Finite Ground CB-CPW Bandpass Filter using Vertically Installed Coupled Open-ended Stubs

Pratik Mondal [1], Susanta Kumar Parui [2], and Rajesh Bera [1]

[1] Department of Electronics and Communication Engineering
Gayatri Vidya Parishad College of Engineering (Autonomous), Madhurawada, Visakhapatnam-530 048, India
pratik665@gmail.com, rajeshkiit12@gmail.com

[2] Department of Electronics & Tele-communication Engineering
Indian Institute of Engineering Science and Technology, Shibpur, Howrah-711103, India
arkapv@yahoo.com

Abstract **─** In this paper, a conductor backed coplanar waveguide (CB-CPW) 3rd order bandpass filter is designed using coupled open-ended stub resonator placed vertically to the signal line. Vertically loaded open ended stubs are designed at quarter wavelength so as to behave like a short circuit at the input terminal thus giving a band-accepted response with lesser metallic area or minimum size. Four such coupled open ended resonators are placed in series and also in closely manner to provide greater field confinement of the proposed bandpass filter. The bandpass filter is designed for a center frequency of 2.5 GHz with FBW of 97.89%, insertion loss of <0.5dB, rising and falling edge selectivity of 30.75 dB/GHz and 27.01dB/GHz respectively with a wide stopband of around 4GHz after the desired passband. Further to validate the design technique six such resonators are placed to obtain 5th order bandpass filter.

Index Terms **─** Bandpass filter, CB-CPW, open-ended, series-stub, vertically installed.

I. INTRODUCTION

Bandpass filter (BPF) is one of the prime components ever for designing any trans-receiver system. Researchers paid much attention on designing of high selective and compact bandpass filter simultaneously in microstrip as well as in Co-planar waveguide (CPW) technology. CPW technology has advantages of easy integration with lumped and active elements. The characteristic impedance of a CPW transmission line is determined by the ratio of w/(w+s), thus unlimited size reduction is possible and the frequency variation of effective permittivity is lower than microstrip which further simplifies broadband circuit design [1]. CPW circuits are low cost, better in performance and easier to fabricate than circuits based on other planar technology. The realization of CPW band pass filter by the discontinuity of the open and short ended stubs has been proposed earlier [2]. Using CPW-structures leaky wave, over moding effect and other undesired modes of propagations are avoided [3]. Conventional CPW has disadvantages of lower thermal dissipation, lower structural strength and experience higher losses compared to microstrip. To solve enormous problems aroused while using conventional CPW with its semi-infinite ground planes, a separate type of coplanar waveguide with electrically narrow ground planes had been developed [4]. This new transmission line which was called conductor backed coplanar waveguide (CBCPW) has several advantages which made it superior for RF and microwave circuit and system design. CB-CPW has an additional lower ground plane which does create a parallel plate waveguide region between the upper and lower ground planes. In a CBCPW circuit, three dominate modes exists; CPW mode, microstrip line (MSL) mode or coplanar microstrip (CPM) [4-5] mode and coupled slot-line mode. These three dominants as well as some higher order modes may be excited and propagate along the structures, thus circuit performance deteriorates. Since the parasitic parallel plate waveguide mode has a lower phase velocity than the CPW mode, power leaks from the CPW mode to the parallel plate waveguide mode [6]. If the top ground planes are wide, then the next higher-order microstrip-like mode may exist and if dielectric substrate is even wider than the structure may support an image-guide-like propagating mode. To solve these problems, several alternatives have been reported earlier including the use of microwave absorbing materials, multiple dielectric layers, metal filled via holes and use of finite ground coplanar (FGC) [5,7]. A thorough and systematic investigation of resonant phenomena in CBCPW and observed that FGC line is better than normal CPW for MMICs and MCMs was reported by Lo et al. [7]. As the ground planes are electrically narrow, spurious resonances created by the CPW ground planes and the metal carrier

Submitted On: January 19, 2018
Accepted On: June 29, 2020

https://doi.org/10.47037/2020.ACES.J.350911

or package base are eliminated and thus, the parallel plate waveguide mode is not established and the problem of spurious resonances is eliminated with improved performances [8-9].

An In this literature, a 3rd order bandpass filter is designed on CB-CPW with major advantage of easy integration with lumped as well as active components with improved performances and higher mechanical strength. The proposed filter is designed and an equivalent resonant circuit for a particular resonant frequency is portrayed. Quarter wavelength vertically loaded open ended stubs are used to provide band-accepted characteristics with smaller design size. The design is optimized in width of the slots to form the discontinuity to achieved the bandwidth of 1-4GHz. Multiple series open ended vertically coupled stub resonators are placed in series to increase the order of the filter and to achieve higher selectivity with low insertion loss. To validate the design technique further six open ended resonators are installed in closed fashion to obtain 5th order bandpass filter. Air bridges are not required due to symmetry of discontinuities [10]. The proposed filter is constructed using FR4 glass epoxy substrate with double side plated CCB.

II. PROPERTIES OF CONDUCTOR BACKED COPLANAR-WAVEGUIDE

The schematic of a CBCPW with finite ground planes in the lateral direction is shown in Fig. 1. Additional lower ground plane provides mechanical strength for a thin and fragile wafer, and acts as a heat sink for circuits with active devices. This configuration of the CPW is known as the conductor-backed coplanar waveguide (CBCPW).

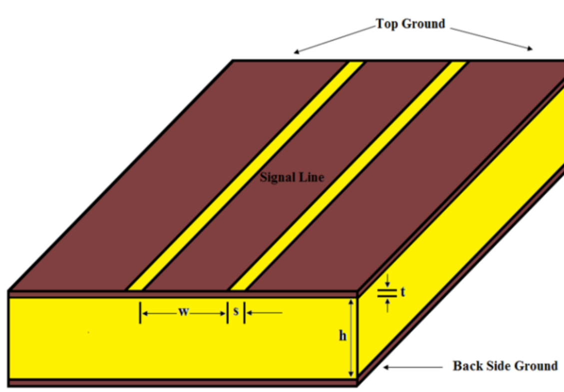


Fig. 1. Schematic of finite ground CB-CPW structure.

A quasi-TEM mode is assumed to propagate on the aforesaid structure. Based on the approximation, Wen's [11] analysis for conventional CPW is extended in [12] to [14] to the CBCPW, analytical expressions as a function of the geometry are expressed as:

$$\varepsilon_{eff} = \frac{1+\varepsilon_r \frac{K(k')}{K(k)} \frac{K(k_3)}{K(k_3')}}{1+\frac{K(k')}{K(k)} \frac{K(k_3)}{K(k_3')}}, \quad (1)$$

$$Z_0 = \frac{60\pi}{\sqrt{\varepsilon_{eff}}} \frac{1}{\frac{K(k')}{K(k)} + \frac{K(k_3)}{K(k_3')}}, \quad (2)$$

where,

$$k = a/b$$

$$k_3 = \tanh(\pi a/2h)/\tanh(\pi b/2h)$$

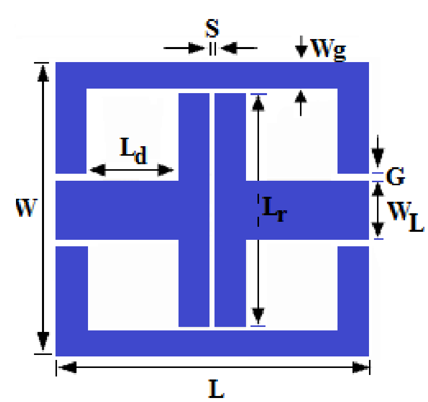
$$k' = \sqrt{1-k^2}$$

$$k_3' = \sqrt{1-k_3^{\,2}}.$$

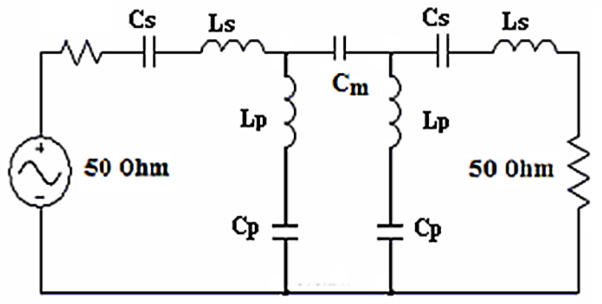
K(k) is the elliptic integral function of the first kind. ε_{eff} and Z_0 are the effective permittivity of the substrate and characteristics impedance of transmission line respectively.

III. CHARACTERISTICS OF VERTICALLY INSTALLED COUPLED OPEN STUB

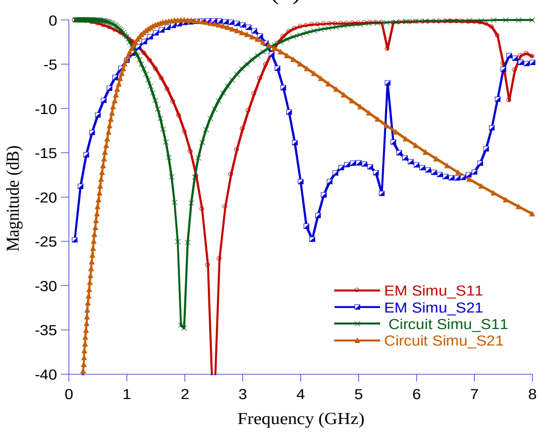
In conventional CPW technology a series stub is designed by creating a discontinuity in the central strip by implementing two slots originating from the edge of the central strip on both sides of the ground such that the slots are connected to each other [10]. In the proposed design of CB-CPW, vertically installed open ended stubs are used and coupled together. This modified in shape stub (vertically loaded) miniaturizes the circuit area in horizontal direct ion along with narrow top ground on both sides of the signal transmission line and electrically small finite bottom ground plane. At the end of the discontinuity an open circuit is created which gives a short circuit at the starting terminal of discontinuity for a length of quarter wavelength of the stub, i.e., λ g/ 4, where λg is the guided wavelength and thus provides a band accepted response [13-15].



(a)



(b)



(c)

Fig. 2. (a) Vertically installed coupled series open ended CB-CPW stubs, (b) equivalent circuit model, and (c) comparison between EM and circuit simulated response.

Table 1: Equivalent circuit components

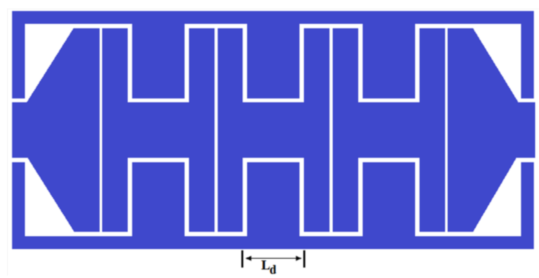
L_s (nH)	C_s (pF)	L_p (nH)	C_p (pF)	C_m (pF)
1.23	3.32	13.514	309.3	0.48

The dimensions of the proposed coupled stub resonator unit is calculated considering quarter wavelength; i.e.; for a substrate having relative permittivity $\varepsilon_r = 4.4$, height of 1.59mm and loss of 0.02, the values of L_r = 16.6mm, WL = 3.8mm, G = 0.2mm, W_r=1mm, W_g = 1mm, W = 18.4mm, L = 18mm and spacing S=0.3mm are chosen for easy fabrication. The characteristic of the CPW circuit primarily depends on the length 'Lr' as depicted in Fig. 2 (a). Now if the length is near to the quarter wavelength ($\sim\lambda_g/4$) then it will behave as a resonant circuit of a resonating frequency of which the quarter-wavelength is considered. Otherwise, if the length is considered to be too large ($>\lambda_g/2$) or small ($<\lambda_g/10$) then the same component will behave as an equivalent inductance or capacitance respectively [7]. The circuit equivalent of proposed vertically loaded coupled open-ended stub resonator is shown in Fig. 2 (b). From circuit analysis equivalent capacitance and inductance values are calculated and tabulated in Table 1, which are further simulated by Quite Universal Circuit Simulator and simulated plots are overlapped with the EM-Simulated one. The plot shows near similar response between the two as shown in Fig. 2 (c). The simulated result shows a band accepted response with 3dB bandwidth of 2.7GHz ranging from 1.2 GHz to 3.5 GHz with an insertion loss of - 0.017dB. The rising edge and falling edge selectivity are found to be 16.89 dB/GHz and 21.33 dB/GHz respectively.

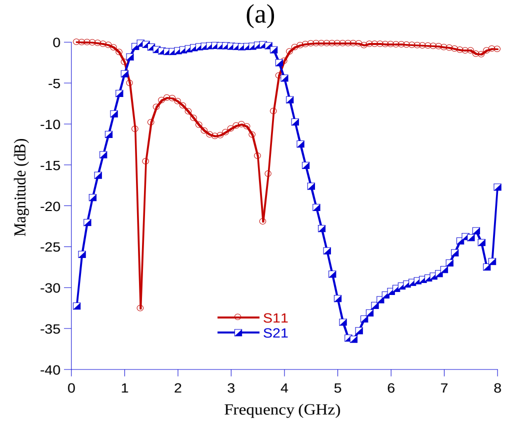
IV. BPF USING PROPOSED COUPLED OPEN-ENDED RESONATORS

A. Design of 3rd order bandpass filter using four such resonators

In order to increase the order of the filter or sharpness four such series coupled resonators are placed such that the resonators are in close proximity to each other to achieve great field confinement within the circuit than that of other open-ended stub in series or shunt. As the order of the filter is also increased, i.e., numbers of pole increase as the number of series stubs are increased.



(a)

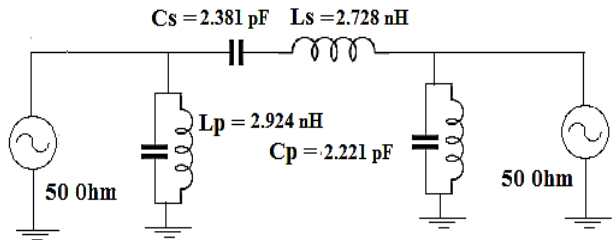


(b)

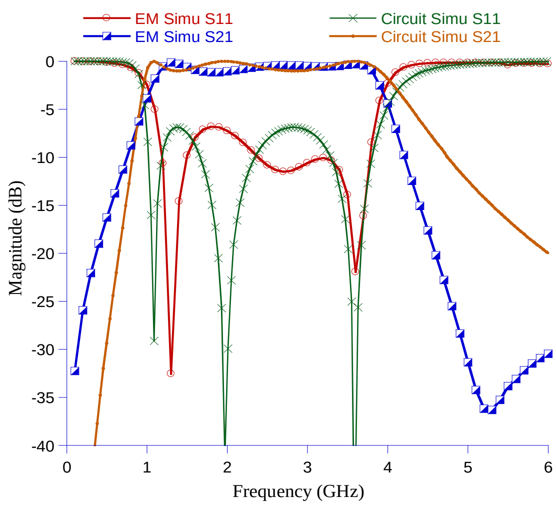
Fig. 3. (a) Schematic of proposed 3rd order BPF using four vertically loaded coupled open-ended series stubs, and (b) simulates S-parameter responses.

Finally, a 3rd order bandpass filter has been designed with higher selectivity or roll off. The layout design of the filter is given in Fig. 3 (a). The distance between two consecutive resonators are chosen of L_d = 1mm. The simulated results show 3dB bandwidth from 1GHz to 3.9 GHz with an insertion loss of -0.48dB and the selectivity of 30.75 dB/GHz at the rising edge and 27.01 dB/GHz at the falling edge with a rejection band of around 4GHz after the desired passband as described in Fig. 3 (b).

Figure 4 (a) shows equivalent lumped circuit model for the proposed bandpass filter having four open stubs in symmetric manner. This lumped model has been further simulated with Quite Universal Circuit Simulator and found the results as similar as of simulated responses as sketched in Fig. 4 (b). The EM and circuit simulated responses are found near similar in nature.



(a)

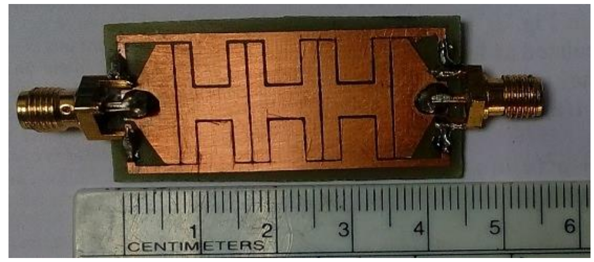


(b)

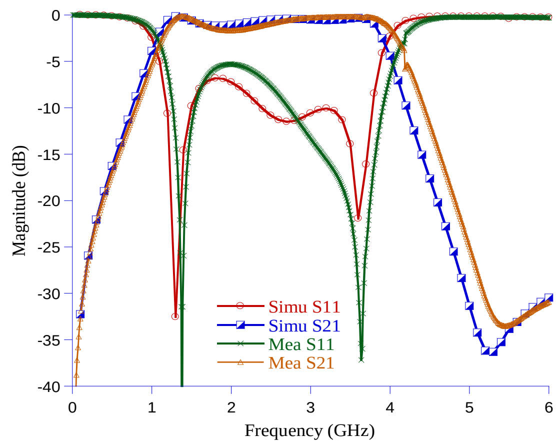
Fig. 4. (a) Circuit equivalent of proposed bandpass filter, and (b) comparison between EM-simulates and circuit simulated S-parameter responses.

Finally, this vertically loaded series coupled open ended stubs-based CB-CPW Band Pass Filter is fabricated using a double side copper plated FR4 substrate having relative permittivity εr = 4.4, height of 1.59mm and loss of 0.02 as portrayed in Fig. 5 (a).

The scattering parameters of fabricated structure are measured by Agilent make Vector Network Analyzer (model N5230A) and obtained results are compared with the simulated responses. It is observed that the measured results have near agreement with the simulated response as shown in Fig. 5 (b). Small deviations in measured results are obtained due to manual fabrication in-accuracy.



(a)



(b)

Fig. 5. (a) Fabricated prototype of the proposed bandpass filter, and (b) comparison between simulated and measured S-parameters.

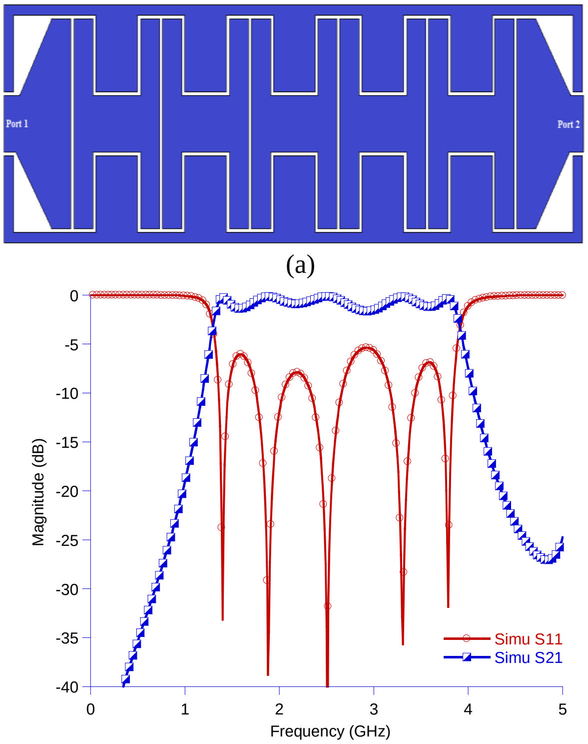
B. 5th Order bandpass filter design

In order to increase further order of the filter, number of vertically installed series open end stubs are also increased.

In a similar manner like the previous design, a 5th order bandpass filter has been realized using EM simulator software. The schematic of the filter is given in Fig. 6 (a). Considering all other design parameters to be same, the new 5th order design is implemented.

The simulated result shows 3dB bandwidth from 1.18 GHz to 3.97 GHz with an insertion loss of -0.62 dB and the selectivity of 58.47 dB/GHz at the rising edge and 56.32 dB/GHz at the falling edge as depicted in Fig. 6 (b). All the five poles of the proposed design are clearly visible and it covers the entire S-band frequency range.

Table 2 shows the comparison of the obtained results of proposed BPFs with some recently reported performance of BPFs. The proposed work has found superior in terms of minimum design complexity and provides adequate performance in every aspects compared in the table includes FBW, insertion loss, selectivity and compactness.



(a)

(b)

Fig. 6. (a) Schematic of proposed 5th order BPF using four vertically loaded coupled open-ended series stubs, and (b) simulates S-parameter responses

Table 2: Comparison between bandpass filters

Ref. No.	3dB FBW	IL (dB)	Size	Sharpness (R.E. and F.E)	Comments
[8]	110%	1.25	0.5λg ×0.4λg	12 dB/GHz 8.58 dB/GHz	High FBW, high IL, moderate size, poor selectivity
[9]	110%	0.9	0.32λg ×0.12λg	30 dB/GHz 30 dB/GHz	High FBW, high IL, compact size, medium selectivity, return loss <10dB
[14]	29%	1.2	0.38λg ×0.16λg	60 dB/GHz 26.6dB/GHz	Moderate FBW, high IL, compact size, higher selectivity, poor return loss
[15]	66%	0.9	0.64λg ×0.46λg	34.3 dB/GHz 21.3 dB/GHz	High FBW, high IL, medium size, moderate selectivity
Proposed Work [3rd order BPF]	145%	0.48	0.48 λg ×0.23 λg	30.7 dB/GHz 27 dB/GHz	Extreme high FBW, low IL, compact size, moderate selectivity, simple design

VI. CONCLUSION

A bandpass filter is constructed by coupled open ended CB-CPW series stub resonator with vertical placement to signal line. The selectivity and bandwidth of filter has been improved using series arrangement with close proximity and increase of resonating stubs. Multiple series open ended coupled resonators are easy to design and the fabrication requires no via holes or air-bridge as the symmetricity is maintained. The filter also provides a stopband of around 4GHz after the desired pass band.

ACKNOWLEDGMENT

The authors would like to acknowledge IIEST Shibpur for necessary support. The authors are also thankful to all the reviewers for their valuable suggestions.

REFERENCES

[1] R. N. Simons, *Coplanar Wave Guide Circuits, Components, and Systems*. John Wiley & Sons, New York, 2001.

[2] R. N. Simons and G. E. Ponchak, “Modeling of some coplanar waveguide discontinuities,” *IEEE Trans. Microwave Theory Tech.*, vol. 36, no. 12, pp. 1796-1803, 1988.

[3] C. C. Tien, C. K. C. Tzuang, S. T. Peng, and C. C. Chang, “Transmission characteristics of finite-width conductor-backed coplanar waveguide,” *IEEE Trans. Microwave Theory Tech.*, vol. 41, no. 9, pp.1616-1624, Sep. 1993.

[4] G. E. Ponchak, S. Robertson, F. Brauchler, J. East, and L. P. B. Katehi, “Finite width coplanar waveguide for microwave and millimeter-wave integrated circuits,” *Int. Symposium on Micro-electronics*, pp. 517-521, 1996.

[5] R. W. Jackson, “Mode conversion at discontinuities in finite-width conductor-backed coplanar wave-guide,” *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1582-1589, 1989.

[6] A. A. Oliner and K. S. Lee, “The nature of the leakage from higher order modes on microstrip line,” *IEEE MTT-S Int. Microwave Symp.* pp. 57-60, 1986.

[7] W. T. Lo, C. Kuang, S. T. Peng, C. C. Chang, J. W. Huang, and C. C. Tien, “Resonant phenomena in conductor backed coplanar waveguides (CBCPW’s),” *IEEE Trans. Microwave Theory Tech.*, vol. 41, no. 12, pp. 2099-2108, 1993.

[8] S. N. Wang and N. W. Chen, “Compact, ultra-broadband coplanar waveguide bandpass filter with excellent stopband rejection,” *Progress in Electromagnetics Research B*, vol. 17, pp. 15-28, 2009.

[9] D. S. Miguel, J. Bonache, and F. Martín, “Compact wideband CPW bandpass filters with transmission zeros based on stepped impedance resonators (SIR),” *IEEE Microwave and Wireless Components Letters*, vol. 21, no. 12, pp. 664-666, 2011.

[10] P. Mondal and S. K. Parui, “Improvement of stop-band performance of a CPW bandpass filter using

DGS," *Microwave and Optical Technology Letter*, vol. 58, no. 3, pp. 593-597, 2016.

[11] C. P. Wen, "Coplanar waveguide: A surface strip transmission line suitable for nonreciprocal gyromagnetic device applications," *IEEE Trans. Microwave Theory Tech.*, vol. 17, no. 12, pp. 1087-1090, 1969.

[12] G. Ghione and C. U. Naldi, "Coplanar Waveguides for MMIC applications: Effect of upper shielding, conductor backing, finite-extent ground planes, and line-to-line coupling," *IEEE Trans. Microwave Theory Tech.*, vol. 35, no. 3, pp. 260-267, 1987.

[13] T. Moyra, S. K. Parui, and S. Das, "CB-CPW based wide band bandpass filter using open-stub resonator," *Journal of The Institution of Engineers (India): Series B*, vol. 94, no. 1, pp. 13-19, 2013.

[14] J. K. Xiao, N. Zhang, J. G. Ma, and J. S. Hong, "Microstrip/coplanar waveguide hybrid bandpass filter with electromagnetic coupling," IEEE *Microwave and Wireless Components Letters*, vol. 26, no. 10, pp. 780-782, 2016.

[15] V. Gholipour, A. A. Moshiri, and A. Yahaghi, "Highly selective wideband bandpass filter using combined microstrip/coplanar waveguide structure," *IET Electronics Letters*, vol. 52, no. 13, pp. 1145-1147, 2016.

Pratik Mondal received his Bachelor of Engineering degree in Electronics and Communication Engineering from the University of Burdwan, India in 2010. He did his Master of Engineering degree in Electronics & Telecommunication Engineering with specialization in Microwave Communication Engineering from Indian Institute of Engineering Science and Technology, Shibpur, India. He has done his Ph.D. from the same Institute in 2018. Presently, he is associated with Gayatri Vidya Parishad College of Engineeering, Visakhapatnam, India, as an Assistant Professor in the Department of ECE.

His research interests include the Microstrip Planar Circuits, Coplanar Waveguide based Circuits, DGS, DMS, Metamaterials etc. He is an Associate Member of Institution of Engineers, India. He is also a student member of IEEE-MTT Society.

Susanta Kumar Parui received the B.Sc. degree in Physics and B.Tech. degree in Radiophysics and Electronics from the University of Calcutta in the year 1987 and 1990, respectively. He did Master degree in Microwave Communication Engineering from Bengal Engineering College, India, in the year 1993. From 1993 to 2000, he worked as Instrument Engineer. Since 2000, he is associated with the Department of Electronics and Telecommunication Engineering of Indian Institute of Engineering Science and Technology, Shibpur, India and presently holds the post of Associate Professor.

His current research interests include the planar circuits, filters, antenna and EBG. He is a Senior Member of IEEE and also presently holds the post of Vice- Chairman of IEEE-MTT Kolkata Chapter.

Rajesh Bera passed B.Tech. degree in Electronics and Communication Engineering, from Birbhum Institute of Engineering & Technology, West Bengal, India in 2010. He received the M.Tech. and Ph.D. degree from KIIT, Bhubaneswar, India in 2012. Presently, he is attached with Gayatri Vidya Parishad College of Engineeering, Visakhapatnam, India, as an Assistant Professor in the Department of ECE. His research interest includes Array Antenna design, Array parameter optimization and beam-pattern synthesis using Evolutionary Computing Techniques.