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A Miniature Dual-Band Filter Based on Microstrip Dual-Mode Resonators

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Abstract—A microstrip dual-band bandpass filter (DBF) with an original miniature design is described. The filter consists of thee microstrip dual-mode resonators, which are rendered dual-mode by splitting their regular strip conductors from one end by longitudinal slots. The formation of one passband of the DBF involves the resonances of even modes of each microstrip double-mode resonator, while the other passband is formed by the resonances of odd modes. The proposed device is simple to manufacture and allows the central frequencies and widths of each passband to be tuned within broad limits. A method of DBF tuning has been developed. Good prospects of the proposed microstrip DBF are confirmed by the high characteristics of its working prototype.

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Bandpass filters are among the most important elements of communication systems, radars, various measuring instruments, and special-purpose devices. In addition to the usual filters with a single working passband, there are many cases where dual-band bandpass filters (DBFs)—with each band possessing a preset central frequency and width—are required. As is known, microstrip filters, including DBFs, are advantageous due to their highly miniature design, effective production technology, and simple integration with other elements of radio circuits. For this reason, microstrip filters are widely used in microwave technology.

The design of microstrip DBFs traditionally employs several approaches. The first is the cascade connection of bandpass and bandstop filters [1]. In this scheme, the bandpass filter must possess a wide passband that covers both passbands of the DBF, while the bandstop filter "cuts" a certain interval inside this wide band so as to form two preset bands of the DBF and ensure the required level of rejection in between. DBFs and even triple-band filters can also be constructed by forming microwave power transmission minima at preset frequencies inside the wide passband of a single-band filter with the aid of additional couplings between non-adjacent resonators [2]. In a microstrip DBF comprising one square-loop dual-mode resonator tapped to two regular resonators, the microwave power transmission minima splitting the wide passband can be created without additional couplings between resonators [3]. The main disadvantages of these DBFs are relatively large dimensions and high losses of microwave power in working passbands.

The second conventional approach to designing DBFs consists in the parallel connection of two usual bandpass filters with the frequency response meeting requirements to the working passbands of a DBF [4–7]. The main advantage of these DBFs is the possibility of creating devices with any required bandwidths and central frequencies of two working passbands. However, these devices still have relatively large dimensions because the parallel connection of two single-band filters stipulates additional matching networks that connect individual ports of each filter to the common ports.

A highly miniature design is inherent in microstrip DBFs implemented on so-called dual-mode resonators (DMRs). In these DBF schemes, the formation of working passbands involves simultaneously the resonances of oscillation modes from each microstrip DMR. This approach decreases the number of resonators and, hence, the DBF size. It should be noted that the order of filtration in each channel is retained, so that the selective properties of DBFs are not decreased. DMRs for DBFs are especially frequently represented by stepped-impedance resonators [8–10], miniature hairpin resonators [11], or resonators with an E-shaped microstrip conductor [12, 13]. As a rule, the first resonance of each DMR is used to form a low-frequency passband of the DBF and their second resonances form the high-frequency passband, which is related to a relatively strong difference between resonant frequencies. For this reason, DBFs based on indi-

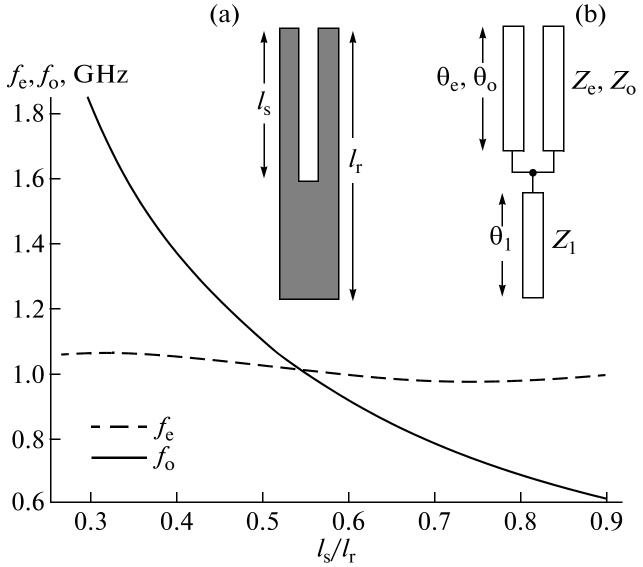

Fig. 1. Dependences of eigenfrequencies of the even (f_e) and odd (f_o) modes of the split-microstrip DMR on the relative length l_s/l_r of slot in the strip conductor. The inset shows (a) schematic diagram and (b) equivalent scheme of the split-microstrip DMR.

cated DMRs cannot provide for substantial proximity of the central frequencies of two passband, which is the main disadvantage of this design. However, recently Wei et al. [14] demonstrated the possibility of constructing microstrip DBFs in which both resonances of one DMR form a low-frequency passband of the DBF, while the resonances of another DMR form the high-frequency passband. This design is free of any restrictions concerning the proximity of central frequencies of the two passbands, but the original scheme [14] is rather complicated.

An interesting element for designing various frequency-selective microwave devices, including DBFs, is offered by a microstrip DMR of the new type with a strip conductor split from one end by a longitudinal slot (Fig. 1a). In contrast to the aforementioned microstrip DMRs with a square-loop conductor and E-shaped conductor, the new design ensures a significantly smaller DMR size and is advantageous to stepped-impedance resonators in admitting independent tuning of both resonant frequencies within broad limits (up to their full coincidence).

Advantages of designing frequency-selective microwave devices using these split-microstrip DMRs have been recently demonstrated by constructing bandpass filters [15] and diplexers [16]. This Letter presents the new design of a miniature DBF based on three split-microstrip DMRs.

The partial splitting of a regular strip conductor by a longitudinal slot from one end (Fig. 1a) leads to the appearance of additional oscillation modes in the DMR. In what follows, the modes for which the currents and voltages on both sides of the slot have the same sign will be called even, while the modes for which these currents and voltages have opposite signs will be called odd. According to the notation given on the equivalent scheme (Fig. 1b) of the DMR, eigenfrequencies f_e of all even modes are solutions of the equation:

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

and frequencies f_o of all odd modes obey the equation

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

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.

Figure 1 shows plots of the eigenfrequencies of the lowest even (dashed curve) and odd (solid curve) modes versus length l_s of the split segment of the DMR. Calculations were performed for a dielectric substrate with thickness $h = 1$ mm and permittivity $\varepsilon_r = 9.8$, total strip conductor length $l_r = 55.3$ mm, width of nonsplit conductor $w = 3$ mm, and conductor spacing $S = 1$ mm. As can be seen, the frequency f_o of the odd mode rapidly decreases with increasing slot length l_s, while the frequency f_e of the even mode remains almost unchanged, and the two frequencies coincide at $l_s \approx 0.56 l_r$. Thus, a DMR with split conductor admits virtually arbitrary relations between the frequencies of even and odd modes.

Figure 2 presents the design of a DBF based on three DMRs with parallel arrangement of microstrip conductors. The scheme is symmetric relative to the longitudinal axis of the middle DMR. The split microstrip conductors of the side DMRs (top and bottom in Fig. 2) are identically directed and strictly fit with respect to each other, while the split microstrip conductor of the central DMR has the opposite direction and is shifted toward the split ends of the side DMRs. The conductors of side resonators are connected to ports of the DBF via capacitors at certain points of the outer pins of split segments.

Investigation of the proposed device revealed several regularities that provided a basis of the method of tuning of a DBF with preset characteristics. In particular, slot length l_s in all resonators is set so as to ensure that $f_e < f_o$. In this case, the resonances of even modes form the low-frequency passband of the filter, while the odd modes form the high-frequency passband. Accordingly, total resonator length l_r determines the central frequency of the low-frequency passband and slot length l_s determines that of the high-frequency passband. Spacing S between the microstrip conductors of adjacent resonators (see Fig. 2) determines their coupling and, hence, simultaneously controls the

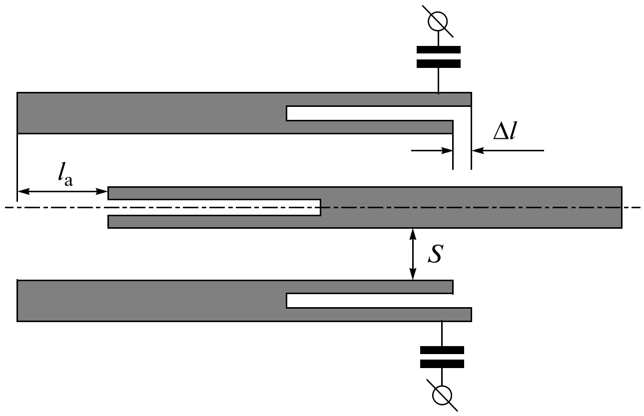

Fig. 2. Layout of a miniature third-order DBF on three split-microstrip DMRs.

width of both low- and high-frequency passbands. Mutual shift l_a of adjacent resonators controls the coupling length for the even and odd modes and, hence, the ratio of bandwidths of the two passbands. An increase in l_a leads to narrowing of the low-frequency passband and simultaneous widening of the high-frequency passband.

The capacitive coupling of input resonators to ports of the filter controls both the level of maximum microwave power reflection in the passbands and the rejection level in the stopbands. Evidently, the coupling increases with the value of capacitance and with the approach of the connection point to the end of the microstrip conductor (where antinodes of the high-frequency voltage for both modes are situated). The optimum coupling of side resonators to ports of the filter simultaneously for both modes (f_e and f_o) is achieved by selecting the capacitance, shifting their connection points, and adjusting difference Δl of lengths of the inner and outer pins in the split part of the strip conductor (see Fig. 2). Since the scheme under consideration represents a third-order filter, each of the two passbands contains at least two maxima of reflection. The reflection level can be controlled by adjusting the resonant frequencies of even and odd modes in the central resonator relative to the corresponding frequencies of the side resonators. In the low-frequency passband of the DBF, this adjustment is achieved by varying length l_r of the microstrip conductor of the resonator, while in the high-frequency passband this is achieved by varying slot length l_s.

Figure 3 shows a photograph of a working prototype of the proposed DBF and presents its frequency response. The prototype was implemented on a 1.0-mm-thick alumina substrate ($\varepsilon_r = 9.8$) with a thickness of 1.0 mm and lateral dimensions of 54 × 17 mm. All resonators had a stripe conductor width of 3 mm and slot width of 1 mm. Both input (side) resonators had a total length of $l_r = 33.0$ mm, slot length $l_s = 13.5$ mm, and difference of the split conductor lengths $\Delta l = 2.0$ mm. The middle resonator had $l_r = 36.0$ mm and $l_s = 13.0$ mm. The spacing between the adjacent resonators was $S = 2.0$ mm. The split end of the middle resonator was shifted relative to the nonsplit ends of side resonators by $l_a = 7.5$ mm. The coupling capacitance was 0.55 pF. All parameters of the filter were preliminarily determined by synthesis based on numerical electrodynamic analysis of a three-dimensional model.

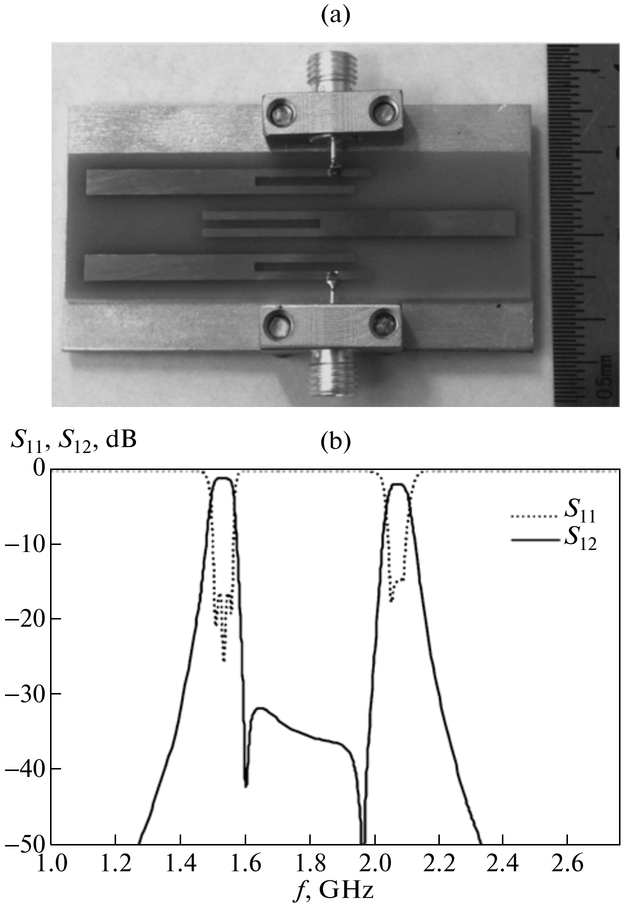

Fig. 3. Microstrip DBF: (a) general view of a working prototype; (b) measured frequency dependences of the return loss (S_{11}) and insertion loss (S_{12}).

Experiments gave the following characteristics of the prototype device. The low-frequency passband had a central frequency of $f_1 = 1527$ MHz, a width of $\Delta f_1 = 71$ MHz (at a –3 dB level), and minimum insertion loss $L_1 = 1$ dB. The high-frequency passband had a central frequency of $f_2 = 2069$ MHz, a width of $\Delta f_2 = 71$ MHz (at a –3 dB level), and minimum insertion loss $L_2 = 2$ dB. The selective properties of the filter were significantly improved by two transmission minimums situated between the low- and high-frequency passbands (Fig. 3), which not only increased the slope of the frequency response, but also reduced the transmission maximum to a level of –31 dB.

Thus, we have proposed and studied a microstrip third-order DBF of an original design. The proposed device is very compact, possesses high electrical performance, and is easy to manufacture and simple to tune. The use of original split microstrip DMRs not only allows the central frequencies of both passbands to be varied within broad limits, but also admits independent adjustment of their bandwidths.

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