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Design and Fabrication of Triangular Microstrip Antenna with Slots Technique for 5G Wireless Communication

This study focused on the equilateral triangular microstrip antenna ETMSA because it has several characteristics, such as lightweight, low cost in manufacturing, and small size. At the same time, a narrow bandwidth is one of the main disadvantages. This work suggests an ETMSA which that operated at a resonant frequency of 6.2GHz to meet a 5G applications. The CST studio simulation program is used to design the ETMSA. Several parameters such as bandwidth, radiation pattern, voltage standing wave ratio (VSWR), and input impedance were calculated. The bandwidth of the pure ETMSA at the resonance state is 2.5%. Slotting technology was used to improve the bandwidth of the proposed ETMSA. A circular and narrow plus-sign slots were designed and fabricated in the ground plane to enhance the bandwidth. Slots in ground plane can be enhanced the bandwidth up to 16% and 10% for the measured and simulated results, respectively. Furthermore, a significant improvement as a result of a two circular, elliptical and plus sing slots in the patch is satisfied. BW percentages are 10.9% for simulated and 18% for measured, is achieved.

Keywords: CST studio; Slots technique; Slotted ground plane; Microstrip antenna
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1. Introduction

Today, the increasing popularity of the web and the progress of smartphone workers and tablets, make the development of the needed wireless communication devices [1]. A significant role in offering easy communication for the current wireless communication systems is done by 5G [2]. The wireless communication system has a valuable component which is the antenna, and the most exceptional selection is the microstrip antenna (MSA) for the present mobile uses and wireless, because of the desirable's properties, such as lightweight, low profile, simplicity of fabrication and low in cost [3,4].

Different shapes of a triangular microstrip antenna TMSA are designed [5]. MSA contains a metal patch attached to an insulating layer (substrate) above ground plane, as shown in Fig. (1). The structure of the patch can be a rectangular, triangular, circular or other geometric shape [6,7]. Their radiation characteristic is the same because they behave like a dipole, despite their differences geometrical forms [3]. There are several methods to feed a microstrip antenna. These methods are divided into two groups: contacting feed, for example, coaxial cable and microstrip feed line, and non-contacting technique for example proximity coupling and aperture coupling [8,9].

In 1953, Deschamps [10] suggested the use of the microstrip as an emitter. At a two decades later, the practical microstrip antenna application have been a took place in the works [11,12], while a TMSA is studied for the first time back to 1978 [13,14]. Compared to other patch geometries, the researchers study the structure of the triangular microstrip patch as a planar circuit component [15] and as an emitting parts conventional [16]. A lower radiation loss is the main difference between the triangular microstrip and the rectangular patch while they have physically smaller radiation properties [17]. Because of the bigger request for tiny antennas for particular communication devices [18], TMSA with a microstrip feed line which has a plentiful interest in this article.

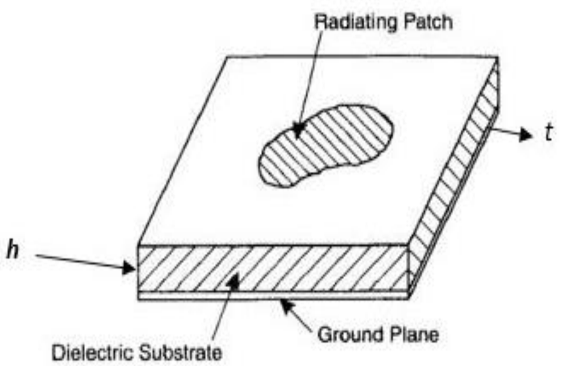

Fig (1) Geometric of microstrip patch antenna (MPA) [4]

Microstrip antennae have several advantages and disadvantages. The most important ones are poor manufacturing cost, lightweight and low volume. Meanwhile, the disadvantages are small bandwidth and reduced gain and efficiency [3]. So, BW enhancement of the antenna is necessary. There are several methods to improve the bandwidth including doubling the dielectric layer, using a material with a low dielectric constant and partial cutting with ground plane [9].

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Slotting technology is an important method used to enhance the bandwidth [19]. Many slots have been employed to provide a suitable bandwidth enhancement for multiband operation [20]. Different shapes of slots such as T-shaped, L-shaped, C-shaped, hexagonal, elliptical and circular are designed. [21].

In this research, a proposed equilateral triangle microstrip antenna ETMSA was designed and fabricated for 5G, Wi-Fi, and UWB applications. Designed ETMSA was simulated vertically by the CST Studio Suite 2023 program, and a practical results was obtained by using vector network analyzer (VNA).

2. Design an Equilateral Triangle Microstrip Antenna

A triangle patch can be made of copper. The proposed pure ETMSA consists of a single-layer substrate FR-4 that has a dielectric constant is ε_r=4.3 and dimension Ls=28.5 and width Ws=28.5, as shown in Fig. (2). The ground plane of the ETMSA which has a thickness t=0.035mm, and dimension in table (1) can be made of copper that same as the patch. A microstrip line is used to feed the ETMSA.

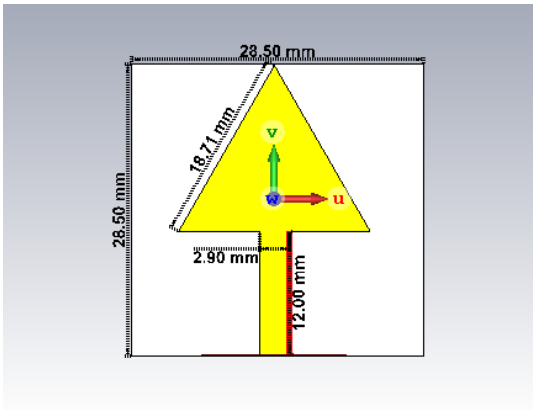

Fig. (2) Design of the equilateral triangle microstrip antenna (ETMSA)

A resonance frequency formula (Eq. 1) [22] is used to determine the dimensions of the ETMSA. According to Eq. (1), A the side length A of the triangle patch [23,24] is:

$$A = \frac{2c}{3f_r\sqrt{\varepsilon_r}}\sqrt{m^2+mn+n^2} \quad (1)$$

where c is the speed of light, f_r is resonance frequency ε_r represent a insulator constant and m, n are integer of TMmn mode.

However, because of the fringing fields, it became necessary to correct the side length of the triangle patch and dielectric constant values, as discussed in [22], [24], [25], and [26].

Firstly, the effective dielectric constant can be calculated by Eq. (2):

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

where h is the depth of the insulator material. For the impedance Z_0=50 ohm, a microstrip line width (W_f) can be calculated using Eq. (3) [18,27]

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1.41}}\ln\left(\frac{5.98h}{0.8Wf+t}\right) \quad (3)$$

and the active segment length of the triangle patch can be calculated as:

$$A_{eff} = \frac{2c}{3f_r\sqrt{\varepsilon_{eff}}} \quad (4)$$

For an ETMSA with a resonant frequency f_r=6.2 GHz and height h=1.6 mm, then, the effective side length of the triangle patch A_{eff} is 18 mm and the effective dielectric constant ε_{eff} is 3.2. Table (1) displayed the definitions of all parameters on a pure ETMSA.

Table (1) Definition of parameters of a pure ETMSA

Parameters	Description	Value
f_r	Resonant frequency	6.2 GHz
A_{eff}	Effective patch triangular side	18 mm
t	Ground patch thickness	0.035 mm
h	Substrate high	1.6 mm
Lf	Feed line length	12.09 mm
Wf	Feed line width	2.9 mm
Lg	Ground plain length	28.5 mm
Wg	Ground plain width	28.5 mm
Ls	substrate length	28.5
Ws	substrate width	28.5

3. Results and Discussion

The input impedance is the resistance showing by the antenna devices at the connection objects, given by the following equation [28]:

$$Z_{in} = R_{in} + jX_{in} \quad (5)$$

where Z_{in} represents the input impedance and R_{in} the real part (ETMSA 's ohmic resistance) and X_{in} the imaginary part (ETMSA 's equivalent reactance). The resonant frequency can be calculated at the value at which the reactance is near to zero and the resistance at its maximum value. At frequency resonance of 6.2 GHz, then, Z_0 is 54 ohm, as shown in Fig. (3).

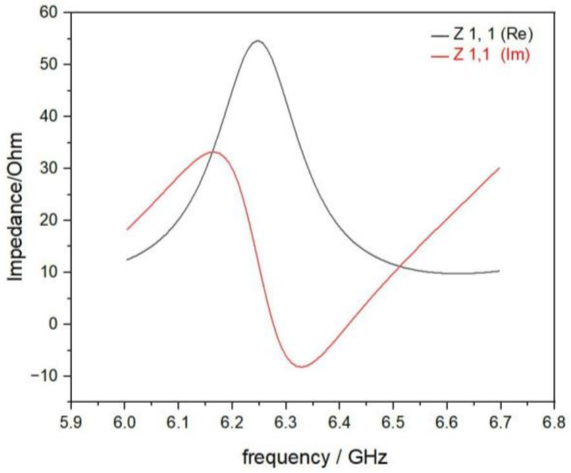

Fig. (3) Input impedance of a pure ETMSA

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The return loss is an important factor for determining the amount of energy falling on the connection point to the amount of reflected power. There is an allowable range that satisfies the condition S_{11}≤-10 dB. The ETMSA operates with high efficiency when the highest amount of power reaches it through the antenna feed transmission line. This situation happens once the input impedance equals the transmission line impedance.

In Fig. (4), the value of return loss is -49.95 at the resonant frequency 6.2 GHz. Also, the bandwidth can be calculated at the two opposite corners of the return loss at -10 dB. BW percentage (BW=2.5%) can computed according to the equation [29]:

$$BW = \frac{f_H - F_L}{f_H + f_L} \times 200\% \qquad (6)$$

Where f_H is the greater frequency and f_L is the minor frequency

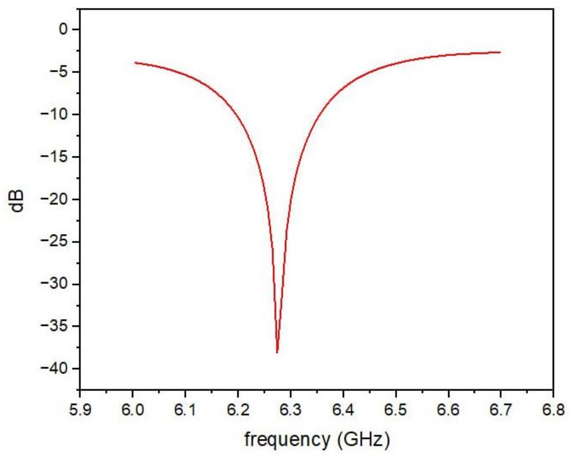

Fig. (4) Simulated return loss of a pure ETMSA

Several reflections of the energy will occur, causing the generation of standing waves called voltage standing waves ratio (VSWR). The value of the VSWR must be between 1≤ VSWR ≤2. Figure (5) shows the value of VSWR which is 1.027. ETMSA's radiation pattern is a fundamental characteristic that conveys the direction and strength of energy concentration or radiation. The radiation pattern represents the normalized values for the field patterns as shown in Fig. (6).

Figure (7) shown the fabricated ETMSA prototype, which is manufactured to work at the same frequency and standard dimensions as the designed ETMSA. Using Vector Network Analyzer, the measured return loss results are shown in Fig. (8). The measured bandwidth is 5% compared with the simulated result of 2.5%.

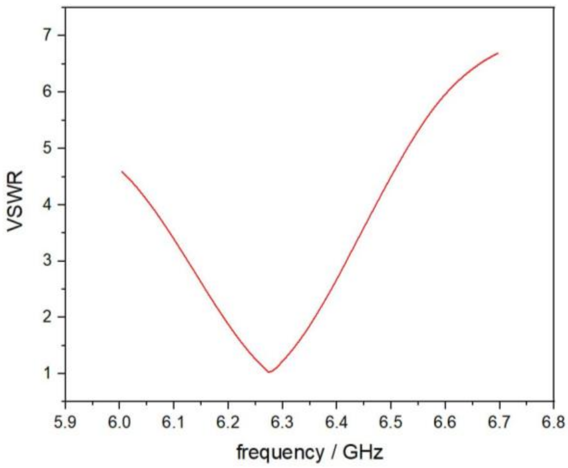

Fig. (5) Simulated VSWR of a pure ETMSA

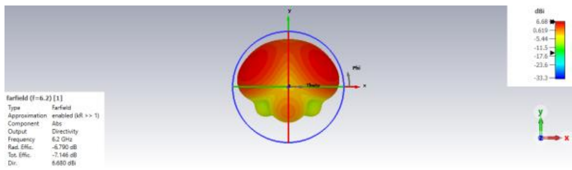

Fig. (6) Radiation pattern of a pure ETMSA

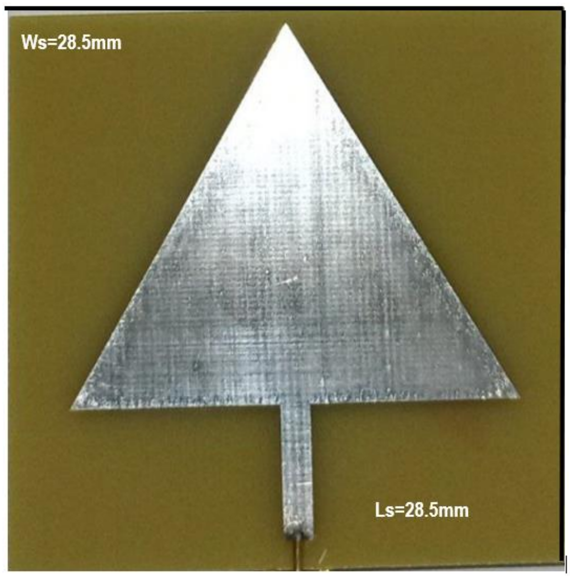

Fig. (7) Fabricated pure ETMSA prototype

4. Improvement BW of ETMSA

A wide bandwidth that meets the requirements of current technology is needed. In this paper, two ways were used:

The first improvement of the ETMSA created two different slots in the ground plane. One of them is a circular slot and the other is a narrow plus sign slot are designed, as shown in Fig. (9).

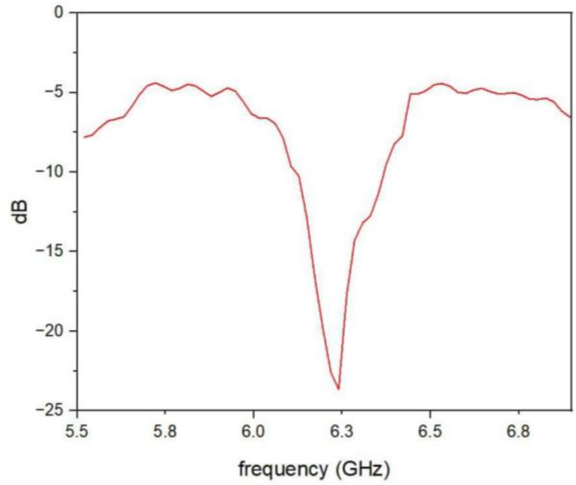

Fig (8) Measured return loss of a fabricated pure ETMSA

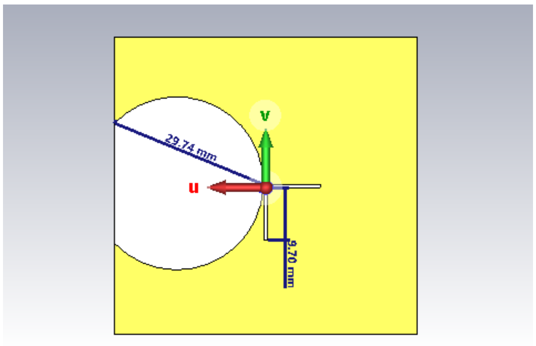

Fig. (9) Designed ETMSA with slotted ground plane

Figure (10) shows the simulated results for ETMSA with slots in the ground plane. The resonant frequency range operates between 6.08 GHz to 6.74 GHz. As a simulated result of the return loss, bandwidth is 10%. A "1.14" is the value of VSWR which is shown in Fig. (11). The simulated radiation pattern of ETMSA with a slotted ground plane is shown in Fig. (12). Slots in the ground plane can be enhanced the bandwidth up to 10% for the simulated results compare with 2.5% for a pure ETMSA.

A fabricated ETMSA prototype with slots in the ground plane is shown in Fig. (13). Return loss is measured by using a Vector Network Analyzer, as shown in Fig. (14). BW is 16% with a resonant frequency range from 5.879 to 6.938 GHz. Slots in the ground plane can be improved the bandwidth to 16% for the measured results compare with 5% on a pure fabricated ETMSA.

To get a bigger bandwidth, it was suggested to add slots in the patch on the improved ETMSA as in the first improvement. Four slots which are one plus sing, one elliptical, and two circles were designed in the patch of ETMSA, as shown in Fig. (15).

Figure (16) shows simulated results of return loss and the bandwidth is 10.9% with a resonant frequency range from 5.58 to 6.58 GHz. A "1.6" is the value of VSWR which is shown in Fig. (17). The gain is 4 dB and the simulated radiation pattern of ETMSA with slots in the patch is shown in Fig. (18). BW improvement as a result of slots in the patch is 10.9% for simulated results compare with 2.5% for a pure ETMSA.

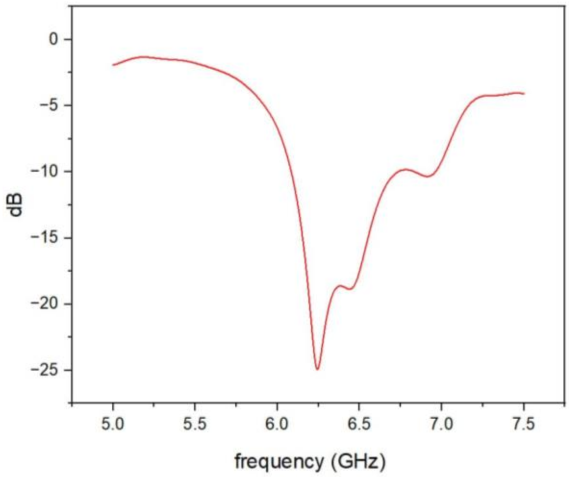

Fig. (10) Simulated return loss of ETMSA with slotted ground plane

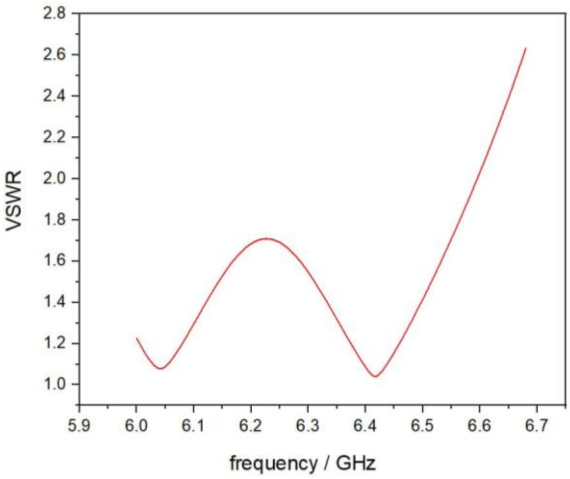

Fig. (11) Simulated VSWR of ETMSA with slotted ground plane

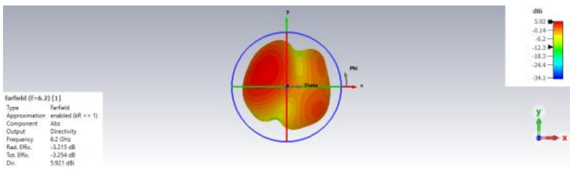

Fig. (12) Simulated radiation pattern of ETMSA with slotted ground plane

Using Vector Network Analyzer, for the fabricated ETMSA which is shown in Fig. (19), the return loss is measured as shown in Fig. (20). BW percentage is 18% (6.03 to 7.29 GHz). The difference between the measured and simulated results occurs because of manufacturing mistakes and work circumstances. BW enhancement as a result of slots in the patch is 18% for measured results compare with 5% for a pure fabricated ETMSA.

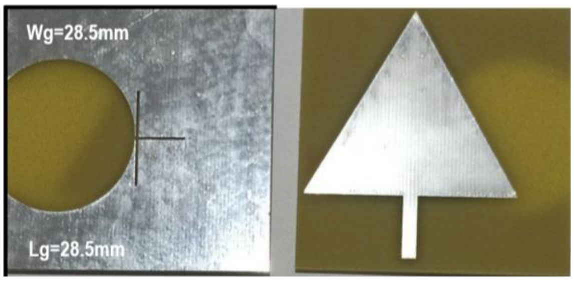

Fig. (13) Fabricated ETMSA prototype with slotted ground plane

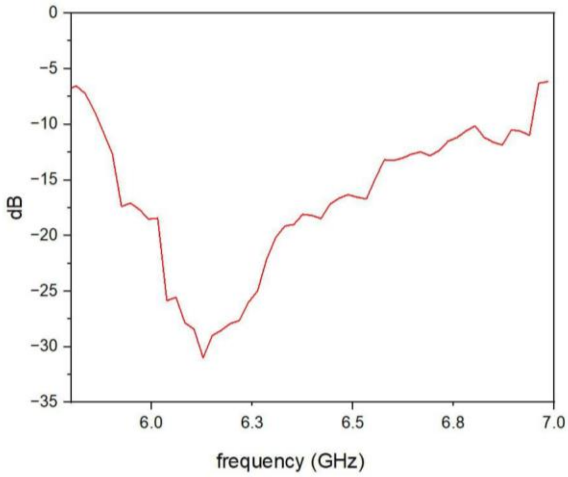

Fig. (14) Measured return loss of ETMSA with slotted ground plane

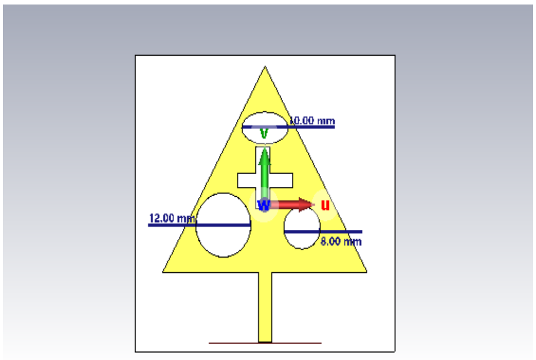

Fig. (15) Designed ETMSA with slots in patch

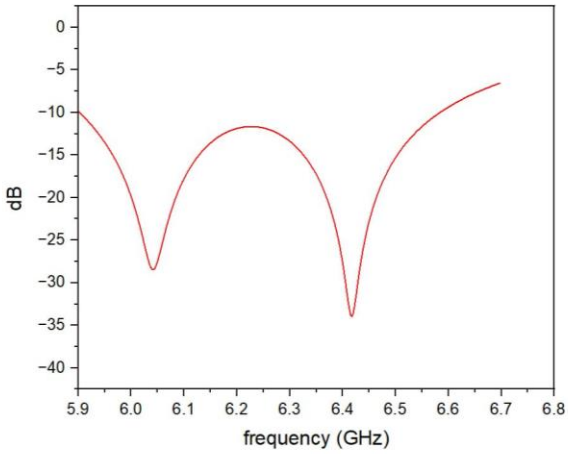

Fig. (16) Simulated return loss of ETMSA with slots in patch

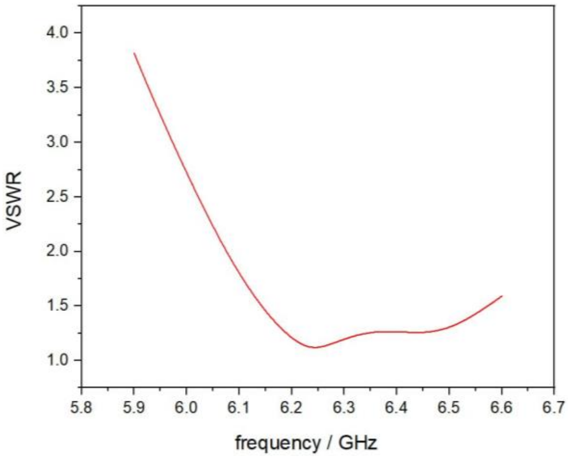

Fig. (17) Simulated VSWR of EMSA with slots in patch

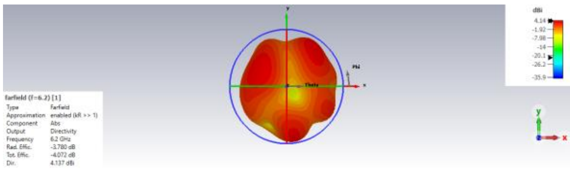

Fig. (18) Simulated radiation pattern of ETMSA with slots in patch

Fig. (19) Fabricated ETMSA prototype with slots in patch

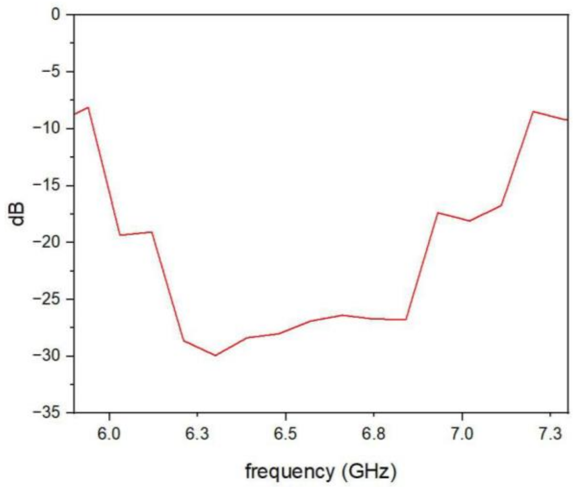

Fig. (20) Measured return loss of ETMSA with slots in patch

Table (2) displays a comparison between the practical and theoretical results on the bandwidth of the two ETMSAs (with slots in the ground plane and in the patch, respectively).

Table (2) Comparison between the simulated and measured results on the bandwidth of the two ETMSAs

ETMSA	Simulated results %	Measured results %
Pure	2.5	5
Slotted Ground Plane	10	16
Slotted Patch	10.9	18

4. Conclusion

An ETMSA is designed and manufactured. The CST studio simulation program is used to design the ETMSA. Several parameters have been calculated such as bandwidth, radiation pattern, voltage standing wave ratio and input impedance. Slot technology can be used to improve the bandwidth. Slots in the ground plane can be enhanced the bandwidth by up to 16% and 10% for the measured and simulated results, respectively. BW improvement as a result of slots in the patch (10.9% for simulated and 18% for measured) is achieved. This paper confirms that using slot technology can increase the bandwidth.

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