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Design and Fabrication of Substrate Integrated Waveguide (SIW) Fractal Micro strip Half Mode Filter For E-training Communication Systems

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Abstract
A technology called substrate-integrated waveguide (SIW) combines the benefits of printed circuit boards and conventional waveguides. SIW is widely used in microwave devices, especially filters, due to its excellent power handling, low loss, and low cost of manufacture. This work proposes a new type of evanescent-mode band-pass filter (BPF). The design and construction of a band-pass Half Mode Substrate Integrated Waveguide filter (HMSIW) are presented in this work, along with simulation results. The HMSIW filter's band-pass range was established to be ranged from 5.220 GHz to 8.808 GHz using ADS software. The HMSIW filter was manufactured using internal printed circuit board (PCB) prototype machinery, and the measured data show a good agreement with the calculated results.

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Keywords: Substrate Integrated Waveguide SIW, Band-pass Filters BPF$_S$, e-Training, HALF Mode Filter HMSIW, ADS Software

1. Introduction

The US Federal Communications Commission (FCC) authorized the unlicensed frequency range of 3.1–10.6 GHz in 2002 for use in industrial ultra-wideband (UWB) applications [1]. The fast advancement of wireless communication systems has resulted in increased strain over the frequency spectrum's resources. As a result, UWB technology has received increased interest from academics and researchers. One important and fundamental passive part of wireless communication systems is the band-pass filter (BPF). Nonetheless, creating a small, high-performing UWB BPF that satisfies the FCC spectral mask remains challenging. Because of SIW technology's well-known benefits of high quality factor, high power capacity, and ease of integration, it offers a strong platform for designing high-performance filters [2]. Thus, with SIW technology, numerous high-performance passive filters have been created [3, 4]. Regretfully, there have not been many reports of UWB filters utilizing SIW technology in relevant technical literature up to now. Furthermore, the physical dimension of the SIW is still too big to satisfy the specifications of high-level integrated circuits when compared to micro strip or coplanar waveguide. Consequently, a small and high-performance UWB BPF is designed using the half-mode substrate integrated waveguide (HMSIW), which can offer features that are similar to SIW while reducing the lateral dimension by over 50%. An innovative slow-wave structure (SWS) is etched as a low-pass filter on the top layer of the HMSIW in order to create a UWB passband with 3.1–10.6 GHz in it. Because of its slow-wave impact, the loaded SWS can further lower the size of the UWB filter in the interim. The transition structure from micro strip to HMSIW consists of two tapered gradient lines inlaid with rectangular slots, which can offer good mode conversion and impedance matching in the UWB region. In order to confirm the feasibility of the suggested structure, a prototype is initially modeled using the full-wave. A small wideband band-pass filter (BPF) based on half-mode substrate integrated waveguides (HMSIW) was proposed by Feng Wei, elt. [5]. The method used to generate a large passband and two transmission zeros in the passband region to boost selectivity involved etching two S-shaped complementary spiral resonators (S-CSRs) on the upper layer of the HMSIW cavity. Utilizing SIW technology in conjunction with DGS dumbbell cells allowed for the realization of an original and distinctive HMSIW C-band band-pass filter design has been investigated by Ahmed Noura *et al* [6]. They found that observed insertion loss of the constructed HMSIW filter is approximately 2.6 dB, the recorded return loss is less than 34 dB, and it is 50% less in size than a comparable SIW filter.

Additionally, good rejection is observed outside of the bands used for filtering. Hichem Boubakar *et al* [7] have been designed a new HMSIW band-pass filters that are smaller in size are being developed and evaluated. The first filter receives the original ECSRR. The simulation results for this filter are markedly good. The second filter is identical to the first in terms of construction and measurements, but it has an additional ECSRR applied to its bottom conductive layer. In addition, N Muchhal *et al* [8] presented a novel miniaturized and selective half-mode substrate integrated waveguide (HMSIW) band-pass filter (BPF) with Hilbert fractal geometry. A non-uniform horizontal periodical DGS (HPDGS) is integrated into the ground plane of the filter to enhance its performance by offering a broad and steep out-band rejection while also further miniaturizing it. A three-pole band-pass filter (BPF) with a central frequency of 3.5 GHz is simulated, investigated, and built on the low-cost substrate FR-4 (εr = 4.4). The filter shrinks and is appropriate for usage in the lower band of the fifth generation (5G) at a range of 3.38 to 4.20 GHz, with a low insertion loss of 1.1 dB and return losses of over 16 db. In this work, to the best of our knowledge a new design of substrate integrated waveguide (SIW) – fractal micro strips half mode filter for e-training communication systems was investigated.

2. Design Procedure

In this paper, the concepts of the suggested SIW-fractal unit cell, the creation of fractal curves, and SIW design have been discussed. Furthermore, it presented the effective parameters of the extraction of SIW fractal unit cells to illustrate how the unit cell functions were below the cutoff frequency of the original SIW structure. This is achieved by utilizing both options to convert the evanescent mode to the propagation mode. Additionally, the intended equivalent circuit that uses lumped elements have been reviewed.

Figure (1) shows both FMSIW and HMSIW side by side. For simplicity, all of the FMSIW's design specifics were provided in the figure (1), however, it will not be reproduced here. The same 1.6 mm-thick substrate with a dielectric constant of 4.3 was used for both FMSIW and HMSIW. Two rows of vias are employed to replicate the operation of the conventional waveguide's side walls. They also work to link the upper and lower conducting layers of the SIW electrically.

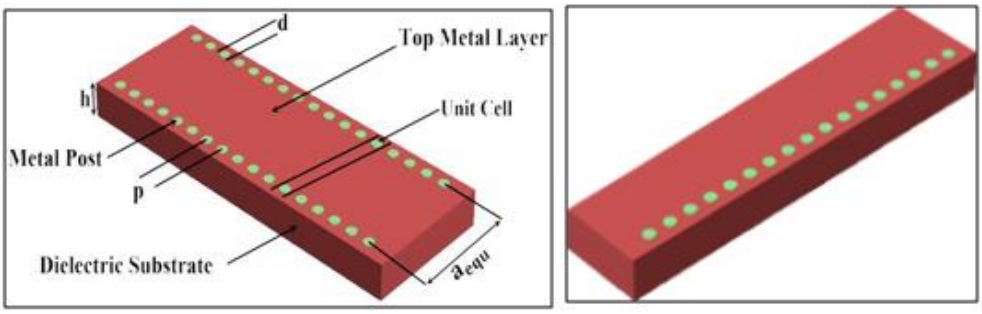


Fig 1: Shows both FMSIW and HMSIW

In the past, the FMSIW filter's miniaturization happened when it used the evanescent-mode approach to operate at the cutoff frequency. In this paper, the miniaturization ratio is reached again by making use of the magnetically symmetrical wall along the waveguide's longitudinal side. This miniaturizes the FMSIW to half (i.e., 50% reduction) to convert it to the HMSIW.

However, the goal of this research is to lower the resonance frequency. The drawback is that the HMSIW has larger radiation losses compared to the FMSIW. The wide-open side results in a larger leakage of the guided electromagnetic signals as radiation, thereby degrading the overall performance. Moreover, this radiation can be lowered to some extent if a row of vias is added to close the wide-open side. But, it is out of this paper's scope.

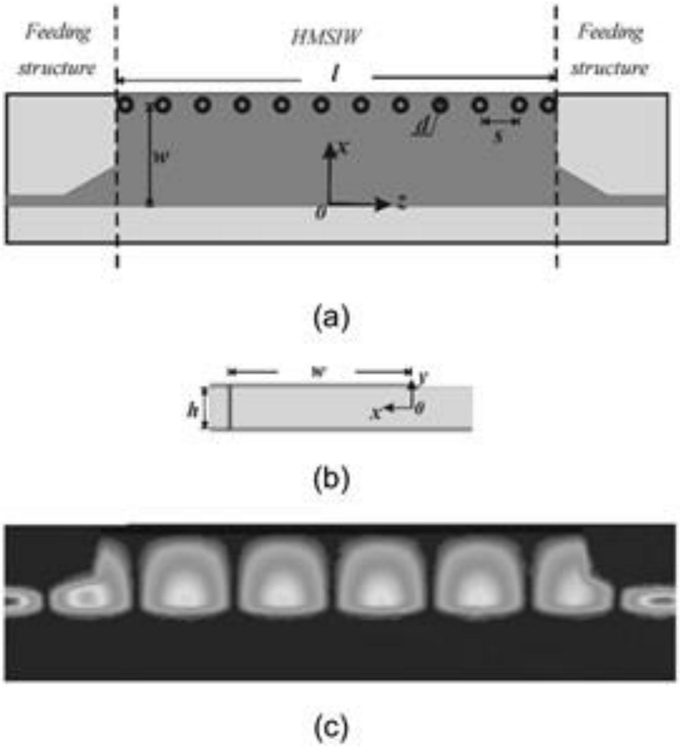
The fringing fields can extend from the wide-open side where more equivalent capacitance will be added, and then the resonant frequency will be slightly shifted down. The FMSIW concurs with the TE10 mode, but the HMSIW supports the TE0.5,0 modes. The modes' current distribution properties are the same.

It is worth noting that the design's substrate has a significant impact on the cutoff frequency. If the structure's dimensions remain constant, the waveguide's cutoff frequency will fall as the dielectric constant. A kind of waveguide with a similar structure but a smaller diameter than conventional SIWs is called an HMSIW (Half-Mode SIW). Its architecture is predicated on simulating the vertical cut of the waveguide as a virtual magnetic wall [9]. This is due to the fact that the vertical center plane of a conventional SIW, which is equivalent to an analogous magnetic wall, has the largest electric field of the main mode along its propagation path. The size of the SIW can be cut in half while preserving its key electromagnetic properties by dividing it using this vertical center plane.

The large ratio of waveguide width to height of the HMSIW allows for almost perfect magnetic wall-like open-side aperture. Because of this, the HMSIW may reduce its size by about 50% while still retaining the majority of the SIW's features. After studying the propagation properties of the HMSIW [10], it is shown that the discrete arrangement of the metallic vias and the high width-to-height ratio of the structure allow only TEp-0.5,0 (p = 1, 2,..) modes to propagate in the HMSIW. In the HMSIW, the TE0.5,0 modes is the most common mode.

The HMSIW is known as the half-mode SIW because the electric field distribution in the traditional SIW is similar to half of the fundamental TE10 mode. Figure 2 shows the electric field distribution of the TE0.5,0 modes in the HMSIW. One may compute the cutoff frequency of the HMSIW's primary mode (TE0.5,0 mode) using [10]:

$$f_c(TE_{0.5.0}) = \frac{C_0}{4\sqrt{\varepsilon_r w_{eff-HMSIW}}} \qquad (1.1)$$



(a)

(b)

(c)

Fig 2: Shows the electric field distribution of the TE0.5,0 modes in the HMSIW

These are the HMSIW configuration's top and side perspectives, which are seen in Figures 2a and 2b, respectively. Metallization is represented by the dark grey shading. Furthermore, the electric field distribution of the TE0.5,0 mode in the HMSIW is displayed in Figure 2c [10].

where we _ HMSIW represents the equivalent width of the HMSIW, which can be expressed as:

$$w_{eff\ HMSIW} = w'_{eff\ HMSIW} + \Delta w \quad (1.2)$$

$$w'_{eff\ HMSIW} = w - 0.54\frac{d^2}{p} + 0.05\frac{d^2}{2w} \quad (1.3)$$

$$\frac{\Delta w}{h} = \left(0.05 + \frac{0.3}{\varepsilon_r}\right).\ln(0.79\,\frac{w'^2_{eff\ HMSIW}}{h^2} + \frac{104\,w'_{eff\ HMSIW}-261}{h^2} + \frac{38}{h} + 2.77) \quad (1.4)$$

It should be noted that "w" denotes the HMSIW's width, "h" denotes its height, "d" denotes the via diameter, and "p" indicates the via spacing. Figure 3 shows the construction process of the fractal curve. It is evident that the fractal curve fills the full allocated region and approaches dimension 2 as the iteration order increases.

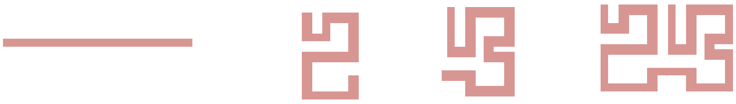


Fig 3: Generation fractal stapes

In this case, the operating principles of a conventional transmission line have been replaced by their fractal slot equivalents. To meet the design requirements, an initial iteration of the fractal was chosen. Instead of using a conventional waveguide micro strip as a transmission line, the SIW was used in the filter shown. The fractal is engraved in the SIW filter on the board's upper layer. Meanwhile, slots can be engraved on the bottom layer of the SIW design to provide a similar response. To minimize noise and radiation losses in high-frequency radio systems, it was preferred to keep the bottom layer, or ground layer, solid. The fractal slot engraved on the waveguide center is excited by the highest electric field of the dominant mode to produce high couplings between the SIW.

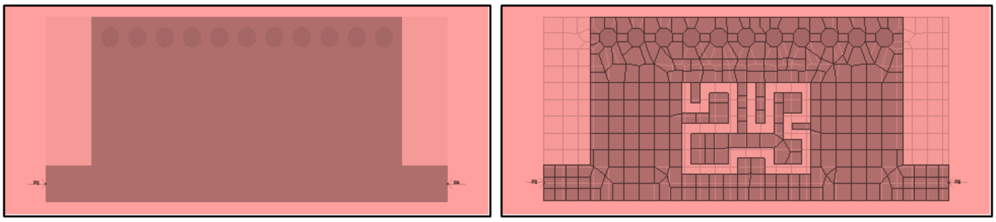


Fig 4: The traditional HMSIW and the first fractal slot iteration of HMSIW

In Figure 5, the simulation and measurement results were compared. The results show that they matched very well, but there were slight differences due to fabrication errors, losses of the SMA connectors, and software ideality. Additionally, Figure 6 displays the simulated transmission coefficients S21 and S_{11} for proposed HMSIW-BPFs. The HMSIW-BPF provides a good response, with the filtering bandwidth extending from 4.8 GHz to 5.7 GHz, covering all wireless applications (5.2 GHz). At resonance, the return loss is about 28 dB, for both simulated and measured results. The passband becomes more flat and the rejection skirt sharper as the order increases.

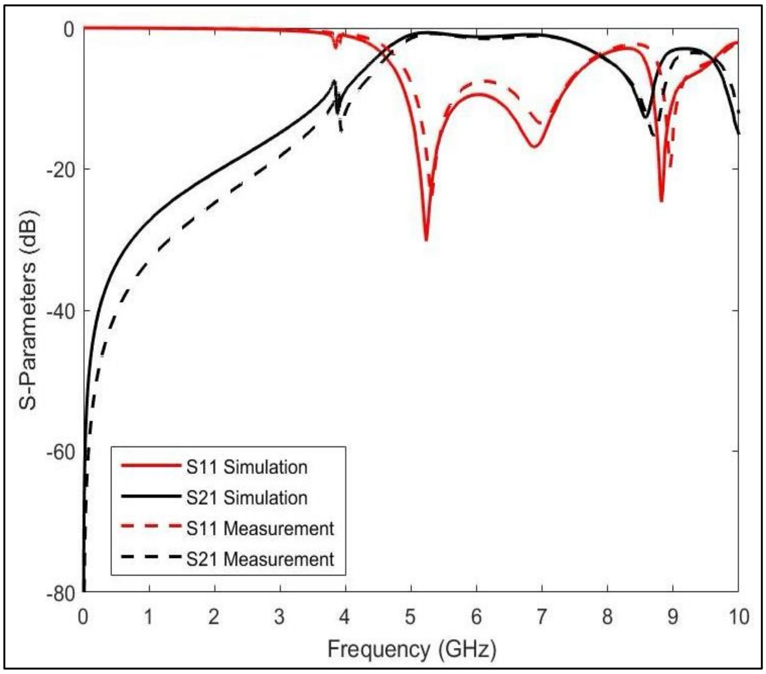


Fig 5: The comparisons between the simulation and measurement results

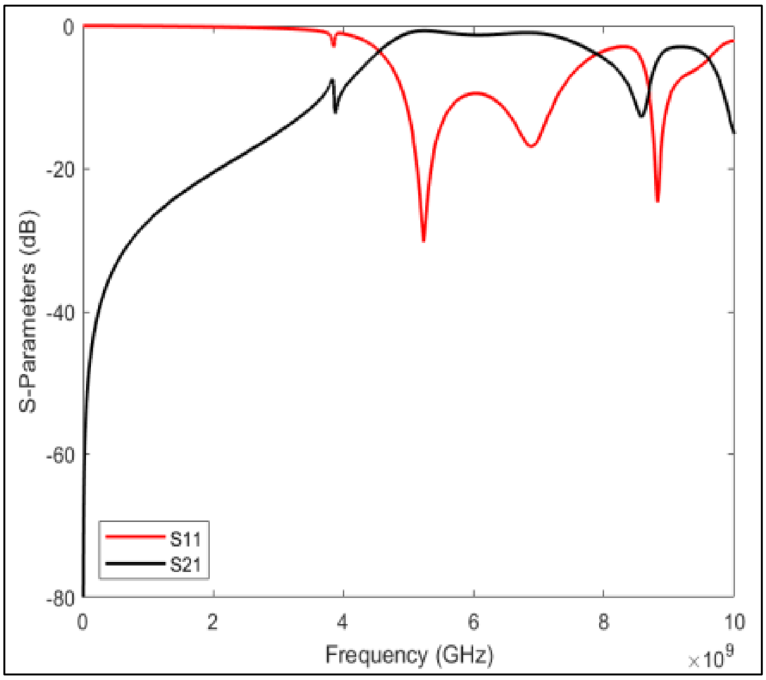


Fig 6: Show the transmission and reflection coefficients of HMSIW

The previous data gives an overview of the frequencies that can be transmitted in a given area using cells. Fractal slots act as magnetic dipoles when excited by the normal electrical fields that extend from the broad wall to the ground of SIW. The magnetic field components are parallel to the upper wall of the substrate-integrated waveguide structure and normal to the sides. As the fractal iteration increases, the center of the pass-band decreases. The substrate-integrated waveguide fractal unit cells display high-pass (HPF) characteristics placed after the pass-band, which shift to frequencies higher than the original cutoff frequency of SIW structures. Since the suggested SIW fractal unit cells limit the dominant modes TE01 by slots, the guides become shorter. Figure 7 shows the current distribution for the HMSIW filter at 5.220GHz and

8.808 GHz frequencies, and how the signals are prevented from propagating under the cutoff frequency.

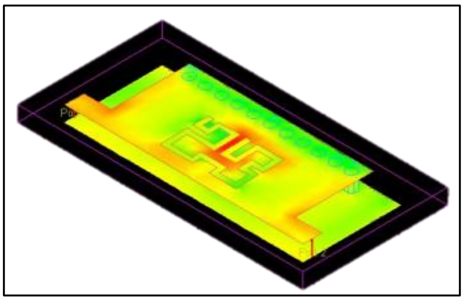


Fig 7: The distribution of current for the HMSIW filter

3. Methodology of Filter Design and Fabrication

After investigating and discussing the proposed SIW fractal unit cells previously in this article, we would then proceed to build filters with only the first iteration for the proposed SIW fractal unit cell (HMSIW). By using a simulator (advanced design system ADS), a filter was simulated. The first iteration of substrate integrated waveguide fractal is illustrated in Figure 8.

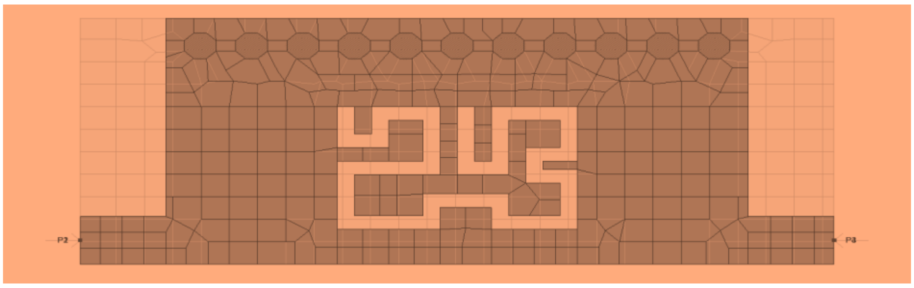


Fig 8: The first iteration of the HMSIW fractal band-pass filter

The dimensions of HMSIW which chosen according to the substrate mentioned above and the cutoff frequency 5.220 GHz, are 22 mm and 9 mm for the width and length of the HMSIW, respectively as shown in Figure 8.

A practical demonstration of accurate simulation design was achieved through the creation of a finalized filter, as shown in Figure 9. The filter features fractal slots that are dispersed linearly over the printed waveguide (SIW) and carved on the upper layer of the SIW structures. The fabrication process used a conventional printed circuit board (PCB) procedure, with a FR4 substrate that had a thickness of 1.5 mm and a relative permittivity of 4.3. To account for any loss, all simulations factored in dielectric and metallic losses by using the substrate's tangent loss of 0.025 and copper's conductivity (σ) of 5.8*107 S/m.

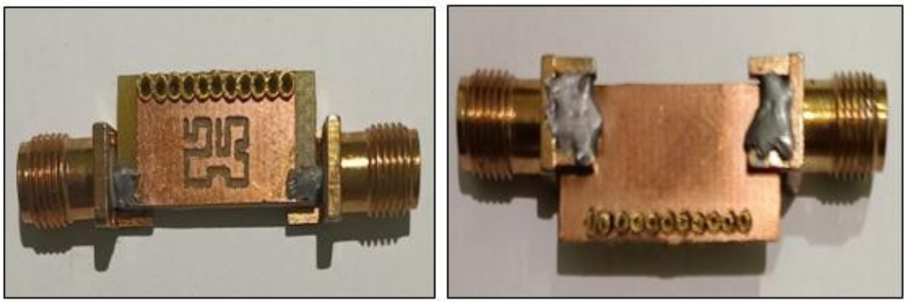


Fig 9: The final HMSIW fabricated Filter

4. Simulation Result

The simulation results of the filter design indicate that the filter is functioning below the cut-off frequency for the conventional SIW, as demonstrated in Figure 9. The cut-off frequencies are 5.220 GHz and 8.808 GHz. Furthermore, the attenuation is approximately 20 dB in the 4.12 to 7.11 GHz range, as shown in Figure 10.

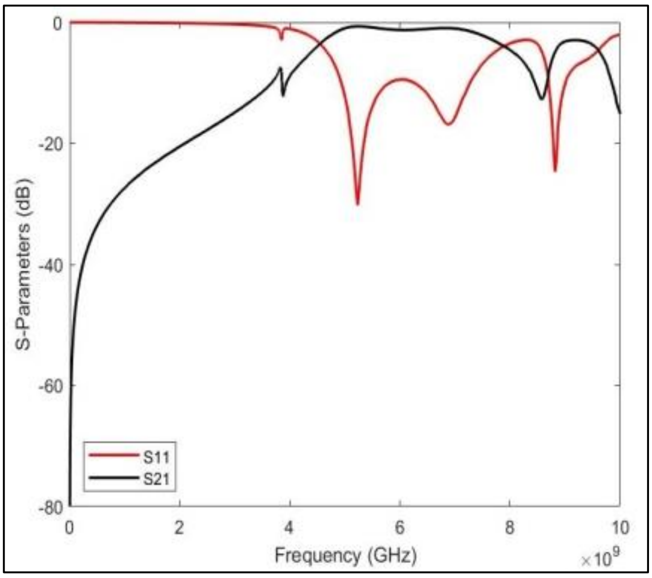


Fig 10: The Scattering Parameters of HMSIW Filter

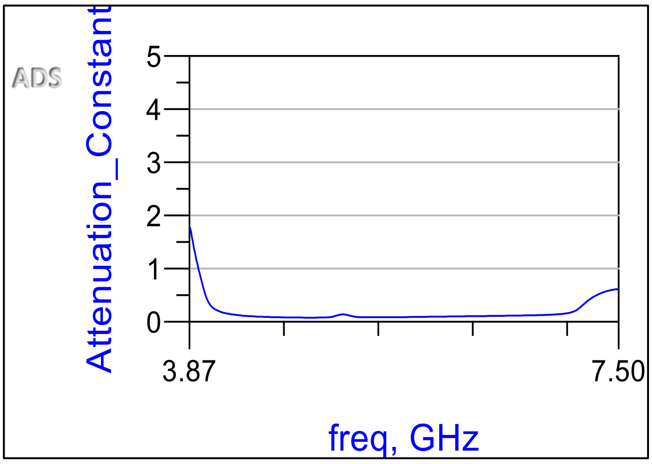


Fig 11: Attenuation constant

In addition, Figure 12 show the S-Parameters of the HMSIW filter measured with VNA. The results indicate that the filter has a good behavior. Due to the high internal coupling coefficient and poor external quality factor, the center frequency f0 is approximately 5.2 GHz and the bandwidth BW at -10 dB is around 1 GHz.

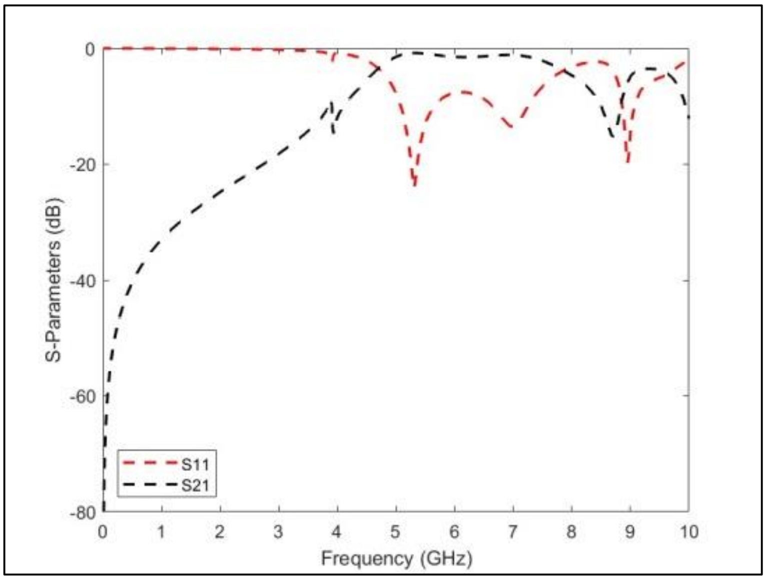


Fig 12: Measuring S-Parameters with VNA

5. Conclusion

This research examined and thoroughly organized substrate-integrated waveguide fractal unit cells. The Agilent Design program ADS was used to design, simulate, and build the first-order band-pass filter that was proposed. The analogous circuit and measurements agreed extremely well with the simulated findings. Less distortion was introduced inside the transmission bands because the group delays were nearly constant due to the nearly linear transmission phases. The paper emphasizes the important role that Half Mode Substrate Integrated Waveguide (HMSIW) plays in determining the band-pass filters' resonance frequency. Because it introduced the lowest resonance frequency, the first iteration was chosen as a consequence. The substrate-integrated waveguide fractal unit cells and filter have low insertion costs and are inexpensive.

6. References

1. Federal Communications Commission. Revision of part 15 of the Commission's rules regarding ultra-wideband transmission systems. First Report and Order FCC 02-48; c2002.
2. Li J, Huang Z, Wu W, Yang Z. Compact UWB band-pass filter with notch band based on SW-HMSIW. Electronics Letters. 2015;51(17):1338-9.
3. Chen RS, Wang L, Yang Y, Wu W. Wideband band-pass filter using U-slotted substrate integrated waveguide (SIW) cavities. IEEE Microwave and Wireless Components Letters. 2014;25(1):1-3.
4. Hao ZC, Hong W, Kuai ZQ, Chen JX, Tang HF, Wu K. Compact super-wide band-pass substrate integrated waveguide (SIW) filters. IEEE Transactions on Microwave Theory and Techniques. 2005;53(9):2968-77.
5. Coves A, Baquero E, Boria VE, Garcia-Garcia J. A novel band-pass filter based on a periodically drilled SIW structure. Radio Science. 2016;51(4):328-36.
6. Wei F, Zhu Y, Xu Z. Half-mode substrate integrated waveguide band-pass filter loaded with S-shaped complementary spiral resonators. Progress in Electromagnetics Research Letters. 2018;77:13-8.
7. Jiang Y, Zhang Z, Wei Y, Xiao Y. Design of compact wideband band-pass filter based on DGS-HMSIW. In: 2021 International Applied Computational Electromagnetics Society Symposium (ACES). IEEE; c2021.
8. Muchhal N, Sangwan A, Gupta N, Tripathi VS. Miniaturized and selective half-mode substrate integrated waveguide band-pass filter using Hilbert fractal for sub-6 GHz 5G applications. IETE Journal of Research. 2023;69(10):6685-92.
9. Hong W, Tang HF, Hao ZC, Xu W, Wu K. Half-mode substrate integrated waveguide: A new guided wave structure for microwave and millimeter wave application. In: 2006 Joint 31st International Conference on Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics. IEEE; c2006.
10. Lai Q, Hong W, Tang HF, Wu K. Characterization of the propagation properties of the half-mode substrate integrated waveguide. IEEE Transactions on Microwave Theory and Techniques. 2009;57(8):1996-2004.