PERFORMANCE ANALYSIS OF PLANAR BANDPASS FILTER WITH DIFFERENT ORDERS

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Abstract - *Filter is a very essential component in modern communication system as it is used to separate out desired signal from entire range of frequency so as to process the signal to acquire the required output. In this work bandpass filters are designed on microstrip patterns through coupled line topology by using the design equations available in literatures at 4.9 GHz frequency on FR4 substrate with dielectric constant 4.5 and same is implemented in commercial simulation software. Subsequently, the coupled line filter topology is attempted with different orders namely 3rd order, 4th order, and fifth order and the effect various orders in filter performance is analysed in terms of insertion loss, return loss, bandwidth, roll-off etc. Further, a comparative analysis is carried out among all the designs and feasibility of practical implementation is discussed in this article.*

Key Words: Bandwidth, Filter, pass band, microstrip, stop band, roll-off, etc.

1.INTRODUCTION

Modern communication system is being migrated from VHF band to UHF and SHF bands hence all the systems need to be realised at mentioned frequency bands. In communication system filter is very important aspect as it allow the desired frequency signal to pass and eliminate the unwanted frequency signals [1]. The performance of filter also getting refined day by day and insertion loss, return loss, bandwidth, roll off etc. have become key performance indicators for any filter. Now a day's most of the filters are operated at microwave frequency band and on that frequency band, designing a filter using lumped components is practically not possible hence the design approach is shifted towards other alternative technologies namely waveguide based filter [2], microstrip based filter [4], meta-material based filter [3], LTCC filters [8], SAW filter [7], SIW based filter [5] etc. Among the available technologies, microstrip based filters are best choice for this study and for commercial applications too, as it has ability to work at high frequency, small size, light weight, low cost and feasibility to integrate with other components.

A lot of research is carried out on microstrip based filter design to improve the performance in terms of insertion loss and return loss as detailed in [4], reduce the size as detailed in [5], cost reduction as detailed in [6], variable frequency as detailed in [9], variable bandwidth as detailed in [9]. Having analyzed various works of literature, it is essential to analyse the effect of order while filter design.

In this research work, a microstrip-based coupled line filter is designed on FR-4 substrate using the design equations available in the literature [10]. Subsequently, similar type of filters are designed with different orders namely third order, forth order and fifth order. All the mentioned filters are simulated in Keysight ADS software and comparative analysis is carried out among their performances. In the end the feasibility for practical implementation of the same is detailed in this article.

2. DESIGN PRINCIPLE

In order to design a band pass filter, firstly a low pass filter prototype is designed and subsequently same is extrapolated to band pass filter. In the process of designing microstrip based coupled line filters following equations are employed-

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2} \cdot \frac{FBW}{g_0 \cdot g_1}} \quad \text{-----(1)}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi . FBW}{2} \cdot \frac{1}{\sqrt{g_j \cdot g_{j+1}}}$$

$$J = 1,2, \ldots, N-1 \quad \text{-----(2)}$$

$$\frac{J_{N,N+1}}{Y_0} = \sqrt{\frac{\pi}{2} \cdot \frac{FBW}{g_N \cdot g_{N+1}}} \quad \text{-----(3)}$$

where $g_0, g_1, \ldots, g_N$ are the element values of a ladder-type low pass prototype with a normalized cut-off frequency $\Omega_c = 1$. The fractional bandwidth of a band pass filter, defined as FBW, is equal to:

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} = \frac{f_2 - f_1}{f_0} \quad \text{-----(4)}$$

Where, $\omega_2 - \omega_1 = B$ is the bandwidth, and ω_0 is the angular resonant frequency.
When the electrical length of each coupled line is equal to half of the wavelength, even-mode line impedance and odd-mode line impedance are obtained (in Ohm).

$$Z_{0e} = Z_0 \cdot (1 + J \cdot Z_0 + J^2 \cdot Z_0^2) \quad \text{-----(5)}$$

$$Z_{0e} = Z_0 \cdot (1 - J \cdot Z_0 + J^2 \cdot Z_0^2) \quad \text{-----(6)}$$

The physical arrangement of coupled line filter is shown in Fig. 1.

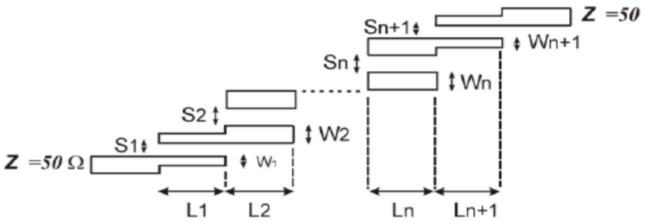
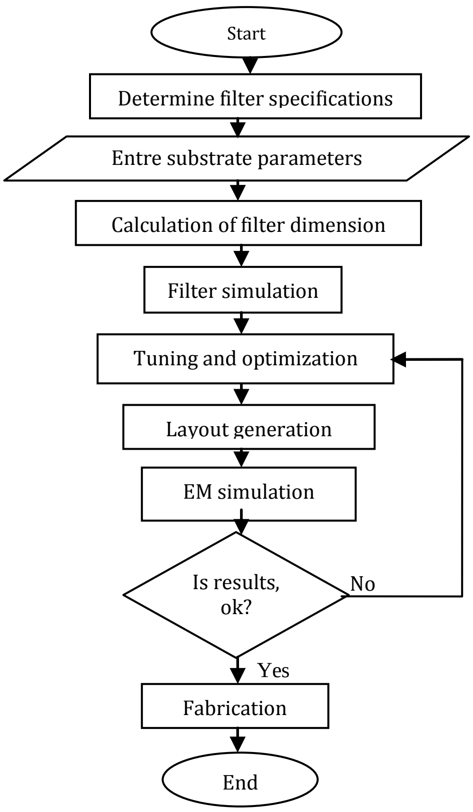


Fig -1: Coupled line bandpass filter schematic [15]

The calculated line length and width and spacing are used in simulation software for further process of design.

3. DESIGN METHODOLOGY

The following flow chart explains the entire design methodology of microstrip coupled line band pass filter-



Flow chart -1: Filter design activity

To begin designing a filter, the first step is to determine its order. The fractional bandwidth and normalized frequency can be calculated using the formulae provided in equation (4) The order of filter can be determined by examining the attenuation vs. normalized frequency graph for 0.5 dB ripple, as depicted in the graph given below.

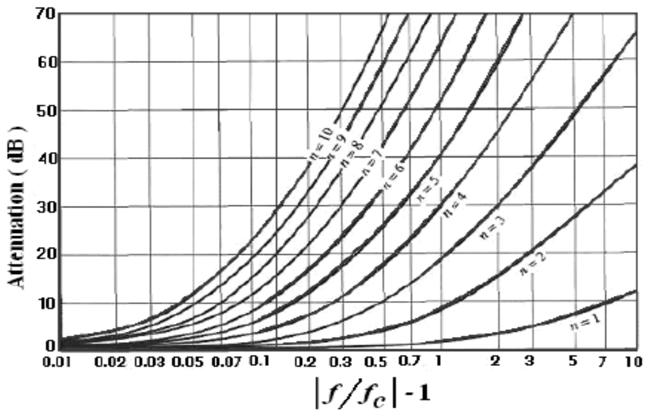


Fig -2: Attenuation vs. normalized frequency graph for 0.5dB. [9]

The element values for third fourth and fifth order filter are determined from Table 1.

Table -1: Table of Element values for 0.5dB ripple [9]

N	g_1	g_2	g_3	g_4	g_5	g_6
1	0.6986	1.0000				
2	1.4029	0.7071	1.9841			
3	1.5963	1.0967	1.5963	1.0000		
4	1.6703	1.1926	2.3661	0.8419	1.9841	
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.000

A low-pass filter prototype with Butterworth response can be designed using normalized values g_1, g_2, g_3...g_N from Table-1. The filter can be designed with three poles, four poles, or five poles. For a 3rd order filter, the element values are g_1 = g_3 = 1.5963 and g_2 = 1.0967, while for a 4th order filter, the element values are g_1 = 1.6703, g_2 = 1.1926, g_3 = 2.3661, g_4 = 0.8419, and g_5 = 1.9841. Similarly, for a 5th order filter, the element values are g1 = g_5 = 1.7058, g2 = g_4= 1.2296, g_3 = 2.5408, and g_6 = 1. The calculated values can be used as prototype values for the filter design.

LC elements were then derived from the normalized element values for the desired mid-band frequency and source impedance of 50 ohms. To create a microstrip bandpass filter that approximates the lumped element filter, Prototype values for a lowpass filter are calculated based on the design specifications provided in below.

Table -2: Specification of filter design

Filter Type	Butterworth
Number of orders	3^{rd} ,4^{th}, and 5^{th}
Upper frequency	4.8 GHz
Lower frequency	5.0 GHz
Centre frequency	4.9 GHz (C band)
Fractional Bandwidth, Δf	0.05 or 5%

then most important step is an appropriate microstrip realization was chosen and fabricated on a substrate with dielectric constant εr=4.5 and thickness h=0.2 to 3.2 mm The J-inverter can convert a low pass filter to a bandpass filter by utilizing the equations presented above equation (1) (2) (3). The equations consist of FBW, which represents the fractional bandwidth of the bandpass filter, as well as Jj and j+1, which denote the characteristic admittances of the J-inverters. The characteristic admittance of the terminating lines is represented by Y0.

To create the J-inverters, the characteristic impedances of the even- and odd modes of the coupled lines are determined using the provided equations.

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad \text{---(7)}$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad \text{---(8)}$$

To determine the width, spacing, and length of each stage, the LineCalc tool in Advanced Design System (ADS), Agilent Technologies software, is employed. This calculation is carried out using the even and odd characteristic impedance values. The characteristic impedance Z0 is usually assumed to be 50 Ohms.

Following the determination of the width, spacing, and length of each stage, the next step is optimization. It is critical to establish all parameters and objectives properly during this stage. The optimization and tuning process is then performed to achieve the best possible results and performance. Ultimately, the dimensions of the width, gap, and length are finalized based on this optimization process. Finally, the coupled line filter is designed in the simulation software environment, Advanced Design System (ADS), where the filter parameters are input and the software generates the physical dimensions of the filter layout along with a simulation of the filter response.

The desired frequency response is achieved by adjusting the parameter values, which have been summarized in Table below. The tuning process involves finding the optimal values for the filter parameters to meet the design specifications.

Although the schematic simulation of the filter provides important insights about its performance, it is not enough to confirm its practical feasibility. Therefore, it is essential to carry out a layout simulation to ensure the design's validity. To achieve this, ADS generates a layout file from the schematic design, which can be simulated with the specified substrate characteristics. The resulting optimized microstrip filter layout is presented below

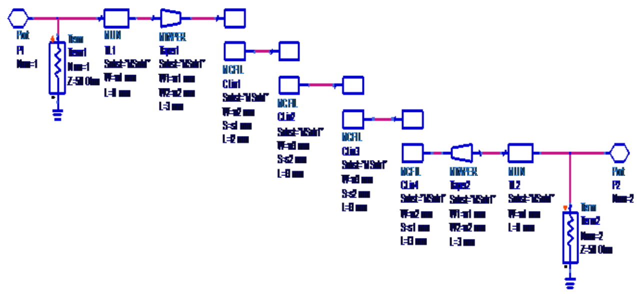


Fig -3: Schematic of third order parallel coupled bandpass filter.

The schematic diagram of the third-order parallel-coupled bandpass filter shown above depicts the arrangement of resonators connected in parallel. Similarly, for the fourth-order and fifth-order filters, the schematic diagrams would show the arrangement of four and five resonators respectively. In each case, the resonators are carefully designed and interconnected to achieve the desired filtering characteristics. The specific configuration of inductors and capacitors is employed to construct the resonators. The input and output ports are connected to the central node of the resonators. By this arrangement, the filter is able to selectively pass a narrow band of frequencies centered around the desired center frequency. The inclusion of additional resonators in the higher-order filters enhances the filter's performance and frequency response shaping.

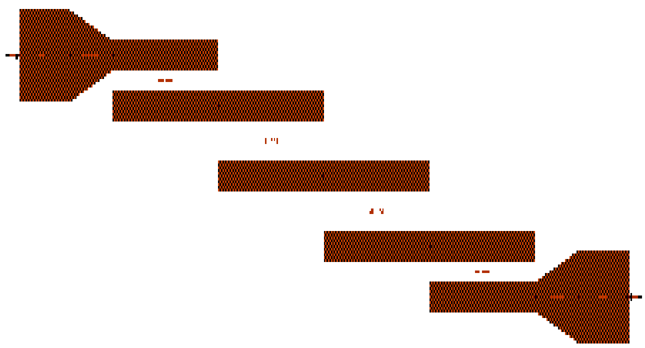


Fig -4: Layout of third order parallel coupled bandpass filter

The layout of the third-order parallel-coupled bandpass filter, as well as the fourth-order and fifth-order filters, is determined by the arrangement of resonators and their interconnections. In the layout, the dimensions and positions of the resonators are carefully specified to achieve the desired filter characteristics. The additional resonators in higher-order filters contribute to improved frequency response and enhanced filtering performance.

4. SIMULATION RESULTS

The calculated parameters namely width, length, and line spacing for each coupled lineare entered in simulation tool the desired filter is visualised. Simulation gives insertion loss and return loss plots of 3rd ,4th and 5th order are mentioned below.

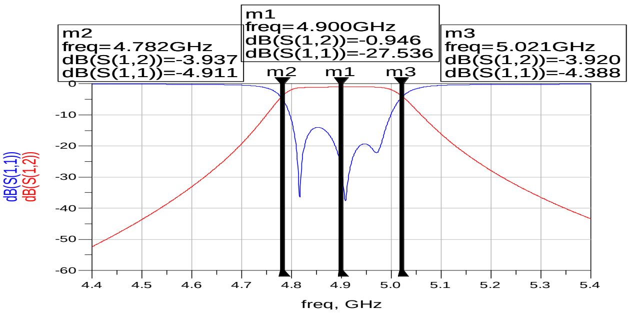


Fig -5: Insertion loss and return loss measurement in third order filter

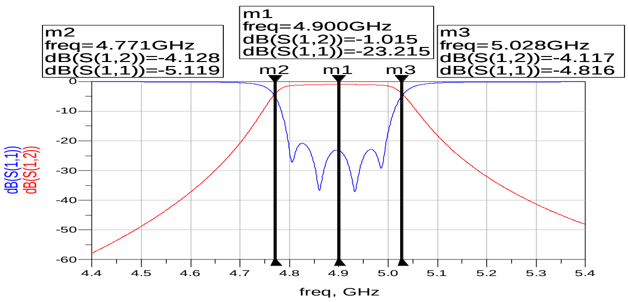


Fig -6: Insertion loss and return loss measurement in forth order filter

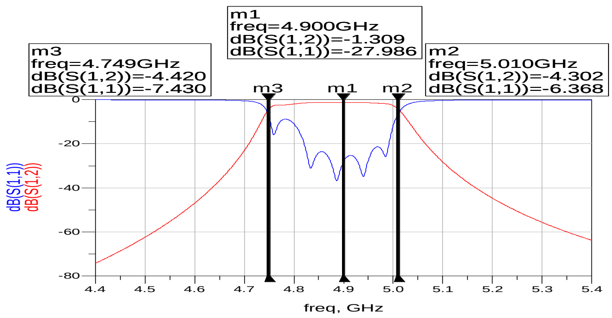


Fig -7: Insertion loss and return loss measurement in fifth order filter

A bandwidth of 0.239 GHz is observed in the 3rd order bandpass filter, with upper and lower frequencies. At the center frequency of 4.900 GHz, an insertion loss of 0.946 dB and a return loss of 27.53 dB are exhibited. Similarly, a bandwidth of 0.257 GHz is observed in the 4th order bandpass filter, with upper and lower frequencies. At the center frequency of 4.900 GHz, an insertion loss of 1.015 dB and a return loss of 23.215 dB are exhibited. In the case of the 5th order bandpass filter, a bandwidth of 0.261 GHz is observed, with upper and lower frequencies of 5.010 GHz and 4.749 GHz. At the center frequency of 4.900 GHz, an insertion loss of 1.309 dB and a return loss of 27.986 dB are exhibited. The parameter variations in the plot demonstrate how the insertion loss and return loss change with an increase in the order of the filter, and they reveal the behavior of the bandpass filter at different frequencies.

4. COMPARATIVE ANALYSIS

There are three coupled line filters are chosen for carrying out comparative analysis.

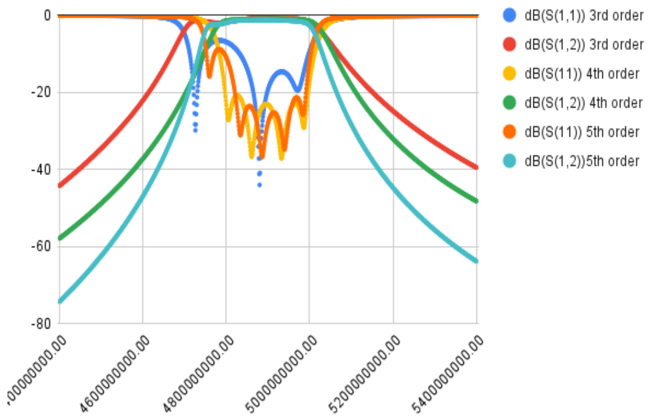


Fig -8: Comparative analysis for filters of different orders.

Table -3: Comparison analysis for filters of different orders.

Filter order	Insertion loss, $\|S_{12}\|$ dB at 4.9GHz	Return loss, $\|S$ $\|$ dB at 4.9GHz	Bandwidth Percentage %	Size, (mm)
3rd order	-0.946	-27.53	4.88%	49.9748
4th order	-1.015	-23.215	5.24%	71.2606
5th order	-1.309	-27.986	5.34%	159.6064

A comparative analysis reveals variations in the parameters of the plotted data for different orders of bandpass filters. The 3rd order filter has a bandwidth of 4.88%, while the 4th order and 5th order filters have bandwidths of 5.24% and 5.34% GHz respectively. The insertion loss and return loss vary among the different orders, with the 3rd order filter generally exhibiting lower losses compared to the 4th and 5th order filters. Additionally, the upper and lower frequencies shift slightly between the different orders, while the center frequency remains constant at 4.900 GHz for all three orders. These parameter variations provide insights into the performance differences and trade-offs associated with higher-order bandpass filters.

5. IMPACT ANALYSIS

Comparative analysis for different orders gives a basic idea for choosing a filter for commercial applications. The impact of various topologies is detailed below-

a) Impact on insertion loss:When comparing the insertion losses, it is observed that as the order of the filter is increased from the third to the fifth order, the insertion loss is also increased. This observation suggests that higher-order filters may introduce a higher degree of signal attenuation. It can be inferred that with the increase in the filter order, there is an associated increase in the amount of signal power that is lost. This increase in insertion loss has implications for the performance of the filters, as it may lead to a reduction in the overall signal quality and effectiveness of the filtering process.

b) Impact on return loss: Upon analyzing the return loss, it becomes evident that higher return loss values are exhibited by the third and fifth-order filters when compared to the fourth-order filter. It is observed that a higher return loss signifies improved impedance matching and decreased signal reflection. As a result of this analysis, it is expected that the third and fifth-order filters will deliver superior performance in terms of reducing signal reflections and maintaining impedance matching in comparison to the fourth-order filter. This implies that the higher-order filters present enhanced signal transmission characteristics and overall performance enhancements.

c) Impact on bandwidth: The bandwidth analysis reveals that the widest bandwidth of 0.261 GHz is observed in the fifth-order bandpass filter, followed by the fourth-order filter with a bandwidth of 0.257 GHz. The third-order filter has the narrowest bandwidth of 0.239 GHz. It is observed that as the filter order increases, the bandwidth also tends to increase, enabling a broader frequency range to pass through the filter. This indicates that higher-order filters facilitate a wider frequency range for signal transmission.

d) Impact on roll-off: The roll-off characteristics were analyzed, revealing that the third-order bandpass filter has a moderate roll-off rate. A steeper roll-off was observed in the fourth-order filter compared to the third-order, resulting in improved attenuation of frequencies outside the passband. The fifth-order filter exhibited an even steeper roll-off, indicating a higher degree of frequency rejection. Higher-order filters displayed sharper roll-off, enabling more precise frequency control and enhanced rejection of out-of-band frequencies. Consequently, higher-order filters provide improved roll-off characteristics, contributing to enhanced filtering performance.

e) Impact on dimension: The impact on dimensions was analyzed for the third, fourth, and fifth-order filters. It was observed that as the order of the filter increases, there is a general trend of increased complexity and a larger physical size. This is because higher-order filters usually require additional resonators or resonant sections, resulting in an overall larger size compared to lower-order filters. Therefore, the dimension of the filter tends to be increased with higher orders, indicating the trade-off between filter complexity and performance.

5. CONCLUSION

The article is aimed to design a microstrip based coupled line filter in different orders and conduct a comparative study among them. In this article filters are designed at centre frequency of 4.9 GHz frequency and 5% bandwidth with order of three, four and five. Further a separate analysis is carried for impact of variation in filter order on commercial applications. The analysis carried out in this research work can be used for improving filter performance.

ACKNOWLEDGEMENT

The authors hereby acknowledge LNCT Indore and HoD, Electronics and Communication Engineering for the successful completion of this work. Also acknowledges Shri Harsh Dashora, Scientist, ISRO, Bangalore for his support and motivation towards this work with valuable inputs.

REFERENCES

[1] Kune, D. F., Backes, J., Clark, S. S., Kramer, D., Reynolds, M., Fu, K., ... & Xu, W. (2013, May). Ghost talk: Mitigating EMI signal injection attacks against analog sensors. In *2013 IEEE Symposium on Security and Privacy* (pp. 145-159). IEEE.

[2] Levy, R., Snyder, R. V., & Matthaei, G. (2002). Design of microwave filters. *IEEE Transactions on Microwave Theory and techniques*, *50*(3), 783-793.

[3] Ibrahim, A. A., Abdel-Rahman, A. B., & Abdalla, M. A. (2014, July). Design of third order band pass filter using coupled meta-material resonators. In *2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)* (pp. 1702-1703). IEEE.

[4] Hsieh, L. H., & Chang, K. (2003). Compact, low insertion-loss, sharp-rejection, and wide-band microstrip bandpass filters. *IEEE Transactions on Microwave Theory and Techniques*, *51*(4), 1241-1246.

[5] Zheng, Y., Zhu, Y., Wang, Z., & Dong, Y. (2021). Compact, wide stopband, shielded hybrid filter based on quarter-mode substrate integrated waveguide and microstrip line resonators. *IEEE Microwave and Wireless Components Letters*, *31*(3), 245-248.

[6] Devi, C. K., Umadevi, H., & Baligar, J. S. (2019, June). Designing of reconfigurable compact bandpass microstrip filter. In *2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA)* (pp. 726-730). IEEE.

[7] Lilhare, Y., Sinha, S., & Jivani, N. R. (2022, April). Considerations for the Accurate Design of Impedance Element SAW filters. In *2022 IEEE 7th International conference for Convergence in Technology (I2CT)* (pp. 1-5). IEEE.

[8] Grubinger, Hannes, Helmut Barth, and Rudiger Vahldieck. "An LTCC-based 35-GHz substrate-integrated-waveguide bandpass filter." *2009 IEEE MTT-S International Microwave Symposium Digest*. IEEE, 2009.

[9] Pozar, David M. *Microwave engineering*. John wiley & sons, 2011.

[10] Stošić, Biljana P., Nebojša S. Dončov, and Aleksandar S. Atanasković. "Response calculation of parallel-coupled resonator filters by use of synthesized wave digital network." *2013 11th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services (TELSIKS)*. Vol. 1. IEEE, 2013.

[11] Pusuluri, Vinod Babu, et al. "Narrowband Hairpin Bandpass Filter for 4G LTEApplications." *2021 IEE International IoT, Electronics and Mechatronics Conference(IEMTRONICS)*. IEEE, 2021.

[12] Cai, Dijia, et al. "Design of 2GHz Interdigital Hairpin Microstrip Bandpass Filter." *2021 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)*. IEEE, 2021.

[13] Nedelchev, Marin, Biljana Stosić, and Nebojša Dončov. "Wave Digital Modeling in Microstrip Hairpin Filter Synthesis." *2021 44th International Conference onTelecommunications and Signal Processing (TSP)*. IEEE, 2021.

[14] Yan, Hang, Xianliang Wu, and Yunfeng Hu. "Cross-Coupling Hairpin Bandpass Filter with Periodic Grooves." *2022 IEEE 5th International Conference on ElectronicInformation and Communication Technology (ICEICT)*. IEEE, 2022.

[15] Kadam, Rajendra N., and A. B. Nandgaonkar. "Design of a Coupled-Line Microstrip Bandpass Filter at 3.5 GHz." *International Research Journal of Engineering and Technology (IRJET)* 2.06 (2015).

[16] Das, Tarun Kumar, and Sayan Chatterjee. "Harmonic Suppression in a Folded Hairpin- Line Cross-Coupled Bandpass Filter by using Spur-Line." *2021 Devices for IntegratedCircuit (DevIC)*. IEEE, 2021.

[17] Ismail, Nanang, et al. "Design of microstrip hairpin bandpass filter for 2.9 GHz–3.1 GHz s-band radar with defected ground structure." *Malaysian Journal of Fundamentaland Applied Sciences* 14.4 (2018): 448-455.

[18] Hong, Jia-Shen G., and Michael J. Lancaster. *Microstrip filters for RF/microwave applications*. John Wiley & Sons, 2004.

[19] Das, Tarun Kumar, and Sayan Chatterjee. "Compact hairpin line bandpass filter with improved spurious passbands suppression." *International Journal of Electronics* 108.8 (2021): 1309-1325.