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# Miniaturizing Bandpass Filter Based on Half-Mode SIW for Sub-mm 5G Applications

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**Abstract**—A miniaturized half-mode substrate-integrated-waveguide (HMSIW) based bandpass filter with defected ground surface (DGS) for sub-5G applications is presented in this research. The novelty in this article is the proposal of an original configuration of a SIW Filter composed of a mix of DGS cells; each couple of C shapes is etched exactly beneath of two cross shapes, which give us long rejection. We have used six periodic cross-shaped slots as DGS in top of the cavity plane for disturbing the current and creating stopband rejection, and we have also used three couples of C-shaped DGS cells in the bottom plane to improve the performances of the proposed filter. This novel bandpass filter is developed on a 1.54 mm-thick FR-4 (with relative permittivity of 4.3 and tangent loss of 0.025) operating in the band ranging from 3.4 GHz to 3.8 GHz with a bandwidth of 400 MHz and having the size of $13.5 \times 38.6\,\mathrm{mm}^2$. The proposed HMSIW-based filter is simulated, fabricated, and measured. The measurement results are in decent agreement with the simulation results.

## 1. INTRODUCTION

Recently, the development of communication systems is focusing on minimizing the weight, compact size, and increasing the reliability in lower prices. Microwave components such as power dividers, antennas, and filters are a very important part of modern telecommunications systems and embedded satellite systems [1]. The most widely used microwave components are rectangular waveguide, but they have large size, are very expensive, and difficult to integrate into planar structures. To solve this problem, scientists have oriented towards the study and development of a new planar structure, which is substrate-integrated waveguide (SIW) [2]. The SIW technology is used for several hyper-frequency components including terahertz antenna [3], leaky wave antenna [4], antipodal antenna [5], and wideband band-pass filter [7]. DGS technique is a geometrical periodic and aperiodic cell engraved on the ground plane of RF integrated circuits. This defected ground plane disturbs the flow of the surface current, and this disorder of the current alters the characteristics of the structure [8]. The HMSIW technique is used to reduce the SIW structure size, keep it with the same performance, and it was widely used in many implementations [9]. In the literature [11–14], many bandpass filters were proposed to overcome the above-mentioned problems. In [11], a microstrip bandpass filter was presented which operated in the range of 2.9 GHz to 3.1 GHz (200 MHz). The substrate material used for the filter was Roger 4350B with size of $53.7 \times 17.6\,\mathrm{mm}^2$. The stopband rejection was available from 3.1 GHz to 4 GHz. In [12], a new compact S-band bandpass filter (BPF) with wideband passband was proposed with high rejection.

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Another HMSIW-based bandpass filter with step impedance resonators operating in the range from 3.4 GHz to 3.6 GHz (200 MHz) with sized of 21 × 12 mm$^2$ was explained [13]. Next, a SIW based Koch fractal electromagnetic bandgap (KFEBG) bandpass filter was presented [14]. The proposed filter operated in the frequency range from 3.2 GHz to 3.6 GHz (400 MHz), and the substrate material used for the filter was Arlon AD1000.

This paper describes a novel miniaturized half-mode SIW based bandpass filter for sub-5G applications. The filter is fabricated using an FR-substrate with a substrate height of 1.54 mm. The overall size of the filter is 13.5 × 38.6 × 1.54 mm$^3$. In this paper, a novel BPF for the TE10 mode based on HMSIW technology is proposed. The proposed filter consists of periodic double cross-shaped slots as DGS on top metallic plane and periodic coupled C shaped DGS cells in the bottom plane for enhancing the filter response. The half mode technique is used to miniaturize the filter size. In the last, the HMSIW BPF is fabricated and measured using a vector network analyzer (VNA). Good results in terms of size and rejection are obtained. This paper is categorized as follows. Design procedures of the proposed DGS filter are presented in Section 2. Section 3 explains the design of a DGS HMSIW bandpass filter. Experimental results of the proposed filer are given in Section 4, and the concluding remarks are available in Section 5.

## 2. SIW WAVEGUIDE DESIGN PROCEDURE

Using the CST, a new SIW-DGS band-pass filter structure for sub-mm 5G is designed. An FR-4 substrate is used which has loss tangent of 0.025, dielectric constant of 4.3, and thickness of 1.54 mm. In the first step, two cross shaped slots are inserted in the upper plane as DGS cells, separated by a vertical distance equal to 3.9 mm and one couple of C-shaped DGS cells in the middle of the bottom plane with a distance between the inverted CDGS equal to 1.61 mm as depicted in Figure 1. For impedance matching, we insert two L-shaped slots in the upper plane. Figure 1(c) illustrates the simulated results of the proposed filter by CST Microwave based on finite integration technique, a relative of FDTD for

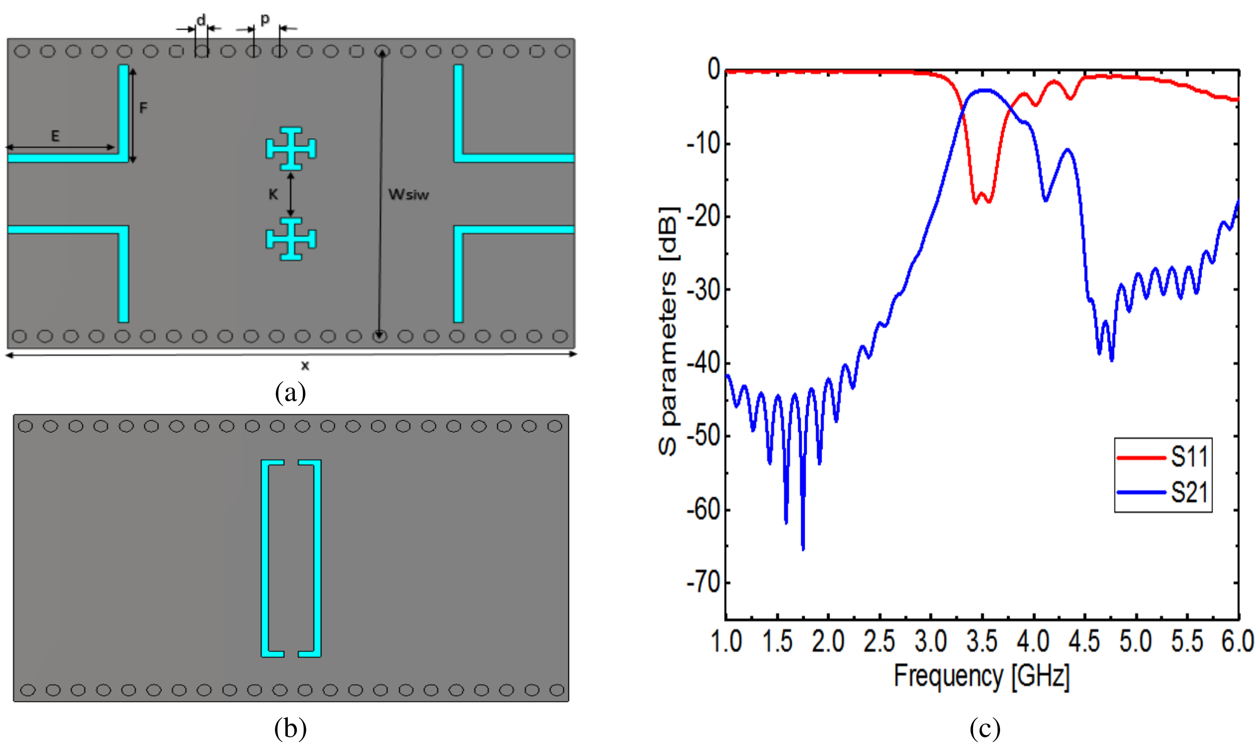



**Figure 1.** DGS-SIW band-pass filter configuration, (a) front view, (b) bottom view with $W_{\text{siw}} = 23.5\,\text{mm}$, $E = 7.8\,\text{mm}$, $F = 8\,\text{mm}$, $K = 3.9\,\text{mm}$, $p = 2\,\text{mm}$, $d = 1\,\text{mm}$. (c) Transmission coefficient and return loss of SIW DGS filter.

its transient solver.

Obviously, the filtering function is done, and the transmitted bandwidth ranges from 3.36 to 3.7 GHz with a return loss and an insertion loss less than −10 dB and −3.5 dB, correspondingly. Also, we noticed that the rejection band ranges from 1 to 3.36 GHz and from 3.7 to 6 GHz with a level less than −20 dB.

In the next step, six cross-shaped slots are inserted as DGS cells in the upper plane with a horizontal distance equal to 5.5 mm between two consecutive DGS cells and a vertical distance equal to 5.5 mm between two opposite DGS cells, and three couples of C shape DGS cells in the middle of the bottom plane with a distance between each couple equal to 1.61 mm as can be seen in Figures 2(a) and (b). Figure 2(c) illustrates the simulated results of the proposed filter obtained by CST Microwave.

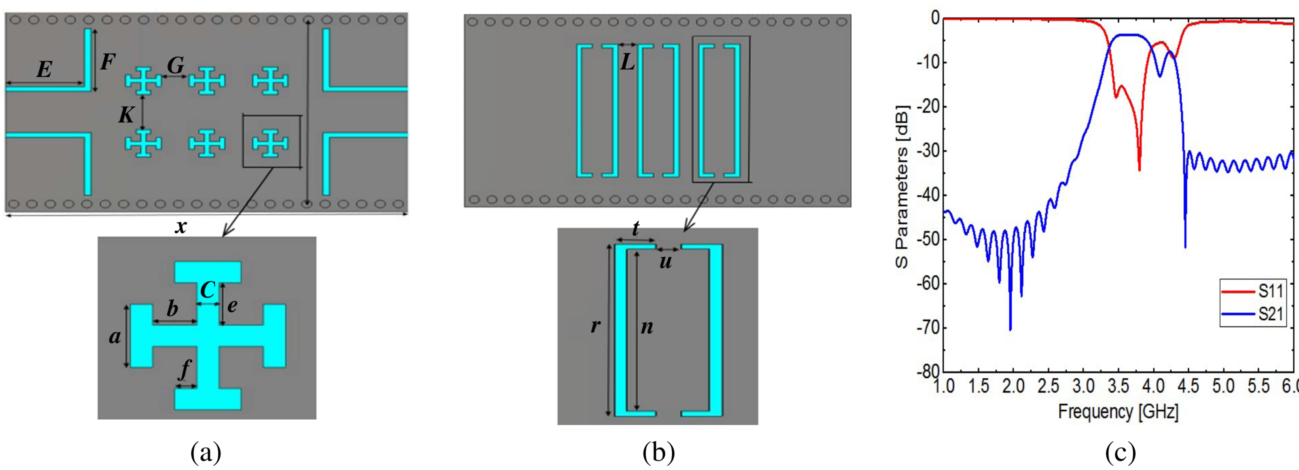



**Figure 2.** DGS-SIW band-pass filter configuration, (a) front view, (b) bottom view with $E = 7.8$ mm, $F = 8$ mm, $K = 3.9$ mm, $G = 2.8$ mm, $W_{\text{SIW}} = 23.5$ mm, $L = 2$ mm, $p = 2$ mm, $d = 1$ mm, $x = 38.8$ mm, $a = 1.5$ mm, $b = 1$ mm, $c = 0.5$ mm, $e = 1$ mm, $f = 0.5$ mm, $r = 12$ mm, $n = 11$ mm, $t = 1.63$ mm, $u = 1$ mm. (c) Transmission coefficient and return loss of SIW DGS filter.

The simulated results show that the proposed filter operates in the band ranging from 3.4 to 3.8 GHz with a long rejection and good return loss as shown in Figure 2(c). The insertion loss is of −3.5 dB, and the reflection coefficient reaches −36 dB at the frequency of 3.7 GHz. It is observed that the stopband rejection extends from 1 GHz to 3.4 GHz and from 3.8 to 6 GHz with an amplitude below −30 dB at all rejection band with many transmission zeros.

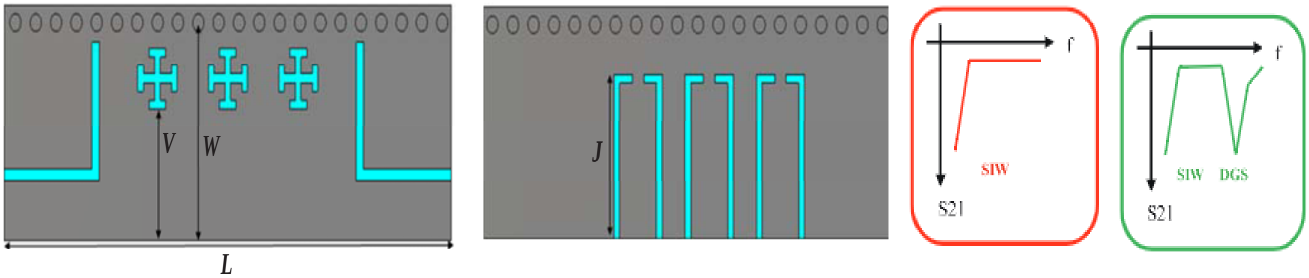
## 3. DESIGN OF A DGS HMSIW BANDPASS FILTER

The design of the novel miniaturized HMSIW band-pass filter is simulated in this section. The filter covers the band ranging from 3.4 GHz to 3.8 GHz, and it keeps the same SIW filter characteristic with size reduction of 50%. The DGS cells positions are optimized by CST. The HMSIW bandpass filter configuration is depicted in Figures 3(a) and (b).

Figure 3(c) illustrates the operating principle of our proposed bandpass filter. As known from the literature, SIW provides a high pass response filter. On the other hand, for getting a bandpass filter response form SIW, we etch the DGS cells on the top metal side of the SIW. This DGS allows us to create the rejection in upper band.

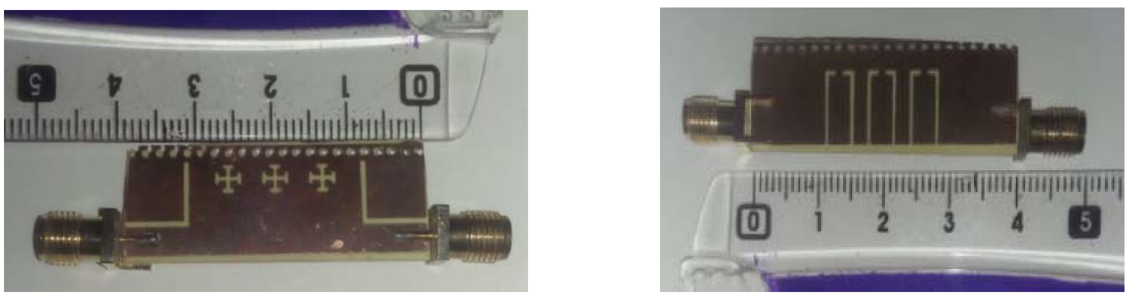
## 4. EXPERIMENTAL RESULTS

To validate the simulated and measured outcomes of the $S$-parameters, the DGS half-mode SIW bandpass filter is fabricated and measured. Figure 4 shows the front and back views of the SIW-based bandpass filter prototype. The measurement results of the return loss and the insertion loss of the proposed filter are shown in Figure 5.



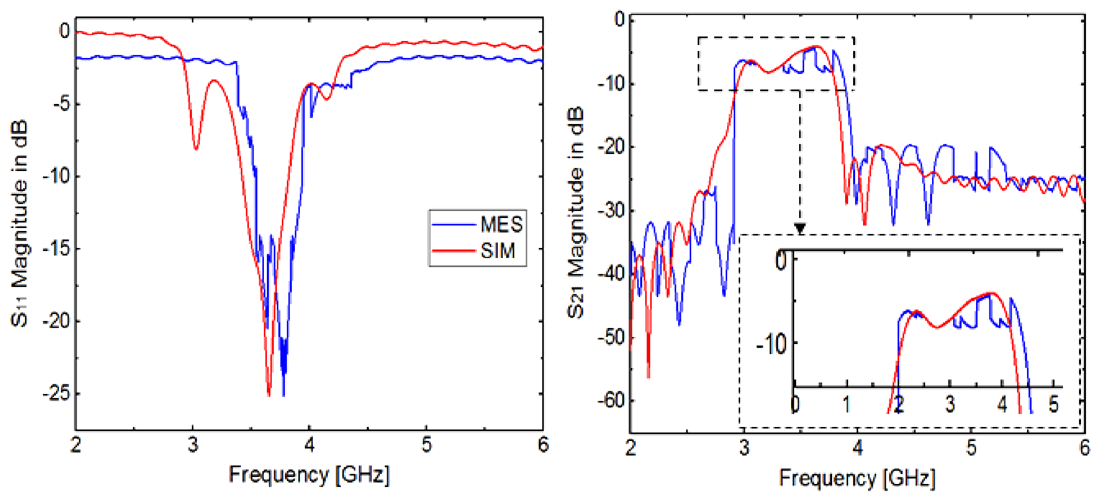

(a) (b) (c)

**Figure 3.** DGS-HMSIW bandpass filter structure, (a) front view, (b) bottom view with $W = 11.75\,\mathrm{mm}$, $V = 7.65\,\mathrm{mm}$, $J = 9.6\,\mathrm{mm}$, $L = 38.6$. (c) Operating principle of proposed pass-band filter.



(a) (b)

**Figure 4.** The fabricated of the proposed filter, (a) front view, (b) bottom view.

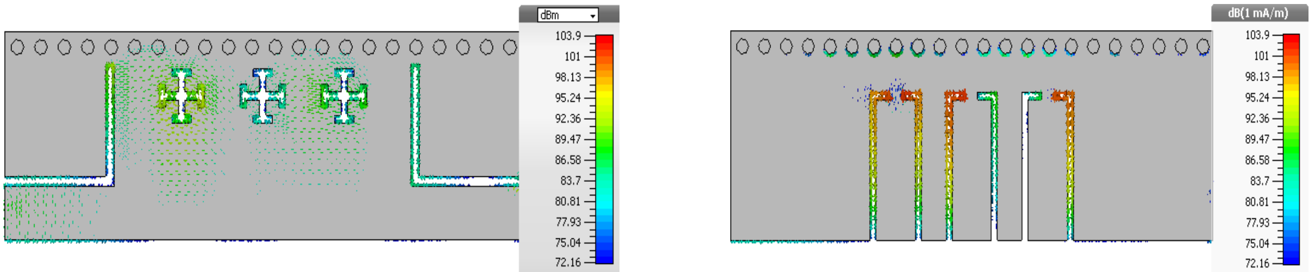



(a) (b)

**Figure 5.** The measured (a) return loss of SIW DGS filter. (b) Transmission coefficient.

The filtering band extends from 3.4 GHz to 3.8 GHz with a resonant frequency at 3.7 GHz and a measured return loss level about −25 dB. The higher measured insertion loss is −4.4 dB in transmitted bandwidth. A good rejection is obtained under 3.4 GHz and upper 3.8 GHz with a level less −20 dB in all rejection bands, and the maximum rejection reaches −46 dB and −32 dB at the frequencies 2.2 and 4.5 GHz, respectively.

The current distribution indicates that the current mainly flows around the L-shape slots and




(a) (b)

**Figure 6.** Surface current distribution at the frequency of 3.6 GHz.

DGS cells while there is very little current in the rest of the surface area as shown in Figure 6. The coupling distance has an important effect on the filter. The coupling between DGS cells increases while decreasing the distance between them, and this leads to shifting the transmitted bandwidth. The design is optimized so that the DGS cells work collectively with coupling effect.

Table 1 represents a comparison between our work and others previous works in the same topic. We notice that our proposed filter has compact size compared to the demonstrated filters, and it features a long rejection.

**Table 1.** SIW DGS bandpass filter compared with other published works.

| **Ref. No** | **Bandwidth (GHz)** | **Stop band Rejection (GHz)** | **Size ($\mathbf{mm^2}$)** | **Insertion loss (dB)** |
|---|---|---|---|---|
| [6] | 6.2–12.7 | 12.7–16 | $60 \times 9.8$ | $< -1$ |
| [9] | 13.2–14.8 | 14.8–17 | $38 \times 9.5$ | $< -2.6$ |
| [11] | 2.9–3.1 | 3.1–4 | $53.7 \times 17.6$ | $< -2$ |
| [12] | 2–4 | 4–7 | $23.6 \times 7.6$ | $< -1$ |
| [13] | 3.4–3.6 | 3.6–5 | $21 \times 12$ | $< -3$ |
| [14] | 3.2–3.6 | 3.6–8 | $106 \times 12$ | $< -2$ |
| **[This work]** | **3.4–3.8** | **3.8–6** | $\mathbf{38.2 \times 13.5}$ | $\mathbf{< -6}$ |

## 5. CONCLUSION

In this paper, a DGS SIW band-pass filter is proposed, simulated, fabricated, and measured for sub-mm 5G applications. The proposed filter is fabricated using an FR-4 substrate of thickness 1.54 mm. The proposed filter has small size and high stop-band rejection. The novel design of the bandpass filter keeps the stopband rejection from 3.8 to 6 GHz. This type of filter is easy for integration with other planar circuits for practical applications compared to using conventional waveguide. The measurement results prove that the filter is a suitable applicant to be utilized for sub-mm applications.

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