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Microstrip Diplexer with Π-Shaped Matching Circuit

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Abstract—We propose a new method to match diplexer channels with a common port in which a Π-shaped strip conductor is used as a matching circuit. The applicability of the method is illustrated by simulating and fabricating a microstrip diplexer for GPS/GLONASS applications. The central frequencies of the channels are 1.234 GHz and 1.597 GHz, and their fractional bandwidths are 6.8% and 7.3%, respectively; minimum insertion losses are 1.05 dB and 1.08 dB. The main advantage of the diplexer is its compact size: 16.8 mm × 9.0 mm × 6.4 mm in housing. Using 1D models and a quasi-TEM approach, the frequency-dependent coupling coefficients between the matching circuit and input resonators of the channels are calculated, and the influence of the matching circuit's geometrical parameters on its coupling with diplexer channels is studied.

1. INTRODUCTION

Diplexers are key elements in the operation of various dual-band systems, such as GPS/GLONASS navigation systems. A basic difficulty developers confront in designing a diplexer involves the proper matching of channel filters with a common port. Several main approaches are used to solve the problem. In stripline technology they are: (1) a combination of low pass filter (LPF) and high pass filter (HPF) or LPF and band pass filter [1, 2]; (2) using a T-junction (or Y-junction) as a matching circuit [3–5]; (3) applying a dual-mode resonator whose 1st mode is tuned to the center frequency of the low-frequency (LF) channel, and the 2nd mode is tuned to the center frequency of the high-frequency (HF) channel [6–11]; and (4) the matching circuit is simply a segment of a line with one end being a common port and the other electromagnetically coupled with input resonators of the channels [12, 13].

Approach (1) is not suitable when the response should have both slopes. Approach (2) also has some disadvantages. For example, matching circuits possess eigenfrequencies, and their resonances spoil lower and upper stopband performance. Because T- and Y-junction circuits consist of 50-ohm lines, the application of substrates with a high-value dielectric constant in order to decrease the size of a device becomes practically impossible. Moreover, the circuits occupy a large area of the substrate, for example, 35% in [3], thus increasing the size of a device. Approach (3) allows matching without occupying extra substrate area, but due to different distributions of voltage amplitude in the resonator at frequencies of the 1st and 2nd modes, the optimal positions of tapping points for different channels do not coincide. In other words, if matching, for example, the LF channel for -20 dB level of reflection, it is not possible to match the HF channel for the same low level of reflection. In approach (4), because the channels influence one another, the designing procedure is complicated. Besides, when a substrate has high dielectric constant, or it is thin, the coupling between the matching circuit and input resonators weakens.

Application of substrates having high (> 10) dielectric constant is the most fruitful way in creating compact microstrip devices. In this paper, we propose a compact microstrip diplexer having substrate dielectric constant $\varepsilon = 80$ and a novel matching circuit that is a Π-shaped strip conductor.

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2. DIPLEXER ON A HIGH DIELECTRIC CONSTANT SUBSTRATE

In Fig. 1, layout of the diplexer is shown along with designation of its structural parameters. The diplexer channels are two-pole filters based on quarter-wave resonators in order to minimize its size. The matching circuit is located between input resonators of the channels and couples with those electromagnetically. It occupies a very small area of the substrate and allows simultaneous matching of both channels of a diplexer for a small level of reflection. In order to optimize interaction with the resonators, the circuit is stepped-impedance. Note that the Π-shaped circuit is not a resonator.

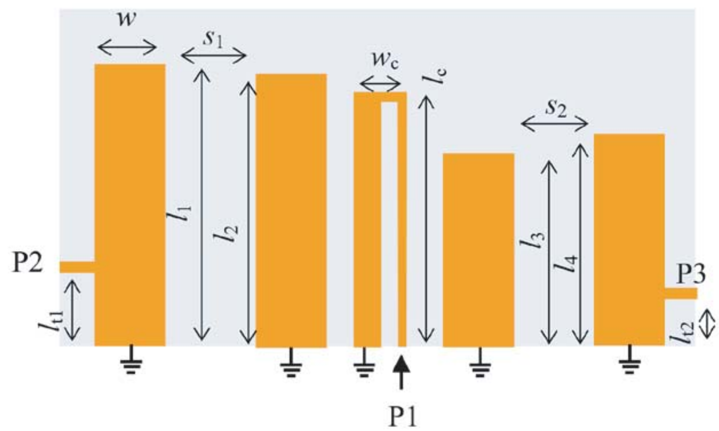

Figure 1. The diplexer structure and parameter designations.

For successful design of a diplexer, it is important to study the influence of the matching circuit's parameters on the coupling with the input resonators of the channels. For this purpose, we calculate the frequency dependencies of the coupling coefficients in the substructures "Π-shaped conductor — input resonator of the channel" separately.

3. INVESTIGATION OF COUPLING BETWEEN THE MATCHING CIRCUIT AND THE CHANNELS

In Figs. 2(a) and (b), the corresponding substructures with parameter designations are shown.

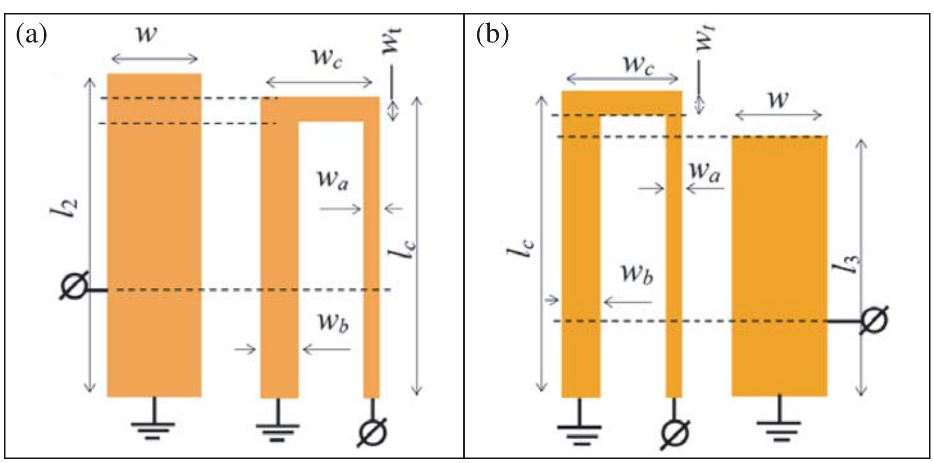

Figure 2. (a) Substructure "Low-frequency channel's input resonator — Π-shaped circuit"; (b) substructure "Π-shaped circuit — High-frequency channel's input resonator." Dashed lines divide the substructures into single and multi-coupled lines.

Computations of the frequency-dependent coupling coefficients are carried out based on a 1D model of a substructure whose line parameters are calculated using a quasi-TEM approach [14, 15]. In this computation, the microstrip substructure is divided into segments consisting of coupled and single lines, as shown by the dashed lines in Fig. 2. Thus, the LF substructure consists of three single lines and two three-coupled lines; the HF substructure contains one single line, one two-coupled line, and two three-coupled lines. The lines are connected in series, and using Kirchhoff equations and the current continuity condition, the distribution of voltage and current amplitudes, and the corresponding distribution of amplitudes of electric and magnetic fields are computed for every specific frequency. From these data, energies E_{RC} (electric field energy stored by the resonator), E_{RL} (magnetic field energy stored by the resonator), E_{MC} (electric field energy stored by the matching circuit), E_{ML} (magnetic field energy stored by the matching circuit), E_{RMC} (electric field energy stored by the resonator and the circuit jointly), and E_{RML} (magnetic field energy stored by the resonator and the circuit jointly) are computed. The coefficients of inductive k_L and capacitive k_C coupling are obtained as a ratio of the jointly stored energy to the total energy [14, 15]:

$$k_L(f) = \frac{2E_{RML}}{E_{RL}+E_{ML}+E_{RC}+E_{MC}} \cdot \frac{1}{K}, \tag{1}$$

$$k_C(f) = \frac{2E_{RMC}}{E_{RL}+E_{ML}+E_{RC}+E_{MC}} \cdot \frac{1}{K}, \tag{2}$$

where K is the modulus of the substructure voltage transmission coefficient. Finally, the total coupling coefficient vs frequency is determined as in [14, 15]:

$$k\left(f\right) = \frac{k_L\left(f\right) + k_C\left(f\right)}{1 + k_L\left(f\right) k_C\left(f\right)}. \tag{3}$$

In Fig. 3, the computed frequency dependencies of the mentioned coefficients are shown. The coefficients appear rather large in the frequency ranges corresponding to the channels. This means that the Π-shaped circuit can ensure a proper bandwidth of the diplexer channels. Moreover, using such a matching circuit, investigation has shown that it is possible to achieve at least 15% fractional bandwidth.

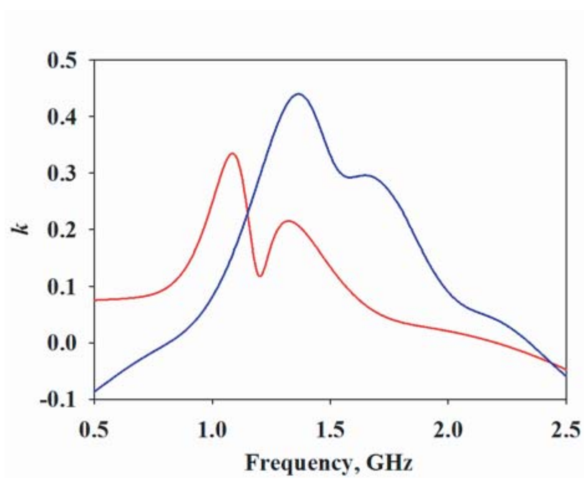

Figure 3. Coupling coefficient of the matching circuit and input resonators of the low-frequency channel (red curve) and the high-frequency channel (blue) vs frequency.

On investigating the influence of the matching circuit's parameters on the value of the coupling coefficients k, we vary some of the parameters l_c, w_c, w_a, or w_b, and compute frequency dependencies of the coupling coefficients. Then from these dependences, k is determined at the central frequencies of the channels.

Results of the investigation are presented in Figs. 4 and 5. The red curves correspond to the LF channel and the blue curves to the HF channel. It can be seen from the figures that by varying the

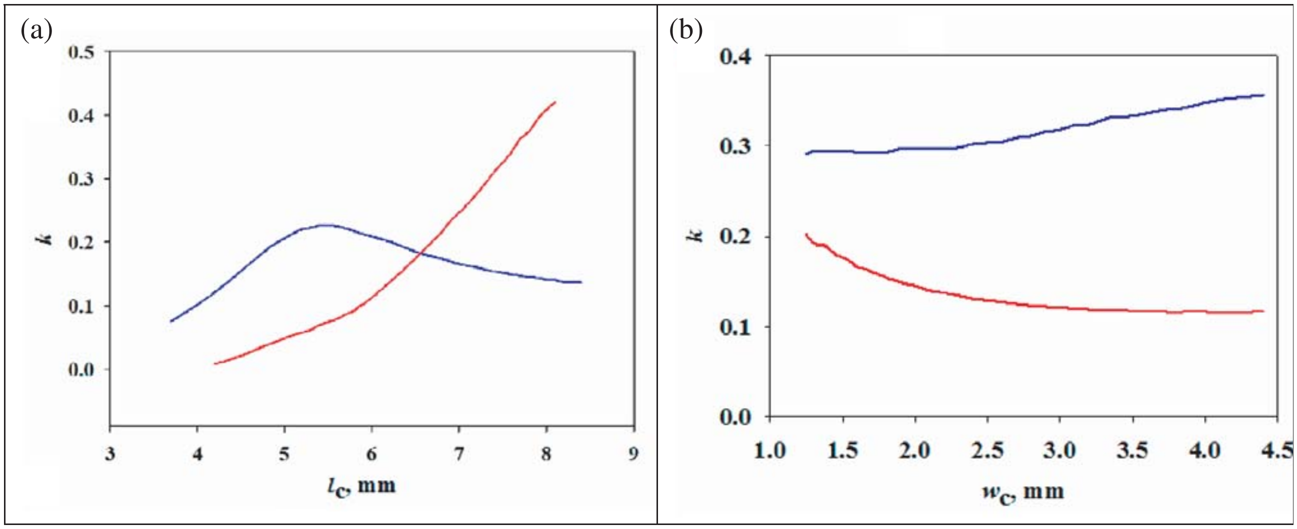

Figure 4. Coupling coefficient k (a) vs "length" of the matching circuit l_c; and (b) vs "width" of the matching circuit w_c.

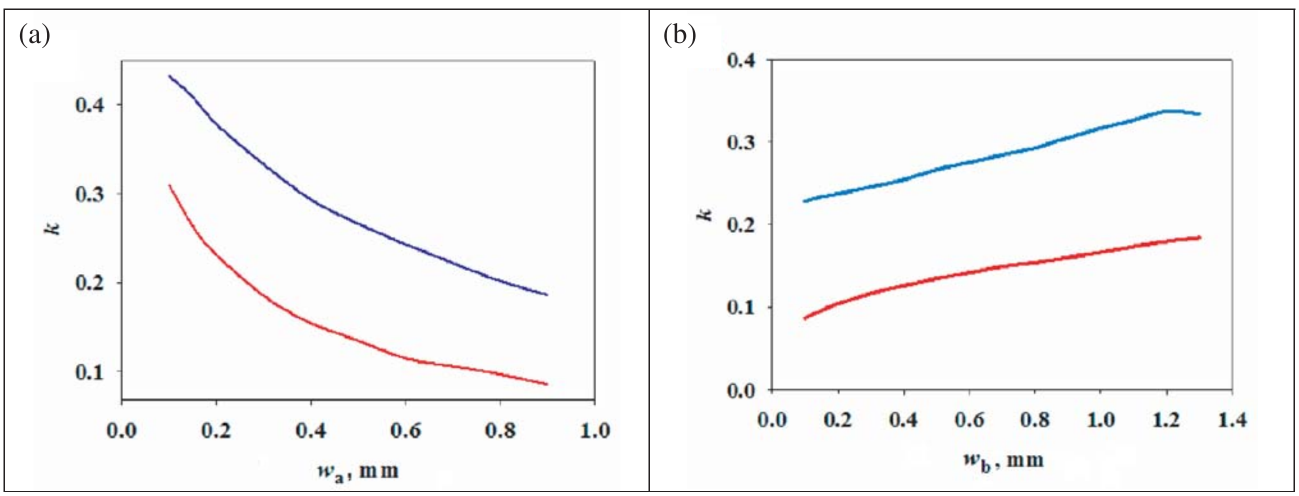

Figure 5. Coupling coefficient k (a) vs high-impedance segment of the matching circuit width w_a; and (b) vs low-impedance segment of the matching circuit width w_b.

mentioned parameters, the coupling between the matching circuit and resonators can be changed rather broadly.

Figure 4(a) shows that l_c value should be more than 5 mm; otherwise, the coupling between the circuit and the resonator in the LF channel vanishes. Besides, the coupling in the channels behaves in the opposite manner with a change in l_c. The same is the case for parameter w_c. The influence of parameters w_a and w_b on the coupling are similar in both channels.

Thus, the results of this study can be used to carry out fine-tuning of the diplexer matching.

4. MICROSTRIP DIPLEXER: SIMULATED AND EXPERIMENTAL RESULTS

Structural parameters of the diplexer (Fig. 1) designed for GPS/GLONASS applications are obtained with a help of Sonnet Software as follows.

Substrate of $\varepsilon = 80$ (mixed Ba, Nb, Sr titanate ceramics) has 1.00 mm thickness and lateral sizes 16.8 mm × 9.0 mm; length of resonator strip conductors $l_1 = 8.175$ mm, $l_2 = 8.05$ mm, $l_3 = 5.85$ mm, and $l_4 = 6.18$ mm; width of all resonators $w = 2.00$ mm; spacing between resonators $s_1 = 2.05$ mm and $s_2 = 2.25$ mm.

Overall sizes of the matching Π-shaped strip conductor are $l_c = 7.00$ mm and $w_c = 1.55$ mm, and its width at the narrow (high-impedance) part is 0.25 mm, and 0.80 mm at the wide (low-impedance) part; spacings between the matching circuit and resonators are 0.45 mm and 0.50 mm in the LF and HF channels, respectively; strip conductors serving as ports P2 and P3 have equal sizes 1.00 mm × 0.30 mm, and they are connected to the points located at $l_{t1} = 1.90$ mm and $l_{t2} = 1.58$ mm from the grounded end of the resonators. Spaces between the Π-shaped strip circuit and input resonators of the channels are determined by an empirical method. The tapping points' locations at output resonators of channels are chosen from the condition of the return loss in the passband to have specified value, for example, less than −14 dB (VSWR < 1.5).

On the diplexer designing, firstly the channels' filters are tuned separately. Then Π-shaped circuit is combined with the channels' filters, and with a help of data from Section 3 maximum coupling between the circuit and the resonators is obtained. At last, changing spaces between the circuit and resonators required coupling is set.

Simulated frequency responses of the designed diplexer are shown in Fig. 6 by dashed black lines. The central frequencies of the channels are 1.228 GHz and 1.591 GHz; minimum insertion losses (ILs) are 0.9 dB and 0.8 dB in the LF and HF channels, respectively; the return loss of the diplexer is less than −19 dB; the fractional bandwidth (FBW) is 6.8% in both channels; the isolation is 35 dB in the LF channel and 55 dB in the HF channel; −30 dB stopbands stretch up to 3.17 GHz in the LF channel and up to 3.95 GHz in the HF channel.

It should be noted that the matching circuit has resonant properties: two of its lower resonances have frequencies of 1.002 GHz and 2.016 GHz, and they seem to be able to spoil diplexer performance. However, the frequencies are far beyond the operation bands of the diplexer. Besides, the circuit is overloaded by the input port (P1, Fig. 1); therefore, the resonances have extremely low Q-factor and do not excite.

Based on the structure described above (Fig. 1), a diplexer adapted to routine fabrication is developed. Its photograph and frequency responses (S_{11}, S_{21}, S_{31}, and S_{32}) are shown in Fig. 6 by colored lines. The responses are measured using a VNA R&S ZVA 40 and appear to be very similar to the simulated ones. The central frequencies are 1.234 GHz and 1.597 GHz; fractional bandwidths are 7.3% and 6.8%; minimum insertion losses are 1.05 dB and 1.08 dB in the LF and HF channels, respectively. Reflection losses (S_{11}) are −20 dB and −15 dB in the HF and LF channels, respectively. The diplexer is very compact: size is 16.8 mm × 9 mm × 6.4 mm in a housing.

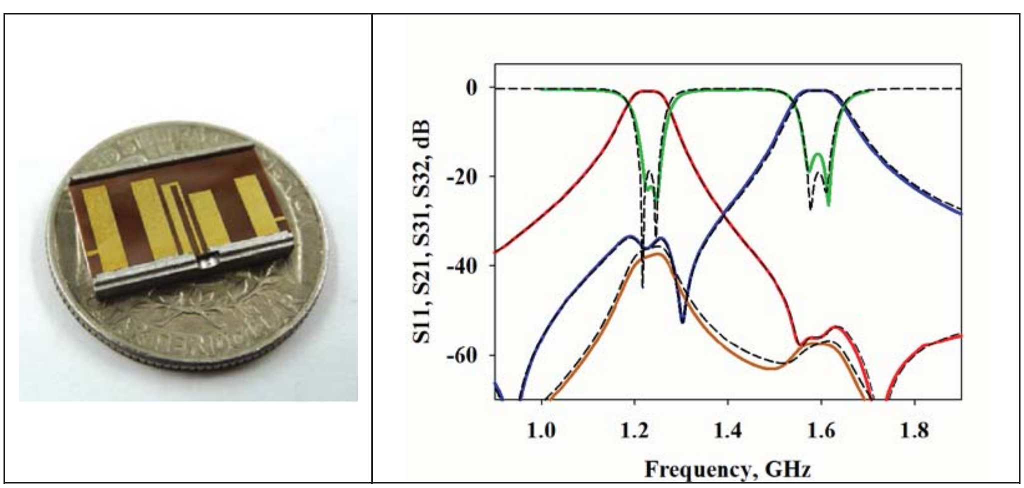

Figure 6. Photograph of the microstrip diplexer and its frequency responses (simulated (dashed) and measured (solid)). Red is S_{21}, blue is S_{31}, brown is S_{32}, and green is S_{11}.

Table 1. Comparison between proposed diplexer and referenced ones.

Ref. #	Matching type	$f_{0\,LF}$, GHz	$f_{0\,HF}$, GHz	Size, λ_g	Size, mm	IL, dB	FBW, %
2	LP/BP	1.5*	2.4	No info	56×97	0.25/2.42	7.6
4	T-junction	1.82	2.5	No info	21.7×33.3	2.51/2.17	$\sim 5/5$
5	T-junction	1.80	2.45	0.25×0.112	26×41	1.9/1.9	3.8/8.2
7	Dual mode	1.95	2.14	0.38×0.56	35×73	1.46/1.44	3.1/2.8
8	Dual mode	1.1	1.3	0.82×0.86	86×90	1.83/1.52	8.0/9.2
9	Dual mode	1.95	2.14	0.38×0.36	50×45	1.2/1.3	4.1/3.74
12	Line segment	1.933	2.105	No info	100×56	1.94/2.2	3.3/2.4
This work	Π-shaped	1.234	1.597	0.47×0.25	16.8×9.0	1.05/1.08	7.3/6.8

*) Cutoff frequency.

where λ_g represents the guided wavelength of 50-Ohm a microstrip line on the used substrate at 1.234 GHz, f_0 is center frequency of the passband (GHz); FBW is -3 dB fractional bandwidth (%), IL is insertion loss (dB).

5. CONCLUSION

Table 1 demonstrates a comparison between proposed and some referenced diplexers using various types of matching. One can see that the proposed diplexer has a better performance than the referenced ones. It may seem that using dual-mode resonator as a matching circuit gives an advantage in substrate area and, consequently, in size of a diplexer. But in a case of the described diplexer, the dual-mode resonator (instead of Π-shaped matching circuit) will occupy a substrate area larger than the Π-shaped matching circuit and input resonator commonly.

Thus, a new method of matching a common port with channels in a microstrip diplexer is proposed. A Π-shaped strip conductor short-circuited at one end plays the role of matching circuit in the diplexer. The common port is connected to the non-closed end of the circuit, because electromagnetic interaction is coupled to the input resonators of the channels. This solution allows a smaller area of the substrate to be occupied, thereby decreasing the size of the device. For example, in the diplexer using a T-junction as a matching circuit [3], it occupies 35% of the substrate area, whereas in the proposed diplexer Π-circuit occupies just 14%. Besides, this method allows designing microstrip diplexers on substrates having high (> 40) dielectric constant.

Based on the described structure, a very compact diplexer for GPS/GLONASS applications is designed and adapted for routine fabrication.

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