination.

The most powerful near - 1 MW gyrotrons are developed for ECR heating of plasmas in nuclear fusion installations. They need superconducting magnets and operate at a fixed frequency in a range from 50 GHz to 170 GHz in pulse of near - 1 s or several-second duration. For the project of the International Thermonuclear Experimental Reactor (ITER) there are being developed gyrotrons at 170 GHz frequency with 1 MW output power in CW regime.

Radiation of the gyrotrons can be effectively used for some plasma chemical processes and formation of intense flows of multi-charge ions. The highest frequency gyrotrons are used for various diagnostics in the nuclear fusion installations.

For some technology applications, e.g. high-temperature processing of materials, gyrotrons with output near or somewhat over 10 kW is usually required now. Mostly, for them superconducting systems are not desirable but either normal solenoids with liquid cooling or permanent magnets. So the operating frequencies of the technology gyrotrons are situated near 30 GHz. Using gyrotrons, it is possible to obtain some materials with unique properties and lesser waste of energy and time as compared with the conventional heating.

The amplifiers, gyroklystrons, are destined usually for various radar systems. Their standard frequencies are near either 35 GHz or 94 GHz. There are developed a number of CW and pulsed gyroklystrons with output power from several kW to several hundreds kW. Radars based on gyroklystrons are used or developed for higher resolution and longer distance detection comparatively with longer-wavelength systems.

INVESTIGATION OF THE MACROSCOPIC CHERENKOV EMP SOURCE

PRODUCED BY OBLIQUELY INCIDENT X-RAY PULSE

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Amplitude-time and angular characteristics of the electromagnetic radiation pulse (EMP) produced by soft X-ray pulse that obliquely incidents on the conducting slab are presented. In this conditions the boundary of the photoelectron current layer moves along the slab with faster-than-light velocity. According to theory such layer is macroscopic source of Cherenkov EMP.

As a soft X-ray source we used Au target plasma produced by short ($\tau_{0.5} \approx 0.3$ ns) pulse of the «Iskra-5» laser facility. An electric field was used to increase an energy of the photoelectrons and thus to enhance the registered effect. For this purpose the X-ray transparent metallic grid was established near the slab. The accelerating potential of the grid may be change in range of 0 – 100 kV. The accelerating potential dependencies of electron current magnitude and amplitude-time EMP parameters have been investigated.

It was found that the generated EMP emanates predominantly in the direction corresponding to specular reflection of the incident X-ray. The registered qualitative and quantitative EMP characteristics are in agreement with the theoretical notions of the macroscopic Cherenkov radiation source.

NEW THERMOMAGNETIC AND GALVANOMAGNETIC EFFECTS ARISING DURING TRANSMISSION OF POWERFUL PULSED CURRENTS THROUGH CONDUCTORS

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It was shown before [1], that the pulsed character of the electric current passing through a conductor results in non-evident features. For example, the temperature to which the conductor surface is heated depends in this case on neither the conductor resistivity nor the current pulse duration. This, at first sight, an unusual result has a very obvious physical explanation related to the fact that the shorter the current pulse duration and the lower the conductor resistivity, the smaller the depth of the skin layer, and, consequently, the cross section of that part of conductor in which this current flows.

In this report, the problem of how the pulsed character of the current affects thermomagnetic and galvanomagnetic effects in conductors is considered.

In the case of powerful pulsed currents transmission through conductors, firstly the azimuth magnetic field arises around a conductor; therewith, the intensity of this magnetic field can considerably exceed the intensity of the external magnetic field that can be attained in practice. Secondly, a very large transverse temperature gradient ($\sim 10^8$ K/m) appears in the conductor due to the skin effect. This results in the appearance of new thermoelectric and galvanomagnetic effects that significantly change the transmission of the current and the heat release in conductor, which accompanies this process. It is of particular importance that the effects associated with the transverse temperature gradient influence the processes occurring along the conductor. These effects introduce a substantial change of the electrical resistance and the thermal resistance of a conductor. Under certain conditions, the influence of such effects can become determinant.

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ELECTRIC FIELD INDUCED IN A CHANNEL TO PROPAGATE INTENSE LIGHT ION BEAM

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There is so strong tendency in a plasma to keep it in a charge neutrality. Practically, the plasma has no charge. Misunderstanding of the plasma, however, which has no electric field because of its charge neutrality, frequently leads us to confusion. The research for fusion science is nothing but the history to straggle with the induced electric field in the plasma and trial to keep the high-temperature-plasma for long time. Our attention being concentrated in half to the propagating ion-beam, investigation is advanced to analyze the electric field induced in a plasma for the following three cases.

1) Electric field induced in a purely neutral plasma by the Galilei Transformation. It is noted here that the electric field should not be zero when the charge in a plasma is zero. The divergent of the electric field should be zero. The divergent-free electric field must be investigated carefully. In a coordinate system O , the plasma has an electric field E and the magnetic field B . In a new coordinate system O' which moves with a velocity v relative to O , the electric and magnetic fields are respectively E' and B' . Then $E' = E + v \times b' = E + E''$. In system O' , the newly induced electric field $E'' = v \times B$ is divergent-free. When the charge-neutral plasma (co-mooving ion and electron beams) propagates in a azimuthal magnetic field, the radial electric field is induced in this way.

2) Electric field induced in a quasi neutral plasma. Because of the smallness of the dielectric constant, usually divergent of the electric field is not zero in spite of the fact that the charge density of the plasma is practically zero. For example, the Bohm diffusion comes from the electric field induced in a quasi-neutral plasma, the thermal energy being transformed to the energy of the electric field.

3) Electric field induced by the beam charge. When an intense light ion beam is launched in a plasma channel in a reactor, the plasma channel is charge neutral. The ion beam system in a reactor is ion dominant and has a strong electric field. This electric field causes the divergent of the ion beam. After the ion beam contacts with the reactor wall, and loses the charge, then the plasma in the reactor recovers its neutrality.

ELECTROMAGNETIC TREATMENT OF EFFLUENT GASES FROM SEMICONDUCTOR PROCESSING SYSTEMS

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Perfluorocompounds (PFC's) gases such as CF_4 , C_2F_6 or C_3F_8 are considered Global Warming Potential (GWP) gases [1]. PFC gases contribute to the warming of the earth by their strong ability to absorb Infra-Red radiation and their long atmospheric life time due to extreme chemical stability. PFC gases are used extensively for most of the semiconductor manufacturing processes due to their good product yield, good cleaning capability and being a non-hazardous gases. During plasma processing of silicon wafers PFC gases are ionized and decomposed into compounds that react with the wafer (dry-etch process) inside the reaction chamber, or are used for cleaning the coating deposition on the chamber walls from the Chemical Vapor Deposition (CVD) process. Effluent gases from the manufacturing processes of semiconductors create an environmental pollution which needs to be reduced. According to the Kyoto protocol [2] a reduction in Greenhouse Gases (PFC's as well) emissions must be achieved within the next decade. Methods for reduction of PFC's include: a) Capture and reuse of the gases, b) Burning at high temperatures, c) Plasma treatment and molecular decomposition. At the present situation where separation and reuse of the gases is far from being established and commercial solutions are based on thermal abatement, the development of a plasma treatment device appears favorable. Treatment of the effluent gases is possible with the use of microwave or RF radiation. Microwave generated plasma decomposes the PFC's directly and through interaction with free radicals. The status of PFC emissions and requirements within the semiconductor industry will be presented and the potential for proper treatment of the gases with electromagnetic radiation will be discussed.

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MICROWAVE HEATING WITH TIME VARYING MATERIAL PROPERTIES

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DEFECT STRUCTURES IN METALS FORMED AT HIGH POWER PULSED MICROWAVE IRRADIATION

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The results of a systematic experimental research of defect structures formed in the subsurface layer of pure metals and alloys (copper, alpha-iron, nickel, molybdenum, stainless steel, Ni₃Fe alloy) exposed to a high power pulsed microwave irradiation are presented. The exposure to microwave irradiation on samples was implemented by single pulses with the interval of 30-40 s with a total number of pulses 2, 50 and 100. The parameters of microwave irradiation were the following: the wavelength was 2.85 and 10 cm, the pulse duration was varied from 50 up to 300 ns, and the irradiation flux was varied from 2 up to 400 kW/cm². As a rule, the vector of the electric field strength of the microwave irradiation was parallel to a sample surface, and in several experiments the samples were placed so, that the vector of the electric field strength was perpendicular to a surface.

A defect structure of the irradiated samples was investigated by transmission diffraction electron microscopy. The technique used allowed to receive of "thin foils" for electron microscopic investigation from any required distance from the irradiated surface of a sample with high accuracy. It was established that the exposure to the high-power pulses microwave irradiation on metals and alloys causes a generation of dislocations in the target subsurface layer, and the dislocation density increases.

As a result, different dislocation substructures are formed. They are the cell-net and cell dislocation substructures with misorientation and without misorientation, the dislocation tangles, and chaotically distributed dislocations. The observed dislocation substructures are similar to the dislocation substructures formed in the deformed metals and alloys. The maximum changes of the dislocation structure happened in the subsurface layer, whose thickness was equal to, as a rule, several microns, i.e. one - three thickness of a skin-layer. Dependencies of dislocation density on distance to the irradiated surface are similar and have the following features. All the curves have a maximum. With an increase of the distance from the irradiated surface the dislocation density increases, reaching a maximum, and then decreases up to the dislocation density of initial state. The maximum of dislocation density locates near a boundary of the skin-layer or beyond the skin-layer. The effect from exposure to the irradiation is much higher at a wavelength of 10 cm, than that for 2.85 cm. The change in dislocation structure is not limited by a skin-layer. At the 10 cm wavelength the dislocation density and the character of dislocation distribution comes to ones of the initial state on distance that is equal to 10 microns.

The generation of dislocations and the formation of dislocation substructures at exposure to the microwave irradiation are observed in all investigated metal materials with a various crystalline lattice, the initial structural-phased state and a magnetic nature (diamagnetism, paramagnetism and ferromagnetism).

The mechanisms of the dislocation structure formation in metals at high power pulsed microwave irradiation are analyzed.

A PULSE TRANSFORMER FOR PLASMA IMMERSION ION IMPLANTATION APPLICATIONS

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The design and construction of high-voltage pulse generator for Plasma Immersion Ion Implantation (PIII) applications are published in our previous publications ⁽¹⁾. When the pulser output impedance is low and the load impedance such as a PIII reactor one is comparatively high ($\approx 2 \text{ k}\Omega$), the pulse transformer becomes an essential part of the high-voltage generator discharging circuit.

The high-voltage pulse transformer design and construction using metglas core are described and analysis of a simplified lumped circuit model is used for estimation of the main transformer characteristics.

It is found that fast rise time of the output pulse requires low leakage inductance and low distributed capacitance. This fast rise time can be achieved by reducing the number of secondary turns in the transformer. However the decreasing of the output pulse rise-time produces larger pulse droop and requires a larger core size. Using computer simulation and optimization by PSPICE code, a conventional pulse transformer with rise time less than 1 μs and pulse droop of 1.5% was built.

The transmission characteristics and pulse time-response were measured in two cases: (i) using standard low voltage pulse generator with 30-150 V amplitude input pulse to the primary turns of the transformer and (ii) using high voltage pulser ⁽¹⁾ with maximal input amplitude of 30 kV. The agreement with the model pulse outputs, compare to the experimentally measured results was good when the simulated transformer characteristic values were used for the transformer construction.

In addition a high-voltage experimental test using PIII reactor as a transformer load was performed. The experimental results for the shapes of voltage and current pulses and voltage-current characteristics of the PIII reactor were obtained. The results show that transformer, matches both generator output impedance and PIII reactor load with negligible energy losses.

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THE SECOND ALFVEN WAVE GENERATION AS A RESULT OF THE EXPLOSIVE INSTABILITY DEVELOPMENT IN THE BEAM - PLASMA SYSTEM

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The paper is devoted to a possibility of the Alfven and magnetosound waves explosive instability existence in the beam - plasma system. The dispersion equations are obtained on the base of MHD equations. The waves energies and synchronism conditions are found. It is shown that explosive instability in system is bounded due to nonlinear absorption associated with weakly harmonics damping of the Alfven modes. The Alfven wave second harmonics effective generation is shown. The results obtained are useful for solid body, laboratory and cosmic plasma. These effects are appearing during the flashing phenomena development in the sun atmosphere. This radiation may be received by satellite and Earth antennas.

NEW SCHEME OF TWO BEAM ACCELERATOR DRIVER BASED ON LINEAR INDUCTION ACCELERATOR

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In the previously proposed schemes of the TBA driver [1], [2] electron beam moves through an alternating discrete row of microwave generators (free electron lasers (FEL), relativistic klystrons, etc.) and reaccelerator sections. The microwave power is totally extracted from the driver after every generation section.

A new scheme of two beam accelerator (TBA) driver based on a linear induction accelerator is suggested in this work. The scheme has the following characteristic properties: a) the electron beam bunching occurs at a rather low initial energy ~ 1 MeV; b) the bunched beam is accelerated in the accompanying enhanced synchronous microwave that provides the steady longitudinal beam bunching along the whole driver; c) there is no total microwave power extraction anywhere in the driver; d) a beam-loaded waveguide (initially corrugated and regular further) is used along the driver.

The scheme has the following merits: 1. The possibility to provide the microwave phase and amplitude stability. The phase stability can be obtained at the expense of quasi-continuity of the system; 2. Due to the bunched beam acceleration it is not necessary to have a high (~ 10 MeV) energy of the initial electron beam bunching to study a TBA driver in principle.

The simulation showed that a steady state is achieved when electron bunches accompanied after a TWT by an amplified microwave are simultaneously accelerated in an external electric field both for continuously distributed system parameters and for discrete parameters of accelerating sections. The total power, which is inserted into the beam by the accelerating field, transforms into the microwave power in the steady state. It was equal to ~ 500 MW/m in our case. Such kind of systems can serve effectively as a rather long (hundreds of meters) driver for the TBA concept.

The experimental setup based on the JINR LIA-3000 to test the new scheme is discussed. It consists of the 800 keV, 200 A injector and two reaccelerating sections. The possibility of studying the bunching, microwave generation, beam propagation and threefold microwave extraction is considered.

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WAVE EQUATIONS AND TRANSMISSION FORMULAS FOR THE OUTPUT OF A RECEIVING ANTENNA

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The vector output of a receiving antenna that translates without rotation with respect to a transmitting antenna is shown to satisfy the homogeneous wave equation outside the minimum convex surface enclosing the transmitting antenna. This result holds for antennas operating in either the frequency domain (narrow-band antennas) or the time domain (wide-band antennas), provided multiple interactions between the transmitting and receiving antennas are negligible. In the frequency domain, if $\mathbf{b}_{pw}(\mathbf{r})$ is the vector sum of the scalar outputs of two mutually perpendicular orientations of the receiving antennas at the position \mathbf{r} , plane-wave representations for the antennas can be used to prove that

$$\nabla^2 \mathbf{b}_{pw}(\mathbf{r}) + k^2 \mathbf{b}_{pw}(\mathbf{r}) = 0 \quad (1)$$

outside the minimum convex surface enclosing the transmitting antenna. The time-domain vector of the receiving antenna, which is related to the frequency-domain vector output by the inverse Fourier transform

$$\mathbf{b}_p(\mathbf{r}, t) = \int \mathbf{b}_{pw}(\mathbf{r}) e^{-i\omega t} d\omega \quad (2)$$

satisfies the time-domain homogeneous wave equation

$$\nabla^2 \mathbf{b}_p(\mathbf{r}, t) - c^{-2} \partial^2 \mathbf{b}_p(\mathbf{r}, t) / \partial t^2 = 0 \quad (3)$$

The frequency-domain vector Helmholtz equation has been used to efficiently compute the near-field coupling between co-sited antennas [IEEE AP-S Trans., vol. AP-30, pp.113-128], and to derive probe-corrected transmission formulas for plane-polar, near-field antenna measurements [IEEE AP-S Trans., vols. 40 and 44, pp. 304-312 and 696-700]. In this paper we use the time-domain wave equation (3) to facilitate the derivation of probe-corrected, time-domain, plane-wave transmission formulas needed for the direct processing of near-field measurements taken in the time domain [IEEE AP-S Trans., vol. 43, pp. 569-584].

ENERGY CONSIDERATIONS FOR SPACE-TIME SYNTHESIS OF COLLIMATED PULSED APERTURES

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In a recent paper [1] we have introduced measures for an effective realization of short pulse antennas. These measures are based on the time domain (TD) spherical waves (or multipoles) expansion of the antenna field and utilize such new concepts as the TD reactive energy and TD Q . The TD reactive energy is a relatively strong energy pulse in the near zone of the antenna: It accompanies the radiated energy pulse but discharges back into the source once the radiated pulse has ended. The effectiveness of the radiation can thus be quantified by the TD Q that measures essentially the ratio between the total reactive energy and the radiated energy.

In the present paper, these measures are used to quantify and contrast the effectiveness of several different realizations of highly collimated, short-pulse aperture distributions. Such realizations typically involve both space and time synthesis of the current distribution [2]. The time-dependent radiation patterns due to these distributions are calculated via the slant stack transform (SST) formulation of [3], which exhibits a direct geometrical projection relation between the current distribution and the radiation pattern. Next, the near zone properties and the TD Q are calculated via the TD multipole expansion formulation of [1]. Finally, these measures are quantified in order to evaluate and compare the effectiveness of the alternative realizations. Specifically we consider and contrast uniform pulse distributions, Gaussian pulse distributions and iso-diffracting distributions [2]. The latter are of particular interest since they provide an effective realization of collimated pulsed beams [2].

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INTERMEDIATE FIELD OF AN IMPULSE-RADIATING ANTENNA

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Much has been done to characterize impulse radiating antennas (IRAs). These include TEM-fed paraboloidal reflectors and TEM-fed lenses. Both kinds are characterized as aperture antennas with fields being calculated by integration over the assumed TEM fields on an aperture plane, at least for the impulsive part of the radiated far field (with assumed step excitation). (The prepulse associated with the TEM feed of a reflector IRA is not discussed here.) As discussed in Sensor and Simulation Note 321 which began this odyssey, the impulsive part of the waveform (on boresight) is not a true impulse. It has a peak which is just the aperture field, but its width decreases like $1/r$, so that its time integral decreases like $1/r$, appropriate to a far field.

In considering the far field of an impulse-radiating antenna there is a problem in that infinite frequencies are included significantly in the impulse, making it difficult to properly define the far field in such an ideal case. This paper adopts a different approach by taking an asymptotic expansion parallel to the aperture normal (z axis) with the aperture step illuminated simultaneously over the entire aperture. By this means we obtain a detailed description of the early-time field which we call the intermediate field. This has a convenient scaling relationship involving narrowing it in time as z increases.

APERTURE EFFICIENCIES OF IMPULSE RADIATING ANTENNAS

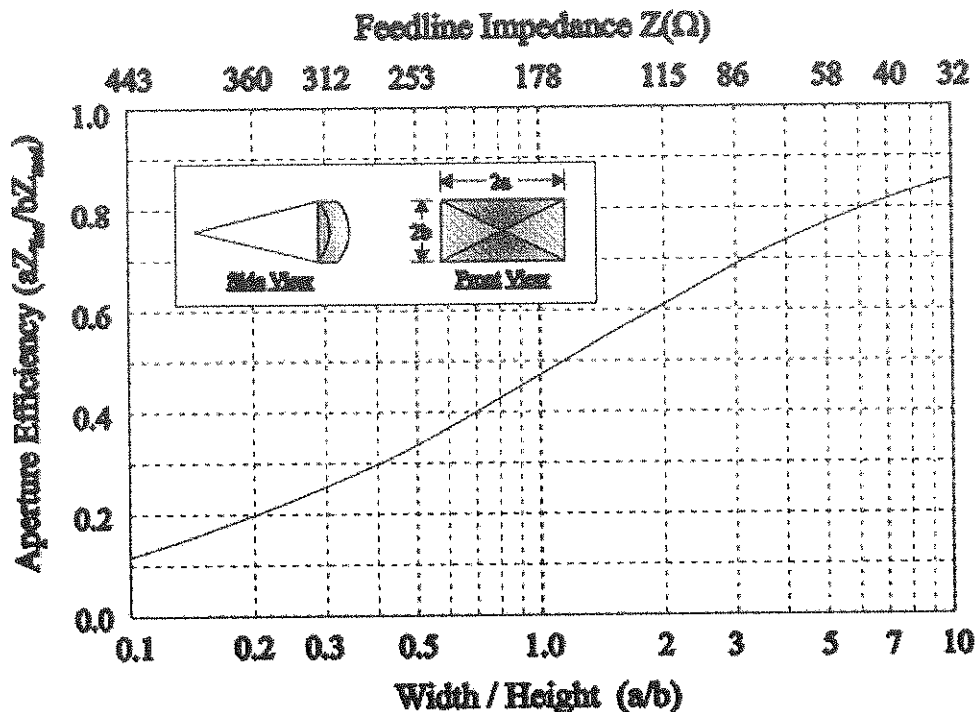
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A concept of aperture efficiency is introduced for the purpose of comparing the performance of impulse radiating antennas (IRAs). The aperture efficiencies of popular lens and reflector IRAs are computed as the ratios of peak radiated power densities on boresight compared with that produced by an ideal IRA with an aperture of equal area and equal total input power. Loss and aperture efficiency occur through two distinct mechanisms: from power that falls outside the aperture and is lost; and from nonuniform power and polarization distributions within the aperture. Both loss mechanisms are addressed using analysis, numerical calculations, and experimental results, and means for increasing efficiencies are identified. One approach to improving the aperture efficiency is by reducing the impedance of rectangular focused-aperture TEM horns used in an array, as depicted in the plot. Aperture efficiencies approaching 100% are feasible in TEM-horn arrays and similar structures.

Flat-Plate TEM Horns with Rectangular Focused Apertures



MULTIFUNCTION IMPULSE RADIATING ANTENNA

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Impulse Radiating Antennas consist of a parabolic reflector and a TEM feed. Such antennas have approximately two decades of bandwidth, and they tend to have very narrow beamwidths. There are times, however, when one would prefer to have a broader beamwidth, even at the expense of some gain. It turns out that one can achieve this simply by defocusing the TEM feed, moving it slightly closer to the reflector. And if one includes a mechanism to adjust the focus, one can have a single antenna with an adjustable beamwidth and two decades of bandwidth. Such an antenna works both for impulse and broadband CW applications, so it is an extremely flexible design. This is particularly useful in applications where aperture area must be conserved, and a single antenna must be used to serve multiple functions. We call the new design a Multifunction IRA, or MIRA.

We have designed, built and tested a MIRA with an eighteen-inch diameter, and a computer-controlled adjustable feed. Antenna pattern data and TDRs are provided. A radiated impulse width of about 50 ps on boresight was observed. Furthermore, the pattern is seen to broaden as the antenna is moved out of focus. The position of the focus is controlled by a servo motor through logic controlled by a personal computer.

The theory describing this antenna is a variation of the off-boresight theory we have presented previously. The difference is that the aperture is not filled suddenly in response to a step-function drive, but is filled gradually. Our theory consists of a new way to calculate the field radiated from a defocused aperture.

The sensors used for these measurements were also designed and built by us. They consisted of a half TEM horn, mounted against a ground plane, with a coaxial feed-through. Such sensors are an effective means of approximately replicating the incident field, and have better sensitivity than conventional D-dot sensors.

A NEW BROAD BAND RESISTIVE WIRE ANTENNA FOR ULTRA-WIDE-BAND APPLICATIONS

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A new wide band antenna radiating short pulses has been designed at the CELAR and the I.R.C.O.M.. This wire antenna based on the TEM horn principle is shown in Figure 1.

The theoretical study antenna is carried out using a space-time « integral equation » (Miller, Poggio and Burke « An integro-differential equation technique for time domain analysis of thin wire structures ». J.Comp. Physics, USA (1973)). This rigorous method allows analysis of the current induced by the pulse generator on the wire antenna. The antenna is excited by gaussian or differential gaussian pulses (rise time < 300ps). The electric and magnetic fields are deduced from the knowledge of the currents on the wire structure.

Following the principle of the Wu-King non reflecting dipole, the geometrical details of the resistive load are varied to optimize the pulse radiation. Compared to the perfectly conducting wire antenna, the « optimized » resistive antenna has better characteristics :

- the temporally short wide-bandwidth pulses are radiated with less pulse distortion,
- the input matching is better.

The performances of this Ultra-Wide-Band system have been « optimized » by adjusting geometrical parameters and compared to experimental measurements made on several antenna models (resistively loaded or not)

- half antenna on ground plane,
- complete antenna in free space (anechoic chamber).

Our optimization showed good agreement with the results of these comparisons.

The antenna is expected to find many applications in topics such as target identification, buried object detection, etc. The first results obtained during experiments in these two last applications will be presented.

Essential electromagnetic characteristics (300 MHz - 1 GHz) :

- input impedance : 200 Ω . A coaxial balun (50 Ω - 200 Ω) has been developed and realized in order to symmetrize the generator impulse on the wires of the antenna and to maximize the feed power,
- TOS < 1,5 (100 MHz - 2 GHz),
- energetical values :
 - gain in the axial direction : 7dBi,
 - aperture angle : E plane : 45°,
 - aperture angle : H plane : 30°.
- pulse distortion : (< 1,1).

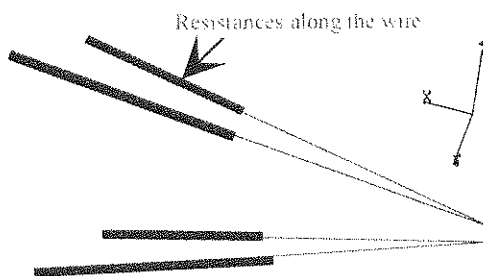


Figure 1 : Complete Antenna in free space

This work was supported by the « Centre d'Électronique de l'Armement de Rennes » (FRANCE).

The baluns and the complete antenna have been manufactured by the Europulse Company (Lot, FRANCE)

TRANSIENT BEHAVIOR OF RADIATED AND RECEIVED FIELDS ASSOCIATED WITH A RESISTIVELY LOADED DIPOLE

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In their frequency-domain analysis, Wu and King have shown that a resistively loaded dipole is a broadband antenna [T. T. Wu and R. W. P. King, *IEEE Trans. Antennas Propagat.*, 369-373, 1965]. Based on their results, an analytical representation of the transient radiated field from this dipole is derived for an arbitrary, pulsed, exciting voltage $V(t)$. The field is expressed in terms of various differential and integral operations on $V(t)$, allowing one to identify the points on the antenna from which radiation occurs. In particular, the transient field at an observation point (r, θ) is written as the sum of four signals: two pulses from the dipole's feed and one pulse from each of its ends. With respect to the signals from the feed, the two pulses emanate simultaneously. One pulse is a retarded replica of $V(t)$, where the retardation time is r/c and c is the speed of light. The other pulse is a time integral of $V(t)$ times an exponential attenuation factor that depends on the transit time h/c , where $2h$ is the dipole's length. Apparently, the attenuation factor is a consequence of the resistive loading. The pulses from the dipole's ends are also time integrals of $V(t)$ with the same attenuation factor; however, they emanate at two later times. In the far field, the radiated pulses from the upper and lower ends are not observed until $h(1 - \cos\theta)/c$ and $h(1 + \cos\theta)/c$, respectively, after observing the pulses from the feed. Because previous work on transient radiation from this loaded dipole considered specific forms of $V(t)$, the aforementioned interpretation of radiation was not apparent.

When a pulsed field is incident on a similarly loaded dipole of length $2l$, the open-circuit received voltage at time $t^* = t - (r_0/c)$ is expressed as the sum of four integrals involving the incident field, where r_0 is the distance from the field's source to the receiving dipole's feed and $t^* = 0$ is the instant that the incident field reaches the feed along the direct path to it. The first term is a time integral of the incident field and is interpreted as a voltage induced at the feed from radiation along the direct path between the source and feed. The second term, a double iterated time integral, also represents an induced voltage at the feed that becomes observable at $t^* = 0$. Also, both the third and fourth terms are double iterated integrals of the incident field. The third term is the open-circuit voltage that is induced at the dipole's upper end and travels along it to the feed. The fourth term is a voltage, which after entering the dipole's lower end, also travels along it to the feed. These observations suggest that the components of the open-circuit voltage which arise from the incident field interacting with the dipole's ends appear at the feed at later times. Although the receiving dipole is resistively loaded, none of the received open-circuit voltages are attenuated. However, if the incident field is transmitted by a similarly loaded dipole, each of the four pulses that comprise the incident field induce an open-circuit voltage at the receiving dipole's input in the four ways described above. In this situation, since three of the four incident pulses are attenuated during the radiation process, the associated induced received voltages also exhibit corresponding attenuations. Moreover, since one incident pulse is not attenuated, the open-circuit voltage associated with it results in four unattenuated pulses.

TRANSIENT GAIN OF ANTENNAS RELATED TO THE TRADITIONAL CONTINUOUS - WAVE (CW) DEFINITION OF GAIN

C. E. Baum¹, E. G. Farr², C. A. Frost³

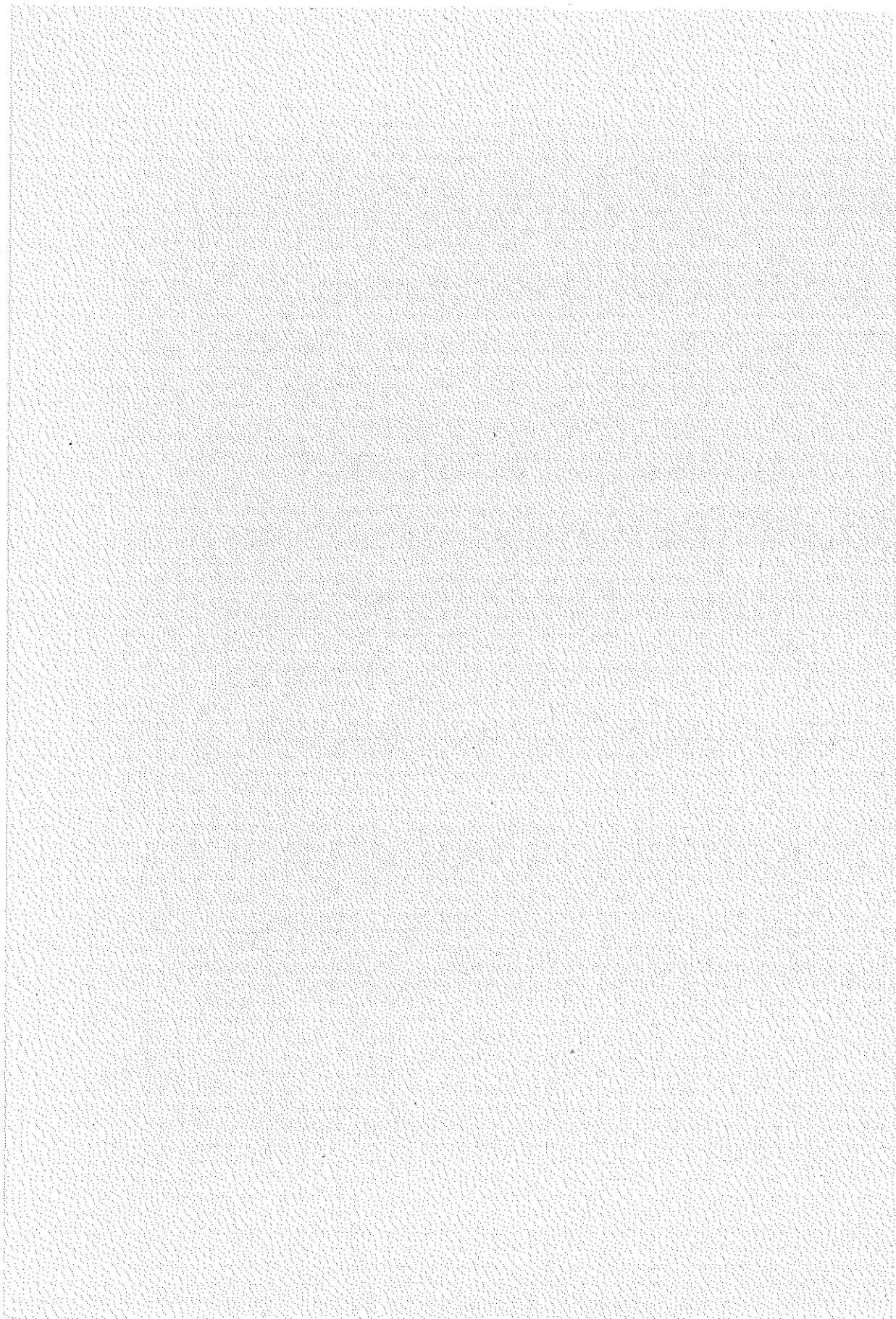
1. *Air Force Research Laboratory (DEHP, Bldg 909) 3550 Aberdeen Ave SE Kirtland AFB NM 87117-5776 USA*
2. *Farr Research Inc 614 Paseo del Mar NE Albuquerque NM 87123 USA*
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There is some ambiguity in relating the usual CW (IEEE) definition of antenna gain to its time-domain response (transmitting and receiving). This involves issues of direction of incidence, polarization, and phase dispersion. In this paper we develop restrictions necessary to simplify this relationship.

In [E. G. Farr, C. E. Baum, and C. J. Buchenauer, *Impulse Radiating Antennas, Part II*, pp. 159-170, in L. Carin and L. B. Felsen (eds), *Ultra-Wideband, Short-Pulse Electromagnetics 2*, Plenum Press, 1995] the problem of appropriate definition of antenna gain and radiation pattern in time domain is considered in some detail. Using time-domain reciprocity the definitions are made to apply in both transmission and reception. Since the time-domain parameters are equivalent to the related frequency-domain parameters considered over all frequencies, the time-domain parameters are not simple numbers, but in general vector convolution operators. Specifically, the gain is related to an appropriately normalized effective height convolution operator. This can in turn be reduced to a scalar number by application of appropriate mathematical norms.

Here we show that it is possible to relate the usual CW antenna gain (IEEE) to the effective height operator which more adequately expresses the time-domain response in both transmission and reception. This relationship results in some loss of information. There is a requirement first of a constant-resistance load at the antenna port, matched to the same constant-resistance input impedance of the antenna, unless one is willing to carry these as extra factors in the relationship. Second, one needs a frequency-independent polarization for the given angle of incidence (e.g., boresight), and a corresponding constant (frequency independent) orientation of the effective height. Third, the loss of phase information results in an unknown dispersion of a pulse. If one is willing to place additional constraints (assumption, as in the case of an IRA of various types) then this phase ambiguity can be resolved.

**TUESDAY,
JUNE 16, 1998**



GERMAN-TEST-FACILITIES FOR HPM-EXPERIMENTS

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Germany, as a partner of the SNR Four Power Group and a member of the RSG 9 is in the condition to do some EME-Tests to determine threshold on smart Ammunition, Missiles and electrical Equipment for Aircrafts.

The philosophy on the experimental area is

low level test	CW and AM modulated
low level test	Pulse modulated
full-Threat test	Pulse modulated up to 50 kV/m

In different locations (Greding, Euskirchen and Munster) there are installed transmitter-equipment to generate, in the frequencies between

100 MHz and 18 GHz, field strength > 200 V/m CW and
 > 5 kV/m up to 50 kV/m Pulse modulated.

In general, this presentation should be show the different measurement equipment, Antennas, TEM-Cells, Anechoic Chambers, are available in the MOD-area of Germany.

In addition, I would like to present the procedure to verify Modeling results with experiments.

VULNERABILITY OF AIRBORNE SYSTEMS BY HPM

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Today there is a great demand to know the risks for airborne systems as aircrafts, drones and missiles against illumination by high power microwave, which could be generated by HPM weapons. Basically this is an EMC-susceptibility problem, which means, there are no a-priori-physical thresholds to be maintained, but the susceptibility thresholds are defined by malfunction criteria of the systems considered under realistic HPM irradiation conditions.

Does this mean, a risk assessment of airborne systems can only be achieved by subjecting aircrafts, drones and missiles (which must be fully operating and there functionality must be monitored) to a full HPM threat scenario ?

There is no doubt on the enormous effort and costs, if the answer is yes. An alternative and much more effective approach is pursued by Dasa and will be presented. Basic idea of this approach is, that the path, electromagnetic energy can penetrate into a system up to a particular electronic component into a equipment box can be followed up to the box boundaries by pure physical methods (numerical calculations as well as low level tests/transfer function measurements). The task to determine the functionality thresholds commences at the box boundaries with the actual electromagnetic field conditions there. The realization of this idea is an HPM experimental pod, which allows to study the penetration path up to the equipment box boundaries by „copying“ the structural features of the airborne systems in the HPM experimental pod (size and material properties of airborne structures, installation details of junctions of structure parts, antenna installations). Inside the HPM experimental pod an equipment is installed to energize, stimulate and monitor the selected equipment boxes and -of course- the equipment boxes of interest are installed inside, too under comparable conditions as in the operational airborne systems. So we fulfill all the required conditions at the equipment box boundaries and are able to investigate the vulnerability in the laboratory with much less restrictions than by using complete airborne systems.

First results will be presented concerning the response of different avionic subsystems on HPM pulse characteristics. Here an additional feature of the experimental pod technique becomes apparent, the quick variation of the external structure up to a full removal. Without external structure the functional limits will be reached at much lower power levels, which allows to study HPM effects with less powerful test facilities up to a large extend. These test results include investigations of the susceptibility of the energizing, stimulation and monitoring system, which is build up by industrial standard components with all the interfaces, needed by the equipment boxes of interest , particularly shielded and filtered for this application. Of particular interest is the fact, that vulnerability by HPM is not necessarily identical with burn-out of electronic components. Many different „equipment boxes“ could be set by pulsed irradiation in an undefined status forever, until the box was reset by power off/on. In practice such a condition is as harmful as a destroyed component, but takes place at lower power levels than needed to kill an equipment. By comparing the results with the same HPM experimental pod configuration, gained in different test facilities, it is possible to define HPM vulnerability test programmes in a very cost effective way.

ELECTROMAGNETIC COUPLING OF HIGH POWER MICROWAVE [HPM] INTO UNMANNED AIR VEHICLE

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The recent HPM-Technology is a significant threat for airborne systems, therefore it's necessary to get informations about the HPM compatibility or vulnerability.

Taking the HPM into consideration the behaviour of generic and operative airborne systems has to be analyzed with different investigations.

STN ATLAS Elektronik performs different studies with a HPM-TESTDRONE, made by STN ATLAS Elektronik.

The version of the HPM-TESTDRONE is based on the design and process technology of an operative Drone.

The characteristics of the HPM-TESTDRONE are:

Stealth technology, metallic and shielded electronic cover and cables and electronic sub-equipment (Flight Control and Navigation System).

Each characteristic has to be investigated with special procedures taking into consideration the HPM-threat.

The transfer function of stealth and metallic structures were analyzed on the basis of following measurements:

Radar Cross Section and Scattering Center Analysis; Surface Current and Shielding Analysis (reflected and absorbed).

The electronic system of the HPM-TESTDRONE will be examined by measurements and theoretical studies.

The theoretical studies (system analysis) cover the actions:

Semiconductor list; determination of interference and destruction energy; determination of critical paths, description of coupling characteristics and analog simulation.

The informations of the system analysis leads to the measurement concept with the parts:

Description of signals which have to be examined; description of the test area and test procedure.

The HPM-test of electronic equipment will be performed together with the EMC-department of the WTD81 in Germany.

The variable parameters of the tests are:

Orientation of the HPM-TESTDRONE in the HPM field; HPM power density and modulation.

The results of the different investigations will offer information on:

Future HPM protection as a part of the common protection; using impuls measurement procedures as susceptibility measurement method for electronic systems; effective parameter of HPM sources; application of introduced and future Drones as carrier systems for HPM payloads as well as for detection and suppression of high radiation sources.

HPM INVESTIGATIONS WITH SYSTEMS OF RADAR ABSORBING COMPOSITE MATERIALS

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Tactical demands for stealth properties require the extensive application of radarabsorbing materials and structures in military component construction. Mainly non-metallic radarabsorbing fibre-reinforced composite materials and core materials are used for this purpose. The present paper deals with the interaction between a high-power electromagnetic pulse in the frequency range from 100 MHz to 100 GHz and a such a camouflaged military system.

In collaboration with different divisions of Daimler-Benz Aerospace AG and STN Atlas Electronic GmbH, a radar-absorbing fin profile and a radarabsorbing structure of an unmanned aerial vehicle were examined as original components. Investigations dealt not only with the transfer function through the radar-absorbing enclosure, but also with the interactions to be expected between the incident microwave energy and the integrated mission-relevant components. Activities were focussed on the determination of the coupling effects through the different radar-absorbing structures and the associated bolted connections, joints and apertures. Another task concerned the assessment of property changes of a radar-absorbing fibre-reinforced composite structure under the influence of high-power energetic electromagnetic fields and pulses.

For determination of the structural behavior, measurements of the transfer function were conducted on the device under test within the above mentioned frequency range. In parallel, suitable calculation methods were used for the performance of numerical calculations on the dielectric layer systems. The properties of the dielectric fibre-reinforced composite structures could also be visualized by means of a two-dimensional radar imaging method.

HPM-COUPLING EXPERIMENTS AND EXPERIENCES WITH ACTIVE SMART SYSTEMS: COMPARISON OF LPM-CW, LPM-PULSE AND HPM-PULSE TEST RESULTS

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The coupling experiments with active smart systems are *based on* analytical and numerical results and also on coupling experiments with the passive systems. The introductory considerations provide information about frequency ranges, coupling paths, coupled currents and voltages on internal wirings. Fig. 1 shows the linkage of the HPM investigation methodology.

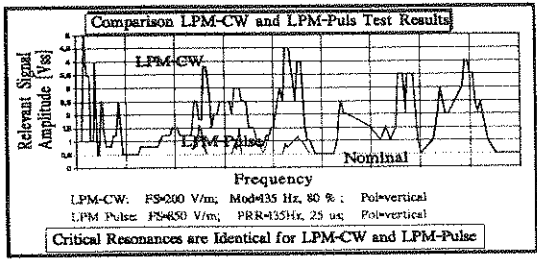
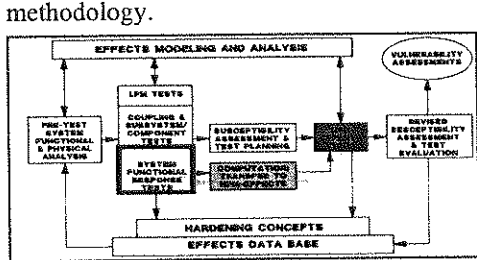


Figure 1: Linkage of HPM-Considerations

Figure 2 : LPM-CW and-Pulse Test Results

The provided analytical, numerical and experimental results of the passive system enables experiments with the active system in an effective way in respect of time as well as radiation parameters.

Only susceptibility investigations with the active system show how the guidance and control loops including electronics and sensors can be interfered. For the LPM-CW and LPM-Pulse Test Result the most interesting point is when we are looking at the susceptibility possibilities of smart systems, i.e. normally the systems are interferable in a broad frequency band. This means that you mustn't hit a very precise frequency for back door coupling. The various resonance peaks can be separated into structure (body) and wire resonances and into fin and slot resonances.

Even the non-disturbing LPM tests are able to provide the most important information in respect of the susceptibility of considered systems and show also the critical coupling paths.

The *comparison* of the signal interferences caused by *LPM-CW and HPM* tests shows that the provided energy is the major key player in case of non-disturbing radiation tests (Figure 3).

At a comparable radiation parameter besides the field strength pulse repetition, the provided energy to the system is for LPM-CW about 48mJ/m²/Hz and for HPM about 16mJ/m²/Hz.

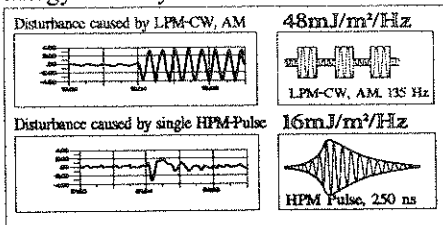


Figure3: LPM-CW and HPM Energies.

The non-disturbing radiation tests have shown, that relevant guidance and control signals of smart defense systems can be interfered. But what does this mean for the mission those systems are designed and built for?

Only a final flight path simulation programm is able to show how the mission is influenced!

A SURVEY OF WORLD-WIDE ELECTROMAGNETIC PULSE (EMP) SIMULATION APPROACHES

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A large variety of EMP simulators exists throughout the world. The end of the Cold War has provided the opportunity to compare simulators and test methods employed in them. While major similarities exist in the EMP simulators developed independently by the West, the countries of the former Soviet Union, and China; there also are some interesting differences in approach.

No one perfect EMP simulator exists. Baum has classified non-source-region EMP simulators in three categories: guided-wave, dipole, and hybrid. This presentation describes several examples of each of these three categories as well as a unique source-region simulator in Russia that does not fit this categorization. All designs have inherent limitations; thus the large variety that exists. Some analysis and extrapolation of results must always be done. The ideal of a simple "zap" test to prove a system hard to EMP is just that -- an unachievable ideal.

RUSSIAN EMP SIMULATORS: MODERN STATE AND OUTLOOK

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The first Russian EMP simulators were founded about thirty years ago. These simulators have been used to verify theoretical estimations of electromagnetic effects and to confirm efficiency of EMP protective devices. The largest are bounded waves simulators. Besides there exist radiating simulators and induced current simulators. At the experimental base of CIPT, there are simulators of different construction and dimension including subnanosecond high precision facilities.

The main aspects of experimental base development are the following:

- reconstruction of simulators with getting a deeper knowledge of the nature and characteristics of EMP effects;
- improvement of EMP simulator characteristics at minimum expenses;
- search for alternative ways of EMP simulators application.

There are many ways to solve these problems.

1. It is known that coaxial lines are capable to transmit ultra-short electric pulses. Therefore, the reconstruction of an EMP simulator consisted in essential change of its field forming system. Consequently, we have created the simulator to reproduce electromagnetic pulses at nanosecond rise time.

PERFORMANCE OF A NEW FAST-RISETIME NEMP SIMULATOR IN HPD AND VPD CONFIGURATIONS

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WIS Germany has operated a bounded-wave NEMP simulator called DISES since 1980 at Munster. The simulator was upgraded in 1995/96 to produce pulses with rise-times from 7 ns to 1 ns. Tests have been performed on more than 120 systems with this simulator.

In 1997, a new HPD simulator was installed at the WIS Munster test site. The new simulator produces horizontally-polarized fields with rise-times to 1 ns. Since the field strength of the horizontally polarized field is limited to 20 kV/m, this simulator will be used to measure transfer functions of systems which were tested in the DISES simulator at full threat level with vertically polarized fields. If selected measuring points are found where the horizontal fields cause damage in a system, hardening devices will be installed in the EMP laboratory at WIS Muster and tested with direct current-injection methods.

The new HPD simulator is a transportable system with a very low operational cost. As a result, this combination of using the transmission line DISES for full-threat-level testing and measuring the influence of horizontal polarization with the new HPD simulator in combination with direct-current injection is a very cost-effective way to perform full-system tests.

A study has been performed to establish the modifications required to allow the pulser of the HPD simulator to effectively drive a VPD antenna, and to predict system performance for a range of antenna heights and resistive termination schemes. Based on the results of the study, a program is planned to develop and test modifications of the pulser and to install the pulser into a VPD antenna at WIS Munster. With the planned modifications and a 12-meter-high antenna, the system should produce a rise time of 3 to 4 ns. Peak amplitude 15 m from the antenna center line should be = 12 kV/m. Detailed performance characteristics of the VPD and HPD versions of the system will be presented.

EXPERIMENTAL VERIFICATION OF THE PXM ANTENNA

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Transient field illumination testing of electrical systems is often used to determine its fast-pulse response and to evaluate its survivability in a pulsed electromagnetic (EM) environment. In some cases however, transient testing is too expensive or unwieldy. An alternative in these cases is to use a swept continuous wave (CW) excitation of the test object, and to reconstruct the transient response by Fourier inversion of the measured complex-valued spectrum [1].

One problem with CW testing is in producing a suitable EM field over the test object that approximates a plane wave. At frequencies over 10 MHz, such fields can be produced using a wide variety of standard antennas (dipoles, loops, log-periodic arrays, etc.). At lower frequencies, however, the test object is often in the near field of the antenna and the excitation ceases to be like that of a plane wave.

To partially alleviate these simulation difficulties at low frequencies, Baum introduced the concept of the P×M antenna [2]. Essentially, this is an antenna consisting of both electric and magnetic dipole moments, which when adjusted in the proper ratio, tend to radiate plane-wave like fields in a particular direction, with a null field in the opposite direction.

A theoretical study of this antenna has recently been documented in [3], and an experimental program to investigate the practical aspects of this antenna was conducted in May of 1997 [4]. The present paper serves to describe briefly the operation of this class of antennas, and then illustrates the measured results for the radiated fields for the special case of a triangular P×M antenna over a perfect ground. Of special interest has been the influence of a lossy earth on the antenna's behavior, and the experimental results obtained for this configuration are also discussed.

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SOME PROBLEMS OF SREMP SIMULATION

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Experimental investigations of electromagnetic pulse (EMP) effects on electronic equipment are carried out with the use of simulators reproducing the required parameters of electromagnetic fields. To study source region electromagnetic pulse (SREMP) effects it is necessary to simultaneously reproduce electromagnetic and ionizing effects in environment and equipment elements. The joint application of the EMP and ionizing radiation simulators do not decide this problem.

First, it is difficult to provide required sequence of electromagnetic and ionizing effects with accuracy about several nanoseconds.

Secondly, environment ionization distorts the electromagnetic field. In some cases, forming field may be completely replaced from test volume of EMP simulator.

It is confirmed by results of experiments on "Aurora" simulator.

We have investigated various ways of overcoming these difficulties. One of the ideas is as follows. The object is placed between two preliminary charged parallel plates. When environment is irradiated the conductivity arises and discharge occurs through ionizing environment and the object. However, when realizing similar methods in practice there appear serious difficulties to form the required characteristics of electromagnetic effects.

More economic are the ways based on direct reproduction of induced current in object combined with local irradiation of testing equipment.

STRIP-LINE ANTENNA SUPPLIED BY 800kV-1ns RISE TIME NEMP GENERATOR

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This paper deals with a strip line antenna to test large equipment with, at choice, the BELL waveform (rise time = 4.2ns, fall time = 180ns) or the IEC wave form (IEC 1000-2-9). This system, unique in the world, is also original by the use of a dielectric lens placed at the geometric discontinuity of the strip line. The experiments conducted on the structure have shown a fast rise time (<2.5ns) over a long distance (>20m) and a good homogeneity of the electric field.

This EMP simulator, located at the "Centre National d'Etudes des Télécommunications" in LANNION (FRANCE), is used for testing large telecommunication equipments with their cabling system.

BACK-LOBE SUPPRESSION DEVICES FOR A CONICAL HORN ANTENNA

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This paper considers a new technique for back-lobe suppression for fields radiated from a conical horn. It consists of a gradual transition from horn to free space via longitudinal tapered strips, both conducting and resistively loaded. Along with an approximate analysis, data for several configurations are presented, and the designs are compared. Typical reduction of the back-lobe is 20 dB to 30 dB, with a slight increase in side-lobe. Two main configurations will be described in detail. The first configuration consists of an array of rectangular notches around the horn, parallel to the horn axis. Its effectiveness in reducing back-lobe emission, compared to that of the horn alone, has been demonstrated both analytically and experimentally. At a particular frequency, notches with lengths equal to an odd multiple of a quarter wavelength will radiate mainly into the forward direction, augmenting the main lobe radiated by the horn and reducing the radiation into the back-lobe but with little effect on the side-lobes. Because it is a resonant structure, it is useful mainly for narrow band applications. The second configuration does not depend upon resonance effects and therefore has broadband applicability. It consists of long tapered strips of conducting or absorbing material attached to the edge of the horn.

ELECTRICAL DESIGN, IMPLEMENTATION AND MEASURED PERFORMANCE OF A 3-GHZ COAXIAL BEAM-ROTATING ANTENNA (COBRA)

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High power microwave sources (Magnetically Insulated Line Oscillator, Relativistic Klystron Oscillator, etc.) often generate radio frequency energy in the circular waveguide TM_{01} mode. The resulting aperture distribution is then azimuthally symmetric, and when launched with a conventional antenna, like a conical horn, produces a ring shaped radiation pattern with a null on boresight. Designs like the Shaped End Radiator and Vlasov antenna have been used to mitigate this effect, but these produce a pattern peak in a direction other than along the longitudinal axis of the circular waveguide. The Coaxial Beam-Rotating Antenna (COBRA) provides a means to radiate a high-gain pattern with a boresight peak from an azimuthally symmetric mode distribution. The resulting boresight field also exhibits polarization diversity, with any elliptical polarization possible on boresight.

Previously, basic concepts and the theory of operation of the COBRA have been presented. A first prototype was fabricated, and measurements of its radiated characteristics verified this theory. The earlier COBRA prototype was not optimized and was found to have approximately a 10% efficiency. A new COBRA prototype has been designed and fabricated with a goal of optimizing the radiated efficiency. The center frequency is 3-GHz, and it was designed and fabricated with four identical segments ($N = 4$). The design utilizes a Cassegrain-type topology with a conical feed horn mounted at the apex of the main reflector. The feed horn is driven by the TM_{01} circular waveguide mode, and its radiated field illuminates the subreflector which in turn reflects the field back into the main reflector. Precise measurements of the antenna's radiated pattern have been made. This paper will present a brief overview of the COBRA theory of operation, a summary of the physical features of this new prototype, and a detailed description of its measured radiation properties. This description will include a presentation of the measured characteristics of the feed horn, and the $N = 1, 2$ and 4 COBRA configurations. Measured data indicative of the radiated field patterns, and the boresight polarization (including relative phase between the two orthogonal radiated field components) and gain characteristics for each of the three configurations will be presented. Also, a few measured patterns at frequencies away from the design frequency will be given to illustrate the potential bandwidth of the antenna for a fixed physical configuration. Finally, an analysis of the total system efficiency will be presented.

MECHANICAL DESIGN AND IMPLEMENTATION OF A 3-GHZ COAXIAL BEAM-ROTATING ANTENNA (COBRA)

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A new COBRA prototype has recently been designed and fabricated, and its electrical characteristics measured. As described in earlier presentations, the COBRA is designed for use with microwave sources that generate RF energy in an azimuthally symmetric mode. This is characteristic of many high power microwave sources. For example, the Magnetically Insulated Line Oscillator generates radio frequency energy in the circular waveguide TM_{01} mode. The resulting aperture distribution is azimuthally symmetric, and when launched with a conventional antenna produces a ring shaped radiation pattern with a null on boresight. The Coaxial Beam-Rotating Antenna (COBRA) provides a means to radiate a high-gain boresight peak pattern with polarization agility from an azimuthally symmetric aperture distribution. The COBRA antenna achieves its properties through a precise orientation of N individually manipulated dish segments, the polarization and gain characteristics being a function of the number of segments and their position. The theory of operation of the COBRA dictates that the exact positions and contours of the four segments be four different paraboloidal shapes. However, we have found that a single paraboloidal reflector can be segmented, and through very precise positioning of the individual segments the desired radiation properties can be achieved. This position control of the individual segments involves a combination of translation and rotation. Previous COBRA prototypes have used two independent mechanical adjustments for each sector, and a complicated and tedious calibration procedure was required to properly align the sectors.

A new COBRA prototype, with a center frequency of 3-GHz, has been fabricated with four segments. The antenna utilizes a Cassegrain-type design with a conical feed horn mounted at the apex of the main reflector. The feed horn is driven by the TM_{01} circular waveguide mode, and its radiated field illuminates the subreflector which in turn reflects the field back into the main reflector. A mechanical control system that utilizes a unique scissors jack assembly has been designed to allow alignment of the dish sectors with only a single mechanical adjustment per segment. In addition, the design permits computer control of the main reflector surface, and permits rapid adjustment of the boresight polarization. This paper will present the details of the mechanical design and fabrication of this newest COBRA prototype. This will include a discussion of the scissors jack assembly, the formation of the main reflector surface and its mounting structure, feed horn design, and subreflector design and mounting details. In addition, the position measurement systems that were designed and manufactured for this system will be described, and an analysis of the resulting positioning errors will be presented. Finally, detailed photographs of the completed prototype, and measured data representative of the resulting COBRA boresight and pattern characteristics will be presented.

A MIXED TIME-FREQUENCY-SCALE ANALYSIS OF THE HYBRID WAVEFRONT RESONANCE THEORY

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Effective classification and identification of target or medium signature rely on the existence of observables in the data. There are basically two types of scattering observables: *global* and *local*. The local ones are conveyed by the traveling wave fields that sense the local features of the medium along the propagation paths, while the global ones have the form of late time resonances that represent the collective effect of the multiple interactions of the traveling waves with the medium. The local observables are therefore localized in the early time signal while the global ones are localized in the frequency spectrum [1]. The classification scheme may therefore utilize both types of discriminants by identifying the scattering signature in a mixed time-frequency domain.

Time-frequency analysis of target signatures have been explored recently via several phase space processing techniques, including the short time Fourier transform (STFT), the multi resolution analysis (MRA) and the adaptive model-based representations (MBR) [2,3]. Extracting the signature via these techniques depends on the choice of the processing window: Narrow windows may resolve the wavefront arrivals while resolving the late time resonance signature usually requires wider windows. The presence of dispersion introduces yet another set of requirements on the window properties. These results call for proper calibration of the processing tools in order to identify the phase space signature of *both* the wavefronts *and* the resonances.

This problem is addressed here in the context of the simplest, yet fundamental problem of transient reflections from a layered medium [4]. We explore both the STFT, the MRA and the MBR processing of the data, the latter is found via the pencil of function (POF) method. Via asymptotic analysis and numerical examples we demonstrate that the combined wavefront-resonance signature can be detected *only* by a window that matches the phase space unit cell generated by the wavefront-resonance lattice. We thus consider a combined time-frequency-scale window that adapts to wave species with non-uniform grid, e.g., dispersive and multilayered media. The numerical signature also reveals the wavefront-resonance interplay, i.e., the process by which the local wavefront events at early time are gradually transformed into the partial resonances corresponding to substructures of the scatterer, and eventually to the global resonances of the composite scatterer [1,4].

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- [4] K.A. Nabulsi and D.G. Dudley, "Hybrid formulations for scattering from the dielectric slab," *IEEE Trans. Antennas Propagat.*, **AP-40**, 959-965, 1992.

ULTRA WIDE BAND SHORT PULSE SENSOR FOR TARGET ELECTROMAGNETIC BACKSCATTERING CHARACTERIZATION

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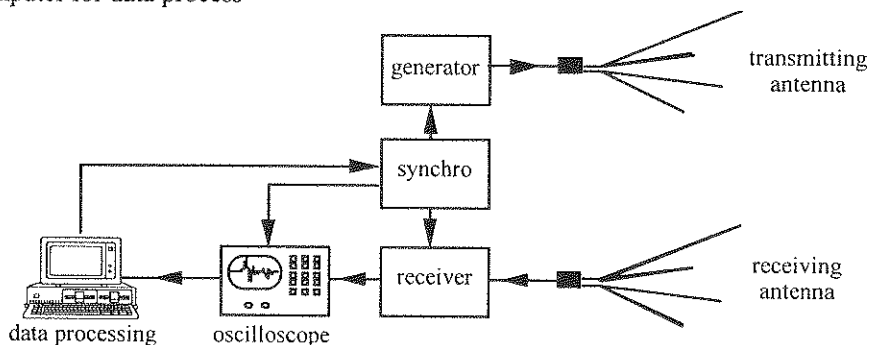
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Usually radar signature measurements consist in target illumination with a frequency scanning and analysis of the backscattered signal. Target impulse response is then obtained by changing from frequency domain to time domain with a Fourier transform. The use of an Ultra Wide Band short pulse sensor makes it possible to measure directly the impulse response from the target. The transient nature of UWB signals is also very interesting for the analysis of electromagnetic scattering mechanisms. It is with this aim in view and considering emerging interest of short pulse and low frequency radar that an Ultra Wide Band facility has been designed and implemented in an anechoic chamber.

We begin by describing this facility which is composed of :

- a generator which transmits a 2 ns pulse from 200 V to 2 kV (peak voltage)
- two strip line antennas which are optimized for short pulse radiating
- a receiver to amplify the signal and to modify the time measurement windows
- a digitizer
- a computer for data process



This facility has been designed to avoid the coupling between emission and reception, and the multipaths by using the time windowing principle. For this application a specific calibration has been implemented, directly in time domain. We present a comparison between :

- results calibrated in time domain
- results calibrated in frequency domain
- results simulated by FDTD and frequency analytic methods

A large number of targets have been measured. The signatures are first interpreted in the time domain in terms of electromagnetic scattering mechanisms . Then 2D holographic images have been computed both in time and frequency domains.

DIRECT CONSTRUCTION OF A ξ - PULSE FROM NATURAL FREQUENCIES AND EVALUATION OF THE LATE-TIME RESIDUALS

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An important type of target identification utilizes the natural frequencies of the target, these being poles in the complex-frequency s -plane as expressed in the singularity expansion method (SEM). Since the location of these natural frequencies s_α in the s -plane is aspect independent (independent of the properties of the incident field such as direction of incidence and polarization), this simplifies the identification problem to the comparison of the target pole patterns stored in some target library. Some of the early schemes used what is referred to as the Prony method in which one fits a sum of damped sinusoids to a waveform. This had various limitations which have been overcome to some degree by what is referred to as a matrix pencil method. These and related techniques are explicit in that they determine a set of s_α from one or more waveforms which are then compared to the target library.

In contrast, implicit methods do not generate a set of s_α from the data. Those used to date have used temporal functions with two-sided Laplace transforms with zeros corresponding to the s_α (poles) of preselected targets. Convolving these with the target impulse response removes (annihilates) the late-time response for the properly chosen target. These go by various names such as K-pulse and E-pulse. In the present paper we go further into this latter type of target identification. This can be aided by application of window Fourier/Laplace and wavelet transforms to the late-time residual.

A FAST MULTILEVEL ALGORITHM FOR WIDEBAND RADAR IMAGING

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Radar imaging has gained wide popularity in a variety of civilian and military applications. The Synthetic Aperture Radar (SAR) images are obtained by processing radar scattering data collected over a range of angles and frequencies. While most processing techniques are formulated as integral transforms, high computational complexity effectively precludes straightforward numerical evaluation of the integrals involved. Conventionally, an integral transform is brought to a multidimensional Fourier transform form whose discrete numerical implementation is effected by a Fast Fourier Transform (FFT) based algorithm. However, in some instances the reduction to a Fourier form can be achieved only at a price of far reaching approximations, which adversely affect the accuracy of the resulting images.

In this paper we propose an algorithm which is applicable to imaging situations that are not amenable to the FFT based methods while approaching their computational complexity. The algorithm is based on the observation that we can, first, form a series of low resolution smoothed images using subsets of the data and, later, aggregate these images into a high resolution final image. Thanks to their band-limited nature, smoothed images can be evaluated at a small number of points, thus reducing the computational cost. The aggregation step involves computationally inexpensive interpolation of the low resolution images to the required resolution with subsequent multiplication by exponential factors. The multilevel algorithm is formed by repeating the aggregation step, while gradually proceeding to higher and higher resolutions. The overall structure of the algorithm resembles that of the FFT and it is closely related to the methods recently introduced in computational electro-magnetics and image processing.

In this paper, the algorithm is formulated, specifically, for the near-field imaging. Numerical examples demonstrating the accuracy and efficiency of the method are presented.

JOINT PHYSICAL OPTICS AND FDTD ANALYSIS OF MICROWAVE SCATTERING

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Introduction. Ultra-wideband radar have been under intense investigation during the past two decades. A number of investigators assume that the scattering response is approximated by the model of point scatterers, and consequently can be represented in frequency domain as a sum of complex exponentials. Further investigation [L. Carin, L.B. Felsen, D. Kralj, S.U. Pillai, and W.C. Lee, *IEEE Microwave and Guided Wave Letters*, Vol. 4, No. 1, pp. 23-25, January, 1994] has shown that the scattering mechanism is more complicated and is better modelled by an exponential expansion with polynomial coefficients:

$$R(\omega) = \sum_{n=1}^N (j\omega)^{\alpha_n} \exp(-j\omega T_n) \quad (1)$$

Here T_n represents time location of the n -th scattering centre, and α_n describes the dispersive properties of this centre. A number of discrimination techniques are based on the pole extraction from data in assumption of pure exponential models. These methods do not work efficiently in presents of dispersive scatterers. This motivates further research in adaptation of existing methods to realistic targets [S. Primak, J. Lovetri, Z. Damjanschitz, and S. Kashyap, in *Ultra-wideband, Short Pulse Electromagnetics III*, 1996, pp 327-334.

Method. We suggest an approach based on the following considerations. A number of approximations can be considered in order to obtain scattered field from a perfectly conducting body. One of them, so called Physical Optics approximation (PO approximation) reflects only a very high frequency properties of scatterers and does not explain $(j\omega)^\alpha$ dependence in (1), predicted by more complicated such as Geometric Theory of Diffraction (GTD) or numerical schemes. We have used this property of PO approximation, allowing application of classical pole extraction techniques (ESPRIT, MUSIC, etc.) to isolate principal scatterers. The information about scatterers location is used to extract parameter α for each scatterer.

Examples. A number of canonical targets (a sphere, a cylinder, a square plate) is considered. Extracted parameters are used to build ISAR images of these objects and in target recognition procedures.

DUAL POLARIZED, UWB RADAR MEASUREMENTS OF SEA AND LAND AT 9 GHZ

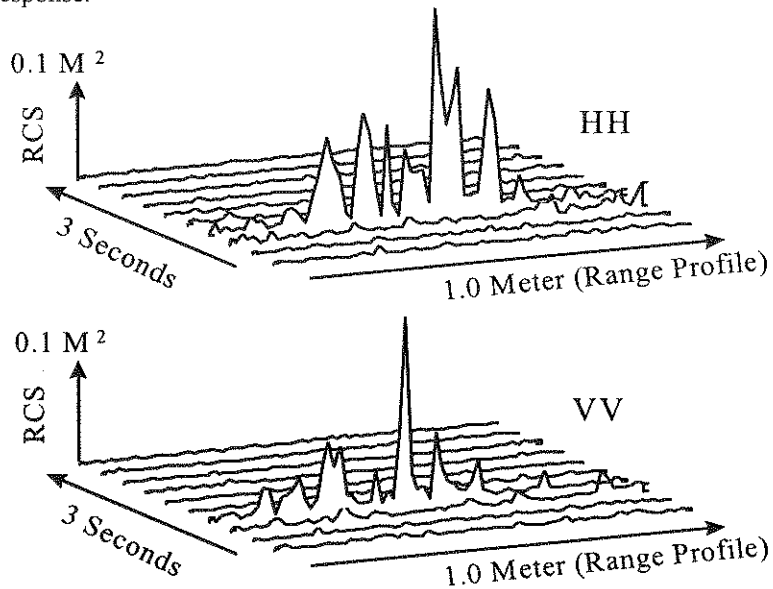
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The range resolution provided by ultrawideband radar measurements contributes to an understanding of the temporal and spatial character of radar backscatter from the natural environment. This paper presents a description of an ultrawideband instrumentation radar, the Microwave Microscope (MWM), along with data examples of backscatter from sea and land features measured at a 9-GHz center frequency with a 5-GHz instantaneous bandwidth.

The MWM system employs a video-impulse-excited/traveling-wave-tube transmitter and dual linearly polarized antennas. A coherent receive function is implemented with hardware that includes multiple sampling heads and a digital sampling oscilloscope. Variable measurement modes include pulse-to-pulse changes both in linear polarization and transmit pulse length. In the ultrawideband mode, the system is capable of transmitting and receiving 150-picosecond wide pulses with a corresponding radar range resolution which is finer than 2 centimeters. With changes in pulse length, the system is also able to contrast real time scattering responses between ultrawideband and conventional radar waveforms.

An example of dual polarized, ultrawideband (2-centimeter resolution) sea backscatter data is shown in the Figure. This data was taken with a range profiling mode where range points spaced every 1.5 centimeters were sampled within 25 microseconds for both linear polarizations and each 1-meter range profile was completed within 1.8 milliseconds. Ten consecutive range profiles, measured 0.3 seconds apart, are shown. The radar was illuminating an upwind rough sea condition at a grazing angle of 4 degrees. Note the resolved sea surface scattering features and the differences in polarization response.



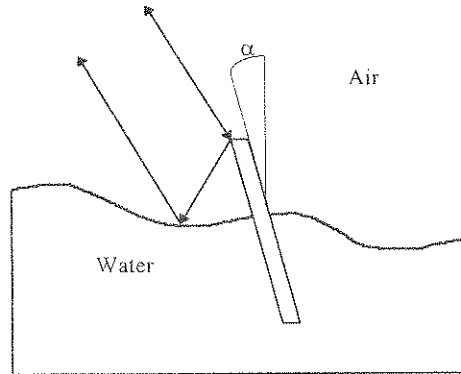
TOWARDS A THEORY OF SUBMARINE MAST DETECTION

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Introduction. This paper addresses the problem of detecting a submarine's masts in a background of sea surface clutter. Aspects of this problem have been studied previously [S. Kashyap, A. Louie, and A. Drosopoulos, *IEEE-URSI AP Conference*, 1997, p. 675]. Some features of the problem can be investigated by considering the simplified scenario shown in the figure to the right. First of all, it is clear that the mast-reflected signal is of low level compared to the response due to the sea surface clutter. Thus, a long observation time is required to distinguish the mast. During this observation time, the position of the mast does not remain constant. It has been shown that even slight changes in the angle lead to significant changes in the response observed by a radar. Considering all these factors, it seems clear that a statistical description of the problem is necessary to model the real scenario.



Method. As the first step toward the modelling of the problem, the angle α is represented as a random function of time. It has been shown [T. Ozaki, *Int. J. Control*, Vol. 57, 1993, pp. 75-96] that α can be considered as a solution of a Van der Pole equation excited by a White Gaussian Noise. This gives a more accurate model of a mast's behaviour than a simple linear motion model. As the next step, a number of responses corresponding to different angles are calculated using numerical methods. Responses obtained by the Physical Optics approximation will be presented and the use of more precise methods, such as the Geometrical Theory of Diffraction, the Method of Moments, and FDTD, will be discussed. Using information from this synthetic data and the statistics of the angle α , the statistics of the response observed by a radar will be calculated. The target response must then be embedded in the sea clutter response. Different models can be used for the sea clutter depending on the properties of radar and its relative position with respect to a sea surface. Many of these models are described in the open literature [see for example D. Pistoia, *Proc. IEEE Natard-97*, 1997, pp. 149-153]. A detection algorithm can then be designed from this theoretical statistical description.

Simulation. We consider results of numerical simulations of a single perfectly conducting cylinder protruding from the sea surface and methods for its detection.

UWB MEASUREMENTS OF CANONICAL TARGETS AND RCS DETERMINATION

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An experimentation is described for measurements of ultra wide band impulse scattering responses from different canonical targets. Ultra wide band radar has not only the potential to perform target identification but also to determine easily the Radar Cross Section.

The basic measurement configuration uses a 36 m x 30 m horizontal ground plane (fig 1). Two identical wire antennas are used and their characteristics are determined to radiate an uniform and homogeneous electric field in the test zone. The bistatic angle is about 5° and allows a quasi-monostatic measurement configuration. The transmitting antenna is driven by a pulse generator which has a pulse output voltage of 80 V and a rise time of 400 ps. The delivered pulse has significant frequency content extending about 1 GHz. The receiving antenna is connected to a digital sampling oscilloscope (Tektronix TDS 820 - 6 GHz) and the target is located at 9 meters of the antennas and is around 40 centimeters above the ground plane level.

The measured canonical targets are :

- a 71 cm x 71 cm flat plate,
- a 355 mm metallic sphere,
- a perfectly conducting cylinder (diameter : 25 cm, length : 62 cm).

The background is subtracted in all measurements, this eliminates any returns due to down range scatterers that are inherent to the facility. It also eliminates the direct coupling from the transmitting antenna to the adjacent receiving antenna. Impulse scattering responses are measured at different heights around 40 cm. Thus an average is used to reduce the ground target reflection even if this one is not really significant for all targets. Each transient response is compared to an FDTD prediction.

The RCS is determined from the knowledge of the theoretical RCS of a calibration target like a sphere or a plate. Finally the RCS of canonical targets are compared to theoretical predictions and differences between measured and expected data is less than 2 dBm² for the maximum gap in the frequency range.

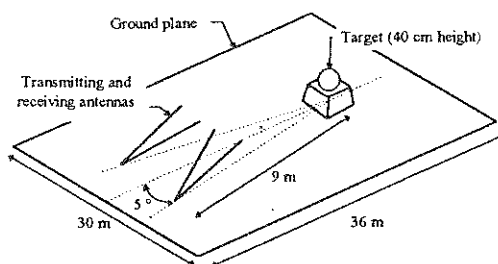


Figure 1 Configuration of UWB system.

MODIFICATION OF THE APERTURE SYNTHESIZING METHOD FOR UNDERGROUND SOUNDING DATA PROCESSING*

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Ground penetrating data processing based on the Aperture Synthesizing Method (ASM) issues are considered in this paper. Ground Penetrative Radars, using video pulse signals, normally produce data which are difficult for identification that implies the great importance of its efficient processing.

ASM is based upon the following two-stage procedure:

- 1.application of compression filter to the reflected by the medium signals (echo-returns); the filter indicates the presence of the object reflected signal;
- 2.spatial convolution of the obtained set of the echo-returns.

The first stage stands for increasing of the depth resolution and the second one — for increasing of horizontal resolution.

ASM seems to be one of the most powerful technique for radio-location data processing. It is successfully used in the fields where Fresnel-Kirhgoff scalar diffraction theory satisfactory acts (this includes location in air and non-dissipative media sounding). Although efficiency of its application to the data, obtained over stratified media having non-negligible resolution is rather limited. One of the basis reasons is strong attenuation of the pulse and its shape distortion while propagation in such media. These processes lead to the failure of the compression filter and thus algorithm does not work correctly.

On the other hand, consideration of approximate a-priory information regarding the medium investigated enables to estimate the pulse shape on the given depth. In this paper we suggest the modification of the SAM that uses construction of the compression filter based on the estimated shape of the pulse. This approach permits to increase vertical resolution in dissipative media.

Another problem connected with using of ASM is significant computational time needed during echo-returns spatial convolution on the second stage. Modification of the computational technique that 3 times shorts computational efforts at this stage is suggested.

We conclude with the natural experiment results, which indicate efficiency of the algorithms.

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* This work is partly supported by the STCU fund (project #366)

PROCESSING OF UNDERWATER ELECTROMAGNETIC SOUNDING USING SIMILARITIES BETWEEN WAVE AND DIFFUSION PROPAGATION

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By using similarities between EM sounding in dielectric and conductive media, it is shown that one can transform between solutions in one type of propagation to the other. The method is based on the similarities of the Laplace transform between the diffusive and the nondiffusive cases. In the diffusive case the equation involves the Laplace variable s in the first power while for the nondiffusive cases similar equations occur with s^2 . Three alternative implementations are developed. The first implementation is based on substitution s^2 for the Laplace transform variable s using forward and inverse numerical Laplace transform. The second implementation is based on expanding the diffusive time response on an exponential time base and replacing it with its image function in the wave case, namely a sinusoidal function. The third implementation is based on direct transformation in the time domain using exponential time interval sampling. Performance of the techniques on synthetic data is demonstrated. The advantages of the techniques are their simple implementation. Other advantages and limitations of the method and each of the implementations are discussed. Application of common techniques used in processing of seismic, radar for processing and EM sounding in conductive media are discussed. The use of the Poynting vector as a means of determining distance and direction is demonstrated.

IDENTIFICATION OF BURIED OBJECTS IN OCEAN ENVIRONMENTS

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The identification of a buried object in the sediment of an ocean has important practical applications, and has received fairly considerable attention.

Our investigation can be summarized as follows. Assume that we know the environment, i.e., given the location of a continuous sound source, we know what sound field will be detected in the case that there is no object existing. Mathematically, this means that we can construct the Green's function for the Helmholtz equation satisfying certain boundary conditions and a radiation condition. We determine the unknown buried object by sending in incident waves and detecting the total waves.

In this talk we present two examples. First we consider the determination of a wave penetrable object buried in the sediment of an ocean, such that the sediment has a finite depth and the substrate of the sediment is rigid. This leads to an inverse scattering problem in a two-layered waveguide. Assuming that we know the acoustic properties of the waveguide, we determine the unknown inhomogeneity by sending in incident waves from point sources in given locations, and detecting the total waves along a line. Numerical examples are presented.

In the second example we present a demonstration of shape determination of an object buried in the sediment of an ocean, such that the sediment can be considered infinitely deep. Wave scattered by an object in such a infinitely stratified medium is much different from that in a homogeneous medium. In a stratified medium, the scattered energy is not spread out spherically. Therefore, the scattered far-field consists of two components: free-wave far-field and guided-wave far-field. In many cases only free-wave far-field or only guided-wave far-field can be measured. Our research concerns the problems of determining the shape of scatterer from the incomplete far-field data. We have found that the choice of incident waves is very important in determination of the shape of the unknown object from only free-wave far-field or only guided-wave far-field. We obtained analytical relations of the object, incident wave and scattered free-wave far-field and guided-wave far-field. These relations are used in reconstruction of the shape of unknown object numerically.

SIMULATION, MODELING, AND EXPERIMENTAL STUDIES OF HIGH-GAIN GALLIUM ARSENIDE PHOTOCONDUCTIVE SWITCHES FOR ULTRA WIDEBAND APPLICATIONS

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The continued development of high-power sources of ultra wideband radiation depends critically on improvements in switches capable of high voltage operation and rapid risetimes. The University of New Mexico (UNM), in collaboration with Old Dominion University (ODU), is using both commercial simulation software and modeling to optimize high-gain GaAs photoconductive semiconductor switches (PCSS). The PCSS is an integrated component of a parallel plate radiation source used for driving a TEM horn impulse-radiating antenna. Commercial software from SILVACO (www.silvaco.com) is used to study the PCSS at the device level. Simulations include charge carriers, electric field and potential profiles at both the rise and fall times of the impulse. Initial results indicate that the transport mechanism is dominated by EL2 traps, exhibiting characteristics of negative resistivity and filamentation at high fields. Impact ionization, trapping and subsequent de-trapping also lead to the formation of a high field region near the anode at the end of a pulse cycle. This formation of a high-field region is a local effect and perhaps independent of the applied bias. The applied bias, on the other hand, influences carrier transport, and charge buildup near the contact and the device surface. Hence, the opposed contact switch exhibits higher hold-off characteristics than the traditional lateral contact switch. A 2-D numerical code developed at ODU probes the role of contacts (Ohmic injection vs. Schottky blocking) on the electrical characteristics and current crowding effects. The guidance and understanding provided by both simulation and modeling are being implemented at UNM where GaAs PCCS's are being fabricated for test and evaluation.

Research supported by an AFOSR New World Vistas Grant

INFLUENCE OF DIELECTRIC ON BULK PHOTOCONDUCTIVE SWITCHES USED FOR ULTRA-WIDEBAND, HIGH-POWER MICROWAVE GENERATION

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The Air Force Research Laboratory (AFRL), in collaboration with the Naval Surface Warfare Center (NSWC), is developing lateral geometry, high-power photoconductive semiconductor switches (PCSS) for use in phased array, ultra-wideband (UWB) sources. The current switch utilizes an opposed contact geometry with a 0.25 cm gap spacing and is an extension of previous work on 1.0 cm PCSS devices. The 0.25 cm PCSS is shown to operate at greater than 20 kV charge voltage, 65 ps rms switching jitter, less than 450 ps risetime and greater than 1 kHz pulse repetition rate (PRR) when triggered using a compact, high-power laser diode. Traditionally, the 0.25 cm PCSS has been operated in a pressurized gaseous SF₆ environment. This work presents the performance of the 0.25 cm PCSS as a function of dielectric environment. The dielectrics investigated include SF₆ and HFE-7100 perfluorinated liquid. The influence of dielectric environment on switch risetime, switch holdoff voltage and switch lifetime is presented.

BREAKDOWN CHARACTERISTICS OF DIELECTRIC MEDIA AT SUBNANOSECOND FORMATIVE TIMES

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Present day ultra-wideband (UWB) radiation sources produce Megavolt pulses at risetimes of hundreds of picoseconds (ps). Empirical data on the breakdown characteristics for dielectric media at these short time lengths and high voltages are either extremely limited or non-existent.

In support of the design of these UWB sources, we are investigating the breakdown characteristics, at these voltages and time lengths, of several dielectric media. These include air, N₂, H₂, He, SF₆, and transformer oil. The two voltage sources used in the experiments are capable of delivering 400 and 700 kV with a 400 ps risetime into an open load. These pulses are applied to the test gap area, capable of housing various gases and liquids at pressures from less than 100 kPa to 15 MPa. From the collected data, an empirical relationship of E-field versus breakdown time for the observed dielectrics is presented. Several other breakdown phenomena at these fast risetimes are observed. Dielectric breakdown strength dependence on polarity is investigated. Streak camera images of the channel during breakdown are captured, providing information on gap closure velocity. Also observed is the statistical lag time of breakdown for gas dielectrics with and without the presence of ultraviolet illumination on the gap.

This work was supported by AFOSR/DOD MURI.

ANALYSIS OF NONLINEAR OPTICAL-ELECTROMAGNETIC INTERACTIONS IN ULTRAFAST MODE-LOCKED LASER DIODES

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The operation of a mode-locked (ML) semiconductor laser diodes (LDs), in common with lasers of other types, is a nonlinear process in which a balance of dispersion and various nonlinearities results in the generation of an ultrashort (~ 1 ps or less) optical pulse, repeated at a laser cavity round-trip frequency or its harmonic and with parameters, averaged over a round-trip, constant, similar to an optical soliton. However, there are some important features in ML that are specific for semiconductor lasers, e.g.:

- Depending on laser parameters, the ML repetition frequency can cover the extremely broad range, from GHz to sub-THz and, as suggested in recent works by ourselves and other authors, into the THz range.
- The same nonlinearities that define the ML properties can also be used to achieve various types of (useful) interaction and conversion between optical and electromagnetic (microwave and mm-wave) signals - sinusoidal or pulsed- either within the laser cavity itself or in a monolithically integrated scheme.

In the paper, we shall theoretically analyse the operation of (sub)-THz modelocked LDs and their application to generating and/or frequency shifting ultrafast electrical signals.

First, time- and frequency domain modelling will be applied to assess the possibility of passive harmonic mode locking at frequencies of several THz. The importance of ultra-fast saturable absorber non-linearities will be discussed and the tolerance of the laser operation to construction parameters assessed.

We shall then analyse the process of parametric frequency conversion in an ultra-fast ML laser under direct modulation of some of the laser parameters (e.g. unsaturated absorption in the intracavity saturable absorber) at a frequency f_s close to the ML repetition frequency f_{ML} . It will be shown that parametric non-linearities in the laser result in the output light being modulated at a difference frequency $f_c = |f_s - f_{ML}|$. Detecting the light will then be shown to provide efficient electro-optical down-conversion of the signal, with the laser acting as both the local frequency oscillator and a nonlinear element, similar to our earlier studies for the case of lower repetition frequencies. The conversion efficiency will be shown to have a resonant dependence on f_c . Absolute efficiencies will also be evaluated and the prospect of application in atmospheric and plasma studies discussed.

Finally, we shall address the issue of the possibility of direct generation of ultrashort electrical pulses and sinusoidal THz signals by direct electrooptical rectification of mode-locked laser signals in a combined optical/THz waveguide structure. The conversion efficiency in tandem and intracavity configuration will be approximately evaluated and the ways of increasing this efficiency discussed.

**DEMONSTRATION OF SUB-MILLIMETER RADIATION
GENERATION FROM STATIC FIELD BY A SUPERLUMINOUS
IONIZATION FRONT IN SEMICONDUCTOR CAPACITOR
ARRAY.**

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Short pulse of radiation in the sub-millimeter range is repetitively generated while superluminous ionization front propagated inside alternately biased semiconductor capacitor array. This scheme for generating radiation from a static electric field is similar to the DARC (dc to ac radiation converter) scheme first presented by Mori *et al* where a laser beam creates an ionization front when propagating inside a capacitor array filed with a working gas. In that case the front velocity was the group velocity of the laser pulse inside the plasma. In the present experiment the radiation produced inside semiconductor crystal by sweeping laser beam in a geometry that lead to generation of superluminous ionization front. The frequency of the emitted radiation is measured by a set of cut-of waveguides filters and waveguide detectors. The emitted signal frequency found to higher then 100GHz.

FUNDAMENTAL PHYSICAL CONSIDERATIONS FOR ULTRAFAST SPARK GAP SWITCHING

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A problem of interest concerns compact, high power ultra-wideband systems which minimize the volume of high pressure gas. Thus, single channel spark gaps are considered because the volume of gas under pressure is much less than that needed for sources containing ring gap switches. However, the intrinsic inductance of single channel spark gaps is prohibitively high to achieve large rates of voltage rise.

For future applications, the limit of spark gap technology for ultrafast switching is explored. Specifically, an estimate of the fastest risetime achievable with a single channel spark gap has been investigated using three approaches. The first examines the growth of the electron avalanche in gases to estimate its growth rate. The avalanche growth rate determines the fastest possible risetime of the resultant pulse. The second approach uses the components of the velocity of electromagnetic propagation to estimate the achievable risetime. The third uses an equivalent circuit of a single channel spark gap to calculate the maximum achievable rate of voltage rise. The first two estimates indicate that risetimes on the order of 1-10 ps are achievable. The last treatment, however, illustrates the dependence of the pulse risetime on the peak voltage and calculates the maximum rate of voltage rise to be roughly $6 \cdot 10^{15}$ V/s.

To reduce the effect of the intrinsic inductance of the channel, a simple geometrical alteration to the spark gap geometry has been devised which effectively reduces the inductance per unit length of the spark gap to that of its transmission line feed. This simple change alleviates the constraint imposed by the maximum rate of voltage rise and is anticipated to permit the realization of picosecond risetime high power electromagnetic sources.

COMPACT HIGH VOLTAGE HIGH FREQUENCY PULSE POWER GENERATORS ON THE BASE OF GaAs SWITCHES

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Impulse antenna excitation with short edge current pulses is one of the methods to generate ultrawideband signals. The bandwidth, in this case, is about $1/\tau_f$, where τ_f is the pulse rise time. Usually radar systems use phased array with current pulse generator for each element. This pulse generators should comply small jitter time, high amplitude stability, small τ_f , high reliability with small weight and overall dimensions.

Here we first present small-size solid-state high-voltage pulse generators of subnano- and picosecond pulses on the base of power GaAs switches. The diodes and dynistors are used as the key elements of these generators. They are capable of high voltage blocking (~ 1 kV) and high amplitude current switching (up to 200 A) with rise times from 30 psec to 300 psec. This paper describes three types of the generators:

- output voltage amplitude $U \sim 3$ kV, $\tau_f = 100$ -300 psec, PRF up to 5 kHz;
- output voltage amplitude $U = 100$ -500 V, pulse width 60-150 psec, PRF ~ 10 kHz;
- output voltage amplitude $U = 100$ -500 V, pulse width 100-200 psec, PRF up to 3 MHz.

The first two types generators are fabricated on the base of GaAs dynistors, which are connected in series with 50Ω load and switch capacitive charging subsystem. Third one is fabricated on the base of GaAs diodes, which are connected in parallel with the load. In last case diodes function as fast opening switches, commute energy of the inductive charging subsystem on the load at the triggering off moment.

For all generators jitter value was no higher 20-30 psec, delay time has typical value about 10 nsec, amplitude and waveform instability of the output signal does not exceed 5%.

**WEDNESDAY,
JUNE 17, 1998**

Lateral switches
4 Element Module



17kV/switch SLED + possible

Solid state switching Problem: Heat dissipation

Polyethylene Focussing lenses

ULTRA-WIDEBAND SOURCES AND ANTENNAS

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Ultrawide Band Microwave Sources and Antennas are of interest for a variety of applications such as transient radars, mine detection, and unexploded ordnance location and identification. Much of the current research is being performed at the AFRL Directed Energy Directorate at Kirtland AFB, NM.

The development of new sources and antennas for the production of high power UWB energy has proceeded along several distinct lines in the past 6 to 8 years and is now beginning to branch out into other lines of technology. The research into UWB transient antennas has also contributed significantly to the development and improvement of wideband continuous wave antenna designs and has brought new knowledge about the complex behavior of ferrites, dielectrics, and resistive materials in ultrawide band and high stress environments. This has in turn led to advances in the technology of transmission lines, insulators, baluns, and UWB optics.

The approach to high power source development has included three main thrusts: high pressure gas switching, oil switching, and solid state switched arrays. Recent improvements in high voltage insulating oil and significant increases in our understanding of solid state switching and short-pulse gas switching have made significant contributions to the UWB technology. Developments in stacked Blumlein and stacked transmission line technology combined with improved solid state switches are opening up new possibilities for compact UWB devices. As the technology progresses, of course, it is also making possible experiments which are teaching us a great deal about material properties under high stress, short pulse conditions.

This paper reviews the progress to date along these lines and discusses new areas of research into UWB technology development.

IRA : H_2 -switch 100 atm. \rightarrow High rep. rate 60-200 Hz
spec. for H_2 > 2000 Hz
Air at $1/3$ of pressure: works, but only to about 100 Hz

Dave Giv: effort to study fast, low jitter (~~trigger~~) switching

Flowing Oil: 2000 Hz

Current Goal: 10^{16} V/s (1 MV @ 100 ps)

BOSS: Bistable Optically-controlled Semicond. Switch

BSSTM: Bulk Avalanche Semicond. Switch

DSLID & SAS: 10 kV @ 5 kHz $t_r = 100$ ps Z_{in}

Drift Step Recovery Diode + Silicon Avalanche Diode

NET I and II: 8x12 Array, Electronically steered
6x8 array 8 kV ps switch

WAVE PHENOMENOLOGY AND AUTOMATIC-TARGET RECOGNITION

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This talk will review the utilization of wave phenomenology in what we have termed physics-based signal processing. The goal of such algorithms is to infuse wave phenomenology - elucidated over the last several decades - into advanced signal processing algorithms. Of interest, for example, are signal processing algorithms which exploit wavefront, resonances, and chirps excited by general targets. Particular algorithms discussed include a newly developed physics-based method of matching pursuits, with application to ISAR and target-identification. With regard to the latter, we utilize the matching pursuits to parse scattering data into its fundamental constituents, which are then applied in a hidden Markov model (HMM) framework to perform target identification. This research builds upon extensive previous research in speech processing, for which HMMs have proven remarkable tools for word identification. In speech, phonemes constitute the fundamental building blocks while, in electromagnetic scattering, wavefronts, resonances and chirps represent the analogue. Additionally, Bayesian constructs are exploited, in the context of target detection in random environments. In this case we are interested in the detection of buried UXO, with data generated by ultra-wideband synthetic aperture radar (SAR) as well as low-frequency electromagnetic induction (EMI). Finally, in the context of radar, we investigate polarimetric techniques, with application to SAR-based mine field detection and discrimination.

Col Baum: Recent Dramatic Developments in
~~Speakers~~ UWB Mine Detection (L. Carin Associates)

Briefing: v Key Technology for Defense in 21. Century v

HIGH-POWER MICROWAVES AT 25 YEARS - THE CURRENT STATE OF DEVELOPMENT

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Microwave Sciences

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It has now been 25 years since the seminal experiments from Cornell University and the Lebedev Institute/Institute of Applied Physics collaboration launched the field of high-power microwaves. This joining of pulsed power techniques with microwave technology has resulted in a variety of sources -- some scale-ups of conventional sources like the magnetron and backward wave oscillator, others entirely new developments like the vircator and the low-impedance relativistic klystron -- capable of producing power levels in the range of hundreds of megawatts to tens of gigawatts in the decimeter-, centimeter-, and millimeter-wavelength regimes. In this talk, we will review current trends in this field, most notably

- An apparent narrowing of the field in the types of sources under development. This focus is based on the understanding gained of the strengths and weaknesses of different sources, and adoption of sources most suited to the applications anticipated for HPM.

- An increased interest in generating manageably high powers at higher efficiency, along with a reduced interest in pursuing ever higher peak powers. The emphasis on efficiency has included both power and energy efficiency. The latter is evidenced by increased concern with isolating and controlling the mechanisms that tend to cause microwave pulse lengths to decrease as the power increases-known as pulse shortening. A resulting trend is a melding of high-power and conventional microwave technology, and we will address the issues in system cost that accompany this development.

- A growing commercial supply of high-power microwave sources and systems. This sign of maturity in the field makes high-power microwave systems more available for a class of users interested more in applications than development.

- A growing internationalization of the HPM research field, with workers found in a wider range of countries.

“Predictions are very difficult, especially about the future.”

* Work supported by the AFOSR HPM MURI Program.

*High Peak power with - manageable weight + volume
- repetitive operation
- tunability
pulse lengthening*

*Changing: Growing internationalization, emerging: S, D, IL, Taiwan, India, Australia
Medium: UK, F, China, Ukraine
Large: USA, Russia*

*Disappearing: Vircators = easy, simple, inexpensive - low efficiency
KREMS: high voltage, req. dielectric*

DRON 1-3.4 GHz sources to 500ns in 50ns steps

*PI: S-Band Vircator, tunable, 200 MW, in expensive for initial tests
Virtode*

GENERATION OF HIGH-POWER SUBNANOSECOND PULSES

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The paper gives a review of work on the production of high-power, high-voltage pulses in Russia for the last 30 years. The case in point is the pulses of duration 0.1-1 ns with a current of $1-10^4$ A, a voltage of up to 10^6 V, and a pulse repetition rate varying from unity to 10^4 Hz. The emphasis is on the results of the work carried out at the Institute of High Current Electronics and the Institute of Electrophysics of the Russian Academy of Sciences. High-power subnanosecond pulses are produced by two methods. The first method involves the storage of energy in a capacitor or in an inductor followed by super-fast switching with a fast spark gap switch being closing in the first case and opening in the second one. Generally used as closing switches are gas (air, nitrogen, hydrogen, etc.) gaps operating at a pressure of up to 100 atm. Most efficient opening switches are semiconductor silicon diodes whose operation is based on the SOS effect recently discovered at the Institute of Electrophysics. These switches make it possible to produce pulses of voltage up to 1 MV with a repetition rate of up to 10^4 Hz. The second method is based on the transformation of nanosecond pulses. A nanosecond pulse is transmitted through a coaxial cable, and initially its rise-time is shortened to 10^{-10} s with a peaker and then the resulting pulse is further shortened. Used as peakers are shock-wave electromagnetic lines, two-electrode spark gaps immersed in a compressed gas, vacuum peakers, etc. To shorten the pulse at the second stage, short-circuited lines, inductance coils, compressed-gas spark gaps, and other devices are used. In the review, emphasis is given to gas-discharge and semiconductor devices. The fast switching effect is treated theoretically. Examples of sub-nanosecond pulse generators designed for pumping lasers, for wide-band location, for production of intense electron beams, etc. are given. The measurement techniques for sub-nanosecond current and voltage pulses are analyzed.

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Radan Research and Design Group

600W $t_r \approx 250$ ps $t_w \approx 350$ ps

→ Air breakdown in focus of peaker

UXO – THE PROBLEM

A. Hooper

Yuma Proving Grounds, Yuma AZ, USA

ELECTROMAGNETIC TERRORISM: ANALYSIS OF POSSIBLE SITUATIONS

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V.Loborev, Y.Parfenov, L.Zdoukhov

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Struggle against terrorism and organized criminality is becoming more urgent. Criminal's actions are characterized by growing impudence and large scale. They try to be equipped with the most advanced technical means. In certain cases, criminals used technical devices unknown to special services.

The actual situation requires anticipating the possible criminal actions and taking preventive measures. For society, it is more expedient than to eliminate the consequences of criminal actions.

Several Russian scientific institutions have conducted experiments, which proved the reality of the following events:

- surmounting of objects protection technical means by using electrotechnical devices;
- organizing the accidents on high power lines with the help of electroconductive aerosols;
- destroy of electric power systems in administrative building, industrial, plants, banks by supplying pulsed voltage into the "core-screen" circuit of power cable;
- generation of electron systems interference through electric power circuits.

The paper will present the execution plans and the results of experiments.

ADVERSE EFFECTS OF HIGH POWER ELECTROMAGNETIC ENVIRONMENTS IN THE INFORMATION AGE

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This paper begins with a brief discussion of the age in which we live -- the information age. The growth of fast, distributed computer power has allowed individuals, businesses and governments to use computers in ways that were not imagined thirty years ago. In addition, businesses in particular have devised new ways to use computers to offer new services or to make themselves more efficient. As a consequence, we are becoming more dependent on this information technology equipment (ITE) to perform even the most routine tasks.

Another aspect of the information age is the proliferation of electronics containing microprocessors. This proliferation has resulted in an increased density of digital equipment inside of homes, office buildings and factories. This aspect, along with the growth of mobile telephones, has created a situation where electromagnetic interference (EMI) between different types of electronics is becoming more common.

While the threat of electromagnetic interference (EMI) is recognized and engineers throughout the world are working hard to prevent the occurrence of problems in advance, it is clear from reports in the media that this process is not always successful. In addition, with the increase of personal computer clock speeds to nearly 500 MHz this year, it is clear that high frequency electromagnetic fields are becoming more of a threat to digital electronic systems. Since most of the problems noted in the media appear to involve continuous wave (cw) fields on the order of 10 V/m or smaller, it is clear that most commercial systems do not have much margin to survive the illumination of larger (HPE) fields, whether they are created accidentally or intentionally.

This paper will review the types of effects that have been documented with regard to EMI and will categorize them with regard to their failure mechanisms and implications. In addition, the authors will describe the planning underway at the International Electrotechnical Commission to deal with this serious problem.

- use redundancy and diverse routing
- degrade slowly if attacked
- should not depend on normal operation of the infrastructure

→ Increase Awareness
Perform Assessments of Potential Risks
Evaluate Consequences
Risk Management Plan

REALITY OF EMP EFFECT

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As a physical phenomenon, accompanying a NEMP was discovered about 50 years ago. When airbursts were conducted there were failures of test equipment, communication and electric power supply systems. Since that time, EMP has been considered to be one of the nuclear explosion effects. At the beginning of the 1960s the large-scale researches were initiated with the aim to determine EMP parameters and mechanisms of the effect on radio-electronic and electrotechnical equipment. Because of the ban on nuclear weapons testing the theoretical models became the basic research instrument of EMP parameters. For this reason among authorities there are disagreements concerning EMP parameters and its significance as one of nuclear effects. Authors of some scientific works predict that EMP level can achieve 20 MV/m. In our opinion such an excessive assessment leads to the corresponding conceptions of EMP overestimated power. As a result, a number of "fabulous" projects has appeared (examples will be presented in the paper).

At the same time the other experts declare that practically used calculated and theoretical model don't take into account a number of limiting EMP level factors. They consider that existing data on EMP level are greater by an order of magnitude. In our opinion, generally used calculated and theoretical models take into consideration all the basic physical mechanisms of EMP generating and correctly evaluate EMP level: for a high altitude nuclear explosion - about 50 kV/m near the earth surface. Such electromagnetic fields are able to result in serious disruptions in the operation of civil communication and electric power supply systems in big territories. Numerous experimental data received with the help of EMP simulators confirm these facts (examples will be given in the paper).

Now 77C subcommittee of IEC is developing the complex of International standards, which contain up-to-date knowledge about EMP parameters, its effect on different systems, test methods and protective means. We consider this work to be of great importance.

STATUS OF THE DEVELOPMENT OF IEC STANDARDS FOR THE PROTECTION OF CIVIL EQUIPMENT TO THE EFFECTS OF HIGH-ALTITUDE EMP

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This paper provides a status report on the standardization work being accomplished by the International Electrotechnical Commission (IEC) to provide high-altitude electromagnetic pulse (HEMP) standards and technical reports for the protection and testing of civil electronic equipment and installations. The current work is organized under technical Subcommittee 77C; the Secretariat of the subcommittee is maintained by Sweden with Manuel Wik holding the position of Secretary and Tomas Wedin serving as the Assistant Secretary. William Radasky of the United States is the subcommittee Chairman.

Since our last presentation at the AMEREM meeting in Albuquerque in 1996, the total list of projects has expanded from 9 to 12, with 4 reports and standards being fully published and available for purchase from the IEC. In addition, 6 other documents have reached the Committee Draft stage (including the voting stage in some cases) and are expected to be completed within the next two years. It should be noted that all of these HEMP standards have been fully integrated into the IEC EMC standard numbering system, which is currently identified by the 61000 series (formerly the 1000 series).

Our presentation will review the HEMP standards in terms of their categories, the particular standard numbers and titles, the project leaders, the basic content covered, and any technical issues of importance. At this time there are four EMC categories considered in the HEMP work including: Part 1 -- General; Part 2 -- EM Environment; Part 4 -- Testing and Measurement Techniques; and Part 5 - Installation and Mitigation Guidelines. The paper will conclude with a discussion of potential new work items and future work areas that have recently been suggested. The authors are looking forward to feedback from the meeting attendees in order to consider the future plans of the Subcommittee.

EVALUATION OF THE SINGLE-ENDED TEM CELL FOR TESTING CIVIL EQUIPMENT TO THE IEC HEMP WAVEFORM

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The International Electrotechnical Commission (IEC) has recently begun work to develop a new measurement standard for the use of TEM test devices for evaluating equipment immunity and emissions for radiated electromagnetic fields. Although the main emphasis of this standard will be on continuous wave (CW) radiated fields, there is also interest in applying these TEM test devices in a standardized way for pulse immunity testing.

The GTEM (Gigahertz TEM) cell is a particular commercial simulator that is of the single-ended type. The authors have analyzed the GTEM 1750 cell for both CW and fast pulse immunity test cases in the past, and have validated the META3D FDTD model against data for these cases. In this paper, the authors will extend the past analyses to consider the applicability of the GTEM 1750 for the IEC HEMP early-time electric field waveform as described in IEC 61000-2-9. The waveform has a rise/fall characteristic of 2.5/25 ns and peaks at a value of 50 kV/m.

This paper will describe the geometry of the empty GTEM simulator in detail and will briefly review the code/data validation work performed in the past. Next, for the case of the IEC HEMP waveform, we will examine the characteristics of the total fields in the test volume. In addition, the impact of placing test objects of different sizes in the simulator will be examined including the responses due to attached conductors such as power cables, which become part of the test being performed. These results will clearly indicate the value and limitations of using the GTEM test device for testing small equipment boxes to the IEC HEMP waveform.

NECESSITY OF CREATION OF INTERNATIONAL PULSED ELECTROMAGNETIC FIELD STANDARD

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Now IEC is creating the complex of international standards on high altitude nuclear EMP. A wide range of problems is considered in these standards including the problem of testing civil objects and systems by using electromagnetic pulse simulators. Characteristics of the simulator's fields differ from each other. Moreover, simulators do not reproduce exactly the pulse given in these standards. Therefore, simulator's application in certification tests becomes problematic. To solve this problem it is necessary to provide unity and precision of pulsed electromagnetic fields measuring. Such approach is realized in Russia by way of periodic comparison of calibration means or sensors with national pulsed electromagnetic field standard.

The necessity of such procedure is partially attributed by the following. At measuring pulses with the rise time of 2.5 ns the rise time of measuring mean transient performance must be less than 1 ns. Creation and calibration of such means are very difficult scientific and engineering tasks. Non-uniformity of the transient performance peak may introduce significant measurement errors. Even at the same time resolution, the presence of a small non-uniformity (in the limits of 5-7%) may cause considerable measurement errors (up to several times).

**ORGANIZATION AND DESCRIPTION OF EMC STANDARDS
DEVELOPED BY THE
INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)**

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Over the past ten years the International Electrotechnical Commission (IEC) has expended considerable effort to develop a comprehensive set of Electromagnetic Compatibility (EMC) standards that can be used by industry to minimize interference between different types of equipment. While the IEC has existed since 1906, its EMC work has been accelerated due to the decision of the European Commission in 1989 to make the achievement of EMC a matter of law. In order to develop the required mandatory standards needed in Europe, the IEC agreed to expedite its work with the goal that the mandatory European EMC standards would be based on International Standards.

This paper will describe in some detail the philosophy of the development of EMC emission and immunity standards within the IEC and which committees are involved in the different aspects. Next, the grouping of the EMC standards into basic, generic, product family and product standards will be discussed, with the major standards of interest being summarized. In addition to the completed (and published) work, a review of ongoing efforts will be reviewed to give the conference attendees some insight into areas of future concern such as Power Quality.

Although the major emphasis in this paper is on the IEC, several other cooperative efforts will be mentioned including the IEC effort to develop standardized sensors to measure the Electromagnetic Fields (EMF) for the World Health Organization (WHO). In addition, several parallel efforts will be mentioned in the areas of automotive and space EMC within the International Standards Organization (ISO).

ELECTROMAGNETIC ENVIRONMENTS PRODUCED BY PULSED MOVING CONDUCTORS

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Over the years there has been continuing interest in the development of pulsed power energy sources and accelerators based on transient magnetic field exclusion and diffusion. Many of these devices involve a stationary source current which produces eddy currents in a moving conductor. Applications include electromagnetic braking and the generation of large power surges from a low impedance source. Figure 1 shows a hypothetical example of a system that embraces many of the essential physical features of the problem.

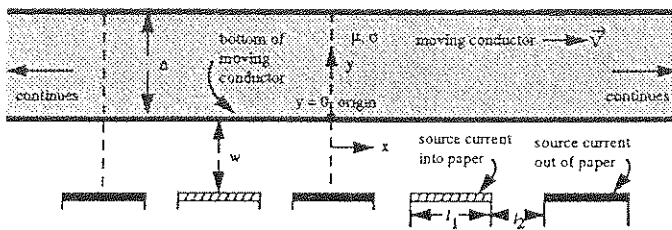


Figure 1. Source Currents and Moving Conductor

In this paper we determine the environmental electromagnetic fields generated by the system of conductors shown in Fig. 1. We solve the following coupled partial differential equations

$$\frac{1}{\mu\sigma} \left[\frac{\partial^2 B_x}{\partial x^2} + \frac{\partial^2 B_x}{\partial y^2} \right] = \frac{\partial B_x}{\partial t} + v \frac{\partial B_x}{\partial x}, \quad \frac{1}{\mu\sigma} \left[\frac{\partial^2 B_y}{\partial x^2} + \frac{\partial^2 B_y}{\partial y^2} \right] = \frac{\partial B_y}{\partial t} + v \frac{\partial B_y}{\partial x}$$

$$\nabla \cdot \vec{B} = 0 = \frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} = 0,$$

subject to the boundary conditions. The model predicts the damped electromagnetic fields generated by the coupled conductors in terms of the geometry, μ and σ , the velocity of the moving conductor and the location of the observer. The principal contributions to the far field magnetic signature are due to the source current distribution and its time dependent image created during the transient pulse.

The exact analytical solution obtained using modal expansions of the electromagnetic field are then compared with quasi-static image theory to establish the effects of relative motion on the penetration of the source field into the moving conductor. Approximations based on perturbation theory are developed.

COMPLEX DEPTH OF THE EM FIELD AND ITS EFFECT ON THE ELECTROMAGNETIC ENVIRONMENT

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Widest possibility of multifunctional computer technology gives us good chance to carry out numerically the most complicated calculations. But as previous it is very important to have obvious idea of various physical phenomenon in qualitative analyses of them especially in education of studentS. One has to have for these purposes simple one-member approximate formula reproduced different physical phenomenon's with the accuracy that is sufficient in practice. The good chance for this gives the method of "limited points" when the precise and approximated formulas have the same asymptotic limits at the small and at the very big values of the arguments.

In region of Electromagnetic Environments such chance gives the "Complex depth of EM field", $h_s = \sqrt{(\rho/j\omega\mu)}$ of the flat Electromagnetic wave $E(x) = E(0)\text{Exp}(\omega t + x/h_s)$ propagated into flat Conducting areas (ρ, μ) .

1. The Mutual additional impedance entered by EM field in the ground between two parallel wires over flat surface of the ground with heights h_1 and h_2 and distance between them b_{12} instead of Carson's Integral is approximately equal (and also self impedance if $h_2 = h_1, b_{12} = 0$) to:

$$Z_{\text{add}} = \frac{j\omega\mu_0}{2\pi} \int_0^{\infty} \frac{e^{-(h_1+h_2)z} \cos(b_{12}z) dz}{\sqrt{z^2 + j + z}} \approx Z_{\text{add}}^* = \frac{j\omega\mu_0}{4\pi} \ln \frac{b^2 + (h_1 + h_2 + 2h_s)^2}{b^2 + (h_1 + h_2)^2} \quad (1)$$

The errors of this formulas arrives the Maximum when $h_1 \rightarrow 0$ and $h_2 \rightarrow 0$:

$$\delta_{\text{max}}(\text{Re}(Z_{\text{add}})) = (\text{Re}(Z_{\text{add}}^*) - \text{Re}(Z_{\text{add}})) / |Z| < 11\% \text{ (when } b_{12} = 2|h_s|),$$

$$\delta_{\text{max}}(\text{Im}(Z_{\text{add}})) = (\text{Im}(Z_{\text{add}}^*) - \text{Im}(Z_{\text{add}})) / |Z_{\text{add}}| < 13\% \text{ (when } b_{12} = 3.5|h_s|).$$

But for real constructions of lines the errors for Mutual Impedance are less then 7% and for Self Impedance they are less then 3%.

2. Internal Impedance of the round wire is approximately equal to:

$$Z_{\text{in}} = Z_0 * \frac{rI_0(r/h_s)}{2h_s I_1(r/h_s)} \approx Z_{\text{in}}^* = \sqrt{Z_0^2 + Z_{\infty}^2}; Z_0 = \frac{k_0 \rho}{\pi r^2}; Z_{\infty} = \frac{k_{\infty} \rho}{2\pi r h_s} \quad (2)$$

where I_0 and I_1 are the Modified Bessel functions, Z_0 and Z_{∞} are impedances of this wire when $\omega \rightarrow 0$ and $\omega \rightarrow \infty$, r is the radius of wire, k_0 and k_{∞} are empirical coefficients, taking into account the multi-wires and lay structure of the wires. The errors of the formula (2) for $0 \leq \omega \leq \infty$ are less then

$$\delta(\text{Re}(Z_{\text{in}})) = (\text{Re}(Z_{\text{in}}^*) - \text{Re}(Z_{\text{in}})) / |Z_{\text{in}}| < 4.9\% \text{ and}$$

$$\delta(\text{Im}(Z_{\text{in}})) = (\text{Im}(Z_{\text{in}}^*) - \text{Im}(Z_{\text{in}})) / |Z_{\text{in}}| < 6.3\%.$$

3. External Impedance of the round insulated wire surrounded by ground with the big depth ($h_g \gg |h_s|$) approximately equal to:

$$Z_{\text{ex}} = \frac{\rho}{2\pi r h_s} * \frac{K_0(r/h_s)}{K_1(r/h_s)} \approx Z_{\text{ex}}^* = \frac{\rho}{2\pi h_s^2} * \ln(1 + h_s/r) \quad (3)$$

where r is the external radius of insulation, K_0 and K_1 are the Modified Bessel functions. The errors of the formula (3) are less then 1.5% for $\text{Re}(Z_{\text{ex}})$ and 3% for $\text{Im}(Z_{\text{ex}})$.

AN AUTOMATED DESIGN TOOL FOR DEVELOPING UNIFIED ELECTROMAGNETIC ENVIRONMENTAL EFFECTS PROTECTION REQUIREMENTS

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A unified approach to electromagnetic (EM) environmental effects protection of electronic systems has been developed and documented [1]. This paper provides an overview of the EM protection concept and a new technical approach for deriving performance requirements that, if met, will provide protection against any combination of EM environments. A key benefit of using this approach is a reduction in system development and manufacturing costs through the common treatment of environmental protection. Further, by taking "credit" for the immunity of electronics equipment, as verified through compliance with immunity standards, adequate protection levels typically can be realized with only modest shielding requirements.

The protection concept is based on enclosing the electronics in an electromagnetic barrier. The purpose of the barrier is to prevent the electromagnetic fields generated outside the barrier from degrading the performance of the electronics enclosed by the barrier in accordance with the system operational requirements. The performance requirements for this barrier are a complex function of the external environments, protection topology and the immunities of the electronics. Simple step-by-step procedures were developed for the determination of the required barrier performance. The same procedures may also be used to develop protection requirements for internally generated EM environments to achieve EM compatibility for subsystems.

The barrier performance allocation procedures and much of the technical information necessary for the application of the protection concept have been implemented in a prototype software package called the Unified Electromagnetic Environmental Effects (UE3) Matrix. The general structure of the UE3 Matrix will be presented and its operation will be demonstrated through system application examples. The software implementation of the protection allocation procedures allows the visualization of distributed shield performance requirements for one or more radiated and coupled electromagnetic environments and for one or more subsystems.

1. W.J. Scott, J.I. Lubell, R.E. Thomas, A.M. Chodorow, W.A. Radasky, "Combined Battlefield Environmental Effects Program Technical Overview," *Journal of Radiation Effects, Research and Engineering*, Vol. 15, No. 1, pp. 92-104, April 1997

"UNIVERSAL SENSOR USING ELECTRO-OPTIC SENSOR PRINCIPLES"

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Techniques like high power microwaves, pulse scattering, EMP, ESD and transient radar still lack reliable electric field monitors. One of the main obstacles to develop such field sensors are the enormous difficulties to miniaturize the sensor head providing simultaneously sufficient sensitivity, dynamic range and electrical isolation. This paper will present a recent prototype development of a fully triaxial photonic field probe for transient and continuous wave electric field measurements. The probe head incorporates nine electrooptic Lithium Niobate (LiNbO_3) modulators packaged in purely dielectric material. The modulators cover a frequency range from dc to 3.5GHz, where in the range dc to 1GHz an amplitude flatness of $\pm 0.5\text{dB}$ can be specified. The modulator input impedance has been optimized to provide maximum electric field sensitivity in conjunction with a broad band dipole antenna.

The sensor system includes an external 100mW low noise, single frequency laser and 18GHz bandwidth GaInP photo detectors and reaches a pulse sensitivity of 4.5V/m. For narrow band measurements a sensitivity limit of about $100\mu\text{V}/\text{m}/\text{Hz}$ can be extrapolated. The 1 dB compression point has been set to 12 kV/m peak to peak and could be increased to about 50 kV/m loosing sensitivity correspondingly. The sensor operates passively and is inherently potential free by means of optical fibers with a length of up to 2 km. The computer performs the data acquisition, spectrum analyzer presetting and signal correction for both, the frequency and the time domain.

MICROWAVE HOLOGRAPHY USING INFRARED THERMOGRAMS FOR MEASURING ANTENNA PATTERNS

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An infrared (IR) imaging technique is being developed to measure two-dimensional electromagnetic (EM) field distributions. Both electric and magnetic field intensities can be measured with this technique. Initial simulation tests to prove the validity, accuracy and sensitivity of this technique have been performed.

The magnitude of the field is determined by measuring the temperature distribution (due to Joule heating) developed in a thin lossy 2D detector screen placed in the region over which the field distribution is to be measured. The measured temperature distribution is presented as an IR thermogram, i.e. as an equi-temperature contour plot, which can be interpreted to yield the value of the field intensity incident on the screen. The phase of the electric or magnetic field can also be determined with this technique using holographic techniques.

The measured phase, in conjunction with the measured magnitude of the field, can be used to determine the radiation pattern of an antenna-under-test (AUT). The phase must be measured in the near field of the AUT where the field intensities are high. Two different techniques for phase-retrieval from magnitude only data are being developed. One technique extracts the phase from the IR thermogram using an iterative APlane-to-Plane@ (PTP) 2D Fourier Transformation convergence method. The other technique extracts the phase from the magnitude only data based on holographic interference patterns developed between the AUT and a known microwave reference antenna standard.

In the PTP method, two IR thermograms must be made several wavelengths apart in the radiating near-field of the AUT. In the holographic interference technique, four holograms must be made at one near-field location, one for the magnitude of the AUT only, one for the magnitude of the reference antenna alone, and two interference patterns with different phase shifts between the reference antenna and the AUT. These data can be processed to determine the complex intensity (magnitude and phase) of the field at any distance in front of the AUT (including the aperture plane).

Numerical simulations of the iterative PTP technique and the holographic interference pattern technique were performed to predict the inherent accuracies of the techniques. The advantages and disadvantages of these two holographic techniques are also compared.

This new EM measurement technique, has the potential to provide extremely accurate measurements of complex (magnitude and phase) EM fields. The phase information can be used to make far-field antenna pattern measurements from near-field data. Also, the amplitude and phase of the elements of a phased array antenna can be determined with this technique.

TERAHERZ-BANDWIDTH ELECTRO-OPTIC FIELD SENSORS

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The electro-optic materials, ZnTe, LiNbO₃, and DAST, have been investigated for use as broadband electromagnetic field sensors. Based on the linear electro-optic (Pockels) effect, these sensors typically have terahertz bandwidths, frequency independent responsivities, and minimal perturbational effects on the electric fields to be measured. An analysis is presented of the responsivity and detectivity of the sensors configured for conventional single-path single-pass detection. RF fields applied across the materials and detected by measuring the rotation of the plane of polarization of a laser beam passing through the material, ranged from 10 Hz to 10 MHz. Microwave field measurements are in progress. Detection sensitivities as low as 0.1 V/m-Hz^{1/2} (27 μW/m² - Hz^{1/2}) have been reported for S/N = 1 (Refs. 1); our analysis suggests that this sensitivity can be reduced by at least two orders of magnitude.

¹Q. Wu and .-C. Zhang, Appl. Phys. Lett. 68, 1604 (1996)

CALORIMETER-SPECTROMETER FOR SINGLE PULSES OF RELATIVISTIC HIGH-CURRENT MICROWAVE OSCILLATORS

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Relativistic high-current microwave oscillators are the sources of powerful radiation, e.g. up to 10^{10} W in the X-band. Nevertheless, the pulse duration is small, usually it does not exceed 100 ns. Therefore it is difficult to measure the total energy of a pulse: the calorimeter surface has to be large in order to avoid a microwave breakdown, and the pulse energy is little, several joules.

In the report we describe a calorimeter-spectrometer with the sensitivity of 0.01 J/GHz for measurements of the spectra of relativistic broad-band microwave oscillators in the range of 5 - 40 GHz.

The calorimeter-spectrometer incorporates 2 calorimeters and filters, comprising of a set of the cut-off waveguides. The frequency characteristics of the filters were measured experimentally and calculated using 3-D simulation code. The examples are given of real microwave spectra of a total radiation flux at the power level of 100 MW.

WAVEGUIDE CALORIMETERS OF PULSED MICROWAVE RADIATION OVER CENTIMETRIC WAVE BAND

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Two modifications of high-sensitive calorimeters intended for measurement of total energy of single pulses and their packets with duration up to 1 sec are developed and tested. One of the calorimeters is located in a section of the rectangular waveguide with cross-section 72/34 mm and another $\frac{3}{4}$ in the circular waveguide of 70 mm in diameter. The principle of calorimeter operation is based on the energy absorption by polar fluid followed by its expansion into capillary tube. Absorbing elements are made of organic glass blocks and have cavities filled with a working fluid. The variation of w.f. level in capillary tube is measured by detecting the change of capacitance formed by two metal strips glued on the outer surface of capillary. The maximum integral sensitivity is 50 V/J. The energy quantities measured by calorimeter are ranged from 100 (J up to 50 J, the absorption coefficient over the frequency range 3 $\frac{3}{4}$ 30 GHz is about 99%. The random error of measurements is not higher than 5% for absorbed energy over 5 mJ. Calorimeters completed with a horn or parabolic reflector could be used for measurements in a free space.

SCANNING APERTURE MM-WAVE NEAR-FIELD MICROSCOPY - APPLICATION FOR LOCAL REFLECTIVITY AND POLARIMETRY OF CONDUCTING LAYERS

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We demonstrate a quantitative contactless technique of mapping resistivity of conducting films using a special 80 GHz near-field scanning aperture probe with a spatial resolution of 10 μm . We report (i) a capacitive method of maintaining a constant probe-sample distance; (ii) quantitative measurements of the near-field mm-wave reflectivity of various metallic films; (iii) mapping local thickness of metallic layers; (iv) near-field local polarimetric measurements. In particular, using a mm-wave scanning probe based on a resonant slit, we measure locally sheet resistance of 80Å-1000Å thick layers of Ag, Ti, Au, Al and yield information about homogeneity of the films. A theoretical model for the magnitude and phase of the mm-wave reflection, based on a plane-wave solution for the reflectivity of thin metal films on substrate, describes our results fairly well. We demonstrate magnitude and phase images of several conducting films and demonstrate that the phase image is very sensitive to defects. We map thickness of a commercial Ti-coated Si wafer using our probe and find good correspondence to the results of the local four-point resistivity measurements. We report a polarization-sensitive mm-wave near-field probe based on a crossed-slit aperture. We demonstrate local polarimetric measurements on test samples.

RESPONSE TIME AND FREQUENCY RESPONSE OF RESISTIVE SENSOR FOR MEASUREMENT OF SHORT HIGH-POWER MICROWAVE PULSES

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At the present time short high-power microwave (HPM) pulses are employed in different physical investigations and military projects. Standard pulse power sensors that measure the envelope of microwave pulse produce small output signal and can handle only a small power level. Therefore, to measure HPM pulse it has to be strongly attenuated. This results in the decrease of the measurement accuracy and confines the application of these devices to the measurement of HPM pulses. To determine pulse power using average power meters the repetitive microwave pulse sequence is necessary. Consequently, the measurement of the single HPM pulse or pulses with low repetition rate is difficult if not impossible to realize using such devices.

It has been shown [AMEREM'96] that resistive sensor (RS) is one of the most promising devices to measure short HPM pulses. It is overload resistant, produces high output signal and can measure HPM pulse power that is practically limited by the breakdown of a waveguide. In the present paper we have investigated the response time and frequency response of the X-band RS.

Electron heating inertia is the physical reason that limits the response time of the resistive sensor. It is very fast process with the characteristic time of $2.9 \cdot 10^{-12}$ s. The actual response time of the RS is determined by the current rise time in the DC circuit of the sensor. Thus, in order to investigate the response time of the RS we used the time domain reflectometry method. The sensor was fed by DC pulses with sub-nanosecond rise time and by analyzing the transient process the response time was estimated. Decreasing the inductance of the RS the transient process has been shortened significantly. It might be expected that the response time of the RS measuring microwave pulses would be better than 1 ns.

The frequency response of the RS was improved by adding additional ballast sensor. The best maximum to minimum sensitivity ratio less than 2 has been obtained in X-band frequency range. In the narrower frequency range 8...11 GHz the sensitivity variation of the order of ± 10 % has been achieved.

The sensors with improved characteristics were tested using HPM pulses in USA microwaves centers.

SYSTEM FOR MEASUREMENT OF RADIO PULSES PARAMETERS

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Nowadays in various domains of engineering different activities connected with development and practical use of generators of single radio pulses. The problem of measurement of radio signals parameters and received information reliability is rather actual. Practically the full absence of measurement means and also the uniform approach to experiment estimation methodics in some cases do not allow to estimate objectively available experimental data, to develop criteria of influence of such signals on modern radio engineering systems and electronic components .

The main radio pulse parameters, which are the cause of these refusals, are a power spectrum, peak capacity, pulse duration and a number of signal parcels in a pulse. The additional information on current processes can be obtained by measuring radio pulse filling frequency and by analysis of its time behavior.

The principle of spectrum parallel analysis is realized in the system, it allows to adapt easily configuration according to experiment conditions .The spectrum parallel analysis is carried out by developed radio pulse parameters measurer (MPRP). MPRP allows to measure:

- radio pulse energy ,
- peak capacity,
- duration of radio pulses,
- pulses quantity in the signal

The system work algorithm allows to carry out measurements of both single and continuously following one after another pulses, which made it possible to use this system for diagnostics and adjustment of various types of accelerators. For measurements of signal carried frequency the measurer of signal envelope instantaneous frequency was developed .It allows to measure the mean frequency value of the signal and the dynamics of its behaviour in time interval 5- 100 ns.

The frequency measurer is realized in a 3-cm wave range .

Pulse signal frequency measurer:

Frequency range 3- cm

Frequency band width -2 GHz

Input signal duration - 5-25 ns

Measurement accuracy of the frequency at 15 ns duration -84 MHz

BLOWUP - MAGNETIC GENERATORS PARAMETERS INVESTIGATIONS

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Blowup magnetic generators (EMG) were created by A.D.Saharov. The papers of A.B.Prishepenko [1,2] are devoted to analysis of various modes of such sources to development of various designs and also to questions of their practical use.

In 1997 with the aim of EMG characteristics estimation the measurements of radiation property of some designs were conducted.

For these measurements the method of spectrum of parallel analysis was used. The spectrum analysis was made on four frequencies 1.3; 2.8; 6.55 and 9.38 GHz. The measurements were carried out with the help of spectrometers, which made it possible to measure the pulse energy, pulse capacity and also the pulse duration and quantity of the pulses during the time of radiation in each range.

The parameters of spectrometer were selected according to analysis of published experimental data. Spectrometers sensitivity depending on rang was as follows:

Energy level - 0.1-0.6 nJ

Peak capacity level 0.01- 0.04 mW

Pulse duration 0.6-0.7 μ s

The measurements were conducted for five different EMG designs. Results of these measurements show that the signals of such devices have small repetition. This fact can be referred to nonperfection of technological cycle.

It is possible to make the following conclusions from measurements result

1. The maximum energy flow in measurement point does not exceed 5×10^{-10} J/cm²
2. Energy spectral density does not exceed 5×10^{-14} J/Hz
3. The signals duration grows by increasing the output frequency.
4. The results obtained allowed to determine the requirements to measurement equipment, which is capable to receive the more detailed data.
5. It is not enough the levels of input signals for destruction of input sections.
6. The EMG test results correspond to test data of 1992.

1. Prischepenko A. B., Schelkatchev M. V. "The working mode of EMG on capacitor loading. PMTF, 1991, 6.(190).

2. Prischepenko A. B., Schelkatchev M. V. "Dissipative and Diffusive Losses in Spiral Blowup-Magnetic Generator. Electricity 8, 1993.

REVIEW OF OPENING SWITCHES FOR FIELDABLE INDUCTIVE STORAGE SYSTEMS

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Opening switches applicable to fieldable inductive storage systems both with short and long charge times of the inductor are reviewed. Main characteristics, required from the opening switch, are formulated. General requirements are reliable repetitive operation and compactness. For systems with a long charge time, e.g., for battery-based power supplies intended for driving Electro-Thermal-Chemical guns, typical parameters are fractions of a second conduction time, peak current of several tens of kA and the opening time less than 0.5ms at a voltage of several kV. No off-the-shelf opening switches possessing such characteristics are available. A comparison of architectures of switches brought us to a conclusion that the hybrid technology is an appropriate one for an inductive storage system with a long charge time. Mechanical switches, e.g., vacuum and SF₆ circuit breakers, are suitable as the first stage, while a stack of semiconductor devices switched off by a counterpulse network seems to be an optimal solution for the second stage of the opening switch. Detailed PSpice simulations, analytical analysis and preliminary test results are presented.

It appears that for the generation of nanosecond high voltage electromagnetic pulses, solid-state opening switches are the only viable candidates for fieldable long-life inductive storage systems. Different types of commercially available and experimental switches are reviewed. It seems that the pulse-sharpening diodes offer a cost-effective solution. The performance results of a Russian-made pulser based on Semiconductor Opening Switch (SOS) are presented.

NONLINEAR PHYSICS OF CHARGING-DISCHARGING DIELECTRICS UNDER PULSED POWER ELECTRON BEAM INJECTION

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Two basic processes: electrical conduction and electron-plasma emission mainly contribute to charging and discharging solid dielectric under the action of high-current-density electron beam.

Electrical conduction is investigated with 200-ps resolution. The sources of primary beam are high-current accelerators of GIN-type with parameters regulated within following intervals: 0.25–0.45 MeV, 1–30 ns, 0.1–10 000 A/cm². Dielectric is considered in such experimental situations when its surface is shut up for critical electron emission into vacuum. Then the integral current consists of three ones: primary beam-, displacement-, and conduction current, the first and the last being responsible for the bulk charging and discharging correspondingly. The mechanism and properties of induced conductivity are shown to depend highly on the dose rate and electric field. If the electric field and dose rate are small then the low-energy electrons and holes are the main charge carriers. If the electric field is small but dose rate is high then the non-ionizing high-energy electrons and holes become to be the main carriers.

Critical high power electron emission. Several types of critical electron emission from dielectric into vacuum induced by electron beam injection are observed and studied during the last sixty years. The most known ones are discovered by Malter (1936) and Dow, Nablo and Watson (1967). Review of the emission intrinsic properties is given. Two theoretical models are proposed and compared with experimental data. The first is field electron emission from dielectric (FEED). It takes into account the following processes: charge and energy deposition of incident electron beam in the sample, distribution of electric field created by injected and trapped charge, additional stopping of the beam by this field, generation-recombination-trapping and detrapping of current carriers in high electric field due to Poole-Frenkel effects and impact ionization of traps according to Keldysh's theory, electron transport due to induced conductivity, and electron emission from dielectric surface into vacuum according to generalized Fowler-Nordheim theory. The model is two-dimensional and takes into account the non-uniformity of the emission current. The FEED-model is realized in the nonlinear system of 18 equations, initial and boundary conditions. The results of computations are following. The pulse of primary beam current density is of 2 ns halfwidth and supercritical value. Intensive electron emission starts with time delay of 2 ns and continues for several nanoseconds after the end of injection pulse due to detrapping of electrons accumulated in the dielectric from various traps: excitons, impurities, and color centers. The emission is highly non-uniform. Its current density averaged upon the emitting surface is about 20% of the injection one and is of the order 10¹–10³ A/cm². But peak value of emission current density on the top of the microtip is of the order of 10⁵–10⁶ A/cm². It means that energy deposition on the top of the dielectric's microtip is of the order of 10⁴ J/cm³ and is enough to induce microexplosions and injection of ion plasmas from the microtip into the vacuum gap. But this is not considered by the first theoretical model. The second model is explosive electron emission from dielectric (EEED). This model takes into account the existence of critical current density. When the emission current density achieves critical value then FEED performs a nonequilibrium phase transition to EEED. Computations show the critical current density for dielectrics to be 1000 times lower than for metals.

DESIGN OF FERROMAGNETIC CORE FOR HIGH-TEMPERATURE SUPERCONDUCTING ENERGY STORAGE DEVICE

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Superconducting Magnetic Energy Storage (SMES) is one of the worthwhile applications of high-temperature superconductors. Using of the ferromagnetic core for increase the stored energy is reasonable taking into account high cost of the wire and a sharp decrease of its critical current in high magnetic fields at the temperatures of liquid nitrogen. The objective of the design is the construction giving a compromise between substantial gain in stored energy, minimal volume and minimal radial component of the magnetic flux density on the winding B_r . We used the software PC-OPERA (Vector Fields Ltd.) based on Finite Element Method to design a superconducting solenoid with ferromagnetic core for SMES device based on BSCCO coil operating in liquid nitrogen.

So-called 'pot-core' configuration of the core was used. The magnetic circuit has to be of constant cross-section. The air gap have to be suited to magnetomotive force of the coil so that the saturation of the core was achieved at maximal operating current of the coil. The latter is critical current that depends on radial component of the magnetic flux density on the winding B_r . Optimizing the clearances between the coil and the core we can made this component less than in the coil without core and by this means increase the critical current. It is a source of the additional gain in stored energy.

Optimization was carried out by consecutive changing of the air gap and the distance between the coil and the core. Initial value of the air gap was taken according to the simple analytical expression derived for its estimation. The distributions of B_r on the surfaces of the coil are demonstrated for different gap and clearance values. The gap can be introduced inside and outside the coil or distributed along the magnetic circuit by using powdered core. The gain in the stored energy depends on the maximal field created by the coil and changes from about 1000% for 0.1 T to 25% for 5 T.

A HIGH REPETITION RATE, LONG LIFETIME MULTISTAGE SPARK GAP

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A high voltage, high repetition rate spark gap switch with long lifetime is described. The high performance is accomplished by the use of a novel compact multistage design*. The design incorporates parallel interleaved electrodes with circular shaped discharge areas. The coupling between the discharge gaps is optically enhanced by means of an axial hole through the center of the electrodes.

A 40kV switch with 39 stages, 0.5 mm gaps, aluminum electrodes and alumina insulators was designed, built and studied. The switch is operated at low pressure (≤ 12 psig) dry air without flow, using a capacitive trigger scheme. Fast recovery time enables operation in a burst mode at repetition rates exceeding 1 kHz. The switch was operated in a continuous mode at a rep-rate of 25 Hz and 1 kA/2.4 mC per pulse for 25 hours ($> 2 \times 10^6$ shots). Only a minor degradation in the surface of the electrodes was observed, suggesting that the lifetime of the switch is much longer. The delay time of the switch is less than 50 ns and the closing time is less than 10 ns.

Calorimetric measurements of the generated heat in the switch were performed by recording its temperature profile. Analysis of the profile in the linear regime shows that 3-4% of the switched power is converted to thermal energy, heating the spark gap. A simplified model of the heat flow within the switch is presented. The model is valid for end-cap temperatures, that do not exceed room temperature by more than 10-20°C. This model assumes axial heat flow and predicts the temperature profile within the switch. Some of the predictions are verified using thermal imaging of the switch in open air.

The current and voltage waveforms of the switch were measured at rep-rates below 100 Hz and were found to be independent of the rep-rate. Integration of the $I \times V$ waveform suggests that ~7% of the switched power is lost.

The voltage drop on the switch implies 75-80V drop per gap, which is in the lower limit of the glow discharge and 3-4 times greater than arc voltages. This mode of discharge may count for the long lifetime of the electrodes and for the short recovery time of the switch. The latter is also achieved by the relatively small gaps, that enable faster recombination and better heat transport from the discharge regions.

* Patent pending

THE USE OF THE FERROMAGNETIC SWITCH WITH ORTHOGONAL CONTROL FIELD FOR DIVERTING OF CURRENT IN AN INDUCTANCE-CAPACITANCE STORAGE

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Diverting of current into the load of inductive energy storage may be effected by sharp increase in the inductance of circuit element connected in parallel to the load. The coil with toroidal core is used for this purpose. The offered system is reusable, as does not including units exposed to destruction, such as for example explosive conductors. In addition to the main (toroidal) field, orthogonal poloidal field is produced in this core. The results of the research presented in the paper show that under certain conditions the core magnetization and, consequently, its inductance may be sharply changed by this orthogonal control field. It is shown that the switching process may be controlled by fairly small currents. At favorable geometrical ratio it is possible to receive inductance change in 3... 10 times. The essential efficiency increase of energy transmission in a load can be received, if instead of the traditional circuit to use bridge circuit, examined in this paper. It use gives a square-law strengthening of energy transmission efficiency to compare with the traditional circuit. The system is efficient for a low-inductance load.

SCATTERING BY PENETRABLE BODIES PARTIALLY SUBMERGED IN A HALF-SPACE

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We study the mathematical formulation for the problem of acoustic scattering from a bounded penetrable scattering obstacle with wave numbers k imbedded between two half-spaces. We assume that the upper half-space has wave number k^+ while the lower portion has wave number k . Moreover, while the boundary of the scattering object is assumed to be smooth, we assume that the interfaces between the upper and lower half-spaces are rough surfaces, the sound wave satisfying transmission conditions on the several boundaries.

We pose an appropriate boundary value problem for the Helmholtz equation in this geometry, show that the problem is well-posed, and suggest a constructive algorithm for the recovery of the shapes of the object from far-field data measured on a screen in the upper half-space.

THE OPTIMAL RECONSTRUCTION OF BURIED OBSTACLES BY NONLINEARIZED METHODS

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The contribution is devoted to the imaging of linear, isotropic, nonmagnetic loss dielectric inhomogeneous or homogeneous obstacles buried in a (lower) linear, isotropic, nonmagnetic loss dielectric homogeneous half-space from the observation of aspect-limited fields which are resulting from the interaction of a given set of time-harmonic sources with these obstacles, both sources and sensors being placed in the upper half-space (air, typically). Focus will be on the retrieval of single and multiple cylindrical obstacles of unknown cross-sections located in a given search domain and illuminated either by E-polarized wave-fields or by H-polarized wave-fields -the field behavior is modeled from contrast-source integral formulations, either of the E field or of the H field, which are obtained rigorously from the application of the Green's theorem. However, the potentialities in more complicated 3-D bounded cases of the non-linearized reconstruction methods envisaged here will also be sketched.

Most of such reconstruction techniques belong to the now well-known class of modified gradient solution algorithms, where one aims at the reconstruction of the electric parameters of every pixel of a distribution of pixels which is made to cover the whole search domain, with or without a binary specialization -the binary specialization is tailored for the case of homogeneous obstacles whose electrical parameters are prescribed beforehand. Emphasis is then on comparisons between the E-polarized modeling and the H-polarized modeling, and between binary-specialized and traditional algorithms, for a variety of reconstruction cases. In addition we consider pros and cons of a rather novel scheme where the unknown is now the cross-sectional contour of the obstacles and is defined as the level 0 of a level set function whose controlled evolution via an appropriate velocity field leads to its retrieval without imposing topological constraints such as star-shapedness with respect to a given interior point (or set of interior points), and prior knowledge of the number of obstacles.

DARPA BACKGROUND CLUTTER DATA COLLECTION EXPERIMENT

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Most technologies in use or proposed for use to detect landmines and unexploded ordnance (UXO) suffer from unacceptably high false-alarm rates, even at modest probabilities of detection. High false-alarm rates are a consequence of the inability to discriminate real UXO and landmines from anthropic and naturally occurring clutter.

The goal of the DARPA-sponsored Background Clutter Data Collection Experiment is to provide data to support the development of techniques that are more adept at discriminating UXO from benign anthropic objects. During the fall of 1996 high areal density site surveys were completed at four different 1.25 hectare sites within the United States, using the following sensor types: magnetometer, infrared, electromagnetic induction systems, and ground-penetrating radar. Preliminary analysis of the survey data has confirmed that a large number of anomalies evident in the data are indistinguishable from anomalies resulting from emplaced inert UXO or landmines.

In order to enhance the understanding of the source of clutter and assist with the development of clutter rejection techniques, approximately 100 of these ordnance-like sensor responses were examined during a one-week excavation effort at the most cluttered site.

A brief summary of the DARPA clutter data collection program, the data collected, the analysis done to date, results of the digging, and how to get the data will be presented.

IMPACT OF RADIOWAVE CLUTTER ON THE DETECTION OF MINES BURIED IN IRREGULAR STRATIFIED MEDIA

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Detection of mines buried in irregular stratified media is significantly complicated by the presence of signal clutter due to scattering from the rough interfaces of the layered structure. Full wave solutions have been derived for the electromagnetic fields scattered by the two rough surfaces, in a realistic physical model of the three media environment of the mines. In general, when the receiver and transmitter are near the rough surfaces, it is necessary to include in the fullwave analysis the complete field expansions which include the radiation fields, the lateral waves and the guided waves of the stratified structure which are coupled by the irregularities of the structure. When the stratified structure is in the far field of the transmitter and the receiver is in the far field region of the scattered fields from the stratified structure only the radiation fields of the complete field expansions need to be considered. They account for five different scattering mechanisms that the waves undergo, assuming that both the transmitter and receiver are above the uppermost interface of the irregular media. Two scattering mechanisms are associated with reflection from above and below the upper interface and two are associated with transmission across the upper interface, the fifth is associated with reflection from above the lower interface.

In view of the fact that in general the two rough interfaces are characterized by independent random rough surface heights (except where the thickness of the intermediate medium, vanishes) the rough surface height joint probability density functions are characterized by a family of probability density functions associated with the gamma functions. Multiple bounces between the two interfaces are accounted for in the analysis. The elements of the incoherent Mueller matrix (that relates the scattered to the incident Stokes vectors) are obtained from the expressions for the scattered fields. From this simulated data it is possible to determine the optimal polarizations and the incident and scatter angles of the waves as well as the wavelength, for purposes of suppressing the impact of the clutter on the detection of buried objects.

ULTRA-WIDEBAND SCATTERING FROM AND THE RESONANCES OF BURIED DIELECTRIC MINES

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A method of moments (MoM) algorithm is developed for the analysis of ultra-wideband (UWB) scattering from and the resonances of buried dielectric mines. To make such an analysis tractable, we utilize the method of complex images to efficiently compute the halfspace Green's function. Moreover, we specialize the analysis to plastic mines that can be modeled as a body of revolution (BOR), i.e., that possess rotational symmetry. We discuss the modeling algorithm in detail, discussing relevant numerical techniques employed to make such an analysis tractable for the UWB applications of interest here. For the case of a low plastic-soil contrast, of interest in many practical applications, we compare the numerically generated scattered fields to the Born approximation. Where appropriate, the Born approximation results in a significant computational savings and is not restricted to the BOR model.

Numerical radar cross section (RCS) calculations are presented for several plastic mines buried in lossy, dispersive soil (with electrical properties measured from real soil). To quantify the ability to detect such targets, we perform RCS comparisons between dielectric and metal mines, as a function of frequency and angle of incidence. Finally, results are presented for the complex resonant frequencies of buried plastic mines. Using the Cramer-Rao lower bound, we quantify the SNR required to extract such from measured data contaminated by additive noise. The characteristics of resonances from plastic and metal mines are compared.

NUMERICAL AND MEASUREMENT BASED STUDY OF THE RESONANCE FREQUENCY TECHNIQUE TO DETECT ANTI- PERSONNEL MINES

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An anti-personnel mine is often mainly a dielectric object which has specific resonance frequencies. It has been suggested [1] that these resonance frequencies could be used to detect such an object. There are however a number of problems which could impede the usefulness of this technique. The resonance frequencies will change when the surrounding medium changes. In a wet soil the losses are high which will damp the resonances and which will strongly attenuate transmitted and reflected waves, both making the detection of the resonance frequencies difficult. Often there are also other objects in the neighbourhood of the mine, such as branches and stones. These objects could have similar resonant behavior than the mine for which one is looking.

In the present contribution we investigate the effect of each of these complications. For this purpose we use an FDTD simulation technique which gives us a large degree of freedom in the geometries that can be studied. To validate the technique simulations of existing, plastic and metallic, mines are performed and compared with measurements in well defined circumstances obtained in the European Microwave Signature Laboratory in Ispra, Italy.

The different effects mentioned above are investigated with the FDTD technique applied on a typical dielectric mine. The change and detectability of resonances is investigated for different parameters: depth of the mine, dielectric properties of the soil, conductivity of the soil, roughness of the soil surface and the influence of other objects. Also the attenuation of waves penetrating through the soil is investigated. Present simulations already give us some insight in the validity of the resonance frequency technique, but at the time of the conference we hope to be able to define the limitations of this technique.

A classical FDTD technique is used with a modified Mur second order ABC or PML. The frequency dependence of the ground is taken into account by considering a Debye or Lorentz model. Time gating, FFT and other signal processing techniques are used to determine the resonance frequencies of the received signals.

[1] M.C. Worthy and C.E. Baum, "A Library of the Natural Frequency Responses for Cylindrical Shaped Buried Plastic Mines," Phillips Laboratory's Interaction Note 530, July 1997.

FEASIBILITY STUDY INTO THE IDENTIFICATION OF LANDMINES USING UWB RADAR: AN ANALYSIS USING SYNTHESIZED DATA

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Introduction. The goal of this research is to detect and identify buried land mines (LM). The technique being investigated is the use of ultra-wideband (100 MHz to 3 GHz) ground penetrating radar (UWB/GPR). The first step is to gain an understanding of the scattered signal received from the use of such a system. A major point of interest is which electromagnetic scattering features and signal processing techniques can be used in the detection/identification process? Possible candidates of scattering features are late-time resonance and diffusion poles, whereas signal processing techniques are ISAR imaging [E.M. Johansson, J.E. Mast, *SPIE* Vol. 2275, pp. 205-214, 1994], correlation and/or E-pulse receivers [L.C. Chan, L. Peters, Jr., D.L. Moffat, *IEEE Trans. AP*, vol. 29, no. 2, pp. 307-311, March 1981]. In a practical situation there will be uncertainty in various physical parameters such as: the local electrical characteristics of the ground, the local heterogeneity of the ground (rocks, layers, tree and plant roots), surface roughness of the ground and covering foliage, position (depth and orientation) of the LM, and relative position of the radar with respect to the ground and the LM. Thus, it is important to determine which of the scattering features, if any, are invariant to such parameters. Currently the main topic under investigation is to determine whether a UWB/GPR system can be designed and tuned such that variations in these parameters will minimally affect the identification process. The only aspects of the system which can be controlled are the antenna design, and pre- or post-processing of the radar signal.

Method. We are using the finite-difference time-domain numerical technique to create a database of synthetic time-domain responses of the backscattering from various buried landmines. Both the ground and the LM's are modelled as lossy dielectrics, and the possibility of a layered ground is also considered. Since the response is caused by an ultra-wideband time-domain signal, we investigate modelling the ground as a dispersive loss dielectric. Debye and Lorentz models are used to model typical sand and clay materials. Synthetic impulse responses are obtained for different bistatic angles above the ground and these are used in the identification process. First we construct ISAR images from the bistatic impulse responses. The effect of the air-ground interface is removed by time-gating. As a second technique, the complex natural resonances of the bistatic responses are tabulated for various angles. Results are presented of using the E-pulse and correlation receiver techniques for performing the identification of the LM. For this study, white Gaussian noise is introduced into the synthetic data when applying the identification techniques.

INVERSE SCATTERING PROBLEMS RELATED TO BODIES BURIED IN A LAYERED HALF-SPACE WITH RESISTIVE BOUNDARIES

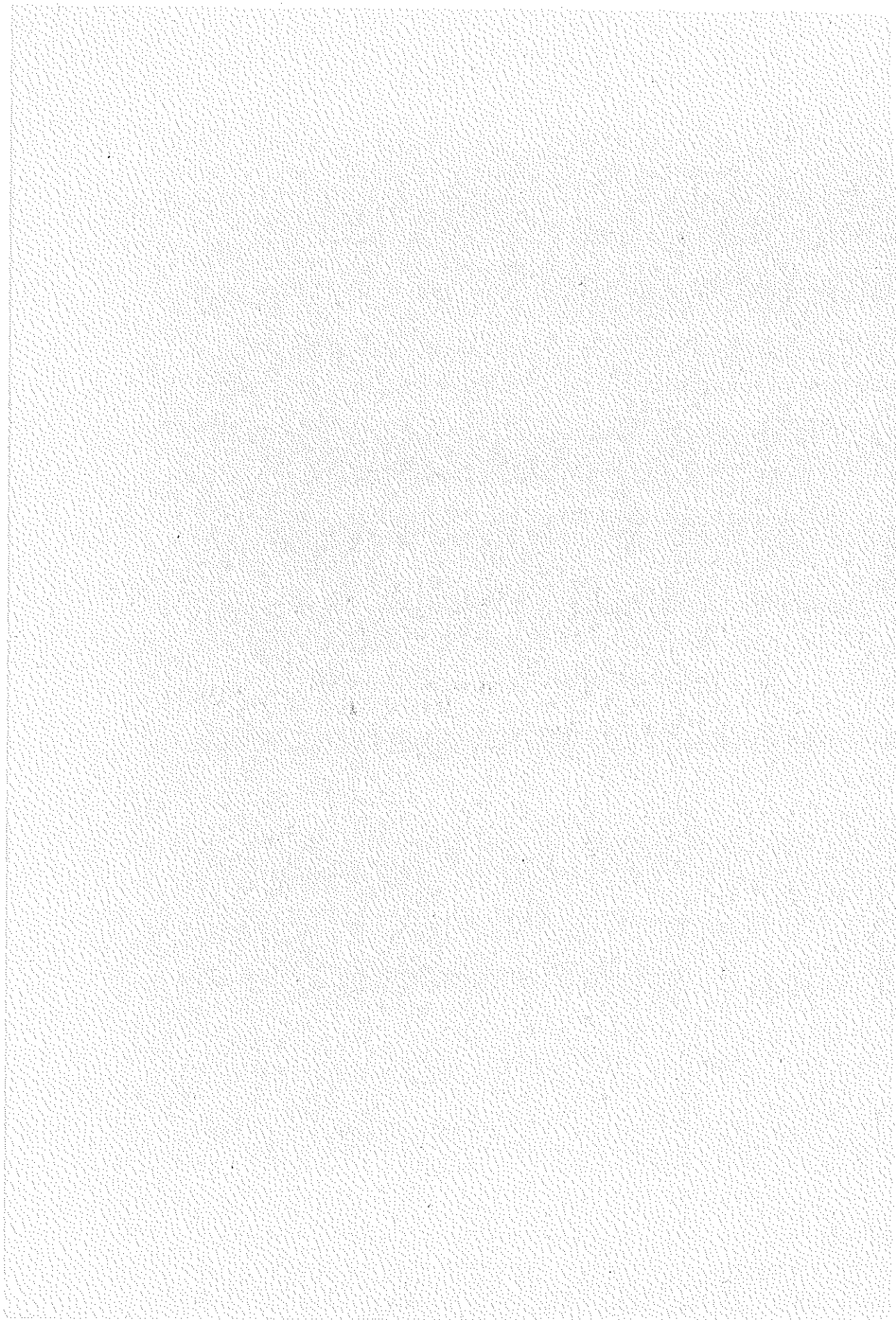
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Due to large domain of applications such as non-destructive probing, geophysical prospecting, determination of underground tunnels and pipelines etc. the inverse scattering problems related to the buried bodies has a particular importance in the inverse scattering theory. Along this line, here we consider an inverse scattering problem connected with bodies buried in a layered half-space whose layers separated by resistive boundaries. For the sake of simplicity, we restrict ourselves to the case of two-layer and cylindrical bodies. In such a problem, the whole space is formed by two half-spaces whose one of them is composed of two-layers (i.e.: a slab and a semi-infinite medium) separated by a resistive plane. The unknown cylindrical body is located inside the slab and is illuminated by a plane wave excited in the half-space not containing the body. The problem is then to recover the electromagnetic constitutive parameters and the location and shape of the body through the scattered field measurements performed in the region where the illumination is made.

Owing to the reflections from two-sides of the slab, the body undergoes the interaction with four plane waves propagating in four different directions in the spectral domain which makes the problem very interesting from both mathematical and practical points of view. Two of these waves are created by the incident wave itself while the other two are due to the Green's function related to the layered half-space not containing the body. In such a case the problem is not solvable through the methods based on the Fourier transform technique because it requires to solve four unknown functions whereas the above mentioned illuminations and measurements can only give one equation. In order to overcome this difficulty, we develop an iterative algorithm of the algebraic reconstruction technique (ART) type that is one of the effective method widely used to solve inverse scattering problems. Illustrative examples show that the method is efficient and gives satisfactory results.

**THURSDAY,
JUNE 18, 1998**



AN ALTERNATIVE APPROACH TO SOLVE THE TELEGRAPHER EQUATIONS FOR NONUNIFORM MULTICONDUCTOR TRANSMISSION LINES

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Introduction. The inclusion of uniform multi-conductor transmission lines (MTLs) in a network simulation is a standard procedure. However, it becomes more complicated if one has to deal with non-uniform multi-conductor transmission lines (NMTLs) due to their approximation by cascaded series of short sections of MTLs, e.g. In order to avoid this concept of a cascaded chain it is worthwhile to look for closed-form solutions for NMTLs. Such solutions can be found by application of the following procedure.

The Procedure. We start with the telegrapher equations in super-matrix form

$D_z \bar{X} = \bar{P} \left(D_z \bar{X} := \frac{d\bar{X}}{dz} \bar{X}^{-1} \right)$ is the product derivative of \bar{X} and transform this equation with

the aid of the relative super-matrices $\bar{T} = \begin{pmatrix} 1 & T_{12} \\ 0 & 1 \end{pmatrix}$ and $\bar{T}^{-1} = \begin{pmatrix} 1 & -T_{12} \\ 0 & 1 \end{pmatrix}$ to a corresponding

equation for \bar{Y} , with $\bar{X} = \bar{T}\bar{Y}$ giving $D_z \bar{Y} = \bar{T}^{-1} \bar{P} \bar{T} - \bar{T}^{-1} \frac{\partial \bar{T}}{\partial z} =: \bar{Q} = \begin{pmatrix} Q_{11} & 0 \\ Q_{21} & Q_{22} \end{pmatrix}$. However, to

create the upper zero-block matrix in \bar{Q} one has to solve the matrix Riccati equation:

$\frac{\partial T_{12}}{\partial z} = P_{11} T_{12} - T_{12} P_{21} T_{12} - T_{12} P_{22} + P_{12}$. The following steps rely on rules for the

calculation with matrizants. The supermatrix \bar{Q} is decomposed into two summands \bar{Q}_1 and \bar{Q}_2 : $\bar{Q} = \begin{pmatrix} Q_{11} & 0 \\ 0 & Q_{22} \end{pmatrix} + \begin{pmatrix} 0 & 0 \\ Q_{21} & 0 \end{pmatrix} =: \bar{Q}_1 + \bar{Q}_2$. This has the advantage that one

can apply a sum rule for matrizant \bar{M} giving $\bar{M}_{z_0}^z(\bar{Q}) = \bar{M}_{z_0}^z(\bar{Q}_1) \bar{M}_{z_0}^z(\bar{Q}_2)$ with

$\bar{S} = \bar{M}_{z_0}^z(\bar{Q}_1) \bar{Q}_2 \bar{M}_{z_0}^z(\bar{Q}_1)$. It is not very difficult to calculate $\bar{M}_{z_0}^z(\bar{Q}_1)$ and $\bar{M}_{z_0}^z(\bar{S})$ and

thereby the entire solution as $\bar{M}_{z_0}^z(\bar{P}) = \bar{T}(z) \bar{M}_{z_0}^z(\bar{Q}) \bar{T}^{-1}(z_0)$.

Conclusion. The benefit of the above approach is not immediately seen, since one still has to solve the nonlinear Riccati equation for T_{12} and to estimate the block matrizants in $\bar{M}(\bar{Q})$.

But there are advantages: (1) The block matrizants which remain to be calculated are of reduced dimension $N \times N$ (instead of $2N \times 2N$, N = number of conductors). (2) The structure of the general solution becomes apparent. (3) For cyclic matrices the $N \times N$ matrizant-problem can be transformed to an effective $N=1$ problem, i.e. to a single conductor (plus reference) problem. (4) In the case that $Q_{ii}(z)$ and $Q_{ii}(z')$ ($i = 1,2$) commute for all z, z' along the line the $N \times N$ matrizants can be expressed as exponentials. (5) For $N = 1$ $\bar{M}(\bar{P})$ becomes a 2×2 matrix. Its components are (scalar) exponential functionals multiplied by $T_{12}(z)$ (and $T_{12}(z_0)$), the solution of the scalar Riccati equation. Thus the solutions for all single conductor lines have the same simple (mainly exponential) structure.

CROSS TALK VOLTAGES INDUCED ON A MULTIWIRE HARNESS

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In many problem of EMC, the prediction of the crosstalk voltages induced at the ends of the various wires of a harness is needed to optimize the protecting devices such as filters or additional screens.

The crosstalk voltage amplitude may be deduced from the application of the coupled Transmission Line Theory (T.L.T.). The accuracy of the predictive models depends on the various terms of the (L) and (C) matrices and on the hypothesis related to the TEM approximation.

In order to point out the validity of such an approach, a test set-up consisting of a Y shape harness 3 meters long, each branch containing seven, four and three wires respectively has been considered. The harness is placed over a metallic ground plane at a height of 5 cm. In the theoretical model, it is first assumed that the per-unit length series impedances and admittances of the lines are uniformly distributed and various combinations of the loads are tested : short-circuit, open-circuit, 50 Ω loads...

From the TLT, the values of currents and voltages are calculated.

As previously mentioned, a comparison between the theoretical and experimental results will be made by emphasizing the role of the frequency range within the 1 MHz - 10 GHz band under consideration.

In a second step, the per-unit length parameters of the line are considered to be randomly distributed. The margin between the minimum and maximum amplitude of the expected crosstalk voltages will be determined by means of a statistical approach and compared with experimental results.

TRANSIENT SIMULATION OF LOSSY TRANSMISSION LINE SYSTEMS BY WAVE DIGITAL FILTER PRINCIPLES

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A new approach for modelling and simulating lossy coupled transmission lines using wave digital filter principles is presented. A continuous-time lossy transmission line system is transformed into an equivalent discrete-time system in order to perform time domain simulations. The approach is based on a lumped elements approach, where the transmission line system is divided into a cascade connection of several unit segments. The losses of each segment are modelled by $2n$ -ports consisting of discrete resistances, while the capacitances and the inductances of the lines are still considered to be distributed. The coupling between the lines is modelled by the mentioned resistive $2n$ -ports networks as well as by ideal transformer $2n$ -ports, where n is the number of coupled transmission lines.

Assuming quasi TEM wave propagation, rigorous transmission line theory can be used for modelling and simulating the signal propagation on coupled lossy transmission lines which are characterised in general by frequency dependent distributed parameters \mathbf{R}' , \mathbf{L}' , \mathbf{C}' , and \mathbf{G}' . For the sake of simplicity, they are assumed to be constant throughout this paper. Based on these assumptions, a wave digital filter (WDF) formulation is proposed, which is derived from rigorous transmission line theory. In the first step the transmission line system is divided into several unit segments. The losses of each segment are represented by resistive $2n$ -ports having a Π -structure. Introducing appropriate transformer $2n$ -ports, the remaining lossless lines can be transformed into decoupled lines which can be treated very easily.

In order to model a transmission line system by wave digital filters the ordinary complex frequency p is replaced by the so-called equivalent frequency $\psi = 2/T \tanh(pT/2)$, where T denotes the sampling period or the basic time step. This replacement is equivalent to performing time domain integration by applying the trapezoidal rule. Moreover, instead of voltages and currents wave quantities are introduced as signal parameters which allow the description of each transfer system by scattering matrices. Then, each lossless transmission line section is modelled without any simplification by a symmetric lattice filter. In order to avoid delay-free loops adjacent blocks consisting of transformers and resistive networks are combined and transformed into one single $2n$ -port. Important quantities of the whole arrangement are the characteristic impedances of the decoupled transmission lines which are adopted as port resistances R_{Tj} of the loss-network. Therefore, the complete arrangement can be modelled without any series adaptor. As the port resistances R_{Tj} are identical for $j = const.$ this strategy preserves also the reciprocity of the whole arrangement.

After the computation of the wave transfer matrices of each filter element the scattering matrix of the overall arrangement can be obtained. This matrix is the basis for computing the voltages at the beginning and the end of all transmission lines through recursive difference equations. Moreover, it has to be taken into account, that the propagation delays of the decoupled lines have to be integer multiples of the basic time step T .

Numerical results based on real life configurations show an excellent agreement with other time as well as frequency domain methods.

USING EM TOPOLOGY FOR CABLE COUPLING PREDICTION : APPLICATION TO EMPTAC AIRCRAFT

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This paper presents an application of the EM Topology theory for the prediction of EM coupling on a large scale system : the EM Test Bed Aircraft (EMPTAC). Since 1993, three experiments involving ONERA, CEG and Phillips Laboratory have been carried out on this system, at the Kirtland Air Force Base (Albuquerque, New-Mexico). The wiring could be excited locally, using voltage or current injections, or globally, thanks to the ELLIPTICUS antenna, radiating on the whole airplane. Most of the predictive calculations have been performed with the CRIPTE numerical code developed at ONERA. In the first experiment held in November 1993, a small test wiring had been introduced and the coupling had been successfully predicted between 300 kHz and 100 MHz [1]. In a second experiment, held in July 1995, the high frequency field coupling was more particularly analyzed on very simple lines, from 100 MHz to 1 GHz

For last experiment, held in July 1996, more ambitious technical objectives were decided, laying on the experience of the two previous experiments [2]. A whole real cable network was considered in a wide frequency range from 100 kHz to 1 GHz. Three scientific questions were to be answered :

1 - do cables keep on propagating energy up to 100 MHz, or are other effects such as resistive or radiating losses more important ?

2 - is the CRIPTE code able to deal with such a large scale network, providing good results on a limited-performance computer, while direct verification measurements are made ?

3 - are transmission line models able to describe high-frequency coupling, and especially the localization of the coupling due to the propagation losses along the line ?

The cable network under study was composed with different harnesses connected together through the volumes of the airplane. The average cross-section of the bundles contained 20 wires but could reach 40 wires in special locations. The assumption was made that the attenuation observed on cables was due to multiple mismatching due to the irregular twisting of wires in the bundles. So each bundle has been decomposed in a succession of small bundles whose geometry has been determined randomly. To manage the large size of the network, the sub-network compacting feature, available in the CRIPTE code, has been widely applied, allowing one to carry out the calculations on the same HP 712/64 computer, with 32 MB Memory only. By this way, 1.3 km of cables have been taken into account.

The results presented in this paper will focus on the pertinence of the model to represent high frequency coupling phenomenon. The conclusion of the paper will also emphasize what kind of difficulties can be encountered on such a big modeling project and how the methodology could be improved considering new theoretical and technical approaches.

[1] J.P. Parmantier, V. Gobin, F. Issac, I. Junqua, Y. Daudy, J.M. Lagarde: "*An application of Electromagnetic Topology on the Test-Bed Aircraft, EMPTAC*", Interaction Notes, Note 506. November 1993.

[2] J.P. Parmantier, V. Gobin, F. Issac, L. Paletta, I. Junqua, Y. Daudy, J.M. Lagarde: "*ETE III : Application of the Electromagnetic Topology Theory on the EMPTAC*", Interaction Notes, Note 527. September 1997.

A HYBRID METHOD FOR FIELD-TO-TRANSMISSION LINE COUPLING CALCULATIONS

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We propose a numerically efficient method for the study of long transmission lines subjected to fast electromagnetic pulses, for which transmission line approximation cannot be applied. In a previous study [1], we derived under the thin-wire approximation a TL-like system of equation, with an additional term $\hat{D}\{I(z)\}$ accounting for radiation

$$\frac{dV^S(z)}{dz} + j\omega L'I(z) = E_z^e(h,z) + j\omega \frac{\mu}{2\pi} \hat{D}\{I(z)\} \quad (1) \quad \frac{dI(z)}{dz} + j\omega CV^S(z) = \frac{1}{2\ln(2h/a)} \frac{\partial}{\partial z} \hat{D}\{I(z)\} \quad (2)$$

We have also proposed an iterative procedure based on the perturbation theory to solve the derived coupling equations. The method can be applied both in time and frequency domains and it has been shown that it converges rapidly to the exact solution calculated with NEC (fig. 1). In this study we propose a method to consider the more general case of a long line loaded at its both ends. The method consists in dividing the line into three distinct regions (fig. 2). The main region is a part of the wire sufficiently far from the terminations, where the influence of electromagnetic fields arising from the load currents may be neglected in comparison with the fields generated by the currents along the wire. The induced current in this region can be expressed analytically assuming the wire as infinitely long. The coefficients of this analytical expression, may be determined using the exact solutions for the current in the two regions near the line ends. We will present a simple method to obtain the asymptotic coefficients using an already existing moment method program for a line of finite length. The validation of the method has been performed by comparing the current in the asymptotic region of a loaded line obtained through the asymptotic approximation and the numerical solution of the scattering problem. A good agreement was found.

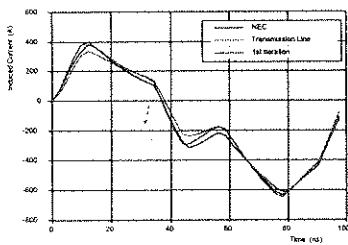


Fig. 1 - Comparison of the iterative method with the solution obtained using NEC for a 20-m long, 5-m high overhead wire above a perfectly conducting ground.

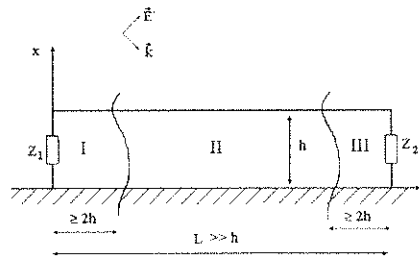


Fig. 2 – Division of the line in three sections.

- [1] S. Tkatchenko, F. Rachidi, M. Ianoz, "Electromagnetic Field Coupling to a Line of Finite Length. Theory and Fast Iterative Solutions in Frequency and Time Domains, IEEE Trans. EMC, vol. 37, No.4, Nov. 1995, pp. 509-518.
- [2] S. Tkatchenko, F. Rachidi, M. Ianoz, L. Martynov, iExact Field-to-Transmission Line Coupling Equations for Lines of Finite Lengthi, Proc. Int. Symp.on EMC, Sept.17-20, Roma, pp.59-63.

CABLE SHIELDING EFFECTIVENESS MEASUREMENT TECHNIQUES

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Shielding Effectiveness (SE) of cable shields can be evaluated by different well-known techniques. Some of them will be discussed and, moreover, a new Direct Current Injection Method (DCI) with a parallel wire as return conductor will be presented.

Using absorbing clamps is one established method. In this test-setup a load is fed by a generator via the cable under test. An absorbing clamp, consisting of a current probe and ferrite rings is attached around it. Thus, the common-mode currents generating the emitted electromagnetic field can be measured. The ratio of transmitted and emitted power is used to determine the SE.

Another method is the evaluation of the voltage induced in the cable under test by a specified electromagnetic field. For unshielded test samples a reference is obtained, which can be used to determine the SE. In this case the SE is defined as the ratio of the voltages induced in the shielded and the unshielded test sample. Apart from the problem of generating an uniform electromagnetic field, it is difficult to obtain an unshielded sample line with the same characteristic impedance.

Further, the quality of a cable shield can be described as transfer impedance. In contrast to the SE, the transfer impedance is defined as the ratio of the measured voltage at the inner conductor and the current through the shield. One procedure is the Triaxial Method. The coaxial cable under test is inserted into a tube, forming a closed circuit which carries the interference current. The induced voltage can be measured between the outer and the inner conductor of the cable. Again, the main problem is the assembly of the tube such that it provides a specified characteristic impedance.

Finally, cable shielding efficiency can be evaluated by Direct Current Injection (DCI). Using a parallel wire as return conductor, two transmission lines are formed and the crosstalk attenuation between them is measured. The characteristic impedance of the outer line, consisting of the cable's shield conductor and the parallel-wire can be readily adjusted by the thickness of the insulation. The inner transmission line consists of the cable's inner and outer conductor. If the outer transmission line's characteristic impedance is well matched, the frequency range of this method attains 3 GHz. The transfer impedance can be calculated readily from the measured crosstalk attenuation.

In this contribution different measurement methods are described and measurement results are compared. Moreover, an analytical method permitting the calculation of the frequency depending transfer impedance for inhomogeneous cable shields is presented.

COMPARISON OF "TRANSFER FUNCTION/BULK CURRENT INJECTION"- METHOD WITH "COMPLETE AIRCRAFT RADIATION"-TESTING

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High Intensity Fields ("HIRF") have to be considered as a great threat to modern aircraft electronic systems. Special test procedures have therefore been developed to achieve and to demonstrate sufficient hardening at complete aircraft level.

Due to the very high field strength levels, which have to be simulated and the large volumes, which have to be considered, generally substitution methods have to be applied.

The test procedure to be applied in the most critical resonant area to demonstrate complete aircraft hardening will consist of the following steps :

- Measurement of "Transfer-Function (TF)" currents on selected cable bundles with low level outside fields
- Extrapolation of induced currents to the amplitudes, which might be expected for the full external threat
- Reinjection of cable currents via "Bulk Current Injection (BCI)"-method" while monitoring relevant aircraft functions

The accuracy of this "TF/BCI"-method is not comprehensively known. It is, however, the only procedure, which can be used for field strength clearance of complete large aircraft up today.

A few years ago a HIRF test facility has been built up at Dasa in Manching. This facility is capable to generate fields up to 150 V/m under far field conditions in the frequency band from 5 MHz up to 30 MHz across complete aircraft up to the size of a fighter.

Based on this facility investigations have been performed to compare the results achieved with the "TF/BCI"-method and the "Complete Aircraft Radiation"-testing. Two typical aircraft cable looms have been considered. The first one is running just between two equipment. The second one represents wide net connections running into different equipment located at different places within the aircraft.

This paper presents results achieved with the "TF/BCI"-method and the "Complete Aircraft Radiation"- method for the both cable looms. Significant differences concerning the susceptibility have been identified with respect to the amplitudes as well as with respect to the functions, which have been affected. - The paper will also present some first explanations about the reasons, which might be responsible for the deviations.

VARIOUS WAYS TO THINK OF THE RESOLUTION OF THE BLT EQUATION WITH AN LU TECHNIQUE

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In the past ten years, Electromagnetic (EM) Topology has moved from the status of theory [1] to the status of applied technique [2]. Many efforts have been carried out to point out the power of the method. Most of the calculations have focused on demonstrating the capabilities of the famous BLT equation. As an example, the CRIPTE code, developed at ONERA since 1990, is now widely considered as a reference in the prediction of EM coupling on large cable networks. Of course, many models are still missing to improve the prediction, especially at high frequency. Nevertheless, the method is nowadays sufficiently mature to allow considering numerical improvements. Indeed, with the success of the method, people want to treat more and more complex theoretical and applied problems. In addition to a convenient computer interface, they now require high performance calculations. Of course, with the compacting capability, the method always provides an efficient way to deal with whatever size of systems. However, the new perspectives of statistical calculations and high frequency modeling would require computation means larger than those of a few years ago if classical numerical methods keep on being used.

The objective of this paper is to emphasize the significance and the structure of the BLT equation in order to improve the calculation speed and the memory requirement. Of course, the straightforward idea is to use the well-known LU inversion process. Instead of considering scalars as usual, the modified algorithm will have to operate on blocks. However, the content of this paper is not a new numerical method. Laying on the numerical aspect, the interesting point considered here is to discover the physics hidden under this process and its relation with the compacting, sub-network formalism. For this, analogies with flow graph theory, generally applied in linear system analysis, will be mentioned.

Compared to a direct method, acting on the whole BLT matrix, the fact of taking into account the presence of zero blocks will always lead to improvements. Moreover, depending on the way the waves are labeled on the network, the computation time and the memory requirement may vary. This paper will present a labeling technique, specific to the BLT formalism, which makes the LU algorithm act as an automatic junction to junction compacting. Comparisons of computation times obtained on the same network with different labeling methods will be presented.

[1] C. E. Baum : "*The Theory of the Electromagnetic Interference Control*". Interaction Notes. Note 478, (December 1989) and, pp. 87-101, in J.B. Andersen (ed.) *Modern Radio Science* 1990, Oxford University Press.

[2] J. P. Parmantier, P. Degauque : "*Topology Based Modeling of Very Large Systems*", pp. 151-177, in J. Hamelin (ed.) *Modern radio Science* 1996, Oxford University Press.

* Actually at "Air Force Research Laboratory/DEHP, 3550 Aberdeen Ave., KAFB NM 87117, USA". This work has been made possible thanks to the support of the scientific prospective bureau of the DGA and the AFOSR.

NONLINEAR AND KINETIC EFFECTS IN PROPAGATION OF INTENSE ELECTROMAGNETIC PULSE THROUGH THE ATMOSPHERE

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A physical model is derived for description of intense electromagnetic pulse propagation through the Earth's atmosphere. The model is based on self-consistent solution to the set of Maxwell's equations coupled with the Boltzmann equation for free electrons (in a two-polynomial approximation). To illustrate capabilities of the model, we demonstrate the results of several simulations of powerful microwave radiation pulse propagation through the atmosphere in different conditions.

RADIAL TRANSMISSION LINE FORMULATION OF RADIATION OVER FLAT CONDUCTING GROUND

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The fundamental understanding of the nature of electromagnetic propagation over real earth is the cornerstone of communication and detection technologies. The usual starting point in the analysis of the radiation of a vertical electric dipole above a conducting half space is the cylindrical wave representation of the vector potential component of a unit strength electric dipole:

$$A_z(\rho, z) = \frac{\mu_0}{4\pi} \int_0^\infty J_0(\lambda\rho) \frac{\lambda d\lambda}{\sqrt{\lambda^2 - k_0^2}} \left[e^{-(\lambda^2 - k_0^2)^{1/2} |z-z'|} + R(\lambda) e^{-(\lambda^2 - k_0^2)^{1/2} (z+z')} \right], \quad (1)$$

where

$$R(\lambda) = \frac{\tilde{\epsilon}_r (\lambda^2 - k_0^2)^{1/2} - (\lambda^2 - k_0^2 \tilde{\epsilon}_r)^{1/2}}{\tilde{\epsilon}_r (\lambda^2 - k_0^2)^{1/2} + (\lambda^2 - k_0^2 \tilde{\epsilon}_r)^{1/2}}.$$

Equation (1) assumes that the region $z \geq 0$ is free space, while the half space $z < 0$ is filled with a dielectric medium with complex relative permittivity $\tilde{\epsilon}_r$. Also, k_0 is the free space wavenumber and ρ the radial distance from the z -axis. The dipole is located at $z' > 0$ and the observation point (ρ, z) is likewise in free space. This representation has a long history starting with Sommerfeld's famous 1909 paper.¹ In our paper, we consider an alternative to the cylindrical representation that appears to offer advantages in the numerical computation of fields radiated by general current distributions. Instead of representing the solution in terms of standing waves $J_0(\rho\lambda)$ in the ρ coordinate and traveling waves along z as in equation (1), the vector potential component will be decomposed into waves traveling radially outward as $H_0^{(2)}(\sqrt{k_0^2 - \lambda^2} \rho)$ and having a characteristic Fourier-like dependence on the z -coordinate. All the advantages of the fast Fourier transform technique can be brought to bear for problem solution. The formulation will be presented and comparisons will be made with the results of more traditional approaches.

¹ A. Sommerfeld, "Propagation of waves in wireless telegraphy," *Ann. Phys.*, Leipzig, Germany, 28, 1909, pp. 665-737.

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POLARIZATION EFFECTS AT THE PROPAGATION OF RADIATION IN AN INHOMOGENEOUS MEDIUM

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Maxwell equations describing the propagation of radiation in weakly inhomogeneous medium (i.e. such that the relative index difference $\delta n / n \ll 1$, for distances of order of wavelength λ) in a paraxial approximation can be reduced to the equivalent Schrodinger equation for the two-component wave function. The quantum mechanical method of coherent states is used to describe the effects of depolarization and change of polarization state of radiation in a graded-index multimode two-dimensional isotropic medium.

Polarization properties of radiation in waveguides are investigated in many papers. Usually the birefringence as a reason of change of polarization is considered.

In this paper it is shown, that the depolarization and transformation of polarization state occur also in an isotropic graded-index waveguide due to the diffraction effects. It is shown that depolarization has a wave nature. Depolarization is enhanced at the increase of axis displacement of incident beam, gradient parameter of waveguide and wavelength of radiation. Oscillations of degree of polarization for the axis beam, i.e. in a single-mode isotropic optical fibre are found. Rytov's rotation of polarization vector in graded-index waveguide is investigated. Effect of irregularity in rotation of polarization vector is found. Influence of polarization on the trajectory of rays is considered. Oscillations of the variance of Berry's phase for the axis beam of wave origin are found. The rotation of polarization vector increases linearly with increasing distance and quadratically with increase of the axis displacement and the incidence angle between the rays trajectory and the waveguide axis.

It is found, that the polarization state of radiation changes at the propagation in an inhomogeneous medium. Linearly and circularly polarized radiation is transformed into elliptically polarized state. Degree of ellipticity of radiation increases with distance. It is shown, that depolarization of linear polarized radiation is determined by the variance of the Rytov's rotation angle or Berry's phase. Depolarization of circularly polarized radiation is determined by the variance of the ellipticity.

The method proposed can be used to investigate the evolution of polarization in waveguides with birefringence, losses or gain, and also with random inhomogeneities.

NON-PARAXIAL PROPAGATION EFFECTS IN INHOMOGENEOUS MEDIA: BOUNDARIES OF THE APPLICABILITY OF RAY AND MODE APPROACHES

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Both the ray and mode representations are used for investigation of propagation of radiation in inhomogeneous media. Choice of the convenient representation (the full set of basic functions) is determined by the conditions of excitation. So, at the distances from the source which do not exceed the mode structure formation length it is convenient to use the ray approach, and at long distances from the source - expansion in terms of modes of medium. However, the boundaries of the applicability of ray description is the open question.

In this paper, the boundaries of the applicability of ray description and formation of mode structure in an inhomogeneous graded-index medium are determined. It is shown that the length of mode structure formation and the average number of excited modes are determined by the axis displacement or the slope of the incident beam at initial plane of the medium.

Exact analytical expressions for the trajectory and width of non-paraxial wave packets propagating in graded-index medium are obtained using the coherent state formalism for the solution of the Helmholtz wave equation. It is shown that the non-axial wave beam diverges at the propagation in graded-index medium and the trajectory of wave beam relaxes on the axis of the medium. The width of the beam increases only up to value determining by the axis displacement or incidence angle of the beam at initial plane. Evolution of the field intensity distribution in transverse plane of waveguide at different distances is investigated. It is shown that intensity distribution of incident localized gaussian beam is taking strongly inhomogeneous structure at propagation. The length of mode structure formation decreases at the increasing of axis displacement or incidence angle of the beam, wavelength of radiation and gradient parameter of the medium. Note, that the mode structure formation length is more sensitive to the change of gradient parameter of medium. Therefore, for the image transmission in optical fibers it is necessary to use the fibres with small value of gradient parameter. In typical graded-index optical fibres with the radius $50 \mu\text{m}$ and gradient parameter $5 \cdot 10^{-3} \mu\text{m}^{-1}$ the mode structure is formed on the distance $\sim 30 \text{ cm}$.

ELECTRON KINETIC EFFECTS IN THE ATMOSPHERE BREAKDOWN BY AN INTENSE ELECTROMAGNETIC PULSE

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A physical model is proposed for description of electron kinetic in the atmosphere when a powerful electromagnetic pulse (EMP) passes through it. The model is based on numerical solution to the Boltzmann kinetic equation for:

- slow electrons ($\epsilon < 1 \div 10$ keV) in the two-polynomial approximation;
- fast electrons ($\epsilon > 1 \div 10$ keV) using a modified macro-particle method taking into account both energy losses in the continuous deceleration approximation and the multiple scattering effect.

It is shown that when estimating radiation-induced conductivity it is necessary to take into account air avalanche ionization by escaping electrons as the ionization therewith occurs in electric fields whose value is lower than that of breakdown fields by an order of magnitude.

EXPERIMENTAL DETECTION OF EXPLOSION-INDUCED MAGNETIC SIGNALS

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A network of magnetic observatories, consisting of ground-based induction magnetometers, has been established to measure geomagnetic perturbations generated by explosion-induced acoustic signals that propagate vertically and interact with the ionosphere through ion-neutral collisions. The interaction launches hydromagnetic waves, which are observable at satellite altitudes and at ground surface. The test bed for these measurements is the Black Thunder Coal Mine near Gillette, Wyoming at which ripple-fired explosions, with yields in the range of 1 to 6 kT equivalent TNT, are conducted every three weeks on average. These explosions are monitored seismically and magnetically. Results of these measurements, along with a description of the experimental equipment, will be presented in conjunction with conclusions regarding the effectiveness of ground-based chemical explosions to excite the above-mentioned effects. A discussion of the physics responsible for these effects will also be presented.

THE EFFECT OF VARIOUS ASYMMETRIC TYPES IN RADIO-EMISSION ACCOMPANYING NEAR-SURFACE AIR BURST

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The results of the systematic research of the basic laws of formation of radio-emission of near surface nuclear explosions caused by the following types of asymmetry is submitted: a geoelectrical field, barometric non-uniformity of an atmosphere, presence of conducting surface. The EMP-model sources, are used known under the opened publications.

The received laws of formation of fields in a wave zone (radio flash of nuclear explosion) can be used in the area of electromagnetic methods for verification of compliance with the nuclear weapons non-proliferation treaty and for the analysis of experimental EMP-data in historical experiences.

GEOPHYSICAL IMPLICATIONS OF THE COSMOLOGICAL ORIGIN OF SPACE GAMMA-RAY BURSTS

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Possible global dangerous geophysical effects due to the cosmological nature of Cosmic Gamma-ray Bursts are considered. If their sources are located at cosmological distances on the order of 10^{28} cm, i.e., with $z > 1$, a Burst of such an object in the Galaxy at distances of 0.1 to 10 kpc from the Sun can exceed the solar X-flux by 10 to 1000 times of 0.1-100 sec. In this case, the electron density in the ionosphere will increase, and the ozone layer will be significantly depleted, but all these effects will not pose global threats. In this report, the threat of an electromagnetic pulse that arises from the directed motion of photoelectrons that appear in the interaction of X-rays and gamma-rays with topside layers of the Earth's atmosphere is analysed in detail. Maximum estimates indicate that the electric field strength could reach as much as 10-1000 Volts/meter, and this constitutes a significant danger to communication wires. The magnetic field strength increases moderately, and does not exceed $3 \cdot 10^{-2}$ Oe. The time dependence of electromagnetic pulse correlates with the time dependence of the Gamma-ray Burst.

ULTRA-WIDEBAND ELECTROMAGNETIC PULSE PROPAGATION IN TRIPLY-DISTILLED WATER

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The dynamical field evolution that is associated with ultrawideband plane wave electromagnetic pulse propagation in triply-distilled water is presented through a consideration of the evolution of an input rectangular envelope modulated field with fixed carrier frequency. The numerically determined pulse evolution due to an input ten-cycle pulse at the chosen carrier frequency as it propagates through this dispersive, lossy medium is presented and explained using the asymptotic saddle point method. The material response is described by the composite Rocard-Powles-Lorentz model of the frequency dispersion of the linear dielectric permittivity of triply-distilled water. As the input carrier frequency is changed, the input pulse spectrum samples different features of the dielectric dispersion and the resultant pulse distortion is correspondingly altered.

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ELECTROMAGNETIC IMPULSE RESPONSE OF TRIPLY-DISTILLED WATER

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The asymptotic description of the dynamical precursor field evolution that is associated with ultrawideband plane wave electromagnetic pulse propagation in triply-distilled water is presented through a consideration of the electromagnetic impulse response of that dielectric material. The numerically determined impulse response of the Rocard-Powles-Lorentz model of the frequency dispersion of the linear dielectric permittivity of water is presented and explained using the asymptotic saddle point method. The asymptotic description proceeds by considering the impulse response of each separate dispersion mechanism that is present in the composite causal model of the dielectric dispersion. This analysis explains each feature present in the numerically computed impulse response, including the observed quenching of the oscillatory relaxation of the Brillouin precursor.

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SPECTRAL ANALYSIS OF PULSED BEAM PROPAGATION IN DISPERSIVE MEDIA

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Pulsed beams (PB) are wave objects which can simulate actual fields radiated by time domain (TD) antennas and, by superposition, can synthesize arbitrary pulsed aperture distributions. While much progress has been made in tracking PB wave packets through nondispersive environments, the TD phenomenologies characterizing PB interaction with dispersive media are as yet inadequately understood. Recent studies [1,2] of PB propagation in lossless, dispersive, homogeneous media with generic frequency-dependent wavenumber $k(w)$ have dealt with these problems via wavenumber spectral decomposition in the frequency domain (FD) and subsequent inversion from the FD to the TD. Using high frequency asymptotic methods, the goal has been to parameterize the PB fields in the dispersive paraxial regime in terms of the space-time evolution of the PB wavefront curvature as well as spatial and temporal beam width, utilizing the local properties of the $k(w)$ dispersion surface. The methodology has been developed in ref. 1 and confirmed in ref. 2 for a simple test object.

The present study addresses the problem in refs. 1 and 2 directly in the TD via spectral wavenumber decomposition of the PB field into a superposition of TD dispersive plane waves. Having solved for the TD wavenumber spectrum excited by PB initial conditions, the total PB field expressed by the synthesizing wavenumber spectral integral is evaluated via paraxial asymptotics to extract the PB phenomenology in the well-developed dispersive regime. Emphasis is again on the parameterization of the paraxial results in terms of the physical PB observables affected by the $k(w)$ dispersion profile, and on combining the results so as to form additional nondimensional critical parameters. While the overall TD field excited by the PB is the same as that obtained by the previous approach [1,2], the direct TD method has different physical content. The differences between the two approaches are discussed and the advantages of the direct TD approach is emphasized.

[1] T. Melamed and L. B. Felsen, "Pulsed beam propagation in lossless dispersive media, Part I: Theory," J. Opt. Soc. Am. A, 15, (1998) to be published.

[2] T. Melamed and L. B. Felsen, "Pulsed beam propagation in lossless dispersive media, Part II: a numerical example," J. Opt. Soc. Am. A, 15, (1998) to be published.

SPECTRAL ALTERNATIVES FOR THE SYNTHESIS OF SHORT-PULSE WAVEFIELDS IN WAVEGUIDES

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The canonical two-dimensional problem of synthesis of short-pulse wavefields in a simple waveguiding configuration is addressed, focusing attention on various alternative spectral synthesis options. Specifically, the non-dispersive generalized-ray representation is set against the dispersive collective description of the spectral wavefield. For the collective representation, two different synthesis options are considered, viz., a conventional summation of modes, versus what we shall refer to as a non-conventional summation of spectral resonances. In the conventional approach the field is synthesized in terms of a time-harmonic spectrum of modes. In the non-conventional approach the time-harmonic integration is performed prior to the integration over the spatial spectrum, leaving the field expressed as a plane-wave spectrum of resonances.

Each representation bears a distinct physical interpretation and has different convergence properties. We explore the trade-off between the alternative representations with respect to the space-time observation regime, the frequency content of the excited pulse and the spatial directivity. An asymptotic analysis is shown to lead to a synthesis of the wavefield constituents in terms of instantaneous frequencies and instantaneous normalized slownesses (normalized wavenumbers), through which a cogent description of space-time-domain wave phenomena is obtained. Configuration and pulse-dependent characteristic parameters are extracted through which the near-zone and far-zone regimes are delineated. Numerical results are presented to elucidate the underlying principles.

SPACE-TIME GREEN-FUNCTION AND SHORT PULSE PROPAGATION IN DIFFERENT MEDIA

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Space-time Green-function (GF) was suggested by L.Weinstein [1] for general analysis of pulse propagation. He used Green-function for consideration of the body of rather long-time pulse. In the given work this approach is applied for the short pulse propagation in the following media:

- conducting media
- long line
- cold plasma
- dielectrics with elastically bound charges

Three from the listed media give explicit form for Green-function. In the last case integral presentation cannot be expressed through the known functions and should be calculated approximately for different ratios z/t , and for great z , where z is distance from plane boundary of medium, where short pulse moves, t is time (we suppose, that short pulse falls on the boundary at $t=0$). Convolution of GF and pulse time function at $z=0$ gives value of the field for any z and t . In separate cases it is possible to find convolution analytically, in other cases different approximations or numerical calculations are used.

Therefore, we can find dynamics of propagating pulse. We consider initial pulse duration, normalized to relaxation time of media as parameter. In other words, it is possible to obtain dependence of interaction between pulse and medium upon relationship between pulse duration and relaxation time. Influence of pulse shape on pulse dynamics and on pulse losses is estimated as well. Numerical examples of pulse dynamics in the media are presented. Experimental setup is discussed.

1. L.Weinstein. Pulses propagation. Uspekhi Fiz.Nauk, 1976, v.118, 339-367

ULTRA-WIDEBAND ANALOGUE CHANNELS USING SOLITONS

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The transmission of ultrashort pulses for long distances over dispersive channels can be achieved using solitons if the transmission medium has sufficient nonlinearity. Soliton transmission has been demonstrated experimentally over optical fibres and microwave transmission lines. While such nonlinear channels can support the transmission of single pulses which are many times shorter than the dispersion-limited linear channel can achieve, there are still limitations on the interpulse time separations that can be permitted when the solitons are used as carriers of information in a pulse train, due to the nonlinear interaction between contiguous pulses in a train. It has recently been shown that for envelope solitons on optical fibres this interpulse interaction can be modelled very well by treating the pulses as quasi-particles, when the pulse train dynamics is described by a completely integrable discrete dynamical system, the Complex Toda Lattice^{1,2,3}, from which a great deal of valuable information characterising the communications capacity of the channel can be obtained. The stability of quasi-periodic pulse trains can be easily established, and the behaviour of various modulation schemes can also be determined. It has been demonstrated that in many respects a long pulse train behaves quite differently to isolated individual solitons.

The corresponding model for interacting baseband soliton pulse trains on a nonlinear microwave transmission line has not been studied at all. In this paper an outline is given of the pulse train transmission characteristics of a millimetre-wave transmission line whose nonlinear waves are described by variants of the Boussinesq and KdV equations, including the effects of noise and interpulse interactions. The simplest approach to this question is by way of a Lagrangian perturbation theory, in which an infinite number of nearly-identical solitons with large temporal separations interact weakly through the overlapping tails of neighbouring pulses in the stream. It emerges quite straightforwardly that the pulse train dynamics is again described by a Toda Lattice. The results of the approximate Lagrangian theory are substantiated by a more detailed analysis using the Inverse Scattering Transform in the cases where the propagation equation of the channel is integrable.

Having established the Toda Lattice as the underlying dynamics of the pulse train, it is possible to study, using elementary methods, the behaviour of various modulation schemes that might be used to impress information on the soliton train. Of these, pulse-position modulation (PPM) has particularly interesting characteristics which are described in detail.

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THE HYBRID RAY-FDTD MOVING WINDOW APPROACH FOR LONG RANGE PROPAGATION ALONG INHOMOGENEOUS DIELECTRIC WAVEGUIDES

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The hybrid ray-FDTD moving window scheme has been presented recently for the propagation of electromagnetic pulses in homogeneous and inhomogeneous media [Fidel, Heyman, Kastner and Ziolkowski, *1994 AP symposium*, pp. 1414-1417]. In this method, the continuous field equations are transformed into a moving frame centered about the propagating pulse and then discretized. The moving frame equations exhibit different characteristics in terms of both numerical dispersion and Absorbing Boundary Conditions (ABC's), compared with the stationary equations. In particular, numerical dispersion errors are significantly reduced, thereby allowing tracking of the pulsed field over very large distances. This method has been applied to paraxial problems as the propagation of pulsed beams in a plane-stratified medium [Pemper, Fidel, Heyman, Kastner and Ziolkowski, *1997 AP symposium*, pp.1006-1009].

This work deals with the application of the moving frame approach to non-uniform, graded index, dielectric waveguides, coated with a homogeneous cladding region. The moving frame travels at the wavespeed of the waveguide center, which, in turn, may vary along the propagation axis. The aforementioned properties of this method allow for very long range modeling of a pulsed field propagating along the waveguide. This modeling provides accurate prediction of all the physical effects such as waveguide dispersion. The CFL criterion in the moving frame is governed by the largest wavespeed in the grid, i.e., the sum of the traveling speed of the frame and the wavespeed in the cladding region.

Special emphasis is given to the derivation of ABC's for the moving frame. Different treatment must be given to the front (leading) boundary, the back (trailing) boundary, and the side (stationary) boundaries. The basic scheme involves the diagonalization of the field equations and identification of the backward and forward propagating one-way wave constituents as the basic two independent unknowns. The first order Engquist-Majda one-way wave equation is applied to both one-way wave constituents, however it is shown that for the forward propagation (incoming) wave, the one way wave equation can be applied *with an arbitrary wavespeed*. In this way, the incoming wave is removed from the computational grid. At the front boundary, the outgoing one-way wave constituent is treated again using the first order one-way wave equation. The incoming constituent is specified to be zero. At the side boundary around the cladding we specify the relevant field components to be zero. This approach serves to annul non-physical, though mathematically valid, exponentially growing solutions in the radial direction.

PULSE SCATTERING ON A HALF-SPACE WITH HARMONICALLY TIME-VARYING CONDUCTIVITY

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Interaction of both aspects of nonstationarity is considered: transient electromagnetic field and medium with time-varying conductivity. One solves the external problem for rectangular video-pulse scattering on the homogeneous half-space with harmonically time-varying conductivity. The conductivity is varying within the limits of positive values and this nonstationarity begins at a definite time moment. The incident pulse is assumed to be completely in the transient region before this moment.

Mathematically the problem is formulated in terms of the Volterra integral equation for the internal and internal fields obtained by the Green's function of corresponding wave equation. The fields are assumed to have only those components which are normal to the x - axis being independent on the y - and z - coordinates. It allows to solve one-space-dimensional problems. In this case the equation for the external field shows that this field can be determined by the function of only one variable ($F(t-x/v)$) and by an incident field, which is due to the assumed homogeneity of the external medium.

The integral equations for the external and internal fields are solved jointly being reduced to a first-order partial differential equation for a new function which determines the internal field in shifted time moments. Its right part is an infinite row of x powers with coefficients which are algebraic expression consisted of the conductivity time-dependence on the half-space boundary and the function $F(t-x/v)$. The exact solution for the internal field is then obtained by this row integration. As the external field is determined by a function of one variable, then the field near the boundary determines the field at any point of the external (stationary) half-space. It makes the row cut grounded when only a few first terms are taking into account.

The next step is to obtain an equation for the function $F(t-x/v)$ by the mentioned above solution for the internal field amalgamation with the initial equation for it. The obtained equation is solved exactly. Its solution together with the incident field (rectangular pulse) determine the scattered field.

Its computer analysis revealed the scattered pulse features dependence on the conductivity frequency. When it is comparable with reverse incident pulse duration then the pulse of scattered field just changes a little in its shape under the same duration. When the conductivity frequency is more then four times as much as reverse pulse duration, the scattered pulse has deep valleys. Their number grows with the frequency increasing. Thus, it becomes a consequence of pulses with joint duration less then that of the incident pulse.

IDENTIFICATION OF METALLIC OBJECTS USING LOW FREQUENCY MAGNETIC FIELDS

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At the present time, the AN/PSS-12 is the U.S. Army's only fielded mine detector. Although this detector is quite sensitive and can detect low metal content mines, its overall value to the foot soldier is severely limited due to many false alarms generated by buried metallic clutter. In fact, in highly cluttered environments, the detector is rendered, for all intents and purposes, useless. In short, a metal detector is not a mine detector!

Baum has shown (Interaction Note 499, Nov. 1993) that the quasi-magnetostatic scattering from conducting scatterers is characterized by natural frequencies (SEM) which are negative and real. Equivalently, the time domain response is characterized by a sum of weighted exponentials. This model affords an opportunity for metallic object identification in that each metallic object is characterized by a small number of distinct exponential decay rates.

We have recently demonstrated in a laboratory setting the ability to discriminate among a set of metallic objects with simple shapes. In general, we view the problem of identification as one of inference from incomplete information calling for a full application of probability theory. Following this philosophy, we have employed a generalized likelihood ratio test (GLRT) as the basis for our identification algorithm. The apparatus and techniques used to measure the objects transfer function will be discussed. We will review several methods for extracting exponential decay rates from measured data including a differential corrections method and a genetic algorithm.

Extracting non-oscillatory exponential decays from measured data can present a challenge. A response containing multiple decay rates can be approximated reasonably well under certain conditions by a model with fewer poles. Furthermore, if the error between the true and approximate model is on the order of the measurement noise, then the lower order (approximate) model is sufficient to characterize the underlying true model. We will demonstrate, through numerical experimentation, that when the maximum error (between the true model and a lower order approximate model) is less than the standard deviation of the noise, most pole extraction methods (Prony's method, Pencil-of-Functions method, Genetic Algorithm, Differential Corrections Method, etc.) cannot identify the parameters (poles and residues) of the true model but instead converge to the parameters of the lower order approximate model. Furthermore, we show that the differential corrections method in white Gaussian noise provides an efficient estimate of model parameters in that the estimate of model parameters have variances near that of the Cramer-Rao lower bound.

TWO-DIMENSIONAL COILS FOR LOW-FREQUENCY MAGNETIC ILLUMINATION AND DETECTION

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These are various applications of coils (loops) operated in a quasi-magnetostatic regime, including detection and identification of metallic targets. In this case, the target is in the near field of the coils and an analysis of the static magnetic fields is appropriate. Such coils can take various shapes such as rectangular and circular. If a rectangular loop is sufficiently elongated, it can be analyzed as a two-dimensional problem, much as a TEM transmission line, with parameters considered on a per-unit-length basis. Such loops consist of two or more wires parallel to the z axis with a zero sum for the currents (in the z direction).

This type of loop can be used to give uniform magnetic field in some limited spatial domain. Combining two coils as a transmitter and receiver one can measure components of a target's magnetic polarizability dyadic. In this case, one would like that one coil not couple to the other so as to maximize the signal-to-noise ratio in the receiver coil. One might also desire some uniformity of detection over some spatial domain, this involving the combined properties of the two loops. Another design consideration or the received coil is to make it insensitive (zero equivalent area to an external incident magnetic field (e.g., from 50 Hz or 60 Hz power lines).

These are two general classes of coil geometry with respect to the target. In one case (such as for security applications) the target may pass through the coil set where a good region of uniform detection is readily attained. In another case (such as for detecting/identifying targets buried in soil) the coils are on the opposite side of an approximate planar boundary from the target, making uniform detection more difficult. Various examples of such coil systems are considered in this paper.

TOWARD DEVELOPMENT OF AN INTERNATIONAL STANDARD SET OF SIMULANT MINES (SIM)

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The international efforts related to Humanitarian Demining as well as Combat Mine Detection and Clearance, require mine detectors with the capability to locate antipersonnel mines which contain very small amounts of metal. Currently, there are several mine detectors, on a world wide basis, which are claimed to perform this function. Tests to select the best detectors or to rank the candidate detectors have been greatly hindered by the lack of a realistic International Standard Set of Simulated Mines (SIM). For reasons elaborated upon below, we propose a set of simple short-circuited wire coils as an easily reproducible mine simulant (or decoy). Our goal is to adjust the coil radius, a , number of turns, N , and wire radius (gauge) so that the coil represents a reasonably good mine simulant. Furthermore, we envision a set of coils that are progressively more difficult to detect. This coil set would enable one to easily rank the performance of the best metal detectors available on the market today.

Metal detectors produce and respond to low frequency magnetic fields. Therefore, a good mine simulant must closely approximate the quasi-magnetostatic response of the actual mine. The quasi-magnetostatic transfer function of a metallic object is high pass and at low frequencies the object may be modeled as a simple series resistance-inductance circuit. The 3 dB point of the objects high pass response is proportional to the reciprocal of the objects time constant, and the time constant is simply the ratio of the objects inductance to resistance. As pointed out by Sower [IN-526], the time constant of a wire loop is proportional to the square of the wire radius (i.e. is a function of wire gauge) and varies only slightly with the loop size. On the other hand, the amplitude of the field scattered by the loop is proportional to the cubic power of the loop radius, and varies only slightly with the wire size (gauge). This feature makes the loop an ideal candidate as a mine simulant since its 3 dB point and amplitude can be adjusted almost independently. A good simulant must also have approximately the same mutual coupling between the detector's transmit and receive coil as does the actual mine.

Our presentation will describe the experimental setup used to measure the quasi-magnetostatic transfer function of a mine. We will also examine the inductively coupled equivalent circuit of a typical pulse-induction mine detector. This circuit is composed of a magnetically coupled primary and secondary inductors representing, respectively, the transmit and receive coils of a typical metal detector. The primary and secondary are, in turn, magnetically coupled to a series L-R circuit which represents the mine or mine simulant. The quality of the simulant is evaluated by comparing the voltage produced at the detectors receive coil to that produced at the detectors receive coil by the actual mine. Finally, we remark that this paper provides a summary of work in progress.

THREE-DIMENSIONAL COILS FOR LOW-FREQUENCY MAGNETIC ILLUMINATION AND DETECTION

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The present paper considers various three-dimensional coil structures. Since multiple coils can be used for the various field components and for transmit and receive, various combinations of the two- and three-dimensional coils are possible. A fundamental concept in designing such coils for producing approximately uniform magnetic fields (and for uniformity of detection involving both transmitter and receiver coils) is symmetry. For the three-dimensional coils it is convenient to expand the static magnetic fields in terms of vector spherical harmonics, the lowest order terms giving the uniform field of interest. Many of the higher order terms are suppressed by the imposition of appropriate point symmetries (rotation and reflection) on the coil designs. Third-order field uniformity (as in the well-known example of a Helmholtz coil) can be achieved by $C_{4t} = C_4 \otimes R_z$ symmetry together with adjustment of the coil geometry to set one remaining expansion coefficient (the second derivative term) to zero. As a practical matter axial symmetry planes are easily included, making the symmetry of a little higher order. Various types of coils are considered, including bodies of revolution (circular loops) surrounding the target, arrays of point magnetic dipoles, and line magnetic dipoles.

There are additional considerations in the selection of coil geometry. One would like the receiver coils to be insensitive to approximately uniform externally incident magnetic fields (e.g., 60 Hz or 50 Hz). This can be achieved by making them as quadrupoles (in transmission, by reciprocity). One would also like each transmitter coil to have negligible mutual inductance (coupling) to other transmitter and receiver coils. This is also attained in some cases by symmetry (particularly if the two coils are associated with orthogonal field components: x, y, z). For the case of transmitter and receiver coils associated with the same field component, the receiver coil can be placed "inside" the transmitter coil to take advantage of the approximately uniform field of the transmitter. In addition, however, one may wish to adjust other parameters of the geometry (retaining the symmetry constraints) to minimize this coupling.

MAGNETIC SIGNATURE MODELS FOR THE DISCRIMINATION OF UXO FROM CLUTTER

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Most magnetostatic techniques used to detect unexploded ordnance (UXO) suffer from unacceptably high false-alarm rates. These high false-alarm rates are a consequence of the inability to discriminate the general magnetic signature of real UXO from anthropic and naturally occurring magnetic clutter. Improvement in detection capabilities of magnetometry and increased discrimination of UXO from magnetic clutter require understanding the phenomenology of magnetic signatures of both the UXO and clutter. This paper presents a theoretical background describing UXO magnetic signature phenomenology and discusses methodologies for the discrimination of UXO from magnetic clutter.

Magnetic signatures of UXO can be modeled to account for many of the physical attributes of real ordnance. In order to develop potential discrimination algorithms, one must use an unexploded ordnance model which accounts for effects of shape, orientation, shell thickness, and addresses the potential for remanent magnetization. With a robust model, it is then possible to determine potential distribution functions characterizing the magnetic signature of different types of UXO. In addition, it is possible, with the help of field data, to determine similar distributions for magnetic clutter. Knowledge of the distribution functions associated with UXO-unique and clutter-unique magnetic features can be used to establish detection criteria more likely to eliminate false alarms.

This paper discusses the foundations for modeling magnetic signatures of UXO. These concepts are used to calculate ordnance characteristics and compare them to expected characteristics of clutter. To pursue the reduction of false alarm rates, a variety of magnetic features are exploited. These include modeled UXO magnetic dipole moment distributions, assuming that the magnetic signature is dominated by induced magnetization. In addition, a basis for the use of higher magnetic moments of near surface clutter as a discrimination tool is presented. Employment of these techniques is discussed from the standpoint of modeling and compared to field collected data (which will be presented more extensively in a separate paper).

ELECTROMAGNETIC INDUCTION SPECTROSCOPY FOR UXO DETECTION AND DISCRIMINATION

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An object, made partly or wholly of metals, has a distinct combination of electrical conductivity, magnetic permeability, and geometrical shape and size. When the object is exposed to a low-frequency electromagnetic field, it produces a secondary magnetic field. By measuring the broadband spectrum of the secondary field, we obtain a distinct spectral signature that may uniquely identify the object. Based on the response spectrum, we attempt to “fingerprint” the object. This is the basic concept of Electromagnetic Induction Spectroscopy (EMIS).

From numerous surveys that we have conducted using our multifrequency electromagnetic sensors (GEM-2 and GEM-3 developed by Geophex), we have accumulated significant evidence that a metallic object undergoes continuous changes in response as the transmitter frequency changes. For instance, we have commonly noticed that the observed anomalies have opposite polarities at certain frequencies, depending on whether the target is ferrous or nonferrous. The phase also depends on the target’s geometrical shape. These observations made over many UXO targets suggest strongly that the EMI anomaly measured in a broad band offers an ability to both detect and identify a target.

Conventional metal detectors are not designed to do any more than simply detect the presence of buried metal objects, because most of them operate at a factory-set single frequency. A few detectors may have capability of operating at two or more discrete frequencies. These detectors have no ability to discriminate ordnance from trash metals and, therefore, the false alarm rate is unacceptably high. We believe that the EMIS technology can provide both detection and discrimination capabilities.

EMIS technology can be particularly useful for detecting buried landmines and unexploded ordnance. By fully characterizing and identifying an object without excavation, we should be able to reduce significantly the number of false targets. EMIS is applicable to many other problems where target identification and recognition (without intrusive search) are important. For instance, someday, an advanced EMIS device at an airport security gate may be able to recognize a particular weapon by its maker and type. Other potential applications may include industrial sorting processes and robotics.

SENSOR DESIGN FOR EM PULSE UXO DETECTORS

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It is expected that time domain electromagnetic, pulse induction, UXO detection devices will gain prominence over conventional, CW, frequency domain metal detectors in areas of electrically conductive or magnetically active soils. While pulse excitation offers much advantage in target discrimination it carries with it the need for a very wide band sensor and detector if the target signal is to be recorded with minimal distortion. In devices where the source and sensor windings are in maximum coupling, the principal source of error is the inability of the sensor to track the extinction of the primary field so that the "detector" transient severely corrupts the target signal. Even in minimally or null-coupled devices, finite detector bandwidth will result in target signal distortion which in turn affects the target recognition abilities of the instrument.

The bandwidth required for faithful signal detection can be determined by examining the relationship between the central frequency of a classical critically damped induction sensor and the time constant of the target signal decay. For a maximally coupled system, we find that the product of the sensor bandwidth and the smallest target time constant should be at least twenty if the signal corruption is to be held below an acceptable level. In null coupled systems where only signal distortion is a concern, acceptable results can be had where the detector bandwidth - target time constant product is only four.

We also examine the possibility of using electronic feedback to the sensor in order to flatten its frequency response curves. Such a device will detect the secondary magnetic field of the target rather than its time derivative as is done with a conventional induction sensor. It carries with it the advantage that the observed target signal amplitude only depends on target geometry. In this case, for a maximally coupled system we find that the required bandwidth-time constant product is lower than for the conventional sensor but so is the observed target signal amplitude. Because a more powerful transmitter is needed for this type of device, it should only be used in special circumstances.

WIDEBAND ELECTROMAGNETIC INDUCTION FOR METAL-TARGET IDENTIFICATION: THEORY, MEASUREMENT AND SIGNAL PROCESSING

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A principal problem with traditional, narrowband EMI sensors involves target identification. As a consequence, in minefield or unexploded ordinance (UXO) detection, for example, each piece of buried metal must be excavated, causing significant false alarms in regions littered with anthropic clutter. Therefore, the principal challenge for the next generation of EMI sensors is development of electronics and algorithms which afford discrimination. To this end, in this paper we operate in the frequency domain, considering wideband excitation and utilize the complex, frequency-dependent EMI target response as a signature.

To test the signature variability of different metal types and target shapes, as well as for calibration of an actual sensor, we have developed a full-wave model for the analysis of wideband EMI interaction with highly (but not perfectly) conducting and permeable targets. In particular, we consider targets which can be characterized as a body of revolution, or BOR. The numerical algorithm is tested through use of a new wideband EMI sensor, called the GEM-3. It is demonstrated that the agreement between measurements and theory is quite good, for both free-space and buried targets.

Finally, we consider development of signal processing algorithms for the detection and identification of buried conducting and permeable targets, using wideband data. The algorithms are described and then tested on data measured using the GEM-3, with results presented in the form of the receiver operating characteristic (ROC) as a function of the number of discrete frequencies employed.

THE DELTA-TECHNIQUE FOR EMI BASED MINE DETECTION*

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The cost, and the closely related length of time spent in searching for mines or unexploded ordnance (UXO), is largely determined by the number of false alarms. False alarms result in time consuming digging of soil or in additional multisensory tests in the minefield.

We introduce an area based method for reducing false alarms, the delta-technique, which exploits characteristics of the statistical distribution of sensory energy in the immediate neighborhood of targets and of false alarms to significantly improve discrimination between targets and false alarms.

The proposed method uses the following property: at mine locations, most of the neighboring energy values are smaller than the one at the center point. We illustrate the advantages of using the delta-technique with abundant data made available by DARPA from measurements at various calibrated sites.

As an example, the significant improvement derived by using the delta-technique on false alarms is illustrated in Figure 1. as a function of the energy threshold θ of the detector. It shows the ratio of false alarm probabilities P_f^{δ} / P_f at the "FP 20" site as a function of the energy threshold θ . The delta-Technique will significantly impact receiver operating characteristic (ROC) curves of an energy detector by reducing the false alarm rates.

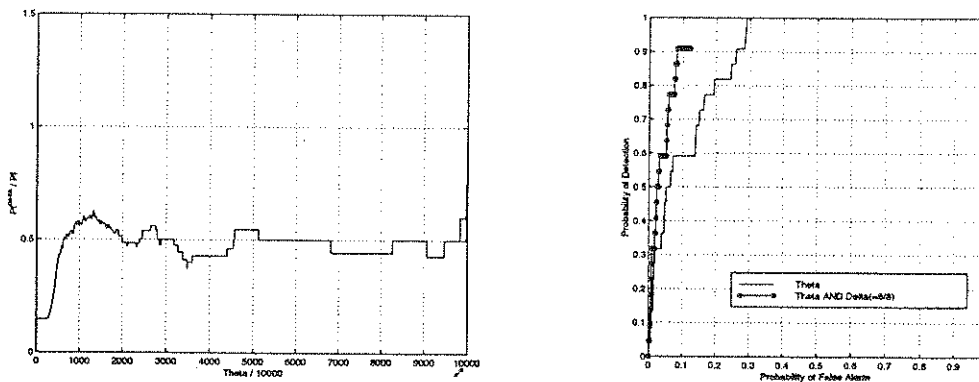


Figure 1: Ratio of false alarm probability with the delta-technique to that with only the energy detector for "FP 20" using 1 m Z coil (left), and the improvements in the ROC curve (right).

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ON THE USE OF A COAXIAL LINE AND CW ANALYSIS FOR PREDICTION OF A/C TRANSIENTS

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A 3D computer code has been used to compare the surface current densities distribution produced on the skin of an A/C placed in a coaxial line, to the distribution given by a plane wave which electric field vector is parallel to the A/C axis. This comparison done for several frequencies has shown good similarities. This allows the use of a coaxial line to simulate plane wave illumination and to derive NEMP transients. CW test induced current measurements are used through Hilbert transform to derive temporal responses. A validation of the method is provided through lightning analysis and test and NEMP waveform excitation of the coaxial line.

ELECTROMAGNETIC EFFECTS DUE TO TRIGGERED LIGHTNING FLASH ON AN AIRCRAFT

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Electromagnetic effects due to lightning flashes have been investigated on an aircraft in flight during several campaigns France.

Most of the lightning flashes recorded on our TRANSALL aircraft are triggered lightning flashes resulting of the only external atmospheric E-field.

The sophisticated instrumentation used on the aircraft has given a lot of information concerning the different phases observed during the entire lightning flashes. The beginning of the event, called the attachment phase, is clearly defined and gives a typical signature corresponding to the multiple-burst phenomena. The successive energetic current pulses which occur during the permanent phase of the lightning flash were recorded and analyzed ; they correspond to the multiple-stroke phenomena.

For each phase of the lightning events, electromagnetic effects on a given instrumented system inside the fuselage were recorded. Comparison can be made between external E and B fields detected on the fuselage, internal E and B fields measured inside the fuselage and induced voltages detected on the system.

These in-flight measurements are also compared to lightning discharge models developed recently at ONERA. Good correlations are obtained and conclusions can be made on the physics of lightning flashes triggered by an aircraft in flight.

CATE - COMPOSITE AND ADVANCED AIRCRAFT TECHNOLOGY ELECTROMAGNETIC PROTECTION

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Partners: Ericsson Saab Avionics, Sweden; British Aerospace, United Kingdom; Aerospatiale, France; Dornier, Germany; Eurocopter, Germany; CEAT (Centre d'Essais Aéronautique de Toulouse), France.

This paper presents the CATE project and give an overall description of the objectives of the programme.

CATE is a European R & D Contract within Brite EuRam, fourth framework. The partners in CATE are Ericsson Saab Avionics (co-ordinators), British Aerospace, Aerospatiale, Dornier, Eurocopter and CEAT.

The objectives of the CATE programme are divided into three areas, *sources, models and protection*, with the following sub-objectives dedicated to the different areas.

◆ Sources

- (i) Identify and evaluate new or aggravated sources of electromagnetic interference.
- (ii) Identify, characterise and specify the Electromagnetic (EM) environment for equipment inside composite structures.

◆ Models

- (i) Validate and determine the accuracy of existing analysis tools for solving EM problems.
- (ii) Improve existing analysis tools, e.g. as regards accuracy or applicability.
- (iii) Develop guidelines to ensure acceptable accuracy when using these analysis tools to solve a specific problem such as coupling to installations inside a composite structure.

◆ Protection

- (i) Assess the shielding effectiveness of composite aircraft structure, apertures and joints.
- (ii) Assess and develop protection methods and develop design guidelines for composite aircraft structures, installations and equipment, including IMA (Integrated Modular Avionics).
- (iii) Optimise protection methods, e.g. as regards cost and weight.

The work is structured into seven tasks, plus a final synthesis task. The objectives of each task are linked to the objectives of one or more of the above described areas.

The outcome of the CATE project will benefit to new knowledge regarding Electromagnetic protection for advanced Aircraft technology.

The objectives of the CATE programme are also aimed towards increasing confidence in the use of analysis tools and modelling techniques for EM assessment of aircraft structures, installations and equipment.

The aspects of this are threefold, namely:

- (i) Assessment of design issues and choice of proper protection methods can be made even before an actual prototype is manufactured
- (ii) More accurate modelling of coupling to internal structures and installations estimates the internal EM environment with higher confidence. This will provide more accurate requirements to be put on equipment and installations.
- (iii) Better optimisation of EM protection methods, regarding e.g. cost and weight.

Yet another aspect of the CATE project is to increase the awareness within the Aircraft industry of the EM threats and their impact on advanced Aircraft systems.

STATISTICAL STUDY OF THE DISTANCE OF CLOSEST APPROACH OF AIRCRAFT TO GROUND BASED EMITTERS

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The flight safety issues associated with the exposure of aircraft to High Intensity Radiated Fields (HIRF) are being addressed by the FAA. The current HIRF environment for aircraft is based on a worst case evaluation of exposure leading to a concern that the required test levels may be excessive and unnecessarily burdensome. A clearer understanding of the interaction of HIRF with aircraft is desirable, in order to understand both the likelihood of occurrences and the intensity of encounters. This report examines one of the main determinants of interaction, the closest approach of an aircraft to a HIRF emitter in the course of normal flight.

Square areas (120 miles on a side) surrounding Denver, Colorado and Seattle, Washington were chosen as study sites. Information on emitter location, frequency, power, etc. was obtained from the Government Master File. Information on aircraft flight positions was obtained from the SAR (System Analysis Recordings) tapes at the Denver and Seattle En Route Centers using the data recorded for the National Traffic Analysis Program. Approximately 5000 flights over three day periods at each site were examined for proximity to emitters.

Observed distributions of closest approach to any emitter were generated separately for the flights at Denver and Seattle. Beacon codes were used to categorize different types of flight operations which were then examined for differences in the closest approach distributions. Local flight operations were observed to have significantly different closest approach characteristics as compared to other types of flights. It was also observed that the smallest values of closest approach to emitters often occurred either at or very near airports. Plots and quantitative evaluations of the statistical distributions have been made for each of the two airport areas. The results for Denver and Seattle showed general similarities but individual differences could be observed. These were identified and their causes examined. Furthermore, issues of resolution, data reliability and validity of generalization to other airport sites have been discussed.

This effort was sponsored by the FAA. The support of the Electromagnetic Effects Harmonization Working Group and its Probability Task Group are gratefully acknowledged.

NUCLEAR ELECTROMAGNETIC PULSE MITIGATION TECHNIQUES APPLIED TO PORT OF ENTRIES OF AN AIRCRAFT SYSTEM MISSION COMPUTER

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An interaction of the high intensity transient electromagnetic field generated by Nuclear Electromagnetic Pulse (NEMP) with sensitive integrated circuit based electronic equipment can cause a great deal of performance degradation, logic upsets, component damage, mission failure etc. Transient electromagnetic pulse generated with sufficient amplitude and specified rise-time can penetrate the computer system through various port of entries (POEs) and create susceptibility problems. The transient electromagnetic field generated by simulator enters the system by (a) diffusion, (b) through seams and apertures (c) airvents, (d) cables and connectors (e) Video Display Unit (VDU). The emission generated consists typically of a plane wave of 50KV/M peak electric field amplitude, a 10 nanosec rise time and an energy density of nearly 1 Joule/M. The available test data has demonstrated that as little as 10 Joules of energy is sufficient to cause an integrated circuit to be damaged. Hence, it is clear that in an "ISLAND CONCEPT" of defence systems, several orders of shielding or isolation, specially, nested type of shielding or isolation, filtering, bypassing, and use of various hardware mitigation techniques at subsystems level are necessary to prevent semiconductor devices from damage by an incident electromagnetic transient field.

The most acceptable nato model of Nuclear Electromagnetic Pulse used in the field test is used. The test methodology is adopted in accordance with MIL STD 461D by parallel plate simulator at a subthreat EMP field level. Tests records also common mode current waveforms in all relevant interconnecting cables under pulse excitation. The 'z' component of the E field and 'x' component of the H field can be easily computed as:-

$$E_z(t-y/V) = [V(t-y/V)] / h \quad (1)$$

Where t=time in secs., h= height of the simulator, w= width of the simulator.

$$H_x(t-y/V) = [I(t-y/V)] / w \quad (2)$$

Subsequently, the full mission computer system is tested based on the injection of simulated but scaled up versions of the recorded current waveforms into each cable in turn, using a "Clamp ON" current transformer driven by an appropriate wave shaping circuit at discrete frequencies. The approach to the shielding of transient electromagnetic field has been based on the Zonal Approach. This approach is found very suitable first to identify the topology of the system which requires hardening by "Allocation". This paper presents the effectiveness of various mitigation techniques particularly the Nested shielding concept against transient electromagnetic field penetration to the electronic subsystem mounted on a fighter aircraft. The hardware, parallel plate simulators, mission computers etc., have been designed and developed indigenously (Fig. 1).

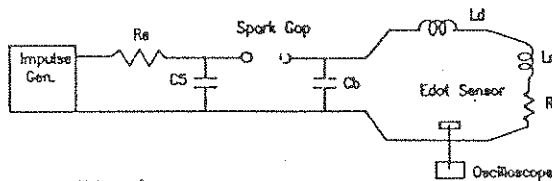


Fig. 1 Parallel Plate NEMP Simulator

VIRTUAL PROTOTYPING OF ELECTROMAGNETIC EFFECTS ON AIRCRAFT

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Modern aircraft are electromagnetically complex systems in that they are made out of a variety of materials and possess safety and mission critical electronic systems which are connected together with an array of complex wiring harnesses. The aircraft are expensive to prototype, and they are also expensive to test in order to validate their robustness to environments such as lightning and HIRF. Because redesign and retrofit are expensive processes, it is necessary that the manufacturer have high confidence that the vehicle will pass the validation test the first time. In addition, because testing is also expensive, it is desirable to off-load as much testing onto simulation as possible. At the same time, the use of modern 3D EM simulation tools is becoming more attractive because of the increasingly friendly human interface, the capability and features of 3D EM solvers, and the proliferation of truly powerful and relatively inexpensive computing platforms.

Virtual Prototyping (VP) is the formalization of the process of using a software simulation to validate aircraft performance in the EM environment. The objective of this paper is to describe the state of the art of VP and what can be expected in the future. Two historical examples of using VP to validate lightning performance are described: The use of simulation tools to qualify the Saab JAS 39 digital fly-by-wire fighter is an example from the military domain, and the certification of the Douglas MD-90 air transport is an example from the commercial domain. Other examples which illustrate the process are also given.

In addition, the relative merits of testing and VP, the capability of modern simulation tools to interface with CAD systems, the status of the human interface with VP tools, and the impact of high performance computing platforms will be described.

LIGHTNING PROTECTION CERTIFICATION OF AVIONIC AND ELECTRICAL SYSTEMS PERFORMING FLIGHT-ESSENTIAL FUNCTIONS: APPLICATION OF THE PROPOSED NEW ROUTES TO COMPLIANCE

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U.S. and European Civil Aviation Airworthiness certifying authorities have long required that electrical and avionic systems performing functions that are critical or essential to safe flight be protected from the effects of lightning strikes which would prevent the continued safe flight and landing of these aircraft or interfere with ability of the flight crew to continue to fly the aircraft safely.

In 1990 the U.S. Federal Aviation Administration (FAA) issued Advisory Circular (AC) 20-136 which sets forth an acceptable means for showing compliance avionic systems with the lightning protection regulations. This AC advised that the applicant for certification (usually the airframe manufacturer, but sometimes an installer of new avionics in an older airplane) develop a Certification Plan which includes ascertaining the lightning-induced transients in interconnecting wiring, establishment of transient control levels (TCLs) for the wiring, and Equipment Transient Design levels (ETDLs) for the equipment, and verification that the aircraft wiring and equipment comply with these levels. This process has involved full-vehicle testing of the airplane to establish and verify the TCLs, and bench-type damage tolerance and system functional upset testing to verify that the equipment can tolerate the lightning-induced transient environment. All of the transport category airplanes, and many rotorcraft and general aviation airplanes have also been certified via their process since publication of the FAA AC. European authorities have accepted certification plans incorporating the same process. When incorporated in a new airplane design and certification program, the process has been carried out efficiently and without excessive cost; however, when applied to avionics upgrades or modifications of existing aircraft, which are often done for small numbers of airplanes, the burden of TCL and ETDL determination and compliance has fallen on the modifier, not the original airframe manufacturers. This has often been prohibitive, and impeded the introduction of new avionics to older airplanes, and to new fleets of smaller airplanes, whose manufacturers have smaller budgets with which to support certification activities. At the same time, the state-of-the-art with respect to aircraft lightning interactions generally and the base of lightning-induced transient data has expanded to the point where certain of the certification activities can be carried out based upon, or with the aid of similarity to test data accumulated since AC 20-136 was published.

In response to this situation, the U.S. and European technical committees responsible for providing technical inputs to the certifying agencies have prepared a technical report which proposes to streamline the routes to certification of a large percentage of the avionic systems presently being installed on new or modified airplanes. This new process depends on the above-mentioned advancements in the state-of-the-art and available data bases. This paper explains the rationale substantiating the proposed process, and gives examples of how it may be applied to typical systems. It is expected that FAA and the European Joint Aviation Authorities (JAA) will adopt the proposed process in forthcoming new or revised advisory material.

THE NEED FOR A PREVENTION POLICY FOR THE GENERAL PUBLIC EXPOSURE TO ELECTROMAGNETIC RADIATION FROM TRANSMISSION BASE STATIONS

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The rapid growth in the last years of cellular phones communication (and users), data communication by RF transmission and new radio and TV- broadcasting stations has led to an increased exposure of the general public to electromagnetic radiation. Thermal risks resulting from electromagnetic radiation are known for many years and are well established. The increased continuous exposure of the general public and the lack of knowledge about exposure risks (large number of people and low radiation fields) require safety regulations and enforcement. Under proper safety regulations, the construction and operation of transmission stations will not cause high and unnecessary exposure to electromagnetic fields. The approval procedure for a base station (based on IRPA or national standards) requires the following: 1) A risk assessment report prior to installation including an evaluation of the risk that may evolve from the radiation field generated by the station, based on the transmission frequencies, power and the surrounding topology. 2) An electromagnetic power density measurement report, before routine operation, including on-site measurements of the RF radiation levels around the site. A national data base of radiating sources should be created by The Ministry of the Environment or a national environmental organization. This data base can be used to create a radiation level's map to identify areas where critical exposure conditions may occur and remedial actions are needed. Such data base can be used also for future investigation of public health effects in the vicinity of the stations. A plan for creating such data base and the required parameters will be presented.

HEALTH AND SAFETY ASPECTS OF HIGH POWER MICROWAVE EXPOSURE

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The U. S. Department of Defense is one of the world's largest developers and users of microwave emitting systems, with estimated an 8000 different types in the inventory. Technology exploiting microwaves for radar, communications systems, and anti-electronic weapons support the U. S. and allied defense forces. In the use of such systems, humans and the environment invariably incur some exposure to low levels of microwaves and run a risk of accidental exposure to higher levels. There are well established bioelectromagnetic interactions from such exposures that can pose health and safety concerns for humans, including burns, induced currents, shock, and increased thermal burden. There is also the possibility of yet to be confirmed or discovered hazards, especially relating to long term or repeated exposures. New systems employing novel types of emissions, such as high power microwave (HPM) and ultrawideband (UWB) emissions, are currently being developed and these emissions must be examined for health and safety hazards before systems are fielded. Processes are in place to assess medical, operational, and research issues dealing with the health and safety of existing systems, as well as those under development. The U.S. Army, U.S. Navy, and U. S. Air Force research programs, collocated at Brooks AFB, contain the largest, best equipped, and expertly staffed facility for microwave bioelectromagnetics in the world. A series of studies have been conducted by the three services to examine the biological effects of very high peak power, short pulse width narrow band microwave radiation. These investigations have focussed on behavioral and ocular effects. A recently completed study found no untoward effects of exposure of the primate eye to 1 MW 1.25 GHz radiation, pulsed at 0.5 to 3 pulses per second; no histopathological changes were seen in the retina as a result of these exposures. Studies have been initiated in our laboratory to allow assessment of the mechanisms of interaction of the unique electromagnetic pulses generated by UWB devices. So far, we have investigated effects on the cardiovascular system, behavior in primates and rats, and on the developing embryo. No effects of exposures up to 250 kV/m have been shown. An investigation of the long-term effects in animals maintained for 18 months after exposure to UWB emissions over a 3 month period has been completed and results are being compiled. The studies described above have been undertaken to identify and manage potential hazards from high power electromagnetic energy, thereby allowing maximal utilization of these systems by the military services with minimal hazard to personnel and the environment.

The opinions expressed in this abstract are the authors' and should not be interpreted as an official position of the U.S. Air Force or the U.S. Government.

NECESSITY OF A SANITARY STANDARDIZATION OF PULSED ELECTROMAGNETIC FIELDS

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The existing sanitary standards cover the area of harmonic electromagnetic fields. At the same time the number of pulsed electromagnetic fields sources are constantly grow (linear accelerators, means of radioelectronic struggle, jammers, electromagnetic pulse simulators and others). It is necessary to investigate the effect of pulsed electromagnetic fields on human health and to develop the appropriate standards. We appreciate electromagnetic environment on the personnel working places where a number of electrotechnical equipment - sources of seldom repeating pulsed electromagnetic field are installed. The levels of the maximum fields intensity were in the range from units up to tens kV/m. Medical examination of the personnel and control group has been conducted. Results of examination specify adverse influence of pulsed electromagnetic fields on health and workability personnel.

In chronic experiments on rats, various changes of behavioral parameters and workability of the animals are revealed depending on levels of electromagnetic fields intensity and quantity of pulses.

Theoretical models of induced currents in biological objects have been developed at various electromagnetic fields influencing characteristics. Experimental results were extrapolated to the human. This extrapolation has been carried out in view of inter-specific laws of dynamics of physiological parameters and predicted induced currents.

Further researches will be directed at the development of sanitary standards for EMP simulator's personnel.

ELECTROMAGNETIC COMPATIBILITY OF THE POWER ENGINEERING SYSTEM WITH THE SYSTEMS OF BIO-, ECO-, AND TECHNOSPHERE

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The humanity is experiencing a rapid advance in science and technology which has tremendously contributed to enhancing the personal comfort of life and creative labor efficiency. Modern life is unthinkable without electricity and wireless communications. However, while making sophisticated tools to improve living standards, the people have been developing the means of life destruction. This misuse of advanced technology has proved to be extremely costly. The 20th century has witnessed the violence of the First and the Second World Wars. The tempest of mass anti-human manifestations such as numerous local conflicts, terrorism, criminality, drugs and alcohol abuse, is circulating around the globe. Drastic changes within the earth's ecosystem have already been detected: some species of plants and animals are endangered to extinction, natural minerals resources which have been accumulated within the biosphere for millions of years are near exhaustion, the protective ozone layer of the atmosphere is depleting. The earth is polluted with nuclear wastes of the atomic energetic and military industry. The entire noosphere is facing a menace of serious ecological and humanitarian crisis. Introducing the fundamental concept of noosphere, one of the great Russian scientists, W.I.Vernadsky, in his paper (i.e. *Am. Scie*, v.33, No.1, 1945), places special emphasis on the possibility of reasonable transformation of the Earth, provided that the necessary understanding is achieved within all the human community and no efforts of mind and labor are wasted on the SELF-DESTRUCTION. The peoples of the whole world are to join their efforts to secure the TOTAL COMPATIBILITY between basic systems incorporating the noosphere i.e. the biosphere (the human community), the ecosphere (the natural environment), and the technosphere. A fundamental breakthrough must be attained in the global concern on the ELECTROMAGNETIC COMPATIBILITY (EMC). The development of various systems of technosphere at the expense of life-sustaining biosphere and ecosphere systems must become inadmissible. The ever-increasing levels of the electromagnetic fields, currents and the extra-high voltage of transmission lines cause the misbalance of their EMC with the other systems of the noosphere. From my view point, the common well-known definition of EMC: "The ability of an equipment or system to function satisfactory in its electromagnetic environment" (IEC-801) is to be regarded as concise and must be revised. The purpose of this paper is to present evidence for introducing a more generalized definition of EMC which could be given as follows: "The electromagnetic compatibility of the two or more systems is an ability to provide a prolonged period of normal operation of each of these systems practically independently of electromagnetic processes occurring in another systems of bio-, eco-, or technosphere which would influence the said system". With regard to the severity of consequences, it is appropriate to subdivide the EMC disturbances into PERILOUS (causing the jeopardy of health and life of people, prolonged malfunction of technosystems, essential ecological disturbances in the natural environment), and HINDERING (causing the decrease of quality in system operation). The utility of the concept proposed is demonstrated by presenting some examples of the EMC disturbances between the SOURCES (the acting systems of bio-, eco-, and technosphere) and the OBJECTS (the systems subjected to the external influence), some technique of disturbance elimination is proposed. To provide the harmony of interactions between all the systems and to overcome the technocratic approach, a new generation of professionals must be educated being completely adequate to the definition "HOMO SAPIENCE". Needless to say, that an engineer must possess excellent professional skills. In addition it is necessary to possess a humanistic general views, a high level of morals and a spiritual culture. To resolve the ecological and humanitarian problems of EMC, it is vital: to accept the legislation on the strict provision of the EMC between all the systems of noosphere including bio-, eco-, and technosphere; to develop standards of the EMC taking into account the cumulative effect of mutual influence of a number of sources of disturbances; to develop a metrological support of EMC supervision, especially with regard to the BIOSPHERE, taking into account the characteristics of biorythmes peculiar to the nervous, cardiac, respiratory and other systems of human body; to provide detailed supervision monitoring certificate of production put into market; to continue designing technical university curricula including humanity disciplines aimed to create the necessary attributes of an educated engineer; to intensify substantially the general courses of environmental education, including problems of EMC, on the secondary school, higher school and university level; to promote educational policy on EMC by publication of a number of special textbooks, manuals, guides; to include the problems on EMC and EME in PROGRAMM of UNESCO : «ECOLOGY SCIENCES AND STABLE DEVELOPMENT».

ACUTE GLAUCOMA AND RETINAL DETACHMENT AT FOUR DAILY LEVELS OF GEOMAGNETIC ACTIVITY (GMA)

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This study was conducted as part of our work in clinical cosmobiology which involves the correlation of environmental physical activity levels with human pathological conditions. We investigated the temporal distribution of two types of ophthalmological emergencies treated at Rabin Medical Center from 1982 to 1996 (5475 days) by level (I-IV) of daily geomagnetic activity (GMA). Our record search yielded 793 patients with acute glaucoma treated on 726 days and 1688 with retinal detachment treated on 1049 days. For acute glaucoma, the ratio of high GMA days (levels III, IV) with (255 days) and without admissions (1487) was significantly greater than that of low GMA days (471 with and 3262 without admissions) ($\chi^2 = 4.218$, $p = 0.039$). When days with more than one admission for acute glaucoma were considered separately, the ratio of high to low GMA days doubled. For retinal detachment, comparison of the highest stormy GMA days (IV) with days of levels I-III indicated a strong trend toward more frequent admissions on the highest GMA days ($p=0.06$). We conclude that high GMA (III, IV) is associated with more frequent occurrences of acute glaucoma, and highest GMA (IV) shows a strong trend toward an association with retinal detachment.

HPM EFFECTS ON AD-CONVERTERS AND CLOCK OSCILLATORS AND SOME SYSTEM ASPECTS OF COMPONENT SUSCEPTIBILITY DATA

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Knowledge about the effects of microwave radiation on electronic components is of great significance for testing, hardening and calculating/estimating systems concerning microwave resistance. Investigations of components give information about differences in susceptibility between different types, technologies, manufacturers, different samples of the same type, technology and manufacturing etc. and also how the parameters (power, frequency etc.) of the microwave radiation will influence the effects on a system.

An AD-converter can be assigned to linear components. Our experiments were performed by direct injection of microwave power into the component, and the effects versus power and frequency were investigated. The effects from microwave power on the function for these types of circuits are often application dependent. However, the effort ought to be to find a value of the effect, which is application independent, but easily by calculations can be converted to actual applications. If this is possible, we do not need to perform new tests for every application in which we use the component. If so, the number of tests on ADC:s can drastically be reduced. The experiments points in this direction, but more experiments for more types of ADC:s have to be done in order to more verify this.

Experiments on crystal clock oscillators were, like the experiments on the AD-converter, performed by direct injection of the microwave power into the components. The goal with these investigations was to get knowledge of how the clock pulses will be disturbed, i.e. how the voltage levels, frequencies, rise and fall times of the output signals will be affected, and also how the supply current changes. The selection of the different oscillators has been done in a manner to give a basis for differences in microwave susceptibility levels between various technologies, manufacturers and also differences between various samples of the same type and from the same manufacturer. As expected, those in TTL technology are the most sensitive. Microwave power in the order of 10 mW at 0.3 GHz up to 100-200 mW at 2 GHz can be allowed if the parameters of the component shall not exceed the defined allowed margins.

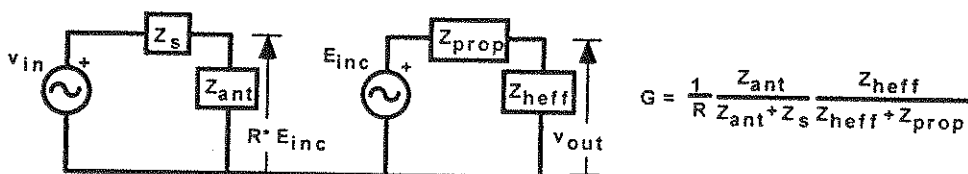
Earlier investigations of microwave effects on components have shown that it is important to have knowledge of components in a system if a test on the system shall be fully relevant, or if estimates of susceptibility levels shall be able to be performed without using too large margins. For example, among the oscillators investigated were included two oscillators which electrically are fully compatible and fully interchangeable in an equipment. But the susceptibility between them differs a factor between 20 to 40. In the actual case, the least susceptible oscillator can have been used in an tested equipment. However, another, not tested equipment of the same type, can contain the most sensitive of the oscillators.

HIGH POWER RF SOURCE OPTIMIZATION USING WIENER-HOPF TECHNIQUES: THEORY AND EXAMPLES

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High power RF applications require knowledge of the optimum source needed to obtain a specified response in some system. The source and response can be specified in terms of an input and an output voltage, v_{in} and v_{out} that are related by the following circuit.



The left portion of the circuit refers to a high power RF system with a source impedance, Z_s , and an antenna impedance, Z_{ant} . This system produces an incident electric field, E_{inc} , at a distance R . The incident field is attenuated by propagation losses denoted by Z_{prop} , and the resultant field couples into a system of interest. The coupling coefficient is given in terms of an effective height like quantity denoted by Z_{heff} . This system can be simplified to input and output voltages, v_{in} and v_{out} , related by a system gain function, G , illustrated in the figure. The problem of interest can be stated now as finding the input voltage that optimizes the output voltage given the system function, G . The input is constrained by some metric such as peak power or total energy. The output feature to be maximized can be the peak time domain response or the peak averaged over some time interval. This optimization is expressed mathematically as finding the extreme of some functional, J , with constraints given in terms of a Lagrange multiplier, h .

$$J = \int_{-\infty}^{\infty} [v_{in}(t) i_{in}(t) h + v_{out}(t) w_{out}(t)] dt$$

$$J = \frac{1}{2\pi j} \int_{-\infty}^{\infty} [V_{in}(s) V_{in}(-s) Y_{in}(s) h + V_{in}(s) G(s) W_{out}(-s)] ds$$

This expression includes a weighting function, $w_{out}(t)$, and results are given in both the time domain and the frequency domain (with Laplace transform variable, s , for complex frequency). When this equation is cast as an extremum problem with the constraint that the optimum input voltage must be causal ($v_{in}(t) = 0$ for $t < 0$) the Wiener-Hopf equation results.

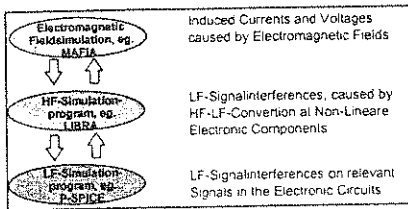
The presentation begins with an outline for the solution of the Wiener-Hopf equation which is causal and constrained in input energy. We will present special cases of this solution including constraints on input power (versus input energy) and allowing for non-causal solutions. The non-causal solution with the input power constrained is the familiar matched filter. Then we illustrate the methodology with simple examples based on analytic expressions (the methodology is general so that it can include impedance terms based on experimental data or numerical calculations). The examples show the optimum source voltages versus time. Since these optimum solutions may be hard to implement with practical hardware design techniques, optimum and non-optimum solutions are compared. The non-optimum solutions result in a larger source output. However the difference between an optimum and a non-optimum source may not be large. Thus the optimal solutions serve as a reference to compare results from practical designs.

HPM-EFFECTS IN LF-ELECTRONIC-CIRCUITS: A NUMERICAL APPROACH

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The interference problem (HF/LF-Conversion) can be functionally divided into three areas. Figure 1 shows the respective electromagnetic effects compared with the corresponding simulation programs during the coupling process. The network analysis requires the induction of these specific simulation tools.



The imprint of high frequency interference source into low frequency electrical circuits has to be done absolutely at a non-linearity at least for non-destroying effects. The reason for this is that only non-linear components are able to transfer part of the induced HF-energy into low frequency interference signals.

Fig. 1. Num. Tools for HF/LF-Couplings

The principle of this HF-LF-conversion or mixture is explained in Figure 2. It shows a sinusoidal amplitude-modulated HF-interference variable $U_{IN}(t)$ with a carrier frequency of 710 MHz and a modulation frequency of 117 Hz. The frequency domain belonging to this signal lies only within the HF-area (Figure 3). This HF-interference variable reaches the diode via a wiring (Figure 4).

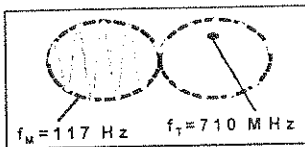


Figure 2: Induced HF Interference $U_{IN}(t)$

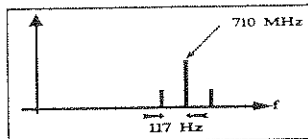


Figure 3: Frequency Domain of $U_{IN}(t)$

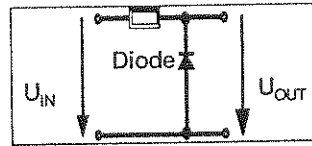


Figure 4: Rectifier

For U_{IN} the diode circuit functions as a rectifier. In case of positive half-waves, the diode blocks and the output signal U_{OUT} follows the input signal. However, in case of negative half-waves, the diode is poled in low resistance direction and U_{OUT} will be short circuited. According to that, the signal after the diode is as shown in Figure 5.

Figure 6 shows the frequency domain of U_{OUT} . U_{OUT} has a domain within the LF-area in contrary to U_{IN} . It consists of a uniform portion and a multiple of the modulation frequency. A distinction has to be considered about powerline or signalline interference.

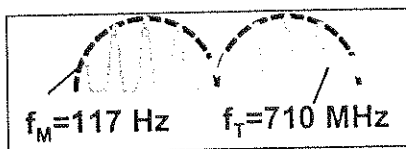


Figure 5: $U_{OUT}(t)$ after the Diode

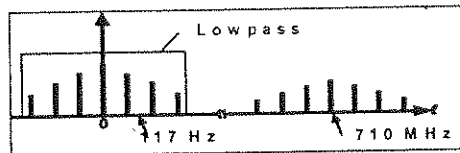


Figure 6: Frequency Domain of $U_{OUT}(t)$

PASSAGE OF SHORT PULSE THROUGH OSCILLATING CIRCUIT WITH DIELECTRIC IN CONDENSOR

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This paper contains the continuation of the authors' previous research (PIERS-97, Cambridge, Ma, USA, Proc p.89, URSI North American Radio Science Meeting, Montreal, Canada, 1997)

A voltage step passing through the circuit of resistance, inductance and condenser with dielectric is studied here. Using the transient polarization expression obtained in previous works we get integral- differential equation for the Laplace transformation of the field the equation is reduced to an algebraic equation of the fourth order. Its solution has an exact inverse Laplace transformation. The resulting establishment is described by the sum of five terms. The first term is the field established in the condenser, fourth others describe the type of the establishment process. There are three types of the establishment process:

1. Two four terms are real ones and are exponents with a negative power (exponential attenuation), two others are complex.

2. Two terms are real functions of the time (exponential attenuation), two others are complex.

3. Four terms form two pairs of complex conjugate terms (two attenuation with oscillations). These types depend on the correlation between macroscopic parameters of the oscillating circuit (time constant of the condenser without dielectric, time constant of the inductance with resistance) and microscopic parameters of the dielectric (resonance frequency and attenuation coefficient of an elementary oscillators, plasma frequency of the charges collection participating in the polarization process). The numerical calculations highlight these dependencies. Possible changes of the short pulse parameters passing through the oscillating circuit are discussed. The comparison between the descriptions of voltage step, passing through oscillating circuit, with the account of the establishment process and without one reveals an essential difference in many cases.

A METHODOLOGY TO DETERMINE AND TO DESCRIBE THE DESTROYING HPM-EFFECTS OF ELECTRONIC COMPONENTS USING A GENERIC ELECTRONIC UNIT (GENEC)

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The analysis of the coupling of HPM-pulses to electronic devices is a very complex task due to the variety of coupling paths, resonance phenomena and nonlinear conversion behavior of electronic components.

To gain a better insight of these coupling and interference effects in electronic circuits both simulation and measurement results have to be compared and combined. Previous analysis of real missiles has shown that the handling of HPM simulation and measuring needs further insight in separated problems such as coupling to power supply wires, coupling to signal wires, coupling to paths on the circuit boards itself or the HF-LF-conversion and the transconductance from the electromagnetic distortion to the information signal due to the frequency dependent nonlinear behavior of the electronics.

Figure 1 illustrates the prospect of the HPM investigations with the GENEC. The Figure 2 shows the electronic design features.

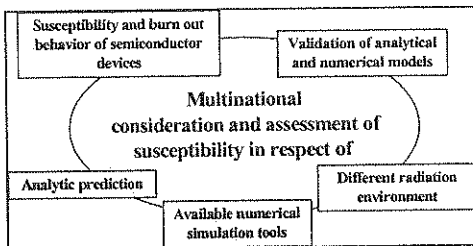


Figure 1: Prospect of GENEC

The system correlates to a simplified, but realistic smart missile in respect of the structure and the electronics (see Fig. 3).

and selected to be able to replace destroyed parts very easily and to be able to use different components from various manufacturers.

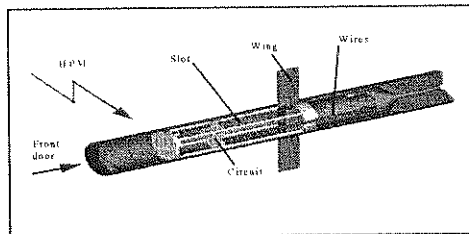


Figure 3: Outboard Profile of GENEC

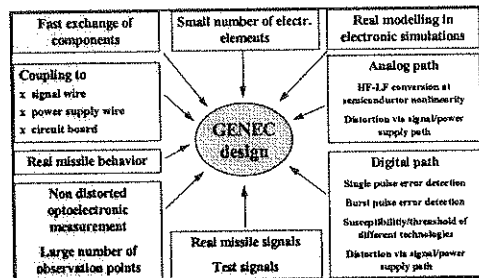


Figure 2: Design Features of GENEC

HPM irradiation tests were conducted to determine the radiation parameters at which the electronic components could be **burned out**.

The test results are correlated to various simulation tools like MAFIA for the induced currents to the wiring and the common resonance frequencies, and LIBRA with PSPICE in respect to network analysis. The destroyed electronic components were analyzed to determine the damage mechanisms. The test results are also used to consider the performance of various simulation tools.

The electronics considers an analog and a digital signal path. The electronic components are in such a way arranged

HIGH POWER MICROWAVE PULSE EFFECT ON LOW NOISE FIELD EFFECT TRANSISTOR

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High power microwave pulse impinging the entrance of a low noise amplifier, leads to a permanent degradation of its microwave properties when the peak power is exceeding a threshold largely over the compression point level. The degradation process is induced by microwave losses and consequently the temperature increases inside the active layer of the device. The critical peak power is depending on the pulse duration, repetition rate and microwave frequency.

Experiment shows that the degradation is due to the failure of the first Field Effect Transistor at the entrance of the amplifier. In order to provide, noise parameter data shift for computer simulation, we have performed test on discrete Field Effect Transistors. We have built an experimental set-up to provide the HPM pulse onto the gate of the FET and to measure the effect immediately after on the noise factor and intrinsic gain of the device. In order to determine the noise parameters of the DUT, we used an automatic noise figure meter in conjunction with a programmable tuner at the entrance of the device. A software enable to extract the parameters from 15 measurements based on a least square-fitting algorithm.

The degradation of the microwave properties and static gate current are obtained similarly for amplifier and discrete device. We observe two degradation steps as the peak power is increasing: the first one is a gradual degradation, the device is still operating with poor noise factor and an intrinsic gain roughly unchanged, the second one is a catastrophic failure with a simultaneous increase of the noise factor and an intrinsic gain decrease. The gate current is increased by about a factor 10 compared to the first step case.

The noise parameter shifts are well correlated with gate current degradation. The optimum admittance for minimum noise factor at 10 GHz is shifting toward the center of the Smith chart on a line with an imaginary part roughly constant. The noise resistance is increasing in two steps: one for the gradual degradation with R_n around 20 ohms order and the other with R_n around 50 ohms .

A noise and scattering parameters modeling has been undertaken with MDS (HP-EESOF) software. It shows that the first step noise factor degradation is well described by the shot noise associated to the reverse Schottky barrier gate current degradation. The catastrophic degradation, noise and gain, is coming from an additional gate current due to a surface leakage probably between gate and source.

METASTABLE CHAOS EXCITATION IN HIGHLY-SUSCEPTIBLE MICROWAVE RECEIVER DEVICES IN THE CONDITIONS OF ULTRASHORT ELECTROMAGNETIC INTERFERENCES

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The study permits to come to conclusion on the very high level of interference-related effects and potential danger of ultrashort pulse signals for the wide range of modern electronic devices, especially for highly-susceptible circuit of communication equipment, radio signals reception and rendering systems. Measures targeted on the protection of electronic equipment from USP influence and countering the formation of interference must include the complex of legal, technological and circuit engineering nature. The study demonstrates feasibility of scaling chaos excitation in the real radioelectronic devices by means of the low-amplitude complex signals. Novel mechanisms of chaos excitation in the radioelectronic devices are studied from the physical standpoint. These mechanisms are based on the unsteadiness of the boundary conditions and mismatch of the radioelectronic equipment components, while from the mathematics point of view they are based on IFS concept. Main distinction of these mechanisms is the fact that the nonlinearity of electronic devices is not required for them to operate and, therefore, they may exhibit in the linear domain of the low-amplitude signals. Effect of the complex pulse sequences on the equipment and analysis of her dynamics in these conditions leads to understanding of importance of the position game concept for the description of electronic equipment operation. The basic results of experiments are as follows: Chaotic response is a standard nonlinear response of the complex electronic system to the external USP signal of even relatively small amplitude. The nature of this response is apparently connected with the nonlinearity and unsteady conditions of the signal propagation and conversion in the RF transmission lines. The complexity of the receiver devices structure and time features of the regimes and parameters of USP interference have an essential impact on the system haotization. The amplitude factor is shown to be a non-dominant one under the conditions of the chaotic regimes excitation in the susceptible circuits of the electronic microwave equipment. The practical application of ATC witnesses of the universal character of the developed procedures for the investigation of the complex dynamics of the electronic systems in course of USP signals transmission, also for the diagnostics and maintenance of the complex electronic equipment in the conditions of the modern electromagnetic environment.

PROBLEMS OF ATTRACTORS CLASSIFICATION AND STATISTICAL PSEUDOMETRICS IN THE SPACE OF ELECTRONIC DEVICES

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The problems of attractors classification are addressed for the electronic systems. Quantitative and metrical characteristics are introduced in the space of the attractors of dynamical systems. Introduced metrics, being the ratio of an equivalence, splits the set of attractors to the classes of equivalence, i.e. to the family of non-empty and non-interlapping sets, so that the sequences (signals), belonging to the single class have the same statistical pattern. The important property of the introduced metrix is the fact that the equity of entropies for two signals does not necessarily mean that the distance between signals is zero, so that these sigals belong to the different classes of equivalence. The ratio, specified by the pseudometrics is more rigorous than the equity of the entropies. Statistic pseudometrics presents a sound opportunity to introduce the informational "distance" between the attractors of the two chaotic systems, treating them as a set of all possible symbolic trajectories for the given system that form the dynamic "language" of the system. The latter is the system invariant, robust to the external noise. Symbolic dynamics and pseudometrics can be applied for the classification of attractors, driven in RAS, and it makes feasible to determine brand of the device that is upset by chaotization, by using only standard characteristics of the attractors for different brands of the same devices.

DISTINCTIONS OF COMMUNICATIONS WITH CHAOS BY MEANS OF ELECTROMAGNETIC FIELDS

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The problem of communications with chaos by means of broadband chaotic signals, produced by means of nonlinear circuits, is of essential interest. Proposed approach permits, at least theoretically, to provide stable and reliable way of communications. However, the theoretical models that were developed so far, leave propagation, reception and transmission of electromagnetic signals beyond the scope of consideration. The latter is essential in case of receiver-transmitter devices. The proposed approach addresses the question on the influence of the spectral characteristics of the receiver-transmitter devices on the quality of the chaotic communications and possibility to minimize this influence.

UXO DETECTION AND REMEDIATION AT BOMBING AND AERIAL GUNNERY RANGES

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NRL's Multi-sensor Towed Array Detection System (*MTADS*), developed with ESTCP sponsorship, represents the state-of-the-art in automated UXO detection technology as demonstrated in blind tests at prepared ordnance ranges. The system incorporates arrays of eight full-field Cs vapor magnetometers and three time-domain EM pulsed induction sensors on low magnetic signature platforms. Target analysis employs a modern, sophisticated data analysis system that can either be used interactively by the analyst or in a stand-alone mode using automated target picking and analysis algorithms.

During the summer of 1997 we conducted about 150 acres of magnetometer and EM surveys at a bombing target and an aerial gunnery target on the Badlands Bombing Range on the Oglala Sioux Reservation in Pine Ridge, South Dakota. Two remediation teams worked in parallel with the surveying operations. An initial area of 18.5 acres was chosen as a test/training range. All 89 analyzed targets were uncovered, documented and remediated. Recovered targets in the training area included 40, M38, 100-lb practice bombs, 4 rocket bodies and warheads, and 33 pieces of ordnance scrap (mostly tail fins and casing parts). The smallest intact ordnance items recovered were 2.25-inch SCAR rocket bodies and 2.75-inch aerial rocket warheads. Information from the training area was used to guide remediation for the remainder of both ranges. The full distribution of target sizes was dug on each range because one goal of the effort was to create a database of both ordnance and ordnance clutter signatures for each sensor system that could be used to develop improved analysis algorithms for discrimination between ordnance and clutter.

Magnetometry and EM data analysis identified 1,462 targets on both ranges. Of these, 398 targets were selected for remediation. Each was waypointed, uncovered and reacquired using DGPS equipment, photographed in place, and subsequently disposed of. An extensive dig sheet was filled out for each target by the remediation team to augment the photographic and digital electronic GPS records. Recovered ordnance-related targets included 67, sand-filled, M 38 practice bombs, 4, M 57, 250-lb practice bombs, and 50, 2.25-inch and 2.75-inch rocket bodies and rocket warheads. In addition, 220 items of ordnance-related scrap were recovered. The average horizontal distance between the waypointed and actual target positions was 12 cm. 90% of all targets were located within 22 cm and 95% were located within 29 cm. The target depths were generally predicted to within 20% of the actual depths of the target centers. *MTADS* has the sensitivity to detect all ordnance at its likely maximum self-burial depth and to accurately locate targets generally within the dimensions of the ordnance.

FEATURE BASED AIDED-TARGET RECOGNITION ALGORITHM FOR DISCRIMINATING BETWEEN UXO AND CLUTTER

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The DARPA Background Clutter Experiment, conducted during the fall of 1996, provides the UXO community with a voluminous set of multi-sensor data collected over four sites containing both clutter and UXO. Two of the sites contained very little clutter. The other two contained large amounts of anthropic clutter. By design, two five-meter wide lanes and one three-meter wide lane contained UXO and mine-like targets of varying sizes, and burial depths up to one meter. A 100 meter by 100 meter center area comprised the clutter region. Excavation of one of the sites, Firing Point 20 at A.P. Hill, gives a baseline by which we can develop feature based algorithms for discriminating between UXO and clutter.

Initial analysis of the sensor data reveals the difficulties inherent in discriminating UXO and clutter. Pixel level statistics for magnetometer data collected at all four sites reveal poor separation between target and clutter distribution functions. In this paper, we describe an aided-target-recognition (ATR) algorithm for identifying and discriminating UXO and clutter. We first segment the sensor data using image processing and mathematical morphology techniques. Employing a feature-level analysis of selected anomalies increases our discrimination abilities. These features derive from the physics of buried UXO and clutter. (A more detailed explanation of these features appears in another talk). Rank-ordering target and clutter items based on these features improves system performance. We present probabilities of detection and false alarm rates for amplitude based algorithms and for our feature based ATR technique. Moving from a relatively clutter-free site to a highly cluttered site, we test the robustness of the ATR algorithm.

NEW APPROACH FOR MODELING AND DISCRIMINATION OF HIGH CONTRAST SCATTERERS

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A principal challenge in the use of electromagnetic sensors for UXO remediation is distinguishing the signature of interesting targets from metallic clutter. We present a unified approach to this discrimination problem using model-driven and data-driven approaches. The application of a model-driven requires a method for computing accurately and rapidly the electromagnetic scattering of a known target. This is a major challenge since the targets have a very high conductivity contrast (which necessitates the use of costly and possibly unstable numerical methods), and have a complex shape and arbitrary orientation (which prevents the use of simplifying assumptions for both analytical and numerical implementations). Further, the high cost of the forward problem with current numerical methods makes the application of inverse theory to discrimination impractical. We present a new approach called the mean field approximation for computing the scattering of electromagnetic radiation from small but not necessarily weak scatterers in a smooth background. The method addresses many of the above concerns. The method bears some similarities to the recent extended Born theory of Habashy et al. (1993) but provides greater accuracy in determining the spatial variation of the internal field while maintaining its computational simplicity. We have derived results for general conductivity distributions as well as for canonical shapes.

In the model-based approach to discrimination we apply inverse theory to infer the model parameters that characterize the target. This approach is highly informative since it yields the physical model parameters such as shape, size, and conductivity that truly characterize the target and separates out the effects of depth, location, and orientation that cause so much data variability. This processing, in effect, reduces the huge size of the sensor data set to its "intrinsic" dimensionality. This eliminates redundant or useless information, and the remaining key features (the model parameters) may then be input into a conventional classifier.

In the data-based approach we seek instead the optimal basis for representing the data. An efficient coordinate system for representing a signal should give large magnitudes along a few axes and negligible magnitudes along most axes when the signal is expanded into the associated basis. We find the optimal basis by using a library of very general bases derived from wavelets and their relatives. The resulting set of expansion coefficients (and their associated bases) that emerge can then be used as input into a classifier. The model-based approach explains the data, whereas the data-based approach represents the data. It is likely that their combined use will yield the most effective discrimination.

THE THERMAL NEUTRON ANALYSIS TECHNIQUE FOR THE DETECTION OF UXO

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Unexploded ordnance (UXO) is one of the most serious and prevalent environmental problems at DOD facilities. The magnitude of the problem has created the need to accurately and reliably assess and characterize the extent of the contamination. Systems based on the detection of metals frequently trigger on shrapnel, bullets and other metal debris as a result of increased sensitivity to detect small or deeply buried UXO. The large false alarm rate of these sensors results in a labor intensive and dangerous method that cannot be scaled economically to the clean-up problem now at hand. A system based on the Thermal Neutron Analysis (TNA) technique has been demonstrated to detect UXO and land mines in various US government tests. Unlike existing sensors TNA response is specific to explosives and as such complements existing technologies. The TNA technology is based on the analysis of gamma-ray spectroscopy following thermal neutron capture. Nitrogen, present in explosives, and not commonly found in soil is detected to indicate the presence of UXO and mines. The paper will discuss TNA-based detection of UXO and will include results from the most recent tests.

MULTISENSOR TECHNOLOGY AND PORTABLE DEVICES FOR DETECTION AND IDENTIFICATION OF BURIED AND HIDDEN EXPLOSIVES

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Various approaches tested for detection and identification of hidden Explosive Charges (EC) and buried Unexploded Ordnance (UXO) proved that the specs of interest for practical application (the sweeping rate up to 100 m²/hour, reliability of detection > 97%, probability of false alarm < 3% in the presence of various natural and man made clutters) could be provided only via using device based on the multisensor technology.

The report is dedicated to description of such a two stage technology, and related portable devices for detection and identification of UXO and EC. At the first stage of the operation express detection (with a high speed of 60 m²/h) of all suspicious targets- possible candidates for UXO and EC (encased or bare) using hand-held neutron-neutron detector is provided with high reliability (up to 99%). The probability of false alarm at this stage could be high enough- up to 20%. At the second stage the portable neutron-gamma detector fulfills the identification of UXO and EC among all detected tentative candidates. Such a combined approach was tested for various surrogate charges, decoys and real EC and UXO in laboratory and real field conditions (custom-houses, special testing fields with buried mines in metallic and nonmetallic shells, ships, separate objects like artillery shells, tubes, boxes, etc.) including test facility at University of California at Irvine, and LLNL mine field at Nevada Test Site.

The data on detection and identification of various UXO, EC and clutters in different ambient conditions (ground, constructions, walls, cars, suitcases, boxes, etc.), are given and analyzed. The results demonstrated EC and UXO identification reliability up to 99% with low false alarm rate of < 3% in the presence of different natural and man made items (clutters).

The design of a combined portable multisensor device for UXO and EC identification with a two-stage operation scenario is discussed.

THE PERMITTIVITY OF SANDS

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Actually, a lot of studies are running about the detection and neutralisation of buried landmines, including the Royal Military Academy in Brussels. Concerning the detection, the Ground Penetrating Radar is taken into account and for the neutralisation of buried landmines, we examine the effects of High Power Microwaves, both in the range from 1 to 4 GHz. We have selected this frequency range as a compromise between the small wavelengths needed for the detection and the attenuation of microwaves in the soils at higher frequencies.

Thus, as we are concerned about *buried* landmines, we are interested in the value of the permittivity of these soils. The soils can vary in chemical composition and in water contents. Since examining the chemical composition of soils in detail is a most difficult task, we started by measuring the permittivity of sands, which are supposed to be composed only of quartz.

For this purpose 3 sand samples were chosen on the basis of their very different textures : white sand with a uniform texture, natural Rhin sand with varying grain sizes and a selected Rhin sand type 05 also with varying grain sizes but bigger grains than the natural Rhin sand. The composition of these sands are examined by an electron microscope : the white sand and the Rhin 05 sand were consisting of only quartz besides some impurities. The natural Rhin sand features a mixture of minerals included quartz.

The permittivity of the samples was measured for different water contents up to a maximum of $0.20 \text{ cm}^3/\text{cm}^3$. The percolation of the water through the sand was limiting this value. The real and the imaginary part of the dielectric constant were graphically represented in function of the water content. These graphs pointed out that the two purely quartz samples were exhibiting the same permittivities, which can be represented by formulas depending only on the water content for the real part and depending on the water content and the frequency for the imaginary part of the dielectric constant. These formulas are consistent with the hypothesis that water is the major agent affecting the permittivity of sand : the real part of the dielectric constant of water is independent of the frequency, but its imaginary part on the contrary is increasing with increasing frequency.

Concerning the natural Rhin sample, there are probably some chemical components that contribute to the conduction of the sample besides the water, as in silt or clay, which induce a different relaxation frequency for this sample.

TIME DOMAIN DESCRIPTION OF THE PROPAGATION OF SHORT PULSES IN SOIL BASED ON RELAXATION TIMES

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Soils have complicated electromagnetic properties, and are typically characterized by complex dielectric constants combined with scattering models. In certain cases mixing formulas can be used to construct an "effective" complex dielectric constant that may incorporate some aspects of the scattering processes. The usual method for evaluating the propagation of pulses in the nanosecond regime is to first determine the frequency response of the complex dielectric constant, and subsequently use the Fourier transform to convolve the propagation transfer function with the input waveform. Good approximations using the method of stationary phase may be possible. On the other hand, in this presentation we show how to analyze the propagation of nanosecond pulses in complex media directly in the time domain from a knowledge of the relaxation times of the free carriers and molecules.

The usual optical frequency dispersion formula may not be the most suitable models for the propagation of nanosecond pulses because optical resonances lie well above the GHz regime. Some experimental observations suggest that attenuation and pulse spreading are better understood in terms of a free carrier relaxation time, τ_{rc} , and/or molecular polarization relaxation time, τ_{rm} . For free carriers the current density, $\vec{J} = N_c \vec{v}$, where N_c is the concentration, \vec{v} is the velocity determined from the equation $d\vec{v}/dt + \vec{v}/\tau_{rc} = q\vec{E}/m$, \vec{E} is the electric field, q is the carrier charge, and m is the carrier mass. The molecular polarization response is composed of two parts: $\vec{P} = \vec{P}_1 + \vec{P}_2$, where $\vec{P}_1 = \epsilon_0 \chi_1 \vec{E}$, and \vec{P}_2 is determined from the equation: $d\vec{P}_2/dt + \vec{P}_2/\tau_{rm} = \epsilon_0 \chi_2 \vec{E}/\tau_{rm}$. The physical constants in these equations are experimentally determined from attenuation and reflection coefficient measurements in a manner that is consistent with causality requirements.

Using the aforementioned material models in conjunction with a corpuscular model for the pulse determines the attenuation and pulse spreading in terms of the local wave impedance and velocity of energy transport. For $\tau_p/\tau_{rc} \ll 1$ the free carriers cannot absorb energy, and propagation occurs with minimal energy loss and dispersion. Conversely, saturation of polarization – with the accompanying reduction in energy loss, favors larger τ_p/τ_{rm} . These two competing processes lead to an optimum value, τ_{po} , that minimizes attenuation. An expression for τ_{po} is derived.

INTERACTION OF THERMAL AND ELECTROMAGNETIC FIELDS

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The aim of this contribution is the determination of interacting thermal and electromagnetic fields in absorbing dielectric media. This influence is investigated with analytical and numerical methods. Up to now studies are dealing with the electromagnetic field calculation or the heat diffusion in dielectrics. Usually in a first step the electromagnetic field is calculated. The absorbed energy causes a heat generation rate. Subsequently this heat generation rate is assumed to be constant and the heat diffusion is determined.

Using that procedure the interaction between the different processes is neglected. With increasing temperature both - electromagnetic and thermophysical material properties - change, and the continuous dielectric heating of absorbing media results in a locally and slowly time dependent change of the heat generation rate.

Existing numerical and analytical methods have been compared with respect to their suitability for a coupled calculation. The criterion is an "as close as possible" interaction between thermal and electromagnetic field calculation.

The methods presented in this paper use the different time scales of thermal and electromagnetic field expansion. The mutual interaction of both processes is approximated in an alternating sequence of determining electromagnetic and thermal fields, which shows the differences between the usual and the alternating calculation method.

In the first step the electromagnetic field is calculated by means of a distributed reflection coefficient Γ_z which takes into account the local change of the electromagnetic material properties. In the next step the thermal field is calculated by means of the Greens function for the appropriate model. If a significant change of the material properties occurs, they are adjusted and a new calculation of the electromagnetic field gives a corrected heat generation rate. The solution with analytical methods is suitable for simple geometries. More complicated geometries can be calculated numerically by an also alternating FEM-analysis. The interaction between thermal and electromagnetic fields is taken into account by adjusting the material properties of the affected elements after each time step if necessary. The results of the alternating calculations show the differences between the usual and the alternating method - here using the material properties of carbon-impregnated polyurethan in an analytical calculation at the time steps $t = 10$ min, $t = 60$ min and $t = 360$ min:

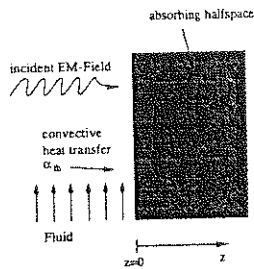


Figure 1: model for the calculation

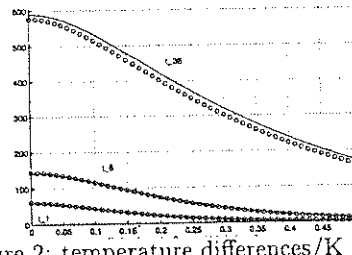


Figure 2: temperature differences/K at z/m
○ temperature dependent
— constant parameters

The full paper will give additional results for other geometries and material properties.

REVIEW OF ELECTROMAGNETIC PROPERTIES OF SOIL: THEORY AND MEASUREMENTS¹

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Soils encountered in nature are generally mixtures of materials that exhibit different electromagnetic characteristics. In many applications, such as the detection of buried targets, it is desirable to treat the microscopically complicated soil mixture as macroscopically homogeneous and characterize the soil by an effective dielectric permittivity. Soils can be treated as multi-phase mixtures, consisting of solid particles, air, water, and other liquids. Water makes the dielectric properties of soils sensitive to small variations in fractional component volumes, because water has a much greater permittivity than the other soil components. Water also dissolves salts in the soil, increasing the effective soil conductivity. These facts make dry and wet soil electromagnetically different. Dielectric permittivity of soils is a frequency dependent complex quantity, primarily due to the presence of water. Therefore, the dielectric properties of water as a function of frequency, salinity and temperature are of major importance.

Several dielectric mixing models have been proposed to explain the permittivity of mixtures from the known dielectric properties and volume fractions of the constituents. A 'universal' mixing rule is presented showing that many other mixing rules are subsets of this 'universal' formula. Comparisons are made between the various mixing theories and results are applied to calculating the complex effective permittivity of soil. Competing dielectric mixture formulas are often judged by their ability to explain and predict experimental data. Many experimental investigations have been conducted over a large frequency range to obtain the complex dielectric permittivity of soils as a function of density, volumetric water content, temperature, and soil type. Results of several of these experiments are presented and discussed in relation to the dielectric mixing models.

Soil texture or structure, such as grain size, shape and orientation, and the size and shape of pores, also influence dielectric permittivity of the soil matrix. Simplified mixing formulas suffer from the disadvantage that they are limited to isotropic mixtures of spherical shapes. We discuss the effects of non-spherical shapes, which are accounted for by including a depolarization factor in dielectric mixing models. When there is a preferred orientation of elliptical inclusions, anisotropy in the bulk dielectric permittivity will result; several examples are presented. Scattering effects in the effective permittivity are not included because the constituent particles of the mixture are assumed to be electrically small in relation to the electromagnetic wavelengths used to interrogate subsurface soil conditions.

UXO CLEARANCE TECHNOLOGY REQUIREMENTS AT ACTIVE TEST AND TRAINING RANGES

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The U.S. Army Research Laboratory (ARL) and the U.S. Army Yuma Proving Ground (YPG) were tasked by the Director, Test Systems Engineering and Evaluation to identify the UXO clearance technology requirements of the active range clearance (ARC) mission area. ARC encompasses active military and training ranges, where UXO clearance operations are performed for safety, operational, and environmental reasons.

In September, 1996, ARL and YPG co-sponsored a workshop at which the participants, primarily range control personnel and explosive ordnance disposal technicians, developed a set of 29 ARC technology requirements. These requirements address UXO detection, location, access, identification, evaluation, neutralization, recovery, and disposal.

The ARC technology requirements that are considered to be high priority address these areas: 1) Detection of surface, near-surface, and buried UXO, 2) Collection, processing and reliable certification of range residue, 3) Improved robotics for remote excavations, demolition charge placement, submunition clearance, and UXO manipulation, 4) Ruggedized in-flight tracking devices to aid in post-flight recovery of test hardware, 5) Neutralization of UXO from safe standoff distances, 6) Advanced personnel protective equipment that is ergonomically correct and provides enhanced ballistic protection, 7) Automatic digital geographic information system to record locations of detected ordnance.

In general, advanced technologies are needed now to support safer, quicker, and more cost-effective range clearance operations. Also, it is expected that additional technological advancements will be needed in the future to comply with evolving regulatory initiatives applicable to UXO clearance at active ranges. Details will be presented on the specific needs and requirements for UXO clearance technology at active test and training ranges.

EFFICIENT CALCULATION OF HORIZONTAL ELECTRIC FIELDS ASSOCIATED WITH GEOMAGNETIC DISTURBANCES

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In the calculation of geo-magnetically induced currents (GICs) on power systems, it is necessary to determine the horizontal electric fields from magnetic fields measured at a limited number of positions. Two simplifying assumptions are useful - in the "sudden onset" portion of a disturbance, the spatial variation of the horizontal magnetic field is small and a one dimensional planar approximation may be made. For the electro-jet, the effective source is a line current at an altitude on the order of 100 km. For both of these geometries, and a few additional associated ones, the horizontal electric field can be solved analytically as a function of frequency (the electro-jet model requires performing an integral over horizontal wave number by quadrature) in terms of the incident magnetic field or the electro-jet current. Efficient calculation of the time history of the electric field can then be done by representing the impedance as a ratio of polynomials in the Laplace variable

$$\frac{E}{H} = \frac{a_n s^n + a_{n-1} s^{n-1} + \dots + a_0}{b_n s^n + b_{n-1} s^{n-1} + \dots + b_0}$$

$$= \sum_n \frac{c_n s}{s - s_n}$$

This procedure is equivalent to breaking the discontinuity along the $-s$ axis of the impedance into segments. (To better represent the leading high frequency behavior, we are really taking the discontinuity in E/sH .) The order of the poly-nominals is chosen based on the range of frequencies desired and the variation in frequency of the impedance ratio. For the sudden onset, a single variation of the impedance is used, for the electro-jet, we calculate $E(\rho)/I$ where the electric field is a function of the horizontal distance from the electro-jet and I is the current in the jet. The highest value of s_n in the procedure is chosen from the following consideration: we have used a high frequency impedance that becomes independent of frequency, while we know that physically the high frequency impedance behaves as $s^{1/2}$, so we need to ensure that the roll-off to constant behavior occurs at a higher frequency than the greatest frequency of interest. After determination of the coefficients c_n , the electric field can be rapidly determined from the magnetic field by integrating

$$\frac{dE_n}{dt} - s_n E_n = c_n \frac{dH(t)}{dt} \quad E = \sum_n E_n$$

which is considerably more numerically efficient than using a one or two dimensional Maxwell solver driven with the time history of the incident field.

HIERARCHICAL INTEGRATED SYSTEM FOR HIGH POWER ELECTROMAGNETICS CAD

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At the present time one can see a progress in electromagnetic CAD. Computational programs for electromagnetic analysis become more and more sophisticated but at the same time they demand much time for development and for users training as well. It leads to a paradoxical situation: many skilled and experienced engineers do not use electromagnetic computational codes in a full measure. The explanation of this phenomena is in the fact, that active developers are an episodic software users, devoting the most their time for hardware problems. They have not enough time to learn each new computational code. More over developers do not need of high accuracy calculations every day. Going through the process of development they make many estimations, and rough but quick calculations.

We are developing the software based on the Hierarchical Integrated System (H.I.S.), a new approach for problem-solving in electromagnetic applications. H.I.S. consists of one interface-monitor module and many computational modules - solvers. Solvers form a hierarchical structure ranges from the very simple and quick solvers used for preliminary analysis and estimations of a problem, to the more complicate solvers needed for high accuracy calculations. H.I.S. concept enables us to make decomposition of a complex problem to a number of solvers, and perform software development in parallel. As a result we spent much less time for software development and propose a broad range of solvers for physicists and engineers. Tree of solvers includes a few families of solvers for calculations electromagnetic fields and charged particles beams dynamics.

AN EFFICIENT EDGE ELEMENT METHOD ON NON-UNIFORM GRIDS

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The numerical solution of Maxwell's equations in anisotropic, inhomogeneous media with complicated geometry presents special challenges since standard staggered grid finite difference schemes have difficulty handling anisotropy and curved boundaries. Finite element methods including edge elements, which are well adapted to these equations, give rise to a mass matrix which can be significant, in particular for higher-order methods, despite its sparse character. This matrix must be inverted at each time-step which can slow down the algorithm dramatically. In our work, we develop a finite element method based on the MurN^l{e}d^l{e}lec hexahedral edge elements which enables us to deal with anisotropy and the complicated geometry encountered in scattering experiments. First, we modify the location of the degrees of freedom for the electric field so that they occur at the Gauss-Lobatto quadrature points. This location ensures, by using the Gauss-Lobatto quadrature formula, that the mass matrix is reduced to a block matrix whose inversion is much cheaper than that of the previous one. In a second step, we choose a suitable function space for the magnetic field which makes the definition of the discrete curl local and avoids the storage of its stencil all over the grid. This property leads to a huge gain of memory. Moreover, by computing the components of the discrete curl carefully, we get very sparse stencils which ensure a significant speed-up of the method. In fact, for 3rd order finite elements, the method becomes as fast as a Yee scheme for an equivalent accuracy. Finally, we use a new kind of PML introduced by Zhao-Cangellaris which can be applied very easily to FEM in order to model unbounded domains.

SIMPLE LINEAR REGRESSION WITH KNOWN BUT UNEQUAL MEASUREMENT ERRORS *

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A new statistical method to analyze error-contaminated or inaccurate measurement data on the independent variable and uncover their true underlying linear relation to the dependent variable is presented. Generic examples are shown. The method applies to, and improves, EM coupling prediction inference from measurements and modeling analyses as well as to *many* regression data fits that have measurement errors, including health and pharmaceutical areas.

The usual simple regression of Y on x estimates from $\{x_i, Y_i\}$ the parameters of a postulated model with the linear-parameter relationship $Y = \alpha + \beta x + \varepsilon$, ε being a random variable with 0 mean and σ_ε standard deviation (S.D.). Here, the "response/prediction" $\{Y_i\}$ are contaminated by a unknown additive random error ε but the "drive/measurement" $\{x_i\}$ are accurate, $i = 1 \dots n$. Such a regression is used to empirically relate and infer one variable from the other, when the model holds and a first principle physics deduction is not feasible.

But in all practical cases, except perhaps for some discrete categorized data, the x themselves have errors. Thus $X_i = x_i + \delta_i$, now X_i being the measured value and δ_i a random variable with 0 mean and σ_i S.D. This, referred to as measurement errors, *greatly* complicated the regression problem. It was heretofore addressed but *not* solved. The conventional wisdom is to ignore these x -errors if they are judged 'small' and to demand reducing them if 'large'.

For the case of known but unequal measurement errors σ_i in X_i , we find a new solution to the simple regression problem. With *both* theoretical analyses and numerical-simulation experiments, the new estimators are shown in virtually all cases to outperform, often by far, the adjusted least squares estimators suggested in the literature. They, of course, converge back to the usual results as all x -errors decrease toward zero. The new approach encompasses relative-error data weighting, beyond n -asymptotic pathology data elimination, n -asymptotic mean square error minimization, iterative estimation, and dimensionless information scaling and bounds. After presenting the theoretical results, we demonstrate with generic examples the huge differences it makes in recovering the true line despite overwhelming measurement errors in x , and exhibit the confidence interval coverage. Further, we illustrate an optimal tradeoff between increasing sample-size and reducing measurement-error to delimit and achieve a specified estimation accuracy under fixed 'cost'.

The extraordinarily wide range of immediate and practical applications to noisy-data based statistical inferences in prediction, forecast, calibration, and correlation are obvious. They will be mentioned briefly.

*Work done under the auspices of the United States Defense Special Weapon Agency (DSWA), formerly the Defense Nuclear Agency (DNA).

THE COMPUTATIONAL METHOD FOR CURRENTS EXCITED IN WIRE ANTENNAS UNDER THE EFFECT OF PULSE ELECTROMAGNETIC FIELDS

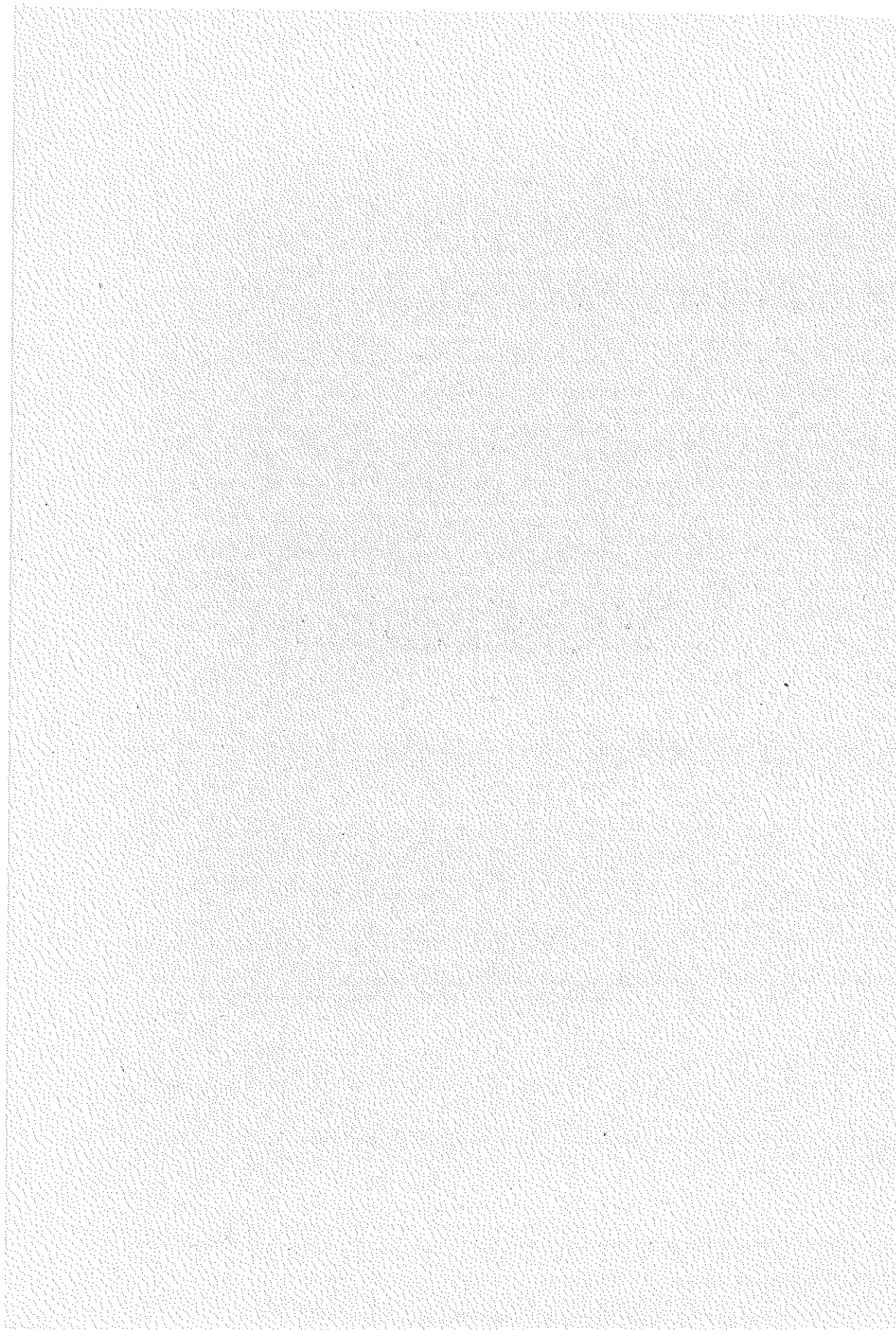
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A method is presented to evaluate the current excited by a plane electromagnetic wave on a thin cylindrical wire in a non-conducting medium. The method relies upon the solution of Poclington equation in the time representation that is reduced, through special replacement, to a system of equations, like telegraph equations, but with nonlocal inductance.

The resulting equations are solved by the finite - difference method. Its performance is illustrated by one problem treating the electromagnetic pulse effect on a thin linear antenna for various ratios between the pulse duration and antenna length.

POSTERS



EXPLOSIVE COMPLEX FOR GENERATION OF SOFT X-RAY RADIATION PULSED FLUXES

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The project of the explosive complex for generation of high-power pulses of soft x-ray radiation (SXR) is suggested and proved. The battery, consisted of the parallel connected disk explosive-magnetic generators (SPRUT system), which, according to the calculations, allows to accumulate the magnetic energy of several hundreds megajoules, was used as a power source. The formation of voltage pulses with the front ≤ 100 nsec is performed with the explosive and plasma-erosion current opening switches using water forming lines. Vacuum wave lines with magnetic insulation are used for transporting of the energy pulse to the load. The conversion of electromagnetic energy to the kinetic one with further thermalization and radiation of space-localized SXR is performed in the geometry of z-pinch collapse using double liner system.

**MEASUREMENTS OF MEGAVOLT VOLTAGES,
MEGAAMPER
CURRENTS AND STUDIES OF MATERIAL SUBSTANCES
IN
ULTRA-HIGH MAGNETIC FIELDS**

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The development of high-power and high energy density facilities requires the application of contactless methods of parameter measurements. They include electrooptic and magneto-optic methods to measure pulsed electric and magnetic fields, high voltages and current intensity based on Pockels and Faraday phenomena. The optical method of data transfer provides no galvanic connection between the recording equipment and the object to be measured, which is a good way to suppress electromagnetic noises, provides safe electric insulation and the possibility to provide measurements under the floating potential, wide range of measurements and their high time resolution. The paper describes a magneto-optic facility to measure intensity of the pulsed magnetic fields and current intensity. The use of special glasses in the Faraday cells allowed the measurement of the pulsed magnetic fields with the strength $H \sim 10^2 - 10^7 \text{ Oe}$ or the current intensity $I \sim 10^4 - 10^6 \text{ A}$. Faraday effect manifested in a single mode quartz fiber provided its use as a current probe. The results of the measurements do not depend on the shape and the size of a fiber trajectory around the current conductor or the current density distribution. Such a facility provided the measurement of the current intensity both at the direct portions of the current conductor and in the coaxial lines up to $I \sim 100 \text{ MA}$, reached in explosive magnetic generators. The paper describes an electro-optical facility to measure pulsed electric fields. Crystals of KDP type are used as Pockels cell. Such a facility provided the measurement of the pulsed electric fields $E \sim 10^4 - 10^6 \text{ V/m}$, which appear in a powerful electron accelerator. The paper describes an electro-optical facility to measure high pulsed voltages, appearing in an inductive storage, when a wire explodes. A value of a high voltage $U \sim 1 \text{ MV}$ and higher is measured. The method is based on determination of the electric potential of a separated conductive sphere using an electric optical probe of the electric field. Since Pockels and Faraday phenomena are similar, the principal and optical schematics of all electro- and magneto-optical facilities described here are similar or identical. This fact resulted in the application of a general approach for their design, implementation and data analysis, though the sizes material, and the shape of the cells and the design of magneto-optical probes are determined by specific conditions of the experiment. To study materials properties in ultra high magnetic fields macro and micro-wave and compensation diagnostics are developed. The paper presents measuring systems.

REPETITIVE SHORT PULSES GENERATION BASED ON SOS DIODES

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The newly discovered possibility of SOS diodes to interrupt high-density currents in subnanosecond time range gives an opportunity for repetitive generation of high-current pulses having the amplitude of hundreds of kV and the length of about 1-3 ns. The circuit approach is based on two series-connected pulse peaking stages, each employing a SOS diode. The first stage generates a pumping pulse several tens of nanosecond long for the SOS diode of the second stage. When the current is interrupted by the SOS diode of the second stage, an output pulse a few nanosecond long is formed at the load. Since the SOS diode is a solid-state element having a small recovery time (less than 1 μ s), the maximum pulse repetition frequency is actually determined either by the thermal operating conditions of the diode or by the frequency parameters of the feeding driver and in the burst mode of operation can be set up to 10 kHz. The paper describes electrical circuits and design of the generators. Experimental results on repetitive high-voltage short pulse generation are presented.

COMPACT FORMER OF CURRENT PULSES IN OBJECT BODIES

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The development results of a small-size current pulse former, providing the flowing of current pulses of exponential form on the object bodies, adjusted in the amplitude range of 1...5 kA and pulse duration on full width at half maximum 40...200 ns with the front not worse than 7 ns, are presented. The former is intended for investigation of the durability of vehicle-born equipment in the conditions of the external interference.

The device consists of the former itself with compact storage capacitor, made of high-voltage ceramic condensers, charging unit and high-voltage synchronization unit. The decisions, making the main advantages of the generators of BING [1] type: compactness, low inductance of the discharge circuit and high commutation characteristics, are the basis of technical realization of the former.

The data of the experimental work out of the former on the active load are presented.

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FAST PULSE INTERFERENCE SIMULATOR

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The creation of interference pulse, which influences on the interface cable wires, is one of the methods for testing of equipment units. Calculation methods of the interference pulse at different influencing factors are widely developed. The task of creation of the universal, compact, retuned in wide range interference generator is very actual.

The development results of the rectangular pulse former, effecting on the inputs of the equipment with wave impedance 50...70 Ohm are presented in the report. Voltage pulse amplitude is adjusted in the range of $10^2 \dots 10^4$ V, pulse duration may be changed in the limits of 5...100 ns. Pulse front is not worse than 2 ns, fall – 3 ns.

The former of the generator BING-5 [1] was used for the bases of the construction. Mechanisms and methods of pulse formation are discussed. The results of the experimental work out of the former are described.

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HYBRID ANTENNA-AMPLIFIER - A NOVEL CONCEPT FOR A HIGH-POWER MICROWAVE SOURCE

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Since the beginning of the 70's, there has been much progress in the field of high power microwave generation. A great variety of microwave sources which are driven by intense relativistic electron beams and, therefore, are capable of very high output power (from 10 MW to 10 GW) have been investigated and constructed. However, there are not so many techniques for extraction of strong microwave radiation. Usually, horn antennas are employed since they are quite simple and natural. Implementation of many other well developed kinds of antennas that are used at low power would result in a wide range of possibilities for high power microwave beam control.

One of the ways for that is to explore the possibility of amplification of microwave signals feeding traveling wave antennas. The physical basis of amplification is stimulated Cherenkov radiation from a relativistic electron beam moving near and along the antenna surface. This system would be a combination of a surface wave antenna and a traveling wave tube that is a novel concept for a high power microwave source.

In the work presented, the linear theory is developed for a relativistic traveling wave tube amplifier in which the slow-wave structure is a circular waveguide with an inner dielectric rod, and the operating mode is the lowest non-axisymmetric mode, the HE_{11} mode, as in well-known and extensively used dielectric antennas. The dispersion relation is derived with regard to non-axisymmetric perturbations for a monoenergetic, fully magnetized, thin hollow electron beam propagating between the rod and outer wall. The achievable gain and bandwidth values are determined from the numerical solutions of the dispersion relation for various waveguide and beam parameters. Special attention is paid to the comparison of spatial growth rates for the HE_{11} mode and the lowest symmetric TM_{01} mode as the latter is usual operating mode for traveling wave tubes. Detailed investigations of the parameter space are carried out to find sets of parameters where one or the other mode dominates. Advantages of the proposed concept and possible approaches to the antenna-amplifier design are discussed.

PECULIARITIES OF FEM WITH CONVENTIONAL AND REVERSED GUIDE FIELDS

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Attractive for various applications free electron maser (FEM) oscillators and amplifiers with reversed axial guide magnetic field are under discussion. The experimental study performed using the JINR linear induction accelerator LIA-3000 (0.8 MeV/200A/200 ns) have demonstrated the high-efficiency (about 25%) single mode generation of 37 MW coherent radiation at the frequency of 31GHz [1,2]. The high-efficiency of FEM amplifier with a reversed guide field was demonstrated in [3] also. In our experiments we had obtained that such FEMs had sufficiently better spectral characteristics comparing with conventional magnetic field FEMs as well. Meanwhile the efficiency of oscillator with conventional magnetic field don't exceed 12% with using of a high brightness electron beam [4]. The influence of various factors, namely the length of the adiabatic increasing of the magnetic field at the wiggler entrance, electron energy spread, a cyclotron resonance neighborhood on a beam transportation and microwave radiation characteristics have been studied. There are comparison of the results of numerical simulations and experimental study of the amplifiers with a guide magnetic field.

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PLASMA WAKEFIELD HELIX GENERATOR

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The concept of broadband generators based on nonrelativistic e-beam modulation by the plasma wake fields has been considered. The generator is proposed to consist of three parts. The tubular electron beam is produced by the magnetron gun that operates in specific conditions to obtain high level noise. In the second part represented by the magnetized plasma wave-guide, these stochastic oscillations are amplified due to the excited plasma wake fields by the modulated e-beam. At the third stage the broadband helix slow wave structure additionally amplifies and takes off the RF power.

Theoretical investigations and computer calculation of the electromagnetic properties of the plasma column placed in the finite magnetic field have been carried out. The experiments have been performed at the installation including magnetron electron gun producing the tubular e-beam of energy 11-11.5 keV, current 2.5-3 A, and diameter 2.5 cm, the plasma wave guide, obtained by neutral gas ionization with e-beam and the helix structure serving both as an amplifier and as an antenna. The RF power of the 12-15 kW level has been obtained in the frequency range 300-500 MHz.

CONTROL OVER THE RADIATION SPECTRA OF A RELATIVISTIC CHERENKOV PLASMA MASER

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Microwave radiation spectrum generated by a plasma relativistic microwave oscillator, in other words, relativistic Cherenkov plasma maser (CPM) depends on the particular parameters of the plasma and the electron beam in use. The theory predicts that both the mean frequency of the microwave radiation and the spectrum width may be varied in a very broad band.

We have shown in our earlier experiments that the CPM is able to generate a broad spectrum, $10 \div 40$ GHz, concurrently in the course of one shot. In this report we present the results of the study of the CPM operation in a comparatively narrow-band regime. Microwave radiation spectrum has been narrowed down to the width of 10%, namely, $29 \div 32$ GHz, by a proper variation of the plasma density and the geometry as well as the energy of the beam electrons. The possibility to tune the radiation parameters was demonstrated: the mean frequency may be shifted and the spectrum width broadened.

The experiments were carried out at the microwave power level of 100 MW.

POWERFUL MICROWAVE SOURCES WITH VIRTUAL CATHODE

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Results of theoretical and experimental studies of microwave generators with virtual cathode are presented. The generation wave length ranges 10-20 cm with microwave power of hundreds of megawatts and nanosecond pulse duration. These devices require either low or no external magnetic field. Numerical simulation of the generators was made with the use of fully electromagnetic 2.5 and 3D PIC code KARAT. Both systems with and without electrodynamic feedback were studied. "Classic" generators with immediate excitation of waveguide eigenwaves were considered as well as generators with RF current conversion to coaxial TEM wave and its further radiation. For feedback containing systems, frequency tuning was demonstrated based on variation of feedback delay time. Experiments were done using periodically-pulsed high current electron accelerators of SINUS type.

THE INDUCED IN PLASMA SPACE CHARGE FIELD EFFECTS ON THE EFFICIENCY OF THE PLASMA-FILLED TWT-AMPLIFIER

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The theoretical and experimental investigations of the induced in plasma space charge field effects on the efficiency of the plasma-filled TWT-amplifier have been carried out.

It was shown, that under conditions of negativity of the longitudinal or radial permittivity of plasma and the optimal values of the depression coefficients, the phase compression of the electron bunch and the suppression of the electron trajectories crossing provided the enhancing of the efficiency and frequency band expansion. The experimental examination of the pilot device completely confirmed the theoretical assumptions.

The obtained results have been used for new plasma-filled TWT-amplifier designing.

EFFECT OF ELECTRON BEAM ENERGY SPREAD ON ITS TRANSPORT AND VIRTUAL CATHODE GENERATION

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The vacuum limiting current defines transport properties of vacuum systems and the ability of virtual cathode formation. Dependencies of this characteristic on beam and guiding chamber parameters are very important for high-power electron beam transport and concomitant problems. One of the problem is a generation of intense microwave radiation in systems with a virtual cathode. Radiation appears due to the virtual cathode oscillations. So, the information of space-time dependence of electrons space charge is needed for theory and applications as well. As was shown in our work, energy spread of an intense electron beam has influence on its energy and current transport and, under certain conditions, may suppress formation of a virtual cathode and its oscillations. Really, dynamics of an electron space charge and efficiency of beam current and energy transport are dependent on energy distribution of the beam electrons. The study of the energy spread effect on beam transport efficiency requires a kinetic consideration.

The results of the computer simulation of a high-power hot electron beam propagation through vacuum chamber are presented. The physical model is based on a kinetic description of an electron beam propagation in self consistent electric field. An external magnetic field provides one dimensional electron motion. We have used a quasi-stationary approach in which the electron motion is described by the Vlasov equation and the electric field is calculated from the two dimensional Poisson equations. The physical model described above was actualized as an independent computational solver BEAM1, included in the H.I.S. - Hierarchical Integrated System.

Simulations, which we have done for different energy spread and types of energy distribution, show that dynamics of a compensation process and efficiency of energy and current transport are strongly dependent on energy distribution parameters. As the results show, electron beam energy spread has an affect on a process of virtual cathode formation. Within this model can be detected an energy spread, which leads to generation suppression.

RESEARCH OF SCREENING EFFICIENCY OF RADIO FREQUENCY CABLES WHEN THE NANOSECONDS PULSED CURRENTS FLOW IN SCREENS

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In many practical problems of electromagnetic compatibility of technical facilities significant interest presents numeric evaluation of screening efficiency of radio frequency cables when the nanoseconds pulsed currents flow in screens. to study the shielding characteristics of cables and experimental checking of the theoretical positions (1,2), the tests of radio frequency coaxial and symmetrical cables were carried out on the experimental base of SRC 26 CSRI (Ministry of Defense).

A cables by the length 15m were used as a test samples. Pulse voltage generator was connected to the cable screen, loaded on the matched external load. Additional screen situated over the insulation shell of cable used as an reverse current-wire. Internal conductor was loaded on both ends on it's wave resistance. Current in the screen and voltages both on the load and between the internal conductor and screen on supplying end of line were measured.

Analysis of measurements results allowed to make the following conclusions:

1. Voltage between the internal conductor and screen on the load has smaller duration and greater amplitude, than voltage on supplying end. Moreover this effect is intensified as velocity of pulse spreading in the internal conductor approaches the velocities of current flow in the screen. Besides, pulses of voltage on supplying end and on the load have a different polarity. This is explained both by particularities of scheme of cable load and by effect of direction, conditioned by the phase dispersion of current at internal conductor (1);

2. Screening factor depends on both what end is used to measure current in the internal conductor and the resistance of load. So as was noted in work (2), this one can not serve universal factor of screening efficiency;

3. Wire screens of radio frequency cables work sufficiently well when current in the screen changes comparatively slowly. Noise pickups in internal conductors reach maximum value when the nanoseconds pulsed currents flow in screens. In this case the evaluation of screening efficiency made by the traditional method, can give a value-added result.

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FORMATION OF ELECTROMAGNETIC PULSES OF UNDERGROUND TRANSMISSION LINE

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In number of problems on test on stability to the influence of EMP nuclear bursts of objects, situated simultaneously under and above the earth surface, formation of horizontal components of electric field seems to be very important factor which often defines stability of testing object to the influence of EMP. Idea of making the simulators, including simultaneously under- and above-ground transmission lines was realised on simulator "SIEGE" (1). This simulator provided generation of low frequency and high frequency components of electromagnetic field on the border of section of two mediums.

Similar idea was developed when designing a complex of simulators SEMP-12 in SRC 26 CSRI. Technical decision of simulator SEMP-12-1 based on formation of horizontal components of electrical field on the border of air and earth surface. Underground transmission line was made from two parallel rows (by length 15m) of vertical rods (by length 8m). Distance between the rows is 50m. Underground transmission line works simultaneously with the above-ground transmission line, situated on the height 10 metres from the earth surface. Excitation of line is provided by the pulse generator (voltage 2,5 MV). Under these conditions are formed horizontal components of electric (up to 70 kV/m) and magnetic (up to 400 A/m) fields in the ground, damped out with moving away the earth surface.

With the use of underground transmission line a number of tests of above-ground plants and devices, antennas of devices, connected with the ground, telecommunication transmission lines etc were conducted.

Results of tests allowed to make a conclusions about efficiency of using of underground transmission lines in terms of solution of some practical problems.

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OPEN-CIRCUIT VOLTAGES INDUCED BY TIME-DEPENDENT POLARIZED INCIDENT E-FIELDS

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When a cable is exposed to an incident electromagnetic (EM) field created by events such as lightning, exoatmospheric nuclear explosions, etc., EM transients will be induced on the cable. These undesirable EM transients may be of sufficient amplitude and duration to upset or even permanently damage the delicate electronics connected to the cable. In order to understand this phenomenon and thereby design the circuitry accordingly to protect the vulnerable parts, a great deal of effort has been devoted to compute these transients. However, the majority of work done in this area assumed the incident EM field to be linearly polarized with constant azimuth polarization angles. In a more realistic environment, this assumption may be overly restrictive, if not false, resulting in erroneous estimates of the induced cable responses.

This paper generalizes the incident EM-field to be of an elliptically polarized double exponential in the xy-plane with a time-dependent azimuth angle, a more realistic case simulating the induced EM environment. To illustrate the effects of this new environment on the cable responses, the open-circuit voltages for two simple but important cable configurations (i.e., a straight cable in space, and a circular cable parallel to the xy-plane) with normal and oblique E-field incidents are calculated and compared to those generated under the ideal and less realistic environment. Potentially significant effects due to the time-dependent polarized E-field are discussed in this paper. The results for these illustrating examples are presented in nine figures.

For a straight cable in space, the peak open-circuit voltages developed over the cable length for linearly polarized incidents are found to be substantially smaller compared to the elliptically polarized values for oblique incidents. For a circular arc cable parallel to the xy-plane in the oblique incident with $\theta_z = \pi/4$, it was found that the elliptically polarized E-incident could induce an open-circuit voltage significantly larger than the traditionally assumed linearly polarized E-incident. This means that, for these two cases, the peak open-circuit voltages could be *under-estimated* in many previous studies for oblique E-incident.

The effects of oblique angle θ_z on the open-circuit voltages and the voltage are further investigated to demonstrate the different temporal behavior between the voltage responses for elliptical and linear E-incident as a function of θ_z . This significant θ_z -dependence may pose a serious problem because there is usually no *a priori* knowledge about the incoming E-incident direction. Measurements of these effects are recommended.

A 100MW, 600PPS ULTRA-WIDEBAND HIGH POWER ELECTROMAGNETIC PULSE GENERATOR WITH PEAKING-CHOPPING SWITCH

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The target of this research is to study the generation of high power UWB electromagnetic (EM) pulse by means of "Peaking-Chopping" switch, as well as some other related techniques playing key-roles in it. An experimental device employing the "Peaking-Chopping" switch technique was designed and setup, which could generate 100MW peak power or 70kV peak voltage (in 50transmission line) UWB EM pulse. The repetition rate is greater than 200pps, up to 630pps. The rise and fall time of the pulse generated by this device are less than 750ps and 350ps respectively, with its pulse-width less than 1ns. While decreasing the gas gap, the rise and fall time of the pulse will be less than 350ps and 250ps respectively, and the peak voltage is 32kV. The 180ps fall time and 80ps rise time have also obtained under lower peak voltage. In this paper, research works on improving the switching speed of high-pressure-spark-gap switch, and the system-stability for the device were presented. The development of high power ultra-fast EM pulse measurement including the design of fast response time capacitor-dividers and its calibration methods is also reported.

EXPERIMENTAL STUDIES ON THE COUPLING OF MICROWAVE INTO A CAVITY THROUGH APERTURES

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The results and summary of experimental studies on the coupling of microwave into a cavity through apertures are presented in this paper. The effective areas of apertures, resonant frequencies and the distribution of induced field in a cavity are obtained in experiments. The results show that: (1) For slot apertures, there is a strongest coupling frequency, that is resonance, it occurs when the long dimension perpendicular to the direction of the incident E-field and the resonant frequency depends on the length of aperture, which can be expressed as $c/f_r=2L$; (2) The thickness of the cavity wall has effects on the coupling of microwave through apertures, when the wall is thick enough, there are several resonant frequencies; (3) For various kinds of aperture, the coupling is very different. All the results can be valuable to high power microwave harden research.

ANTENNA-SOURCE INTEGRATED ULTRA-WIDEBAND ELECTROMAGNETIC PULSES RADIATING DEVICE

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In the transmission of ultra-wideband (UWB) impulsive signals through feed lines and balloons, between high-power, fast-risetime pulse generators and UWB antennas, the existence of transit-time dispersions, skin and dielectric losses, and electrical breakdown effects can degrade the system performance and increase pulse rise-and-fall time. By combining the generator and antenna in an UWB electromagnetic pulse (EMP) radiating device, those loss mechanisms are reduced due to the elimination of feed lines and balloons. This paper presents the design of the device, of which the antenna is pulse charged to approximately 100kV and subsequently excited by the shorting of the oil spark switch located at the feed point of the antenna. The conical symmetry geometrical structure provides preferable boundary conditions for the antenna to radiate spherical TEM waves, the exciting of which is decided by the antenna dimension and the performance of the oil spark switch. The theoretical analysis and numerical simulation of the antenna is given. The charging and radiating pulses of the antenna are measured by a capacitance divider and TEM horn sensor respectively. Analysis, design, and test of the device suggest it suitable for radiating high power UWB pulses or driving other kinds of impulse Radiating Antennas.

CROSSTALK ON PC BOARDS

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Crosstalk phenomenon exists generally in/between electric systems or electric elements, and is inevitable in most cases. Crosstalk of several geometries on PCB (Printed Circuit Board) including parallel-coupled lines coupled lines with bends, and parallel-coupled lines with nonlinear loads on them have been studied here in time domain. While doing this research time-stepping method has been adopted. Therefore, three steps should be followed: First of all, model transmission lines on PCB by using distributed element network under high frequency circumstance, meanwhile, discontinuities on lines should be identified by equivalent circuits; Secondly, obtain distributed parameters of the model, and this is of the most difficulty part of the whole problem; Thirdly, setup and solve iterative equations of voltage and current on the model. Programs have been developed to predict crosstalk on PCB, they are simple but will run much time and occupy huge memory. Calculated and experimental results of these cases will be presented.

SHORT-PULSED MAGNETIC FLUX COMPRESSORS FOR LIGHTNING SIMULATION

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Advances in modern technologies claim a considerable attention to the high quality and reliability of the electrical supplying systems to their lightning protection. In many cases testing of the objects on lightning endurance is demanded to be made at the places of their locations. Compact transportable explosively driven magnetic flux compressors (MFC) seems to be the most convenient equipment for this purpose. MFC can produce powerful electrical impulses with the parameters very close to that of the lightning.

In the present work we consider the possibility of short-pulsed MFCs for the lightning simulation. A metal stake 5 m long in the ground was a load in these experiments. The ohmic resistance of the load contour was 19 ohm and it's inductance - about 20 μ H. Before explosions special experiments with the Marx generator and exploding wires opening switch were performed. Currents up to 10 kA with the rise time of hundreds nanoseconds were obtained in the load. It is shown that the values of the load resistance at high impulse currents are less than that of at the stationary conditions.

THE POWERFUL ELECTROARC DISCHARGES IN NONLINEAR SURGE ARRESTORS VOLTAGE UP TO 1150 kV.

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The wide application of Surge arrestors for protection of the equipment of electrical internal elements of a construction and ejection of arc gas through holes in tank (gates). The thermal and mechanical effects can be so intensive, that the destruction of the device has character stations and substations from dangerous effects of waves of electrical voltage has created a problem of safe operation and devices of Surge arrestor. The norms MEC establish conditions of test Surge arrestors on explosion safety for want of internal short closures. For want of it the amplitude of a current of short closure of industrial frequency reaches 80 kA. The plasma of the closed arc discharge is formed as a result of competing processes of evaporation of walls of explosion, that is inadmissible. In the given operation experimentally and with the help of computer models the parameters of plasma for want of closed arc discharge (temperature, pressure, conductivity) are studied with the purpose of obtaining adequate submissions about the temporary and scale characteristics of effect in tank of the Surge arrestors. Experiments with devices of Surge arrestors with characteristic sizes: height 0,5 m, diameter 10 cm - are conducted for want of significances of amplitude of a test current of industrial frequency 10-20 kA. The volt-ampere characteristics, obtained in these experience, of the category with acceptable accuracy managed to be described with the help simplified ablation-gas-dinamic of a model of the closed arc discharge. The data accounts have allowed to make a conclusion about existence in the closed discharges of pressure reaching 10^{11} Pa and temperatures 40000 - 50000K. However impulses of pressure are limited to significances 10^7 Pa/s, that is explained rather short from time to time existence of so high parameters of arc plasma. The indicated values of parameters of plasma meet to conditions of occurrence of the arc discharge directly in thicker hard isolation of the device. If the arc closure occurs in an air split stipulated in some constructions Surge arrestor, the parameters of digit plasma appear more moderate (temperature makes 5000 - 10000 K). Obtained characteristics can be used for want of to valuation of short-term durability of devices of Surge arrestor for want of internal short closures.

MODERN AND PERSPECTIVE MEANS OF INCREASE OF EFFICIENCY AND RELIABILITY OF PROTECTION OF OBJECTS FROM DIRECT IMPACTS OF LIGHTNINGS

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The experience of operation of systems protection of objects from direct impacts of lightnings of various purpose (ground objects, flying devices, objects of marine engineering) shows, that now damage from direct impacts of a lightning has the tendency to growth on all kinds of objects and practically worldwide, especially in most advanced. Protection of objects from direct impacts of lightnings of such objects as iron roads, transmission line, communication facility, means of transport, flying devices, marine court and the equipment in each state is executed under the special specifications authorized by appropriate competent bodies. It means, that IEC does not accept responsibility issue of the recommendations practically on all most responsible objects.

In laboratory of super-high powers of the St.-Petersburg State Technical University together with State Optical Institute and SRC 26 CSRI be actively ordered operations on increase of reliability protection of objects from direct impacts of lightning of objects of marine engineering. The system protection of objects from direct impacts of lightning by displacement up to 180000 tones of tankers was developed. The system of increased reliability protection of objects from direct impacts of lightning of oil storage and port structures is offered. The operations on increase of reliability of lightning-protection, executed jointly St.-Petersburg State Technical University and 26 CSRI have shown, that the most perspective direction in increase of reliability protection of objects from direct impacts of lightning is the application volumetric and isolated lightning-protectors.

Now increases of reliability protection of objects from direct impacts of lightning can achieve by two main methods: passive with use volumetric and isolated the receiver of impacts of lightning; active with use of methods protection of objects from direct impacts of lightning, shown high efficiency for want of tests on large-scale models. To the most perspective active methods protection of objects from direct impacts of lightning it is possible to attribute: shelter of object by an electrical field, use potential the receiver of impacts of lightning, aerosol method protection of objects from direct impacts of lightning, laser technology of maintenance protection of objects from direct impacts of lightning.

The analysis of possibilities of practical realization of the indicated active methods protection of objects from direct impacts of lightning has shown, that on a modern level of development of a science and engineering most effective and sold is the laser technology of protection of objects from direct impacts of lightning.

TESTING AND CALIBRATION OF MEASURING SYSTEMS FOR VERY FAST TRANSIENTS IN GAS INSULATED SUBSTATION

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This paper describes the construction of four probes adjusted for very fast transients (VFT) in gas (123 kV SF₆) insulated substation (GIS). The primary requirement was the ability to monitor without distortion VFT containing frequencies up to 200 MHz. An experimental apparatus was developed for testing different probes. The functionality of the experimental apparatus was verified by a complex computer-experimental technique. During the test various effects on the measuring system characteristics were analyzed with respect to materials used for the components of the system.

The analysis of the measuring system showed that three measuring probe designs (Types A, C and D) enable measurement of VFT in the GIS. The type B probe was not reliable for the measuring of VFT in the GIS. Experimenting with the dielectric of low voltage capacitors in Type C and Type D probes indicate that polyester is the preferred dielectric in low-voltage capacitor. The type D probe is most interesting for further investigation and improvements. The following research activities are suggested:

- 1) improve measuring system response to measuring waves with less than 5ns rise time;
- 2) examine the effects of different dielectrics in the low-voltage capacitors;
- 3) determine the effects of sensor dimensions on the measuring system response and
- 4) adopt this measuring technique in the laboratory for further research in disconnection operations in the GIS.

THE INFLUENCE OF BUILT-IN RADIOACTIVE SOURCES ON GAS FILLED SURGE ARRESTERS CHARACTERISTICS

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Gas filled surge arresters (GFSA) is the most efficient and the most reliable elements of electron devices for over-voltage protection on low-voltage system. Range of their protection can be from few tens until thousand volts. Application of this element in military industry and space technology of electronic devices makes problem of optimization its characteristics very important.

In this work is examine influence of radiation sources inside of GFSA to find optimal constructional solutions. In GFSA model used in these examinations are built in ^{241}Am and ^{90}Sr sources, respectively. In experiment as alpha emitter is used ^{241}Am which activity is 1735 1/s with energy 5485,6 keV and 267 1/s with energy 5442,9 keV. As beta emitter is used ^{90}Sr , with energy spectra which maximum is on 546keV. During examination due to detailed analysis influence of radiation sources on GFSA characteristics were changed type of gas and gas pressure in chamber.

First series of experiments was examination of two electrodes system model isolated by nitrogen with cylindrical electrodes and work point left from Paschen's minimum (2,5 mbar-mm). Examination uses static and dynamic breakdown voltage without source of ionization radiation and with existence of ^{241}Am and ^{90}Sr , mentioned above which are located inside of GFSA model chamber. In both cases, source centers are 1cm far away from middle of inter-electrode space. Due to theory, the experiment approved that using of radiation sources leads to decrease of dynamic and static breakdown voltage. Also, with this pressure is figured out that ^{241}Am source has bigger influence than ^{90}Sr source on decreasing scattering values of dynamic and static breakdown voltage. It has influence on narrow volt-second characteristics.

Second series of experiments was examination of GFSA model which is different than previous one in location of work point which is now right on Paschen's minimum (50mbar-mm). During examinations are used same sources under same conditions as in first one. Also, there is noticed similar improvement of GFSA parameters. Only difference is ^{90}Sr source which came out as better in decreasing of static and dynamic breakdown voltage, e.g. in narrowing of volt-second characteristics.

In this work chronological sequence and the histogram of the values of static breakdown voltage and dynamic breakdown voltage before and after radiation effects. The obtained results are explained theoretically.

RADIOACTIVE RESISTANCE OF MEMORY COMPONENTS

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Aim of this work is examination of resistivity of magnetic and semiconductor computer memories. This problem is very important in military and space technology.

The magnetic disk technology has been driven by the demands of the computer industry for higher density and more compact data storage, and by the competition from MOS memories to significant density increases and size and cost reduction. The major disadvantage of the magnetic disk is that it has mechanical moving parts which are inherently not as reliable as semiconductors. The significant cost advantage which the disk technology has managed to maintain has given it a competitive advantage over the semiconductor competition. In this work EPROMs and EEPROMs memory types will be considered. The major advantages of EEPROM over EPROM are elimination of expensive UV erase equipment and much faster erasing process (in milliseconds compared with minutes for high density EPROMs). On the other hand a major disadvantage of the EEPROM is the large size of the two transistor memory cell compared to the EPROM one transistor cell. Since both of these MOS devices utilize a similar gate structure, their radiation response is similar as well.

Magnetic memories (BASF computer 3,5 inch diskettes) are radiated in HERBE reactor system. In two measurements three diskettes are examined, one in center of reactor and other two on the edges of reactor dish. One of these two diskettes was covered by cadmium which use to absorb thermal neutrons. Integral total energy was 18800 Ws.

Radiation damages of MOS memories are mostly achieved by accumulation effect caused by continually gamma spectra. Examination of EPROMs and EEPROMs radiation resistivity is done in gamma radiation field of ⁶⁰Co. Average energy of gamma quantum is 1,25 MeV. As the initial condition the value of logic "0" is written in all memory locations. Radiation is achieved in few steps and contents of all memory locations is examined after each step. There is notice that first errors, e.g. values of logic "1" appeared for 100 Gy doses. As doses are increased the number of errors became higher. The number of deleted locations in examined memories was different. During this EEPROMs were more sensitive than EPROMs, which was expected by theory.

The obtained results are explained by interaction of gamma radiation, e.g. secondary electrons with oxide layer. As the active volume is very small (oxide layer), the very important fluctuation of absorption energy is noticed. It causes that some memory elements can accept one magnitude higher specific energy than average dose in chip. Regarding this only few memory elements are destructed.

STATISTICS OF THE ELECTRIC BREAKDOWN VOLTAGE IN GASES RANDOM VARIABLE

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This paper considers relation between electric breakdown mechanism in gas and statistic distribution of electric breakdown voltage in gasses random variable. The paper has theoretical and experimental part. Theoretical part describes electric discharge mechanism in gases that effects breakdown voltage probability distribution. The experiment was designed to measure electric breakdown voltage in gases. During the measurements following parameters were varied: gas pressure, interelectrode gap, electric field, type of gas, and the applied voltage shape. The gas pressure was varied from 1mbar to 5bar. The inter-electrode gap was varied from 0.1mm to 10cm. Four types of electric field (homogenous, divergent, convergent, and divergent-convergent) and three types of gas (electronegative - SF₆, electropositive - N₂, and noble - He) were used. The applied voltage shape was static (rate of rise 8V/s) and pulse (1.2/50+s). The obtained results were analyzed by using originally developed procedure. Our findings are explained theoretically.

POSSIBILITY OF APPLICATION OF PASCHEN'S LOW IN ELECTRICAL BREAKDOWN FOR NON-UNIFORM FIELDS

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Paschen's low as a special form of a similarity low for electrical breakdown in gases is valid only for uniform electrical field. This paper investigates possibilities for extension of Paschen's low that it might be applied on non-uniform electrical field. Theoretical analyze of relationship between similarity low for electrical breakdown and Paschen's low was done in this paper. conditions for extension of Paschen's low for non-uniform electrical fields ware examine. Generalized form of a Paschen low that obtain in this way, was experimentally verify. The experimental procedure and theoretical analyze was based on measurement of the voltage breakdown of a homogenous, convergence, divergence and convergence-divergence electrical field. Inter-electrode gap, different type of gases and gas pressure are various parameters that were used during the experiment. Static(DC) voltage that has the rate-of-rise of 8 V/s and pulse voltage of 1.2/50 s waveform were applied.

MODELING RULES FOR THE DESIGN OF GAS-INSULATED SYSTEMS

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This paper covers the problem how the dielectric-test results done on small laboratory samples can be applied on real final products. A statistical model that takes into account the increase of all three dimensions has been developed, and corrections necessary for upsizing the sample results to the final product have been identified. Both the statistical model and upsizing corrections have been verified by experiment. During the experiment, following parameters were varied: gas pressure, inter-electrode gap, electrode materials, electrode surface topography and the applied voltage shape. All initial discrepancies of theory and experiment were resolved and the final theoretical model has been developed. The results of this paper can be applied for designing gas-insulated systems.

STATISTICAL MODELING OF GAS PULSE BREAKDOWN

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The stochastic nature of gas pulse breakdown voltage is considered in this paper. The introduction covers the microscopic processes of gas breakdown, and both the deterministic and stochastic microscopic breakdown processes are outlined. Based on these, a macroscopic model of gas pulse breakdown has been developed. This model has several advantages in comparison to the existing theory of pulse breakdown in gasses. The model has been applied in calculating the pulse breakdown voltage and pulse characteristics. The results thus obtained have been compared to experimental data collected under well-controlled laboratory conditions. During these measurements, following parameters of the random variables pulse breakdown voltage/ and breakdown time/ were varied: gas pressure, inter-electrode gap, electrode materials, electrode surface topography and the applied voltage shape.

ELECTROMAGNETIC RADIATION FROM LARGE RING OF PULSE CURRENT : SIMULATION AND EXPERIMENT*

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Results of investigations of ultra wideband electromagnetic pulse radiation (UWBEP) from a magnetic dipole of large spatial size are presented. There are several reasons to study these system, namely: possibilities to achieve ultra high power wideband emission ($\Delta f \sim f$) with high antenna efficiency in a case of largest diameter of the dipole $2r_0/c \gg \tau$, and to calculate the UWBEP emission parameters with high accuracy and to compare with measured data, and to calibrate electromagnetic probes in real arrangement, and finally to investigate some aspects of an electromagnetic compatibility. The large magnetic dipole consists of 96 small antennas, each made of copper wire with 9 cm long and 0.2 cm thickness. They are connected in series forming the large antenna ring of $2r_0 = 2.8$ m diameter. A pulse power generator is placed at the centre of large antenna. It produces a unipolar current pulse with parameters: $\tau=3-5$ ns rise time, 1.2 kA current peak value, and up to 100 Hz pulse repetition rate. A pulse currents of 96 wire antennas are transmitted simultaneously along radial beams of 1.4 m by 96 coaxial 50 Ω cables. They are allocated uniformly on azimuth and are connected in parallel on the central pulse generator. Current magnitude of the antenna is 15 A and 3.5 A/ns current rate of rise. Electromagnetic fields have been measured at 10 m from the antenna centre. Several electromagnetic probes have been tested. The best was found to be a double balanced probe consisting of a couple of symmetric magnetic dipoles. Probe signal contained also up to 15% parasitic electric signal in a case of travelling pulse electromagnetic wave. But using good known single symmetrical magnetic dipole, we have obtained worse result: only 25% of total magnitude of an useful signal. Reflected wave signals from surroundings came later than 20 ns. It was detected as sharp rise of the signal being produced by longitudinal magnetic field component. Typical peak values of electric fields of the UWBEP wave was 100-200 V/m at 10 m distance. Computer simulation of real emission scheme was performed using the fully electromagnetic 2&3D KARAT code.

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RADIATION OF RING STRUCTURES WITH ns-DURATION OF CURRENT PULSES

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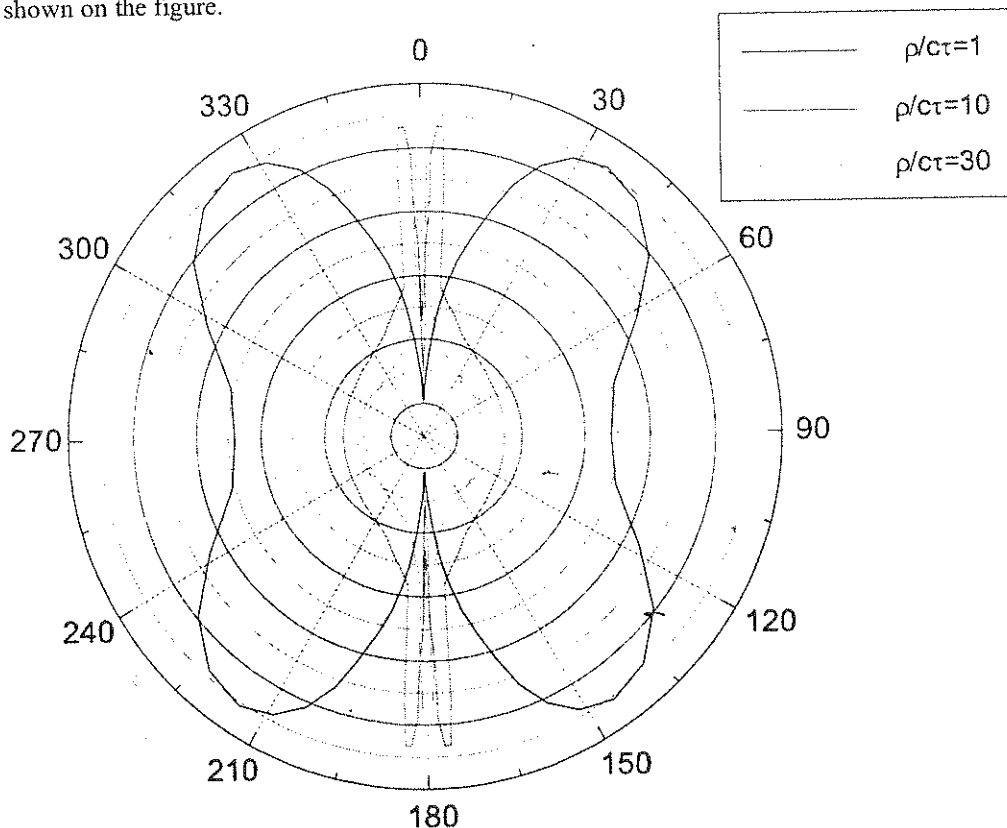
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The particularities of spatial distribution and spectral composition of radiation field of fast changing ring currents are explored. It is shown that $\rho/c\tau$ -parameter (ρ -ring radius, τ -current time scale) has crucial influence on radiation efficiency, directivity and width of spectrum. The influence of current pulse form (simple decay, bell-form, bipolar-pulse) on efficiency and directivity is considered too.

The radiation patterns for ring current of "bell"-form for different $\rho/c\tau$ -values are shown on the figure.



PROPAGATION OF ULTRAWIDEBAND PULSED RADIATION IN CONDUCTING MEDIUM

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A canonical problem concerning a situation in which an electromagnetic pulse having an arbitrary time form is incident from the free space ($z > 0$) onto a plane boundary $z = 0$ of a homogeneous conducting halfspace ($z < 0$) is considered. It is required to determine the envelope forms of the reflected pulse and the one transmitted into a conducting medium as well as the distortions of the reflected pulse away from the boundary.

In contrast to the usually adopted methods we have applied a novel method which consists in the following. The reflected pulse envelope is determined by Fourier integral from the product of the spectral function and reflection coefficient. Then the incident wave envelope is expanded into orthonormalized Laggere functions series and by transforming the Fourier integral into Laplace one we will reduce the problem to the calculation of residues at the poles of integrand. This procedure allows to determine the envelope of the pulse transmitted into medium at the boundary.

Now, after determining the pulse envelope at the boundary, we can establish its evolution away from the boundary. To determine the pulse envelope in an arbitrary distance from the boundary, we will carry out the further analysis as follows. Wave equation for vector potential can be reduced in the conducting medium to the Klein-Gordon equation. His general solution may be represented by the series expansion on its particular nonseparable solutions. Expansion coefficients are determined from the continuity boundary conditions. Using Hilbert-Schmidt orthogonalization the initial basis is transformed into a new basis of the functions that is more preferable.

Numerical computations of the reflection of the E- and H-polarized field have been done for some cases. One may observe an essential difference in the form of the pulses reflected by an ideally conducting surface and the one with finite conductivity. The changes in the reflected and transmitted pulse envelope are caused by the dependence of the reflection coefficient on the frequency and incident angle. There is an essential difference between the reflection of the E- and H-polarized pulses for the incident angle close to the Brewster angle. Particularly, the H-polarized reflected pulse has a longer duration than the E-polarized one. Analogical properties of the transmitted pulses with E- and H-polarizations have been discussed in detail.

So, when analyzing an ultrawideband signal propagation in the conducting medium, it is possible to use its expansion into a series by the functions of time and coordinate that allows to avoid using the spectral representation resulting in the decrease of calculation amount and, respectively, in the increase of accuracy of the solutions obtained.

THE PROBLEMS OF A SMALL BASE ULTRAWIDEBAND RADAR

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In the paper, new approaches for solving the problem of determining a location of radar objects and a subsequent reconstruction of their form when synthesizing an aperture in case of a small angular base of an ultrawideband radar system are suggested.

To determine a location of a radar object, an algorithm based on the signal convolution from a transmitter and receiver with their preliminary transform into the analytical ones using an integral Hilbert transform has been suggested. At an ultrawideband sounding this approach allows to obtain the evaluations of a range with an accuracy higher than the spatial dimension of the signal. A direction to a radar object is determined by the set of relative delays in the system of closely diversified receivers. Application of a regularized factor based on the similarity of temporal forms of the reflected pulses essentially increases the accuracy of determining the location under the conditions of high noises. A simulation modeling has shown that for a 2-ns long sounding signal and at a 2-m base of a receiving system, an error of determining the spatial coordinates of a target disposed at a 50-km distance at the noise level up to 20% didn't exceed 10 m.

A reliable determination of a target location allows to realize a highly accurate synthesizing of an aperture and to approach to solving the problem of its form reconstruction. On the basis of a generalization of Louis-Boyiarski integral identity with introducing standard fragments for the shadow regions of radar objects and aperture synthesizing at a small base ultrawideband sounding, a method of a form reconstruction of their visible part was suggested. It has been shown that at a synthesizing of an aperture corresponding to a 10% angle base the accuracy of a form reconstruction of a two-dimensional model object exceeded 50% at a 1% noise level and fourfold frequency overlap in a pulse. Application of standard fragments for the shadow object parts allows to introduce a current control of the reconstruction accuracy, its form being unknown beforehand.

MULTICHANNEL ANTENNA SYSTEMS FOR RADIATION OF HIGH-POWER ULTRAWIDEBAND PULSES

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Investigations are directed to develop multielement antenna systems intended to radiate gigawatt-power level ultrawideband electromagnetic pulses, the power of a single radiating element being of ~ 100 MW. An antenna presenting a combination of an electrical monopole and magnetic dipole is used as an array element. Such antenna has a constant phase center in a wide frequency band, a cardioid pattern of a linearly polarized radiation and is capable to work in steering antenna arrays. At present, array excitation is realized from one bipolar voltage pulse generator with distribution of power among the radiators without the wave beam control.

In the paper, investigation results are presented that can be conditionally divided into three parts:

- a. characteristics of a single radiator and a four-element array (2x2) on the basis of combined antennae;
- b. mutual influence of short plane radiators in a four-element linear array at a wave beam steering;
- c. numerical simulation of a plane steering antenna array in the approach of absence of mutual influence of radiators with a cardioid pattern.

The main experimental investigations have been carried out at the antenna excitation by a 3-ns long low-voltage bipolar pulses.

TIME-FREQUENCY ANALYSIS AND NOISE SUPPRESSION WITH SHIFT-INVARIANT WAVELET PACKETS

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Time-frequency representations map one-dimensional signals into two-dimensional images that indicate their energy content in the joint time-frequency plane. These representations combine time-domain and frequency-domain analyses to yield a more revealing picture of the temporal localization of spectral components. They have proven indispensable in a wide range of applications, including the study of non-stationary phenomena in high power microwave tubes, such as mode build-up and competition and pulse shortening.

A popular time-frequency analysis tool is the spectrogram, a squared magnitude of the short-time Fourier transform. Its major limitation is the inherent trade-off between time and frequency resolution for a particular window function. Since good time resolution requires a narrow window while good frequency resolution requires a wide window, high resolution simultaneously in both directions is unattainable. This limitation promoted the development of bilinear time-frequency representations that attempt to match the window function to the analyzed signal. Unfortunately, the bilinear nature of the latter representations results in a high noise sensitivity and presence of interference terms, which restrict their practical application.

In this paper, we present a wavelet-based method for constructing an efficient time-frequency representation, which is characterized by high time-frequency resolution, noise immunity and reduced interference terms. This method also provides a robust nonlinear technique for estimating a discrete signal from its noisy measurement.

Suppose we have noisy observed data y , which consists of an unknown true signal f to be estimated and white Gaussian noise: $y = f + n$, $y, f, n \in R^N$, $n \sim N(0, \sigma^2 I)$. The proposed method estimates the signal component from the data using the *shift-invariant wavelet packet decomposition* (SIWPD) and the *Minimum Description Length* (MDL) principle. Utilizing the MDL, a well-known information-theoretic principle, to rank the bases in a library of wavelet packet bases, the SIWPD selects the best basis, which most facilitates the estimation problem.

Let $y = \sum_{k=1}^N c_k \varphi_k$ be the best-basis expansion of the noisy data. We show that based upon the MDL principle, the coefficients implying an optimal coding length satisfy $|c_k| > \sigma \sqrt{3 \ln N}$. Accordingly, the estimated signal is given by $\hat{f} = \sum_{k \in \Lambda} c_k \varphi_k$ where $\Lambda = \{k \mid |c_k| > \sigma \sqrt{3 \ln N}\}$. Subsequently, an appropriate time-frequency representation for \hat{f} is obtained by $TFD_{\hat{f}} = \sum_{k \in \Lambda} |c_k|^2 W_{\varphi_k} + 2 \sum_{(k, k') \in \Gamma} \text{Re}\{c_k c_{k'}^* W_{\varphi_k, \varphi_{k'}}\}$, where W_{φ_k} is the Wigner distribution of φ_k , $W_{\varphi_k, \varphi_{k'}}$ is the cross the Wigner distribution of φ_k and $\varphi_{k'}$, and the set $\Gamma = \{(k, k') \mid k, k' \in \Lambda, 0 < d(\varphi_k, \varphi_{k'}) \leq D\}$ restricts the summation of cross-terms to “close” basis-functions. The metric function d measures the distance between basis-functions in the time-frequency plane, and the threshold D is adjusted to balance the cross-term interference, the useful properties of the distribution (time/frequency marginals, energy conservation, instantaneous frequency, etc.), and the computational complexity.

The full paper contains a comparison with known alternative time-frequency representations and examples illustrating the superiority of the proposed method.

FREQUENCY UP SHIFT BY SELF GENERATED SPATIAL MODULATED RELATIVISTIC IONIZATION FRONT IN SEMICONDUCTOR PLASMA.

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The propagation of relativistic ionization front in semiconductor plasma was experimentally studied. An electron-hole plasma generated by a short laser pulse (100fs,800nm) while it propagation inside a semiconductor crystal. The ionization process involve two-photon absorption. A relatively large propagation distance of the laser pulse into the crystal was obtained due to the dependence of absorption depth of two-photon process on the intensity of the laser pulse. A frequency upshift of 80nm was detected. The relative density of the plasma is measured with spatial resolution and found to be modulated. The modulation wavelength was about 500 microns. The modulation was contributed to nonlinear effects of focusing and defocusing that take place while the laser pulse propagates inside the crystal. The focusing is due to large non-linear dielectric constant and defocusing due to the generation of denser plasma. The frequency upshift may be related to copropagation of shifted pulse and its self-generated ionization front. .

ABOUT MECHANISM OF WIDEBAND MICROWAVE RADIATION AT EXPLOSION OF CONDENSED HIGH EXPLOSIVES

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The fact of electromagnetic fields generation at explosion of charges of condensed high explosives known for a long (HE) has been time¹⁻⁵. According to the results of these experiments, the characteristics of electromagnetic pulses (frequency range, intensity, duration, delay time from the moment of HE initiation, and others) depend on the mass and class of HE, on existence of the shell, on material and geometry of the shell, on the method of the HE priming and others. The known attempts to explain this phenomenon⁶ concern the generation of quasi-stationary electromagnetic fields near the explosion place, when the field depends on the distance from explosion site (r), as r^{-3} , but not to the microwave radiation itself. The presence of the microwave radiation, when field is proportional to r^{-1} , has not been explained still, though it was observed experimentally in some works.

The physical model, which make it possible to explain as the fact of wide-band microwave radiation at explosion of condensed HE itself, as its main characteristics is proposed. In particular, on the basis of the developing model, the dependence of the radiation intensity on the mass of HE for explosions without shell was explained. Some effects, connected with the existence of conductive shell, are considered.

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CORNER TYPE FEEDER IN BUILDING LOFT

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The TEM numerical analysis of the feeder of the corner type placed in the metallic loft of buildings (Fig.) is based on the equivalent electrodes method application [1]. The values of the characteristic impedance are tabulated and compared with corresponding approximate results presented in the Laport's book "Radio antenna engineering" (pp. 390-392).

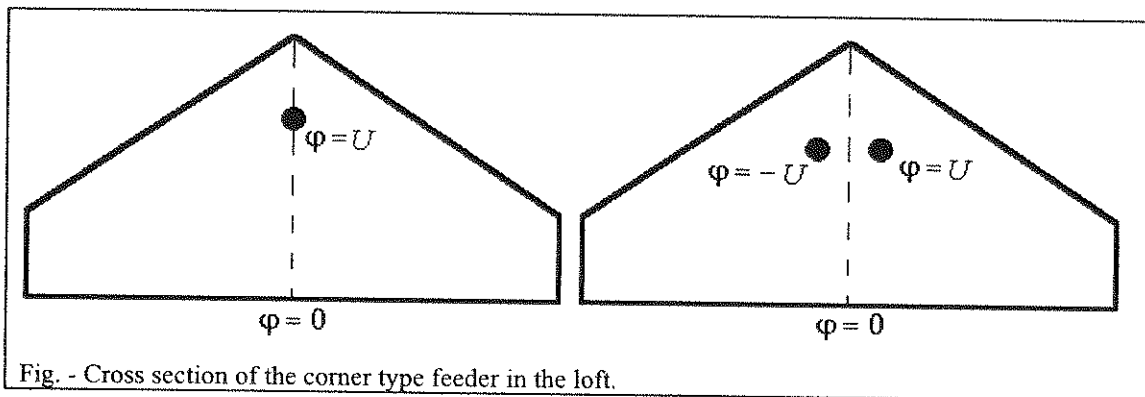


Fig. - Cross section of the corner type feeder in the loft.

- [1] D. M. Velickovic, Equivalent Electrodes Method, Scientific Review, pp. 207-248, Belgrade, 1996.

INFLUENCE OF LF ELECTRIC FIELDS TO THE HUMAN BODY

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The influence of LF electric fields to the human body is investigated. The analysis is based on the electric potential integral equation for human body model and equivalent electrode method for its approximate solving [1]. A very realistic model of the human body is performed. Several examples for different postures of the model will be given.

- [1] D. M. Velickovic, Equivalent Electrodes Method, Scientific Review, pp. 207-248, Belgrade, 1996.

INFLUENCE PRESOWING HIGHFREQUENCY ELECTRO- MAGNETIC RADIATION OVER GROWTH AND DEVELOPMENT OF BARLEY

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Provide ecology purity food, reduction time production quality crop and an increase in output is important problem for any country of production.

Electromagnetic waves different frequency and power have specific characteristics for positive influence over growth and development of every agriculture plant. Application resonance properties of objects and power source has provide maximum effect at energetic and information level influence. Energetic level influence is about 10^2 - 10^5 Watt. Information level is about 10^{-2} - 10^{-3} Watt. This is energy saving technology.

Laboratory and field research for determination influence presowing high frequency electromagnetic radiation over growth and development of barley "Prestige" has been received. Experiment seeds were inter-grow earlier than control seeds at 2-3 days. Effect was present during 3 weeks after treatment. Mushrooms infection seeds were absent at all variants of experiments.

Power-intensive of treatments process was bellow 15-30 kWh/t seeds.

Information for the determination of the fundamental conformity to natural lows of interaction of objects of processing with the high frequency electromagnetic field, ranges of expedient parameters of irradiation has been determined. Principles of equipment construction which provide ecological safety of agriculture, increase crop yields has been elaborated.

1 MV, 20 ns PULSE GENERATOR FOR HIGH-CURRENT MAGNETRON

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The most easy and reliable method to sharpen an electromagnetic pulse is to use plasma erosion opening switches (PEOS). This method does not require a "fast operating" capacitor bank. In this method the energy stored in a "slow operating" capacitor bank is converted into a magnetic inductance energy, which is switched to a load. When an inductive storage circuit of breaks, a short electromagnetic pulse is generated which is delivered into a load. PEOS operation is based on the property of a high-current discharge in a plasma to increase resistance sharply, when the current reaches a critical current. Because of the fact that power increase is followed by significant voltage increase, the generators based on PEOS have found wide application in accelerator engineering aimed at generating electron beams and microwave pulses.

In the present paper there are given the results of investigations aimed at the development of small-size high-current generator for relativistic magnetron. The generator with two sharpening cascades forms at 120 kJ energy stored a megavolt 100 kA current pulse with 10-20 ns duration. To decrease the size, magnetic insulation is applied in a high-voltage section of facility and load. The developed generation of megavolt pulses is highly promising as a means for physics researches because of its high specific characteristics.

RESEARCH OF PLASMA SWITCH WITH EXTERNAL MAGNETIC FIELD

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In the work the results of experiments on the research of a microsecond plasma opening switch (POS) are described. In order to reduce a drift of the POS plasma flow, the magnetic field was generated inside the vacuum inductive storage between the downstream of the plasma injection and the load.

The experiments were conducted at PIRIT-40¹ facility with the energy store up to 40 kJ, peak current 200 kA and duration of powering POS about 1 μ s. The external magnetic field with the amplitude up to 2.5 T was produced by a coil powered from 900 μ F, 6 kV capacitor bank. The coil was comprised by the copper turns laid down on the external tube of the inductive storage. The magnetic flux penetrated into the vacuum gap of POS through the stainless steel as thick as 0.15 cm for 100 μ s. The plasma in the POS was produced by six plasma guns, which were energized from the 0.8 μ F, 60 kV capacitor bank. In the area of POS plasma injection the magnetic field was not very high because of the considerable thickness of the metal cases of the plasma guns and external tube of the inductive storage.

In the paper the distribution of the external magnetic field in the inductive storage and the characteristics of POS are given. The usage of the magnetic field allows to diminish the sizes of the storage and the time of switching, as well as to reduce the drift of the plasma flow and to increase the working current density of POS by factor of 2-3.

¹ A.I. Pavlovskii, N.F. Popkov, E.A. Ryaslov, A.S. Pikar', V.I. Kargin et al. "Characteristic optimization of pulsed energy sources with plasma switches" in Megagauss magnetic field generation and pulsed power application, Ed. by M.Cowan and R.B.Spielman, Nova Science Publishers, New York, 1994, p. 757

PIRIT-10-10 MJ, 10 TW, 25 MA STATIONARY FACILITY

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In this paper the project¹ of the pulsed PIRIT-10 facility is described. We choose the idea and substantiated the main parameters of the 10 MJ, 10 TW, 25 MA of the stationary facility intended for applications in plasma physics and pulsed power. The facility is based on a capacitive storage and plasma opening switching of microsecond inductive storage currents.

The facility is comprised by 60 six-stage Marx generators with the voltage in shot of 1 MV, which are connected in parallel in 20 modules with the total capacity of 20 μF and inductance of 15 nH. The energy is extracted from each module through a vacuum insulator and magnetically insulated coaxial line with the total inductance of 6 nH, and is fed into a vacuum chamber with the inductance of 4 nH. In the vacuum chamber the currents from the capacitive modules are summated using a post-hole convolute.

The total inductance of the circuit is 25 nH, which allows to reach for 1 μs the maximum magnetic energy which is 0.87 of the capacitive storage. The power of the capacitive driver of the facility will be higher than 8 TW. The use of the current opening plasma switch provides that the current front at the load is 100 ns and the peak voltage is up to 2-3 MV. In this case the power of the facility will be as high as 20 TW.

PIRIT-10 facility is intended for applications in experiments on the compression of shells, Z-pinchs, acceleration of plasma Torii's and for generation of electron beams.

¹ The present effort is being fulfilled under the contract F617094W0905 with European Office of Aerospace Research and Development.

GENERATION OF HIGH-POWER SHOCK WAVES ON PIRIT-2 FACILITY

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To study the equation of material state by a dynamic method, it is required to generate a strong shock wave. Such wave can be obtained by different methods: with the aid of HE; with the help of a striker possessing high speed; using a flux of laser and x-ray radiation. At $2 \cdot 10^{12}$ W/cm² x-ray radiation intensity there are created shock pressures up to 10 Mbar¹. At loading by a high-power radiation flux it is formed in the sample a strong shock wave.

In the present paper there are given the results of first experiments carried out in accordance with radiation hydrodynamics program on PIRIT-2 facility. Z-pinch was used as a radiation source. The density of the flux of soft x-ray radiation energy constituted 10^{11} W/cm². To register shock velocities there were applied a photochronography method and laser interferometric velocity instrument (LIIS). At the registration by LIIS method of mass velocity there was placed some transparent material on the sample boundary, its parameters being close by dynamic rigidity to the sample ones. There are analyses the results of first experiments on PIRIT-2 facility and their comparison with calculation results.

¹ J.J. Ramirez, The X1-Z-Pinch Driver, IEEE trans. on Plasma Science, vol. 25, No. 2, 1997.

NUMERICAL SIMULATION OF MAGNETIC FLUX COMPRESSION IN HELICAL CONE EXPLOSION MAGNETIC GENERATORS

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Results of physical process numerical simulation at magnetic flux compression in magnetocumulative generator of large diameter core are presented. The generator under consideration is the modification of the developed earlier multy-megadjoule energy source and is designed to power the PIRIT-EMG stationary electro-physical facility by pulse energy at 80 MJ level.

Its output parameters should not only be calculated but optimize the generator dimensions, selected the shape and thickness of the core wire, insulator type, its electric strength and etc., developed magnetocumulative generator. Package, allowing to perform simulation of helical-cone generator operation and numerically research the physical processes, at magnetic flux compression was developed by the authors for these purposes. Eiler equations for opposing sliding detonating waves are solved to calculate the dynamics of liner fly apart. The equation system is integrated by numerical method on two-dimensional stable nets, adapting to the flux peculiarities. Liner collision with core wires and insulator failure are considered in two-dimensional coordinate system within the model frames of non-viscous, nonheat conducting gas. Magnetic flux compression is calculated with the use of dynamic problems analytical solution and one-dimensional counting of magnetic field nonlinear diffusion in conductors. At that if using sufficiently simple algorithm one succeeded to account main losses of magnetic flux, associated with diffusion, cut-off on joints of sections and wires, losses, associated with non-axis of the core and liner.

AUTONOMOUS MAGNETOEXPLOSIVE GENERATOR OF MEGAVOLT, 100 ns PULSES

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V.N. Nudikov, A.S. Pikar, N.F. Popkov, E.A. Ryaslov, A.F. Saratov

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There are presented the results of the works carried out at different stages aimed at the development of autonomous magnetocumulative generator of megavolt 100 ns current pulses. The device developed is designed to substitute magnetoexplosive energy source for stationary megavolt current generator PIRIT-01. The usage of generator on permanent magnets as a source of initial energy as well as the multiplication of this energy by a cascade of magnetoexplosive generators allows to accumulate in a contour the energy at 100 kJ level. The generator with a permanent magnet does not require additional energy source for its operation, thus, it is convenient in service and always ready for operation. The sharpening of magnetoexplosive generator current pulse up to 1 ms is implemented by a high-voltage explosive opening switch¹. With the aid of the first sharpening cascade the energy source voltage increases up to 500 kV. Further shortening of current pulse duration up to 100 ns and voltage increase up to 1 MB is planned to be implemented with the help of plasma opening switches in accord with a two-cascade scheme of formation². Such scheme allows to decrease the strength of electric fields in the insulator area and to use magnetic insulation in a high-voltage section of the facility.

¹ A.I.Pavlovskii, N.F. Popkov, A.S. Pikar', E.A. Ryaslov, V.I. Kargin
EXPERIMENTAL STUDIES OF ELECTRON BEAM EXPLOSIVE HIGH-POWER
GENERATORS *Proceedings of the 10th Int'l Conf. on High Power Particle Beams*, (Ed.
W. Rix and R. White), San Diego, CA, (NTIS, 1994)

² A.I.Pavlovskii, N.F. Popkov, A.S. Pikar', E.A. Ryaslov, V.I. Kargin TWO-STAGE
SYSTEM FOR SHORT CURRENT MC GENERATOR PULSE FORMATION *Megagauss
Fields and Pulsed Power Systems*, (Ed. V.M. Titov and G.A. Shvetsov), N.Y.: Nova Science
Publishers, 1990. p.393-397

CALCULATION OF AUTONOMOUS MAGNETOCUMULATIVE GENERATOR WITH THE PERMANENT MAGNET

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Numerical calculations results of autonomous magnetic cumulative generator with permanent magnets based on barium oxide are presented. The use of barium oxide magnets allows to create a closed magnetic circuit with 4 working gaps and to provide the magnetic flux compression in axial geometry. The generator with permanent magnet doesn't require an additional energy source for its operation, that's why it is convenient in operation and is always to operation state.

Numerical calculations are discussed in the paper; their comparison with experimental sample tests is given. The numerical model describes magnetic flux capture process, its compression by copper stretching liner, energy losses if the flux is cut off and nonlinear diffusion in magnetic field in conductors. Scheme of optimized design of MKM-48 autonomous generator with permanent magnet is presented. Energy output of the generator is executed by low inductive transformer.

The generator on permanent magnets with explosive charge of some tens grams in mass provides the magnet energy receipt at 30 J; it is quite sufficient to power cascade amplifiers of submegajoule range.

HPM WEAPON EFFECTIVITY

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The HPM main antenna beam, is assumed, does not illuminate obstacles, and the beam is generated at wavelength where transmission path loss is negligible. The Antenna is the beam weapon problem that shall be considered, and so is to get the power to the 377 ohms of space.

The target collection efficiency depends on its receiving polarization. Another issue that will be considered is the loss between the target effective collecting area and the victim component. The HPM weapon should be capable of self-protection. A large percentage of the power available at the antenna feed is lost in the antenna's back and side lobes. EMC difficulties with other electronic equipment shall be considered. The beam weapon can attack, no faster than its beam can be steered, accurately positioned on the target. The HPM beam weapons effectiveness is a function of its operating frequency. To achieve HPM weapon "on frequency" operation, the victims pass-band must be known or detected in order to be efficient.

ABOUT OBTAINING OF SECONDARY RADIATION USING THE POWERFUL PULSE ELECTRON MICROBEAMS AND HIGH-CURRENT DISCHARGES

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O.S. Druy, V.A. Keyashko, E.M. Lat'sko, A.V. Pashchenko, V.F. Prokopenko, N.G.
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High density of secondary radiation energy (photons, positrons, neutrons, EMR, etc.) received using the powerful pulse electron microbeams and high-current discharges is the main factor for a wide range of applications.

Investigations, which are directed on obtaining the secondary radiation of a high power, have been carried out for a long time and in many laboratories of the world. Nevertheless, a contradictory information about the maximal density of electron beams and its track in a substance-converter as well as outputs of secondary radiation takes place in literature. It is caused by a variety of conditions of experimental realization (various plasma-vacuum conditions in the presence of super-strong own electromagnetic fields of beams), and by interpretation of the received results.

In present report, the experimental results on converting the pulse microbeams of relativistic electrons into secondary radiation during their interaction with substance-converter are presented.

For explanation of the received results the various phenomena, not enough described in the literature are involved. Among them are field ionization, desorption and ionization of gases from the anode surface by plasma radiation, formation and development of anode ectons, beam-streamer discharges, etc.

ABOUT RADIATION PROTECTION PROPERTIES OF VOLUME-CHARGED DIELECTRICS

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It is known that basic radiative danger for outside elements of cosmic satellites and stations (for example, solar power elements) is produced by fast electrons. Total dose of cosmic radiation for such elements, protected by radiation-protection cover, is formed by penetrating fraction of electrons and braking radiation. It is found that the presence of internal electric field in the volume of the cover can significantly reduce both of these factors. On purpose to investigation of above-mentioned phenomenon the mathematical model for numerical simulation of interaction of electron beams (with the energy within the limits 100 keV - 20 MeV) with solid high-molecular dielectrics and inorganic glasses was developed. This mathematical model describe the propagation of particle beams throw the sample sickness, the accumulation and relaxation of volume charge and shock-wave processes, as well as the evolution of electric field in the sample. The calculation of energy deposition by electron beam in a target in the presence of non-uniform electric field was calculated with the assistance of the semi-empirical procedure, formerly proposed by author of this work. For description of hydrodynamic processes the system of equations of continuum mechanics in elastic-plastic approximation and the wide-range equation of state were used. The processes of the volume charge accumulation and relaxation and the electric field evolution in high-molecular dielectrics was described with the did of Rose-Fowler system of equations and the equations for calculation of high-energy carriers of charge kinetic. Calculation of the radiation conductivity in inorganic glasses is based on the experimental data, approximated by the semi-empirical equation.

The obtained results give a rather full description of the radiation protection properties of volume-charged dielectrics.

TECHNIQUE FOR THE DETECTION OF PRODUCTION AND STORAGE OF NUCLEAR FUEL USING EMISSION RECORDING IN MICROWAVE RANGE

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Work experience of Siberian group of chemical enterprises (Russia) shows [1], that technological cycle for plutonium melting and processing is most dangerous for population. The problem of nuclear terrorism is very urgent now.

In the given paper the remote detection technique for radioactive ejection is described. This technique is based on the recording of atomic hydrogen and OH radical emissions in super high frequency range.

Atomic hydrogen and OH radical formation is conditioned by the decay of water vapor using ionizing emission. Hydrogen emission with frequency of 1420 MHz is not usually recorded under the Earth conditions. This emission is excited by super fine splitting of fundamental atomic energy level into two neighboring sub-levels. This splitting is conditioned by the interaction between the electron and nuclear spins. The atom energy is higher, when these spins are parallel, and this energy is lower, when they are antiparallel. Electron spin directions are changed, when atoms are collided.

The generation of the emission at frequency of 1420 MHz [2] accompanies the spin variations. The emission can be recorded too at 1612, 1665, 1667, and 1721 MHz frequencies. These frequencies correspond to super fine transitions in OH radical being present in water decay reactions like hydrogen atom [2].

Experimental results show that power of atomic hydrogen emission can be recorded using modern radiolocation at the distance of 25 km from nuclear production. If more sensitive receiver will be placed on the airplane or satellite, the global monitoring of the Earth can be made. Therefore, the places for storage and processing of radioactive scraps can be found.

Hydrogen atoms not only radiate, but they absorb at the frequency of 1420 MHz. Then the radioactive source can be found using emission absorption at the frequency of 1420 MHz due to the additive background.

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THE PECULIARITY OF THE PROPAGATION OF THE WAVES IN THE MAGNETOHYDRODYNAMIC MEDIA

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At present the investigation of the movement of ionized media taking into account their interaction with the electromagnetic field acquire special cognitive the technical importance. [1] deals with new methods of solution of interior and exterior diffraction boundary-value problems, where the Green's function is decisively used. The proposed set-up for a boundary-value problem solution is convenient for problems of volumetric dissipation, diffraction of the Alfvén, magneto-acoustic waves on nonuniformities in the problem of MHD flow. For this purpose, the integral equations of linear magnetic hydrodynamics are derived. These equations are fully equivalent to the corresponding differential equations of magnetohydrodynamics and boundary conditions at the boundary of non-uniformity in laboratory non-uniformities at the problem of MHD flow. For this purpose the integral equations of linear magnetic hydrodynamics are derived. These equations are fully equivalent to the corresponding differential equations of magnetohydrodynamics and boundary conditions at the boundary of non-uniformity in laboratory system of coordinates, that is taken into account the perturbation of the surface discontinuity under small perturbation of the falling field.

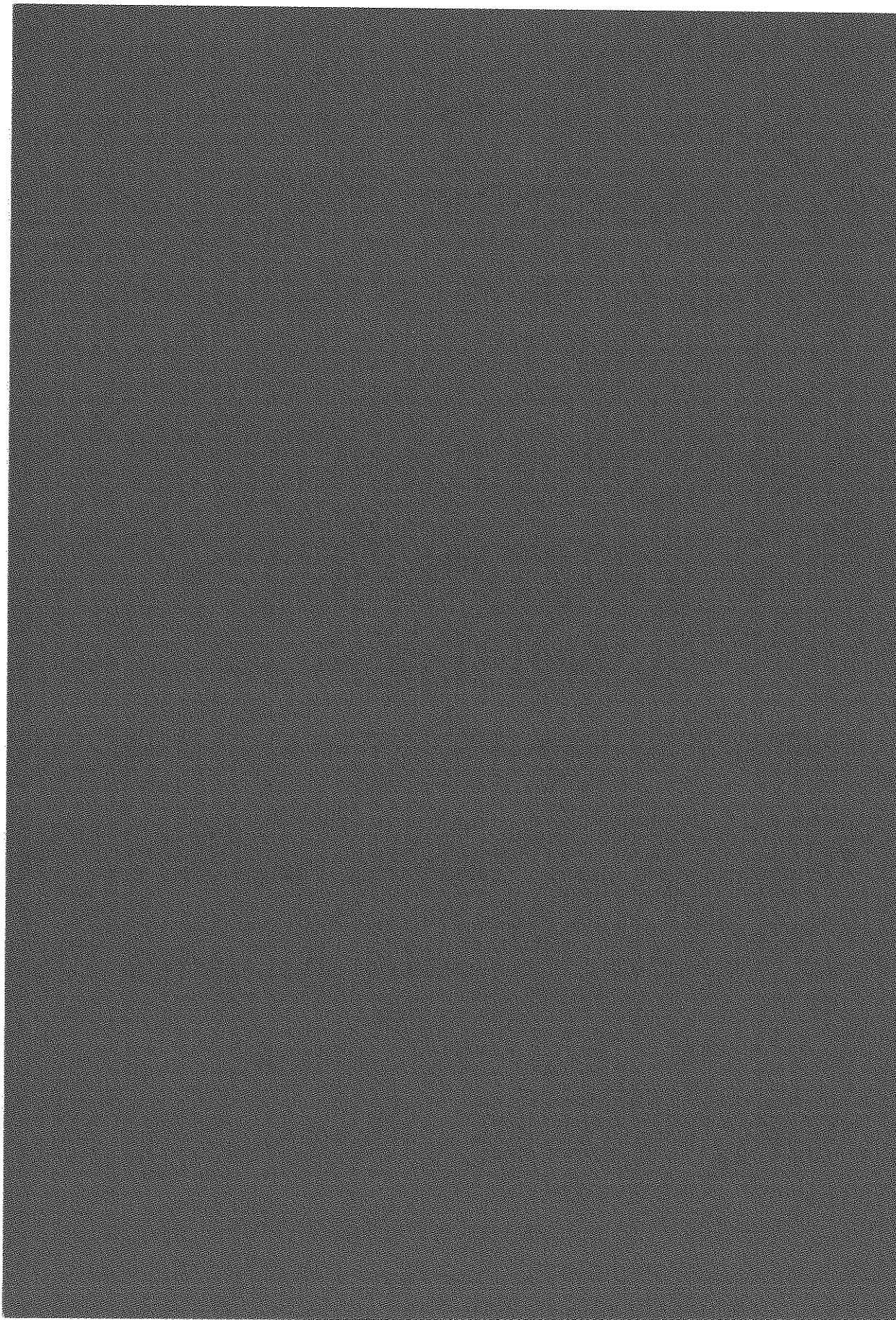
A space filled with MHD medium is considered, confined by a constant magnetic field, medium's density, the sound velocity and the Alfvén velocity. Assume that there is some kind of spatial discontinuity in this medium characterizes analogical parameters and also diffusion ratio. Viscosity is always present in the real media. That is why it seems reasonable to consider the case of limited conductivity internal media of the boundary-value problems. Besides, we assume that the discontinuity move with the constant velocity. The developed algorithm of solution for the self consistent boundary-value problem is demonstrated by an example of incidence of a packet of plane monochromatic waves onto a homogeneous MHD half-space. The model in which one type of MHD waves was bound with another through plane boundary by two media is an important first approximation for the description of propagation of small perturbations in strongly inhomogeneous MHD media. Spectrum of waves propagation in a conductive medium is rather large (Alfvén waves, rapid and slow magneto-acoustic waves). Therefore, boundary problems of magnetohydrodynamics have some peculiar features in particular mutual transformation of waves of different kinds.

We give the detailed results for the wave refraction in a particular case, when there are no disturbed movement of the media. So consider the influence of dissipative phenomena on the wave refraction. Thus, the considered phenomenon of dependence of the propagation velocity of both Alfvén's and magneto-acoustic waves and wave absorption on the frequency demonstrated the presence of dispersion, and the considered media are dispersive.

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