Stepped and Hairpin Combined Wideband Bandpass Filter for ISM Band

[1]Mangesh J. Joshi, [2]Girish G. Bhide,[3]Ashish B. Vartak
Department of Electronics
Finolex Academy of Management & Technology, Ratnagiri, India
[1]mangeshjoshi2407@gmail.com, [2]girishbhide72@gmail.com, [3]vartak.a@gmail.com

***Abstract*— This work explains the design of wideband bandpass filter for ISM 2.4 GHz band. 800 MHz of filter bandwidth is attained without compromise for insertion loss. FR4 material is used as substrate with dielectric constant 4.4 and height 1.6mm. Return loss at center frequency is approximately -34 dB and the insertion loss varies between of -0.7 to -1 dB which found to be stable in 800 MHz bandwidth range. In this combination of hairpin and stepped impedance is used to design the proposed filter.**

***Keywords*— CST, Hairpin, Industrial –Scientific- Medical (ISM), Stepped impedanc, Ultra-wideband filter**

I. Introduction

A new wideband and ultra-wideband systems being deployed with frequency spectrum crowding, there is demand for wideband filters [1]. There are lots of techniques can be used to design the type of filters. In this techniques enhancement of coupling at the starting and ending stages is considered [2]. Multimode resonators, defected ground structures (DGS) and combination of high pass and low pass filter can be used to design such filters [3]-[5]. 3.1 to 10.6 GHz is range of UWB systems [6]. There are various types of filters exists such as edge coupled, stepped impedance, hairpin, baluns etc. [8]; with each have its own favorable and unfavorable conditions. We can improve the results of filter by hybriding the two types of filter structures. Then designed filters are tuned to obtain required results. In this paper design of combination of stepped and hairpin filter is proposed. Stepped impedance filter give better return loss and hairpin structure controls the bandwidth. Design of proposed filter can carried out be following steps given below:

Steps:
1] Initially design the stepped impedance Low-Pass filter.
2] Design the Hairpin filter for desired frequencies.
3] Make hybrid of both Stepped and Hairpin filter.
4] Simulate the design using CST Simulation software and optimize the structure for desired results

II. Theoretical implementation of Filter

Image parameters method or insertion loss method can be used to design the filter [9]. In image parameter method two port filter sections are cascaded without specifying required response, which offers good attenuation but more number of iterations are required to achieve the required results. While in insertion loss method cut –off frequency is specified as design target and we met the required specification with less number of iterations. In this paper the design is carried out using insertion loss method. The proposed design can be used for Industrial –Scientific- Medical band, with low insertion loss as much as possible. There are various ways to design the filter for specific application with specific requirements, such as Bessel, Chebyshev, and Gaussian etc.
In general in insertion loss method design starts with low pass filter prototype design then transformation is done from low pass to band-pass and at last frequency and impedance transformation is done.
In this work stepped impedance and hairpin filter is design and combining both filters wideband response is achieved.
The mathematical formulas for designing above filters are same as given in [8][9].

A. *Stepped impedance low pass filter design*

Impedance parameters can be obtained by deriving approximate equivalent circuits for quarter wavelength transmission lines [9]

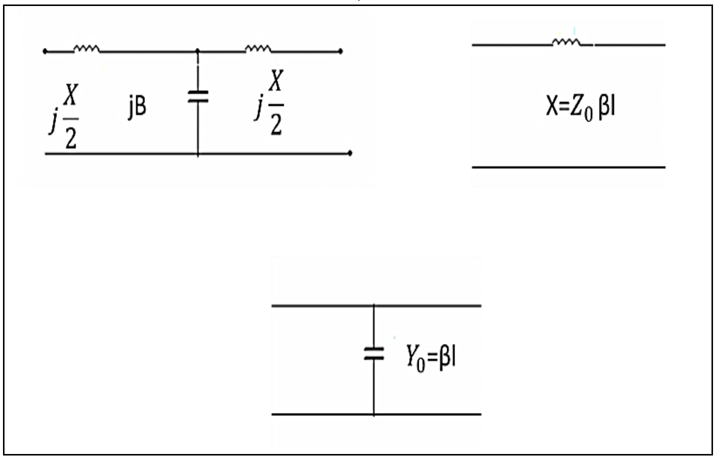

Fig. 1. T-section equivalent for quarter wave transformer

$$Z_{11} = Z_{22} = \frac{A}{C} = -jZ_0 \cot\beta l \quad (1)$$

$$Z_{12} = Z_{21} = \frac{1}{C} = -jZ_0 \sec\beta l \quad (2)$$

$$Z_{11} - Z_{12} = -jZ_0\left(\frac{\cos\beta l - 1}{\sin\beta l}\right) = jZ_0 \tan\left(\frac{\beta l}{2}\right) \quad (3)$$

Deriving further and applying scaling equations, inductors and capacitors can be obtained as [9],

$$\beta l = \frac{LR_0}{Z_h} \quad (4)$$

$$\beta l = \frac{CZ_l}{R_0} \quad (5)$$

B. Hairpin resonator design

By folding half wavelength parallel coupled lines we can obtain hairpin resonators theoretically [8][9]. Equations of edge coupled resonators are applicable for hairpin design. But due to folding of parallel coupled resonators in U shape, coupling between two resonators reduces that should be considered while designing of filter. Low-pass prototype filter can be designed by similar way as described in [8]. Bandpass filter can be converted from low pass filter by using

$$Q_{e1} = \frac{g_0\, g_1}{FBW} \quad (6)$$

$$Q_{en} = \frac{g_n\, g_{n+1}}{FBW} \quad (7)$$

$$M_{i,i+1} = \frac{FBW}{g_i\, g_{i+1}} \quad (8)$$

In which $Q_{e1}$and Q_{e2} are external quality factors at input and output and coupling coefficients between two adjacent resonators can be given by $M_{i,\,i+1}$.

Based on theoretical analysis of odd and even mode analysis of quarter wave transformers, for hairpin elements we can write,

$$Z_{oeven} = \frac{1}{j\omega c_2} \,||\, \left(j\omega L_1 + \frac{1}{j\omega c_1} + \frac{1}{j\omega c_3}\right) \quad (9)$$

$$Z_{oodd} = j\omega L_1 + \frac{1}{j\omega c_3} \quad (10)$$

The transfer function for hairpin resonator can be written as,

$$S_{21} = \frac{Z_0(Z_{oeven} - Z_{oodd})}{(Z_{oeven} + Z_0)(Z_{oodd} + Z_0)} \quad (11)$$

Hairpin resonators can be divided into electric coupling, magnetic coupling, the first mixed coupling, and the second mixed coupling [10].

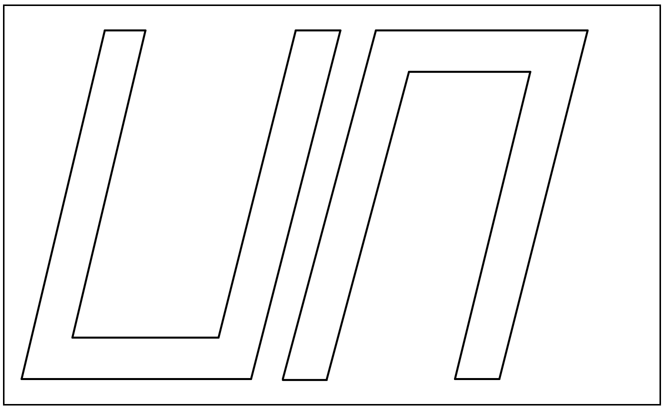

Fig. 2. Fixed coupling for hairpin resonators

Two hairpin resonators are cascaded through branch coupling who's A_1 matrix can be shown below,

$$A_1 = \begin{bmatrix} \frac{Z_{oeven}+Z_{oodd}}{Z_{oeven}-Z_{oodd}}\cos\theta_c & j\frac{(Z_{oeven}-Z_{oodd})^2-(Z_{oeven}+Z_{oodd})^2\cos^2\theta_c}{2(Z_{oeven}-Z_{oodd})\sin\theta_c} \\ j\frac{2\sin\theta_c}{(Z_{oeven}-Z_{oodd})} & \frac{Z_{oeven}+Z_{oodd}}{Z_{oeven}-Z_{oodd}}\cos\theta_c \end{bmatrix} \quad (12)$$

the equivalent circuit can be written as,

$$A_2 = \begin{bmatrix} \cos\theta_c & j\frac{\sin\theta_c}{Y_0} \\ jY_0\sin\theta_c & \cos\theta_c \end{bmatrix} \begin{bmatrix} 0 & \frac{j}{J} \\ -jJ & 0 \end{bmatrix} \begin{bmatrix} \cos\theta_c & j\frac{\sin\theta_c}{Y_0} \\ jY_0\sin\theta_c & \cos\theta_c \end{bmatrix}$$

$$= \begin{bmatrix} \left(\frac{J}{Y_0} + \frac{Y_0}{J}\right)\sin\theta_c\cos\theta_c & j\left(\frac{J}{Y_0^2}\sin^2_{\theta_c} - \frac{\cos^2_{\theta_c}}{J}\right) \\ j\left(\frac{J}{Y_0^2}\sin^2_{\theta_c} - \frac{\cos^2_{\theta_c}}{J}\right) & \left(\frac{J}{Y_0} + \frac{Y_0}{J}\right)\sin\theta_c\cos\theta_c \end{bmatrix} \quad (13)$$

Matrices in equation (12) and (13) are conceptually equal [10]. Here we can obtain even and odd mode impedances as

$$\begin{cases} Z_{oeven} = \frac{1}{Y_0}\frac{1+(J/Y_0)\csc\theta_c+(J/Y_0)^2}{1-(J/Y_0)^2\cot\theta_c} \\ Z_{oodd} = \frac{1}{Y_0}\frac{1-(J/Y_0)\csc\theta_c+(J/Y_0)^2}{1-(J/Y_0)^2\cot\theta_c} \end{cases} \quad (14)$$

III. Filter Simulation And Results

The designed filter can be simulated in CST microwave studio. The CST Microwave studio works on method of moments. Using described concept stepped and hairpin filters have been designed to make hybrid to achieve improvement in results. After number of trials of low pass-bandpass ,bandpass- low pass final connection approach is fixed as shown in fig 3.

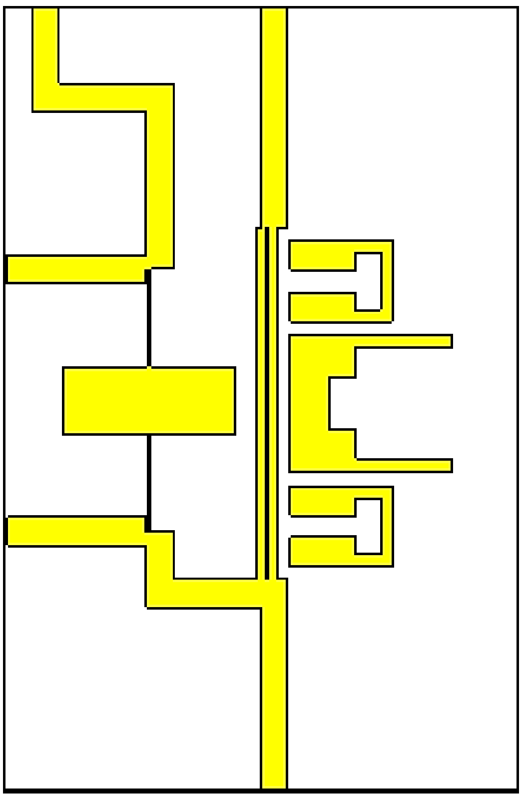

Fig. 3.Realized Filter Structure

Fig. 4 shows the return loss of the designed filter which works in frequency band from 2.00 to 2.8 GHz with 2.4 GHz as centered frequency

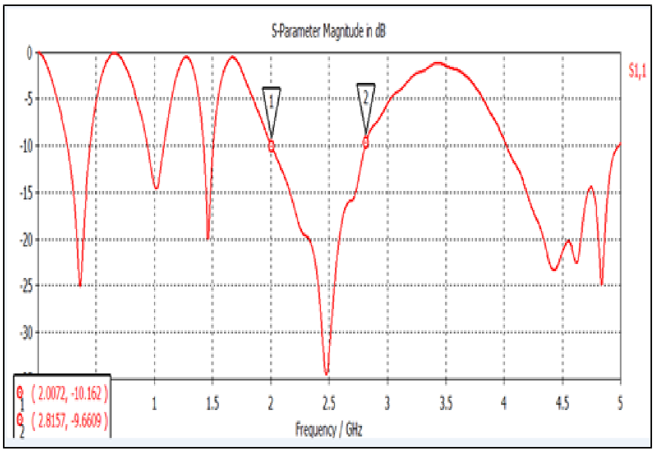

Fig. 4. Return loss of the designed filter

Fig. 5 shows the insertion loss of the designed filter ranging in 0.7 to 1 dB in passband range which is less as requirement of practical filter

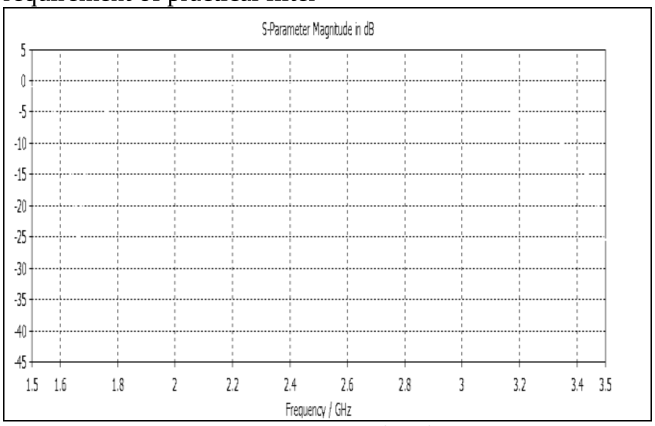

Fig. 5. Insertion loss of the filter

IV. Hardware And Test Results

Fig. 6. Shows the hardware implementation of Proposed filter which is fabricated on FR-4 substrate.

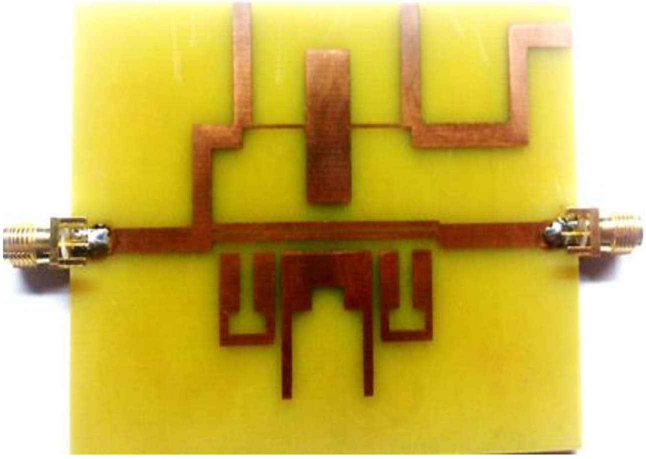

Fig. 6.Hardware Implementation of Filter

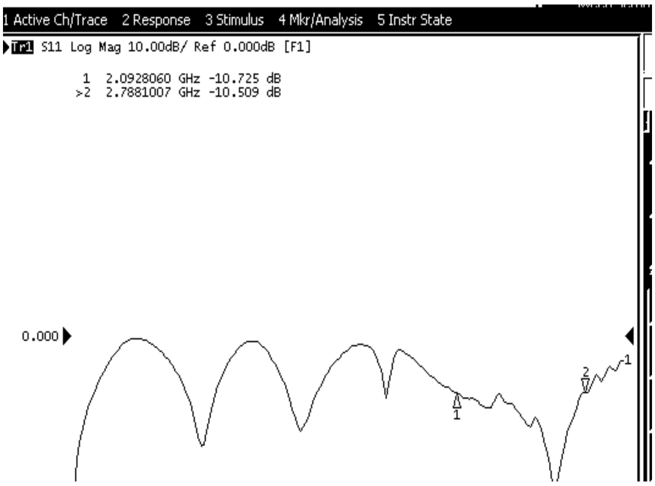

Fig. 7. Return Loss of Fabricated Filter

Fig. 7. Shows the return loss of the fabricated filter which gives operating frequency band from 2.09 to 2.8 GHz with nearly centered at 2.4 GHz which matches with the simulated filter response.

V. Conclusion

In simulated results the return loss of filter is about -34 dB and achieving 800 MHz bandwidth as shown in Fig. 4. The filter have dimension of around 60 mm X 86.75 mm which is observed in Fig. 3.

Fig. 6. and Fig. 7. Shows the hardware implementation of proposed filter which gives the return loss nearly same as that observed in simulation respectively. 0.7 to 1db is observed range of Insertion loss of over the filter bandwidth,

References

[1] Reed, J.H.; Bernhard, J.T.; Jung-Min Park, "Spectrum Access Technologies: The Past, the Present, and the Future," Proceedings of the IEEE , vol.100, no. Special Centennial Issue, pp.1676,1684, May 13 2012

[2] Shaman, H.N., "New S-Band Bandpass Filter (BPF) With Wideband Passband for Wireless Communication Systems," Microwave and Wireless Components Letters, IEEE , vol.22, no.5, pp.242,244, May 2012

[3] L. Qiang, Y.J. Zhao, Q. Sun, W. Zhao, and B. Liu, "A compact UWB HMSIW bandpass filter based on complementary split-ring resonators," *Progress In Electromagnetics Research C, Vol. 11, 237-243, 2009.*

[4] Gomez-Garcia, R.; Alonso, J.I., "Systematic Method for the Exact Synthesis of Ultra-Wideband Filtering Responses Using High-Pass and Low-Pass Sections," Microwave Theory and Techniques, IEEE Transactions on , vol.54, no.10, pp.3751,3764, Oct. 2006 [5] M.Shobeyri and M.-H. Vadjed-Samiei, "Compact ultra-wideband bandpass filter with defected ground structure," *Progress In Electromagnetics Research, Vol. 4, 2008, pp. 25-31.*

[6] Steven K. Jones, "The Evolution of Modern The Evolution of Modern UWB Technology: A Spectrum Management Perspective", *FCC/OET Laboratory Technical Research Branch May 11, 2005*

[7]Anil Kamma, Swapnil R. Gupta, Gopi S. Reddy, and Jayanta Mukherjee, "Multi-Band Notch UWB Band Pass Filter With Novel Contiguous Split Rings Embedded In symmetrically Tapered Elliptic Rings", *Progress In Electromagnetics Research C, Vol. 39, 133-148, 2013.*

[8] Jia-Sheng Hong, M. J. Lancaster, "Microstrip Filters for RF/Microwave Applications", New York: John Wiley & Sons, 2001

[9] David m. Pozar, "Microwave Engineering", Second edition,Wiley publication

[10] Wensong Wang, Shuhui Yang, Yinchao Chen, "Experimental Design on Microstrip Line Bandpass Filters for WCDMA", *Multimedia Technology (ICMT), 2011 International Conference on, vol., no., pp.3054,3057, 26-28 July 2011*