Wideband Substrate-integrated-waveguide BPF Incorporated with Complimentary-split-ring-resonators

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Abstract— This paper discusses the development and characterization of wideband substrate-integrated-waveguide (SIW) bandpass filter (BPF) incorporated with two reversely arranged complimentary-split-ring-resonators (CSRRs). The proposed filter is intended to have bandwidth response more than 8 GHz suitable for applications in wireless communication systems. The incorporation of CSRRs on the SIW surface allows the extension of passband area at the higher frequency region yielding the wideband response of filter. A 1.6 mm thick FR4 epoxy dielectric substrate with the dimension of 40 mm × 45 mm is applied for filter implementation. The characterization result shows that the proposed filter has the fractional bandwidth of around 135% at the center frequency of 6.74 GHz. This result was achieved through measurement setup to demonstrate a good agreement between the simulation and experimentation.

1. INTRODUCTION

It is already well-known that electronic filter is one of essential devices in wireless communication systems applied to either limit or allow the desired frequency or signal and put the undesired one away [1]. The technology of filter development has been existing for many decades ago along with the invention of radio communication [1, 2]. Over the years, there have been numerous proposed methods for implementing the filter throughout the progress of wireless technology, sensor application, and radar system. One of the methods is implemented using microstrip technology which has the advantage to design the filter with many variations of shape [3]. The microstrip technology also allows incorporation of other methods to enhance the filter performance such as square loop resonator (SLR), stepped impedance resonator (SIR), defected ground structure (DGS), split ring resonator (SRR), and substrate integrated waveguide (SIW) [4–8].

Among the methods above, the latter mentioned one, i.e., SIW method, recently has been one of the most research topics that attract researchers and academicians. Basically, the method is implemented by forming rows of metallic cylinders or vias used as the sidewalls of waveguide [9]. These vias are usually embedded in a dielectric substrate connecting the top and bottom metal layers. There are some merits of using SIW method which have been implemented on some devices such as the possibility to incorporate non-planar waveguide structures in planar substrates and the capability to provide high-rate signal transmission with high power handling [10, 11]. As a filter application, the SIW method is also possible to be integrated and arranged with other methods such as DGS and SRR to improve the filter performance. In [12], a filter was realized using SIW method with DGS incorporation to improve the bandwidth responses. Whilst, the combination of SIW method and complimentary-split-ring-resonators (CSRRs) has been implemented to gain a filter with compact size [8, 13].

In this paper, the SIW method integrated with CSRRs is proposed for the development of wideband bandpass filer (BPF). Two reversely arranged CSRRs are incorporated into the SIW surface of BPF aimed to allow the extension of passband area at the higher frequency region yielding the wideband response of filter. The proposed SIW BPF which is designed on a 1.6 mm thick FR4 epoxy dielectric substrate is intended to have more than 8 GHz suitable for wireless communication applications. Prior the realization, some parametric studies are performed to obtain the optimum design of SIW BPF. Hence, the filter characteristics such as bandwidth response, return loss, and insertion loss will be analyzed and used as performance indicators in the design evaluation. Some discussions related with the parametric studies as well as the characterization results will presented and followed by the conclusion.

2. DESIGN OF SUBSTRATE-INTEGRATED-WAVEGUIDE BPF

The construction of proposed SIW BPF incorporated with CSRRs is illustrated in Figure 1. It is designed on a 1.6 mm thick FR4 epoxy dielectric substrate with the relative permittivity (ϵ_r) of 4.3. The proposed SIW BPF consists of 2 reversely arranged CSRRs separated in a distance of s_r which are incorporated into the SIW conductor surface on the top side of dielectric substrate with the width of w_p and the length of l_p. Each CSRR has the diameter of d_ro and d_ri for outer and inner rings, respectively, while the slot widths of ring, i.e., w_so and w_si, are set to have different value. Surrounding at the side of each CSRRs, there are 9 vias with the diameter of d_v and the separation between vias of s_v which connect the SIW conductor surface on the top side and the groundplane on the bottom side. The input and output signals for the filter are fed into I/O ports with the width and length of w_p and l_p, respectively.

To achieve the optimum design, parametric studies upon the physical parameters of proposed SIW BPF are performed through simulation in which substrate and conductive losses of used materials are accounted for. It should be considered that each part of SIW BPF such as the dimension of SIW conductor surface, the dimension and separation of CSRRs, the diameter and separation of vias, and the dimension of I/O ports has own contribution to the characteristic of filter. The parametric studies shows that the separation of CSRRs and the diameter of vias have the significant impact to the achievement of return loss and insertion loss, and the bandwidth response, respectively. Figure 2 plots the simulation result of proposed SIW BPF with different separations of CSRRs. It shows that the narrower separation of CSRRs affects to the value of return loss and insertion loss in low frequency region, and vice versa. While in Figure 3 which depicts the simulation result of proposed SIW BPF with different diameter of vias, the bigger diameter the wider bandwidth response. However the bigger diameter of vias will take the space more, therefore the diameter is then limited by the space availability.

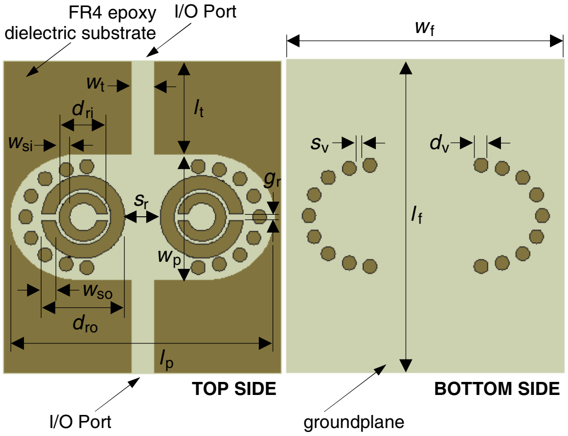

Figure 1: Construction of proposed SIW BPF incorporated with CSRRs.

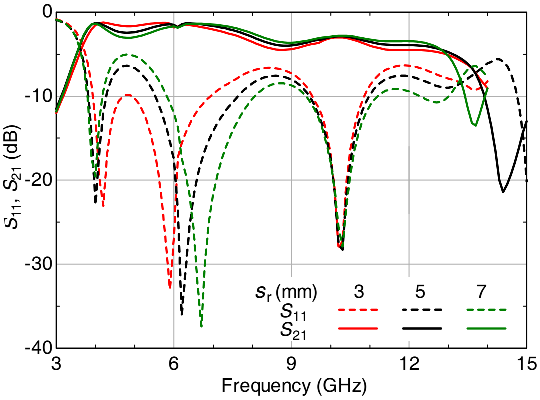

Figure 2: Simulated result of proposed SIW BPF with varied separation between CSRRs (s_r).

Furthermore, the effect of CSRRs existence to the filter performance especially in obtaining the wideband characteristic response is also investigated through parametrical studies. Figure 4 shows the result comparison for SIW BPF with and without CSRRs incorporation. It seems that the incorporation of CSRRs into the SIW conductor surface provides the possibility of bandwidth enhancement by omitting the bandstop response yielding the proposed SIW BPF obtaining wideband characteristic response. Table 1 summarizes the optimized parameters of SIW BPF incorporated with CSRRs which produces the optimum performance to be used for the realization.

Table 1: Optimized parameters of SIW BPF incorporated with CSRRs.

Parameters	w_l	l_f	w_p	l_p	w_t	l_t	s_r	g_r	d_ro	w_so	d_ri	w_si	s_v	d_v
Value (mm)	40	45	18	38	3.1	13.5	5	1	12	2	7	1.5	1.2	2

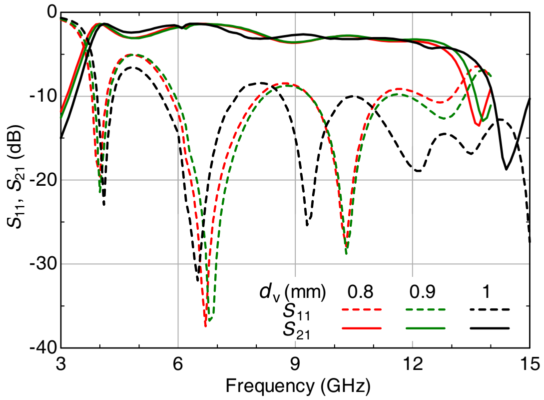

Figure 3: Simulated result of proposed SIW BPF with varied diameter of vias ($d_{\rm v}$).

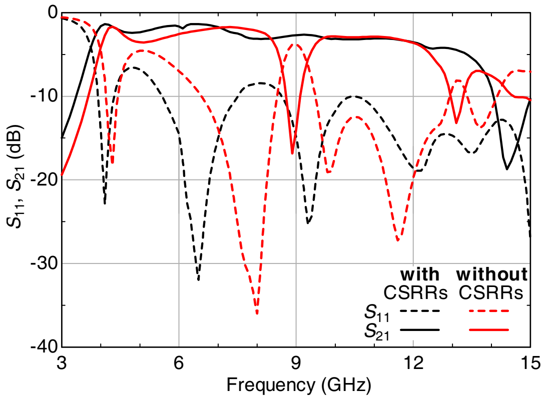

Figure 4: Comparison of simulated result for SIW BPF with and without CSRRs incorporation.

3. REALIZATION AND MEASUREMENT

Figure 5 shows the picture of SIW BPF incorporated with CSRRs prototype realized using wet etching technique of a 1.6 mm thick FR4 epoxy dielectric substrate. To experimentally characterize the realized BPF, there are 2 SMA connectors attached at the input and output ports. While to connect the SIW conductor surface at the top side of dielectric substrate and the groundplane at the bottom side, a short wire is put in each via hole and soldered at the both sides. The measurement setup is performed using a Vector Network Analyzer to measure the characteristic responses, i.e., return loss and insertion loss. Figure 6 plots the measurement result of realized SIW BPF with the simulation result depicted together as comparison.

In general, the measurement result of realized SIW BPF has agreed with the simulation result. The realized SIW BPF shows the wideband characteristic response with fractional bandwidth of 134.72% at the center frequency of 6.74 GHz. Meanwhile, the measured return loss and insertion loss at the center frequency are 18.29 dB and 3.78 dB, respectively. This is comparable with the simulation result which has fractional bandwidth of 140.39% at the center frequency of 7.18 GHz with the return loss of 12.08 dB and the insertion loss of 2.12 dB. The discrepancies which occur between the measurement and simulation results are mostly evoked by the material issues, i.e., relative permittivity and tangent loss, used in the realization and simulation. From the result, it shows that the relative permittivity in the simulation is higher than in the realization. This difference causes shifting of frequency response in the middle of passband area to others at the higher frequency region. In other hand, the tangent loss of dielectric substrate for simulation is lower than the realization. This is indicated by the percentage of return loss and insertion loss in the realization which is worse than in the simulation.

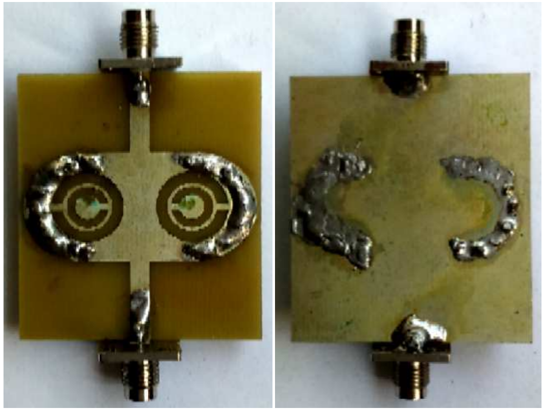

Figure 5: Prototype of SIW BPF incorporated with CSRRs; left is top side; right is bottom side.

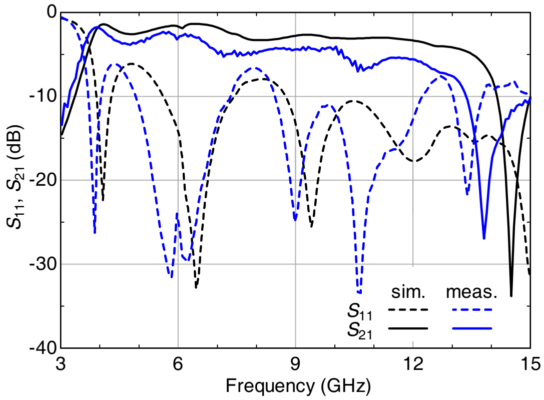

Figure 6: Measured and simulated results of SIW BPF incorporated with CSRRs.

4. CONCLUSION

The development of wideband substrate-integrated-waveguide (SIW) BPF incorporated with complementary split-ring-resonators (CSRRs) has been demonstrated. Some physical parameters of proposed SIW BPF has been investigated showing own its contribution to the performance of filter. It has been shown that the CSRRs incorporation into the SIW method was worthwhile in the extension of passband area at the higher frequency region yielding the wideband response. From the characterization result, although there were some discrepancies in terms of center frequency, bandwidth response, return loss, and insertion loss, it could be inferred that the realized SIW BPF has good agreement qualitatively with the design one particularly in the bandwidth achievement which is suitable for applications in wireless communication systems.

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