Design and Analysis of Elliptical Microstrip Antenna with Partial Ground and Slots Techniques for UWB Applications using CST Studio 2023

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This study introduced a novel method for modeling, manufacturing and enhancing bandwidth of the elliptical microstrip antenna (EMSA) with the help of Computer Simulation Technology CST tool. The developed EMSA exhibits the following characteristics at its resonant frequency 7.05 GHz, operating bandwidth 5.7% for simulated results and 4.28% for measured, return loss -42dB, impedance matching 50Ω, radiation gain 8.57 dB and Voltage standing wave ratio VSWR 1.016 dB. A drawback of these standard EMSA is their narrow bandwidth. Two approaches have been used to improve bandwidth. First improvement is achieved by using a partial ground plane and the second by slots technique in patch. Bandwidth of 146% and 167% for simulated and measured results, respectively, can be achieved by miniaturization ground plane to partial. BW improvement was significantly achieved by using two slots which at two left-right sides of patch. Bandwidth of 160% and 180% for simulated and measured results respectively.

Keywords: Elliptical microstrip antennas; Partial ground plane; Ultra-wide band (UWB)
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1. Introduction

The antenna is crucial to the transmission of energy in a system that has multiple points of communication. In this system, the efficiency of the energy transfer and the gain and reduction of interference from the waves are increased. Today, the area of multiple band communication systems is expanding in order to accommodate development needs [1]. Information can be transmitted in the form of video, email, text, audio, etc. Because of the significant evolution in the world of communications, the elliptical micro strip antenna (EMSA) has become significant in the peaceful and non-peaceful applications that it has participated in [2]. EMSA has a very thin metallic coating (copper) that is placed just above the ground plane of conductivity (copper), this is separated by a dielectric substrate (FR-4) [3]. Low cost, light weight, low profile antennas that can sustain great performance over a wide spectrum of frequencies have been popular in commercial and government communication systems [4]. The various EMSA advantages and disadvantages are given in table (1) [5].

Table (1) Advantage and disadvantage of EMSA

No.	Advantage	Disadvantage
1	Low weight	Low efficiency, narrow BW
2	Low profile	Low gain
3	Thin profile	Large ohmic loss in the feed structure of arrays
4	Required no cavity backing	Low power handling capacity
5	Linear and circulation polarization	Excitation of surface waves
6	Capable of dual and triple frequency operation	Polarization purity is difficult to achieve

There are several methods to improve the bandwidth in EMSA by including double of the dielectric layer, make slots within patch, using a material with a low dielectric constant, partial cutting with patch or ground and slotted work [6]. Elliptical notch in microstrip patch antennas is a design technique that involves introducing openings or cuts in the radiating patch to achieve specific performance objectives [7].

The bandwidth of the antenna may be impacted by the partial ground plane configuration. Designers need to optimize the dimensions to achieve the desired bandwidth for the application [8].

This antenna is designed to work in UWB since these UWB technologies have a high data rate and large bandwidth in microwave systems, they can send video, audio, and data files much quicker. Multiple articles on various antenna designs have been published to demonstrate the profits of UWB applications in real world wireless communications. Furthermore, microwave antenna researchers all worldwide have attempted to construct ultra-wideband antennas utilizing a variety of bandwidth extension methods [9,10].

Computer simulation technology (CST) was used to obtain simulation results, while a vector network analyzer (VNA) was used to obtain practical results. The proposed antenna is intended for radiolocation and satellite communications, making it smaller than most UWB antennas, measured on a substrate [11,12]. Table (2) shows the applications and resonant frequency ranges over which they operate for elliptical micro strips antenna [13].

Table (2) Applications and resonant frequency ranges of EMSA

Communication Systems	2GHz - 7GHz L/S/C Bands used for wireless communication
Direct Broadcast Satellite	11.7-12.5 GHz L/S/C/X Bands
Remote Sensing	L/S/C/X Bands
Aerospace Radar Systems	X/Ku/K Bands

2. Design Elliptical Microstrip Antenna

The proposed antenna arrangement is an elliptical patch built on a flat surface, called an "elliptical microstrip antenna" (EMSA) with a smaller radius (V) and the larger radius (M). This was simulated vertically by the CST Studio Suite 2023 program. The designed antenna can be fed by a microstrip line technique. EMSA have been consists of a single layer substrate of thickness *h*=1.6 mm and a dielectric constant of ε_r= 4.3, and table (3) shows parameters of the EMSA [14]. EMSA is designed to operate with a resonant frequency of 7.05 GHz for 5G mobile and UWB.

The length of the patch L_p can be determined using the equation [15]:

$$f_r \cong \frac{c}{2L_p.k} \quad (1)$$

$$K = \sqrt{\varepsilon_{eff}} \quad (2)$$

Where *c* represents the speed of light in a vacuum

According to Eq. (1) [16], the length of the patch L_p can be calculated. L_p is 16 mm (smaller diameter 2x*V*) then, the smaller radius (*V*) is 8 mm, the larger radius (*M*) 10 mm and ground plane with the size of 40×50mm^2. The strip line method is used to feed the EMSA [17] as shown in Fig. (1). The effective permittivity (ε_{eff}) is a valuable parameter. For FR-4 substrate relative dielectric constant (ε_r) of 4.3 and loss tangent (tanδ) of 0.025 [18]. It can be determined from Eq. (3) and typically comes out to be around 1.82, as shown in table (3).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{Wtrl}}}\right) \quad (3)$$

For the impedance of Z_0=50Ω, microstrip line width (*Wtrl*) can be calculated using Eq. (4) [19]. *Wtrl* can be closed to 3 mm.

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1.41}} \ln\left(\frac{5.98h}{0.8Wtrl+t}\right) \quad (4)$$

Table (3) parameters list of EMSA

No.	Symbol	Value in mm	Description
1	M	10	Large radius
2	V	8	Small radius
3	Lf	20	Feeding length
4	Wstrl	3	Width of feeding length
5	X	40	Width of EMSA
6	Y	55	Length of EMSA

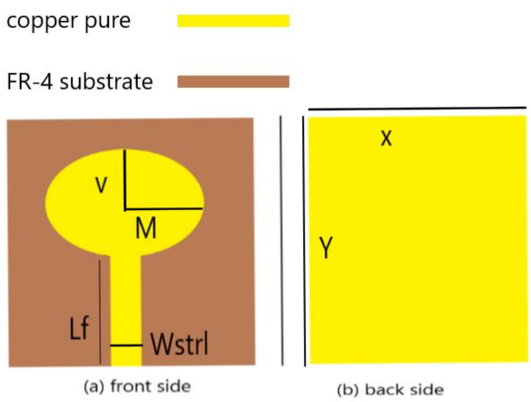


Fig. (1) Scheme of the proposed EMSA

3. Results and Discussion

3.1. The Simulated Results of EMSA

The input impedance must be matched at 50 Ω. Input impedance Z_{in} is one of the important parameters. The resonant frequency occurs when the reactance value is zero f_r=7.05 GHz and input impedance Z_{in}=50Ω. Simulated results of the imaginary (reactance) and real (resistance) as shown in Fig. (2).

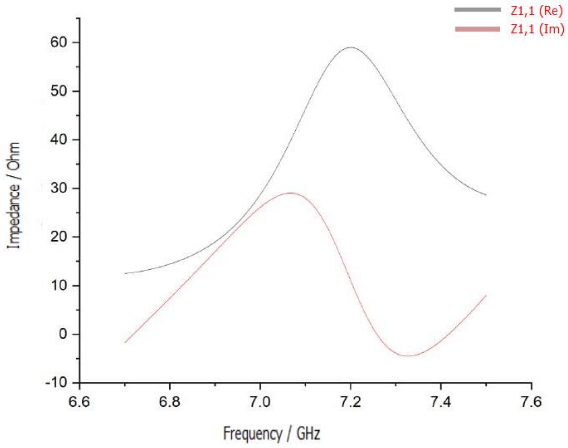


Fig. (2) The input impedance calculated by CST (-Z1,1 (Re), Z1,1 (Im))

Figure (3) shows -42dB is the computed return loss value. The frequency range at the two opposite corners of the return loss at -10dB is used to compute the bandwidth. As a percentage of bandwidth for the proposed antenna (5.7%) is described in Eq. (5).

$$BW = \frac{F_h-F_L}{F_h+F_L} \times 200\% \quad (5)$$

Where F_h represents the larger frequency and F_L is the smaller frequency [20]

At a resonant frequency of 7.05 GHz, voltage standing wave ratio (VSWR) is 1.016, as shown in Fig. (4).

Figure (5) shows the polar electric field distributions for the H-plane and E-plane, respectively. The normalized values for the field patterns are represented by the radiation pattern. It is shown that the radiation pattern is broadside and lacks side lobes. One of the fundamental features of an antenna is its radiation pattern, which indicates the direction of the energy concentration or the strength of radiation, whether it is coming from a single direction or coming from all directions in physical medium or space. It is feasible to ascertain the antenna's orientation in the event of transmission or reception based on the radiation pattern.

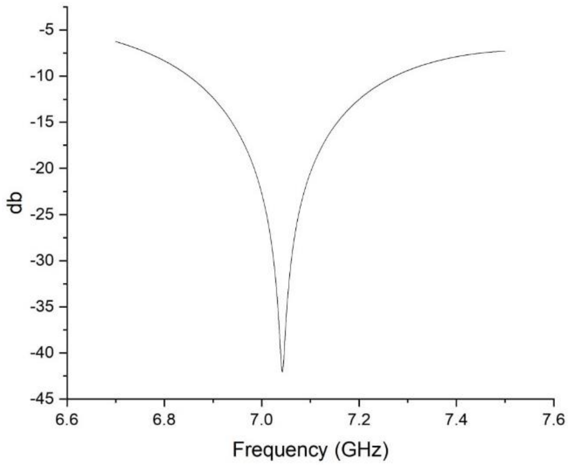


Fig. (3) Simulated return loss by CST for EMSA

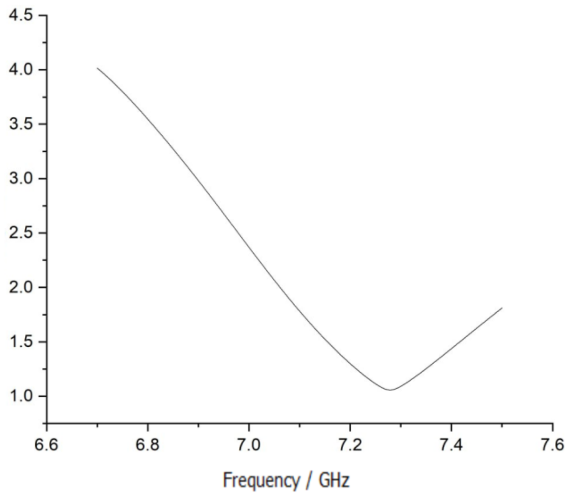


Fig (4) Simulated VSWR by CST for EMSA

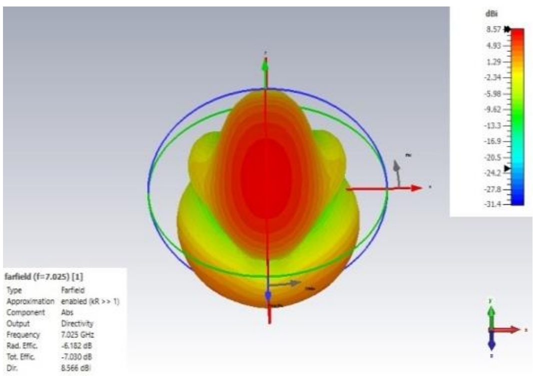


Fig. (5) Simulated radiation pattern by CST for EMSA

3.2. The Measured Results of EMSA

Figure (6) shows the fabricated prototype of EMSA which is manufactured to operate at same both all the frequency and dimensions of the designed prototype by CST program.

Using vector network analyzer, return loss is measured. Figure (7) shows the measured results of the manufactured EMSA. The measured bandwidth is 4.28% compared with 5.7%.

3.3. Improvement BW of EMSA

The improvement process was initiated to obtain a larger bandwidth that meets the needs of modern technology. The antenna was improved twice:

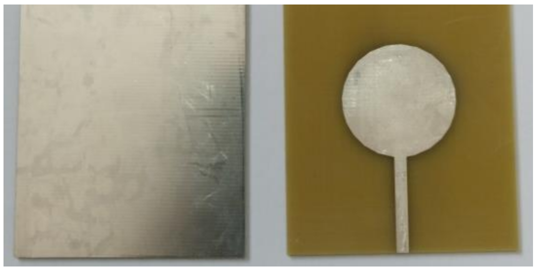


Fig. (6) Fabricated prototype of EMSA

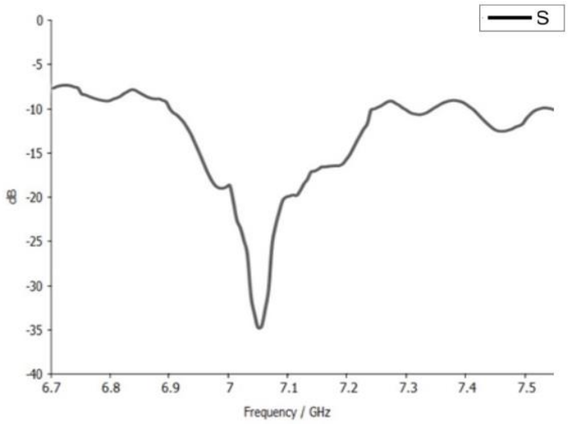
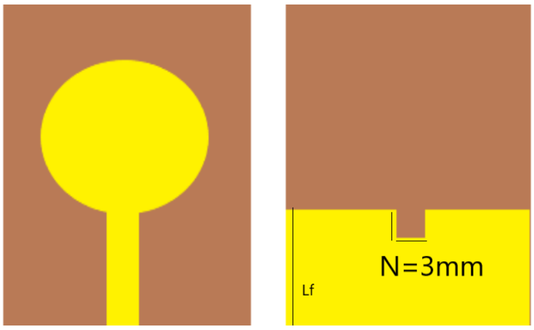


Fig. (7) Return loss measured by vector network analyzer of EMSA

3.3.1. First improvement (partial ground plane)

The first improvement of the EMSA achieved by miniaturization ground plane to partial with the size of 40×22 mm^2 and a square notch with the size of NxN=3x3 mm^2 on top of the base layer was placed. The obtained results of designed EMSA are plotted in Fig. (8). Figure (9) shows return loss with partial ground plane calculated by CST. The resonant range between 2 GHz to 13 GHz. From the simulated return loss, bandwidth is 146% which is used in UBW applications. The value of VSWR is between 1 and 1.5 along the resonant range. The gain is 6.22, as shown in Fig. (10). Radiation pattern is shown in Fig. (11).

Again, EMSA with partial ground plane was manufactured as shown in Fig. (12). Using vector network analyzer, return loss is measured as shown in Fig. (13). BW is 167% for measured results with resonant range from 1.5 GHz to 18 GHz. Miniaturization ground plane will affect the range of resonant frequency and BW enhancement.



(a) (b)

Fig. (8) The proposed EMSA with partial ground plane (a) top view (b) bottom view

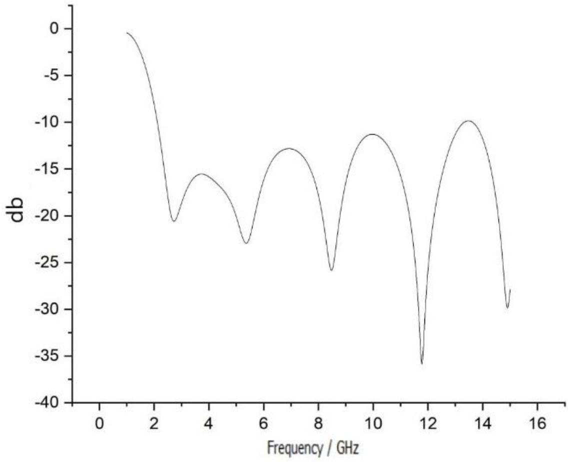


Fig. (9) Simulated return loss of EMSA with a partial ground plane

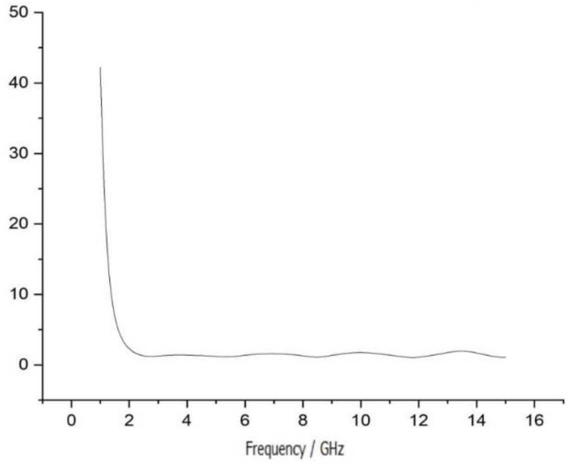


Fig. (10) Simulated VSWR of EMSA with partial ground plane

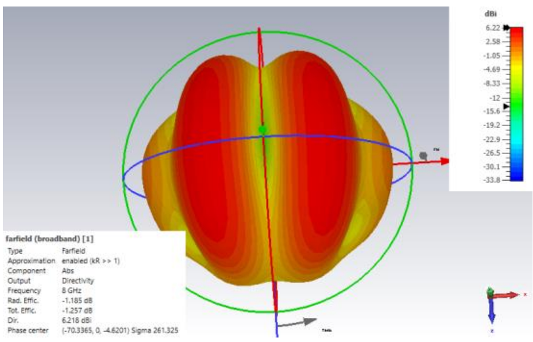


Fig. (11) Simulated radiation pattern of EMSA with partial ground plane

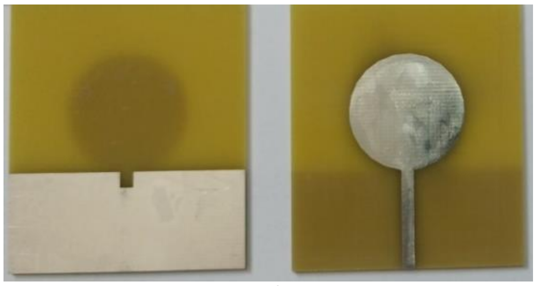


Fig. (12) Fabricated prototype of EMSA a partial ground plane

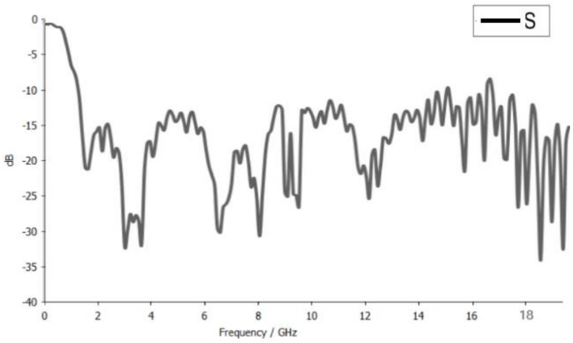
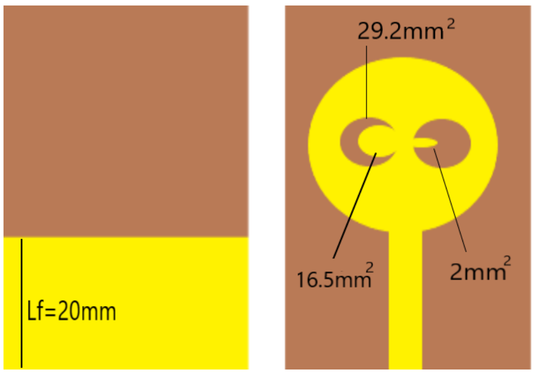


Fig. (13) Measured return loss measured of EMSA with a partial ground plane

3.3.2. Second improvement (slots in patch)

In order to obtain a larger bandwidth that meets the requirements of the UWB applications, the proposed antenna was modified again. The second enhancement is achieved by adding two slots with left-right on the elliptical patch with remaining on a partial ground plane. The dimensions and size of these slots are shown in Fig. (14).

Figure (15) shows that the calculated value of return loss. The simulated results on bandwidth are 16 GHz or (160%) with resonant frequency from 2 to 18 GHz.



(a) (b)

Fig. (14) Simulated EMSA with slots in patch (a) top view (b) bottom view

Value of VSWR is between 1 and 2 along the resonant range and gain is 6.36 dB as shown in Fig. (16). Radiation pattern is shown in Fig. (17). Again, EMSA with slots in patch with a partial ground plane was manufactured as shown in Fig. (18).

Using vector network analyzer, return loss is measured as shown in Fig. (19). BW is 18 GHz with

180% (2-20 GHz). Decreasing ground plane and introducing slots in patch plays an important role for improving the antenna performance and BW enhancement. This difference occurs because the dimensions of the measured prototypes are accurate enough.

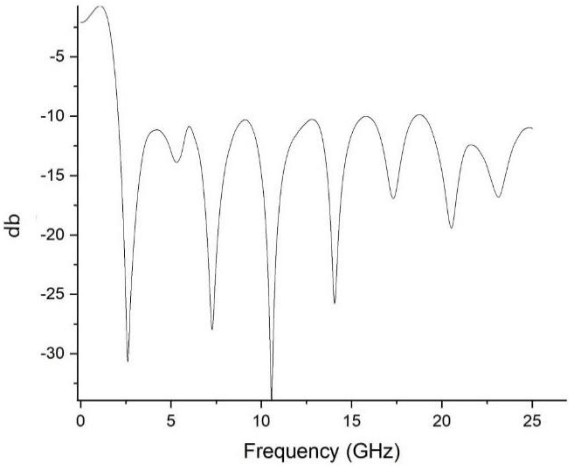


Fig. (15) Simulated return loss of EMSA with slots in patch

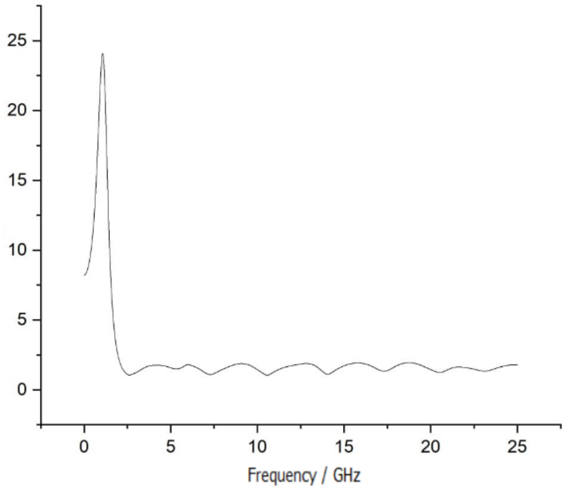


Fig. (16) Simulated VSWR of EMSA with slots in patch

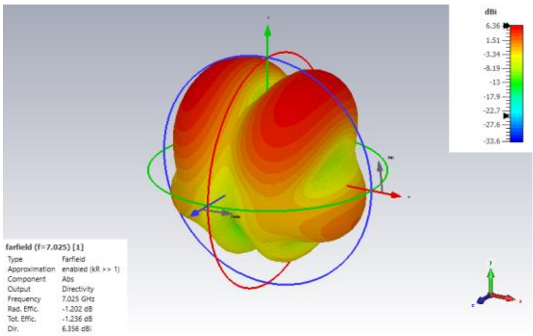


Fig. (17) Simulated radiation pattern of EMSA with slots in patch

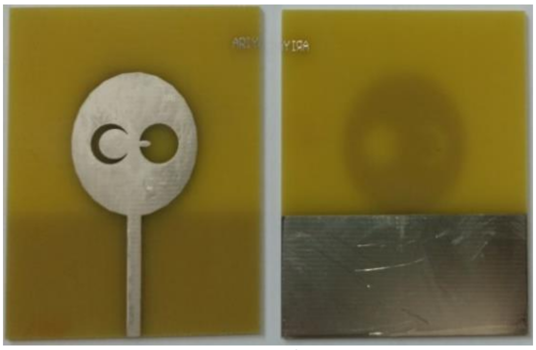


Fig. (18) Fabricated prototype of EMSA with slots in patch

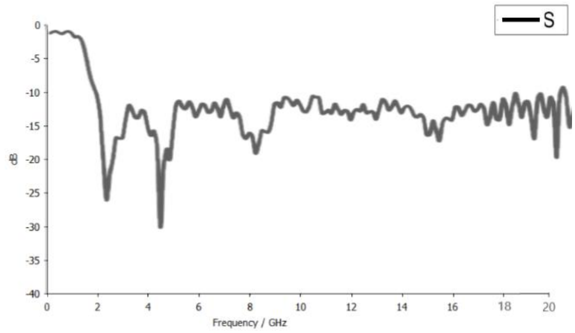


Fig. (19) Measured return loss of EMSA with slots in patch

4. Conclusion

In conclusion, the addition of a partial ground plane with a square notch significantly improved the performance of the antenna. BW between 2 GHz to 13 GHz (146%) and 1.5 GHz to 18 GHz (167%) for simulated and measured results, respectively, can be achieved by miniaturization ground plane to partial width gain of 6.22 dB. The improvement in bandwidth was significantly achieved by using two slots which are drilled at two left-right sides of patch. The bandwidth is between 2 GHz to 18 GHz (160%) and 2 GHz to 20 GHz (180%) for simulated and measured results, respectively, with gain of 6.36 dB.

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