Progress In Electromagnetics Research Letters, Vol. 20, 77–86, 2011

A NOVEL G-SHAPED SLOT ULTRA-WIDEBAND BAND-PASS FILTER WITH NARROW NOTCHED BAND

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Abstract—A novel G-shaped slot ultra-wideband (UWB) bandpass filter with a very narrow notched band is proposed. The basic ultra-wideband filter is short-circuited stub bandpass filter consisting of shunted $\lambda/4$ short-circuited stubs and $\lambda/4$ connecting lines. To avoid the interferences such as WLAN signals. The G-shaped slot embedded in the stub filter is used to obtain the notched band inside the UWB passband. Additional U-shaped defected ground structures are adopted to improve the out-band suppression. Measured results show that the proposed filter has an ultra-wide bandwidth from 3.1 GHz to 10.6 GHz, and the insertion loss is less than 1 dB. Specifically, the fabricated filter possesses a 10 dB notched fractional bandwidth (FBW) of 2.36% at the notched center frequency of 5.8 GHz. It also achieves a stop band with 20 dB attenuation.

1. INTRODUCTION

UWB technology, which is adopted by the Federal Communications Committee (FCC) in February 2002 of the unlicensed use, operating in a broad frequency range from 3.1 GHz to 10.6 GHz has shown great achievement for positioning, rescue radar system, short range high speed wireless communications and wireless personal area networks (WPANs) for personal computer and electronic devices [1]. UWB systems have several advantages: They have a bandwidth of 7.5 GHz, which support a high transmission data rate (up to 500 Mb/s); they have a low energy density over a wideband spectrum generated by short pulse excitation, which not only makes the UWB system difficult to intercept but also minimizes interference from other radio systems; and

Received 1 December 2010, Accepted 6 January 2011, Scheduled 25 January 2011
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they have an extremely low transmission energy (less than 1.0 mW), which is favorable for hand held radio systems [1].

Refs. [2–4] show various methods of realizing the UWB filters such as the employment of multiple mode resonators (MMR) [2], composite right/left handed structure [3] and defected ground structure (DGS) loaded techniques [4]. In this paper, an UWB bandpass filter using $\lambda/4$ short-circuited stubs is proposed, which has a lower insertion loss.

There are some undesired narrow band radio signals, such as wireless local area network (WLAN), which may interfere with UWB systems. WLAN is operated at the frequency of 5.8 GHz (5725 MHz–5825 MHz) [5]. In order to avoid the interference from WLAN signals, UWB BPF with notched band using different structures are proposed [6–8]. The notch band in these structures are relatively wide, however, much narrow 10 dB notched fraction bandwidth is required.

In order to realize good characteristics, it is required for UWB bandpass filters to have a good harmonic out-of-band suppression. Compact defected ground structure (DGS) offers a controllable bandgap response and demonstrates the effectiveness in harmonics suppression of various RF/MW circuits. A pair of U-shaped DGS used in this article achieves a stop band with 20 dB attenuation.

In this paper, a compact UWB BPF with a very narrow notched band is proposed by using short-circuited stubs and a G-shaped slot in the transmission line. With the G-shaped slot line structure embedded in the transmission line, a desirable notched band to avoid the interference of WLAN signals is achieved. Furthermore, a couple of U-shaped DGS with high Q-factor is adopted to improve the attenuation performance in the stop band. Both simulated and measured results demonstrate good passband and stopband performances of the proposed filter.

2. DESIGN OF UWB BAND NOTCH BANDPASS FILTER

Figure 1 shows the configuration of the proposed G-shaped slot structure UWB bandpass filters. The filter with and without band notch structure are given in Figs. 1(a) and (b) respectively. Fig. 1(c) shows U-shaped DGS structure embedded in the ground. In order to introduce a narrow notched band, a compact G-shaped slot embedded in the transmission line is used. A pair of U-shaped DGS is also proposed for harmonic suppression. The proposed bandpass filter is implemented on a microstrip substrate with a relative dielectric constant of 2.65 and a thickness of 1 mm.

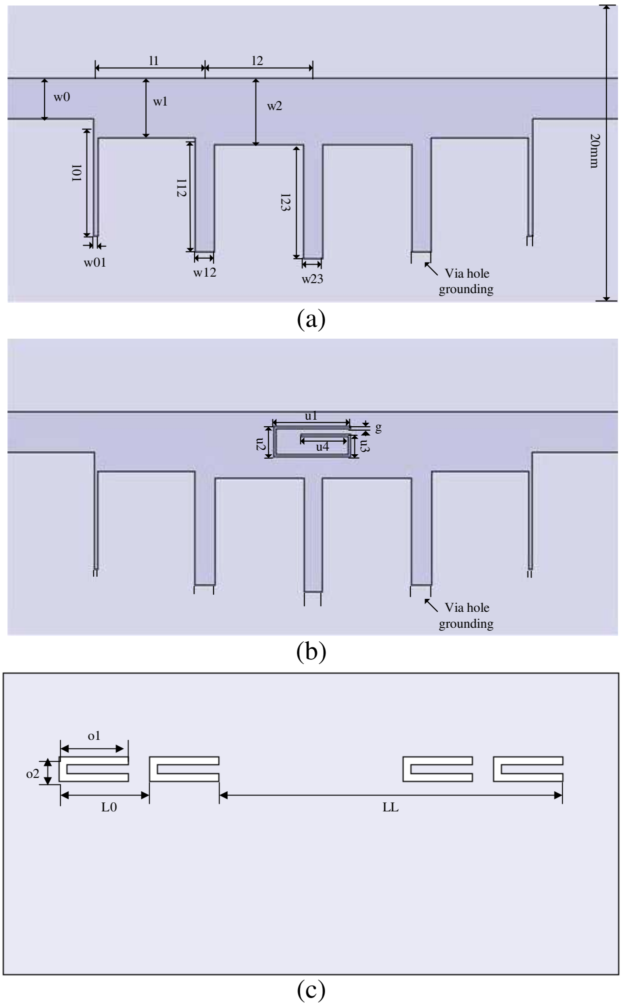

Figure 1. Configuration of the proposed UWB bandpass filters. (a) Top view of the proposed UWB BPF, (b) top view of the proposed UWB BPF with band notch implementation, (c) bottom view of the proposed UWB BPF with harmonic suppression.

2.1. Short-circuited Stubs UWB Filter

Figure 1(a) depicts the schematic of the proposed microstrip line UWB bandpass filter. The short-circuited stubs UWB filter is a traditional filter for broadband application. The transmission line of short-circuited stub UWB filter in Fig. 2 is comprised of shunt short-circuited stubs and connecting lines and both of which are quarter-wavelength length. For a given filter degree n, the stub bandpass filter characteristic impedance can be driven by [9]. For a given filter degree n, the stub bandpass filter characteristics will depend on the characteristic admittances of the stub lines denoted by Yi ($i = 1$ to n) and the characteristic admittances of the connecting lines denoted by $Yi,\ i+1$ ($i = 1$ to $n-1$). The design equations for determining these characteristic admittances described in [9] are given by

$$\frac{J_{1,2}}{Y_0} = g_0\sqrt{\frac{hg_1}{g_2}}, \qquad \frac{J_{n-1,n}}{Y_0} = g_0\sqrt{\frac{hg_1 g_{n+1}}{g_0 g_{n-1}}} \tag{1}$$

$$\frac{J_{i,i+1}}{Y_0} = \frac{hg_0 g_1}{\sqrt{g_i g_{i+1}}} \qquad \text{for } i = 2 \text{ to } n-2 \tag{2}$$

$$N_{i,i+1} = \sqrt{\left(\frac{J_{i,i+1}}{Y_0}\right)^2 + \left(\frac{hg_0 g_1 \tan\theta}{2}\right)^2} \qquad \text{for } i = 1 \text{ to } n-1 \tag{3}$$

$$Y_1 = g_0 Y_0 \left(1 - \frac{h}{2}\right) g_1 \tan\theta + Y_0 \left(N_{n-1,n} - \frac{J_{n-1,n}}{Y_0}\right) \tag{4}$$

$$Y_n = Y_0 \left(g_n g_{n-1} - g_0 g_1 \frac{h}{2}\right) \tan\theta + Y_0 \left(N_{n-1,n} - \frac{J_{n-1,n}}{Y_0}\right) \tag{5}$$

$$Y_i = Y_0 \left(N_{i-1,i} + N_{i,i+1} - \frac{J_{i-1,i}}{Y_0} - \frac{J_{i,i+1}}{Y_0}\right) \qquad \text{for } i = 2 \text{ to } n-1 \tag{6}$$

$$Y_{i,i+1} = Y_0 \left(\frac{J_{i,i+1}}{Y_0}\right) \qquad \text{for } i = 1 \text{ to } n-1 \tag{7}$$

The proposed UWB filter with a five pole ($n = 5$) Chebyshev lowpass prototype possesses a fractional bandwidth of 1.095 at a center frequency of 6.85 GHz. The computed design parameters using the above equations are summarized in Table 1. The short-circuited stubs UWB filter has the advantage of low insertion loss, which is less than 1 dB in most of the UWB frequency spectrum.

Table 1. Circuit design parameters of proposed UWB filter.

i	Yi (mhos)	$Yi, i+1$ (mhos)
1	0.0067	0.0259
2	0.013	0.0279
3	0.0126	0.0279
4	0.013	0.0259
5	0.0067	

2.2. Embedded G-shaped Slot-line Structure

To avoid interferences such as WLAN signals, a G-shaped slot-line structure is embedded in the transmission line. This novel structure can easily achieve the desirable notched band inside the UWB operation. It is found that the center frequency of the notched band can be adjusted by varying the whole length of G-shaped slot to about $\lambda/2$. Besides, the bandwidth of the notched band can be controlled by tuning the width of the embedded G-shaped slot-line structure and a smaller fractional bandwidth (FBW) of 2.36% is achieved.

2.3. U-shaped DGS Structure

U-shaped DGS structures are proposed to suppress the harmonic frequency in 11.0 GHz–12.0 GHz [10]. U-shaped DGS structures are embedded in the ground. The S-parameters of single and couple U-shaped DGS with different bandwidth are given in Fig. 3. The frequency characteristic of the U-shaped DGS can be modeled by a parallel RLC resonance circuit in the transmission line. The equivalent circuit of the U-shaped DGS is shown in Fig. 4, where the circuit parameters are extracted from the simulated scattering parameters as:

$$C = \frac{w_c}{2 * Z_0 * (w_0^2 - w_c^2)} \tag{8}$$

$$L = \frac{1}{4 * \pi^2 * f_0^2 * C} \tag{9}$$

where, w_0 is the angular resonance frequency, w_c is the 3 dB cutoff angular frequency, and Z_0 is the characteristic impedance of the microstrip line.

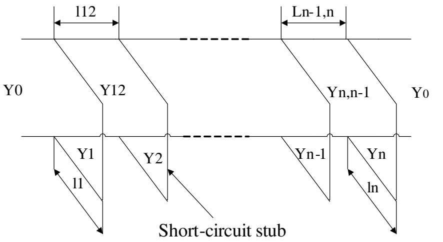

Figure 2. Transmission line bandpass filter of proposed UWB BPF.

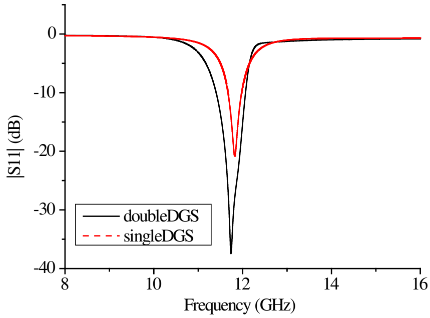

Figure 3. Simulated scattering parameters S_{11} of single and couple DGS.

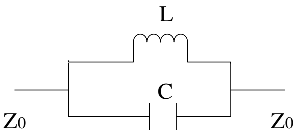

Figure 4. The equivalent circuit of the U slot DGS.

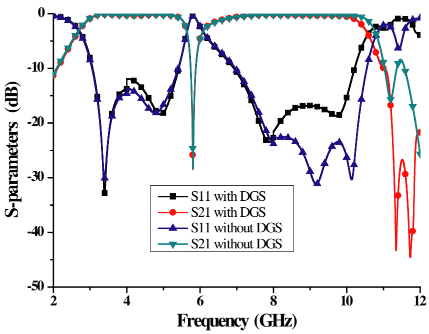

Figure 5. Simulated scattering parameters of the proposed UWB filter with and without DGS.

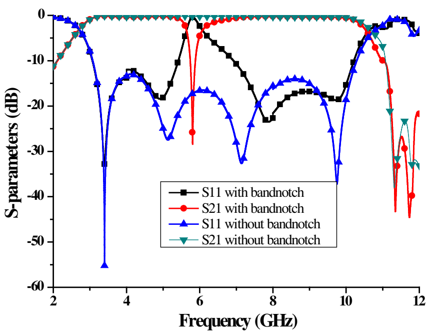

Figure 6. Simulated scattering parameters of Case (a) UWB BPF without band notch Case (b) UWB BPF with band notch.

In the parallel resonance circuit, the Q factor is proportional to the susceptance slop parameter $\sqrt{\frac{C}{L}}$. The calculated Q factor of the U-shaped DGS is 9.82 (3 dB bandwidth is 1.197 GHz and the resonant frequency is 11.757 GHz).

The proposed UWB BPF needs wide harmonic suppression bandwidth. Fig. 5 shows the S parameters of proposed UWB BPF with and without a couple of U-shaped DGS structures, which gives -20 dB harmonic suppression in 11.0 GHz–12.0 GHz.

2.4. Proposed Filter Design

To demonstrate the operation of the proposed structure above, the full-wave EM simulator is used. Two cases are compared and studied as follows. Case (a) is the structure of the short-circuited stubs UWB filter, Case (b) is the structure of case (a) with the G-shaped slot-line structure embedded in the transmission line. The physical parameters are list in Table 2. The G-shaped meander slot-lines shown in Fig. 1(b) have width of 0.15 mm and electric length of 90° at 5.8 GHz. The results of two cases are compared in Fig. 6, respectively. Fig. 6 shows that UWB response can be achieved by the short-circuited stubs UWB filter. The frequency range is 3.1 GHz to 10.6 GHz, with the center frequency at 6.85 GHz and the fractional bandwidth (FBW) of 110%. Fig. 6 also shows that the proposed UWB BPF has obtained UWB frequency spectrum and has achieved a notched band with center frequency of 5.8 GHz and fractional bandwidth (FBW) of 2.36%. Figs. 7(a) and (b) show the simulated frequency response of the proposed filter by tuning the width and length of the embedded G-shaped meander slot-line structure, respectively. It is clearly observed that with increasing whole length, the notched band is shifted to lower frequency and with decreasing slot-line width, the bandwidth of the notched band slightly decrease. With choosing the length of 17.15 mm and width of 0.15 mm, a 10 dB notched FBW of 2.36% at the notched center frequency of 5.8 GHz can be achieved.

Table 2. Physical parameters of proposed UWB BPF (unit: mm).

$w_0 = 2.7$	$l_2 = 7.19$	$w_{01} = 0.23$	$u_2 = 2$	$o_1 = 4.6$
$w_1 = 4$	$l_{01} = 7.81$	$w_{12} = 1.3$	$u_3 = 1.5$	$o_2 = 1.6$
$w_2 = 4.43$	$l_{12} = 7.53$	$w_{23} = 1.23$	$u_4 = 3.3$	$L_0 = 6$
$l_1 = 7.22$	$l_{23} = 7.54$	$u_1 = 5.15$	$g = 0.15$	$g_1 = 0.5$
$L_L = 22.82$				

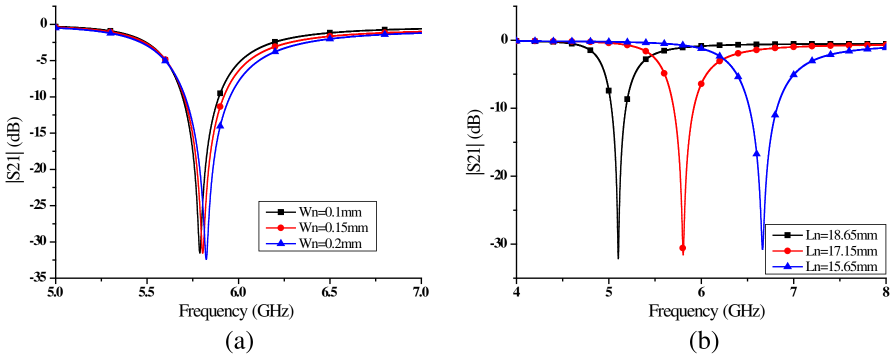

Figure 7. Effects of G-shaped slot structure on notched band. (a) Curve to relate the bandwidth of notched band to slot-line width W_n. (b) Curve to relate the center frequency of notched band to slot-line length L_n.

3. SIMULATED AND EXPERIMENTAL RESULTS

To validate the analysis, a G-shaped meander slot-line short-circuited stubs UWB filter is fabricated and measured. Fig. 8 shows its photograph. Fig. 9 shows the comparison between the predicted and measured frequency response of S_{21} and S_{11}. Over the wide frequency range of 1.0 GHz to 12.0 GHz, the predicted and measured results are found to be in close agreement with each other. The 3 dB passband covers the range of 2.7 GHz–10.7 GHz and it has a fractional bandwidth of 119.4%. Moreover, the measured results show the notch band at 5.8 GHz with −28 dB insertion loss and 10 dB notched FBW of 2.36%. Fig. 10 shows the measured group delay of the proposed filter. The maximum measured group delay variation within the passbands is 1.23 ns.

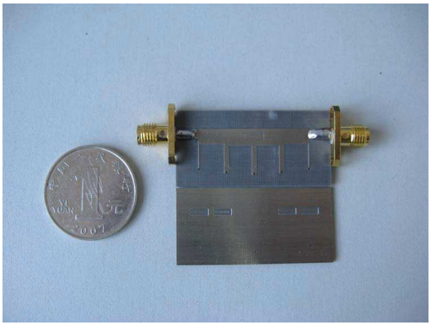

Figure 8. Fabricated UWB bandpass filter.

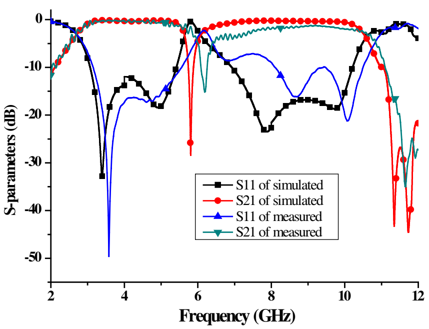

Figure 9. Measured and simulated *S*-parameters of proposed UWB BPF with an ultra narrow notched band.

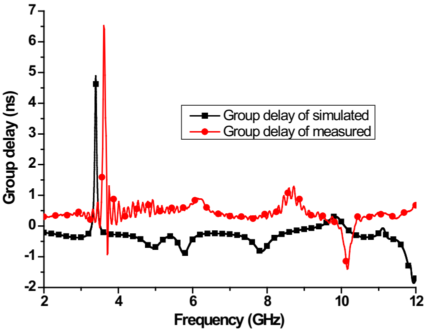

Figure 10. Measured group delay of proposed UWB BPF with an ultra narrow notched band.

4. CONCLUSION

In this paper, a novel ultra-wideband bandpass filter with a G-shaped slot for a narrow notch band and U-shaped DGS for harmonic suppression is proposed. The short-circuited stubs UWB filter is constructed to meet the UWB requirement. To achieve the notched band, a G-shaped slot structure is embedded in the UWB BPF. Specifically, the proposed filter exhibits an ultra narrow notched band at 5.8 GHz with −28 dB insertion loss and 10 dB notched FBW of 2.36%. The U-shaped DGS is also employed for harmonic suppression, which give −20 dB harmonic suppression in 11.0 GHz–12.0 GHz. With close agreement in simulated and measured results, the proposed UWB bandpass filter is attractive to the UWB systems for the purpose of blocking WLAN signals.

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