The Effect of Chamfering Structure towards the Design of Open Loop Resonator Bandpass Filter for Microwave Applications

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***Abstract*—Filter is the most essential components in the transceiver system. It is used to accept and reject any unwanted frequencies that falls out of the bands. Recently, the design of bandpass filter (BPF) has been a great challenges for RF designer. Although many researches have designed filter in the unlicensed frequency but most of the filter suffered from high insertion loss, inadequate selectivity and wider bandwidth. Therefore, this project design an Open-Loop Resonator Bandpass Filter (OLRBPF) to produce a low loss filter to operate at 2.4 GHz frequency. In order to overcome the high insertion loss, chamfered bend is introduced and implemented at the OLRBPF's structure. This will reduce the radiation loss produced and enhanced the coupling between both resonators of the filter. The results show that the proposed OLRBPF produce better insertion loss compare to conventional filter.**

***Index Terms*—Bandpass Filter; Chamfering; Coupling; Low Loss; Radiation Loss.**

I. INTRODUCTION

Recently, the design of bandpass filter (BPF) has been a great challenges for RF designer. Although many passive filters have been designed in the unlicensed frequency, but there are some lack in their filters such as high insertion loss and larger bandwidth allocated. Therefore, BPF with low insertion loss is preferable due to their importance in the transmission system. A perfect filter is able to pass the desired signal with zero insertion loss. But, this filter cannot be accomplished because there are always some loss happen due to reflections from the end terminations [1]. In order to design OLRBPF with low insertion loss, a method of chamfering the filter's structure is proposed. Chamfered bend is design to overcome the inevitable discontinuities at the bends of microstrip filters [2]. Besides, chamfered bend also help to minimize return and insertion loss in BPFs. As in previous research, the implementation of chamfered bend at the microstrip transmission line reduce the insertion loss significantly [3]. The research achieves a very good RF performance by utilizing chamfered bend on the signal conductor.

This paper presented the design of OLRBPF implemented with different types of chamfering bend to reduce the losses of the proposed filter design. The OLRBPF is designed on FR4 substrate with 1.6mm thickness and relative permittivity, ε_r of 4.6.

II. DESIGN OF OLRBPF

OLRBPF was introduced by a researcher name Hong in 1995 [4]. The filter structures has been widely used in many RF filter and wireless systems. The structures of OLRBPF can be constructed as a building block for planar microstrip filters that consist of folded half-wavelength resonator. It is composed of microstrip line with both ends loaded with folded stubs. The folded arms of the open stubs helps to increase the loading capacitance and it is designed for the purpose of inter-stage or cross couplings. The resonators shape could be design with any shape as long as it can match with different size of substrate. Obviously, OLRBPF help to obtain the transmission zeros in determining desired filter performance. The transmission zeros can be achieved by introduce cross coupling between the nonadjacent resonators. OLRBPF also provide some advantages to get the best filter performance such as easier to achieve a narrow bandwidth in order to produce the two attenuation poles. The cross-coupled structure is utilized to increase the selectivity characteristics with transmission zeros that can enhance the skirt rejection of microstrip filters. Figure 1 shows the configuration of OLRBPF filter.

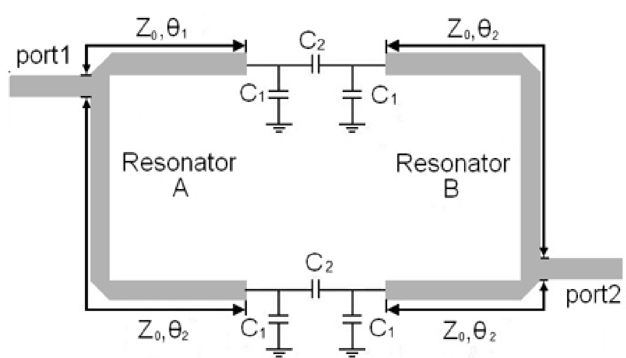

Figure 1: The equivalent circuit of OLRBPF [5]

OLRBPF with Chebyshev design is proposed to achieve a better filter performance. Chebyshev filter is a filter that can provide a great advantage to design the filter with the desired operating frequency.

Different types of filter shows the difference in terms of pass-band, transition region, stop-band and step response is summarized in Table 1 [6] [7]. Four types of filters are; Bessel, Butterworth, Chebyshev and Elliptic filter are characterized in terms of their unique properties. Butterworth filter produce maximally flat magnitude respond within the pass band with steeper transition region compare to Bessel filter with no ringing at the stop band. Bessel filter has delay properties act as low pass characteristics. Meanwhile, Chebyshev filter allow ripples in the passband amplitude response know as equal ripple response filter which depend on type of Chebyshev filter. With steeper roll-off near the cutoff frequency compare to Butterwoth filter. Other characteristics of Chebyshev filter is ripple in the passband, sharper transition band and poorer group delay with all poles are located on an ellipse inside the unit-circle.

Table 1
Comparison of active filter performance. [6][7]

Filter Types	Pass-band	Transition region	Stop-band	Step response
Butterworth	Maximally flat magnitude respond	Steeper than Bessel but as steep as Chebyshev or Elliptic filters	No ringing	Some overshoot and ringing, but less than the Chebyshev or Elliptic filters
Elliptic	Flat magnitude respond	Steeper than Butterworth, Bessel and Chebyshev filters	More ringing than other filters	More overshoot and ringing, but less than Elliptic filters
Chebyshev	Have ripple	Steeper than Butterworth and Bessel but not as steep as Elliptic filters	No ringing	Fair degree overshoot and ringing but less than Elliptic filters
Bessel	Flat magnitude respond	Slower than Butterworth, Chebyshev and Elliptic filters	No ringing	Very little overshoot / ringing compared to Butterworth, Chebyshev and Elliptic filters.

Chebyshev filter characteristic is applied in the filter design to help the OLRBPF to exhibit single pair of attenuation poles at finite frequencies [8]. Chebyshev filter could improve the selectivity of the filter because the attenuation poles was form near to the cut-off frequency and this lead to the sharper filter skirt.

A. *Design of OLRBPF*

The main objectives to design the OLRBPF is to achieve better transmission zeros in the filter performance in order to produce high selectivity characteristics [9]. The OLRBPF structure is illustrated as in Figure 2. It shows the configuration of the filter using two open-loop ring resonators with asymmetric feed lines tapping the resonators to produce impedance matching. Both input and output feed lines are divide in two sections of L1 and L2. The total length for the resonator are the combination of L1 + L2 = λgo/2 where λgo is the guided wavelength at fundamental resonance. Others parameter that need to be taken into consideration is the feed line width, W, gaps, Cg and feed lines, L.

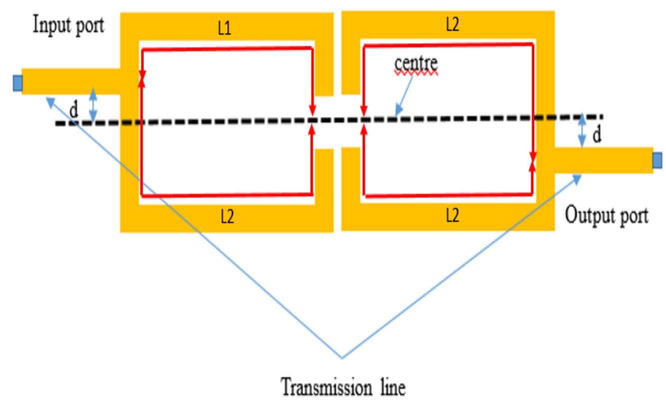

Figure 2: OLRBPF structure designed using EM simulator

The feed line width, W will affect the filter performance when the line width ratio is decreased. This will change the filter performance by moving the BPF to high frequency. Besides that, the gap, Cg between two open end ring resonators also affect the filter performance. When the gap between them are reduced, it will increase the double loop coupling between the resonators. Practically, the smaller the gap will result in a stronger coupling between the resonators. The feed lines, L1 and L2 can also independently control the filter frequency response. By adjusting the value of L1 and L2. The insertion loss of the filter can be conveniently adjusted.

In transmission line design, impedance matching is very important when dealing with passive devices. This is used both to maximize and minimize the reflections from the load. Therefore, in this design, both measurement pad and filter line is matched to achieve input impedance, Zin of 50Ω as shown in Figure 3. The two transmission lines with asymmetric structure are integrated with the BPF design structure. The high impedance line is designed between pad and structure with Zin = 50Ω.

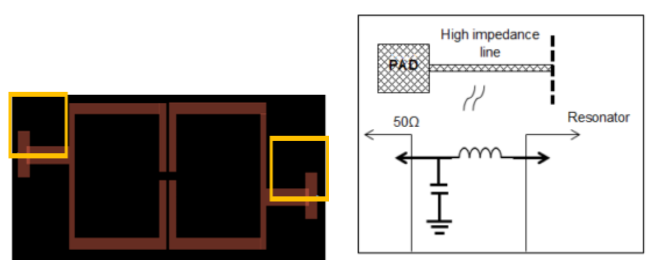

Figure 3: Measurement pad equivalent circuit for impedance matching configuration

B. *Chamfering design*

The OLRBPF design used a microstrip circuit which provide some advantages such as easy to fabricate and allows appropriate integration of passive and active component constructed on FR4's substrate with 1.6mm thickness. Even though microstrip offered some advantages but it faced some problems due to the certain discontinuities at bends, step changes in widths and junctions. Hence, this problem cause the degradation in circuit performance due to discontinuities existed from parasitic reactance that lead to phase and amplitude errors, input and output mismatch and possibly spurious coupling or radiation [2].

When designing OLRBPF, typical microtrip discontinuities might occur especially in bend [10]. 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. Figure 4 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 [11]. Chamfered bend has been used to reduce the losses at the right bend corner.

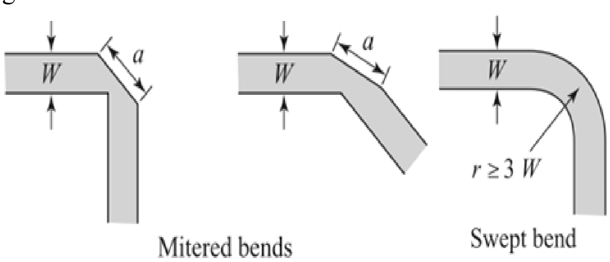

Figure 4: Techniques to design chamfered bends [11]

Figure 5, Figure 6, Figure 7 and Figure 8 show the structure of OLRBPF employed with three different design of chamfered bend, Chamfered A, Chamfered Bend B and Chamfered Bend C. As shown in Figure 4 is chamfered bend A, where the right angle bend of the filter is compensated by mitering the corner with an optimum value of miter length, a. The value of a = 0.18W is used to mitered the right angle bend because the value is often used in practice.

Figure 7 shows the designed of Chamfered Bend B employed in OLRBPF's structure. For this structure, only the outer curve of the filter is altered with a round curve while the inner curve is maintain as 90° right curve. The width of the outer curve is measured with W = 2.2 mm which is same as the width of the resonator. In addition the design of Chamfered Bend B has be implemented in recent research. The research prove that Chamfered Bend B are very effective to transmit signal with low losses [4].

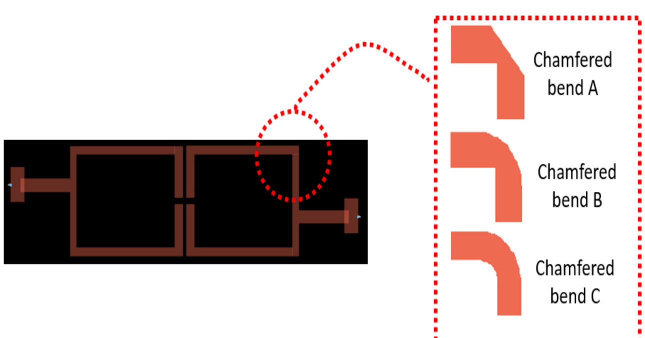

Figure 5: Proposed Chamfered Bend

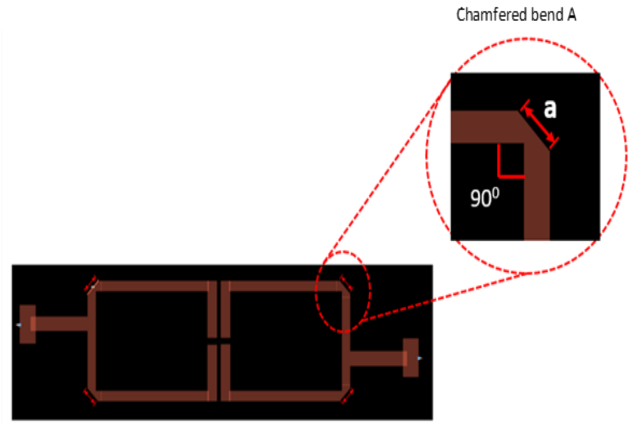

Figure 6: Proposed OLR BPF employing Chamfered Bend A

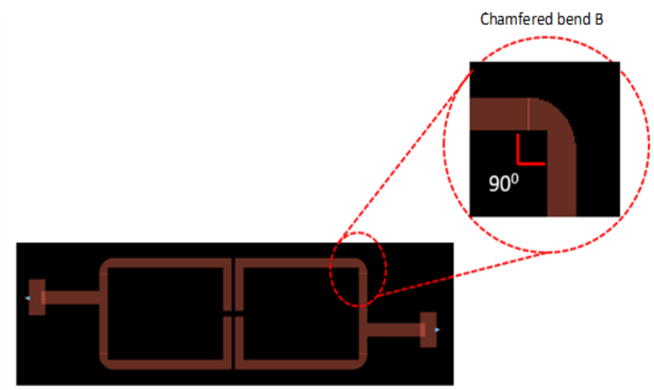

Figure 7: Proposed OLR BPF employing Chamfered Bend B

Figure 8 shows the Chamfered Bend C designed. The radius of the chamfer bend is measured to be three times larger than the width of the resonators and by assuming the effective radius to be $R_{eff} = R_{inner} + 0.3W$ [10]. This technique can be used to lower the parasitic capacitance which exist at the right-angle curve of OLRBPF.

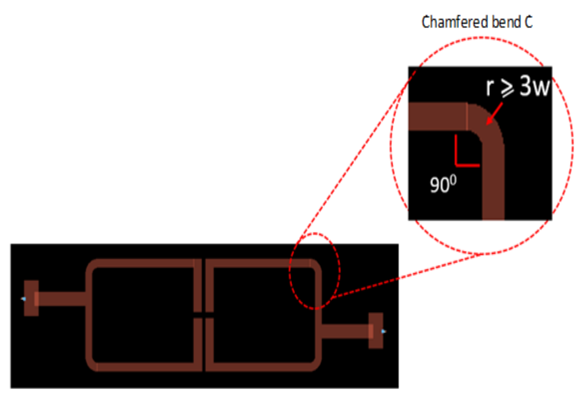

Figure 8: Proposed OLRBPF employing chamfered bend C

III. Results and Discussions

Simulation had been carried out to analyse the effect of three different chamfered bend structures on the OLRBPF and the result is shown in Figure 9 and Figure 10.

As shown, all the proposed chamfered bend structures have good impedance matching. Among the three chamfered bends, the maximum return loss is produced by the Chamfered Bend A which is 18.69dB at 2.32 GHz. However, Chamfered Bend A produce the higher insertion loss compare to others as shown in Figure 8. The design of Chamfered Bend B is employed also and the result shows the insertion loss is reduced to 4.37dB. The structure of Chamfered Bend B is very effective to reduce the loss of OLR filter. Chamfered Bend C is also proposed to this filter design and produce the lowest reduction of insertion loss of 3.87dB at 2.31 GHz. Instead of chamfered bend B, chamfered bend C is the best chamfer that improve the filter performance. Therefore, it is proven that the structures of chamfered bend gives an effect to the performance of filter to reduce the loss.

Figure 11 and Figure 12 shows the simulation results for the proposed OLRBPF employed with Chamfered Bend C compare to the conventional OLRBPF. It is shown that the proposed OLRBPF produce better return loss around 11.24dB at 2.31GHz compare to conventional filter of 10.06dB at 2.27GHz. For insertion loss, the proposed filter produce is 3.87dB at 2.31GHz compare to 7.44dB at 2.7GHz.

Table 2 shows the summarize results for the conventional filter and proposed OLRBPF with three different design of chamfered bend. It is shown that conventional OLRBPF suffered from high insertion loss and the loss is overcome by implementing Chamfered Bend A, B and C. All the structures of chamfered bend reduce the loss of the conventional filter. However, among the three chamfered bend, the lower insertion loss is produced by Chamfered Bend C which is -3.87dB. This shows that Chamfered Bend C produce best filter performance. It is also shown that the centre frequency is shifted to the higher frequency due to the effect of changing the electrical length of the filter via chamfering method.

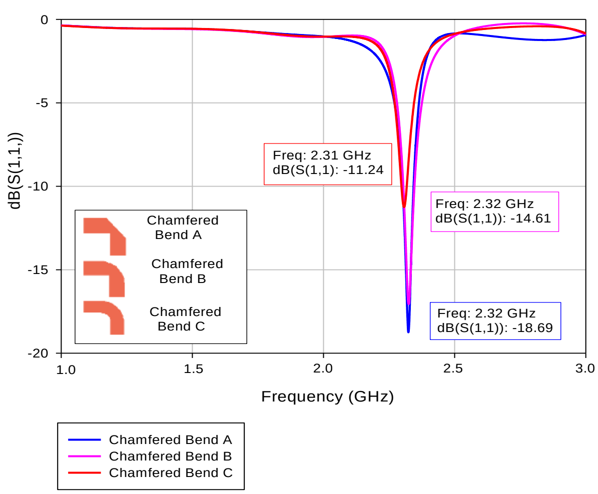

Figure 9: Simulated return loss for 3 different chamfered bend

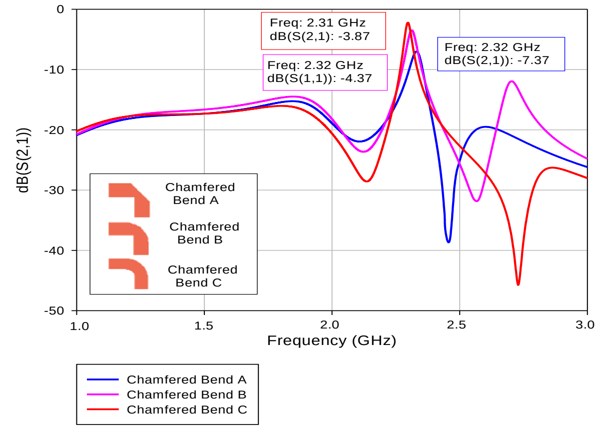

Figure 10: Simulated insertion loss for 3 different chamfered bend

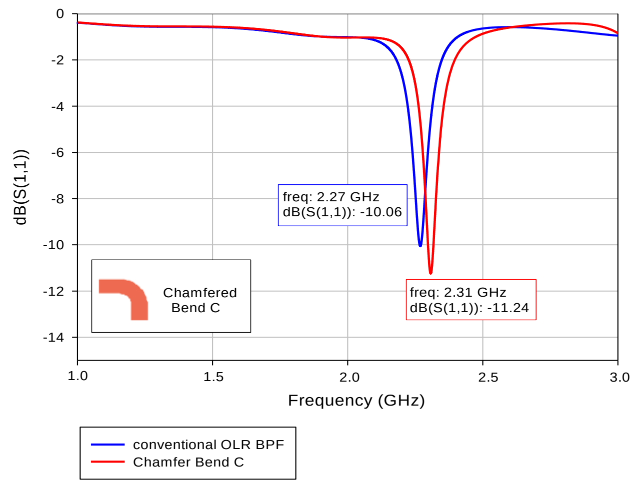

Figure 11: Comparison of simulated return loss for conventional OLRBPF with proposed OLRBPF with Chamfered Bend C

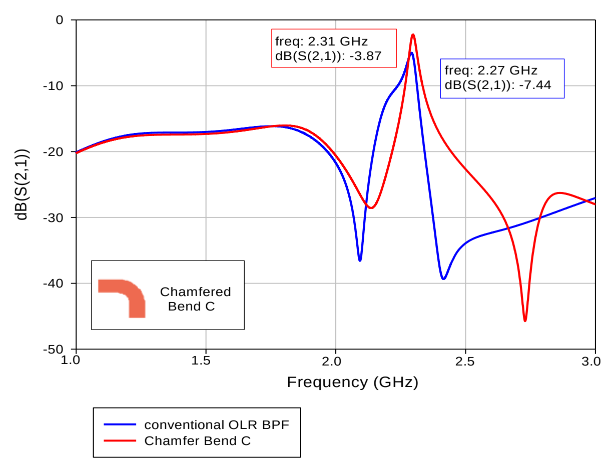

Figure 12: Comparison of simulated insertion loss for conventional OLRBPF with proposed OLRBPF with Chamfered Bend C

Table 2
Comparison between different chamfered bend structures

Types of chamfering	Centre frequency	S11	S21
Conventional	2.27	-10.06	-7.44
Chamfer A	2.32	-18.69	-7.37
Chamfer B	2.32	-14.61	-4.37
Chamfer C	2.31	-11.24	-3.87

IV. CONCLUSION

The proposed OLRBPFs are presented in this paper. Different techniques of chamfering resulted improvement of the filters especially on reducing the return loss compare to conventional filter. From the proposed chamfering type, type C is selected to be applied and improve for the passive circuit application which produce the lowest insertion loss and better return loss for future microwave transmission system.

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