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Performance Analysis of Line Feeding Microstrip Patch Antenna Using Different Layers of Substrate Materials for Terahertz (THz) Applications

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Abstract:*A rectangular shape microstrip patch antenna with different layers of substrate are proposed in this paper to show how the performances are changed for Terahertz (THz) applications by using different layers. The silicon dioxide as single layer, roger RT/duroid 5880(tm) and silicon dioxide as double layers, roger RT/duroid 5880(tm), silicon dioxide and FR4_epoxy as triple layers are used whose dielectric constant are 2.2, 4.0 and 4.4 respectively. But all times the height is same. A comparative report is created among the layers. Among them, triple layer gets the better performances. The return loss, bandwidth, gain, directivity and Voltage Standing Wave Ratio (VSWR) of the triple layers are -24.34 dB, 1.82 THz, 5.88 dB, 6.309 dB and 1.05 dB respectively. This triple layer antenna is resonated at 12.98 THz which can be used for biomedical applications.*

Keywords:*Single, double, triple layer substrate, return loss, bandwidth, gain, directivity, efficiency, ansoft HFSS.*

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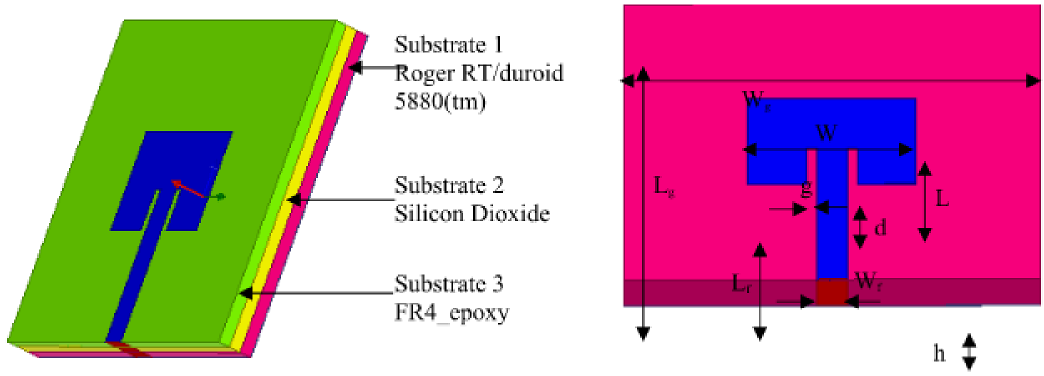
I. Introduction

Microstrip patch antenna that consists of a metallic patch on the grounded substrate first proposed by Deschamps in the early 1953 and serious attention was given from 1970 [1]. Day by day with the development of wireless communications, microstrip patch antenna are gradually applied in many communication devices for their tremendous advantages such as low profile, small size, low fabrication cost [2]. In the recent year, microstrip patch antenna is used as terahertz (THz) applications. Terahertz creates the electromagnetic spectrum in micrometer wavelength instead of millimeter wavelength. This band of electromagnetic spectrum are used in various applications [3,4]. Specially screening of weapons, explosives and bio hazards, imaging, sensing and spectroscopy are the unique applications of terahertz [5]. In paper [6], for the detection of plastic explosive semtex, terahertz microstrip patch antenna is proposed with FR4 substrate material whose resonance frequency, return loss and gain are 4.32 THz, -52.10 dB and 5.88 dB respectively. In [7], polyimide substrate material is used for terahertz applications whose resonance frequency, return loss, bandwidth, gain and directivity are 0.75 THz, -35.00 dB, 6.67%, 5.09 dB and 5.71 dB respectively. The dielectric constant of 3.2 is used for microwave to terahertz properties in [8] whose resonance frequency and return loss are 12.00 THz and -18.50 dB. The terahertz radiation is controlled by using tunable metamaterials presented in [9] and for terahertz optoelectronics, the details overview of graphene is discussed in [10]. The matematerial loop antenna is proposed to enhance the performances of the antenna whose gain is 5.71 dB [11]. A rectangular patch antenna with fishnet based matematerial is presented in [12] whose gain and bandwidth are 3.57 dB and 8.2%. The artificial magnetic conductor and finite ground plane structure with bowtic-shaped antenna is designed in [13] to enhance the directivity. Two segment labyrinth metamaterial for THz is used to bandwidth enhancement in [14] whose resonance frequency, return loss and bandwidth are 9.55 THz, -14.115 dB and 12.3% respectively. The single layer with silicon dioxide substrate material is used in [15] to enhance the performances of microstrip patch antenna whose resonance frequency, return loss, gain, directivity and bandwidth are 13.00 THz, -27.57 dB, 5.30 dB, 5.32 dB and 12.3% respectively.

In this paper, a rectangular shape line feeding microstrip patch antenna with different substrate layers that means single, double and triple layers with same height are gradually used to show the performances of different types of layers.

II. Antenna Design Procedure And Dimensions

The overall geometry of the proposed antenna are shown in Fig.1. Three substrate layers are shown in Fig. 1(a). The all dimensions of the proposed antenna are shown in Fig. 1(b) where W×L is the width and length of patch and $W_g \times L_g$ is the width and length of ground and substrate.



(a) (b)

Fig.1 : Geometry and dimension of proposed antenna (a) three substrate layer (b) overall dimensions

The substrate height is h and ground & patch height is t. Now if f_r is the frequency and ε_r is the dielectric constant of the antenna, then the width (w) of rectangular patch is [5]

$$w = \frac{C}{2 f_r} \times \sqrt{\frac{2}{\varepsilon_r + 1}} \text{---------------(1)}$$

Where, C is the velocity of light.

If ε_{eff} is the effective dielectric constant of that substrate material [5] then

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{w}}} \text{-------(2)}$$

Where, h is the height of that substrate material, ε_r is dielectric constant of desired substrate material and W is the width of the rectangular patch.

L_{eff} is the effective length of the patch [5] then

$$L_{eff} = \frac{C}{2 f_r \sqrt{\varepsilon_{eff}}} \text{----------------------(3)}$$

The length extension of the patch is calculated by the equation [5]

$$\Delta L = 0.412h \frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \text{------(4)}$$

The actual length (L) of rectangular patch is [5]

$$L = L_{eff} - 2\,\Delta L \text{-----------------------(5)}$$

The width (W_g) and length(L_g) of the ground dimensions are [5]

$$W_g = 6h + w \text{----------------------------(6)}$$
$$L_g = 6h + L \text{----------------------------(7)}$$

Here silicon dioxide is used as single layer, roger RT/duroid 5880 (tm) and silicon dioxide as double layer & roger RT/duroid 5880 (tm), silicon dioxide and FR4_epoxy as triple layer whose dielectric constant are 2.2, 4.0 and 4.4 respectively. Always the height is same that means when single layer is used then substrate height is h, when double layer then one half of h is used as roger RT/duroid 5880 (tm) and another half is for silicon dioxide & when triple layer, roger RT/duroid 5880 (tm), silicon dioxide and FR4_epoxy all are used one third of h. The HFSS software is used to design the antenna.

Now the overall dimensions of the proposed antenna are shown in Table I.

Table I: Optimized Dimensions of Proposed Antenna

f_r 13 THz	**W** 7.2 µm	**L** 4.8 µm	**W_g** 18.09 µm	**L_g** 15.6 µm	**h** 1.8 µm
t 0.01 µm	**W_f** 1.3 µm	**L_f** 10.8 µm	**g** 0.45 µm	**d** 2.0 µm	

III. Results And Discussion

The performances of single, double and triple layers of substrate material with same height that means resonance frequency, return loss, bandwidth, gain directivity and VSWR have been given below —

A. Return loss and Bandwidth:

The return losses plot of single, double and triple layer are shown in Fig.2 and Table II. From the graph and Table it is seen that the return losses of single, double and triple layers are -22.44 dB, -21.85 dB and -24.34 dB with their resonance frequency at 13.75 THz, 13.41 THz and 12.98 THz respectively and the bandwidth of single, double and triple layers are 1.53 (12.96-14.49) THz, 1.64 (12.57-14.21) THz and 1.82 (12.08-13.9) THz. From the graph and Table it is also observed that the triple layer substrate material gets the lower return loss and greater bandwidth and its resonance peak is close to the 13 THz.

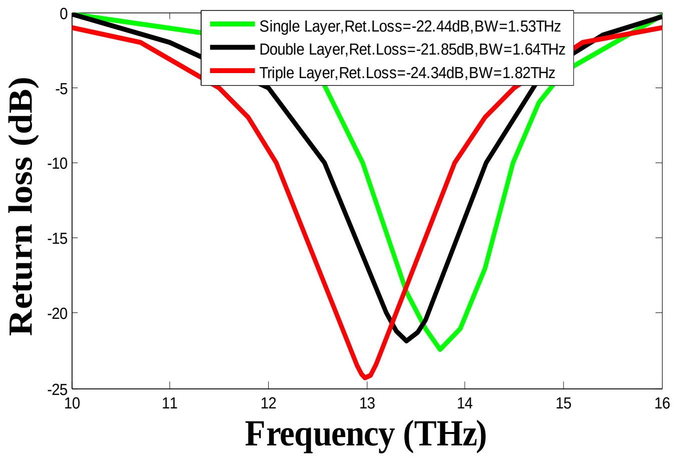


Fig: 2: Return losses of single, double and triple layer substrate

B. Voltage Standing Wave Ratio (VSWR):

The VSWR of single, double and triple layers are shown in Fig. 3 and Table II. From the graph and Table it is shown that the VSWR of single, double and triple layers are 1.31 dB, 1.4 dB and 1.05 dB respectively. It is also observe that the triple layer gets the lower VSWR.

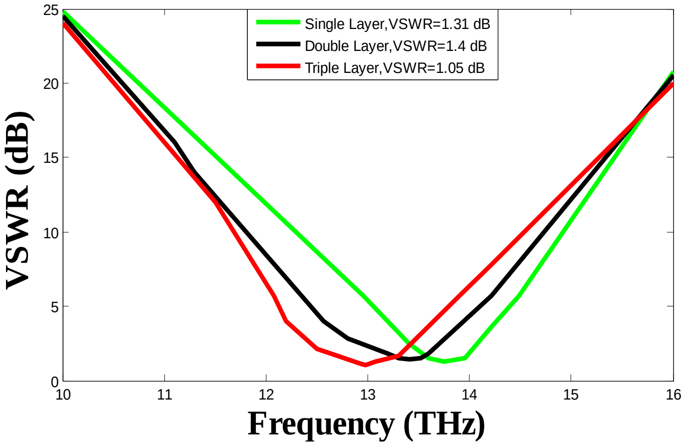
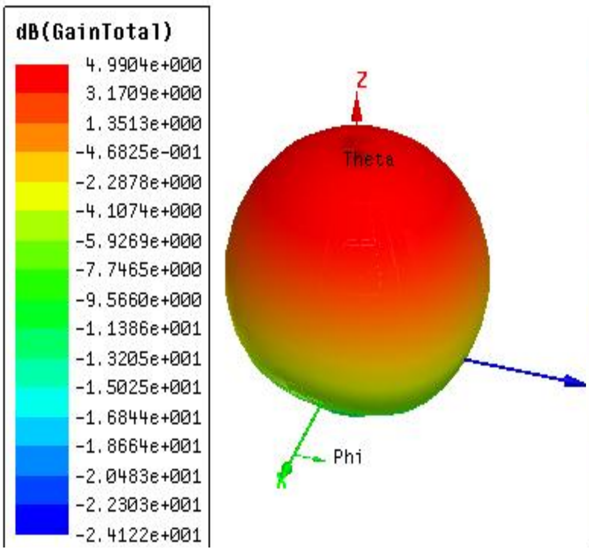


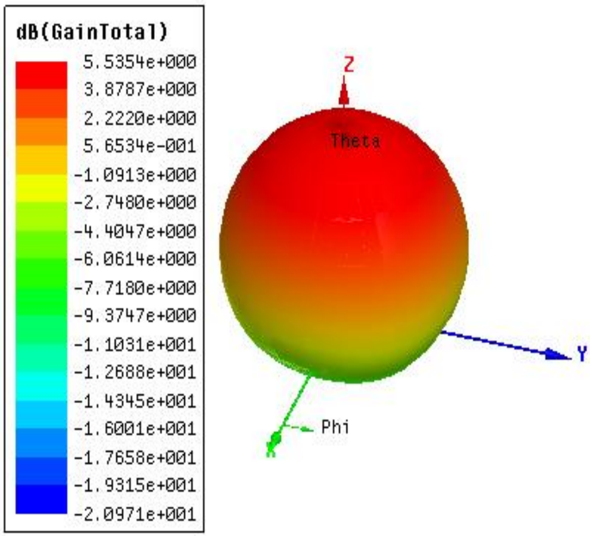
Fig: 3: VSWR of single, double and triple layer substrate

C. Gain:

The gain of single, double and triple layers are shown in Fig. 4 and Table II. It is seen that the gain of single, double and triple layers are 4.99 dB, 5.53 dB and 5.88 dB respectively. It is also observed that the triple layer gets the greater gain.



(a)



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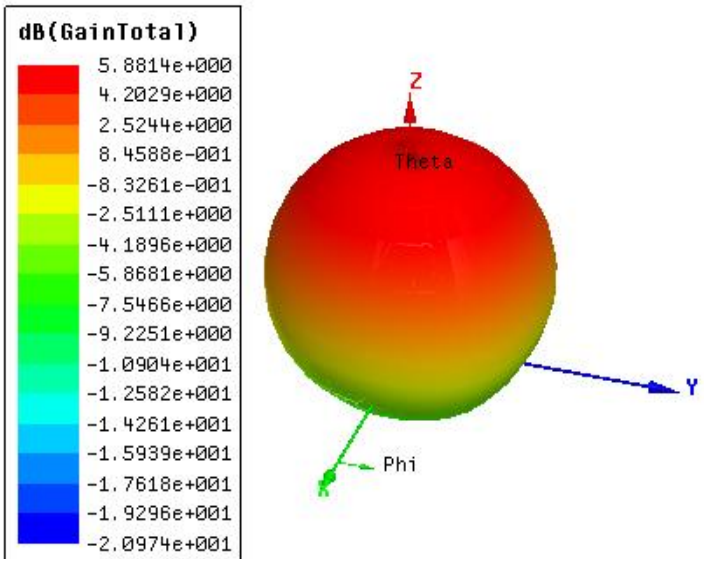
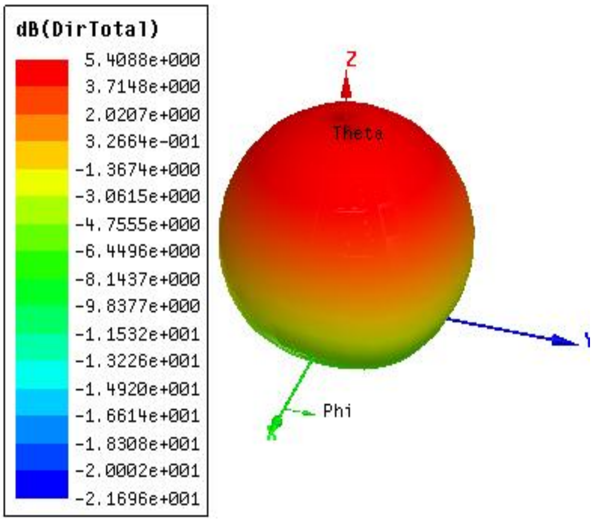


(c)

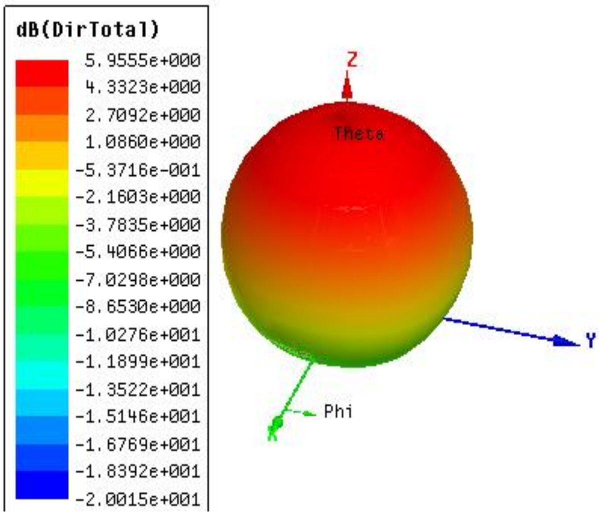
Fig.4: Gain of (a) single, (b) double, (c) triple layer

D. Directivity:

The directivity of single, double and triple layers are shown in Fig. 5 and Table II. It is seen that the directivity of single, double and triple layers are 5.408 dB, 5.95 dB and 6.309 dB respectively. It is also observed that the triple layer gets the greater directivity.



(a)



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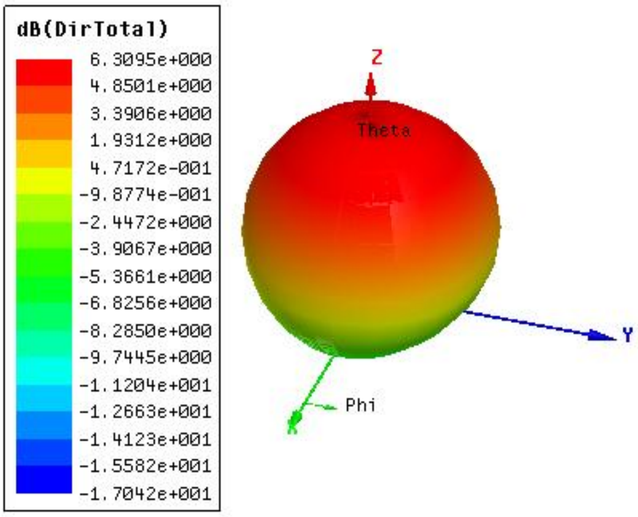
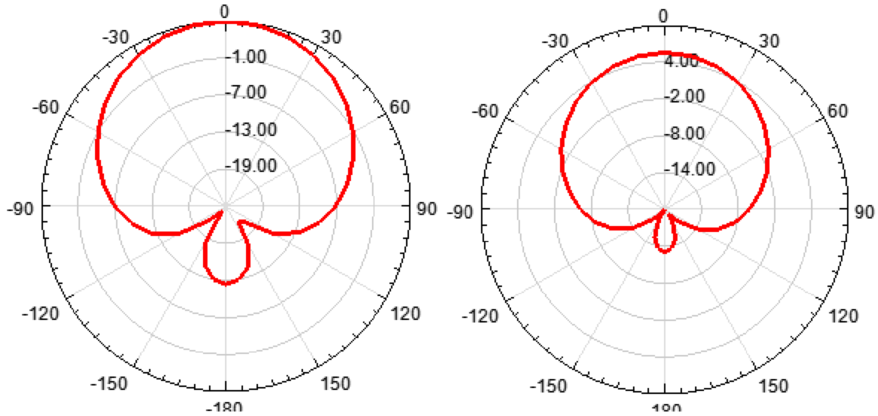


(c)

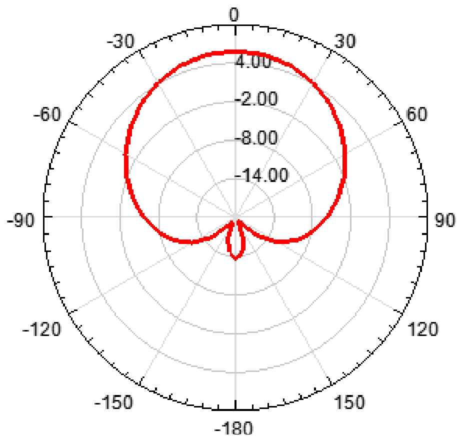
Fig.5: Directivity of (a) single, (b) double, (c) triple layer

E. Radiation Pattern:

The 2D radiation pattern of single, double and triple layers of substrate material have been given in Fig 6.



(a) (b)



(c)

Fig. 6: Radiation pattern of (a) single, (b) double, (c) triple layer

A comparative report among the single, double and triple layer substrate material with line feeding microstrip patch antenna are summarized in TABLE II.

Table II: Comparative Results

Parameters	Single layer	Double layer	Triple layer	comments
Resonance peak (THz)	13.75	13.41	12.98	Triple layer's freq. is close to 13 THz.
Return loss (dB)	-22.44	-21.85	-24.34	Triple layer is better.
Bandwidth (THz)	1.53	1.64	1.82	Triple layer is better.
Gain (dB)	4.99	5.53	5.88	Triple layer is better.
Directivity (dB)	5.408	5.95	6.309	Triple layer is better.
VSWR (dB)	1.31	1.4	1.05	Triple layer is better.
Efficiency	92.2%	92.9%	93.2%	Triple layer is better.

IV. Conclusion

Rectangular shape line feeding microstrip patch antenna with different layers that means single, double and triple layers are proposed in this paper. The antenna is designed for THz application at resonance frequency 13 THz. Among the layers, the triple layers gets the better performances that is resonated at 12.98 THz. This proposed antenna achieves a better bandwidth, gain and directivity of 1.82 THz, 5.88 dB and 6.309 dB respectively compared with the similar single layer antenna [15] in Table III. This antenna can be used as biomedical applications.

Table III: Comparison of proposed and similar single layer [15] antenna

Parameters	Ref. [15]	Proposed (Triple layer)
Resonance peak (THz)	13.00	12.98
Return loss (dB)	-27.57	-24.34
Bandwidth (THz)	1.63	1.82
Gain (dB)	5.30	5.88
Directivity (dB)	5.32	6.309

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