IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 11, Issue 6, Ver. IV (Nov.-Dec .2016), PP 54-59
www.iosrjournals.org

Design of Integrated Filter Antenna with Methods of Co-design and Cascading for Microwave Applications

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Abstract: *In microwave system, filter and antenna are the most important and irreplaceable components. Basically filter and antenna are connected independently in microwave transmission network, and both device need to produce excellent performance on the system. Recent researches show the ability of both devices to be design together and connected directly. But, this will lead to impedance mismatch at the filter antenna junction and will degrade the system's performance. In order to solve this problem, an integrated open loop resonator bandpass filter antenna is proposed in this paper. The integration of filter antenna may decreased the size of the system and also enhance the performance of the system. In this research,, a notch-cut microstrip patch antenna is designed and integrated with the proposed filter with two methods, cascading and co-design.. The structure is designed in FR4 substrate thickness of 1.6 mm. The results show low return loss with increase of bandwidth and higher directivity.*

Keywords: *Antenna, open loop resonator filter, low loss, filter-antenna, higher selectivity*

I. Introduction

Filter and antenna are the two important passive devices in microwave transmission system. In designing both filter and antenna separately, several issues such as high insertion loss, impedance mismatches, high cost and bigger size are the main issues for the RF designer. Traditionally, filter and antenna are connected individually and directly in order to remove undesirable signal in the operating bands by using traditional 50-ohms interfaces which caused to impedance mismatches and high insertion loss in whole systems. Due to the demand of low cost, simplicity, miniaturization, low insertion loss as well as high performances of transmitter and receiver, many researches have been focusing on the integration of both filter and antenna into one module [1-4]. In order to have low insertion loss in filter-antenna design, many types of the filter-antenna have been proposed by recent researchers [4]. Dealing with the impedance mismatches is one of the crucial concerns that all the designers should take seriously in designing integrated filter-antenna due to separate interconnection between them that will contribute to extra impedance transformation needed [5].

Recent research shows that different researchers introduced different design and method on integrating filter and antenna. For example, the co-design approach are being presented inside a wireless access point (AP) for wireless local area network (WLAN) has achieved good selectivity and rejection in out of band regions and omni-directional radiation patterns within two [5]. Not only that, the cascaded approach or known as traditional method also still being used in integrating filter-antenna due to certain criteria [6]. In this paper, microstrip patch antenna with notches is proposed in this research.Notches in the antenna helps in getting best performance in filter and antenna in terms of bandwidth [7]. While having low insertion loss in filter structure, high selectivity band-pass filter is desired to be design. An open loop resonator (OLR) filter is proposed in this research. This filter has high coupling coefficient and it can helps to select more rejecting signal that operates outside of the operating band [8].Two types of method are presented in this project which are co-design approach and cascaded approach to get the desired value of microwave frequency bands.

II. Integrated Olr Filter Antenna

A. Designing the filter

Open loop resonator (OLR) is one examples of the compact and miniature filter. It is composed of a microstrip line that having both end loaded with folded open stubs.Folded arms of open stub is generally not only for increasing the loading capacitance to the ground, but it is also used for producing cross coupling. In facts, this kind of resonator filter is definitely differ from the miniaturized hairpin resonator especially in terms of their concepts and purposes. The researchers stated that the cross-coupled structure will helps to achieve high selectivity characteristics with transmission zeros. Thus, it can improve the skirt rejection of the microstrip filter. Not only that, filter with high selectivity would give the best performance with minimum insertion loss. Fig. 1 shows the example of the OLR filter are designed with asymmetric feed line [8].

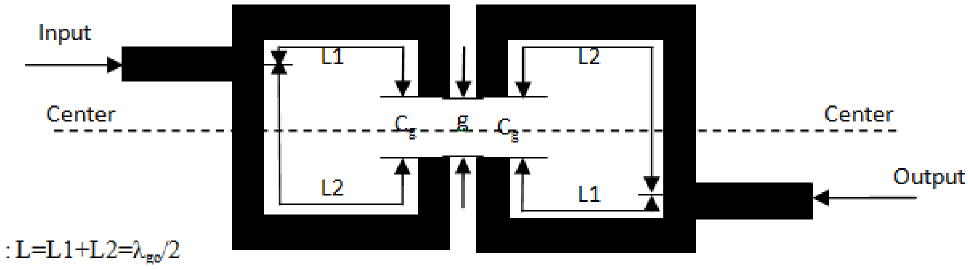


Fig. 1. Example of the open loop resonator filter design with asymmetric feed line

The filter design will be affected by the feed lines tapping which normally can be connected in asymmetric or symmetric structure. Recently, the researcher proved that the asymmetric structure get the better out of the band rejection as compared to the symmetric structure for the two open-loop ring resonator. Other than that, the researcher also proved that BPF type will change its characteristics to high frequency if the width ratio of the filter (W1/W2) is decrease [8]. In Fig. 1, if the line width (W1) and (W2) is increases, it will caused slow wave effect. Thus, this make the OLR have special characteristics that very beneficial for image-rejection. Besides, by reducing the gap, (g) at the stub ended of the OLR, it will increase the coupling coefficient. So, the problem on narrow bandwidth is solved, since the gap will make the bandwidth wider. Besides, different position of the feed line also changed the filter's performance.Since in this project focused on the low insertion loss, adjusting the L1 and L2 would help in minimizing the insertion loss. Thus, the transmission zero of the frequency responses also can be changed [9]. In this project, the OLR filter is proposed with implementation of the chamfered bend structure in BPF design as shown in Fig. 2. In order to improve the insertion loss of the filter as well as in tuning the electric coupling for both resonators chamfered bend will be one of the suitable solution.

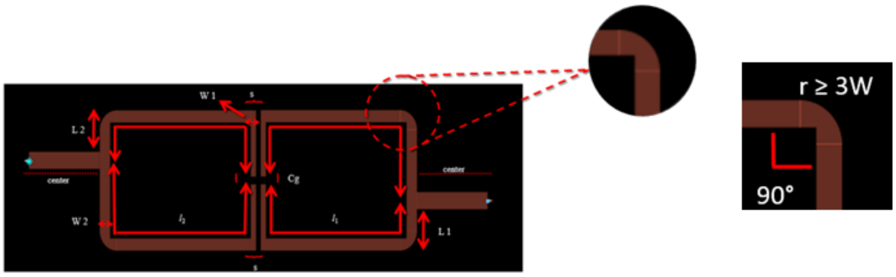


Fig. 2. Implementation of chamfered bend in OLBPF

The implementation of the chamfered bend in the OLRF design is done by using the conventional filter that having right-angle bend. The chamfered bend then employed the alteration of the right-angle bend to become rounded corner at the edges of the filter design. For the inner part of the design filter, the right-angle is preserve to have 90° angle. Theoretically, the rounded curve is measured to have less than or equal to the three times of width of the resonator. This implementation of the chamfered bend helps to reduce the excess capacitance at the bend edges of the filter [10]. When designing OLRF, typical microtrip discontinuities might occur especially in bend [9]. This will increase the frequency increased inductance or decreased capacitance value in the design. Experiments on various bends have been proven with $2.5 \leq \varepsilon r \leq 25$ and $W/h \geq 0.25$. The effect of discontinuities can be eliminated by constructing an equivalent circuit such as adjusting the circuit parameters. In this research this effect can be minimize by introducing different type of chamfering or mitering at the right bend of the conductor. Chamfered bend is designed to curve in microstrip line. Fig. 3 shows some techniques used to design the chamfered bends. Based on previous research, the position of the chamfered bend and the modification of the response of the bend inclination is analysed [9]. Chamfered bend has been used to reduce the losses at the right bend corner.

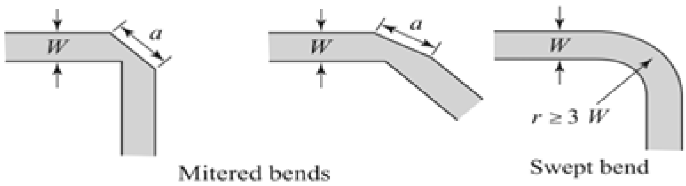
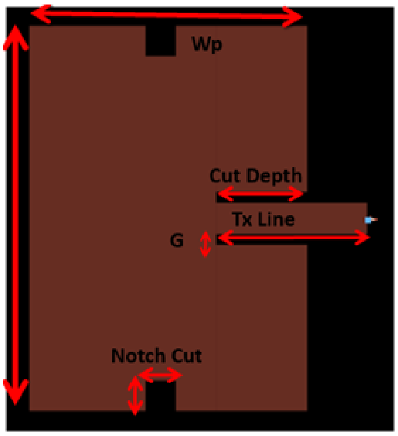


Fig. 3. Techniques to design chamfered bends [9].

B. Notch Antenna Design, Co-design and Cascaded Antenna

Fig. 4 shows the proposed antenna design that employed a pair of notch-cut. Since the notch are implemented, it helps in improving the bandwidth of the antenna. Other than that, the implementation of notch-cut with the size of 3mm is capable to enhance the resonance frequency with the design specification for proposed notch-cut MPA.



Design Specification

Length of patch (L): 27.5 mm

Width of patch (W): 38 mm

Cut Width-Gap: 1 mm

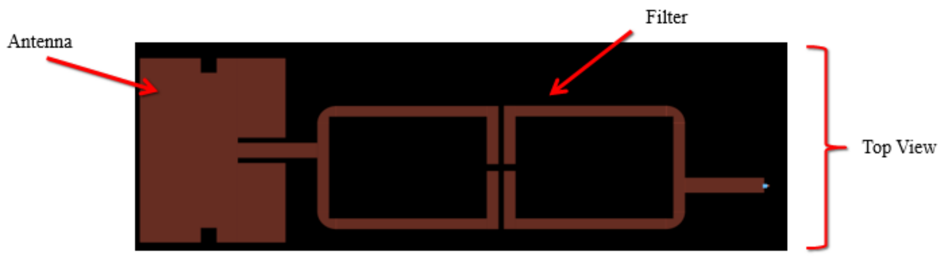
Cut Depth: 9 mm

Length of Feed: 15 mm

Width of Feed: 3.1 mm

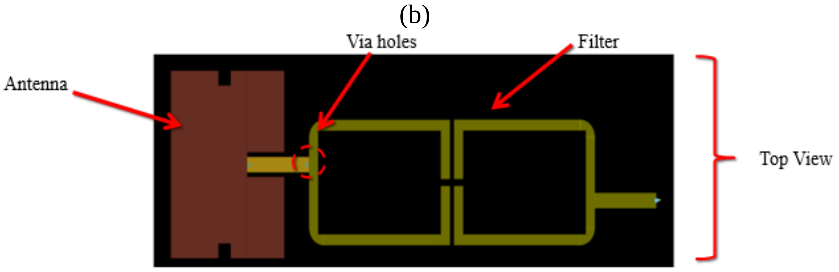
Fig. 4. Notch-Cut Microstrip Patch Antenna Design

In order to have low cost, small in size and high performances of the filter and antenna, two types of integrating method are presented in this project which are cascaded and co-design approach. Both two types of integrating method are different in the way how the filter and antenna being connected.Initially, the filter and antenna are connected individually in a system. Therefore, by having cascaded method of integrating, it can reduce the size of the system, low loss and having excellent performances. In this method, both filter and antenna are being integrated in same ground plane as shows in Fig. 5(a) and Fig. 6(a).It then being feed by the 50-Ohms impedance (input) at the filter. The antenna design is being feed by the transmission line of the filter. In this types of method, it is involving only one layer of the substrate. It also indicates the front view of the cascaded approach in integrating filter antenna. By using this method, it can improve the performance of S11 return loss as well as the bandwidth.The simulated result of this cascaded method are observed based on their performances of S11 return loss, bandwidth, gain, directivity and radiation efficiency.Co-design approach are designed to have the connection between them in separate layer. Both filter and antenna will shared the same ground plane and being connected by using via holes.Via holes acts as the connector for both filter and antenna. As shown in Fig. 5(b) and Fig. 6(b) it shows top view and front view of the integrated filter antenna in co-design approach.



(a) Cascaded design

(b)



(c) Co-design

Fig. 5. Top view of cascaded and co-design approach

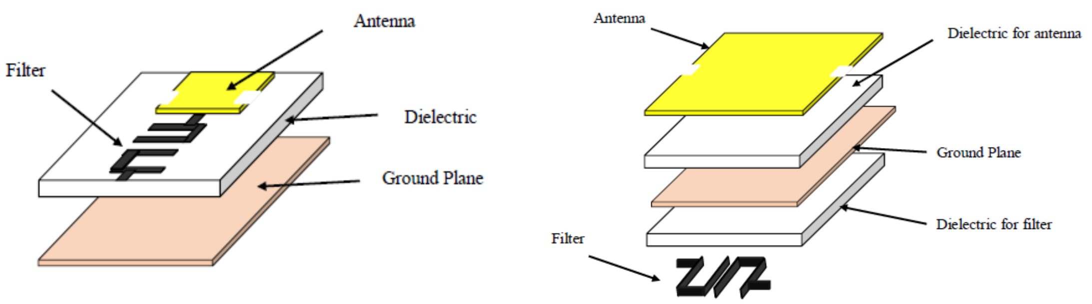


Fig. 6. Side view of Cascaded and co-design approach of integrated filter-antenna [12]

III. Result And Discussions

Cascaded method is applied when both filter and antenna are integrated on the same ground plane and feed by 50 Ohms impedance interfaces. The OLR Filter are integrated with Notch-Cut MPA in order to achieve miniaturization and enhancing the bandwidth performances. Bandwidth for this type integration method system is about 8.78% as calculated. It is increases as being compared to the bandwidth of the single Notch-Cut MPA. As the bandwidth become wider, it allows to have many frequencies drops within the bandwidth range. Therefore, the limitation of using microstrip patch antenna that having narrow bandwidth are being solved after the filter structure are integrated. From Fig. 7, the S_{11} is falls at -23.441 dB to show that the impedance matching are good. Since the resonance frequency drops from 2.40 GHz to 2.30 GHz, it evidenced that the current path is longer due to the combination of notch-cut antenna and the OLR Filter [11]. Thus, the resonance frequency is reduced.

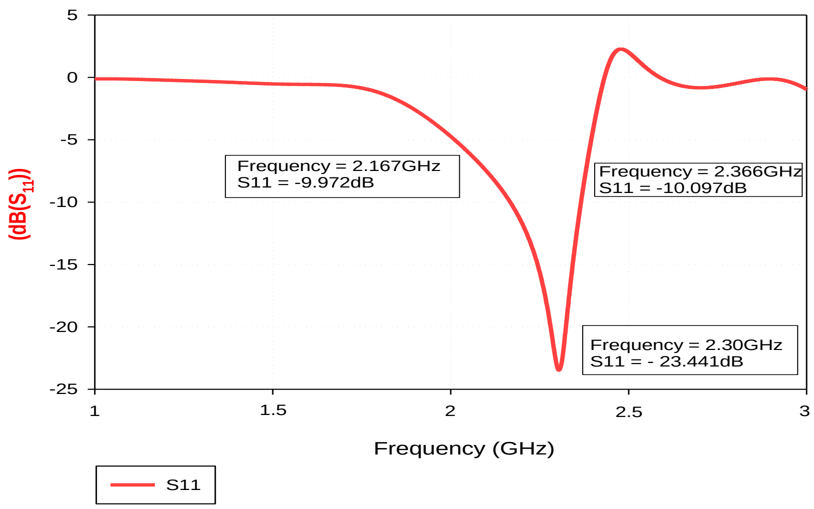
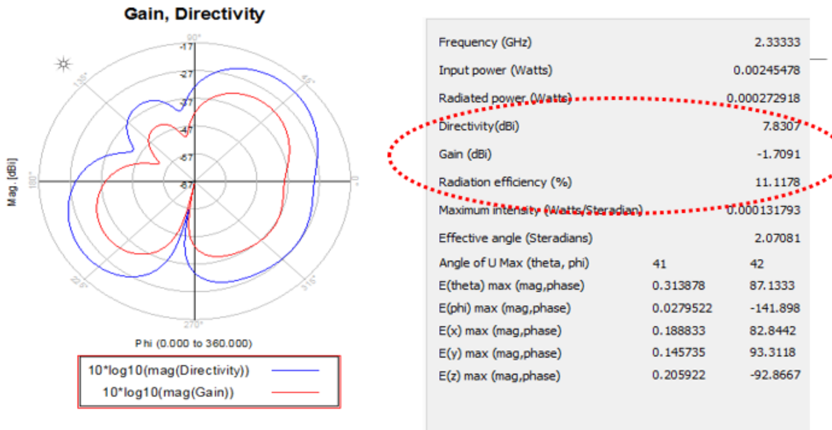
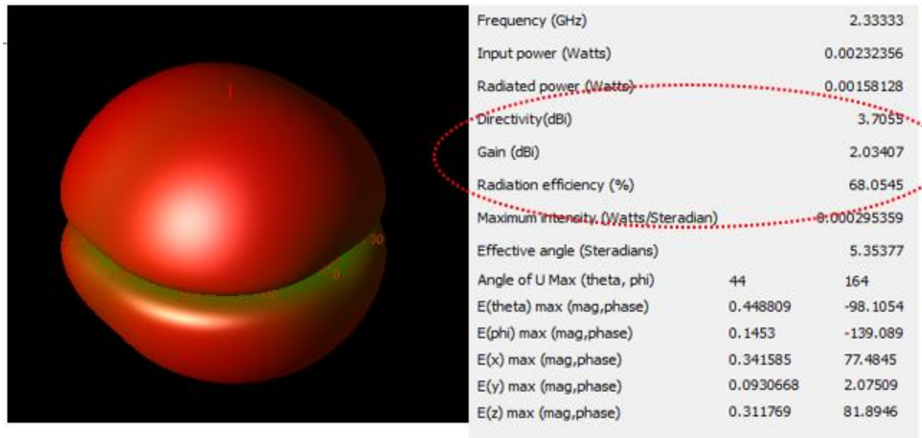


Fig. 7. Simulated result of S_{11} return loss for cascaded approach

Next part is the radiation pattern of the integrated filter antenna for cascaded approach.From Fig. 8(a), it shows that the gain and directivity radiation pattern of the integrated filter antenna for cascaded approach and its parameter. The maximum directivity of this system is 7.8307 dBi. It allows higher performances of directivity compared to the single Notch-Cut MPA. However, as for the gain, this system are having -1.701dBi less than to the Notch-Cut MPA. It may happens due to loss of capacitance in the systems.Since the best performance of the co-design approach is by using 4 via holes, the gain, directivity and radiation efficiency is being observed. Afterwards, the comparison between the cascaded approach and co-design approach being made. Since the connection between the filter and antenna are involves in two layer, the system are having both sided radiating pattern. Thus, it will increasing the radiation efficiency of the system itself. The directivity is 3.7055 dBi and the gain is 2.03 dBi. As for the radiation efficiency, it is effective up to 68.05 %. Fig. 8(b) shows the 3D of the radiation pattern with its parameter.



(a)



(b)

Fig. 8. Gain and directivity radiation pattern and antenna parameter of integrated filter antenna for cascaded approach

IV. Conclusion

Both filter antenna have been designed with cascading and co-design structure. The return loss, S_{11} of the integrated filter antenna for cascaded approach is drops at -23.441 dB. While the best performances of return loss in integrated filter antenna for co-design approach is -15.616 dB. It shows that both methods achieve good impedance matching.It proved that the S_{11} return loss for cascaded approach are higher as compared to the co-design approach. This may be happens due to the loss that produces from via holes [8].The performances for the cascaded approach is about 8.78%. As for the co-design approach, the bandwidth is 4.54%. The bandwidth for the cascaded approach are higher as compared to the co-design approach. In addition, the gain for the cascaded approach is about -1.70 dBi to show that there are loss in the system. As for the co-design approach, the gain is 2.03 dBi. It shows that the gain of the co-design is higher than the cascaded approach. For the directivity, the cascaded approach perform 3.70 dBi value while the co-design is 7.83 dBi. The cascaded are having higher directivity as compared to the co-design approach. Last but not least, the radiation efficiency.Cascaded approach having only 11.11 % while for the co-design approach are having about 68.05 %. It shows that the radiation efficiency of the co-design is higher because of having 2 layer radiating elements.Table 1 summarize the results for both designs.

Table 1: Comparison of OLRBPF with chamfered bend, notch cut MPA integrated antenna

Design	**Result Analysis**		
	Return loss	***Bandwidth***	***Resonance frequency***
OLRBPF with Chamfered Bend	-27.671 dB		2.420 GHz
Notch-Cut Microstrip Patch Antenna	-24.723 dB	1.77 %	2.453 GHz
Integrated Filter Antenna (Cascaded Approach)	-23.441 dB	8.78 %	2.30 GHz
Integrated Filter Antenna (Co-design Approach)	-15.616 dB	4.54 %	2.378 GHz

Acknowledgements

This research is being supported by Universiti Malaysia Sarawak (UNIMAS) Small Grant Scheme (SGS) with number F02(S181)/1325/2016 (5).

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