

Filtenna Designed with Defected Ground Structure (DGS) for Ultra-wideband Applications

Dayang Azra Awang Mat, Lee Yee Hui & Dyg Norkhairunnisa Abg Zaidel

Department of Electrical and Electronics Engineering, Faculty of Engineering, University Malaysia Sarawak (UNIMAS), 94300 Kota Samarahan, Sarawak, Malaysia

*Corresponding author: amdazra@unimas.my

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ABSTRACT

In microwave imaging applications, filter and antenna are the key components as front-end devices and function independently. Antenna radiates and receives signals to or from nearby scattered objects while filter is used to suppress unwanted signals noise before and after the required bandwidth. Current antennas suffer from high loss, bandwidth limitation and impedance mismatch and deteriorate their performance near the band-edges if connected as a stand-alone device. Due to the current trend towards simplicity and size reduction, researchers are focusing on integrating the filter and antenna into a single module called integrated filter-antenna (IFA) or filtering antenna (filtenna). These would improve the noise performance of the system and pre-filtering requirements such as complexity algorithm in inverse scattering techniques. This paper introduces a novel contribution in the field of UWB antenna design by incorporating Defected Ground Structure (DGS) on both the antenna and filter. Thus, the main aim of this research is to conduct detail parametric studies of the proposed integrated filter-antenna with defected ground structure (DGS) to enhance the performance of imaging system. The proposed IFA will be analysed on Rogers RO4003C dielectric substrate by using EM tool, Computer Simulation Technology (CST) and measured using R&S Vector Network Analyzer (VNA). A compact ultra-wideband (UWB) filter and UWB elliptical antenna are designed and examined in detail before combining the devices. Different types of DGS are designed and act as the ground layer of the proposed filtering antenna. The bandwidth of each design is then compared with and without the existence of DGS. The results show that the proposed IFA with DGS implementation achieve the targeted objective, with compact size, enhanced bandwidth and better performance compared to the conventional design of filter and antenna. By integrating filter and antenna into one subsystem, it can help to reduce the loss and enhancing the bandwidth of the system thus letting the antenna to operate at more different frequencies that fall within the range. Both simulated and measured results prove that by integrating filter and antenna into one module, a low loss and larger bandwidth can be accomplished. High performance compact IFA can act as microwave transceiver to improve the overall performance of the microwave imaging system, MIS.

Keywords: Integrated Filter-Antenna (IFA) or Filtering Antenna (filtenna), Defected Ground Structure (DGS), Ultra-wideband (UWB), Rogers RO4003C dielectric substrate, Computer Simulation Technology (CST), R&S Vector Network Analyzer (VNA).

INTRODUCTION

In the past two decades, Microwave Imaging System (MIS) has been studied as a novel imaging and diagnostic approach for breast cancer diagnosis. Several early clinical tests on a modest scale have clearly demonstrated the technology's promise, while also showing considerable remaining obstacles. MIS is also acknowledged as a viable alternative (or complement) to existing medical imaging

methods such as X-ray, ultrasonic, and magnetic resonance imaging, several technological hurdles must be resolved (Commission, 2002).

Recently, ultra-wideband (UWB) technology has shown great attention due to the potential in the development of modern wireless communication systems. Since early February 2002, the US Federal Communication Commission (FCC) has permitted the unlicensed use of the ultrawideband (3.1-10.6 GHz) frequency spectrum for indoor and

handheld wireless communication (Nyangwarimam Obadiah et al., 2015). Many researchers have been focused on the design, research, and development of UWB filters and antennas (Al-yasir et al., 2020), which are mostly the combination of monopole and wide slot antennas due to their quasi-omnidirectional radiation pattern and wide bandwidth. Besides, planar antennas are a viable approach for achieving low-cost and reliable radiating devices for UWB systems; hence, some work in this field has been accomplished (Wei-Jun Wu, Qi-Feng Liu, Qi Zhang, 2013). In the traditional designing concept, antenna and filter are two essential elements of a wireless communication system. Although for signals reception and transmission antenna is responsible, the filter's function is to pass wanted and reject unwanted signals. Microwave filter and antenna can be considered the most crucial passive components in the microwave system. Typically, antenna and filter are linked separately and directly to exclude unwanted signals in the operational bands using conventional 50-ohm connections, resulting in impedance mismatches and substantial insertion loss across the whole system. These losses have emerged as researchers' main concern (Al-yasir et al., 2020).

As a result, several researchers are interested in constructing an antenna with a filtering system and combining antenna and filter into a device with radiating and filtering capabilities to achieve small compact, high integration, low insertion loss, and absence of impedance mismatches. To achieve minimal insertion loss in filter-antenna design, current researchers have suggested several filter and antenna designs. One of the most crucial considerations for all designers is how to deal with impedance mismatches. When constructing integrated filter-antenna owing to their separate connectivity, which will need additional impedance transformation (Shome et al., 2021).

One of the most popular structures in recent years is the microstrip filter-antenna integration design due to their compact size, low profile, light weight, and ease of fabrication. Filtering antenna designs have many RF applications, where filtering and efficient radiation pattern responses concurrently achievable (Gangwar et al., 2021). Additionally, reconfigurable microstrip filtering antennas have grown in popularity recently due to their ability to provide more features. (Tu et al., 2020). Besides, filter antennas' ability to block out-of-band radiation has further advantages in that it eliminates the mutual coupling that could occur between an antenna and other electrical equipment (Gangwar et al., 2021).

Recent study demonstrates that several researchers have developed various designs and methods for merging antenna and filter. The co-design technique is provided in (Tu et al., 2020) in order to have size reduction, cheap cost,

and excellent signal selectivity in their suggested design or by etching complementary split ring resonator (CSRR) on the patch of the antenna design (Jadhav & Deore, 2017). Another method for creating a filtering antenna is called "filter synthesis," and it requires replacing the last step of the filter with a radiating antenna. (Hsieh et al., 2015). Step impedance resonators and aperture coupled feed are one of the techniques to design filtering antenna, in this method, antenna is fabricated on the top layer of three-layer PCB and the filter is fabricated in the bottom layer (Boudaghi et al., 2012). Another topology that makes use of slotted ground structure incorporates the filter in the ground plane of the antenna design via slotted ground structure (Azizi et al., 2019).

The filtering antennas were achieved by different forms, such as circular patch antennas (X. Liu et al., 2020), slot dipole antennas (Sahoo et al., 2017a), monopolar antennas (Al-Yasir et al., 2020; "Design and Development of Filtering Antenna for S-Band Applications with High out-of-Band Rejection," 2019; Sahu et al., 2018), and rectangular patch antennas (Q. Liu et al., 2017a). In this paper an UWB monopole antenna with filter configuration is presented. An UWB filter is cascaded with an UWB antenna on the feed position of the antenna.

METHODOLOGY

DESIGN SPECIFICATION

An UWB IFA's shape and setup are shown in Figure 1. The filtering antenna consists of four parts—the elliptical-shape radiating patch, the MMR BPF with dual symmetric multiple-mode resonators, the feeding microstrip line, and DGS. The elliptical-shape patch has a dimension of 15X13mm, with about half a guided wavelength at the operating frequency. The multiple-mode resonators can be divided into three sections. Two of the arms are extended in the x-direction with length and width. The other one is inset into the elliptical-shape patch in the y-direction with length and width. is about a half-wavelength long. The resonator and the patch have gaps and apart. Besides, two types of DGS are implemented on the ground plane. The U-shape DGS is implemented under the feedline of patch while meandered line DGS under the resonators of filter.

The integration concept was proposed because the impedance mismatch between the proposed antenna and filter separately causes interference, increases insertion loss, and consequently affects the overall performance of the circuit. Therefore, both filter and antenna are integrating by using cascading method. As for the cascaded method, antenna and filter are integrated on the same ground plan as shown in Figure 1. This technique utilizes only one

single layer of substrate. The radiator and filter are fed by a 50- Ω microstrip transmission line, which is terminated with a sub miniature A (SMA) connector for the

measurement purpose. The structure is fabricated on one side of a Rogers RO4003C substrate with a thickness of 0.813 mm and a dielectric constant of 3.38.

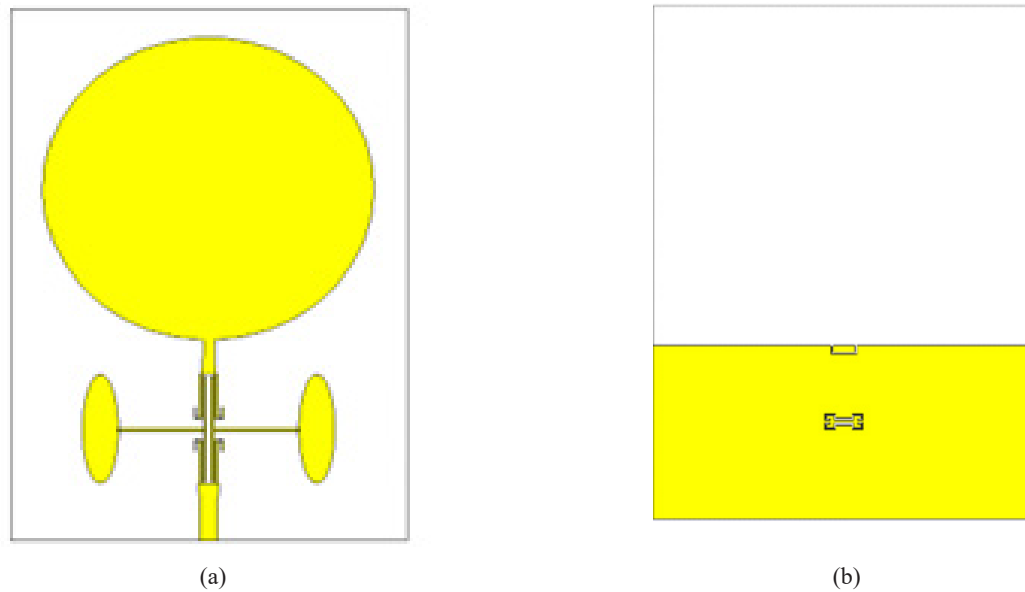


FIGURE 1. Proposed IFA (a) front view (b) back view

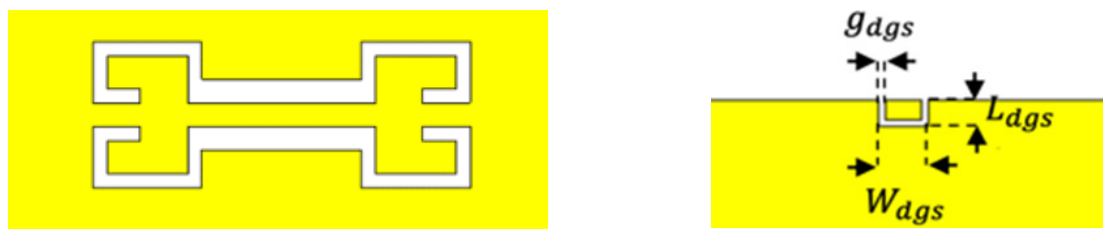


FIGURE 2. DGS structures

RESULTS AND DISCUSSION

In the proposed IFA, the antenna and filter integrated together with impedance matching network by feed modification. The performance of proposed IFA is examined at first in Figure 3. The frequency band for this IFA operate from 2.95 GHz-10.72 GHz, which is cover whole ultra-wideband (UWB) spectrum.

Typically, it has been challenging to determine the resonance modes of a broad band antenna using Smith charts. However, the return loss curve suggests that at some frequencies, impedance matching is satisfactory. The diameter of the patch of the antenna, which roughly corresponds to a quarter wavelength at this frequency, is

observed to determine the initial resonant frequency. The subsequent resonances appear to be the initial resonance's harmonics. Consequently, the overlap of closely spaced multiple resonances produces an ultra-wideband width.

The feed modification for impedance matching between antenna and filter is discussed in following subsection. After that, the performance of IFA is investigated in terms of radiation pattern and measurement result.

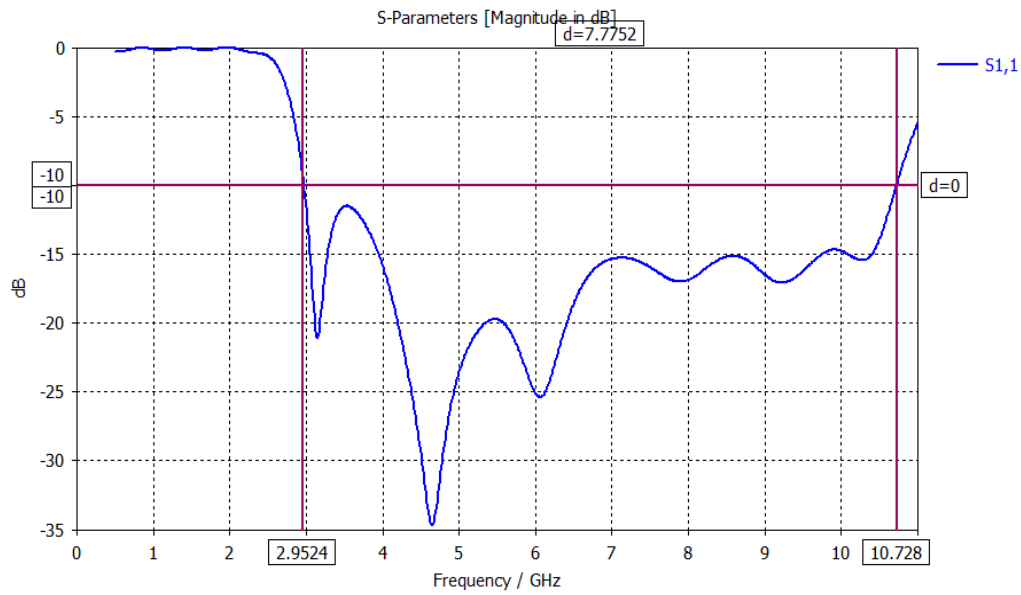


FIGURE 3. Simulation Result of proposed IFA

FEEDLINE MODIFICATION

As seen in Figure 4, the feedline of the filter has been adjusted to improve the performance of the IFA in the proposed IFA design by thickening the feedline between

the filter. Within the simulation programme, the parameters of the extended line are optimised. Impact of the feedline modification have studied and stated in figure 5 In the Figure 5, the proposed IFA with feed modification do improve the performance in S11 result compare the original.

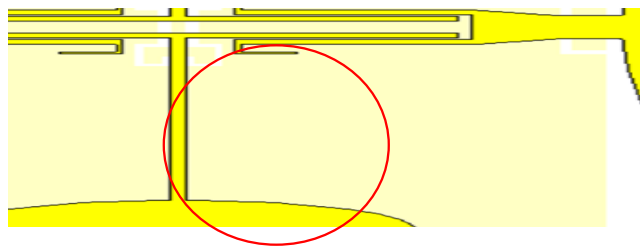


FIGURE 4. Feedline modification in proposed IFA\

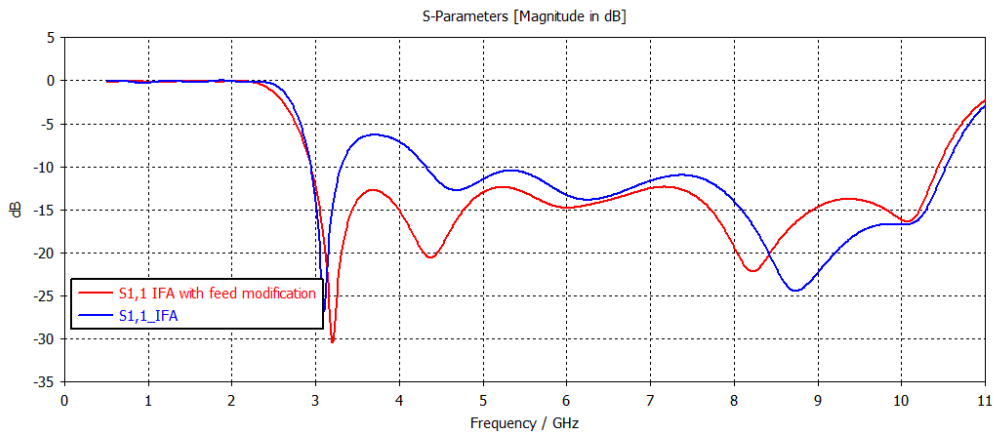


FIGURE 5. Simulation result of the proposed IFA on feed modification

PARAMETRIC STUDIES ON FEEDLINE

The parametric studies of the feedline of proposed IFA are conducted and presented in Figure 6~8F. “ Lf_1 ” is the length of the feedline between 50-ohm connector and the filter while “ Lf_2 ” and “ Wf_2 ” are the length and width of the feedline between filter and antenna. Based on the result in Figure 6, it shows

that Lf_2 varies the second cut-off frequency and bandwidth values. However, the value of Lf_1 do not shows much impact on bandwidth in S_{11} (dB) graph. The value of Wf_2 is optimized to obtain a wider bandwidth and shown in Figure 7. Wf_1 is not consider in the studies due to mandatory fit to 50-ohm to ensure the performance of IFA design when connect to microwave system.

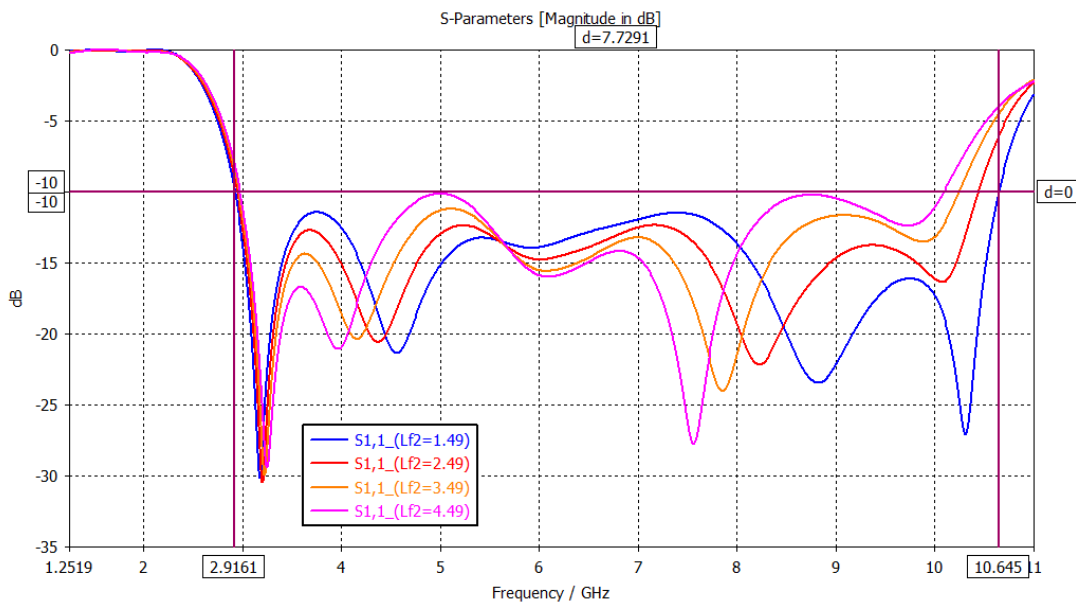


FIGURE 6. The result of S_{11} (dB) parametric studies on Lf_2

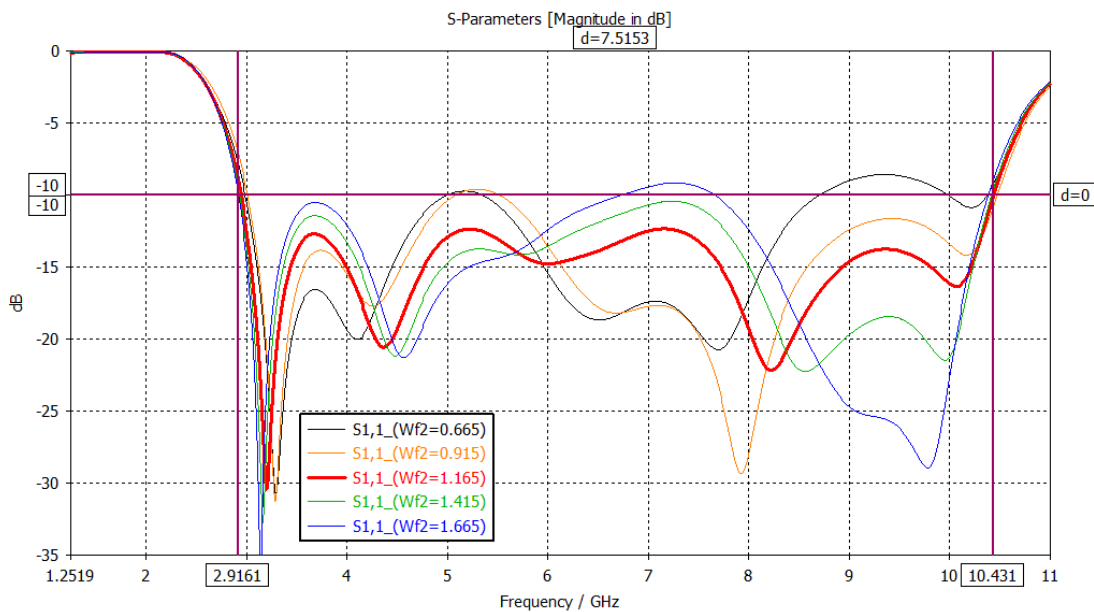


FIGURE 7. The result of S_{11} (dB) parametric studies on Wf_2

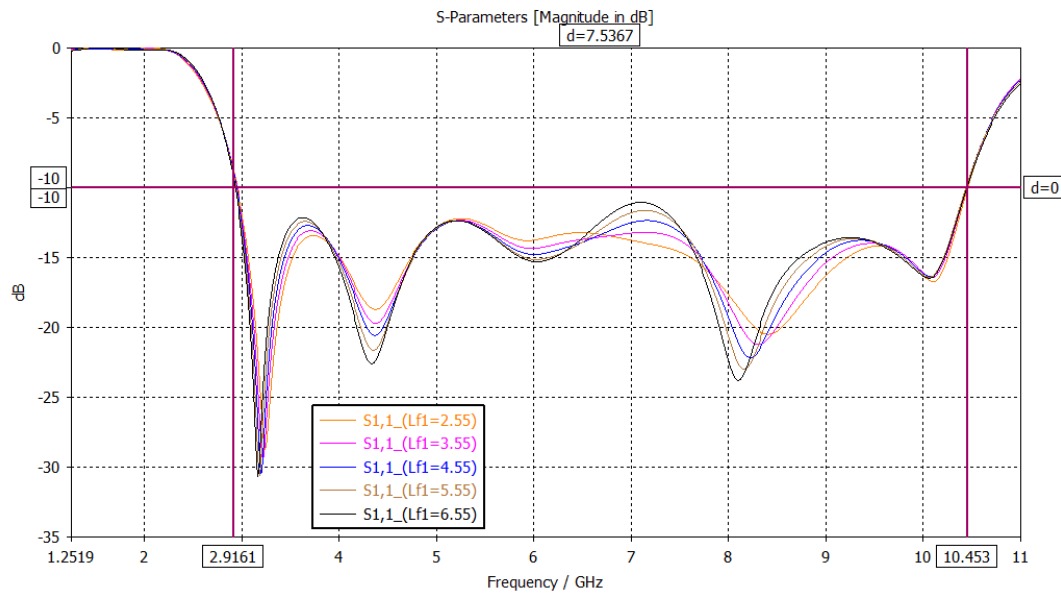


FIGURE 8. The result of S_{11} (dB) parametric studies on Wf_2

RADIATION PATTERN OF IFA

Figure 9-12 depicts the E-plane and H-plane radiation patterns of the UWB IFA configuration at 3.2, 4.4, 6 and 8.23 GHz. At all simulated frequencies, the radiation pattern of the H-plane is entirely omnidirectional. At all simulated

frequencies, the E-plane radiation pattern is extremely directed along 0° and 180° , respectively. At all simulated frequencies, the geometry of the E-plane radiation pattern remains unaltered. Consequently, the UWB IFA arrangement displays a steady and stable radiation pattern at all frequencies.

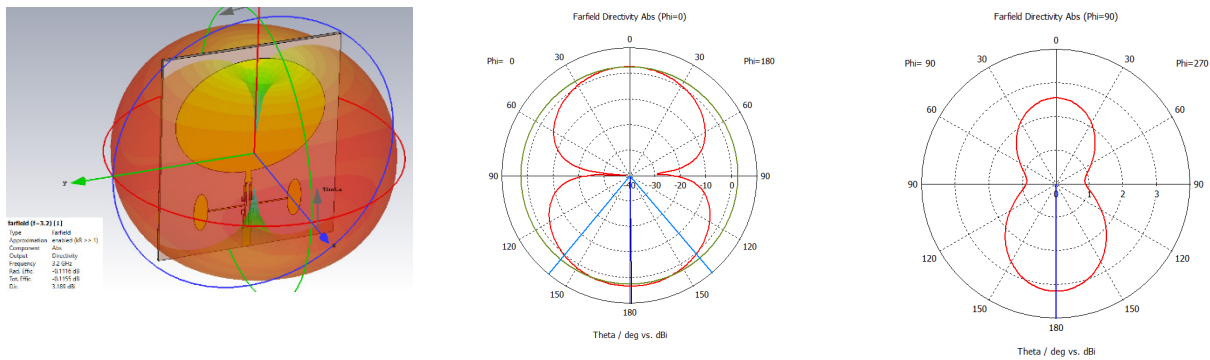


FIGURE 9. 3D and 2D radiation pattern of monopole antenna at $f=3.2$ GHz (E and H-plane)

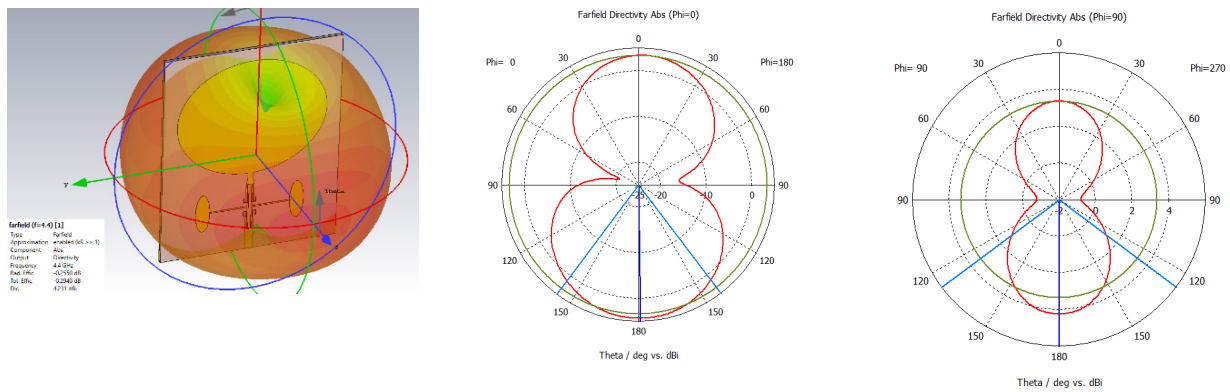


FIGURE 10. 3D and 2D radiation pattern of monopole antenna at $f=3.2$ GHz (E and H-plane)

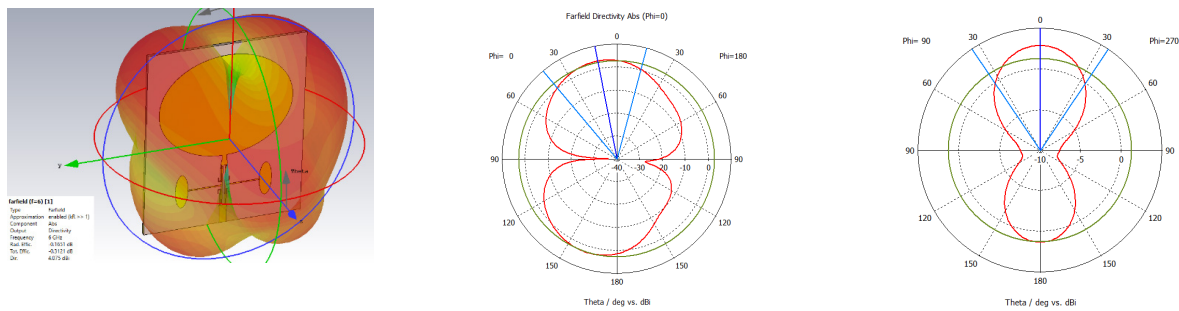


FIGURE 11. 3D and 2D radiation pattern of monopole antenna at $f=6$ GHz (E and H-plane)

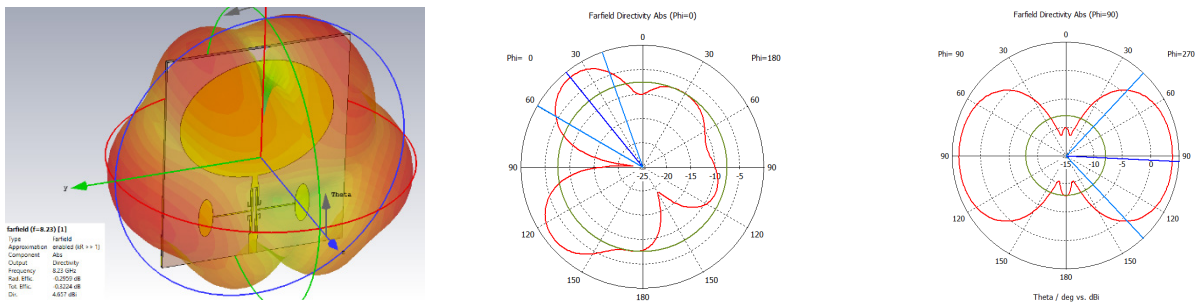


FIGURE 12. 3D and 2D radiation pattern of monopole antenna at $f=8.23$ GHz (E-plane and H-plane)

MEASUREMENT RESULT OF IFA

The proposed IFA that resulted the best performance is then fabricated as shown in Figure 13. The IFA is then fabricated using Rogers RO4003C as substrate. The size of the fabricated antenna is 51.79 mm X 40.80 mm.

The proposed IFA's simulated and observed reflection coefficients are compared in Figure 14. The measured passband has a 30 MHz shift to the lower frequency, which might be due to the substrate's changing dielectric constant.

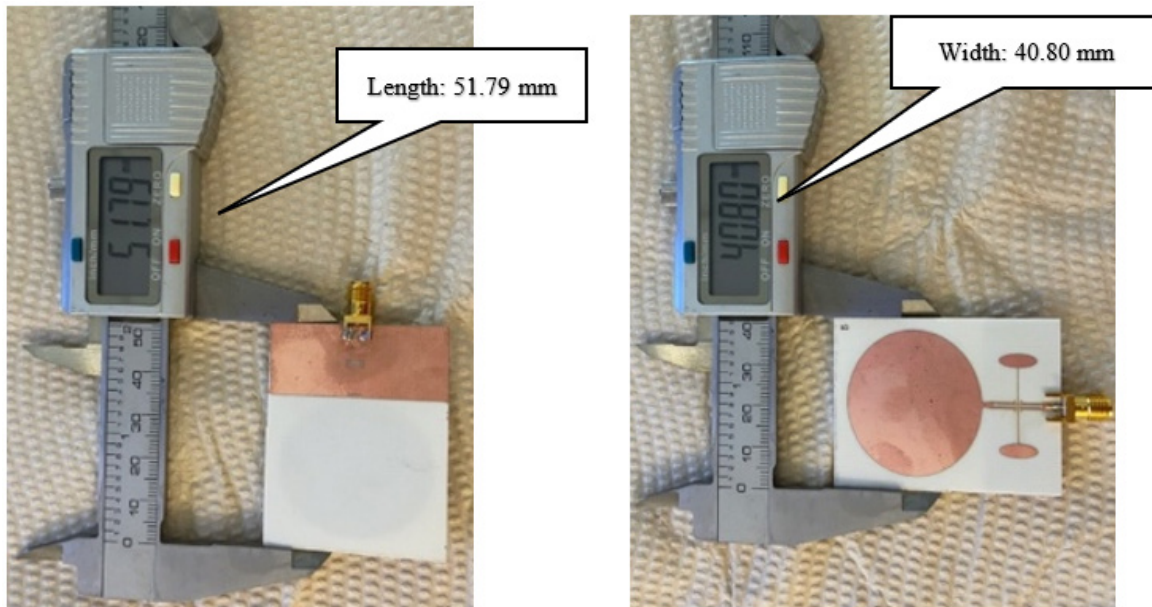


FIGURE 13. Dimension of Fabricated IFA (a) Length (b) Width

S11 Comparison Graph

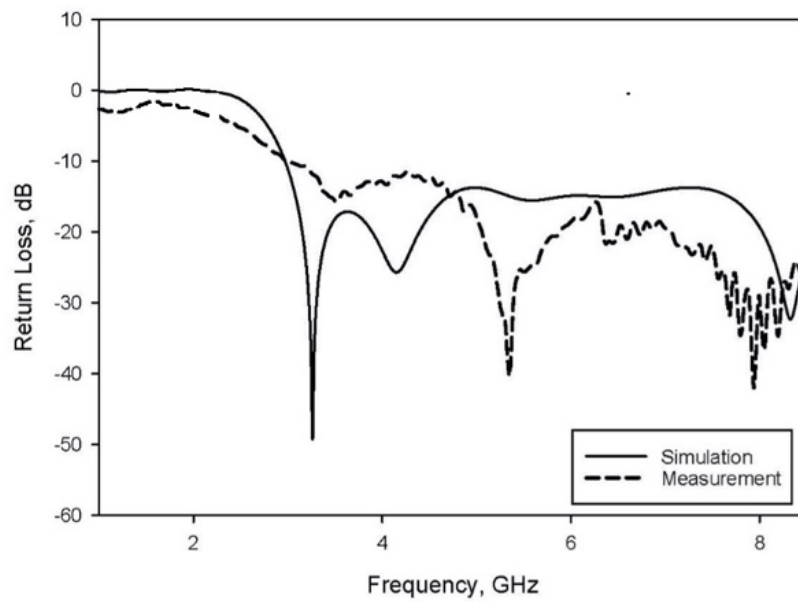


FIGURE 14. S11 (dB) return loss simulations and measurements for the proposed IFA

COMPARISON WITH EXISTING WORK

A detailed comparison about this research with some similar reported filtering antennas on some key indicators is shown in Table 1. The design presented is preferable to others in terms of structure size, design complexity, bandwidth, and reflection coefficient characteristics.

TABLE 1. Comparison of similar work

Authors	Size (mm)	Bandwidth (GHz)
(Liu et al., 2017)	32.0 × 20.0	3.5 to 10.6GHz
(Zheng et al., 2018)	46.5 × 76.8	2.6 to 10.9 GHz
(Sahoo et al., 2017)	42 × 53	3.1 to 10.6GHz
Proposed IFA	37.15x50.33	2.95-10.73 GHz

CONCLUSION

The paper shows a simple coaxial-feed microstrip filtering antenna with a good operating and filtering response in a single-layer structure. The design process follows the cascaded technique of the proposed filter and antenna are integrated on same ground plane and coupled through 50-ohm impedance connections. After fabricating and testing, the measured results indicate that the proposed antenna can realize a wide BW (2.95-10.72 GHz), a good out-of-band rejection level and compact.

Most of the functionality of filter to filter the unwanted signals may be accomplished with the filtering microstrip antenna. The proposed UWB IFA design is simple and compact providing wideband impedance matching, and reliable radiation pattern within the UWB frequency range.

The all-planar design makes it simple to employ into existing microwave circuit designs, such as the prefiltering of printed antenna arrays. The paper This letter can offer a different approach to future IFA designs without the need for additional filtering circuits.

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DECLARATION OF COMPETING INTEREST

None

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