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Compact printed microwave filters for wireless communication applications

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ABSTRACT

A novel coupled-line-free wideband bandpass/bandstop filter configuration is designed and tested. The filter is based on a reentrant structure with unequal dielectric constants for the internal and external fillings. As a result, additional symmetrical transmission zeros are generated in the lower and upper stop bands of the bandpass filter; this leads to an elliptic function response and improvement of the pass band and selectivity. Similar conclusions are made about the bandstop filter in terms of the return loss. The general TEM circuit model, in terms of the two-port series connection, is presented for the proposed filters, and then, it is used to determine its electrical parameters. The experimental prototype was fabricated using conventional printed circuit board technology. The measured S-parameters show acceptable agreement with the analytical and full-wave simulations, showing promising potential for different applications.

1. Introduction

Microwave filters are extensively used components in many communication systems for different purposes. Recently, multilayer structures have become a hot research topic in microwave component design for size reduction, including low-temperature-fired ceramic (LTCC) technology. With this trend, the reentrant coupling section can be used to produce filters formed from single transmission line segments with internal elements shielded from the ground by a solid conductor. This complete shielding can intensify the line interaction, and it has been used for wideband coupled-line-free four-port directional filter design [1,2]. The two-port filters, on the base of the reentrant structure, are the focus of the investigation. As will be demonstrated, such a structure can be a base of the novel elliptic bandpass/bandstop (BPF/BSF) filter without lumped components or hairpin and open-loop resonators. The filter possesses a broad band symmetric insertion-loss-versus-frequency response around the pass or stop band, an acceptable frequency range and a compact planar structure that is suitable for multilayer implementation.

The elliptic filter can be designed based on comb line, stepped digital and cross-coupled filter configurations [1,3–5]. Recently, these configurations have been further developed in many studies, and some results can be found elsewhere [6–9]. However, the capacitive (inductive) loading of an open-end resonator complicates a marked size reduction, and additionally, designing a broad band planar structure that has lumped-element-free requirements is difficult. In the present study, a novel approach for the design of reentrant elliptic filters using well-known multilayer technology is proposed. As a result, a bandpass filter with two transmission zeros is designed, fabricated and tested. The simulated and measured results are reported, and they show good agreement.

2. Formulation of the problem

The basic reentrant coaxial section consists of three conductors, A, B, and C, as shown in Fig. 1 [10]. The A and B conductors are coaxial transmission line centre conductors with a characteristic

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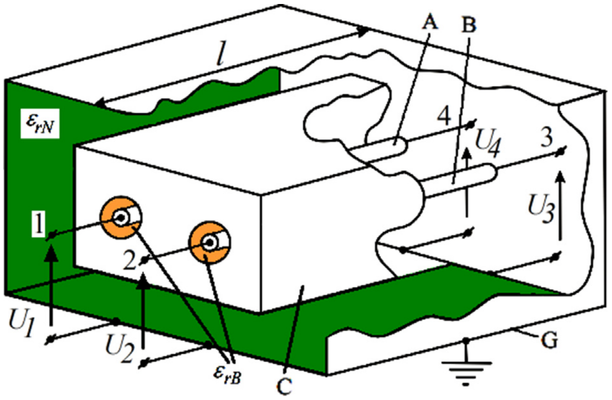

Fig. 1. Basic four-port reentrant coaxial/bar structure.

impedance Z_B and electrical length $\theta_B = 2\pi l\sqrt{\varepsilon_{rB}}/\lambda$ (in the following, it is designated as transmission line (Z_B, θ_B)) within intermediate conductor C, where C is the centre conductor of a strip (bar) transmission line with a characteristic impedance Z_B and electrical length $\theta_N = 2\pi l\sqrt{\varepsilon_{rN}}/\lambda$ within ground conductor G, where l is the section length and ε_{rB} and ε_{rN} are the relative dielectric constants of the coaxial and bar transmission line fillings, respectively. It should be noted that a strip transmission line equivalent to the basic reentrant coaxial section was described in Ref. [11].

It is well known that, if $\varepsilon_{rB} = \varepsilon_{rN}$, the section depicted in Fig. 1 behaves as a conventional quarter-wave directional coupler with corresponding even- and odd-mode characteristic impedances, Z_{0e} and Z_{0o}, respectively: $Z_{0e} = Z_B + 2Z_N, Z_{0o} = Z_B$ [10]. Thus, if port 1 in Fig. 1 is the input port, port 2 is the coupled port and port 3 is the isolated port. Through classical consideration, the discontinuity reactances are neglected, and then, the isolation and input matching are perfect when the terminating line characteristic impedance Z_0 is equal to $\sqrt{Z_{0e}Z_{0o}}$. The methods of its connection to conductors A and B, with appropriate design procedures, have been described previously [9–13]. Thus, the section depicted in Fig. 1 may be used as four-port, as well as two-port.

However, more than ten two-ports can be obtained from the section shown in Fig. 1 by placing open or short circuits on various terminal pairs or by joining the ends of the A and B conductors. To determine the electrical parameters of the section formed as a two-port, a pertinent port condition application is necessary, as described elsewhere [5,14–17]. It is evident that the additional two-port number can be obtained from the section depicted in Fig. 1 by placing the short circuit on the end of conductor C or by the connection of the ends of conductors A and/or B and C together. In general, $\varepsilon_{rB} \neq \varepsilon_{rN}$; this satisfies a multilayer strip line realization. Thus, it is necessary to describe the novel additional two-ports using adequate equivalent circuits that take the reentrant nature into account and may be used for the determination of electrical parameters Z_B, θ_B, Z_N and θ_N with the prescribed values of relative dielectric constants ε_{rB} and ε_{rN}. The values can be selected as appropriate initial properties to be used in full-wave simulation and the following optimization by a proper electromagnetic solver.

3. Application of the technique

3.1. Equivalent circuit derivation

A key to developing the equivalent circuit and solution of the associated problems is the corresponding decomposition. Our technique employs the multi-port device series connection that is not typical in microwave design technology and a summation of their impedance matrices under the condition of TEM mode existence in the lines. This condition cannot be regarded as a limiting factor because new technological methods used for standard strip-line device implementation substantially expand the applications of this condition in microwave engineering. Subsequent full-wave simulations and experimental results agree with this explanation.

Let us consider the filter element formed from the reentrant circuit shown in Fig. 1 when ports 3 and 4 of coaxial transmission line centre conductors A and B are short-circuited to the butt-end of shielding bar line conductor C, as depicted in Fig. 2. In other words, in this case, the cable conductors are short-circuited to the cable armours. It is clear that, if the filter two-port element was formed when conductors A and B were short-circuited to ground conductor G, it could be analysed by adding boundary condition $U_3 = U_4 = 0$ and using known analysis methods [15–17]. However, in the case under consideration, the boundary condition for the structure shown in Fig. 2 is $U_3 = U_4 \neq 0$ and the filter element can be represented by the model depicted in Fig. 3a and then as a two two-ports series connection shown in Fig. 3b with the corresponding impedance matrices Z_B and Z_N:

$$[Z_B] = jZ_B \tan\theta_B \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad [Z_N] = \frac{Z_N}{j\tan\theta_N} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \tag{1}$$

When the scattering matrix

$$[S] = [E] - 2([Z]/Z_0 + [E])^{-1} \tag{2}$$

is calculated from the sum matrix

$$[Z] = [Z_B] + [Z_N] \tag{3}$$

one can find and analyse the insertion and/or return loss of the filter two-port element, where $[E]$ is the identity matrix. The dependence of insertion loss L on frequency f (a) for $Z_B = 60\ \Omega$, $Z_N = 40\ \Omega$, $\varepsilon_{rB} = 4\varepsilon_{rN}$, $Z_0 = 50\ \Omega$, where f_{0N} is the reference frequency of the filter element external part at which $\theta_N = \pi/2$, is shown by the solid line in Fig. 4. The result indicates that the filter element can be categorized as a section of the bandstop filter with infinite numbers of the stop bands centred at odd multiples of reference frequency f_{0N}.

Now, let us investigate the two-port filter element that appeared under the assumption that the ends of the conductors A, B and C are connected together and short-circuited to ground conductor G. Here, as in the previous case, we cannot use boundary condition $U_3 = U_4 = 0$ because the bar line conductor is short-circuited to ground conductor G, and the problem cannot be reduced to the earlier-described situations [15–17]. Therefore, the investigated filter element can be represented by the analogy from Fig. 3b, as a

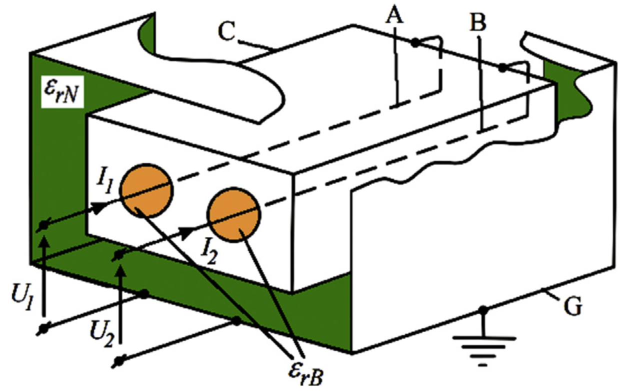

Fig. 2. Proposed coaxial/bar two-port reentrant bandstop filter element.

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