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High Gain Terahertz Antenna on Flexible Substrate

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Abstract: In this work, a high gain compact planar antenna array is proposed for Terahertz (THz) application. Proposed architecture is designed on Liquid Crystal Polymer (LCP), a flexible type substrate to make the structure conformal in shape. Parasitic coupling topology has been adopted to achieve high-gain of around 19.2 dBi on the planar configuration for 100 GHz application, suitable for several medical imaging purposes. The proposed antenna is fabricated using standard PCB industry and would be experimentally investigated for impedance and radiation pattern measurements thereafter. The work concludes with the electrical modeling of the antenna array structure.

Keywords: THz antenna, flexible substrate.

1. Introduction

Terahertz communication, of late, is finding unprecedented wide-spread applications in several pure and applied science fields and has been touted as one most promising technologies for next generation short-range communications and associated applications. In spite of fundamental limitations of extremely high propagation loss in the medium, because of several appealing features and characteristics, such as, huge bandwidth, high speed data transfer, no problem of electromagnetic interference, THz technology is getting increasingly popular amongst EM researchers in general. Particularly, in case of healthcare section, ‘non-ionizing’ radiation of THz beam becomes a key feature for medical imaging of several part(s) of human body[1].THz technology offers very clear imaging solution for medical diagnosis without causing any harm to the human organs[2].

Medical imaging demands suitable miniaturized antennas with high-gain and super-wideband characteristics, preferably fabricated on a non-toxic substrate[3]. Liquid Crystal Polymer (LCP) is a suitable substrate for such applications. In addition, extra feature of 'flexibility' of the LCP substrate make it an attractive choice for realizing conformal antennas for biomedical applications[4].

Present article proposes design and realization of a parasitic-element embedded THz rectangular microstrip antenna array (T-RMAA) with very gain on 4-mil thick LCP substrate for 100-GHz application. High peak gain of around 19.2 dBi has been achieved with the planar configuration having 5-elements connected in cascade configuration with series feeding. Each of these 5-elements excites two parasitic patches placed on both sides of the non-radiating edges of the primary patch.

2. The Thz antenna

2.1 Design: Proposed THz rectangular microstrip antenna array (T-RMAA) comprises series-fed five patch elements, each having length L and width W and loaded with parasitic patch elements of length and width L and W_p on both sides of non radiating edges of the five elements. Figure 1 shows the schematic of the proposed antenna. Width W and length L of the patch having resonating frequency f_r, are evaluated using[5] (2.1) and (2.2) and given by

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{1+\varepsilon_r}}, \tag{2.1}$$

$$L = \frac{c}{2\sqrt{\varepsilon_{eff}}\, f_r} - 2\Delta L, \tag{2.2}$$

where ε_{eff} is effective dielectric constant and ΔL is extended length on both sides of the radiating patch due to the fringing field[5]. Segments of the transmission-line in between the patches are responsible for phase matching. The dimension of these transmission lines i.e. length l_{t_1} and l_{t_2}

and width W_{t_1} are computed from[6]. Proposed antenna is designed on flexible LCP substrate ($\varepsilon_r = 2.9$, $\tan\delta = 0.002$) of 4 mil thickness.

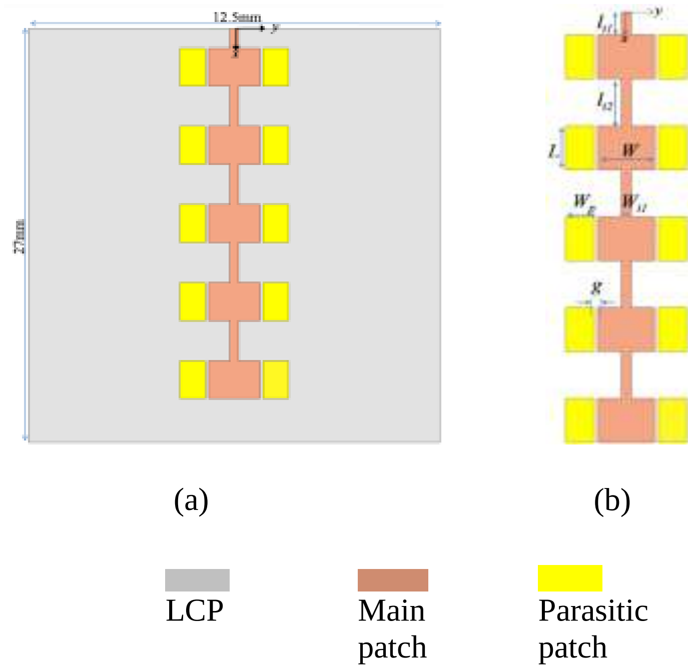
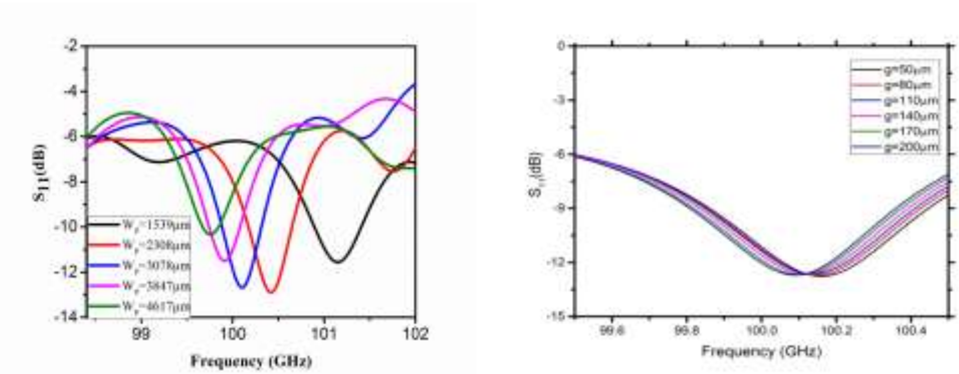


Figure 1. (a) Top view and (b) dimension of the proposed antenna

The choice of resonating frequency f_r determines the dimensions of patch and here whole design exercise is accomplished for the centre frequency of $f_r = 100$ GHz. Rabbani et al.[7] reported basic configuration for several THz-bands, but the gain of the antenna was limited to 15 dBi. Reference[8,9] has enhanced gain with help superstrate effect but it is non planar structure. However the present design maintains simplicity, flexibility and exhibits much increased gain of 19.2 dBi.

2.2 Implementation of Parasitic Patches: Implementing parasitic patches at the non-radiating edges of main patch array effectively enhances the aperture size of the array structure which in turn increases the gain of antenna. Introduction of these patches inherently alters the capacitive loading phenomenon. The gap between the main antenna and parasitic patch decides the amount of field coupling. To ensure strong coupling and optimal excitation of the parasitic patch element, its gap g from the main radiating element should be as less as possible[10]. Systematic parametric studies have been carried out to get an optimum value of gap g and width of parasitic patch W_p, and is indicated in the S_{11} plot of Fig.2. As can be noted from the plot of Fig. 2(a), for a gap dimension of 50 to 100µm, there is hardly any difference in resonant frequency, but a slight change is observed in refection coefficient curve. Actually flux linkage phenomenon is not captured clearly with the results. But, when the width of parasitic patches W_p changes, it changes the impedance of antenna and current vector also. The dimension of all design parameters have been optimized and summarized in Table-1.



(a) (b)

Figure 2. (a) S-parameter for gap ‘*g*’ (b) S-parameter for width ‘w_p

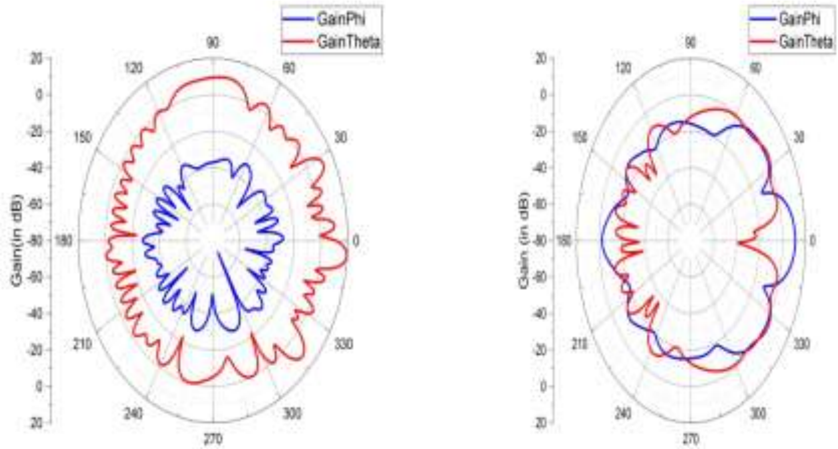
3. Simulated Results

Simulated far field radiation pattern of the antenna is shown in Fig.4. H -plane indicates the broad side profile at the broadside direction and X -polarization level is 38dB below than Co-polarization. E -plane pattern is like a flower with multi-shape petals. Peak simulated gain is obtained as 19.2dB.

Table 1 Optimized dimensions of T-RMAA

Variables	**Without parasitic elements (µm)**	**With parasitic elements (µm)**
L	2489	2489
W	3078	3078
l_{t1}	1293	1293
l_{t2}	2685	2685
w_{t1}	690	500
w_p	-	1539
g	-	200
h	100	100

The bandwidth of antenna considering S_{11} below -10dB was observed as 400MHz. By varying length of parasitic patches slightly from main patch length L will responsible for different resonating frequencies around 100GHz and thus bandwidth of whole antenna structure can be increased.



(a) (b)

Figure 3. Far field radiation pattern (a) E-plane (b) H-plane plots

4. Equivalent Circuit

Equivalent circuit model is used for representing the antenna impedance. This helps in extracting features of the antenna. A RLC resonator model has been widely used in modeling antenna impedance. Similar model is attempted here. The proposed array structure consist of five main radiating elements, transmission line segments in between them, ten number of parasitic patches and feed line as shown in Fig.4. Main radiating elements are represented by lossy tank circuit (L_{10}, R_{10} and C_{10}) corresponding to TM_{10} mode. Feeding network is represented by series combination of L_f and R_f due to finite conductivity of metal used. Parasitic patches are nothing but capacitive or dielectric loading depending upon substrate electrical properties. Hence, it can be modeled as leaky capacitor. Transmission line segments between the patches are represented by combination of lossy inductor and capacitor, corresponding to the parasitic capacitance effects. This lumped circuit is simulated in ADS and tuned to 100GHz. The obtained lumped components values are listed in

Table 2. The S_{11} parameter from lumped circuit and T-RMMA structure is shown in Fig.5.

Table 2 Lumped components values for simulated Equivalent Model

Variables	**Values**	**Variables**	**Values**
R_f	0.01Ω	R_f	161.12Ω
L_f	$54pH$	C_{gi}	$16.45pF$
L_{10}^i	$4.28pH$	C_p^i	$16.45pF$
R_{10}^i	44Ω	R_{ij}	55.56Ω
C_{10}^i	$0.591pF$	R_{pi}	161.12Ω
C_{qi}^i	$16.45pF$	L_{ij}	$1100pH$
C_{pi}^i	$16.45pF$	C_{ij}^i	$7.4pF$
Note: i varies from 1 to 5 and $j=i+1$ varies from 2 to 5			

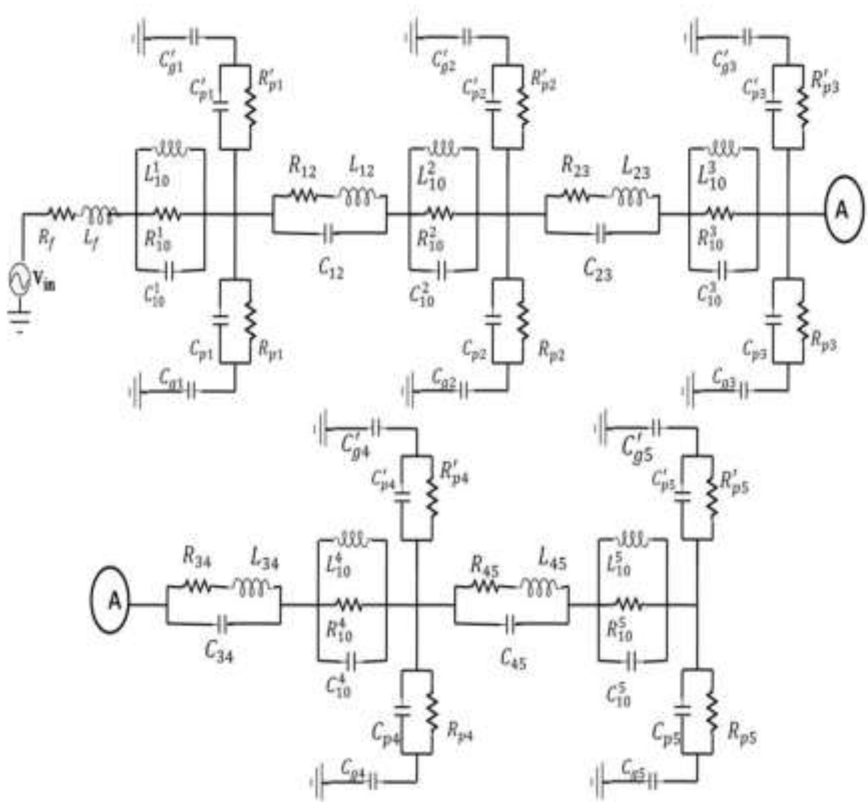


Figure 4. Transmission line model for the T-RMAA with parasitic patches

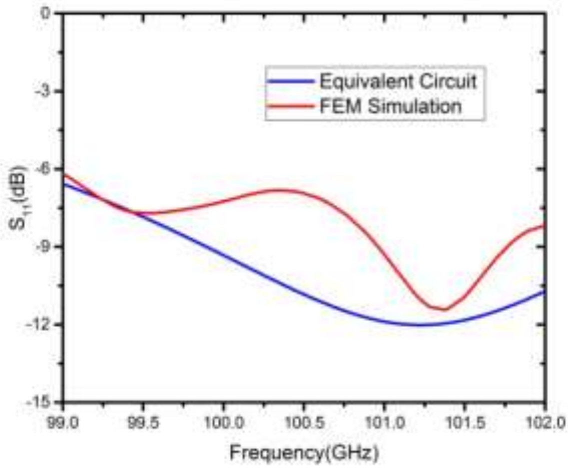


Figure 5. S_{11} comparison of T-RMAA with parasitic patches and Equivalent Model

5. Conclusion

This work reports a simple, easy to realize planar version of Terahertz antenna array which can be wrapped outside the rigid body for faithful communication at high frequency of around 100GHz with 19.2 dBi gain. As per authors' knowledge, till date such a high gain antenna at THz frequency regime has not been reported on simple planar version. This antenna has low level of cross polarization in the broadside direction as X-polarization level is 38dB below than Co-polarization level. The electrical circuit modeling is also done and FEM simulated s-parameter results shows close relevance with this circuit modeling.

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