A Compact Wide Bandpass Filter based on Substrate Integrated Waveguide (SIW) Structure

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Abstract: **In this pare, a wideband three-order bandpass filter (BPF) is proposed. The proposed wideband filter is designed using the substrate integrated waveguide (SIW) structure by loading T-shape slots. A BPF with two resonators is formed by etching T-shape slots with different size on the top metal plane of the SIW structure. The proposed filter is investigated with the theory of coupled resonator circuits. The T-shape slots which etched on the SIW structure are used to form up a new multiple-mode resonator (MMR) in order to achieve a wide passband of operation while keeping the overall size of the proposed filter to be much compact. The design procedure as well as design curves of the filter are given and discussed here. Compared with some other reported BPFs with SIW technique, the presented BPF using the SIW structure loaded by T-shape slot has great improvements on size reduction and selectivity. In order to prove the validity, the proposed wideband SIW BPF on a single layer printed circuit board (PCB) is designed and experimentally examined. The measured results show that the filter achieves an insertion loss of 1.1 dB at 6.4 GHz and a return loss of higher than 22 dB. The proposed filter has a pass-band covers 5.1 to 7.99 GHz and its simulated and measured 3 dB fractional bandwidth is about 44.3%. The measured results are in a good agreement with the simulated results.**

Index Terms- microwave filter, substrate integrated waveguide (SIW), wide bandpass.

I. INTRODUCTION

Recently, the substrate integrated waveguide has provided a very attractive platform to design of various filters with low-cost, high quality factor, and easy integration with planar circuits [1-2]. The SIW structure is synthesized on a planar substrate with linear periodic arrays of metallic vias or metallic slots by standard printed circuit board (PCB) or other planar circuit processes. In the other words, the SIW structure is a type of rectangular waveguide synthesized in a substrate, which is composed of two rows of metallized via-holes or channels connected with two metal plates on the top and bottom sides [3]. The

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working mechanism of SIW is quite similar to a traditional rectangular waveguide however, the Q-factor of an SIW is smaller than a classic air-filled metal rectangular waveguide because of the dielectric filling and volume reduction [4]. One key advantage of the SIW structure is the easy connection between SIWs and other types of transmission lines or circuits which are embedded in or surface mounted on the multilayer substrate. Therefore, this structure is widely used in the realization and implementation of microwave devices such as filters, power dividers, diplexers and etc.

On the other hands, wideband radio system design techniques have been attractive in academia and industry and they are very suitable for its high data rate and supporting multiple adjacent narrow bands transmission. Filters with a wide passband, sharp frequency cutoff edges, and flat group delay are essential for broadband communication systems. For these reasons, various researchers works on the design of wideband BPFs to meet some advantages such as compact size, broad-bandwidth, low insertion loss and high return loss with sharp rejection. For example, in [5], a SIW filter using electric coupling formed by slots is introduced. In [6], a super-wide SIW bandpass filter (BPF) is designed by using the periodic structure. In [7], a wideband FSIW filter combined with stripline resonant cells is proposed. But, the above mentioned wideband filters have drawbacks such as narrow fractional bandwidth, large size and design complexity. To overcome such disadvantages and miniaturize the overall size, an effective procedure based on the multiple-mode resonator (MMR) has been proposed in [11]. This method has been broadly used to design of numerous wideband BPFs [8-15].

In this paper, a novel wideband SIW filter by loading two T-shape slot with different sizes on the metallic plate of a SIW structure are introduced which is provided a few resonant modes. The T-shape slots on the metallic plate of the SIW structure could produce three transmission poles which make the wide passband and one transmission zero, aiming to sharpen the selectivity and extend the upper stopband. After geometric optimization, a three order wideband BPF is designed in a single layer planar circuit board (PCB). With this proposed structure, the low insertion loss performance in the passband, high Q factor and compact size could be obtained. In comparison with the previous works, due to the small electrical size of the T-shape slots, the proposed SIW filter is very compact.

II. ANALYSIS OF PROPOSED MULTI-MODE SIW LOADED BY T-SHAPE SLOTS

The design procedure is based on the theory of the coupled resonator circuits. The magnetic and electric couplings are used in this structure in order to designing the BPF operating at 6.5 GHz. The magnetic coupling create by the via-holes while the electric coupling is simply controlled by adjusting the physical dimension of the T-shaped slots etched on the surface of SIW structure. The configuration of the proposed SIW filter is depicted in Fig. 1. As shown in Fig. 1, the proposed filter consists of two microstrip feed lines which the 50 Ω microstrip feed line used here for the purpose of measurement. The parameter l_s is used to control and adjust the coupling between the SIW structure, input and output ports. On the other hand, there are two etching T-shape slots on the top metal layer of the SIW structure in order to divide the SIW structure into two resonators with different sizes. The designed T-shape resonators are excited by the electric coupling. The coupling topology between the T-shaped resonators is given in Fig. 2. S and L stand for the source and load excitation. According to the coupling topology shown in Fig. 2, the adjacent coupling between two resonators with different sizes are strong coupling which is produced two poles and the passband.

The proposed SIW structure is designed to have a cutoff frequency of 5.1 GHz and the T-shaped are designed to have a stopband at 8 GHz initially. By adjusting the parameters of T-shaped unit cells, the proposed SIW filter with wide passband could be constructed. Fig.3 illustrate transmission poles and zero produced by the proposed filter under weak coupling. The components of the designed T-shape slots are mainly targeted to produce a few resonant modes in the SIW structure. By using two different sizes of T-shape slot two transmission poles are produced. The resonant modes between the T-shape slot are used to create the wide passband and the electric coupling between the T-shaped resonators can also generate a transmission zero in the upper-stopband to improve the upper-stopband performance. Due to the presence of the magnetic coupling, the first transmission pole namely f_1 which is related to the initial highpass band of the SIW structure is obtained. Because of the presence of the electric coupling, the other transmission poles f_2, f_3 and also transmission zero f_z are achieved. It should be noted that, the increasing height of the slots in T-shaped unit cells lead to that f_3 and the transmission zero f_z, to shift to the lower frequencies and thus causing a narrow passband. Therefore, the proposed T-shaped resonators gives a zero-transmission frequency at

$$f_z = \frac{c}{2w_{eff}\sqrt{\varepsilon_r \mu_r}} \tag{1}$$

Table I exhibits the dimensions of the proposed SIW filter shown in Fig.1, where all of them are in millimeters.

Table I
Dimensions of the proposed SIW filter (units: mm)

$l_{SIW} = 10$	$l_2 = 3.9$
$w_{eff} = 13.8$	$l_3 = 2.4$
$s = 0.8$	$l_4 = 2$
$d = 1.5$	$w_1 = 4.3$
$l_1 = 4.8$	$w_2 = 4$

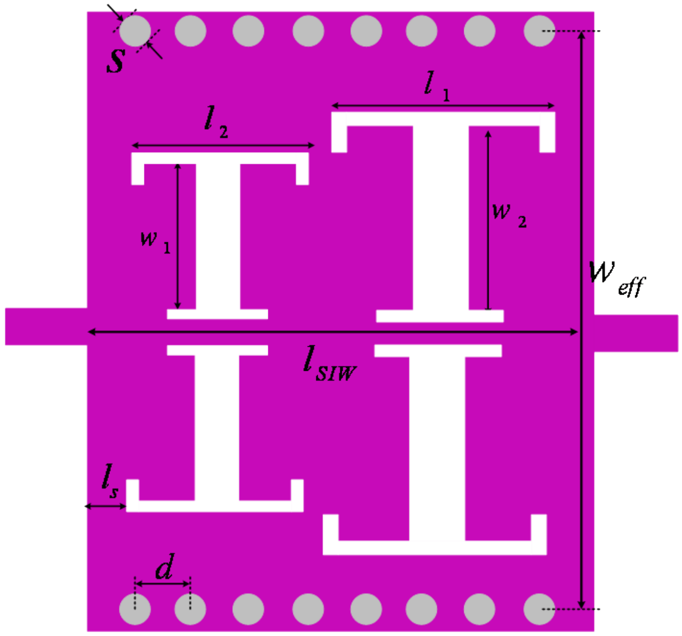


Fig.1. Configurations of the proposed SIW T-shape slot filter.

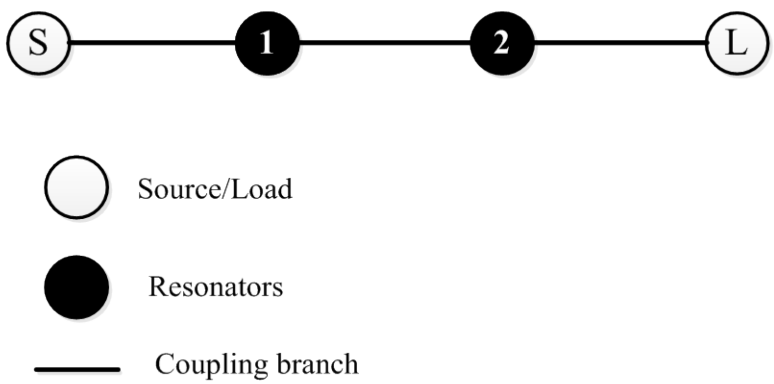


Fig.2. Coupling topology of a proposed SIW filter with two poles.

Accordingly, the total size of the filter is less than 13.8mm × 10 mm. The substrate is chosen to be Rogers RO4003 with the relative permittivity 3.55 and the thickness of 0.0508 mm. In the simulations, the metallic and dielectric losses have been taken into account by using the conductivity of copper $\sigma = 5.8\times10^7$ S/m and the loss tangent $\tan\delta = 0.0027$ of the substrate. As analyzed above, the SIW structure with T-shape slots could be used to design a compact wideband SIW filter. As illustrated in Fig. 4, by changing the size of the T-shaped resonators, the resonant frequency of the T-shaped resonators could be easily moved and varied passband characteristics are observed. Note that, as shown in Fig. 4, compared with T-shaped resonators of Fig. 1, T-shaped unit cell is scaled by a factor of 0.8 and 1.2. As well as, the bandwidth of this filter could be easily tuned by the coupling between two T-shaped resonators.

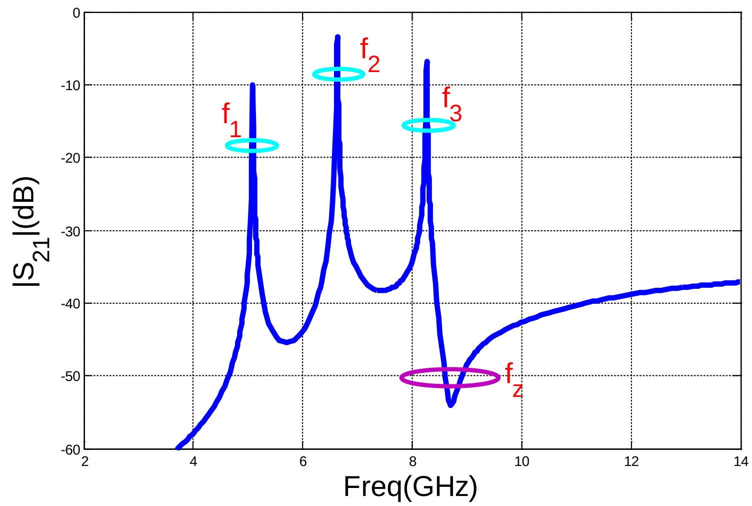
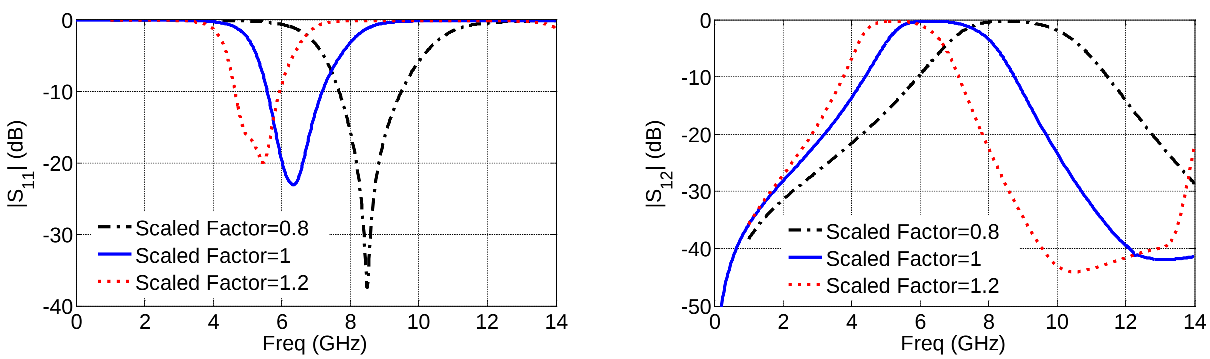


Fig.3. Simulated frequency responses of the proposed filter with weak coupling.



(a) (b)

Fig.4. Frequency responses (a) |S11| and (b) |S12| of the proposed SIW filter when the whole dimensions, multiple in variation factor.

Since the filters are based on the construction of periodic structures, so by inserting more cells better performance with a higher selectivity can be achieved. Consequently, T-shaped SIW filter with series-cascaded two cells is also designed. Fig. 5 shows the configuration of the designed two-stage SIW filter using the unit cell shown in Fig. 1 which is achieved after some simple tuning. The simulated response of the proposed two-stage SIW filter is also plotted in Fig. 6 and their geometric parameters are provided in Table II. The designed two-stage SIW filter has a simulated center frequency of 6.5 GHz and a 3-dB bandwidth of 3 GHz. Its minimum passband insertion loss is approximately 2 dB, which includes the extra loss caused by increasing the total size of the filter. Its in-band return loss for designed two-stage SIW filter is better than 10 dB. Due to the existence of the transmission zeros, this filter exhibits a stopband rejection better than 40 dB up to 16 GHz, as observed in Fig. 6. Also, by cascading two T-

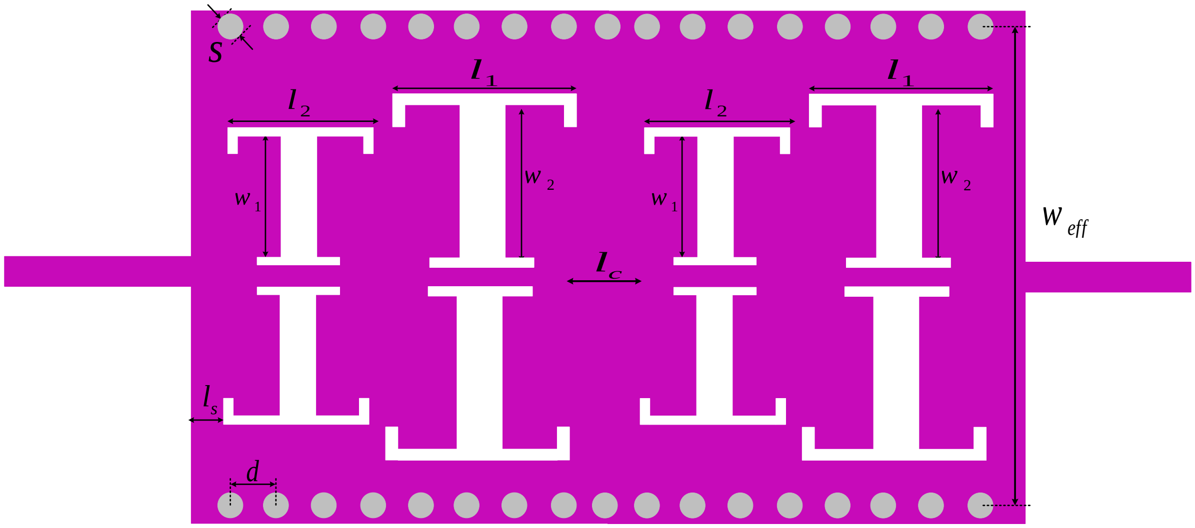


Fig.5. Configuration of the proposed two-stage SIW filter with its geometric parameters listed in Table II.

Table II
Geometric parameters of the proposed SIW filter (units: mm)

$l_{SIW}=10$	$l_2=3.9$
$w_{eff}=13.8$	$l_3=2.4$
$s=0.8$	$l_4=2$
$d=1.5$	$w_1=4.3$
$l_1=4.8$	$w_2=4$
$l_s=1$	$l_c=3$

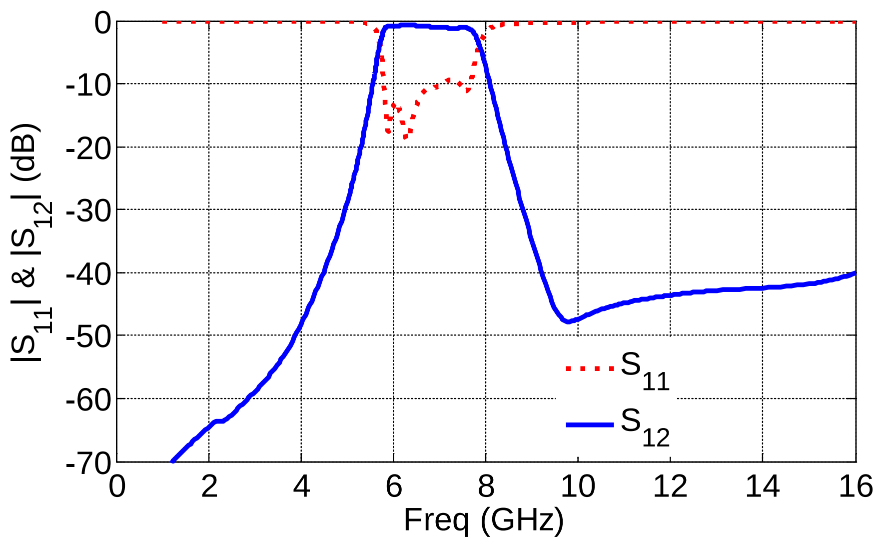


Fig.6. Simulated results for the SIW filter loaded by two-cells of the T-shaped resonators.

shaped resonators, the proposed SIW filter exhibits an abrupt transition band at the lower or upper edges of the filter.

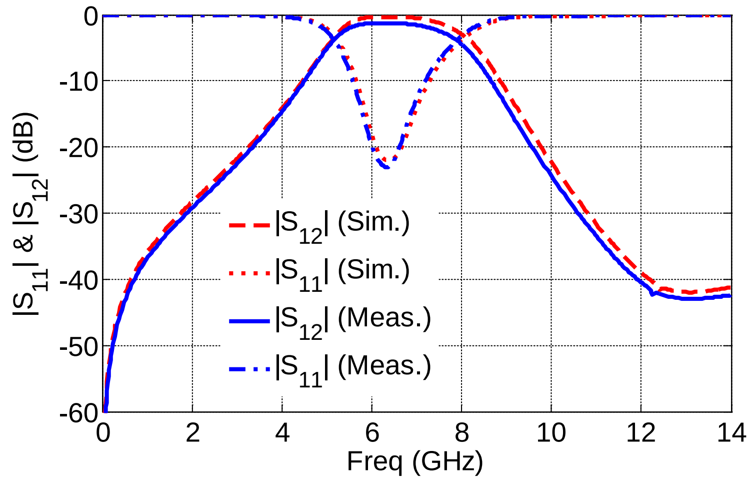


Fig. 7. Simulated and measured frequency responses of the proposed wideband filter.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A wideband bandpass SIW filter operating at the frequency range of 5.1–7.99 GHz is designed, fabricated and tested. The simulated frequency responses of the peropsed filter is achieved using a 3-D electromagnetic simulator (Advanced Design System (ADS)). Fig. 8 shows the simulated (dashed line) and measured (solid line) transmission responses of the proposed SIW filter which has been measured by the employment of a network analyzer Rohde & Schwarz, zkv. The proposed bandpass SIW filter exhibits an insertion loss smaller than 1.1 dB, and a return loss more than 22 dB in both simulated and measured results. The proposed BPF filter has a 3 dB fractional bandwidth of 44.3%. Meanwhile, a wide upper-stopband with the insertion loss higher than 40 dB in the range of 8 to 16 GHz is achieved. Three transmission poles and one transmission zero are observed within the pass-band. The transmission zero is created to improve the upper-stopband performance. Furthermore, due to the use of T-slots in the proposed SIW structure, these slots may produce radiation in the upper half space. The simulated radiation loss is illustrated in Fig.8 (a) which extracted by using the below equation:

$$R_r = 1 - |S_{11}|^2 - |S_{12}|^2 \tag{2}$$

The radiation loss is less than 0.6% within the desired frequency band with loss free dielectric and metal. This implies that the slots have a little effect on the radiation loss. Also, in Fig. 8(b), a comparison by including all the losses (which contain radiation loss + dielectric loss + conductor loss) for these resonators is presented which finally leads to a 1.1 dB insertion loss for the proposed structure. Finaly, Table III summarizes the comparison of the proposed filter with other reported filters. As illustrated in Fig. 9, the group delay is less than 0.36 ns in the passband of the designed SIW filter.

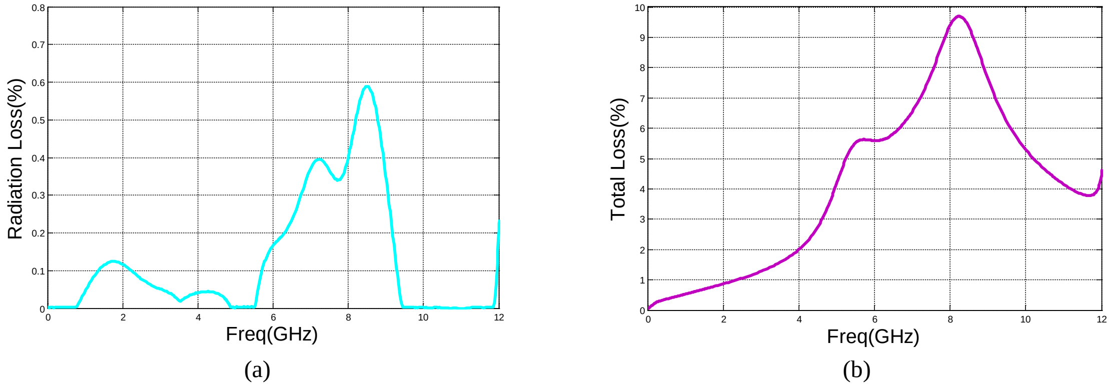


Fig.8. (a) The simulated radiation loss and (b) The simulated total losses of the proposed filter.

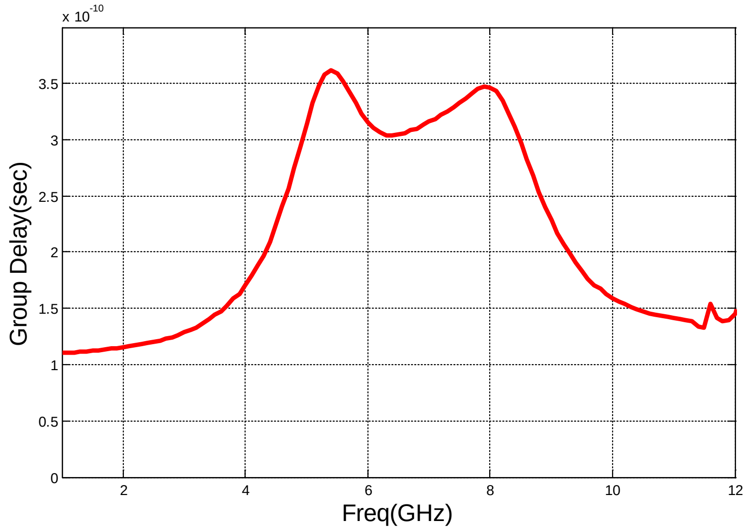


Fig.9. Simulated group delay of the proposed filter.

A photograph of the fabricated filter is shown in Fig. 10, which demonstrates the quite small size of the filter. The measured results has a good agreement with the simulation one. Some minor discrepancies between measured and simulated result may be caused by the limited precision of fabrication and measurement.

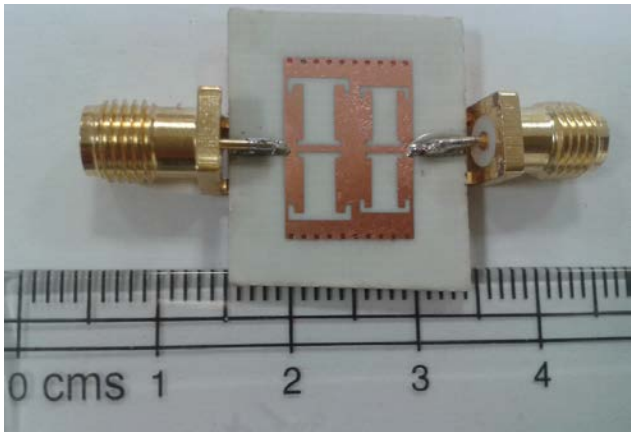


Fig.10. Photograph of the fabricated filter.

Table III:
Performance comparisons of the recent filter with the other.

Reference number	*FBW (%)*	*IL (dB)*	*RL (dB)*	*Size* $\lambda_g \times \lambda_g$
[7]	61.5	1.55	10	1.38×0.37
[8]	77.2	2	10	0.53×0.37
[9]	63.7	1.2	13	0.30×0.085
[10]	42	1.1	11	0.66×0.34
This Work	44.3	1.1	21	0.15×0.11 (13.8×10 mm^2)

IV. CONCLUSION

A compact wideband BPF SIW filter by loading the T-shape slots has been presented in this paper. The characteristic of the proposed resonators has been simulated to analyze and verify in details. The proposed wideband filter has three transmission poles and one transmission zero. The transmission zero is created to improve upper-stopband performance. The proposed SIW filter exhibits the passband of 5.1–7.99 GHz. The insertion loss is smaller than 1.1 dB and the return loss is more than 23.6 dB in simulated results. In addition, a wide upper-stopband with the insertion loss higher than 40 dB in the range of 8 to 16 GHz is achieved. It is shown that this filter is very compact and easy integrated with the other planar circuits. Finally, the proposed SIW filter has been fabricated and measured. The measured insertion loss is better than 1.1 dB with the return loss better than 22 dB. As well as the FBW is 44.3% and confirmed in experiment.

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