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# Balanced-to-balanced dual-band bandpass filter with common-mode rejection spurious suppression and independent bands

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A novel balanced-to-balanced dual-band bandpass filter is presented. The structure is obtained by combining two single-layer balanced-to-balanced bandpass filters (BBPF) with microstrip lines. Characteristics of each band can be designed independently. The final structure exhibits a reduced size with 0.4  $\lambda g \times 0.22 \lambda g$  where  $\lambda g$  is the guided wavelength at the lower frequency. A good out-of-band response is achieved with a spurious frequency value of 5.6 times the lowest central frequency. Common-mode rejection is 58 and 45 dB for the first and second central frequencies, respectively.

Keywords: dual-layer; common ground; microstrip; bandpass filter; balancedto-balanced; dual-band; miniaturized; common mode rejection; high spurious attenuation

#### 1. Introduction

In recent years, balanced structures have been taking great interest in microwave devices due to the high immunity to electromagnetic interference.[1] Several works in relation to these kinds of structures including mixers, low noise amplifiers, antennas, filters and diplexers are found in the literature.[2–4]

Multiband filters with differential signalling operation is a relatively new area of investigation. In [1], a dual-band balanced filter based on stepped impedance resonators (SIRs) is presented. Dual-band operation is obtained by properly adjusting the impedance ratio of the SIRs, to control the first spurious position. However, since there is not an entire independence in the design process between the two pass-bands, the design characteristics must be partially satisfied for each band [5] and for this reason, the filter presents poor insertion loss, non-flat pass-bands and low selectivity, especially at the higher frequency band.

In [6], SIRs are used, once again, to achieve a dual-band balanced filter. High rejection for the common mode (CM) signals is achieved; however, lumped components with a wide frequency of operation range are required, increasing the fabrication costs and design/fabrication complexity. More recently, in [7] a balanced dual-band bandpass filter with embedded resonators and defected ground structures (DGS) is presented. The structure presents poor CM behaviour, therefore, complementary structures (DGS) are used. Besides, although the embedded topology leads to compact size (since the smaller resonator is contained in the bigger one), this approach will always have an intrinsic

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compromise between the central frequencies, the filter order and the design couplings, limiting the design independence of each bandpass.

A new kind of balanced-to-balanced dual-band bandpass filter, where each band can be designed independently, is introduced in this work. A novel approach of two-layer structures to obtain a miniaturized size, is also introduced. With the proposed filter, high attenuation for CM mode signals is achieved without the use of complementary structures.

#### 2. Design of the dual-band balanced bandpass filter

The proposed structure is presented in Figure 1(a). It comprises two fourth order balanced-to-balanced bandpass filters (BBPF), the crossover sections (or feeding structures) and two microstrip connecting networks. In order to have a miniaturized size, and an easier design methodology, a multilayer approach, that allows to have identical connecting lines and feeding structures vias for the input and output sections of the Dual-band BBPF is used. The BBPF is implemented with a common ground scheme (see Figure 1(b)), where the top substrate is used to include the first filter and its associated structures, while the bottom one is used for the second filter and its associated structures.

The design process of the dual-band BBPF is as follows: first, each BBPF is designed with the desired characteristics (Section 2.1). Then, the crossover sections or feeding structures are made (Section 2.2). Subsequently, the electrical characteristics of the microstrip connecting lines are determined (Section 2.3). Finally, the structures are combined into a single device to form the two-layer with common ground balanced dual-band bandpass filter.

#### 2.1. Balanced bandpass filters

The BBPF must present good selectivity properties to assure that frequencies between the two pass-bands are correctly suppressed. In the same way, each one of the individual filters, should present high spurious suppression to guarantee an extended out-of-band response and to avoid interference from the lower frequency band filter into the bandpass of the higher one.

In this way, the minimum frequency spacing between the two pass-bands will be a function of the selectivity of the individual filters, whilst the maximum frequency



Figure 1. (a) General scheme of the dual-band balanced bandpass filter with differential ports and (b) transversal section indicating device's layers.

spacing depends on their out-of-band response. For these reasons, we decided to use BBPF based on ring resonators with a shorted stub.

In Figure 2(a) and (b), the layout of the two four order BBPFs are shown. The frequency response up to 4 GHz of each filter is presented in Figure 2(c). The central frequencies of the filters are 1 and 1.8 GHz; both of them were implemented using the RO4003C ( $\varepsilon r = 3.48$ , h = 0.81 mm) substrate. Two 4th order, Butterworth filters FBW = 10%with were designed. The design coupling factors are:  $Q_{ext1}^d = Q_{ext4}^d = 7.65$ ,  $M_{12}^d = M_{34}^d = 0.084$  and  $M_{23}^d = 0.0541$ . These factors are obtained from the design requirements (filter type, ripple, order and bandwidth) of each filter. Then, the electrical characteristics of each resonator are determined from the resonant frequencies. Finally, gaps among the structures are found from full-wave simulations and the required coupling factors, multiple simulations are performed to obtain coupling factor



Figure 2. Layout of the (a) 1 GHz, (b) 1.8 GHz, balanced bandpass filters (not scale) and (c) transmission parameters of the two individual filters. R1 = 8.13 mm, R2 = 9.6 mm, R3 = 6.6 mm, R4 = 4.8 mm, W1 = 1.8 mm, W2 = 0.46 mm, S1 = 0.3 mm, S2 = 4.93 mm, S3 = 1.6 mm, S4 = 1.33 mm, S5 = 0.25 mm.

curves like those presented in Figure 3, where the couplings are mapped to physical gaps between structures. For a detailed description of the design process of these kind of BBPFs, we refer the reader to the reference [8].

#### 2.2. Feeding structures

Wideband crossover sections may be used to feed each one of the filters; however, for a planar implementation, crossover networks would increase the size of the entire structure. For this reason, we decided to use a double-layer with a common ground plane scheme. This way, crossover networks can be replaced with three ports two-layer feeding structures.

The three port network is shown in Figure 4(a); port 1 is the main signal entry, port 2 the signal input for the upper layer (layer associated to the 1 GHz BBPF) and port 3 is the signal input for the lower layer (associated to the 1.8 GHz BBPF). A three dimension zoom of the feeding structures is presented in Figure 6.

In Figure 4(b), the transmission scattering parameters for the structure are presented, it can be noticed that near the 1 GHz frequency ports 2 and 3 presents similar transmission power. Moreover, for higher frequencies the via network presents a better transmission performance, for this reason, lower layer is chosen to be the 1.8 GHz BBPF's layer.

#### 2.3. Connecting lines

Four balanced microstrip lines (see Figure 1) are used to connect each BBPF to the other one without mutually affecting their behaviour. Their characteristic impedances



Figure 3. Coupling curves for the (a) 1 GHz and (b) 1.8 GHz BBPFs.



Figure 4. (a) 2D view of the three ports feeding structure (grey for the top layer section) and (b) transmission parameters. V1 = 6.5 mm, V2 = 4.5 mm, V3 = 3.3 mm.

are  $Z_0 = Z_1 = 50 \ \Omega$ . Thereby, the only unknown variables to be found are the electrical lengths of the connecting lines ( $\theta_1$ ,  $\theta_2$ ). For this purpose, simulations using an ideal transmission line with characteristic impedance  $Z_0 = 50 \ \Omega$  and unknown electrical length  $\theta_1$ , is connected at one end to the feeding structure, and at the other end to the 1 GHz BBPF. Figure 5 presents the group of connecting lines for the input or output sections (which are the same). Then, the required electrical  $\theta_1$  to provide an open circuit condition  $\Gamma 1$  at 1.8 GHz is found from the smith chart. The second group of connecting lines is determined in a similar manner.

The shape of each group of connecting lines is found to be adequate to connect the feeding structures and the BBPFs.

At this point, every part of the two-layer with common ground dual-band BBPF is already known and the final layout can be obtained by combining all the filter's elements into a single three-dimensional structure as the one presented in Figure 6.



Figure 5. Combined view of the connecting lines. 1.8 GHz filter's lines on the bottom layer (black) and 1 GHz filter's lines on the top layer (grey) 1 GHz BBPF.  $L_{fo} = 16.1$  mm,  $L_{f1} = 14$  mm,  $W_L = 1.8$  mm,  $W_{f1} = 7.35$  mm.



Figure 6. 3D view of the two-layer dual-band BBPF with common ground plane and differential ports. (Light grey corresponds to the top layer circuit).

#### 3. Simulation and experimental results

In Figure 7, pictures of the superior (1 GHz filter's layer) and inferior layer (1.8 GHz filter's layer) of the prototype are shown; measurements were realized with a Signal Integrity Network Analyzer. The measured two-ports parameters were transformed to two balanced ports parameters using the technique shown in [9]. Simulations were performed in a full-wave simulator [10]. Simulated and experimental results of the transmission and return parameters for the DM are presented in Figure 8(a) and (b), respectively. Finally, the CM transmission is shown in Figure 8(c).



Figure 7. Pictures of the two-layer with common ground dual-band BBPF prototype. 1 GHz layer (left) and 1.8 GHz layer (right).



Figure 8. Measured (dotted lines) and simulated (solid lines) scattering parameters (a) transmission DM, (b) return loss DM and (c) transmission CM.

	This	[7]	[5]
Measured 1st/2nd bands CM suppression	58 dB/45 dB	22 dB/17 dB	36.2 dB/31.1 dB
Suppression at middle frequency	57 dB	38 dB	40 dB
Fully independent bands	Yes	No	No
Complementary structures	None	DGS	Lumped capacitors and resistors
Total size Filters order	$0.4 \ \lambda g \times 0.22 \ \lambda g \\ 4$	Not mentioned 2	$\begin{array}{c} 0.413 \ \lambda g \times 0.31 \ \lambda g \\ 4 \end{array}$

Table 1. Comparison with previous reported studies.

For the DM, return losses are better than 10 dB around the central frequency of each band. Insertion losses are 2.8 and 2.1 dB for the central frequencies of the first and second band, respectively. Measured and simulated central frequencies and bandwidths are:  $f_{0S} = 1.03 \text{ GHz}$ ,  $f_{0M} = 1.05 \text{ GHz}$ ,  $f_{1S} = 1.8 \text{ GHz}$ ,  $f_{1M} = 1.89 \text{ GHz}$ , FBW<sub>0S</sub> = 0.06, FBW<sub>0M</sub> = 0.1, FBW<sub>1S</sub> = 0.1, FBW<sub>1M</sub> = 0.1.

High attenuation for the frequencies between the two pass bands is obtained with 57 dB at the middle point in the measured data and 52 dB for the simulated data. On the other hand, an excellent out-of-band response can be observed, since the first spurious is up 5.6 times the lowest central frequency; moreover, the transmission parameter for the spurious frequency is lower than 13 dB. This extended rejection band characteristics represents an extra advantage of the proposed circuit. It is important to notice that the high spurious suppression was achieved without the use of any kind of complementary structures like DGS or passive components.

Finally, the proposed circuit exhibits a good CM rejection along the measured bandwidth and excellent rejection around the two pass bands. Measured CM rejection is 58 and 45 dB for the first and second central frequencies, respectively.

Some of the main characteristics of the presented filter are compared to the current literature in Table 1. The structure presents higher attenuation for CM signals at the central frequencies of each pass band; this behaviour is only associated to the weak direct coupling between the external resonators, whilst in the other works, DGS or lumped capacitors and resistors are necessary to achieve a good CM performance. Suppression at the middle frequency between the two pass bands is 57 dB, indicating that signals with frequency values within the two pass bands are strongly attenuated. Finally, one of the main advantages of the proposed topology is having a methodology of design for dual BBPF where the characteristics of each pass band can be established in an independent way, providing a greater flexibility of design than the other alternatives proposed in the literature.

#### 4. Conclusions

A novel two-layer with common ground dual-band balanced bandpass filter was introduced in this paper. The filter can be obtained from two BBPFs and simple microstrip transmission lines. Both bands can be designed independently giving great flexibility of bandwidth, filter type and number of poles per band. Good agreement between simulations and experiment was achieved. For the central frequencies, a measured minimum suppression value of 45 dB under CM excitation was obtained without the use of any kind of complementary structures like DGS or passive components. At the same time, excellent out-of-band performance was achieved with the first spurious frequency of 5.6 times the lower central frequency. The filter exhibits compact size due to its two-layer configuration.

#### **Disclosure statement**

No potential conflict of interest was reported by the authors.

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