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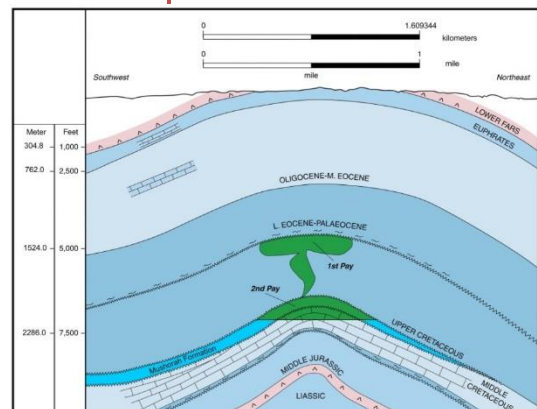
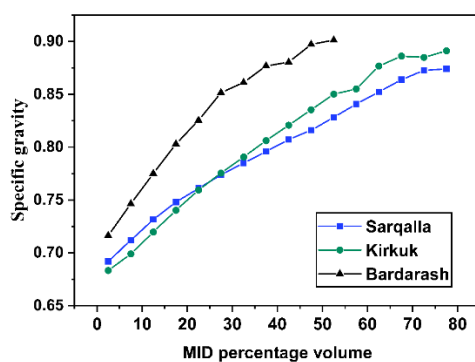
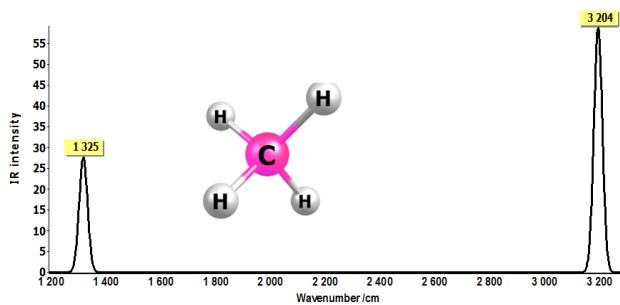
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# Parametric Study of an Elliptical Microstrip Patch Antenna for X-band Applications

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*Elliptical patch antenna, Microstrip antenna, X-band frequency, dielectric substrate.*

## Abstract

In this article, the design of a single element elliptical microstrip patch antenna (EMSPA) operating at the X-band frequencies is proposed using the Computer Simulation Technology (CST) simulator. The inset-fed technique is employed in the design to feed the patch. Also, various patch eccentricity with different substrate materials of various thickness have been investigated in order to obtain the optimum realized gain and bandwidth (BW) of the antenna. The simulated results have shown that an elliptical patch having a size of 48.71 mm<sup>2</sup> provides a gain of 3.94 dBi and a BW of 389 MHz at the center frequency 9.8 GHz. Moreover, the efficiency of more than 71.6% is predicted when the Taconic\_RF-60A substrates of thickness  $h=1.0$  mm and patch eccentricity values of  $e=0.5$  are utilized. Additionally, the gain and the BW of the EMSPA can be further enhanced when a Rogers\_RT5880 substrate of thickness  $h=1.4$  mm and patch eccentricity values of  $e=0.7$  are utilized. Comparing the simulated antenna response to the available theoretical and practical results obtained by other researchers previously, a very good agreement is observed. The proposed EMSPA is low profile and very efficient which could be of interest in some radar applications.

## Introduction

Recently, wireless communication systems have been developed significantly to meet the demands of the users towards the compactness and high data rate capability. To achieve these, researchers have been focused extensively on the front-end components of wireless systems, particularly antennas [1-3] and [4-6]. Since their appearance, microstrip patch antennas (MSPAs) have been employed in various applications due to their versatile, low cost, light weight and easy to fabricate on a planar structure [7-9]. However, the inherent narrow BW and the high insertion loss when operating at higher operating frequency are considered as the main drawbacks of this type of the antenna [10-11]. Different shapes for the patch of MSPAs have been investigated in the literature. Each one of them has been designed for a particular application [12-16]. The BW and gain enhancement of a rectangular and circular MSPA arrays operating at X-band frequencies were investigated using defecting ground planes and introducing slots using different feeding techniques [17-19]. In addition to enhancing the MSPA BW, a probe-fed technique employed in the design of compact inverted S-shaped rectangular and elliptical patch with various slot shapes were presented in [20] to obtain multi-band frequency. Different shapes for the patches of MSPA were investigated in [21-25] in order to achieve multiple resonant frequencies at C-and X-band frequencies for mobile and radar application systems.

Moreover, different feed techniques were employed for the design of an X-band elliptical microstrip patch antenna (EMPA) mainly to achieve larger BW and gain [26]. On the other hand, a comparative study of an elliptical and a circular patch of MSPAs were investigated using method of moment (MOM) with the help of the analytical cavity model [11]. The works mentioned above have studied mainly the performance of

rectangular and circular MSPA. However, very little literature work has been presented on the design of elliptical MSPA with linear polarization.

In This article, a design study is presented for a single elliptical microstrip patch antenna (EMSPA) operating in the X-band frequencies. The patch proposed for the EMSPA provides flexibility including more degrees of freedom when comparing to the conventional rectangular and circular patches. The design study is performed through the identification of optimum substrate permittivity, optimum thickness and reliable elliptical patch axial ratios that maintain wider BW and higher antenna gain. An inset fed technique is utilized in the design of the EMSPA. Finally, different dielectric substrate material with various thickness as well as several elliptical patch axial ratios are investigated using the Computer Simulation Technology (CST) simulator.

### Theory of the Antenna Design

A conventional EMPA having a major radius of ( $a$ ), minor radius ( $b$ ), and eccentricity ( $e$ ) with an inset-fed used to excite the patch is presented in (Figure:1). The patch is assumed to be printed over the dielectric substrate material of relative permittivity ( $\epsilon_r$ ) with thickness ( $h$ ) having a length of ( $L_g$ ) and a width of ( $W_g$ ). The conductor ground plane has the same dimensions as the substrate material. The elliptical patch major and minor axes are calculated using the equations given by [27] as follow:

$$L_g = 4 \times b \quad (1)$$

$$W_g = 4 \times a \quad (2)$$

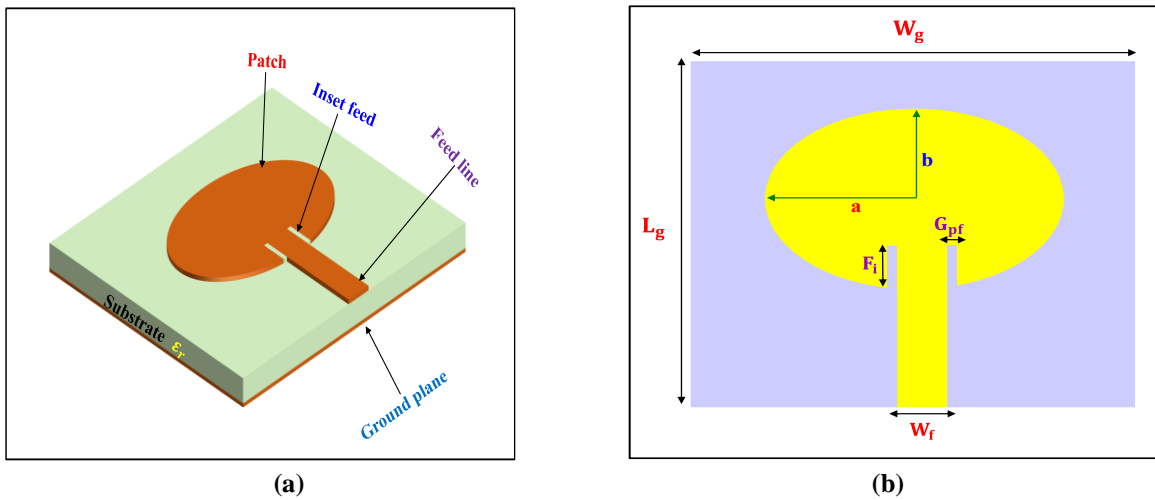


Figure- 1: (a) 3D view, and (b) top view configuration of EMSPA with inset-fed representation.

Once the operational frequency of the patch and dielectric substrate permittivity with its thickness are specified, the EMSPA radiuses ( $a$ ) and ( $b$ ) can be calculated through the expressions given by [14], [26]:

$$a_{eff} = \frac{15}{\pi e f_{11}^e} \sqrt{\frac{q_{11}^e}{\epsilon_{ref}}} \quad (3)$$

$$b_{eff} = \frac{15}{\pi e f_{11}^o} \sqrt{\frac{q_{11}^o}{\epsilon_{ref}}} \quad (4)$$

where, ( $e$ ) is the eccentricity of the ellipse and it can be expressed by:

$$e = \frac{\sqrt{a^2 - b^2}}{a} \quad (5)$$

The  $(f_{11}^e)$  and  $(f_{11}^o)$  are dominant resonance frequencies related to the even and odd mode operations, while  $(q_{11}^e)$  and  $(q_{11}^o)$  are related to the ellipse eccentricity. They can be expressed mathematically by a polynomial expression given by [14], [26] as:

$$q_{11}^e = -0.0049 e + 3.7888 e^2 - 0.7278 e^3 + 2.3140 e^4 \quad (6)$$

$$q_{11}^o = -0.0063 e + 3.8316 e^2 - 1.1351 e^3 + 5.2229 e^4 \quad (7)$$

On the other hand, due to the formation of the fringing field at the end of the patch, the permittivity ( $\epsilon_r$ ) of the dielectric material must be replaced by its effective values as schematically displayed in (Figure: 2). Thus, for the elliptical patch shapes, the effective substrate permittivity is expressed in [28] using the following relation:

$$\epsilon_{ref} = \epsilon_r - 0.35 \epsilon_r \left[ \frac{h}{a} + \frac{h}{b} + \frac{h^2}{ab} \right] \quad (8)$$

In addition, the formation of flinging fields also led to an extension of the elliptical patch major and minor axes which are related to the effective substrate relative permittivity and thickness, and are given in [26 and 28] as follows:

$$a_{eff} = \left\{ a^2 + \frac{2ha}{\pi\epsilon_{ref}} \left[ \ln\left(\frac{a}{2h}\right) + (1.41\epsilon_{ref} + 1.77) + \frac{h}{a} (0.268 \epsilon_{ref} + 1.65) \right] \right\}^{1/2} \quad (9)$$

$$b_{eff} = \left\{ b^2 + \frac{2hb}{\pi\epsilon_{ref}} \left[ \ln\left(\frac{b}{2h}\right) + (1.41\epsilon_{ref} + 1.77) + \frac{h}{b} (0.268 \epsilon_{ref} + 1.65) \right] \right\}^{1/2} \quad (10)$$

The value of the microstrip fed line width ( $W_f$ ), length ( $F_i$ ) and gap distance ( $G_{pf}$ ) between the patch and fed line can be calculated using the following mathematical equations [26]:

$$W_f = \frac{2h}{\pi} \left\{ \frac{377\pi}{2Z_o\sqrt{\epsilon_r}} - 1 - \ln\left(\frac{377\pi}{2Z_o\sqrt{\epsilon_r}} - 1\right) + \frac{\epsilon_r - 1}{2\epsilon_r} \left[ \ln\left(\frac{377\pi}{2Z_o\sqrt{\epsilon_r}} - 1\right) + 0.39 - \left(\frac{0.61}{\epsilon_r}\right) \right] \right\} \quad (11)$$

$$F_i = \frac{b}{\pi} \cos^{-1} \sqrt{\frac{Z_o}{Z_{in}}} \quad (12)$$

$$G_{pf} = \frac{4.65 \times 10^{-18} c \times f_r}{\sqrt{2 \epsilon_{ref}}} \cos^{-1} \sqrt{\frac{Z_o}{Z_{in}}} \quad (13)$$

The design procedure steps for achieving an inset-fed EMSPA with a high gain and large BW and having small area are summarized into the following steps:

- Specifying the operation frequency ( $f_r$  in GHz).
- Choosing dielectric substrate material permittivity ( $\epsilon_r$ )
- Selecting the substrate thickness ( $h$  in mm).
- Specifying the ellipse eccentricity ( $e$ ).
- Calculating the ground or substrate dimensions ( $L_g$  and  $W_g$  in mm).
- Finding approximate value of the EMSPA major and minor radius ( $a$  and  $b$  in mm)
- Selecting feeding method (inset-fed).
- Determining the feed position ( $W_f$ ), length ( $F_i$ ) and gap distance ( $G_{pf}$ ).

Following the above design procedure steps and equations, a MATLAB code has been written, and implemented to determine the fundamental patch and ground plane with inset fed dimensions.

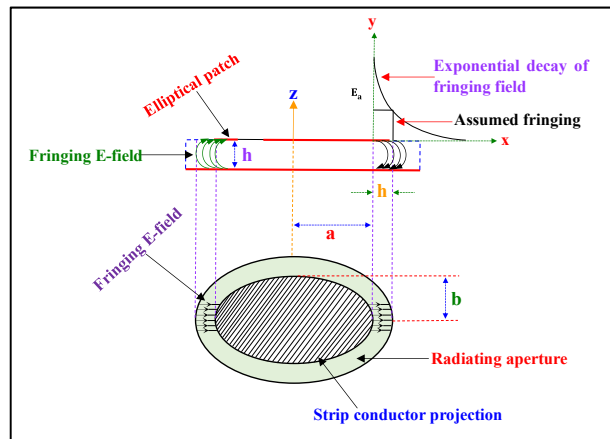


Figure- 2: Representation of the fringing fields formation at the end of the patch [28].

## Results and Discussion

The proposed EMSPA operating at 9.8 GHz following the design procedure mentioned above is shown in (Figure: 3). In the first step, the operation frequency is chosen at (9.8 GHz), eccentricity at ( $e \approx 0.6$ ), and the substrate thickness at ( $h = 1.2$  mm). Then, the effect of substrate permittivity types on the antenna performance is examined. In the second step, the variation of substrate thickness is studied. Finally, the effect of changing ellipse eccentricity is performed with the optimized substrate thickness and permittivity performed in the previous steps. These steps are performed in CST simulator, and discussed in details in the following sections.

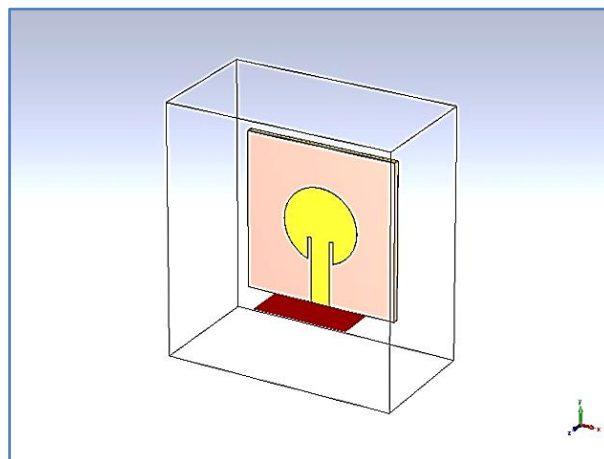


Figure-3: The proposed EMSPA modeled in CST.

### *Effect of Substrate Material*

In this section, four different dielectric substrate material types of thickness ( $h = 1.2$  mm) with elliptical patch eccentricity values of ( $e \approx 0.6$ ) are investigated. The dimensions of the ground plane, inset-feed, and elliptical patch radius found throughout the equations presented in section 2 and are implemented in CST as

summarized in Table 1. Later, with the use of these dimensions, the fundamental electrical parameters of the EMSPA are simulated. The simulated S11 and VSWR parameter responses with the use of considered substrate materials are given in (Figures: 4). While the estimated values of the other mentioned EMSPA parameters are represented in the form of histogram as shown in (Figure: 5). It is clearly seen from (Figures: 4) that all substrate material maintains S11 values less than (-10 dB) and VSWR values near to unity which in turn indicate the resonant impedance matching between the feed-line and elliptical microstrip patches. On the other hand, the results presented in (Figure: 5), imply that the Rogers\_RT5880 substrate provide higher gain, directivity and efficiency with reliable BW and larger patch area. In contrast, this figure also displays that the Taconic\_RF-60A substrate maintain smaller patch area with suitable directivity, gain, efficiency and BW values compared to the other considered substrate ones.

Table-1: Dimension parameters of designed EMSPA operating at (9.8 GHz) with various substrate materials of fixed substrate height ( $h = 1.2 \text{ mm}$ ) and fixed Copper patch thickness ( $t_p = 0.035 \mu\text{m}$ )

| Ground and patch characteristics in (mm) | Relative Permittivity ( $\epsilon_r$ ) |                       |                       |                        |
|--|--|-----------------------|-----------------------|------------------------|
|  | $\epsilon_{r1} = 2.2$                  | $\epsilon_{r2} = 3.5$ | $\epsilon_{r3} = 4.3$ | $\epsilon_{r4} = 6.15$ |
| Material Types                           | Rogers RT5880                          | Rogers TC350          | FR-4 Epoxy            | Taconic RF-60A         |
| Loss tangent ( $\delta$ )                | 0.0009                                 | 0.002                 | 0.025                 | 0.0028                 |
| Ground width ( $W_g$ )                   | 30                                     | 23.76                 | 18.805                | 15.5                   |
| Ground length ( $L_g$ )                  | 24.8                                   | 18.4                  | 13.7858               | 11.5                   |
| Feed line Gap ( $G_{pf}$ )               | 0.75                                   | 0.53                  | 0.4                   | 0.75                   |
| Feed line length ( $F_i$ )               | 3.64                                   | 3.4                   | 3.06                  | 2.38                   |
| Feed line width ( $w_f$ )                | 3.7                                    | 2.71                  | 2.33                  | 1.8                    |
| major radius ( $a$ )                     | 7.42                                   | 5.94                  | 5.3                   | 4.5                    |
| minor radius ( $b$ )                     | 5.9575                                 | 4.662                 | 4.278                 | 3.607                  |

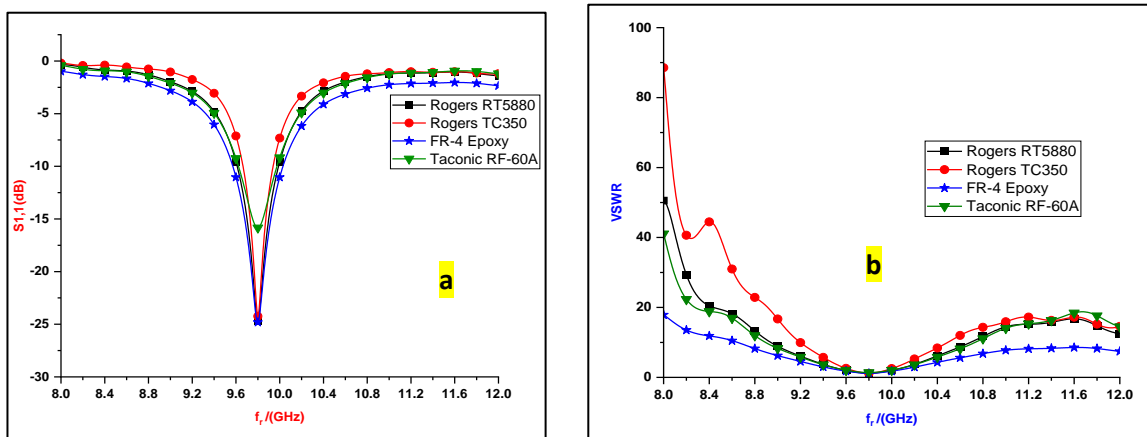


Figure-4: Variation of (a) S11 and (b) VSWR as a function of frequency with different substrate permittivity of thickness ( $h = 1.2 \text{ mm}$ ).

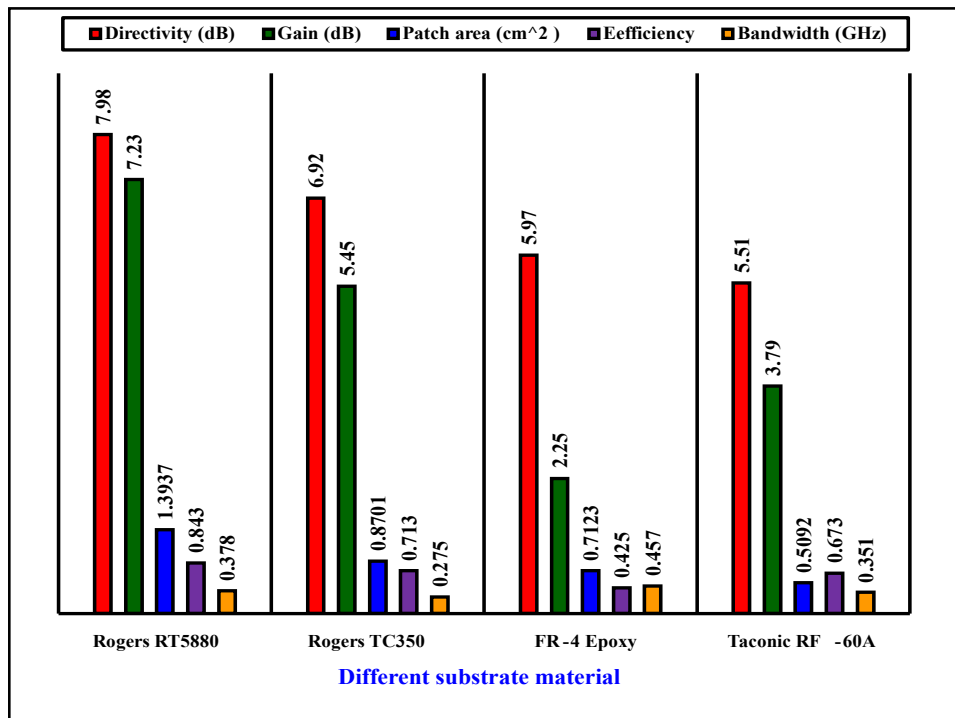


Figure-5: Histogram representation of EMSPA parameter with the use of different substrate relative permittivity of thickness ( $h = 1.2\text{mm}$ ).

Regardless of the patch area, it can be said that the Rogers\_RT5880 generally provides higher EMSPA parameters, while a smaller patch area with suitable radiation performance is commonly achieved with the Taconic\_RF-60A substrate material. Hence, in the next step of this study, these two substrate materials are selected and tested with different substrate thickness to verify which of them and with which thickness they provide adequate higher gain and wider BWs.

### Effect of Substrate Thickness

In this section, the substrate material Rogers\_RT5880 and Taconic\_RF-60A with their thickness allowed varying from (0.2 mm to 1.4 mm) and elliptical patch eccentricity value fixed at ( $e \approx 0.6$ ) is investigated. With the implementation of these design specifications, the ground plane and inset-fed line dimensions as well as elliptical patch radius are computed through the CST simulation techniques and the results are summarized in Table 2. By employing these dimension parameters, the return loss (S11), gain and BW of the EMSPA operating at (9.8 GHz) are computed for both mentioned dielectric substrate materials and the results are displayed in (Figure: 6 and 7), respectively. It is obviously seen from (Figure: 6), that all substrate thickness maintains S11 parameter values less than (-10 dB) for both substrate materials.

Moreover, (Figure: 6-a) displays that the Rogers\_RT5880 substrate with a thickness value of ( $h = 1.0\text{ mm}$  and  $h = 1.4\text{ mm}$ ) gives lower S11 values of the order of (-30 dB), while Taconic\_RF-60A substrate with a thickness value ( $h = 1.0\text{ mm}$ ) gives lower S11 values of the order of (-45 dB) as clearly seen in (Figure: 6-b). In addition, (Figure: 8-a) reveals that a wider BW values of (0.456 GHz) and reliable gain values of (7.28 dB) is achieved with substrate thickness ( $h = 1.4\text{ mm}$ ) for Rogers\_RT5880 substrate, while moderate BW values of (0.369 GHz) and suitable gain of (4.12 dB) are obtained with Taconic\_RF-60A substrate of thickness ( $h = 1.0\text{ mm}$ ). Therefore, in the next step of our investigation, these two reliable substrate thickness for corresponding substrate materials are considered for the verification of the influence of elliptical patch eccentricity values on the overall EMSPA radiation performance.

Table-2: Dimension parameters of designed EMSPA operating at (9.8 GHz) with the use of Rogers\_RT5880 and Taconic\_RF-60A substrate with different substrate thickness and fixed Copper patch thickness ( $t_p = 0.035 \mu\text{m}$ ).

| Ground, fed line and elliptical patch dimensions<br>in (mm) |                | Substrate height (h) in mm |       |       |       |       |       |       |
|---|----------------|----------------------------|-------|-------|-------|-------|-------|-------|
|   |                | 0.2                        | 0.4   | 0.6   | 0.8   | 1     | 1.2   | 1.4   |
| Ground width ( $W_g$ )                                      | Rogers_RT5880  | 28                         | 28.6  | 29    | 29.97 | 29.97 | 30    | 30.04 |
|   | Taconic_RF-60A | 14                         | 14.5  | 15    | 15    | 15.2  | 15.5  | 16    |
| Ground length ( $L_g$ )                                     | Rogers_RT5880  | 20                         | 21    | 22    | 23.6  | 23.6  | 24.8  | 24.8  |
|   | Taconic_RF-60A | 10                         | 10.5  | 11    | 11    | 11.2  | 11.5  | 12    |
| Feed line Gap ( $G_{pf}$ )                                  | Rogers_RT5880  | 0.3                        | 0.4   | 0.55  | 0.7   | 0.7   | 0.75  | 0.8   |
|   | Taconic_RF-60A | 0.29                       | 0.4   | 0.45  | 0.5   | 0.7   | 0.75  | 0.95  |
| Feed line Length ( $F_l$ )                                  | Rogers_RT5880  | 4.18                       | 4.08  | 3.98  | 3.88  | 3.76  | 3.64  | 3.5   |
|   | Taconic_RF-60A | 2.72                       | 2.68  | 2.62  | 2.54  | 2.48  | 2.38  | 2.30  |
| Feed line width ( $w_f$ )                                   | Rogers_RT5880  | 0.62                       | 1.3   | 1.89  | 2.46  | 3.081 | 3.7   | 4.33  |
|   | Taconic_RF-60A | 0.32                       | 0.57  | 1.1   | 1.3   | 1.5   | 1.8   | 1.95  |
| major radius (a)  | Rogers_RT5880  | 7.35                       | 7.37  | 7.39  | 7.4   | 7.4   | 7.42  | 7.44  |
|   | Taconic_RF-60A | 4.45                       | 4.46  | 4.47  | 4.48  | 4.49  | 4.5   | 4.515 |
| minor radius (b)  | Rogers_RT5880  | 5.922                      | 5.93  | 5.93  | 5.922 | 5.924 | 5.957 | 6.023 |
|   | Taconic_RF-60A | 3.578                      | 3.58  | 3.58  | 3.58  | 3.593 | 3.607 | 3.608 |
| eccentricity (e)  | Rogers_RT5880  | 0.592                      | 0.593 | 0.596 | 0.599 | 0.599 | 0.596 | 0.587 |
|   | Taconic_RF-60A | 0.594                      | 0.596 | 0.598 | 0.598 | 0.599 | 0.597 | 0.601 |

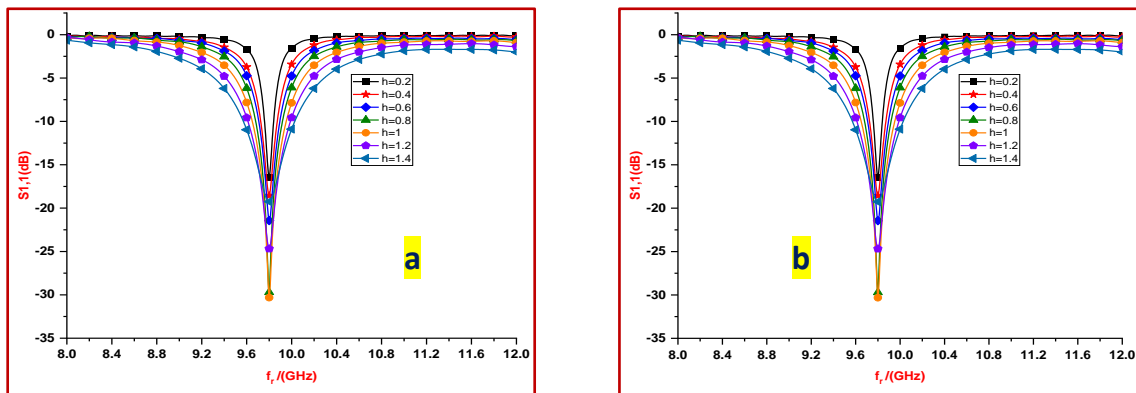


Figure-6: Variation of S11 for EMSPA as a function of frequency for substrate relative permittivity (a). ( $\epsilon_r = 2.2$ ) and (b). ( $\epsilon_r = 6.15$ ) with different substrate thickness and elliptical patch eccentricity values of ( $e \approx 0.6$ ).

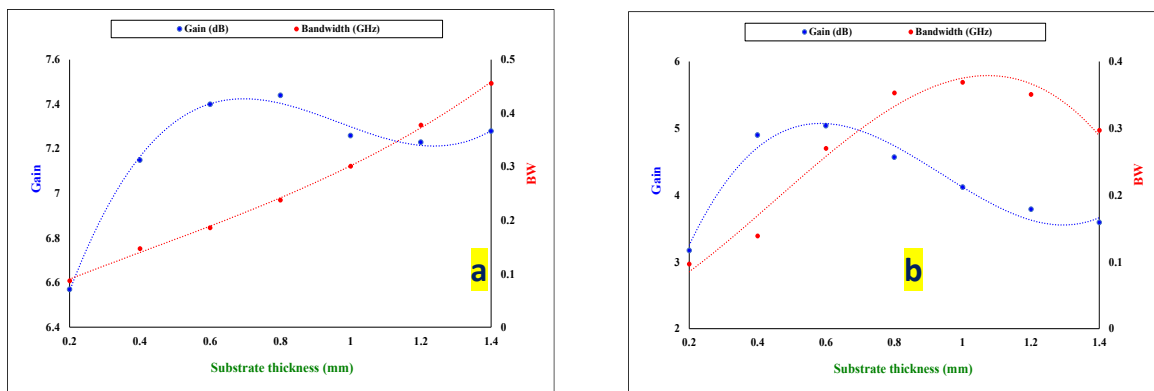


Figure-7: Variation of EMSPA gain and BW as a function of substrate thickness with substrate relative permittivity (a). ( $\epsilon_r = 2.2$ ) and (b). ( $\epsilon_r = 6.15$ ) and elliptical patch eccentricity values of ( $e \approx 0.6$ ).

Effect of Ellipse Eccentricity

In this section, the Rogers\_RT5880 dielectric material of thickness ( $h = 1.4$  mm) and Taconic\_Rf-60A substrate material with thickness ( $h = 1.0$  mm) are used and four different elliptical patch eccentricity values are tested. The calculation of the elliptical patch major and minor axis as well as ground plane and fed line dimensions for both mentioned substrates with their considered thickness is evaluated using CST methods and the results are presented in Table 3. With the implementations of these dimension parameters, the S11, gain and BW for both mentioned substrates are computed and the results are presented in (Figures: 8 and 9), respectively. Figures: 8, reveals generally that all considered eccentricities provide (S11) values less than (-10 dB) and among which the elliptical patch eccentricity values of ( $e = 0.5$ ) for Taconic\_Rf-60A and ( $e = 0.7$ ) for Rogers\_RT5880 substrate maintains lowest (S11) values of the order of (-40 dB) and (-52 dB), respectively.

Table-3: Dimension parameters of designed EMSPA operating at (9.8 GHz) with the use of Rogers\_RT5880 and Taconic\_RF-60A substrate with different elliptical patch eccentricity and fixed Copper patch thickness ( $t_p = 0.035 \mu\text{m}$ ).

| Ground, fed line and elliptical patch dimensions in (mm) |                | Ellipse eccentricity values ( $e$ ) |             |             |             |
|--|----------------|-------------------------------------|-------------|-------------|-------------|
|  |                | $e_1 = 0.3$                         | $e_2 = 0.5$ | $e_3 = 0.7$ | $e_4 = 0.9$ |
| Ground width ( $W_g$ )                                   | Rogers_RT5880  | 26                                  | 29.04       | 32          | 34          |
|  | Taconic_RF-60A | 13                                  | 14.2        | 17          | 21          |
| Ground length ( $L_g$ )                                  | Rogers_RT5880  | 21.8                                | 23.8        | 25          | 26          |
|  | Taconic_RF-60A | 9                                   | 10.2        | 14          | 16          |
| Feed line Gap ( $G_{pf}$ )                               | Rogers_RT5880  | 0.8                                 | 0.8         | 0.8         | 0.8         |
|  | Taconic_RF-60A | 0.7                                 | 0.7         | 0.7         | 0.7         |
| Feed line length ( $F_i$ )                               | Rogers_RT5880  | 4                                   | 3.6         | 2.9         | 2.1         |
|  | Taconic_RF-60A | 2.88                                | 2.58        | 2.38        | 2.08        |
| Feed line width ( $w_f$ )                                | Rogers_RT5880  | 4.33                                | 4.33        | 4.33        | 4.33        |
|  | Taconic_RF-60A | 1.5                                 | 1.5         | 1.5         | 1.5         |
| Elliptical major radius ( $a$ )                          | Rogers_RT5880  | 6.588                               | 7.126       | 8.5         | 9.3         |
|  | Taconic_RF-60A | 3.94                                | 4.26        | 4.82        | 5.67        |
| Elliptical minor radius ( $b$ )                          | Rogers_RT5880  | 6.24                                | 6.1185      | 5.785       | 5.648       |
|  | Taconic_RF-60A | 3.718                               | 3.64        | 3.512       | 3.28        |

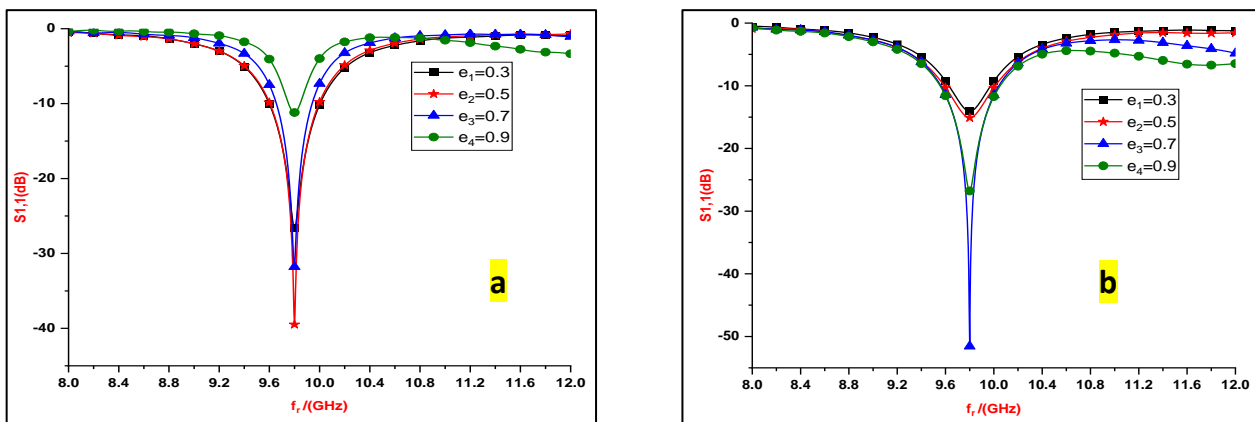


Figure-8: Variation of S11 for EMSPA as a function of frequency with different elliptical patch eccentricity for substrate relative permittivity (a). ( $\epsilon_r = 2.2$ ,  $h = 1.4$  mm) and (b). ( $\epsilon_r = 6.15$ ,  $h = 1.0$  mm).

Moreover, the computation of EMSPA BW and gain also indicate that a wider BW with reliable gain values is generally obtained with ( $e = 0.5$ ) for Taconic\_Rf-60A and ( $e = 0.7$ ) for Rogers-RT5880 substrate as clearly observed in (Figures: 9).

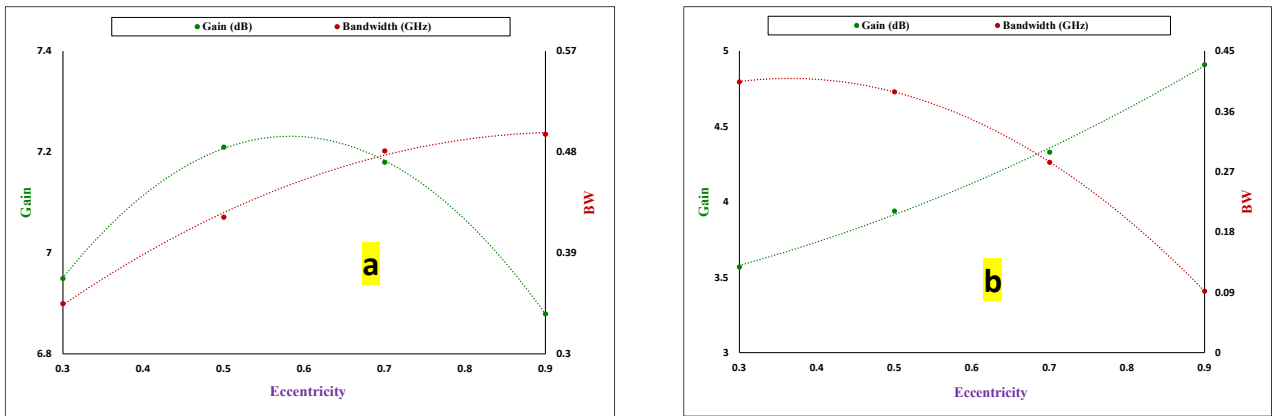


Figure-9: Variation of EMSPA gain and BW as a function of elliptical patch eccentricity with substrate relative permittivity (a). ( $\epsilon_r = 2.2$  ,  $h = 1.4$  mm) and (b). ( $\epsilon_r = 6.15$  ,  $h = 1.0$  mm).

Therefore, it can be said generally that the elliptical patch eccentricity values of ( $e = 0.7$ ) for Rogers-RT5880 and ( $e = 0.5$ ) for Taconic\_Rf-60A substrate maintained overall higher antenna radiation performance. Accordingly, the final fundamental EMSPA parameters with the implementation of the observed optimum substrate material types with their corresponding substrate thickness and reliable elliptical patch eccentricity values are simulated with CST and the results are summarized in Table 4. Besides, the 2D-view E-plane and 3D-view power flow radiation pattern for both Rogers\_RT5880 and Taconic-Rf-60A substrates with their optimized substrate thickness and elliptical patch eccentricity values are shown in (Figures: 10 and 11), respectively. These figures display that the Rogers\_RT5880 substrate provide higher power density values compared to Taconic-Rf-60A ones due to its larger patch occupation areas.

Table-4: Final EMSPA parameters operating at (9.8 GHz) with dielectric substrates Rogers\_RT5880 and Taconic\_RF-60A of relative permittivity and thickness ( $\epsilon_r = 2.2$  ,  $h = 1.4$  mm) and ( $\epsilon_r = 6.15$  ,  $h = 1.0$  mm).

| Patch and fed line Characteristics in (mm) | Unit of measurement (mm) |                | Antenna Parameters            | Rogers_RT5880 | Taconic_RF-60A |
|--|--------------------------|----------------|-------------------------------|---------------|----------------|
|  | Rogers_RT5880            | Taconic_RF-60A |                               |               |                |
| Ground width ( $W_g$ )                     | 32                       | 14.2           | ( $f_r$ ) GHz                 | 9.8           | 9.8            |
| Ground length ( $L_g$ )                    | 25                       | 10.2           | BW (GHz)                      | 0.480         | 0.389          |
| Feed line Gap ( $G_{pf}$ )                 | 0.8                      | 0.7            | Gain (dB)                     | 7.18          | 3.94           |
| Feed line length ( $F_i$ )                 | 2.9                      | 2.58           | Efficiency (%)                | 85.9          | 71.6           |
| Feed line width ( $w_f$ )                  | 4.33                     | 1.5            | Directivity (dB)              | 7.84          | 5.39           |
| major radius ( $a$ )                       | 8.5                      | 4.26           | VSWR (dB)                     | 1.005         | 1.021          |
| minor radius ( $b$ )                       | 5.785                    | 3.64           | S11 (dB)                      | -51.55        | -39.48         |
| eccentricity ( $e$ )                       | 0.7                      | 0.5            | Patch area (mm <sup>2</sup> ) | 154.47        | 48.71          |

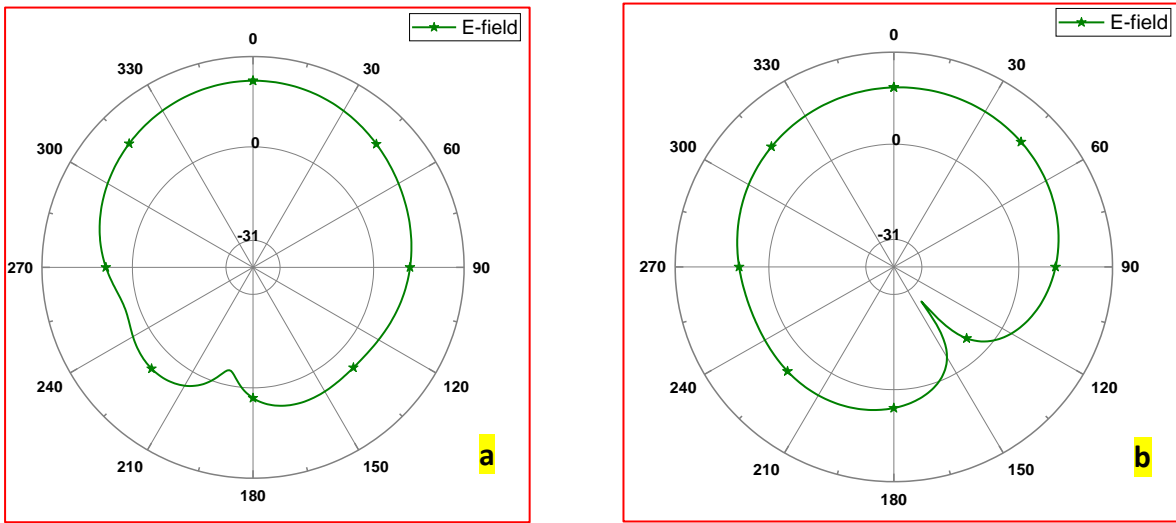


Figure-10: 2D-view of E-plane polar pattern of EMSPA with substrate (a). Rogers-RT5880 ( $e = 0.7, \epsilon_r = 2.2, h = 1.4$  and  $\delta = 0.0009$ ) and (b). Taconic-RF-60A ( $e = 0.7, \epsilon_r = 2.2, h = 1.4$  and  $\delta = 0.0009$ ).

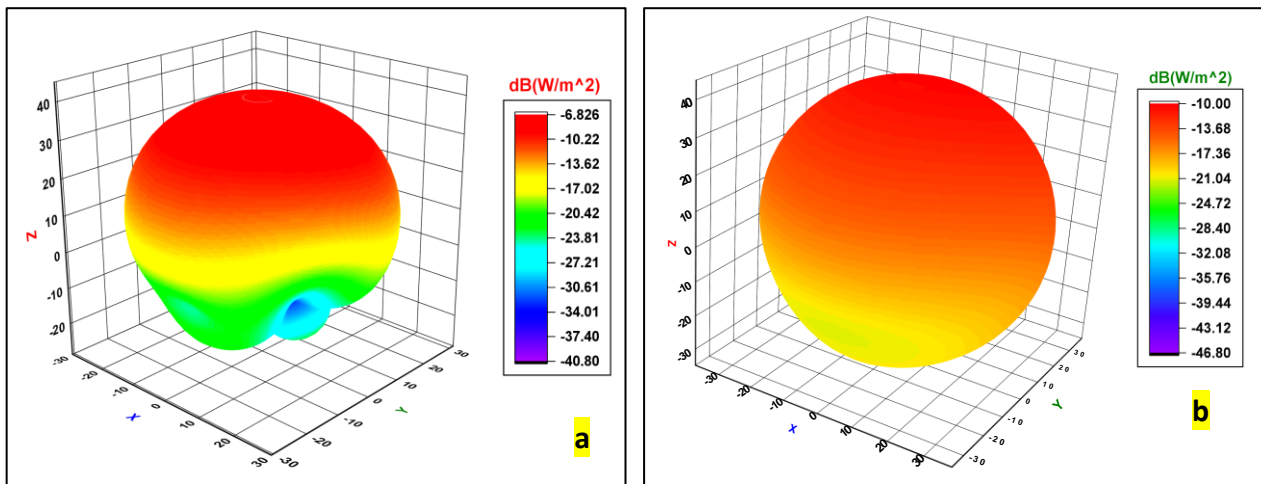


Figure-11: 3D-view of power flow polar pattern of EMSPA with substrate (a). Rogers-RT5880 ( $e = 0.7, \epsilon_r = 2.2, h = 1.4$  and  $\delta = 0.0009$ ) and (b). Taconic-RF-60A ( $e = 0.7, \epsilon_r = 2.2, h = 1.4$  and  $\delta = 0.0009$ ).

Finally, a good agreement between the overall computed EMSPA parameters for both considered substrate materials are observed as compared to the available corresponding values obtained by other research works on different patch shapes and operating at the same frequency bands as seen in Table 5. Furthermore, the progress achievement made in this work lies in the design analysis of elliptical microstrip patch shapes, which has not been previously studied in this detail especially in terms of patch and substrate dimension optimization for application in radar or other wireless communication systems.

Table-5: Comparison between computed EMSPA parameters with those previously obtained by other researcher of various patch shapes operating at X-band frequencies.

| Antenna characteristic        | Present Work |           | References |           |           |           |           |           |           |
|-------------------------------|--------------|-----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|
|                               |              |           | [26]       | [16]      | [1]       | [3]       | [22]      | [23]      | [13]      |
| Simulation method             | CST          | CST       | CST        | HFSS      | CST       | HFSS      | CST       | HFSS      | HFSS      |
| Feed technique                | Inset fed    | Inset fed | Edge fed   | Inset fed | Inset-fed | Inset fed | Inset fed | Inset fed | Inset fed |
| $f_r$ (GHz)                   | 9.8          | 9.8       | 9.8        | 9.2       | 10.0      | 10.0      | 10.16     | 10.30     | 10.0      |
| Patch shape                   | EMSPA        | EMSP      | EMSPA      | EMSPA     | RMSPA     | RMSPA     | EMSPA     | RMSPA     | RMSPA     |
| Material Type                 | Rogers       | Taconic   | Rogers     | FR-4      | FR-4      | Rogers    | FR-4      | FR-4      | Duroid    |
| Permittivity ( $\epsilon_r$ ) | 2.2          | 6.15      | 4.5        | 4.3       | 4.4       | 3.66      | 4.3       | 4.3       | 2.2       |
| Thickness $h$ (mm)            | 1.4          | 1.0       | 0.6        | 0.8       | 1.6       | 3.1       | 1.6       | 2.5       | 1.588     |
| Return loss (S11)             | -51.55       | -39.48    | -24.308    | -20.753   | -31.00    | -19.61    | -38.80    | -29.21    | -29       |
| BW (MHz)                      | 480          | 389       | 337.9      | 797       | 500       | 226.2     | NA        | NA        | 600       |
| Efficiency (%)                | 85.9         | 71.6      | 99.93      | 95.9      | 73.8      | 94.2      | 73.76     | NA        | 98.02     |
| VSWR (dB)                     | 1.005        | 1.021     | 1.129      | 1.204     | 1.01      | 1.82      | NA        | 1.1       | 1.02      |
| Gain (dB)                     | 7.18         | 3.94      | 6.607      | 4.0       | 4.60      | 6.58      | 4.208     | 5.01      | 7.55      |
| Directivity (dB)              | 7.84         | 5.39      | 6.610      | 4.17      | 6.23      | 6.83      | 5.706     | NA        | 7.70      |

### Conclusions

According to the results obtained in the analysis design of EMSPA operating at X-band frequencies, it has been found that the substrate material types with its thickness and elliptical patch eccentricity has a significant influence on the overall proposed EMSPA antenna radiation performances. The computed parameters generally have indicated that a higher radiation performance with larger patch area of the order of (154.47 mm<sup>2</sup>) was achieved with the Rogers\_RT5880 substrate material ( $\epsilon_r = 2.2$ ) of thickness (1.4 mm) and elliptical patch eccentricity values of (0.7). While, a small patch area of the order of (48.71 mm<sup>2</sup>) with a reliable EMSPA parameter reasonable for radar application system was maintained with the Taconic\_RF-60A substrate material ( $\epsilon_r = 6.15$ ) of thickness (1.0 mm) and patch eccentricities of (0.5). With these specifications of the substrate material with their corresponding thickness and patch eccentricities, the designed EMSPA operated with a gain (3.94 dB, 7.18 dB), BW (389 MHz, 489 MHz), efficiency (71.6%, 85.9%), directivity (5.39 dB, 7.84 dB) and S11 (-39.48 dB, -51.55 dB) for Taconic\_RF-60A and Rogers\_RT5880 substrate, respectively. Moreover, a good agreement between simulated results and those previously obtained by other researchers on different patch shapes operating at the same frequency bands were also observed. Finally, further improvement could be done by fabricating EMSPA with the designed specification achieved in this work and comparing the measurement with the computed antenna parameter results.

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