Dual Band Bandpass Filter Using Multilayer Structure

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Abstract **─** In this paper, a new method to design a dual band bandpass filter (BPF) is presented. This method is based on a simple principle: different substrates (dielectric constants) will result different resonant frequencies for a resonator. The basic structure of this method is studied and then a planar band pass resonator is designed to utilize in this structure. Response of the proposed dual layer filter is tuned using resonator shifting and resonator scaling. In addition to improve the filter response, resonator shifting improves the filter size. The final structure is designed, fabricated and measured and simulation results are in good agreement with measured values. The central frequencies of this dual band BPF are f1=3.85 GHz and f2=5.3 GHz and a deep transition zero at 4.57 GHz, guarantees isolation between passbands.

Index Terms **─** Coupling, dual band, effective dielectric constant, multilayer structure.

I. INTRODUCTION

With the rapid development of modern wireless technologies, multi-service communication systems have become a widespread tendency. The dual-wideband bandpass filter (BPF) is an important requirement of these systems. In order to meet these requirements, various approaches were applied to design different kinds of the dual band BPFs. Parallel connect of two single-band BPFs as an important method in dual-band BPFs design (method 1) was presented in [1], [2]. This method requires a complex design process and large circuit size. In [1], the authors have presented a multilayer dual-band BPF in a low-temperature co-fired ceramic (LTCC) substrate for ultra-wideband applications. This bandpass filter consists of two wideband bandpass filters and matching circuits. A class of the wideband dual band BPFs with controllable response was proposed in [2]. In this approach, two multi-mode resonators (MMRs) with short-circuited stubs have been parallel connected to form the basic structure of the proposed dual-band BPF.

One of the direct design methods of the dual-band BPFs (method 2) formed by inserting a bandstop filtering response in between a wide passband to divide it into two passbands [3], [4]. A dual-band filter consists of a bandstop filter and a wideband bandpass filter in a cascade connection, was proposed in [3]. In this structure, the bandstop filter has been implemented using a coupled-serial-shunted line, while the wideband bandpass filter was constructed using a serial-shunted line configuration. In [4], a dual-wideband BPF was presented, which is divided into two parts: the wideband passband filter and the narrowband stopband filter. Both filters have been designed with conventional synthesis methods, under the assumption that the common connecting lines serve as J- and K-inverters simultaneously. In this approach, tuning is still needed after combining the BPF and BSF. Another type of dual-band BPFs was formed by applying the fundamental-order and its higher order resonances to build up various dual-band BPFs (method 3), as discussed in [5]. A dual-band response was obtained via a large perturbation in a single resonator and second-order dual-mode dual-band filters were realized by a new cascading principle in [5]. Coupling coefficients between the two resonators in both bands of this filter is controlled independently, but the band control in this approach is difficult compared to the mentioned methods. On the other hand, odd/even-mode methods (method 4) were applied to form a different coupling path for each passbands of a dual band BPF, as discussed in [6-9]. A microstrip dual-band BPF using a single quadruple-mode resonator (QMR) has been proposed in [6]. According to the even/odd-mode method, two pairs of symmetrical resonant modes are shown in this structure. In [7], the authors have presented a tri-stubs loaded multimode resonator (TSLMR) for designing dual-band BPFs. The TSLMR produces four splitting modes. A pair of even/odd modes is used to

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form the first passband, while another pair produces the second passband. This descriptive method cannot be used in the complex structures. The configuration of a multi band BPF can be based on either multilayer [10-12] or single layer [13]. In [10], a compact dual-layered quad-band (DLQB) BPF was presented to provide four passbands at the desired frequencies. The designed filter was fabricated on two FR4 boards. This proposed DLQB-BPF consists of two L-shaped resonators on the top layer and two coupled SIRs on the second layer. The bottom of the second layer is the ground plane. Based on open-loop resonators (OLRs), an independently tunable dual-band (ITDB) BPF was presented in [11]. The top layer of the proposed ITDB BPF is composed of transmission feed lines and OLRs in a SIR structure. The bottom layer is constructed by OLRs in an asymmetrical SIR with a defect-grounded structure. A multilayer dual-band BPF embedded in a low temperature co-fired ceramics (LTCC) has been presented in [12].

Some of the novel dual-band BPFs have proposed having a compact size, high selectivity and high isolation [14-16]. Many of the recent researches have focused on tunable or reconfigurable BPFs for applications in the multi-band communication systems [17-20]. Authors in [17] have presented a novel multilayer dual-band filter using two dual-mode cross-slotted patch resonators. In this work, the operating frequency and bandwidth in each passband can be individually controlled and the design procedure based on the coupling matrix has been presented. A novel approach to the design of tunable dual-band BPF was presented in [18]. The proposed filter structure offers two tunable passbands, as well as a fixed first passband and controllable second passband. In this filter, the first passband center frequency has a tunable range of 34.14% from 0.85 to 1.2 GHz, and second passband center frequency has a tunable range of 41.81% from 1.40 to 2.14 GHz. A new varactor-tuned microstrip dual-band BPF has been investigated in [19]. In this approach, by employing the dual coupling paths, the two passbands can then be fully controlled and designed independently. In addition, for the electronic tuning, three varactors are loaded on the open-ends of each resonator. There is an increasing interest in utilizing the high-temperature superconducting (HTS) structures in dual band BPFs design. In [20], a miniaturized high-temperature superconducting dual-band bandpass filters (DBPFs) using stub loaded meander line resonators has been proposed. In this approach, the center frequencies of the bands can be independently controlled. The bandwidths of the DBPF can be flexibly adjusted using a capacitance-loaded microstrip line between the resonators.

In this paper, a dual band BPF is presented using a simple principle: different dielectric constant results in different resonant frequencies. This condition creates using multilayer configuration. To verify the validity of the proposed method, a dual-band BPF prototype is designed, fabricated, and measured. Compactness, simple design process and tunable passbands are realized by this method.

II. BASIC STRUCTURE

Figure 1 shows the basic structure of the dual band BPF. This structure is composed of two equal bandpass resonators (R1 and R2), which are coupled together. The first resonator is placed on a substrate with the relative dielectric constant of εr and thickness of 2H and the top layer of this resonator is free space. The second resonator is surrounded by two substrates with the relative dielectric constant of εr.

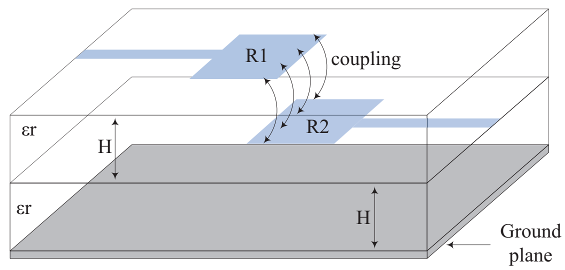

Fig. 1. Proposed structure of the dual band BPF.

According to equations (1, 2) the effective dielectric constant of the R2 is greater than R1, therefore the resonant frequency of them are different.

For w/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\{[1 + 12\frac{h}{w}]^{-0.5} + 0.04[1 - \frac{w}{h}]^2\}$$

$$z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln[8\frac{h}{w} + 0.25\frac{w}{h}]. \qquad (1)$$

For w/h ≥ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{w}]^{-0.5}$$

$$z_c = \frac{\eta}{\sqrt{\varepsilon_{re}}}\{\frac{w}{h} + 1.393 + 0.677\ln[\frac{w}{h} + 1.444]\}^{-1}. \qquad (2)$$

III. FILTER DESIGN

In order to design a dual band BPF using proposed structure, a band pass resonator must be designed and utilized in proposed structure. Figure 2 shows the layout and simulation results of a H-shape resonator which is designed on the RT/DUROID 5880 with εr=2.2, thickness of 15 mil. and loss tangent of 0.0009.

The dimensions of this resonator are as follows: a=0.24 mm, b=3.92, c=3.2 mm, d=9.15, e=0.24, g=0.71 mm, h=7 mm, i=3 mm, n=0.95 mm, m=1.17 mm. As it is shown in Fig. 2 (b), the resonant frequency of the H-shape resonator is 5.14 GHz and return loss in the passband is 29.8 dB.

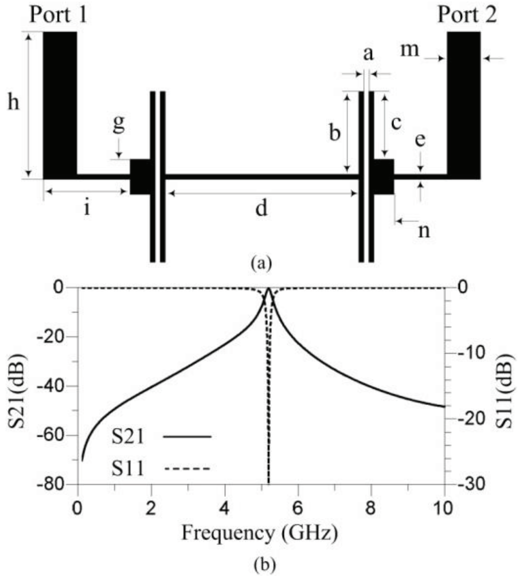

Fig. 2. Proposed H-shape resonator: (a) layout and (b) simulation results.

The basic structure using H-shaped resonator is shown in Fig. 3 (a). A comparison between simulation results of the H-shape resonator and basic dual-layer BPF is shown in Fig. 3 (b). The RT/DUROID 5880 is used as the substrate of the layers.

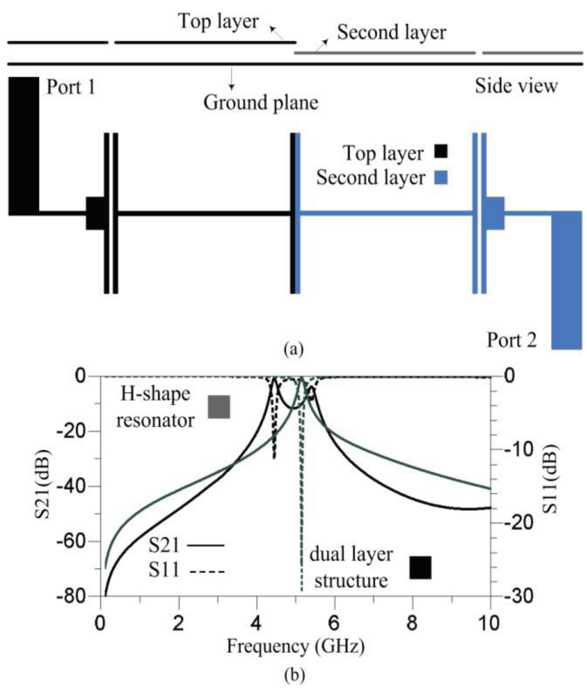

Fig. 3. Dual-layer proposed structure using H-shape resonator: (a) layout and (b) simulation results in comparison with the H-shape resonator response.

As shown in the Fig. 3 (b), two passbands are created in 4.44 GHz and 5.4 GHz by the resonators on the second layer and top layer of the dual layer structure. According to the equation (1), the effective permittivity of the top layer is 1.71 and for the second layer the effective permittivity is 2.2 (for a line with w=0.24 mm). The effective permittivity of the single layer H-shape resonator for a line with w=0.24 mm is 1.74, which has a value between 1.71 and 2.2; therefore, passbands of the dual-layer BPF have created in sides of the H-shape resonator passband. It is evident from Fig. 3 (b) that, passbands performance and isolation between them are not optimized. The passbands frequencies are tuned using resonator scaling and shifting them toward each other. Resonator shifting impresses two passbands frequencies simultaneously and decreases them because the coupling between resonators is increased. Figure 4 (a) and Fig. 4 (b) show the layout and simulation results of the resonator shifting in proposed dual layer structure.

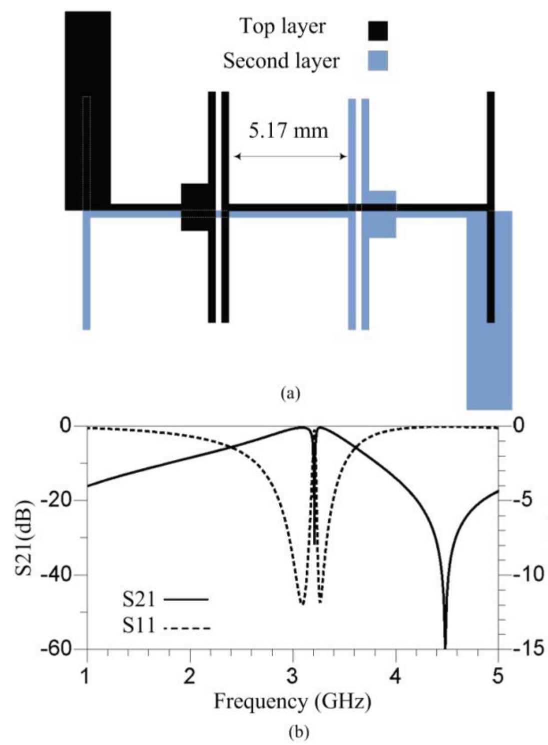

Fig. 4. Resonator shifting in proposed dual layer structure: (a) layout and (b) simulation results.

As it is shown in Fig. 4, resonator shifting in addition to increasing the isolation between bands, reduces the dimension of the filter. But the passbands frequencies are closed together.

In order to improve the response of the proposed dual layer structure, resonator scaling is used. Figure 5 (a) shows the layout of the proposed dual band BPF.

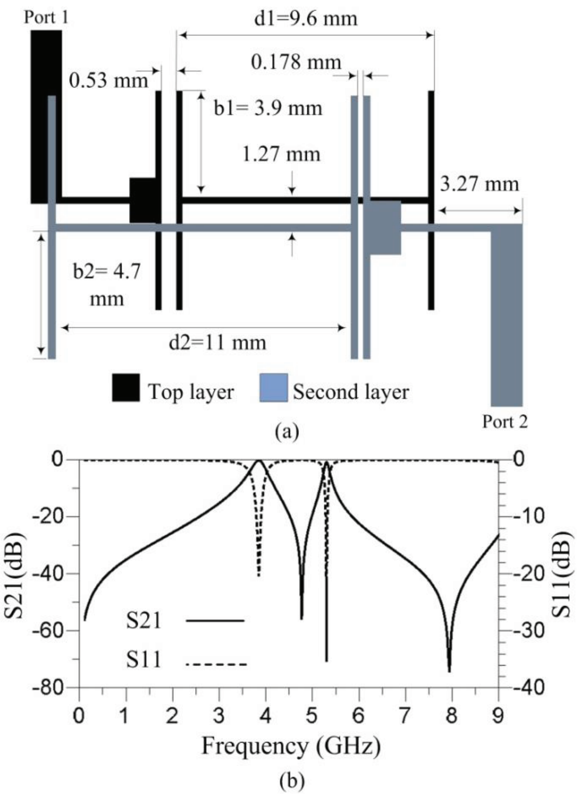

Fig. 5. Proposed dual band BPF: (a) layout and (b) simulation results.

Figure 5 (a) shows the dimension of the proposed filter. The important things about the filter layout are as follows:

- The end of the H-shape resonator in the second layer is coupled with the 50 Ω input line in the top layer.
- Central transition lines in top and second resonator are parallel and have a weak coupling.
- In order to improve the passband performance, coupling distance of the top resonator is increased to 0.53 mm because the substrate thickness has been increased.
- In order to band tuning, the dimensions of the second resonator are scaled with the rate of 1.2.

Filter design was done in 3 steps:

1. Creation of different resonant frequencies for two equal resonators through creating different dielectric constants for them (as it is shown in Fig. 3).
2. Minimizing the filter size and increasing the isolation between bands through overlapping the resonators in top and second layer (as it is shown in Fig. 4).
3. Tuning the passbands using resonator scaling (as it is shown in Fig. 5). If the dimension of the top resonator increase/decrease, the second passband shifts to the lower/higher frequencies, and if the dimensions of the second resonator increase/decrease, the first passband shifts to the lower/higher frequencies.

Between the dimensions of the filter, b1, b2, d1, d2 have the most effect on the filter response. Figure 6 shows the filter response as a function of b1, b2, d1, d2.

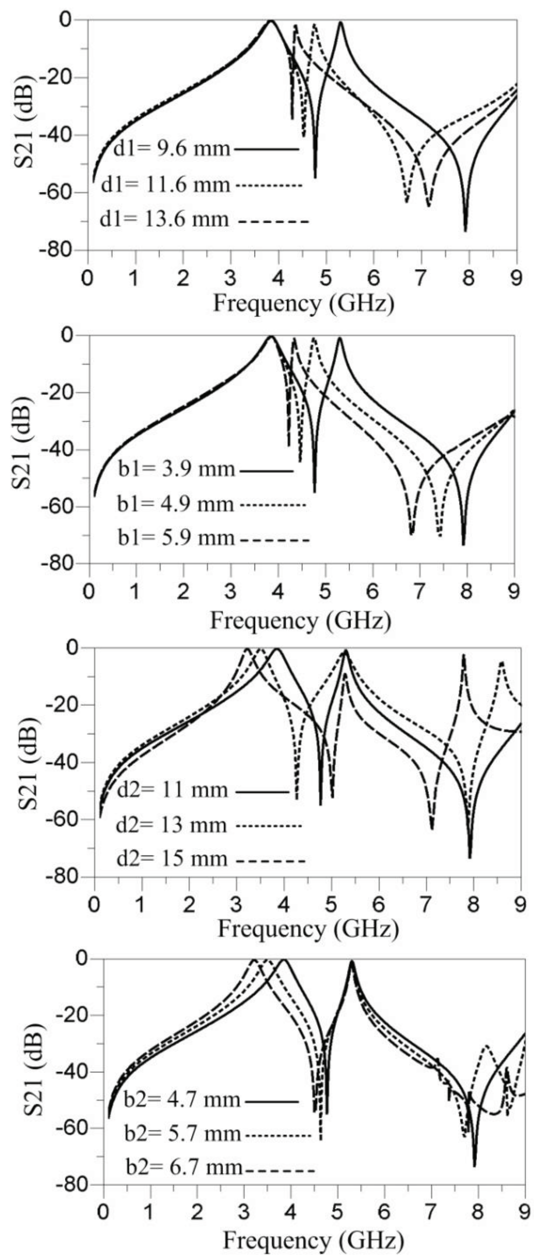

Fig. 6. Filter response as a function of b1, b2, d1, d2.

Figure 7 depicts the fabrication pictures and simulation/fabrication results of the proposed dual band BPF. The top/bottom of the top layer and the second layer are shown in Fig. 7 (a) and Fig. 7 (b), respectively.

The bottom of the top layer is not metalized but the bottom of the second one is metalized, as the ground plane.

Circles on four sides of the resonators in both layers have created simultaneously. These circles have perforated at the top and bottom layers and with overlaying these holes, the correct distance between the resonators is realized.

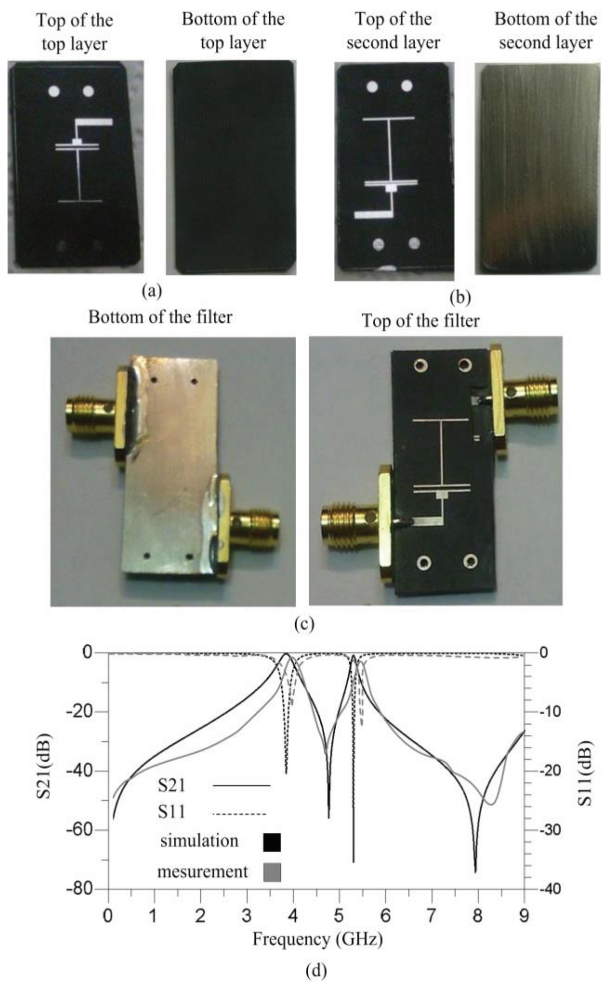

Fig. 7. Proposed dual band BPF: (a) fabrication picture of the top layer, (b) fabrication picture of the second layer, (c) fabrication picture of the filter, and (d) simulation/fabrication results.

IV. RESULT DISCUSSION

The proposed dual-band BPF fabricated on the RT/Duroid 5880 substrate. As illustrated in Fig. 6, the simulated central frequencies are 3.85 and 5.3 GHz with fractional bandwidths of 4.7 and 2.2%, respectively. A deep transmission zero between the two bands was located at 4.75 GHz, resulting in high isolation with an attenuation level of more than 58 dB. The return losses of the first and second bands (at the central frequencies) are 21 dB & 36 dB and insertion losses of them are 0.68 dB & 0.23 dB. Table 1 compares the proposed design method with those are mentioned.

Table 1: Comparison between design methods

Methods	Advantages	Disadvantages
Proposed	Compactness-simple design process-tunable passbands	Difficult fabrication
Method 1	Simple passband control	Complex design process-large circuit size
Method 2	Compact size-good isolation	Complex design process-difficult tuning
Method 3	Simple structure	Difficult passband control
Method 4	Tunable passbands	Complex design process

V. CONCLUSION

In a novel dual band bandpass filter presented using a simple dual-layer method. At the top layer, designed H-shape resonator was placed and the scaled H-shape resonator was used on the second layer. Due to differences in the effective dielectric constant of the resonators, the resonant frequencies of them are different. Tuning of the passbands performances are possible using resonator scaling and shifting them toward each other. The central frequencies of this dual band BPF are f_1=3.85 GHz and f_2=5.3 GHz.

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