

# Compact Wideband Broadside-Coupled Microstrip-Slot Bandpass Filter for Communication Applications

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## Abstract

*This paper proposes a compact size design of wideband bandpass filter (BPF). The broad-side coupling microstrip-slot technique is used to accomplish a good passband response with very low insertion loss across a wideband frequency range. The BPF that is designed using Rogers RO4003C substrate shows a good performance with the respective maximum reflection coefficient and insertion loss of -10 dB and 1.2 dB between 0.92 GHz and 5 GHz. This type of BPF filter is useful in any communication applications.*

**Keywords:** Bandpass Filter, Broad-side Coupling, Microstrip-Slot, Stub, Wideband

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## 1. Introduction

The immense needs in the direction of high-speed wireless communication connection appear to be never end, despite the current facilitation of the fourth generation (4G) of the wireless communication system. Where, the technology of wireless communication actuates toward fifth generation (5G) with the concept of communication that not restricted to humans but additionally the machine-to-machine and vehicle-to-vehicle, which anticipated by the year 2020. This intense 24/7 desire of the ubiquitous and limitless high-speed communication access to any apparatus at anytime pilots to excessive challenge and problem to the engineers and researchers implying network planning, and radio frequency (RF) and microwave component design. Subsequently, the vital front-end component features in the wireless communication system, includes bandpass filter (BPF). In recent years, it can be seen that various rapid developments in the variety of BPF designs have been reported in the literature [1-7].

In [1], the authors present a theory and direct synthesis of a wideband progressively coupled BPF. The designed filter is claimed adequate to accomplish similar manageable number transmission zeros as that of resonators over the passband. The resonators contain a parallel pair attached capacitive loaded, and grounded inductive stubs are linked over a short section of a transmission line with a certain assigned electrical length, which allow the filter to have a wide range of stopband.

Besides, numbers of researchers have also proposed a design of bandpass filter by using defected ground structure (DGS) technique [2-3]. In [2], the design has four coupled U-shaped DGS on the common ground plane. Meanwhile, at the top of the designed filter, shunt coupled T-shaped microstrip lines is added in order to act as an inverter for the filter. As a result, the BPF displays two transmission zeros on either side of the passband, thereby improving the selectivity of the filter on both sides of the passband. Similar to the filter reviewed in [3], the DGS has been implemented into the filter designed whereas the motivation of the DGS technique is impending from the bandgap structures of electromagnetic/photonic (EBG/PBG). In the paper, the authors introduce the function of metamaterials. Metamaterials are employed in order to accomplish a variety of performance-enhancement features. The authors have claimed that the filter design with DGS and metamaterials to be simpler compared to the complex EBGs/PBGs.

The design of BPF introduced in [4] implemented the broadside-coupled technique that has a combination of transition between microstrip and coplanar waveguide (CPW). This CPW has been placed at the ground plane. The BPF has shown to be operated from 3 GHz up to 10.63 GHz. Meanwhile in [5], the authors designed the BPF by using parallel coupled line without and with the implementation of DGS. The results show that the BPF with DGS produces better results compared to another design without DGS.

The filter based on broadside coupled microstrip-slot aims to achieve a very tight coupling over a very wide frequency band range [6-7]. In [6], the authors implement a multilayered structure of microstrip-slot couplers. This design has an integration of dumb-bell-shaped slots in the ground plane. Meanwhile, H-shaped stubs are added to the input and output ports' transmission lines to accomplish well-soaring performance of passband and band-rejection. Meanwhile in [7], the authors implement stepped impedance resonators and radial slots to achieve wide upper stop band. Besides, the designed filter is claimed to have a very wide upper stopband that extends up to above 20 GHz. Both BPF in [6] and [7] worked for the ultra wide-band frequency range.

Therefore, due to the good performance achieved by implementing the broadside-coupled microstrip-slot technique, a new wideband BPF filter design with compact size is proposed in this paper. The broadside-coupled microstrip-slot technique has been implied into the design in order to have a strong coupling filter with wideband frequency range performance. Rogers RO4003C substrate with 3.38 relative permittivity, a very low loss tangent of 0.0027, substrate thickness of 0.508 mm and 17  $\mu\text{m}$  copper cladding is used in the design of the proposed wideband BPF.

## 2. Design of Wideband Bandpass Filter (BPF)

Figure 1 and 2 present the proposed design of the wideband BPF. The BPF is constructed with two layers of the top layer and bottom layer of a common ground plane. The microstrip patches of BPF are located on the top layer with transmission lines of input and output port. Meanwhile, the bottom layer that acts as the ground consists of slotline. As seen in both figures, both top and bottom layers have elliptical-shaped or tapered coupled lines, which meaning to provide nearly consistent strong coupling in order to realize flat and low insertion loss response characteristic of filter over the pass band. The signal from the input port is broadside coupled between the top and bottom layer and guided to the output port. Referring to Figure 2, the overlapped structure of stepped impedance resonator is added into the design.

Rectangular stubs are added onto the port's transmission lines of Type 2 BPF to observe their effect in eliminating unwanted reflected signal across a wider frequency range. The dimension of the rectangular stub located at the top layer can be calculated by using (1) to (4) [8]:

$$l_e = \frac{c}{f\sqrt{\epsilon_e}} \quad (1)$$

Where,  $\lambda_e$ ,  $c$ ,  $f$  and  $\epsilon_e$  are the respective effective wavelength, speed of light, design frequency and effective relative permittivity. The effective relative permittivity,  $\epsilon_e$  can be obtained from (2) [8]:

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{\frac{12h}{wf}}} \quad (2)$$

Where,  $\epsilon_r$  is the relative permittivity. Meanwhile,  $d$  and  $wf$  are the height of substrate and width of 50  $\Omega$  microstrip line, respectively. Thus, the value of stub length,  $g$  can be computed from (3):

$$g = 0.32\lambda_e \quad (3)$$

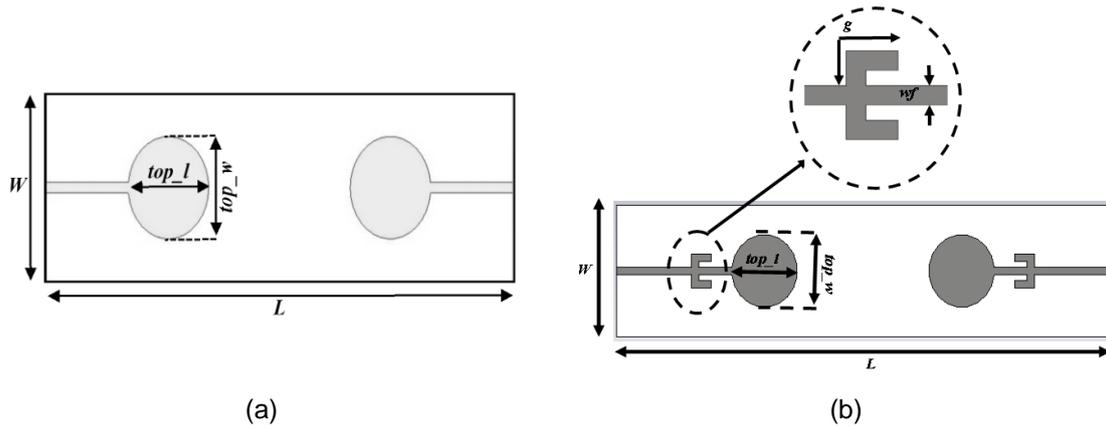


Figure 1. Proposed wideband bandpass filter design (top layer): (a) Type 1 and (b) Type 2

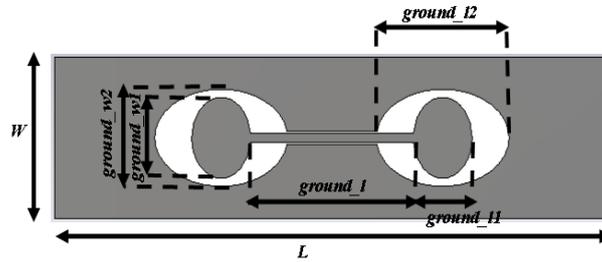


Figure 2. Proposed wideband bandpass filter design (bottom layer/ground) for Type 1 and Type 2

Whilst, width of 50Ω microstrip line, wf can be determined through the following equation (4) [8]:

$$\frac{wf}{h} = \frac{2}{\rho} \left[ \frac{e^{\hat{e}}}{B} - 1 - \ln(2B - 1) + \frac{e_r - 1}{2e_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{e_r} \right) \right] \quad (4)$$

Where,  $B = 377\pi / (2Z_0\sqrt{\epsilon_r})$ , and  $Z_0$  is the thickness of the substrate and characteristic impedance, accordingly. In the design, Rogers RO4003C substrate with dielectric constant of 3.38, thickness of 0.508 mm, loss tangent of 0.0027 and 17 μm copper cladding is applied. CST Microwave Studio software is implemented to design and optimize the proposed wideband Type 1 and 2 BPF, which the finalized and optimized dimensions are indicated in the following Table 1.

Table 1. Optimized dimensions of the proposed BPF.

Parameter	Dimension (mm)	
	Type 1	Type 2
L	75	75
W	20	20
wf	1.128	1.128
g	-	4
top_l	9.5	10
top_w	11	11
ground_l	30	30
ground_l1	10.5	8
ground_l2	11.5	18
ground_w1	10	10
ground_w2	12	12

### 3. Results and Analysis

The performances of the reflection and transmission coefficients for the designed wideband Type 1 and 2 BPF are shown in Figure 3. From the plotted results, the proposed wideband Type 1 BPF performs a well wideband operation from 1 to 5 GHz with a reflection coefficient lower than -10 dB. Its transmission coefficient demonstrates  $-0.58 \text{ dB} \pm 0.57 \text{ dB}$ . In contrast, the reflection coefficient,  $S_{11}$  of Type 2 BPF is less than -10 dB between a narrower band of 0.8 GHz and 2.2 GHz. Meanwhile, its transmission coefficient,  $S_{21}$  is greater than -0.17 dB. The addition of stubs to port's transmission lines has reduced the BPF wideband performance. Since Type 1 BPF has wider bandwidth performance compared to Type 2, it is chosen to be fabricated, and tested in the laboratory.

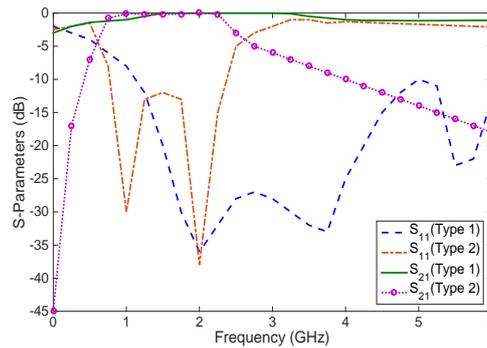


Figure 3. Simulated performance of Type 1 and Type 2 bandpass filter

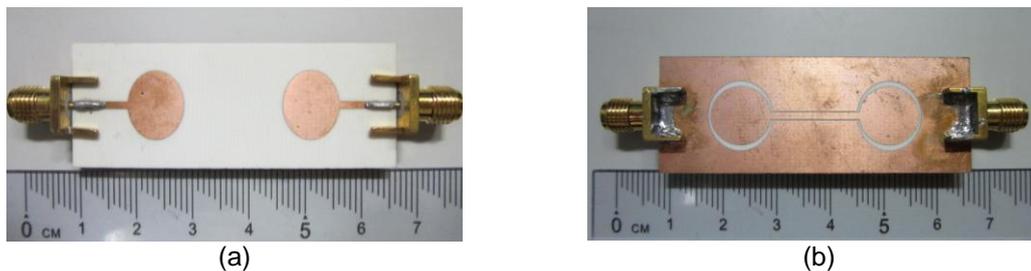


Figure 4. Prototype of Type 1 bandpass filter without stub; (a) top view and (b) bottom view

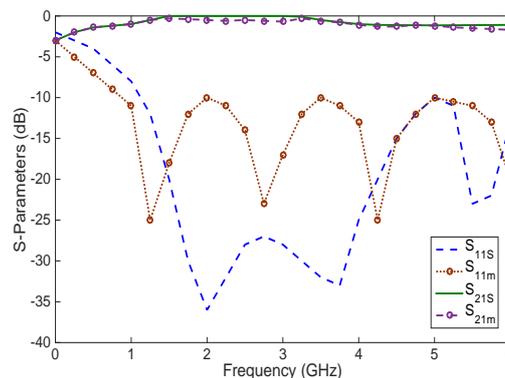


Figure 5. Simulated (s) and measured (m) performance of Type 1 bandpass filter.

Figure 4 shows the fabricated Type 1 BPF, which its Port 1 and 2 are connected to subminiature A (SMA) connector for testing purposes. The wideband performance of the

fabricated Type 1 BPF is measured by using a vector network analyzer (VNA). The simulated and measured results of Type 1 BPF are plotted and compared as presented in Figure 5. The measured results display slightly better performance in term of bandwidth that covers from 0.92 GHz to 5 GHz compared to the simulation. The measured transmission coefficient is  $-0.75 \text{ dB} \pm 0.45 \text{ dB}$  with the reflection coefficient less than  $-10 \text{ dB}$ . The obtained results indicate that the designed BPF (Type 1) has very minimal insertion loss with a maximum of 1.2 dB and good return loss, which better than 10 dB. The measured performance of this proposed BPF is then compared to [1], [9] and [10], which summarized in Table 2.

Referring to the comparison made in Table 2, the insertion loss and return loss of the proposed wideband BPF are performing better than [1], [9] and [10]. The proposed BPF that designed at the center frequency of 3 GHz has the insertion loss of 1.2 dB compared to the respective 1.03 dB, 1.62 dB and 1.55 dB of design in [1], [9] and [10]. This good performance of insertion loss is accompanying by reasonably good return loss of at least 10 dB across the widest fractional of 136% that covers from 0.92 GHz and 5 GHz. Even though design in [9] has the best return loss, unfortunately, it is covering the narrowest bandwidth of 27.2 % with worst insertion loss of 1.62 dB.

Table 2. Comparison with previous works in [1],[ 9-10]

Parameter	BPF ref [1]	BPF ref [9]	BPF ref [10]	Proposed BPF
Center frequency [GHz]	1.7	1.0	2.92	3
Return Loss [dB]	> 10	> 11.7	> 7	> 10
Maximum Insertion Loss [dB]	1.03	1.62	1.55	1.2
Bandwidth [GHz]	1	0.272	2.03	4.08
Fractional Bandwidth [%]	58.8	27.2	69.5	136

#### 4. Conclusion

A design of wideband BPF with and without stub has been proposed by introducing the broadside-coupled microstrip-slot technique in order to have a strong coupling filter with wideband frequency range performance. Type 1 design without stub has better bandwidth performance compared to Type 2 with stubs, which then fabricated and verified. The proposed Type 1 BPF has a good wideband performance with low insertion loss of 1.2 and the return loss greater than 10 dB. It has minimal insertion loss with 136% fractional bandwidth compared to the designs in [1], [9] and [10]. This wideband BPF is suitable to be used in various communication applications, especially at the front-end transceiver system.

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