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Modified back-line inset feed 1x4 array microstrip antenna for 5.8 GHz frequency band

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ABSTRACT

This paper presents the design of 1x4 array microstrip antenna utilizing modified backline feeding technique at 5.8 GHz frequency band. The antenna, designed on flame retardant (FR-4) substrate with a dielectric constant of 4.4, aims to achieve reduced harmonics and mutual coupling between closely spaced antenna elements. The primary scope of the paper is investigating the performance of a single band microstrip antenna employing the proposed modified backline feeding method. Moreover, developed design came out with the result and critical analysis by various parameters such as, gain, return loss, voltage standing wave ratio (VSWR), and directivity. Therefore, the proposed design of microstrip antenna with backward linefeed (BLF) demonstrates a directivity of 10.29 dBi, return loss of -21.947 dB, and VSWR of 1.173; are significant improvement compared to recent literature shown in this paper. The adoption of proposed back line feeding technique (BLF) represents a promising alternative for addressing poor wireless connectivity issues in terms of antenna design, gain, and direction within microstrip technology.

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1. INTRODUCTION

An antenna convert electrical power into radio wave and vice-versa. Modern antenna systems demand versatile adaptability and low profile [1]-[5]. Recently, the microstrip patch antenna has shown potential improvement in the realm of small-scale microwave systems. However, the performance of a microstrip antenna highly depends on the structure design and shapes, feeding techniques and its directivity. Hence, inset line feed, coaxial feed, aperture coupled feed and proximity coupled feed techniques are prominent methods for designing antennas [6]. Furthermore, a microstrip antenna can operate with omnidirectional and bidirectional radiation patterns [7]. Traditional inset feed antennas, particularly in microstrip antenna designs encounter several challenges, prompting engineers to explore alternative feeding techniques. Common issues associated with traditional inset feed antennas are radiation pattern distortion, impedance matching, limited bandwidth, feedline radiation, cross-polarization, side lobes, and sensitivity to substrate variation. To address these issues, multiple methods have been proposed in the literature, such as the use of versatile feeding techniques like backline feeding.

Ali *et al.* [8], the author proposed an inset-feed multi band technique that shows improvement in return loss but suffers from low gain, low efficiency, low directivity, and narrow bandwidth. Refered to Inset-Feed Multi-Shaped technique in [9] that shows better performances of return loss and directivity based on different design shapes however suffered from low gain and narrow bandwidth. Moreover, the study in [10] demonstrated inset-feed MSA single band method shows limited frequency range, performance variability, radiation pattern, low gain and low directivity. Abdulhussein *et al.* [11] proposed metamaterial parasitic coplanar wave guide (CPW) fed technique that laks in power loss, gain variation, radiation efficiency, low gain, low directivity. According to the recent literature in [12], the micrsotrip array issues with lower-than-desired gain and directivity, poor radiation efficiency due to array configuration with closely spaced antenna elements and materials. Furthermore, the study in [13] investigated the feed line resistance losses, dielectric, or radiation losses that reduce the amount of power delivered to the antenna, resulting in decreased radiation efficiency and overall performance. Additionally, the work in [13], the author proposed transmission line-feed 1x2 array to enhance radiation efficiency related to resistance loss, dielectric, and radiation losses. In contrast, the study in [14], identified the lack of exploration into the specific antenna design parameters and configurations optimized for efficient energy harvesting from radio frequency (RF) sources in nano-devices. Therefore, it require innovative feedline design approaches tailored to nano-device applications. To address these problems, a micrsotrip antenna with modified back line feeding technique has been proposed in this paper which represents the major contribution of the work. Following this, the proposed backline feed array anntena was simulated using computer simulation technology (CST). However, the performance of the simulation design was assessed through a fabricated prototype developed in a controlled laboratory environment, marking another significant contribution of this work. The analysis of micrsotrip antenna with modified back line feeding technique has shown significant improvement. Nonetheless, the hardware prototype has further validate the success of proposed approach.

The backline feed technique is a method used particularly to design and implementation of microstrip antenna of this research. In traditional microstrip antenna configurations, the feedline is typically connected to the front side (radiating side) of the patch or radiator element. However, in the backline feed technique, the feedline is connected to the back side of the patch. The key aspects of the backline feed technique have been found by connecting the feedline from the back side, the front side of the antenna remains uninterrupted, enabling a more compact and low-profile antenna structure. Besides, it helps to reduce mutual coupling between closely spaced antenna elements in array configurations. When implementing backline feeding, careful consideration has been given to the design of the feed network, impedance matching, signal loss, and manufacturing techniques. Optimization of these factors is crucial to achieving desired antenna performance. In summary, the backline feed technique offers advantages in integration, miniaturization, reduced mutual coupling, and potentially improved radiation characteristics in antenna designs, making it a valuable approach in modern antenna design practices. This paper proposes a 1x4 array microstrip antenna designed with the backline feed technique at 5.8 GHz and evaluates its performance, particularly focusing on the S1,1 parameter.

2. METHOD

The development of the proposed backline feed microstrip array antenna has been conducted in two stages, following a suitable design technique to avoid circuit complexity as shown in Figure 1. Initially, an experimental simulation of the backline feed microstrip patch antenna was simulated using CST (Computer Simulation Technology). Subsequently, the research progressed to the development of an experimental hardware prototype for further validation in a controlled laboratory environment.

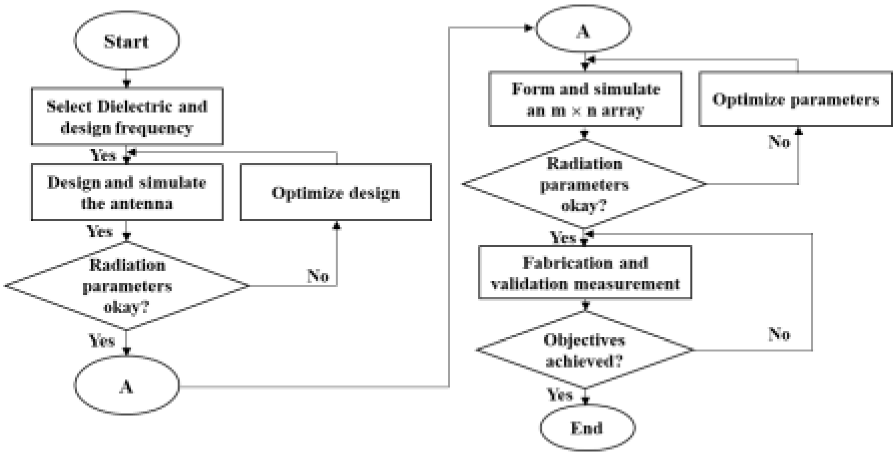


Figure 1. Methodological flow chart

2.1. Designing proposed model

The proposed design consists of two major sections which are MSA radiator design and backline feed design. Hence, substrate 1 selected for radiating element while substrate 2 for feedline. The performance of the proposed antenna depends on the resonant frequency, operating frequency, radiation efficiency, and return loss [15]. Hence, to design the proposed microstrip antenna model in CST, following parameters have been identified and listed in Table 1, which are also related to substrate material properties, and units. Initially, the simulation calibrated with operating frequency range is (1-7) GHz.

For effective design, implementation, and performance of a proposed backline feed microstrip patch antenna, it is required to use FR-4 substrate which is useful material for good conductivity. Therefore, arrangement of array in microtrip antenna is important to get good directicvity and radiation pattern [16], [17]. High dielectric constant value favored for low profile frequency because of maximize power loss and low dielectric constant values favored for high profile frequency because of minimize power loss in applications [18]. Here, dielectric constants $\varepsilon r = 4.4$ is used for frequency 5.8 GHz.

Table 1. List of proposed microstrip antenna specification

Parameters	Measurement
Resonance frequency	5.8 GHz
Operating frequency	1-7 GHz
Substrate material	FR 4 (Lossy)
Dielectric constant	4.4
Patch material	Copper (Annealed)
Patch width (Pw)	15 mm
Patch length (Pl)	11.87 mm
Substrates thickness (radiating element)	1.6 mm
Substrates length for (radiating)	119 mm
Substrate width for 1 (radiating)	21 mm

2.2. Geometry of wideband microstrip array antenna using back-line feed technique

As mentioned, 1×4 rectangular shape arrays have been selected to design the proposed microstrip patch antenna with 5.8 GHz frequency. Considering better conductivity, this design used copper (annealed) as antenna material. In the meantime, individual arrays are designed by precisely measuring their length and width, which are calculated using standard formulas. Additionally, software is utilized for parameter sweeping during the design process. The distance between the four arrays is consistent, which is 12 mm according to the parameter measurement shown in Figure 2.

In the proposed antenna, feedline connects with arrays horizontally from the backward side of substrate 1 ground plane. For that, every array has a small hole which is used to connect the terminal of transmission line by copper wire, and it needs to be soldered. The look of the antenna is T shape which mean substrate 1 constructed vertically and the patch have at front side besides, substrate 2 located horizontally as illustrated in Figure 2. By varying the following antenna parameters, the patch's width (W) and length (L), the feeding line's height above the patch element, the air gap's height, and the ground plane's and substrate's dimensions the antenna bandwidth can be increased [19].

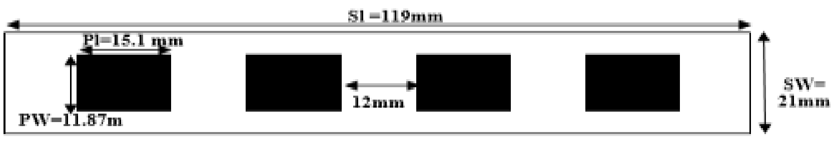


Figure 2. Geometry of proposed microstrip antenna

2.3. Design of backline feed

Backline feed was implemented using via holes drilled through the substrate to connect the microstrip transmission line to the back side of the patch radiator. The via holes were positioned strategically to minimize impedance disruptions and ensure proper signal transmission between the feedline and the radiating element. Usually, microstrip lines T -junction is constructed with the array on the same plot of an antenna [20]. To design the backline feed the same substrate material is used. In this design we have used low dielectric constant 4.4 to get the high-profile frequency and use power divider which is shown in Figure 3. For feedline configuration and impedance matching, the feedline was designed as a microstrip transmission line with a characteristic impedance of 50 ohms to match the impedance of the antenna and the

RF system [21], [22]. The proposed antenna is a self-complementary design with important parameters, and it has a wide frequency band of 5.8 GHz. To determine the input impedance (2), it is required to determine the dielectric constant effect by using the standard formula of (1) [23]-[26]. Important variable parameters to design backline feed have been shown in the list of specifications which is Table 2.

Dielectric constant effect, ε_{eff}

$$= \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}[1 + 12\frac{H}{W}]^{-5} \quad (1)$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2}[1 + 12\frac{1.6}{119}]^{-5}$$

$$= 4.2774\, F.mm^{-2}$$

Characteristic impedance, Z

$$_0 = \frac{120\pi}{(\sqrt{\varepsilon eff})\,[\frac{H}{W}+1.393\frac{2}{3}In\frac{H}{W}+1.44}\Omega \quad (2)$$

$$= \frac{120\pi}{(\sqrt{4.2774})[\frac{1.6}{119}+1.393\frac{2}{3}In\frac{1.6}{119}+1.44}\Omega$$

$$= 50.094\,\Omega$$

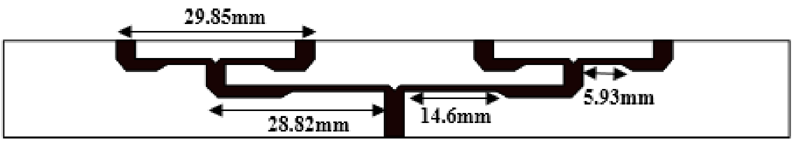


Figure 3. Dimension of the designed backline feed by using power divider

Table 2. List of backline feed specification

Parameters	Measurements
Substrate material	FR-4 (lossy)
Substrate 2 height	1.6 mm
Substrate thickness	0.035 mm
Dielectric constant	4.4
Substrate 2 length (Sl2)	119 mm
Substrate 2 width (Sw2)	15 mm
Line impedance	50 Ω
Quarter wave transformer $\frac{\lambda}{2}/\frac{\lambda}{4}$	100 Ω/70 Ω/50 Ω

3. RESULTS AND DISCUSSION

3.1. Simulation result

As mentioned, the proposed backline feed microstrip array antenna was simulated using CST. The required parameters were inputted into CST for the simulation design. The simulation results highlighted the bandwidth and resonance frequency. Additionally, the results determined essential figures such as the radiation pattern, gain, and directivity, which characterize the proposed backline feed microstrip array. The following section discusses all the simulated results in detail.

3.1.1. Bandwidth of resonance frequency 5.8 GHz

The antenna bandwidth is defined as the frequency range where the magnitude of S1,1 is -10 dB. Therefore, it measures with S1,1 magnitude as a function of frequency which has been achieved through simulation result shown in Figure 4. However, the bandwidth frequency determined by the simulation has been further validated using (3) that indicates the accuracy of the proposed array antenna.

Referring to the frequency range from simulation result in Figure 4, the maximum frequency is 5.9087 GHz, while the minimum frequency is 5.6245 GHz. Thus, the operating frequency has been calculated using (3) and demonstrated. It is worth mensioning that the calculated operating frequency further validates the successful simulation result shown in this paper. Consequently, the bandwidth of the proposed approach has observed 5% (calculated in percent) as calculation shown:

$$BW = \frac{fh-fl}{fo} \times 100\% \quad (3)$$

Where,
fh = High frequency
fl = Lower frequency
fo = Operating frequency

$$\text{So, } fo = \frac{fh+fl}{2} \quad (4)$$
$$= \frac{5.9087 + 5.6245}{2}$$
$$= 5.77 \text{ or } 5.8 \text{ GHz}$$

Therefore, bandwidth (in percent),

$$BW = \frac{fh - fl}{fo} \times 100\%$$
$$= \frac{5.9087 - 5.6245}{5.8} \times 100\%$$
$$Bandwidth = 5\% \; (calculated\ in\ percent)$$

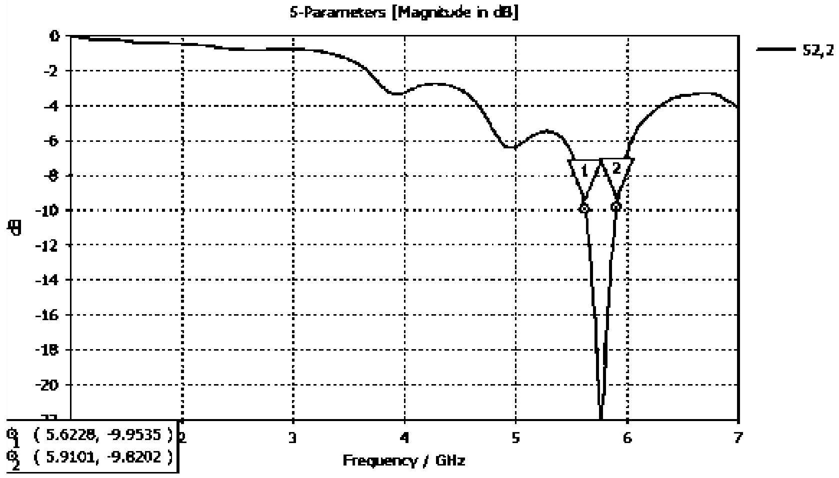


Figure 4. Simulated bandwidth result of proposed antenna

3.1.2. Radiation pattern: E-field

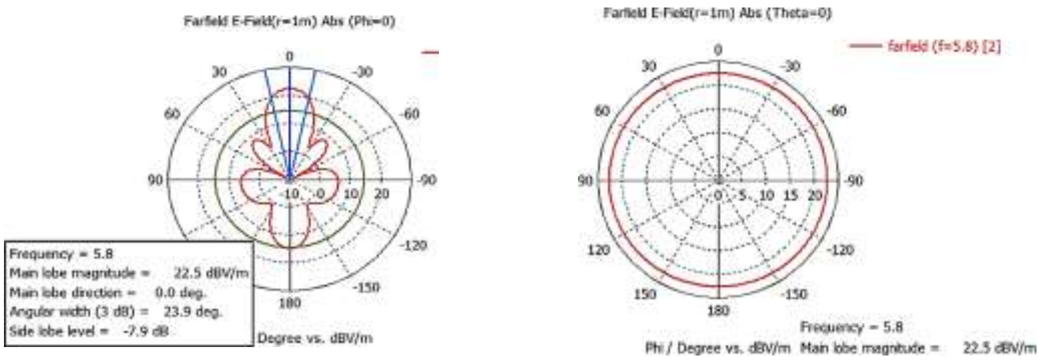
The simulated radiation pattern of the proposed approach is described based on E-field and H-field polarization. Subsequently, each field polarization is further defined as co-polarization and cross-polarization. Figure 5 represents the E-field polarization, illustrating the radiation pattern in polar form. In co-polarization plot in Figure 5(a), the main lobe magnitude is 22.5 dBV/m, half power beam width in 3 dB is 23.9º and the side lobes are -7.9 dB. While cross-polarization plot represents the main lobes magnitude which is the same as co-polarization. However, the half power beam width is 0º in 3 dB that has no side lobes as shown in Figure 5(b).

3.1.3. Radiation pattern: H-field polarization

From Figure 6, it represents the co-polarization and cross polarization of H-plane called electromagnetic field radiation pattern which is in polar form. Co-polarization plot in Figure 6(a) exibits that, the main lobe magnitude is -29.9 dBV/m, half power beam width in 3 dB is 106.1º and side lobes is -7.8 dB. From cross-polarization plot in Figure 6(b), here the main lobes magnitude is -35.8dBV/m with main lobe direction 90º, half power beam width is 24.4º in 3dB and the side lobes are -3.2dB which is bigger than co-polarization.

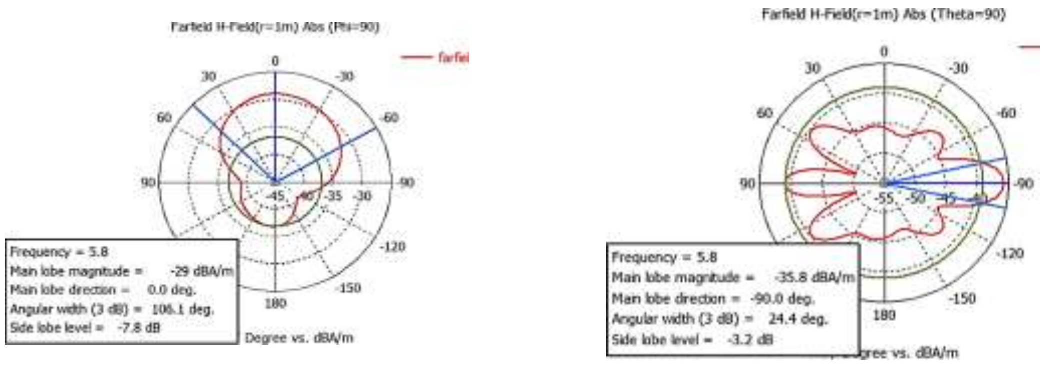
3.1.4. Realized gain

The simulated gain of the proposed approach is representing the main lobe magnitude 7.73 dB, half power beam width or angular width is 23.9º, and side lobe is -7.9 dB. In 5.8 GHz, here also Side lobes are always different from the main lobes because it is the lobes of local maxima in the farfield radiation pattern. Here, radiation efficiency -2.543 dB, total efficiency -2.553 dB and realized gain is 7.735 dB. Realized gain is smaller than directivity gain because of its mismatching loss.



(a) (b)

Figure 5. Simulated E-field polarization (a) E-plane co-polarization and (b) E-plane cross-polarization



(a) (b)

Figure 6. Simulated H-plane polarization (a) H-plane co-polarization and (b) H-plane cross-polarization

3.1.5. Directivity

Referred to Figure 7, the corresponding directivity of 5.8 GHz resonance frequency representing the value of radiation efficiency -2.543 dB, total efficiency -2.553 dB and directivity 10.3 dB. So, this antenna will be radiated with 10.29 dB to the specific direction.

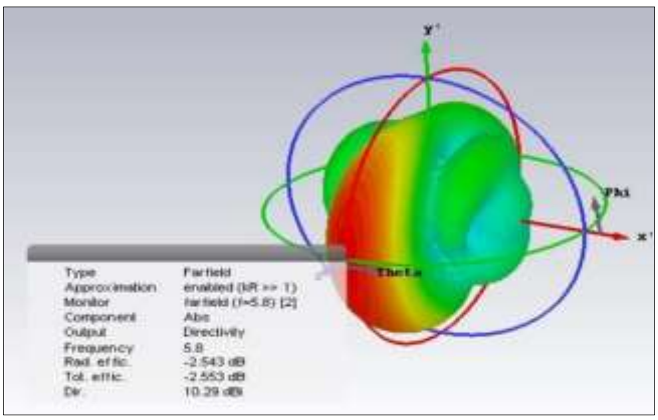


Figure 7. Directivity of proposed antenna

3.2. Result analysis and discussion

This study investigated the effects of lower mutual coupling between closely spaced antenna elements. While earlier studies have explored the higher mutual coupling and performance; they have not explicitly addressed its influence on the design of lower mutual coupling feeding technique (BLF). Table 3 represents the performance analysis of studied methods with proposed techniques based on various band and different-shaped microstrip antennas using the traditional inset feed technique. It has the S11 parameter results between the ranges of frequency (5.5-5.8) GHz, return loss -20.86 to -24, gain 2.72 to 6.70 dBi, directivity 6.8 to 9.36 dBi, VSWR 1.13 to < 2. Likewise, the proposed method provides return loss -21.497, gain 7.73 dBi, directivity 10.3 and VSWR 1.17 which correlates with the significant performance improvement of an antenna. Therefore, the proposed method in this study tended to have modified the traditional inset feeding technique to back line feeding technique. Our study suggests that lower mutual coupling is associated with more reliable performance in microstrip antenna by implementing independent closely spaced antenna element. Overall, it operates at a higher frequency, and demonstrates competitive performance in terms of return loss, gain, directivity, and VSWR to the existing techniques.

Table 3. Comparison of studied methods with proposed technique

Ref	Studied Methods	Published	Frequency f_r (GHz)	Return Loss R_l (dB)	Gain (dBi)	Directivity (dBi)	VSWR
Ali *et al*. [8]	Inset-feed multi band	2019	2.4/5.5/28	NA	1.95/3.76/7.35	NA	< 2
Olan-Nunez *et al*. [12]	T-Junction feed-line miniature patch microstrip array	2020	5.8	-20.86	6.70	7.1	1.19
Mahmoodha *et al*. [13]	Inset-feed stratified structure MPA	2021	5.8	-24	6.22	6.8	1.13
Al-Mumen *et al*. [14]	Transmission line-feed 1x2 array	2022	5.8	-23.283	2.72	9.36	< 2
Proposed Method	Modified back-line inset feed		5.8	-21.497	7.73	10.3	1.17

3.3. Experimental result

In order to validate the simulation results, the proposed arrays were fabricated and measured, as depicted in Figure 8. FR-4 was chosen as the dielectric substrate material for its desired electrical properties. The integration of the feedline was achieved through proper impedance matching between the feedline and the antenna elements, while the metallization process applied using copper (annealed). The final prototype includes Figure 8(a), showcasing Substrate-1 of the proposed array with measurements (119 mm × 21 mm), Figure 8(b), featuring Substrate-2 backline feed with measurements (119 mm × 15 mm), Figure 8(c), displaying the printed array antenna and Figure 8(d), presenting the final assembled prototype.

In our experiment, we observed prominent harmonics in the return loss of the microstrip array backline feed antenna, a phenomenon not fully replicated in our simulations which is shown in Figure 9. The inconsistency between the simulated and experimental results highlights the complex interaction of real-world conditions and theoretical models in antenna design, urging a closer examination of factors such as material properties, environmental influences, and fabrication tolerances. However, further and in-depth studies may be needed to eliminate the harmonics with precise fabrication especially regarding feedline with arrays. Our findings indicate conclusive evidence of the proposed design that provides promising performance compared to the recent approach.

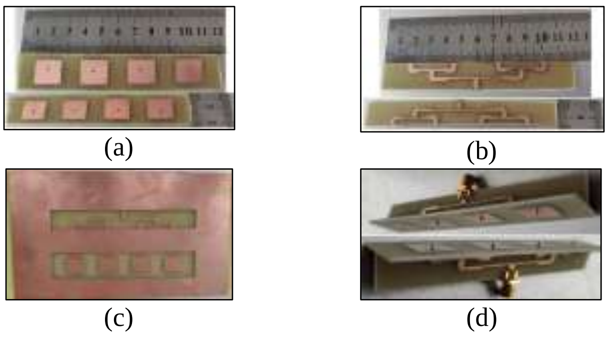


Figure 8. Fabricated arrays of proposed antenna: (a) substrate-1 array (W x L), (b) substrate-2 back line feed (W x L), (c) printed array antenna, and (d) final prototype (assembled)

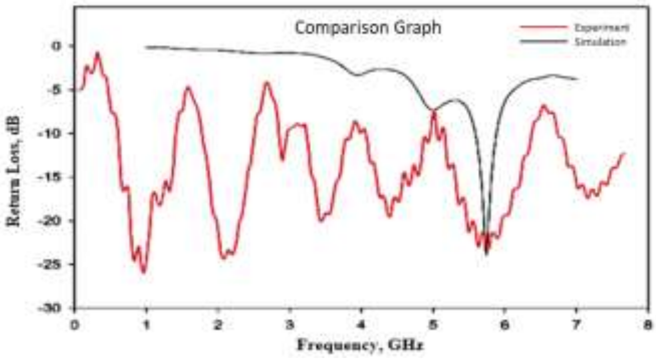


Figure 9. S11 (dB) return loss simulation and experimental result of proposed antenna

4. CONCLUSION

This paper succesfully presented the proposed backline feed microstrip array antenna design. The simulation result of the proposed method shows the return loss -21.497, gain 7.73dBi, directivity 10.3 and VSWR 1.17 which consider as a significant performance improvement compared to studied methods. Overall, the proposed method operates at a higher frequency, and it demonstrates competitive performance in terms of return loss, gain, directivity, and VSWR compared to the existing techniques. However, the experimental results show prominent harmonics in the return loss, a phenomenon not fully replicated in our simulations which is limitation of our work. Further analysis is required to clarify the origins of these harmonics and refine our understanding of antenna performance in practical scenarios which is left for future research. It is reccommended to analysis the material properties of proposed antenna, environmental influences, and fabrication tolerances. The proposed simulation and hardware models in this paper provide a promising alternative for modern antenna practices.

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