Design of coplanar waveguide band-pass filter for S-band application

Pratik Mondal, Amit Ghosh, Susanta Kumar Parui

Department of Electronics and Telecommunication Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah 711 103, India
E-mail: pratik.mondal.1987@ieee.org

Published in *The Journal of Engineering*; Received on 21st December 2014; Accepted on 23rd February 2015

Abstract: Coplanar waveguide (CPW) has a huge demand for designing band-pass filter (BPF). In this study, the filter designed by open-ended CPW series stub which acts as a resonant circuit thus giving a band-pass response. As the number of open stub discontinuity is increased, the frequency response and roll-off rate of the proposed BPF has improved gradually. Electromagnetic simulated and measured results show a very good agreement with each other. The proposed filter is designed to obtain a frequency range of 1.97–4 GHz (S-band) having rising edge and falling edge selectivities of 35.9 and 45.7 dB/GHz, respectively.

1 Introduction

Band-pass filter (BPF) is an important component of every transreceiver. It is a passive component which selects certain bands of frequencies and rejects frequencies outside of the specified range, especially those frequencies which have the potential to interfere with the information signal. Previously, many research papers showed the design mechanism of compact BPF, parallel coupled BPF of image parameter method [1]. Coplanar waveguide (CPW) technology has a major advantage of easy integration with lumped elements as well as active components. Moreover, in CPW technology, the characteristic impedance is determined by the ratio of $w/(w+s)$, so size reduction is possible without limit. The realisation of CPW BPF by the discontinuity of the open stub has been proposed previously [2–4].

In this paper, an S-band BPF is designed by utilising CPW technology, having a major advantage of easy integration with lumped elements as well as active components, which is strongly desired in communication systems. The S-band spectrum is a leading application in the field of satellite mobile services, and is also used by weather radar, surface ship radar and by the National Aeronautics and Space Administration to communicate with the space shuttle and the International Space Station [5]. Our filter has not only considered the length of the open-ended series stub to form the equivalent resonant circuit at any particular resonant frequency, but has also optimised the width of the slots to form the discontinuity, such as the frequency response is achieved to obtain the bandwidth of 2–4 GHz, and by multiple series stubs arranged accordingly to achieve sharp selectivity and low insertion loss. Circuit cross talk parasitic radiation is minimised by series stubs being arranged in the central strip, and by fields being confined to the central strip only. Furthermore, air bridges are not required because of the symmetry of discontinuities [3].

The BPF is constructed using flame retardant 4 (FR4) substrate material of thickness 1.59 mm, relative dielectric constant of 4.4 and loss tangent of 0.02, which is a single side plated copper coated board (CCB). The software used for simulation of designs is carried out by the computer simulation technology (CST) software which computes by the field solving technique method of moments.

2 Design of open-ended series stub

In CPW technology, a series stub is designed by creating a discontinuity in the central strip by implementing two slots originating from the edge of the central strip on both sides of the ground, such that the slots are connected to each other as shown in Fig. 1*a*. At the end of the discontinuity or series stub, an open circuit is created which gives a short circuit at the input port for a length of quarter wavelength of the stub, that is, $\lambda_g/4$ where λ_g is the guided wavelength and thus giving a band-pass response [6].

The characteristic of this CPW circuit primarily depends on the length '*L*' as depicted in Fig. 1. Now if the length is near to the quarter wavelength ($\sim\lambda_g/4$), then it will behave as a resonant circuit of resonating frequency of which the quarter wavelength is considered. Otherwise, if the length is considered to be too small ($<\lambda_g/10$), then the same component will behave as an equivalent capacitance [7].

Thus, we will focus on the length of the stub to be quarter wavelength

$$L = \lambda_g/4 \tag{1}$$

where λ_g is the guided wavelength and is given by

$$\lambda_g = \lambda_0/\sqrt{\varepsilon_{eff}} \tag{2}$$

where ε_{eff} is the effective permittivity and is approximately given by

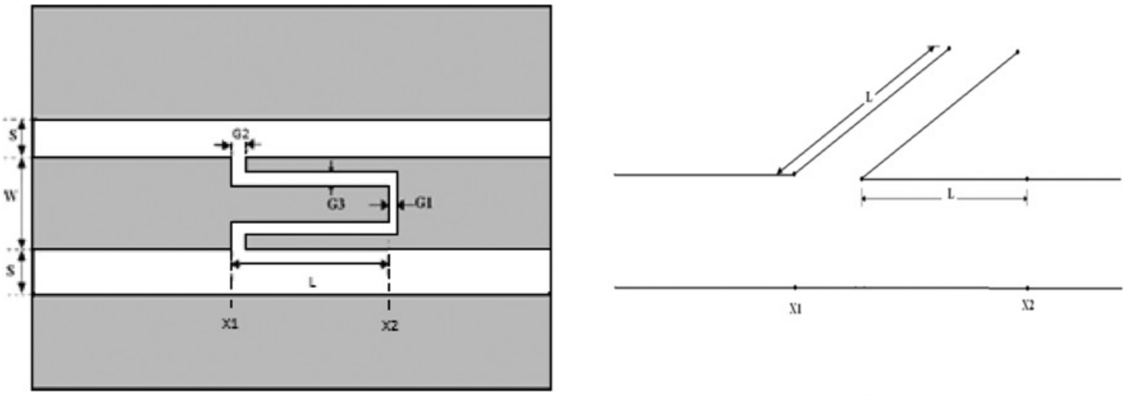
$$\varepsilon_{eff} = (\varepsilon_r + 1)/2$$

The discontinuity formed will be that of a quarter wave open-ended CPW series stub. Therefore the equivalent transmission line model as shown in Fig. 1*b*, which shows an open-circuited stub of length $\lambda_g/4$ which transforms a short circuit at the starting terminal of discontinuity which is responsible for a band-pass response.

3 BPF using oppositely oriented open-ended stub

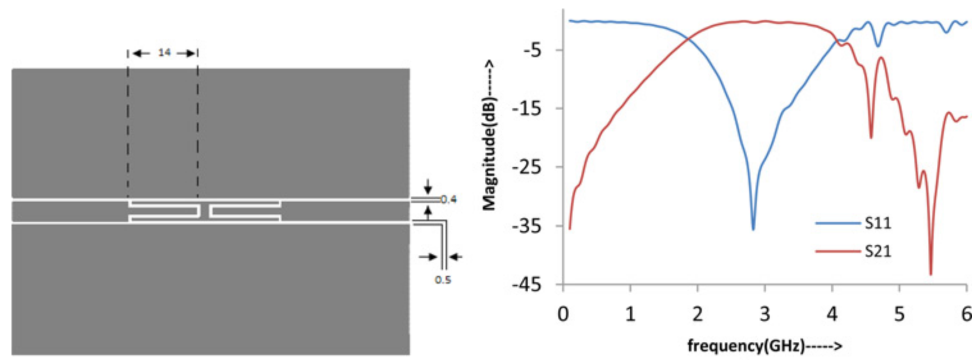
The basic filter design is constructed by implementing two $\lambda_g/4$ open stub oppositely oriented such that the discontinuities of each stub are close to each other as shown in Fig. 2*a*. The pattern formed with these slots is like a metal I-shape at the central strip, keeping in mind that the discontinuities must be kept closer to each others which provides a greater field confinement.

The length of the stub is chosen to have a centre frequency near to 3 GHz and the gaps have been optimised to have a good response [8]. This schematic diagram is then simulated using CST software and the result obtained is that of BPF having a 3 dB pass band from 1.87 to 4.04 GHz, thus covering the S-band with low insertion loss of −0.35 dB but the roll-off rate is observed to be poor as



a b

Fig. 1 *Central strip on both sides of the ground such that the slots are connected to each other*
a Open-ended series CPW stub
b Equivalent transmission line model



a b

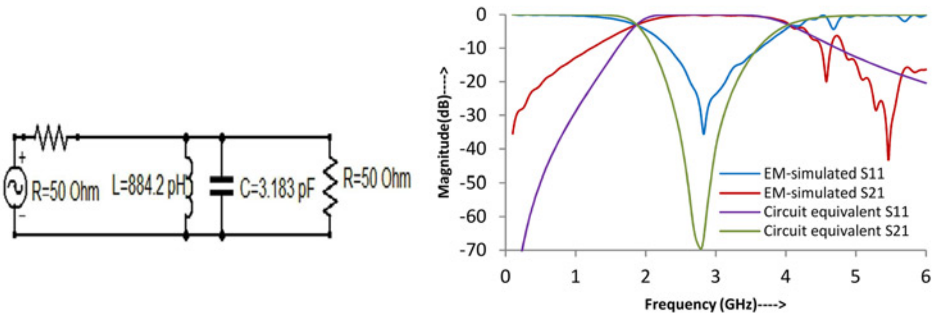
Fig. 2 *Basic filter design is constructed by implementing two oppositely oriented $\lambda_g/4$ open stub*
a Schematic of two oppositely oriented open-ended series stub (all dimension in millimetres)
b EM-simulates *S*-parameter responses

shown in Fig. 2*b* having rising edge selectivity of 12 dB/GHz and falling edge selectivity of 14.65 dB/GHz.

As open-ended series stub of length $\lambda_g/4$ transforms a short circuit at the starting terminal of discontinuity, the equivalent circuit model can be realised by the parallel inductance and capacitance (LC) resonator circuit as shown in Fig. 3*a*. The simulated results of the equivalent circuit model as described in Fig. 3*a* are compared with electromagnetic (EM)-simulated results and good agreement is obtained as shown in Fig. 3*b*.

4 Design of the proposed BPF

Now in order to increase the sharpness of the filter, the order of the filter needs to be increased thereby its component in the design.



a b

Fig. 3 *Simulated results of the equivalent circuit model*
a Equivalent circuit modelling
b Comparative study of circuit simulated and EM-simulated response

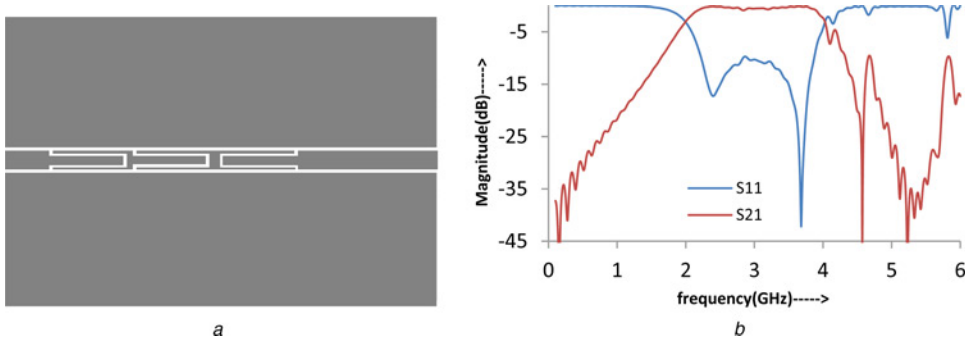


Fig. 4 *Open-ended stub in series*
a Schematic of BPF using three open-ended series stub
b EM-simulates *S*-parameter responses

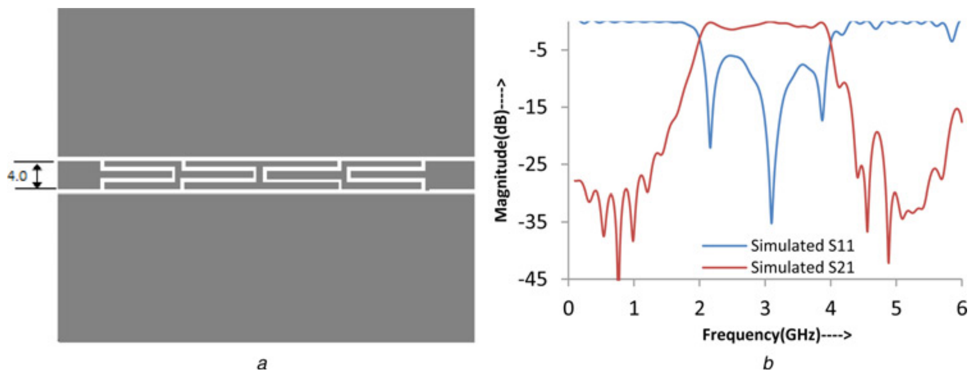


Fig. 5 *Layout design of the proposed CPW BPF is given along with its precise dimensions*
a Schematic of the proposed BPF using four open-ended series stub in symmetric manner (all in millimetres)
b EM-simulates *S*-parameters

Hence we add another open stub in series with the previous figure as seen in Fig. 4*a*. It is then simulated to observe the result as shown in Fig. 4*b* having a bandwidth of 2 GHz, ranging from 2 to 4.02 GHz with an insertion loss of −0.88 dB having an improved sharpness in the band-pass response of 18.89 and 34.69 dB/GHz rising edge and falling edge selectivities, respectively.

To obtain more sharp BPF or to achieve sharp skirt-selectivity, another stub is provided on the other side to have a complete symmetric structure such that a good possible compactness is implemented to achieve a greater field confinement within the circuit than that of other straight open stub in series or shunt stubs. It is also to be noted that the order of the filter is also increased; that is, the number of poles increases as the number of series stubs are increased. Finally, a three pole BPF has been obtained with quite higher selectivity or roll off. The layout design of the CPW BPF is given along with its precise dimensions as shown in Fig. 5*a*. Now this layout design is simulated and the corresponding result shows an S-band filter response from 1.97 to 4 GHz with an insertion loss of −1.07 dB and here we observe the sharp selectivity of 35.9 dB/GHz at the rising edge and 45.7 dB/GHz at the falling edge as shown in Fig 5*b*.

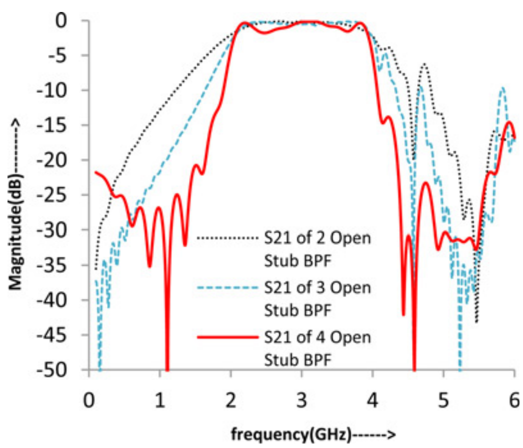


Fig. 6 *Comparative study of open-ended series stub BPF*

Then, we made a comparative study starting from the first diagram of two oppositely oriented open stubs, then three stubs, and finally four stubs, and the response is observed. We have seen that the bandwidth for all the cases is almost the same from 2 to 4 GHz but there is a notable change in the sharpness of the filter response; as the number of stubs is increased, the roll-off rate of the BPF response improves gradually, as shown in Fig. 6. However, with the increase of stub discontinuities, the insertion loss slightly increases, although the loss is quite low.

Fig. 7*a* shows an equivalent lumped circuit model for the proposed BPF having four open stubs in a symmetric manner. This lumped model has been further simulated with quite universal circuit simulator and the results are also similar to the EM-simulated response as shown in Fig. 7*b*.

Finally, this schematic diagram of multiple stub series CPW BPF is then fabricated using a single side copper plated FR4 substrate having relative permittivity $\varepsilon_r = 4.4$ and the height of the substrate to be 1.59 mm. After proper pattern being etched on the material, it is then connected to 50 Ω SMA connectors at both the ports and the complete fabricated picture is shown in Fig. 8*a*. The scattering parameters of fabricated structure are then measured by Agilent make Vector Network Analyzer (model N5230A) and the result

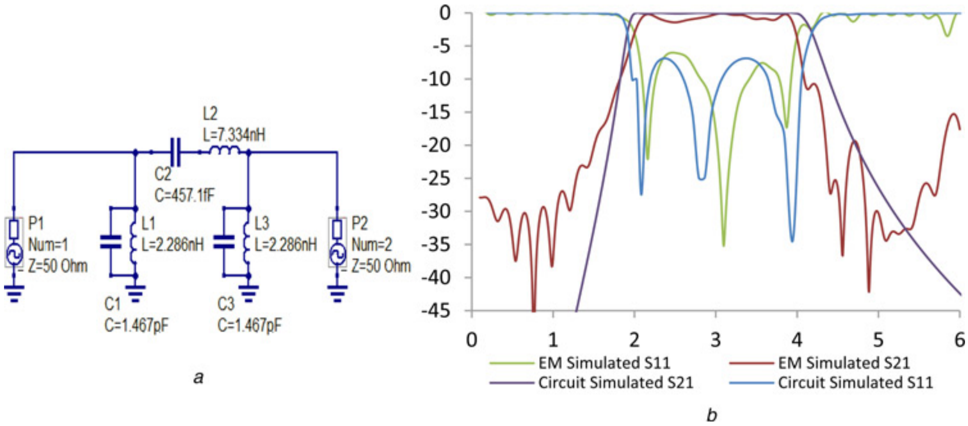


Fig. 7 *Equivalent lumped circuit model for the proposed BPF having four open stubs*
a Circuit equivalent of the proposed BPF
b Comparison of EM-simulates and circuit simulated *S*-parameter responses

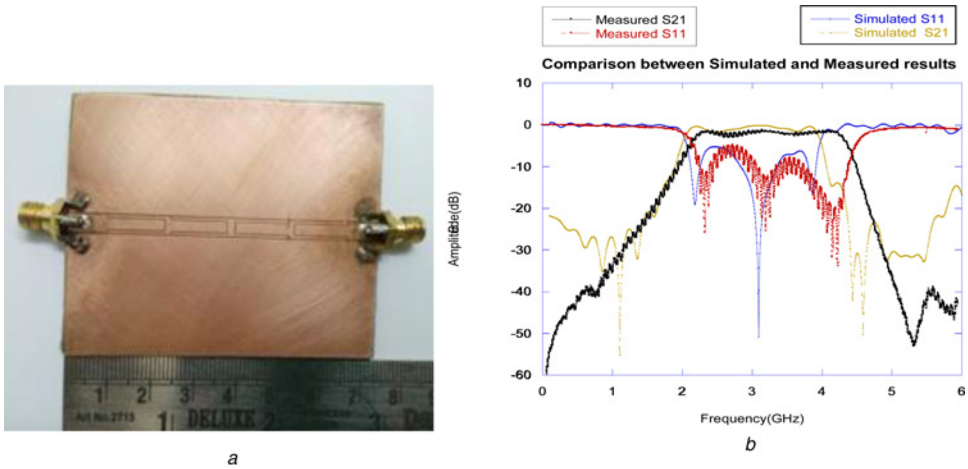


Fig. 8 *Ports and the complete fabricated picture*
a Fabricated prototype of the proposed BPF
b Comparison between simulated and measured *S*-parameters

obtained is compared with the previous simulated response, which is observed to have near agreement in the response as shown in Fig. 8*b*.

5 Conclusion

A BPF is constructed by open-ended CPW series stub which acts as a resonant circuit, thus giving a band-pass response. In this paper, the sharpness of the filter has been improved by proper arrangement and increase of series open-ended stubs, thus providing higher-order BPF. As it is designed with CPW technology having a complete uniplanar structure, there is an ease of fabrication to a single-sided CCB board and a good relaxation in design, as it primarily depends on the width to gap ratio. This multiple series stub design is easy to design and fabricate, not requiring any via holes or air bridge but providing a simple yet effective way to design a filter having a very good roll-off rate. Moreover, the simulated and measured results show a very good agreement with each other. S-band BPF is utilised over the application of satellite and radar communication.

6 Acknowledgment

This work was supported by the University Grants Commission (U.G.C.) Government of India.

7 References

[1] Dai G.L., Xia M.-Y.: 'Novel miniaturized bandpass filters using spiral-shaped resonators and window feed structures'. Progress in Electromagnetics Research, PIER 100, 1997, pp. 235–243
[2] Simons R.N., Ponchak G.E.L.: 'Modeling of some coplanar waveguide discontinuities', *IEEE Trans. Microw. Theory Tech.*, 1988, **36**, pp. 1796–1803
[3] Dib N.I., Katehi L.P.B., Ponchak G.E., Simons R.N.: 'Theoretical and experimental characterization of coplanar waveguide discontinuities for filter applications', *IEEE Trans. Microw. Theory Tech.*, 1991, **39**, pp. 873–882
[4] Hettak K., Dib N., Sheta A.-F., Toutain S.: 'A class of novel uniplanar series resonators and their implementation in original applications', *IEEE Trans. Microw.*, 1998, **46**, (9), pp. 1270–1276
[5] Rainee N.S.: 'Coplanar wave guide circuits, components, and systems' (John Wiley & Sons Inc., New York, NY, 2001), pp. 272–274
[6] Weller T.M., Katehi L.P.: 'Miniature stub and filter designs using the microshield transmission line'. IEEE MTT-S Digest, 1995, **2**, pp. 675–678
[7] Sharma A.K., Wang H.: 'Experimental models of series and shunt elements in coplanar MMIC's'. IEEE Int. Microwave Symp. Digest, Albuquerque, NM, 1–5 June 1992, pp. 1349–1352
[8] Masood R., Mohsin S.A.: 'Optimization of the S-parameter response of a coplanar waveguide series short stub for broadband applications'. IEEE, 2010, pp. 384–388