Compact Ultra Wide Band (UWB) Bandpass Filter using Hybrid Microstrip Coplanar Waveguide Structure

Vishal P.Kothawade
Dept. of E&TC
RCPIT, Shirpur, Dist.-Dhule.

P.J.Deore, PhD
Dept. of E&TC
RCPIT, Shirpur, Dist.-Dhule.

J.B.Jadhav
Dept. of E&TC
RCPIT, Shirpur, Dist.-Dhule.

ABSTRACT

Filters are the key components in communication system. Compactness of filters is an important design constraint. Due to limitations in design methods for filters at low frequency, several newer techniques for filter design at higher frequency are invented. Hybrid microstrip coplanar waveguide technique among these techniques gives a way to design a compact filter structure meeting the required (UWB) specifications. In this paper, a filter based on hybrid microstrip coplanar waveguide structure is designed. The passive elements are realized using the microstrip, coplanar waveguide (CPW) and transitions between microstrip and CPW. A high pass filter prototype and a connecting capacitor between input and output ports is used to design a UWB bandpass filter having three transmission poles in UWB band. Capacitor acts as a controlling element for UWB band. Quasilumped microstrip structure is used to realize high pass filter elements and connecting capacitor can be realized using parallel coupled microstrip stubs. The coupling between top microstrip and bottom CPW helps to get a flat band within 3.1 to 10.6 GHz.

General Terms

Filter techniques, Scattering Parameters, Group Delay, Passband, Stopband (attenuation).

Keywords

Microstrip, Coplanar Waveguide, UltraWideBand, Bandpass Filter, Coupling, High Pass Filter.

1. INTRODUCTION

Federal Communication Commission (FCC) sanctioned the unlicensed use of frequency band starting from 3.1 GHz to 10.6 GHz as UltrWideBand (UWB) in Feb. 2002. This band gives a spectrum of about 7500 MHz. Since then, researchers are tryimg to develop a bandpass filter which shows a good performance in UWB band. There are several advantages of UWB such as maximum bandwidth for transmission and reception of signals, low power values while communication, high speed wireless data transmission, coexistence, avoids unauthorized access of UWB signals etc.

Ultra-wideband (UWB) technology finds many applications such as imaging system, ground penetrating radar, Communications and Measurements, Vehicular radar, wall imaging, Surveillance and medical systems. The term fractional bandwidth denoted as B_f is used to define the UWB performance of designed UWB devices. For UWB band, the fractional bandwidth seems to be 110% which is more as compared to other existing systems.Fractional bandwidth is defined as:

$$B_f = 2\left[\frac{(f_h - f_l)}{(f_h - f_l)}\right] \tag{1}$$

where f_h and f_l are the higher and lower 3 dB bandwidth, respectively. In [4], several UWB filter techniques are given. A broadband is achieved using hybrid structure of microstrip and CPW in [5].In [5], Input port is at top microstrip and output port is taken at bottom CPW. Electromagnetic coupling between microstrip & CPW plays important role in getting broad band. In [6], by adjusting the bottom CPW slots and appropriate coupling between microstrip & CPW, a five pole filter structure is designed. In [7], a broadside coupled structure is used to design UWB bandpass filter. A three & five pole compact UWB bandpass filter is designed with the help of quasilumped elements in [8]. Combination of short circuited CPW quarter wavelength resonator at bottom & parallel coupled microstrip at top is used to design a simple UWB bandpass filter in [9]. In [10], a four pole UWB bandpass filter using CPW split mode resonator at bottom and coupled microstrip at top is designed.

2. UWB BANDPASS FILTER

The frequency range for UWB is 3.1 GHz to 10.6 GHz. The center frequency for this band is 6.85 GHz. A high pass filter prototype is used to design a UWB bandpass filter. High pass filter comprised of two series capacitors and a single shunt inductor. Using this structure, a high pass filter having a cut-off frequency near to lower UWB band edge is designed. This cut-off frequency can be set using the values of lumped elements i.e. series capacitors and shunt inductor. The microstrip to CPW transition is used to realize series capacitors and the shunt inductor is realized using short circuited stub of CPW at bottom of substrate. To change the frequency response from high pass to bandpass, a capacitor connecting input and output port need to be introduced. The connecting capacitor acts as a controlling element which controls the position of transmission zeros in passband. This connecting capacitor is implemented by means of a parallel coupled microstrip stubs at the top of substrate. The short circuited CPW at bottom of common substrate performs the function of shunt inductor. The square shaped conducting patch of CPW provides a coupling to the coupled microstrip segments and microstrip patches at top of substrate. The substrate used is Rogers 4003C with ε_r=3.38, tanδ=0.002, h=0.508mm.The series capacitors are labeled as C_1, the shunt inductor as L_1 and connecting common capacitor as C_2.The increasing or decreasing of C_2 has an effect on the location of transmission zeros within passband.

As the value of C_2 is increased the lower transmission zero moves towards higher frequency. This also have an effect on upper transmission zero. The upper transmission zero moves towards lower frequency values as value of C_2 is increased. The value of C_2 can be changed by changing the dimensions of parallel coupled microstrip stubs at top of substrate. The length of parallel coupled microstrip stubs at top of substrate have an effect on value of C_2. As the length of parallel coupled microstrip stubs at top of substrate is increased, the value of C_2 is increased. Thus the position of transmission zeros can be changed by changing the length of parallel coupled microstrip stubs at top of substrate. As the physical structure of filter is symmetrical, the even-odd mode analysis technique can be used for analysis [12]. Firstly, the even and odd mode impedances are formulated. Secondly, using the formula for transmission coefficient and equating it to zero (S_{21}=0), the transmission zeros can be located. The figure 2.1 shows the structure. The orange coloured structure is microstrip (top) and green coloured structure is CPW (bottom).

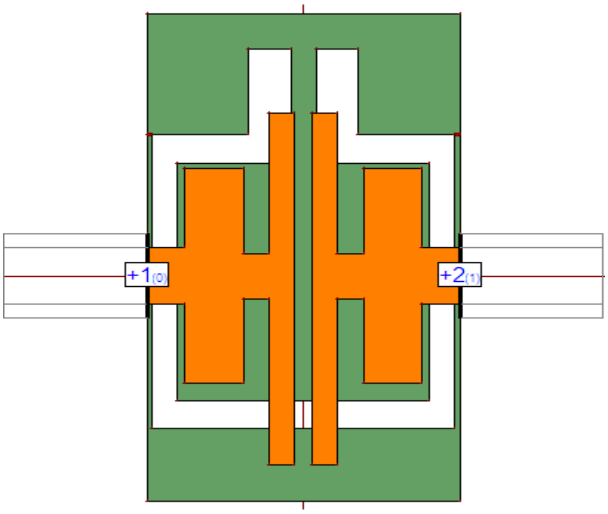

Fig. 1 UWB Bandpass filter

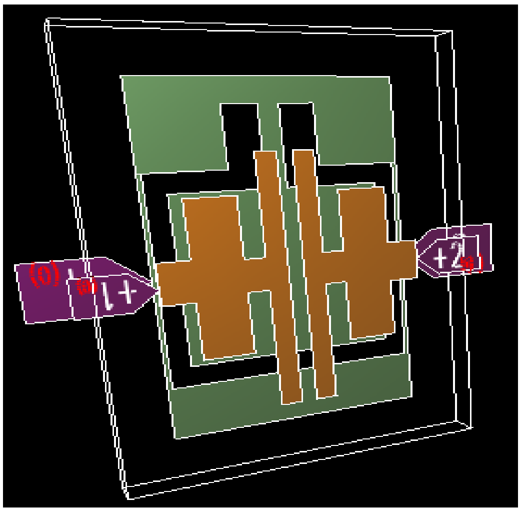

Fig. 2 Top microstrip structure

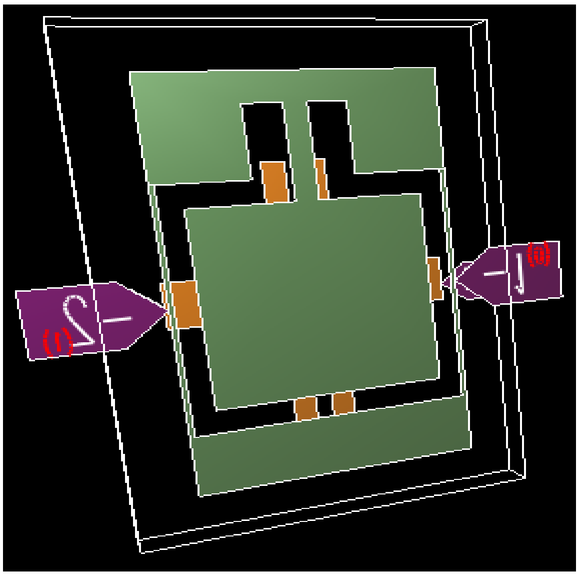

Fig. 3 Bottom CPW structure

The microstrip structure at the top of substrate is shown in figure 2.2 and coplanar waveguide (CPW) at the bottom of substrate is shown in figure 2.3. The characteristic impedance of input and output microstrip at top of substrate is 50 ohm. The equivalent circuit of this structure is shown in figure 2.4.

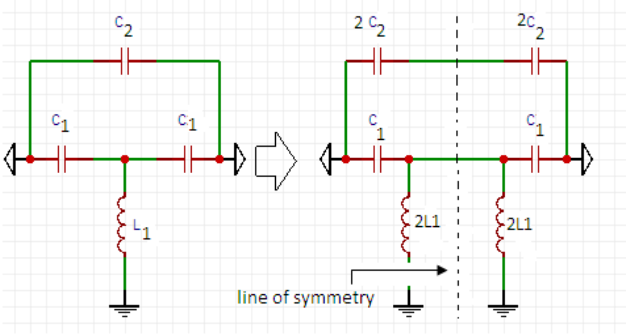

Fig. 4 Equivalent circuit – Symmetrical network

The even and odd mode impedances can be formulated from the equivalent circuit.

2.1 Even mode Impedance

Under even mode condition, the line of symmetry acts as a open circuit as shown in figure 2.5. The capacitor C_2 will be disconnected from circuit.

$$Z_{even} = R + jX \tag{2}$$

$$Z_{even} = 0 + j(X_L - X_C) \tag{3}$$

$$Z_{even} = j\left(\omega L_1 - \frac{1}{\omega C_1}\right) \tag{4}$$

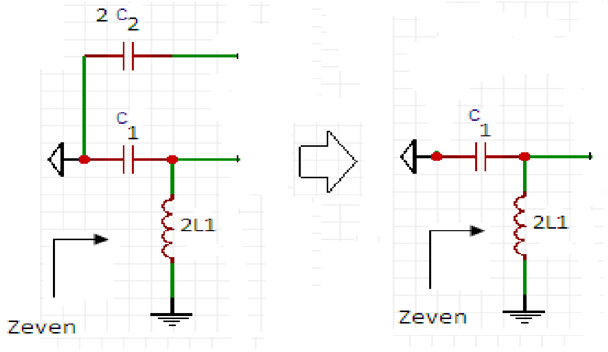

Fig. 5 Even mode impedance

2.2 Odd mode Impedance

Under odd mode condition, the line of symmetry acts as a short circuit as shown in figure 2.6. The inductor L_1 will be shorted to ground.

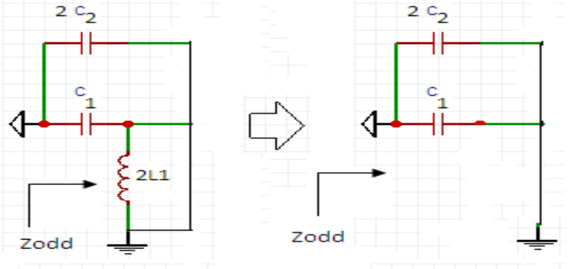

Fig. 6 Odd mode impedance

$$Z_{odd} = R + jX \tag{5}$$

$$Z_{odd} = 0 + j(X_L - X_C) \tag{6}$$

$$Z_{odd} = \frac{1}{j\omega(C_1 + 2C_2)} \tag{7}$$

Using the theorem of superposition, the transmission coefficient S_{21} is given as,

$$S_{21} = \frac{(Z_{even} - Z_{odd})Z_0}{(Z_{even} + Z_0)(Z_{odd} + Z_0)} \tag{8}$$

Using formula of S_{21}, the transmission zero can be found by equating to zero as there is no transmission of signal for this frequency. So, equating S_{21} to zero gives equality of even and odd mode impedances. The input and output port is having characteristics impedance Z_0. The characteristic impedance of input and output port is taken as Z_0 equal to 50Ω. The center frequency for UWB band is 6.85GHz. The width of input and output microstrip port is calculated in accordance with height of substrate, effective dielectric constant, free space impedance and characteristic impedance [14].For characteristic impedance of input and output port to be 50Ω, the width of input and output microstrip is taken to be 1 mm.

3. SIMULATION RESULTS

The structure is simulated using MentorGraphics IE3D electromagnetic simulator. The simulator uses method of moments to analyse the structure. IE3D is a full wave simulation and optimization package for the analysis and design of 3D & planar microwave circuits. Basically, it solves the Maxwell's equations in an integral form. The simulated results are shown in figure 3.1. While simulating the structure, the ground is considered as finite ground. Differential port is applied to the structure.

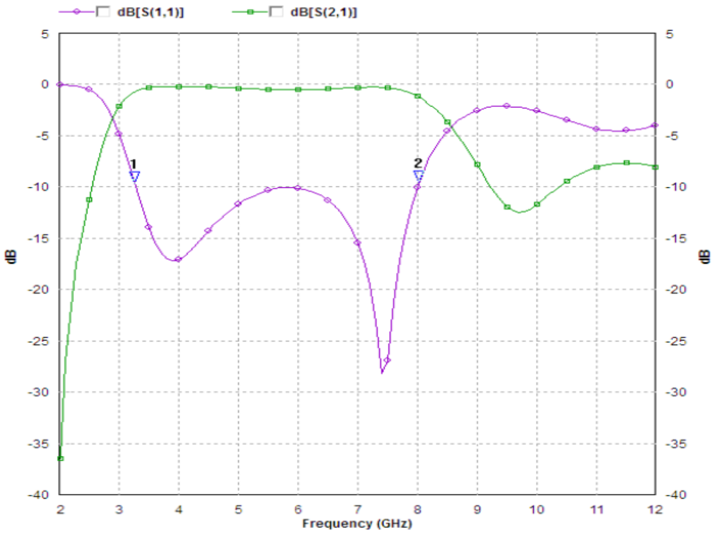

Fig. 7 Simulated results S-Parameters

As seen from figure 3.1, the insertion loss (S_{21}) is minimum in the UWB passband. The S_{21} is almost equal to zero within UWB passband. The return loss is less than -10dB within UWB passband. The return loss within desired UWB band is very less so that there will be proper transmission of signal from input to output port.

4. CONCLUSION

Hybrid microstrip coplanar waveguide technology can be used to design a very compact filter structure having a good frequency response in UWB band. The size of designed filter is almost equal to 1cm x 1cm. The results are more satisfactory than those obtained in the previously proposed designs. The designed filter shows good rejection in out of band response. The technique of hybrid microstrip/CPW gives more flexibility in designing the structure. Use of quasilumped elements gives compactness to the structure. With the help of connecting capacitor between inut and output port, the location of lower and upper transmission zeros can be adjusted appropriately.

5. REFERENCES

[1] Revision of part 15 of the Commission`s rules regarding ultra-wideband transmission systems, FCC, Washington, DC, Tech. Rep, ET-Docket 98-153, FCC 02-48, adopted in Feb. 2002.

[2] G. R. Aiello and G. D. Rogerson, “Ultra-wideband wireless systems," IEEE Microw. Mag., vol. 4, no. 2, pp. 36-47, Jun. 2003.

[3] C.-C. Chong, F. Watanabe, and H. Inamura, “Potential of UWB technology for the next generation wireless communications," in Proc. 2006 , IEEE 9th Int. Symp. Spread Spectrum Techniques and Applications, Aug. 2831, 2006, pp. 422-429.

[4] Zhang-Cheng Hao and Jia-Sheng Hong. “Ultrawideband Filter Technologies", IEEE Microw. Mag., pp. 56-68, Jun. 2010.

[5] L. Zhu and W. Menzel, “Broad-band microstrip-to-CPW transition via frequency-dependent electromagnetic coupling," IEEE Trans. Microw. Theory Tech., vol. 52, no. 5, pp. 1517-1522, May 2004.

[6] H.Wang, L. Zhu, and W. Menzel, “Ultra-wideband bandpass filters with hybrid microstrip/CPW structure," IEEE Microw. Wireless Compon. Lett., vol. 15, no. 12, pp. 844-846, Dec. 2005.

[7] K. Li, D. Kurita, and T. Matsui, “An ultra wideband bandpass filter using broadside-coupled microstrip-coplanar waveguide structure," in IEEE MTT-S Int. Microwave Symp. Dig., 2005, pp. 675-678.

[8] Tsung-Nan Kuo, Shih-Cheng Lin, and Chun Hsiung Chen, “Compact UltraWideband Bandpass Filters Using Composite Microstrip Coplanar Waveguide Structure,"IEEE Trans. Microw. Theory Tech., vol. 54, no. 10, October 2006.

[9] N. Thomson and J.-S. Hong, “Compact ultra-wideband microstrip / coplanar waveguide bandpass filter," IEEE Microwave Wireless Compon. Lett., vol. 17, no. 3, pp. 184-186, Mar. 2007.

[10] T.-N. Kuo, C.-H. Wang, and C. H. Chen, “A compact ultra-wideband bandpass filter based on split-mode resonator," IEEE Microwave Wireless Compon. Lett., vol. 17, no. 12, pp. 852-854, Dec. 2007.

[11] X. Luo, J.-G. Ma, K. Ma, and K. S. Yeo, “An ultra-wideband bandpass filter using hybrid structure of microstrip and CPW," Microw. Opt. Technol. Lett., vol. 51, no. 10, pp. 2470-2473, Oct. 2009.

[12] D. M. Pozar, Microwave Engineering, 2nd ed. New York: Wiley, 1998.

[13] Rainee N. Simons, Coplanar Waveguide Circuits, Components and Systems, John Wiley Sons, Inc.

[14] J. S. Hong and M. J. Lancaster, Microstrip Bandpass Filters for RF/Microwave Applications. New York: Wiley, 2001.

[15] Mentor Graphics IE3D electromagnetic simulator.