

Ultra Wideband Bandpass Filter Using Microstrip-Slot Couplers Combined with Dumbbell Slots and H-Shaped Stubs

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Abstract — A bandpass filter (BPF) that covers the ultra wideband (UWB) frequency range of 3.1GHz to 10.6GHz is presented. The filter uses multi-layer microstrip-slot couplers combined with dumbbell slots in the ground plane and H-shaped stubs at the input/output ports to achieve high quality bandpass and band-rejection performance. The simulated results show that the designed filter has a UWB passband with an insertion loss less than 0.5dB and a return loss greater than 25dB at the centre of the passband. The device also exhibits sharp and wide low and high frequency stopbands. The simulated group delay of the filter indicates a low peak-to-peak variation of around 0.2ns across the passband. It features a compact size of 1.5cm×2cm when developed on RT6010 with dielectric constant of 10.2.

Index Terms— Bandpass filter, multilayer, broadside coupling, slotted ground.

I. INTRODUCTION

Bandpass filters (BPF) are key devices in communication systems. For ultra wideband (UWB) applications, the BPF is required to have low insertion loss over the band 3.1 GHz to 10.6 GHz, and a flat group delay performance within that band. Moreover, it should exhibit a very good selectivity below 3.1GHz and above 10.6GHz in order to meet the FCC spectrum mask.

A number of UWB BPF filters have already been reported in the microwave literature [1]-[12]. The early planar BPFs were designed using end-coupled coplanar waveguides (CPW) [1]. CPW BPFs based on the combination of lowpass and highpass periodic structures were also presented [2]. The parallel-coupled microstrip line with a slotted ground plane was employed to give a tight coupling for a wideband BPF [3]. In [4] a UWB filter was constructed by mounting a microstrip line in a lossy composite substrate so as to attenuate the signals at high frequencies. In another method, a bandpass filter was designed by using two stopbands of a filter block with two tuning stubs on a ring [5]. In [6], a microstrip ring filter with dual stopbands, below 3.1 GHz and above 10.6 GHz, was built to make up a UWB filter with sharp rejection. Compact UWB bandpass filters in microstrip technology were designed using multimode resonators [7]-[8].

In [9], a UWB BPF was developed by adopting a highpass filter prototype and transition stretch stubs to create the lower

and upper stopbands. In [10], a technique for the design of ultra-wide bandpass filters with harmonic passband suppression is proposed. The design approach involves combining a standard UWB BPFs design with an electromagnetic bandgap periodic structure.

In [11], a BPF is composed of five short-circuited stubs separated by connecting lines that contribute to the filter's selectivity. In addition, a cross-coupling between the input/output feed lines is introduced to generate new pairs of attenuation poles at each side of the passband. Although performance of the filter shows a sharp cutoff at 3 and 12 GHz, it has a narrow low and high stopbands. Moreover, the manufacturing process is complicated as it needs many vias.

The tolerance of the microstrip and CPW fabrication process imposes an upper limit upon coupling levels for parallel- and edge-coupled structures. This makes the manufacturing of UWB filters which utilize those structures difficult as their performance is very sensitive to manufacturing errors. This difficulty can be circumvented by implementing tight coupling using broadside coupling technique [12]. In [12], elliptical shaped broadside microstrip-slot couplers were used to construct UWB bandpass filters. In order to improve the performance at the high stopband, multiple broadside-coupled sections of up to five were utilized. The drawback of this approach is an increased size and degradation of passband characteristics.

In this paper, the shortfalls of the design presented in [12] are overcome by combining two multilayer microstrip-slot couplers with dumbbell slots in the ground plane and H-shaped open-ended shunt stubs at the input and output ports. This approach reduces the overall size of filter and enhances the high stopband performance. The advantages of the new design are demonstrated via full-wave electromagnetic simulations.

II. PROPOSED DEVICE

The proposed BPF configuration, whose middle part is based on an initial broadside-coupled multilayer configuration of [12], is shown in Fig.1. The structure includes three conductive layers interleaved with two substrates. The top layer (Fig. 1a) and the bottom layer (Fig.1c) have two similar elliptical shaped microstrip patches which are coupled via an elliptical slot at the mid layer of the structure (Fig.1b).

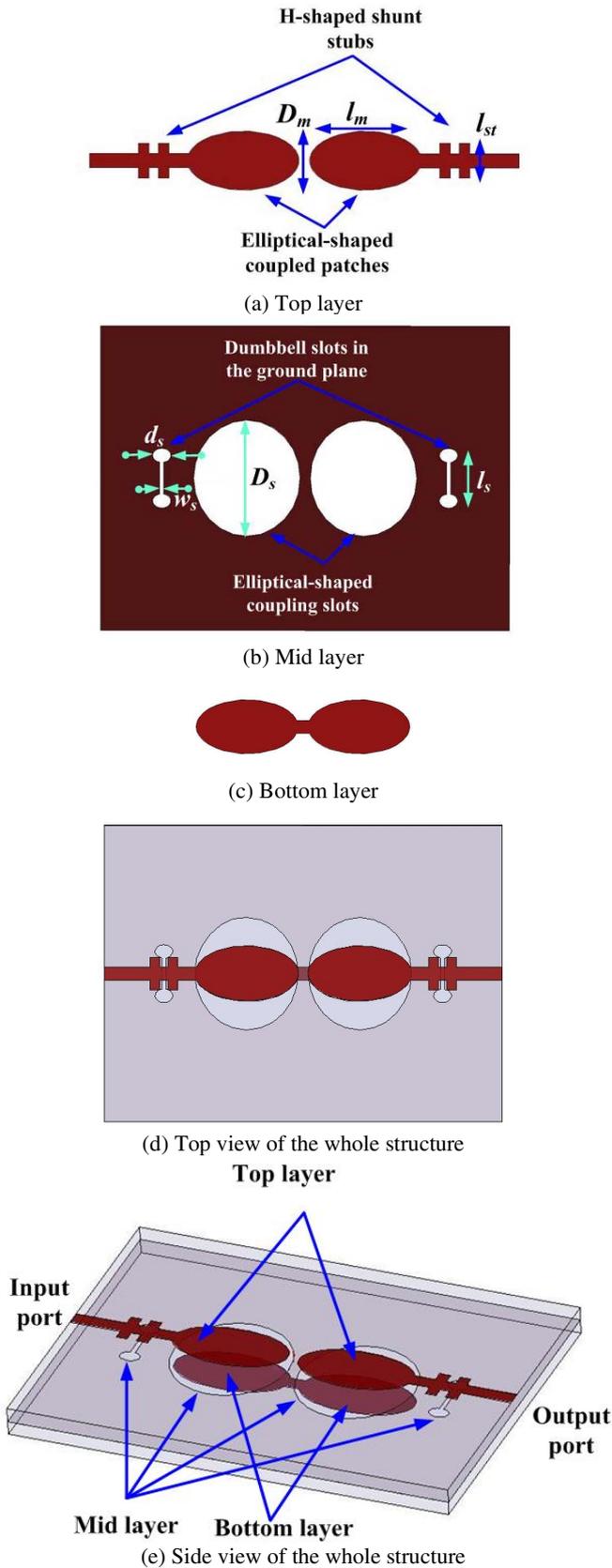


Fig.1. Configuration of the proposed multilayer broadside-coupled bandpass filter.

The ground plane of the whole structure is located in the mid layer. The reason for the choice of this broadside-coupled configuration is that it provides an almost constant tight coupling, which is important to achieve the required filter's characteristics, across the ultra wideband as indicated in [13]-[14].

The main modification introduced in this paper is the inclusion of a coupled dumbbell slot in the ground plane (mid layer) as shown in Fig. 1b and H-shaped shunt open-ended stubs connected with the input and output ports at the top layer as revealed in Fig. 1a. This added circuit behaves as a low pass filter, which improves the high stopband characteristics of the entire filter without the need to add more middle sections.

The design procedure for the proposed filter includes two main steps: The first step concerns designing the two-section broadside-coupled structure to accomplish a passband that extends from 3.1 to 10.6 GHz, whereas the second step is to design the combined slotted ground plane and open-ended shunt stubs to have a sharp cutoff at frequency larger than 10.6GHz.

Concerning the broadside-coupled part of the filter, the detailed design method presented in [12]-[14] is applied to find its dimensions assuming that the passband of the filter covers the ultra wideband 3.1 to 10.6 GHz. It is clear from the theoretical analysis of [12] that the important parameter that defines the design procedure is the required value for the coupling factor C . Following the analysis presented in [12], it is possible to show that the effective scattering parameters for the two-section broadside-coupled structure (S_{11ef} and S_{21ef}) are given as [12];

$$S_{11ef} = S_{11} + \frac{S_{21}^2 S_{11}}{1 - S_{11}^2} \quad (1)$$

$$S_{21ef} = \frac{S_{21}^2}{1 - S_{11}^2} \quad (2)$$

$$S_{11} = \frac{1 - C^2 (1 + \sin^2(\beta_{ef} l))}{[\sqrt{1 - C^2} \cos(\beta_{ef} l) + j \sin(\beta_{ef} l)]^2} \quad (3)$$

$$S_{21} = \frac{j 2C \sqrt{1 - C^2} \sin(\beta_{ef} l)}{[\sqrt{1 - C^2} \cos(\beta_{ef} l) + j \sin(\beta_{ef} l)]^2} \quad (4)$$

where β_{ef} is the effective phase constant in the medium of the coupled structure, and l is the physical length of the coupled structure which is chosen such that; $\beta_{ef} l = \pi/2$ at the centre of the passband (6.85 GHz).

For the configuration under investigation, it is possible to show that [12];

$$\beta_{ef} = \frac{\beta_e + \beta_o}{2} = 2\pi \sqrt{\epsilon_r} / \lambda \quad (5)$$

where β_e and β_o are the phase constants for the even- and odd-mode respectively, λ is the free space wavelength, and ϵ_r is the dielectric constant of the substrate.

Solving (1)-(5) for the coupling factor C that gives the best possible performance across the passband (3.1 to 10.6 GHz) results in $C=0.7$. Using this value with the design approach for the broadside-coupled structures [13] results in the following values for the design parameters shown in Fig. 1 assuming that the substrate is Rogers RT6010 (with $\epsilon_r=10.2$, thickness= 0.635mm, and tangent loss=0.0023); $D_m=2.8\text{mm}$, $D_s=5.7\text{mm}$, $l_m=5.2\text{mm}$.

The broadside-coupled structure designed in the previous steps results in a BPF that has the required passband (3.1 to 10.6 GHz) and good low frequency stopband (below 3.1 GHz). However, the performance at the high stopband shows a slow cutoff and a spurious response that appears at integer multiple of the midband frequency [12]. The most pronounced spurious response is the one that appears at 13.7GHz.

To improve the performance of the BPF at the high stopband, H-shaped shunt open-ended stubs connected with the microstrip line of the top layer and coupled with dumbbell shaped slots at the ground plane of the mid layer are employed. The slotted ground plane disturbs the current distribution in the ground plane, and thus changes the line capacitance and inductance of a transmission, whereas the shunt stubs added a reactive element to the transmission line. The equivalent circuit for the combination of the slotted ground plane and shunt open-ended stubs is as shown in Fig. 2 after using the approach presented in [15], [16]. This circuit forms a LPF with a wide high stopband.

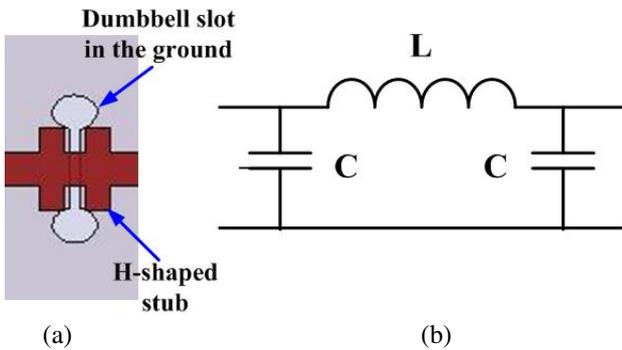


Fig.2 Configuration of the LPF (a) and its equivalent circuit (b).

The rough design for the LPF shown in Fig. 2 is to choose length of the stubs and the slot in the ground plane to have half of the effective wavelength at the required cutoff frequency. For the proposed filter, the cutoff frequency is chosen to be at the first spurious response of the broadside-coupled structure, i.e. at 13.7GHz. After optimization using the software CST Microwave Studio, length of the slot in the ground plane (l_s) and of the shunt stubs at the top layer (l_{st}) are equal to 2mm and 1.7mm, respectively, whereas width of the slot in the ground plane was fixed at 0.2mm, width of the shunt stubs is 0.5mm, and radius of the circular slots that

form the two ends of the dumbbell slot is 0.4mm. In finding the above mentioned values, the substrate was considered to be Rogers RT6010 with thickness of each layer equal to 0.635mm.

III. RESULTS & DISCUSSIONS

In order to verify performance of the proposed BPF, the device is simulated using the software CST Microwave Studio. The overall dimension of the designed filter used in the simulations including the microstrip feeders at the input and output is 1.5cm \times 2cm indicating a compact device.

Variation of the scattering parameters (S_{11} & S_{21}) with frequency is shown in Fig. 3.

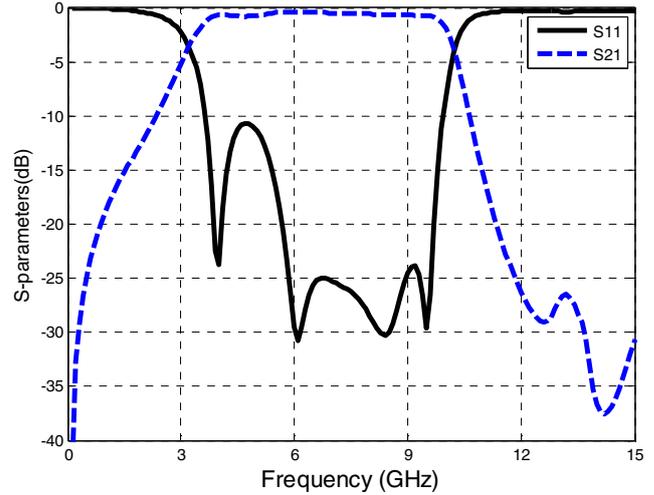


Fig.3 Variation of the scattering parameters (S_{11} & S_{21}) with frequency.

It is apparent from Fig.3 that the designed filter has a passband which covers the ultra wideband range of 3.1 to 10.6GHz. The insertion loss at the centre of the passband is less than 0.5dB, whereas the return loss is larger than 25dB. Also, the results of Fig. 3 reveal the sharp low and high frequency stopbands. The sharp low frequency stopband is a natural behavior of the broadside-coupled structure used in the configuration [12], whereas the sharp stopband at the high frequency is due to the used lowpass filter which consists of the dumbbell slot in the ground plane and H-shaped shunt open-ended stubs connected with the input/ output ports at the top layer.

Effect of incorporating the coupled H-shaped stubs and dumbbell shaped slot on the performance of the BPF can be clarified if the performance of the two-section broadside-coupled BPF designed in this paper is compared with performance of the two-section broadside-coupled BPF that does not include the coupled H-shaped shunt stub/ dumbbell slot as presented in [12]. It is obvious from the comparison that although the two structures have the same size and the same passband and low stopband performance, the modified structure of the BPF presented in this paper has a sharper and wider high stopband. Also, the design presented in [12] has a spurious response at the high stopband. In [12], five sections

of broadside-coupled structures were utilized to improve the performance of the BPF at the high stopband.

For impulse radio systems, the BPF is strongly required to have a flat group delay across the passband to keep the distortion of the pulse shape to minimum. Thus, variation of the group delay of the designed filter should have a sub-nanosecond peak-to-peak variation across the passband. The simulated results of the group delay for the proposed filter is shown in Fig. 4 which depicted a peak-to-peak variation in the group delay of 0.2ns across the band 3.5GHz to 9.5GHz.

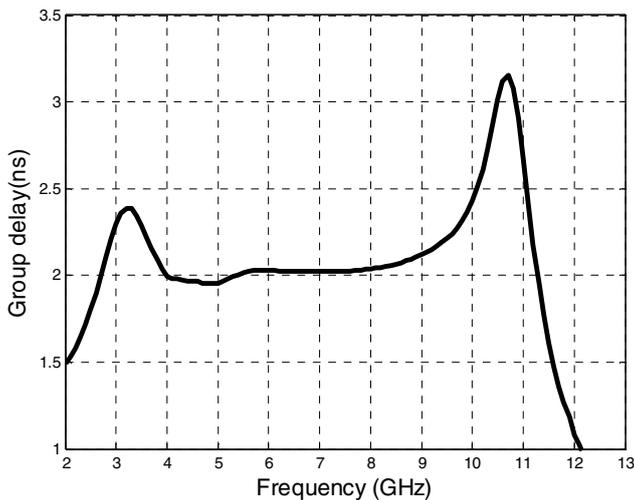


Fig.4 Variation of the group delay with frequency.

IV. CONCLUSION

A bandpass filter that covers an ultra wideband frequency from 3.1 to 10.6 GHz has been presented. The device uses microstrip-slot couplers to achieve bandpass operation. To improve the cutoff performance at the high frequency band and to extend the high stopband, a combination of dumbbell slot in the ground plane and H-shaped open-ended stubs connected to the input/output ports is utilized. The simulated results have shown that the designed filter has a passband that extends from 3.1GHz to 10.6GHz with an insertion loss which is less than 0.5dB and a return loss which is larger than 25dB at the centre of the passband. The results have also shown sharp low and high frequency stopbands. The high stopband is wide as it extends to above 15GHz. The simulated group delay of the filter has indicated a peak-to-peak variation of around 0.2ns. This reveals the distortionless performance of the filter when used with ultra wideband pulsed systems. The device has a compact size of 1.5cm×2cm, which is welcome in many applications. At the time of writing this paper, the filter is in the manufacturing stage.

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