ISSN 1063-7850, Technical Physics Letters, 2012, Vol. 38, No. 8, pp. 743–746. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © B.A. Belyaev, A.M. Serzhantov, V.V. Tyurnev, 2012, published in Pis'ma v Zhurnal Tekhnicheskoi Fiziki, 2012, Vol. 38, No. 16, pp. 25–33.

A Microstrip Diplexer Based on Dual-Mode Resonators

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Received March 16, 2012

Abstract—A miniature third-order microstrip diplexer comprising a traditional T-shaped dual-mode resonator at the input and one dual-mode resonator of original design, with regular strip conductors split from one end, at the output of each channel. The passband formation in each channel of the diplexer involves two resonances of the lowest modes of one split microstrip resonator and the resonance of one of the two modes of the T-shaped microstrip resonator. The proposed device is simple to manufacture and allows the central frequencies and bandwidths in each channel to be varied within broad limits. The good prospects of the proposed microstrip diplexer are confirmed by the high characteristics of its working prototype.

DOI: 10.1134/S1063785012080172

Multichannel communication systems widely employ multiplexers—frequency-selective devices intended to separate or combine several radio signals with different frequencies [1]. One approach to designing multiplexers is based on the use of independent two-channel devices—diplexers, which are usually implemented on coupled resonators. At present, microstrip diplexers have become very popular due to their small dimensions and effective production technology. Various constructions of microstrip diplexers are known that contain coupled microstrip resonators forming two bandpass filters with a common port [2–7]. This common port is coupled to resonators of the filters either electromagnetically (via a stub) [2–4] or via a branched conductor [5–7].

Microstrip diplexers of miniature design frequently employ dual-mode resonators, the two lowest eigenfrequencies of which coincide with the central frequencies of two channels of the diplexer. Such a resonator connected to the common port replaces one resonator in the filter of each channel, thus reducing the diplexer size. Various ways to implement this idea have been described [8–12]. In particular, the function of dual-mode resonators can be performed by stepped impedance resonators (SIRs) [8–10] implemented on strip conductors with stepwise-varied width that admit independent tuning of two resonant frequencies, albeit in rather narrow limits [13]. However, this limitation can be removed by using a dual-mode resonator with a T-shaped strip conductor [11, 12], which makes possible independent tuning of resonance frequencies of the first two modes in rather broad limits.

Chen et al. [10] showed that not only the input resonator of a microstrip diplexer, but also some of the sequential resonators that form bandpass filters of different channels, can be dual-mode. However, it should be noted that microstrip diplexers can be implemented entirely on dual-mode coupled resonators, which makes possible further reduction in the device size. This possibility has been demonstrated theoretically and experimentally [8] in application to a second-order diplexer implemented on a pair of dual-mode microstrip SIRs. In this device, the parameters of both passbands can be independently varied in broad limits. Optimum coupling of resonators to ports is provided by capacitors. A disadvantage of the aforementioned diplexers [8, 10] is the impossibility of using closely spaced passbands, which is related to some specific features of the design of the used dual-mode resonators [13].

This Letter describes a new, simple in design and manufacture miniature third-order microstrip diplexer, in which all three resonators are dual-mode. In contrast to previous art [8], the proposed design allows the frequency-selective characteristics of channels to be improved by merely increasing the number of resonators.

The dual-mode resonators employed in the proposed device comprise rectangular strip conductors of length l_r split from one side by a narrow slot of length l_s (Fig. 1). This resonator features two lowest oscillation modes—even (whereby charges on the ends of split conductors are of the same sign; see inset (a) to Fig. 1) and odd (whereby charges on the ends of split conductors have opposite signs; see inset (b) to Fig. 1)

The resonant frequencies of the even (f_e) and odd (f_o) modes of the split microstrip resonator are the roots of a system of two equations:

$$Z_e \tan\theta_1 + 2Z_1 \tan\theta_e = 0, \qquad (1)$$

$$\cos\theta_o = 0, \qquad (2)$$

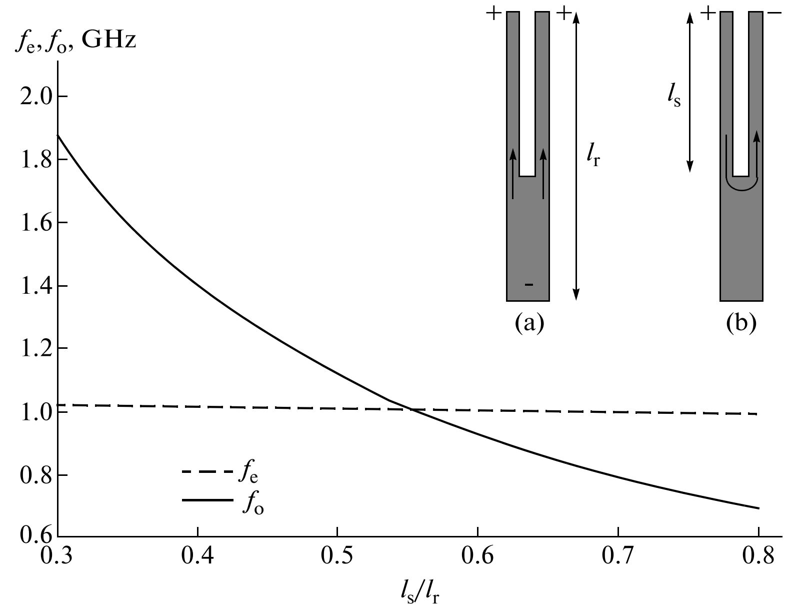

Fig. 1. Dependence of the eigenfrequencies of the even (f_e) and odd (f_o) modes on the relative slot length l_s/l_r. The inset shows a schematic diagram of the dual-mode microstrip resonator.

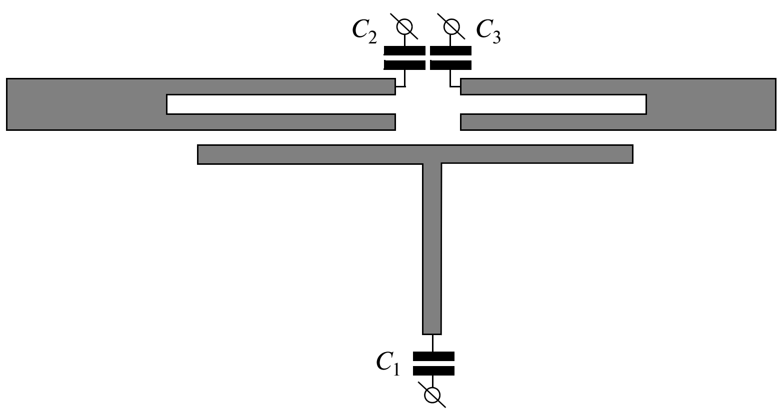

Fig. 2. Design of a third-order microstrip diplexer based on dual-mode microstrip resonators.

where Z_1 and θ_1 are the characteristic impedance and electrical length, respectively, of a segment of the single microstrip line in the nonsplit part of the resonator; Z_e, Z_o and θ_e, θ_o are the characteristic impedance and electrical lengths, respectively, of the coupled microstrip lines on the split part for the even (e) and odd (o) modes. Note that the resonant frequency of the even mode is almost independent of the length of the split part (dashed line in Fig. 1), whereas the frequency of the odd mode strongly depends on this length (solid curve in Fig. 1). As a result, the dual-mode resonator under consideration can ensure almost any ratio of the frequencies of even and odd modes and, hence, the spacing of the central frequencies of passbands in a diplexer based on these resonators can be varied within very broad limits.

Figure 2 shows a schematic design of a third-order microstrip diplexer based on dual-mode microstrip resonators. The scheme comprises a single T-shaped microstrip resonator and two split microstrip resonators electromagnetically coupled to the first one. Coupling of resonators to ports of the diplexer is provided by three capacitors: C_1 (connecting the T-shaped microstrip resonator to the common port), C_2 (connecting the port of a low-frequency channel to the "long" split microstrip resonator), and C_3 (connecting the port of a high-frequency channel to the "short" split microstrip resonator). The central frequency of the passband of each channel is determined by the length of the corresponding stub of the T-shaped microstrip resonator and the length of the rectangular microstrip conductor of the corresponding split reso-

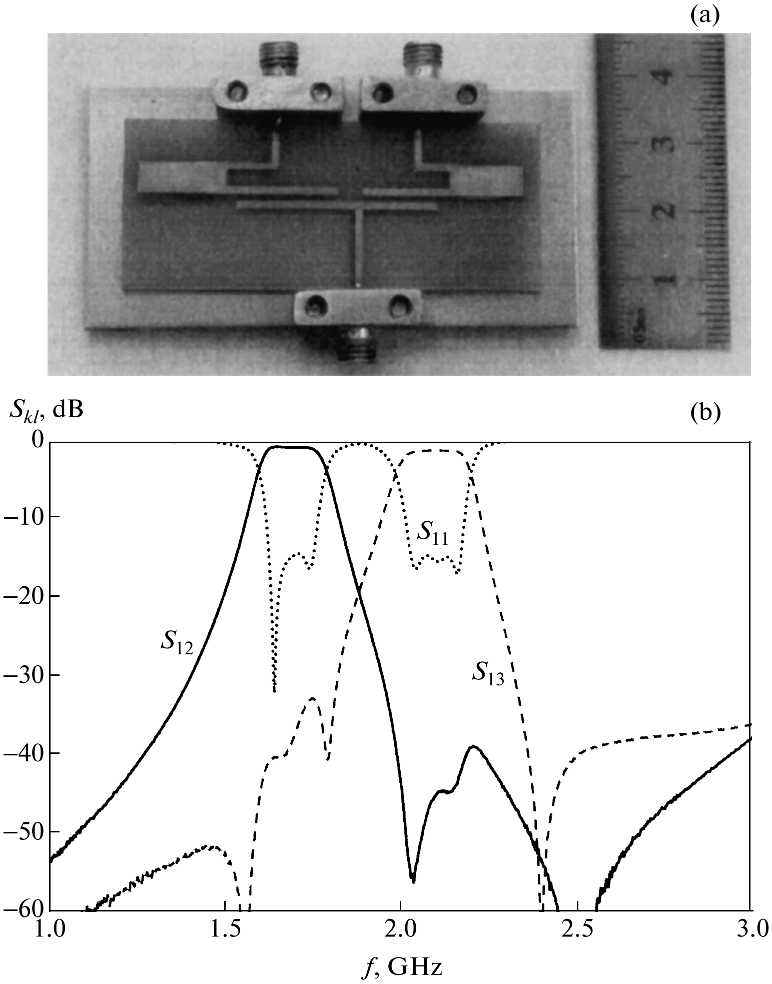

Fig. 3. Microstrip diplexer: (a) general view of a working prototype; (b) measured frequency dependences of the return loss on the common port (S_{11}) and transmission losses in the first (S_{12}) and second (S_{13}) channels.

nator. The bandwidth of each channel is determined by (i) the slot length of the corresponding split resonator, which determined the frequency difference of the even (f_e) and odd (f_o) modes, and (ii) the spacing between this resonator and the corresponding stub of the T-shaped microstrip resonator. The levels of maximum reflection in the passbands are determined by the corresponding values of capacitances coupling the resonators to ports of the diplexer.

Thus, the passband formation in each channel of the diplexer involves three resonances, two of which are resonances of the two lowest modes of the split resonator, the third being a resonance of one of the two modes of the T-shaped resonator. It is important to note that, in the diplexer scheme under consideration, each split dual-mode resonator is involved in the formation of only one passband, which eliminates the need to simultaneously tune the resonator coupling on two separated frequencies (in contrast to the case of diplexers implemented on dual-mode resonators described in [8, 10]). This circumstance not only simplifies the process of designing diplexers according to the proposed scheme, but also expands the boundaries of realizable relative bandwidths (independently in each channel of the device).

As was noted above, the channel bandwidth in the diplexer depends on the absolute value of the difference of frequencies of the even and odd modes in the corresponding split resonator. However, this frequency difference can be both positive and negative (Fig. 1). Therefore, there exist two possible values of slot length in the split resonator that correspond to a desired bandwidth of any channel.

Experimental verification of the described device has been performed on a diplexer prototype implemented on a 1.0-mm-thick alumina substrate with a permittivity of $\varepsilon_r = 9.8$, which is widely used in microwave device technology. The prototype device was preliminarily designed in a CST Microwave Studio program package. For certainty, the central frequency of the low-frequency channel was set at $f_1 = 1.7$ GHz, that of the high-frequency channel was set at $f_2 = 2.1$ GHz, the absolute widths of their passbands (on a

−3 dB level) were set at $\Delta f = 0.2$ GHz, and the maximum level of microwave power reflection in these bands was selected as no worse than −14 dB. The width of strip conductors in nonsplit parts of both dual-mode resonators was 4.5 mm, and that in the split parts, as well as in all conductors of the T-shaped resonator, was 1 mm, so that the slot width in the dual-mode resonators was 2.5 mm. The spacing between a split resonator and the corresponding coupled stub of the T-shaped resonator was also set the same (1 mm) in both channels. Accordingly, the channel bandwidth could be tuned both by varying the length of the split part of the corresponding dual-mode resonator and by changing the length of the region of coupling to the corresponding stub.

Synthesis yielded the following values of the diplexer design parameters. The length of a stub connected to the common port via capacitor $C_1 = 1.0$ pF was 11.5 mm. The lengths of two other stubs of the T-shaped microstrip resonator amounted to 17.0 and 10.8 mm. The conductor length in the first split resonator (connected to the low-frequency port via capacitor $C_2 = 1.1$ pF) was 28.5 mm and that of the second split resonator (connected to the high-frequency port via capacitor $C_3 = 0.4$ pF) was 23.3 mm. The lengths of the split parts of these resonators amounted to 16.0 and 12.5 mm, respectively. For the sake of convenient assembly, the ends of conductors connected to ports of the diplexer were bent toward the substrate edge. This bending is neither essentially significant nor does it influence the device operation, but it does slightly increase the device area to 58×27 mm^2.

Figure 3 shows a photograph of a working prototype of the proposed microstrip diplexer and its frequency response measured using a vector network analyzer (Rohde & Schwarz). Experiments showed that the low-frequency channel passband has a central frequency of 1.69 GHz and a bandwidth of 0.19 GHz (at a −3 dB level), while the high-frequency channel passband has a central frequency of 2.09 GHz and a bandwidth of 0.21 GHz—in good agreement with the calculated parameters. The measured minimum losses of microwave power were 0.6 dB for the first channel and 1.1 dB for the second one. The maximum level of reflections in the passband of the first channel was −14.2 dB, and that in the passband of the second channel amounted to −14.4 dB.

Thus, we have proposed a simple, miniature, and easy to manufacture microstrip diplexer of the third order implemented entirely on dual-mode microstrip resonators and possessing rather high electrical performance. The use of original split dual-mode resonators in the diplexer design not only allows the central frequencies of passbands to be varied within broad limits, but also admits the formation of bandwidth in broad limits independently of each other.

Acknowledgments. This study was supported in part by the Siberian Branch of the Russian Academy of Sciences (interdisciplinary integration project no. 109) and the federal targeted program "Scientific and Pedagogical Personnel of Innovative Russia (2009–2013)."

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Translated by P. Pozdeev