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The dual-band reentrant power splitter

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ABSTRACT

A novel configuration of the microwave dual-band power splitter is presented in this paper. The proposed power splitter is based on the reentrant structure in which the metallic body with a floating potential is asymmetrical. As a result, two adjacent work bands are created, leading to quasi-flat maximum responses and that improves the weight, compatibility and cost of the splitter. The general TEM circuit model for the proposed splitter, in terms of a series multi-port connection, is designed and used to determine the initial electrical parameters. An experimental printed unit has been manufactured using conventional printed circuit implementation. The measured S-parameters show an acceptable agreement with analytical and full-wave simulations and that paves the way for a variety of applications.

1. Introduction

The microwave splitters are fundamental components extensively used in many microwave devices. The approach, in which the dual-band operation is growing, has become an attractive feature towards the size and cost reduction [1–4]. A multilayer implementation has become a hot research topic in the microwave component design, including the low-temperature co-fired ceramic (LTCC) technology. With this trend, the reentrant structure may be also used to realize splitters formed on a base of transmission lines shielded from the ground by a solid conductor. This complete shielding leads to the intensive interaction of the lines and for brick-like solid conductor form that has been successfully used for the design of quadrature directional couplers [5], wideband four-port directional filters [6] and two-port band-pass elliptic filters [7]. If the brick-like solid conductor is realized in other symmetrical (for example, pyramid-like) or asymmetrical forms, then it is possible to realize the next generation of reentrant four-ports. As it is shown later, the asymmetrical structure can create the dual-band power splitter which possesses two almost symmetric insertion-loss-versus-frequency responses around the central frequency and acceptable frequency ranges of the bands.

Among various microwave passive four-port units, the quadrature component is one of the most fundamental networks in engineering and it is used in various microwave applications including power amplifiers, mixers, frequency multiplexers and antenna feed networks [8–12]. Besides, the optical couplers and splitters are fundamental and very useful components in optical communication links. Recently, many optical components, where a photonic crystal fiber can be used as a splitter/coupler of intensity, were presented [13–21].

Referring to the microwave region, we can consider two general forms through which the four-port microwave component can be taken: namely, uncoupled-line and coupled-line realizations. The first way leads to a relatively simple branch-line-like uni-planar implementation, whereas the second one requires the dielectric sheets for multi-layer fabrication. The reentrant realization paves the third way, in which the two transmission lines are initially uncoupled. Only at the final stage, both lines are mounted inside the third intermediate conductor with a floating potential. In the present study, for the first time, we propose an approach to design the reentrant asymmetrical power splitter with two adjacent frequency bands. For the created splitter, a good agreement is reached between the TEM-model, full-wave simulation-derived and measured results.

2. Problem formulation

The classical reentrant structure first described in [22] consists of three conductors A, B, C and two dielectric fillings (Fig. 1(a)). Conductors A and B are the center ones of transmission lines with

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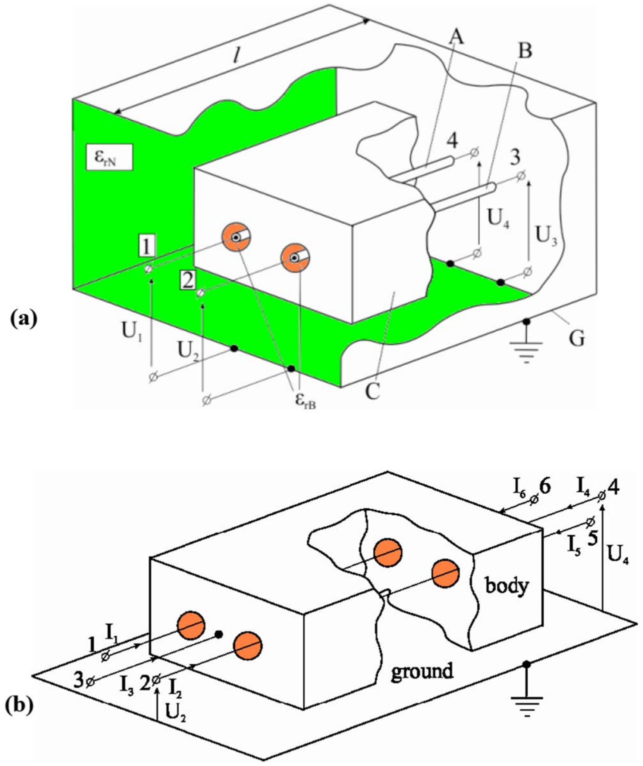

Fig. 1. The classical reentrant structure with a brick-like body: (a) the four-port representation, (b) the six-port one.

characteristic impedance Z_B and electrical length $\theta_B = 2\pi l\sqrt{\varepsilon_{rB}}/\lambda$ within the intermediate conductor C which is the brick-like body that plays the role of inner conductor of a bar transmission line with characteristic impedance Z_N and electric length $\theta_N = 2\pi l\sqrt{\varepsilon_{rN}}/\lambda$. These three conductors are mounted inside the pipe-like ground conductor G with a rectangular cross-section, where l is the section length, ε_{rB} and ε_{rN} are the relative dielectric constants of the internal and external dielectric fillings, respectively. The intermediate body is under the floating potential and the corresponding strip line equivalent was described earlier [23]. It is well known [22] that, if $\varepsilon_{rB} = \varepsilon_{rN}$, the section in Fig. 1(a) behaves as a quarter-wave directional coupler with the corresponding even- and odd-mode characteristic impedances Z_{0e} and Z_{0o}, respectively: $Z_{0e} = Z_B + 2Z_N$, $Z_{0o} = Z_B$. That is, if only port 1 is excited, as designated in Fig. 1(a), then port 2 is the coupled output, whereas port 3 is the isolated one. Through the conventional TEM-approach, the isolation and input matching of the four-port coupler will be perfect if the characteristic impedance Z_0 of the outgoing uncoupled lines is equal to $\sqrt{Z_{0e}Z_{0o}}$. The methods and implementations of their connections to conductors A and B, including the corresponding design considerations, are described elsewhere [23–26]. As it seems, the section in Fig. 1(a) may be categorized as a symmetric four-port with two axes of symmetry. If the metallic brick-like body C with a floating potential is implemented in other symmetrical (for example, trapezoidal) or asymmetrical forms, it is possible to realize the next generation of nontraditional reentrant four-ports. The objective of the following Sections is to show how the transformation of the above-mentioned body leads to the creation of power splitters. Generally speaking, both fillings play the role of supporting sheets with unequal dielectric constants ($\varepsilon_{rB} \neq \varepsilon_{rN}$) and that satisfies a multilayer strip line realization. Thus, it is necessary to describe the proposed four-port using an adequate TEM circuit model which accounts for the reentrant nature and may be used for the prediction of electrical parameters Z_B, θ_B, Z_N and θ_N with prescribed dielectric constants ε_{rB} and ε_{rN}. The parameters can be taken as the appropriate initial quantities in the full-wave simulation using the proper electromagnetic solver, as well as in a standard printed circuit board (PCB) process.

3. Application of the technique

3.1. Equivalent circuit derivation

To consider the equivalent circuit and to solve the associated problems, including the key parameters optimization, the corresponding device decomposition was carried out. Our technique employs the series connection of multi-port devices (which is not traditional in the microwave design technology) under the condition that the TEM mode exists in the lines. This condition cannot be regarded as a limiting factor because new technological methods applied for implementing standard strip-line devices substantially expand the application of this condition in microwave engineering. The subsequent full-wave simulations and experimental results confirm this assumption. At first, let us consider the basic reentrant structure proposed in [22] as a six-port device (Fig. 1(b)) rather than as a four-port one (Fig. 1(a)). Such nontraditional six-port representation is based on the general systematic approach [27]. Let us consider $[Z^B]$ as the symmetric impedance matrix of the transmission line 1 ↔ 6 (or 2 ↔ 5) inside the metallic body if the body itself is grounded in each of their points (Fig. 2(a)):

$$[Z^B] = \begin{bmatrix} Z_{11}^B & Z_{12}^B \\ Z_{12}^B & Z_{11}^B \end{bmatrix} \tag{1}$$

As to the transmission line 3 ↔ 4 (stand-alone metallic body above the ground), $[Z_N]$ can be denoted as the symmetrical impedance matrix if nodes 1, 2, 5 and 6 are omitted (Fig. 2(b)):

$$[Z^N] = \begin{bmatrix} Z_{11}^N & Z_{12}^N \\ Z_{12}^N & Z_{11}^N \end{bmatrix} \tag{2}$$

Now, applying the systematic analysis described in [27], the overall impedance matrix $[Z_6]$ of the six-port device (Fig. 1(b)) is given by:

$$[Z_6] = \begin{bmatrix} Z_{11}^B + Z_{11}^N & Z_{11}^N & Z_{11}^N & Z_{12}^N & Z_{12}^N & Z_{12}^B + Z_{12}^N \\ Z_{11}^N & Z_{11}^B + Z_{11}^N & Z_{11}^N & Z_{12}^N & Z_{12}^B + Z_{12}^N & Z_{12}^N \\ Z_{11}^N & Z_{11}^N & Z_{11}^N & Z_{12}^N & Z_{12}^N & Z_{12}^N \\ Z_{12}^N & Z_{12}^N & Z_{12}^N & Z_{11}^N & Z_{11}^N & Z_{11}^N \\ Z_{12}^N & Z_{12}^B + Z_{12}^N & Z_{12}^N & Z_{11}^N & Z_{11}^B + Z_{11}^N & Z_{11}^N \\ Z_{12}^B + Z_{12}^N & Z_{12}^N & Z_{12}^N & Z_{11}^N & Z_{11}^N & Z_{11}^B + Z_{11}^N \end{bmatrix} \tag{3}$$

The corresponding equations for the matrix entireties in (1) and (2) were listed earlier [5,22,28]. If the ports 3 and 4 shown in Fig. 1(b) are open circuited, the reduced device is fully equivalent to the reentrant directional coupler proposed in [22] and it is shown in Fig. 1(a). Note that, in Fig. 2, the ground conductor G is shown, for simplicity, as the metallic plate rather than the metallic rectangular cross-section pipe. Now, let us consider the five-port device containing the asymmetrical metallic body with port designations by the letters “a”, “b”, “c”, “d”, and “e”, as depicted in Fig. 2(c). After the decomposition of this structure, as shown in Fig. 2(d), we have the circuit that consists of the reentrant transmission line with the metallic body designated by number “1” and the above-mentioned six-port device with the metallic body designated by number “2”. It seems that the left node of body “1″ is open circuited, whereas its right node is connected to the left node of the body “2” whose right node is port “c”. If this port is also open circuited, then we have the so-called “asymmetrical reentrant” four-port device (Fig. 2(e)) with port numbers 1, 2, 3 and 4 terminated by the transmission lines with characteristic impedance Z_0.

After the scattering matrix

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