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Design of High Gain Microstrip Antenna for THz Wireless Communication

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ABSTRACT: The current space aviation demands high data rate wireless communication which leads to the exploration of an unallocated frequency spectrum viz. the terahertz spectrum spanning from a frequency range of 300GHz to 30THz. The problems of limited bandwidth and spectrum scarcity can also be resolved due to the use of these frequencies. The recent breakthrough in semiconductor technology has resulted in development of terahertz devices which amplified the interest of scientists in exploring terahertz region. High atmospheric attenuation and high free space path loss of THz waves acted as limiting factors for using THz waves for communication. But application of THz waves for space communication will not be affected as it is atmosphere free and free space path loss can be reduced by using high gain antenna. In this paper a high gain microstrip patch antenna has been designed using photonic band gap structure. The designed THz antenna proved to be advantageous for wireless space applications. The designed THz antenna provides a gain of 14.2 dB and a directivity of 14.54 dBi.

KEYWORDS: THz antenna, THz space communications, High gain microstrip antenna, Wireless space communications

I. INTRODUCTION

As per survey the required data rate for wireless space communication in near future may reach to several tens of Gbits/s [1]. These high data rates can be achieved by increasing the available bandwidth which is possible only above 300GHz frequency as it is unallocated [2]. This has resulted in exploration of a new frequency spectrum for space communication known as THz spectrum, frequencies ranging from 300GHz-30THz. THz waves can see through dust, clouds etc. [3] which results in better space communication in adverse weather conditions. The use of THz frequencies for space communication has some other added advantages as it reduces the problem of spectrum scarcity, bandwidth limitations and interference in present wireless communications. THz waves provide secure communications than microwaves as they are highly directional and scatter less compared to microwaves [4] [5]. THz wireless communication requires small size antennas which reduces the size and weight of space vehicles and thus helps in reducing their operational cost. Thus the use of THz antenna in space vehicles is also gaining wide interest. Hwu *et al.*, (2013) explored the potentials applications of terahertz wireless communication for space craft interior as well as for inter orbital data transfer. It has been reported that 10 Gbps per GHz data rate is achievable at THz frequencies [6].

In this paper, a high gain microstrip patch antenna that operates in the THz band has been designed. The designed antenna uses an optimized PBG substrate which increases the gain and directivity making it useful for wireless space communication.

II. CHALLENGES

The usage of terahertz technology in astronomy, atmospheric and planetary science is already in practice since last decade [7] [8]. However the usage of these terahertz waves is not yet fully evolved due to lack of suitable devices. But the recent breakthrough in semiconductor technology has resulted in development of terahertz devices [9]. Antennas that already exist are not suitable for THz communication as conductive loss is more due to small skin depth at terahertz frequencies. Communications using THz waves suffer high free-space path loss due to their small wavelengths ranging from 3mm to 30μm limiting its application to short range communications. However long range

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communications can be achieved by using high power transmitters [6]. High free space path loss can also be compensated by using an antenna with high gain and high directivity. The other disadvantage of THz waves is high atmospheric attenuation. However atmospheric attenuation is not an issue for communication in space as it is atmosphere free.

III. DESIGN OF THZ ANTENNA

Space communication using THz waves require an antenna with high gain, high directivity, highly efficient, with wide bandwidth, small size and low cost. Photoconductive antennas can be used for such applications. However when these antennas are connected to a photomixer it results in low output power due to poor impedance matching. The use of microstrip patch antennas can be a solution to this problem.

Microstrip patch antenna has several advantages such as low weight, ease of fabrication and integration, compact, portable, and low cost. Another advantage of using microstrip patch antenna is that it is conformable on any curved surface. Proper impedance matching can be achieved by optimizing the position of insertion of feed into the patch. Hence these antennas are best suited for space applications which require small size, low cost antennas and which can be easily installed. Hence this paper illustrates the design of a highly directional antenna with high gain and low return loss in terahertz range.

A. Design of Microstrip Patch Antenna

Figure 1 shows a rectangular microstrip patch antenna which has a ground plane below the substrate and a patch and a feed line that are etched above the substrate. The fringing fields that arise between the patch and the ground plane results in radiation in microstrip patch antenna.

The ground plane supposed to be a perfect electric conductor. Hence in this design ground plane is made of PEC material. Highly conductive material such as copper is used to design the patch and the feed line. Patch is made of rectangular shape as it can be easily analysed involving simple calculations. The design uses planar technology as it provides the possibility of higher integration [10].

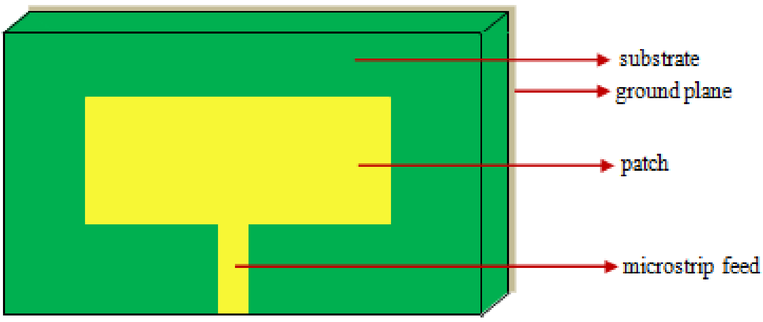

Fig. 1 Microstrip patch antenna

The input impedance offered by the patch is very high ranging between 150Ω-300Ω when the feed is inserted at the edge of the patch. The characteristic impedance of the feed line is designed to be 50Ω. This can lead to poor impedance matching which results in low output power. The solution to this problem can be achieved by inserting the feed into the patch by creating a gap as shown in Figure 2.

The input impedance offered by the patch when the feed is inserted at a distance '*y*' from the edge of the patch can be calculated using formula given by

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$$Z_y = Z_{edge} \times \cos^2\left(\frac{\pi y}{L_p}\right)$$

where Zy: input impedance of patch at distance 'y' form edge

Z_{edge}: input impedance at the edge of the patch

$L_{p:}$ length of the patch

The required resonating frequency of the design is considered to be 0.68 THz. The dielectric constant and the thickness of the substrate are taken as 3 and 10 µm respectively. The thickness of patch and microstrip feed is 5 µm. With these known values the other required dimensions of the antenna are calculated and tabulated below in Table I.

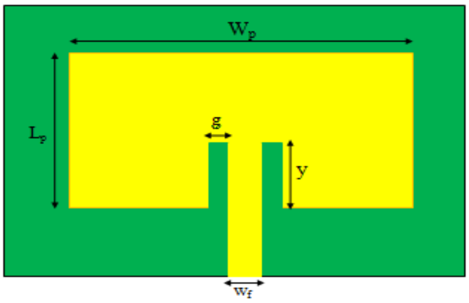

Fig. 2 Microstrip patch antenna with inset feed

TABLE I
DIMENSIONS OF RECTANGULAR MICROSTRIP PATCH ANTENNA

Design Parameters	Dimensional Value
Width of the patch (Wp)	151.5 µm
Length of the patch (Lp)	19.54 µm
Width of ground and substrate	211.5 µm
Length of ground and substrate	179.54 µm
Width of the feed (Wf)	23.53 µm
Inset feed position (y)	38.64 µm
Notch gap (g)	10 µm

The microstrip patch antenna model is designed by means of the dimensions mentioned in Table I and simulated in FEM based EM software using MATLAB interfacing and the obtained results are tabulated below in Table II.

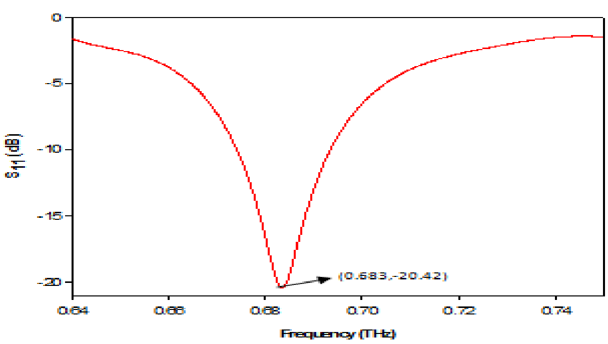

Fig. 3 Return loss characteristics of microstrip patch antenna

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The return loss of the designed microstrip patch antenna can be observed from Fig. 3. The antenna resonates at a frequency of 0.683 THz with a return loss of -20.42 dB. The gain, directivity and bandwidth of the designed model are 5.131 dB, 6.263 dBi and 2.79% respectively.

TABLE II
PERFORMANCE PARAMETERS OF RECTANGULAR MICROSTRIP PATCH ANTENNA

Frequency	0.683THz
Scattering parameter *S11*	-20.42dB
Gain	5.131dB
Directivity	6.263dBi

Analyzing the above results shows that the designed antenna has very narrow bandwidth, low gain and low directivity. The possible solution to this problem is to increase the size of the patch. Hence the size of the patch was increased and the antenna was designed with the optimized values. However this antenna with increased dimensions require a thicker substrate which results in a loss known as surface wave loss as most of the radiated power gets trapped inside the thicker dielectric substrate.

A possible solution to this problem is to use a thin substrate material with a low dielectric permittivity which reduces surface wave trapping. But this will affect the directivity of the antenna [10]. Another possible solution to improve the gain is to use an array of microstrip antennas. But this makes the communication system large and massive which poses a constraint for space applications. A capable solution to this problem can be achieved by using a Photonic Band Gap (PBG) substrate [10][11].

B. Design of PBG based Microstrip Patch Antenna

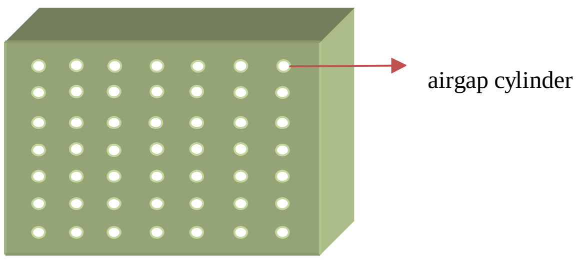

Fig. 4 PBG Substrate

PBG substrate is designed by implanting air-gap cylinders periodically on a substrate as shown in Figure 4 which helps in reducing the effective dielectric permittivity of the substrate [12]. The bandwidth of a microstrip patch antenna using PBG substrate can be above 35% of a microstrip patch antenna with normal substrate [13]. PBG structures attenuate wave propagation in a certain frequency band gaps [14]. Due to these frequency band gaps surface waves can be eliminated thus improving the bandwidth and directivity.

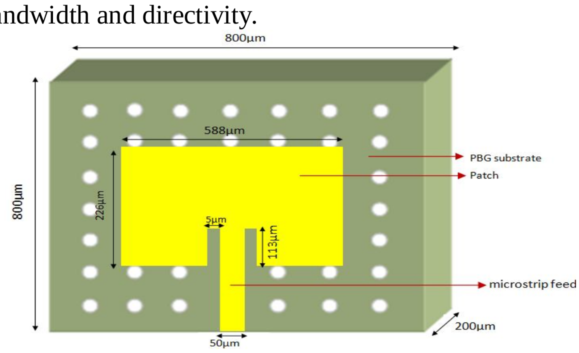

Fig. 5 Microstrip patch antenna with PBG Substrate

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Figure 5 shows the design of microstrip patch antenna with PBG substrate implemented and simulated in FEM based EM software using Matlab interfacing. Table III shows the results that are obtained using this design.

TABLE III
PERFORMANCE PARAMETERS OF ANTENNA WITH PBG SUBSTRATE

Frequency	0.693THz
Return loss	-64.304dB
Gain	14.21dB
Directivity	14.54dBi

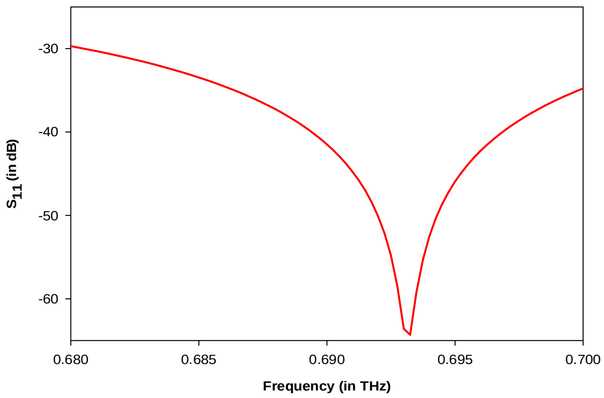

Fig. 6 Return loss characteristics of PBG based patch antenna

The designed rectangular microstrip patch antenna with PBG substrate gives a return loss of -64.304dB at a resonating frequency of 0.693 THz as shown in Figure 6. The obtained gain and directivity at 0.693 THz are 14.21 dB and 14.54 dBi respectively which show an improvement in the performance of patch antenna.

IV. CONCLUSION

A high gain microstrip patch antenna is designed on a PBG substrate using FEM based software. The design uses an inst feed technique in order to obtain proper impedance matching between the patch and the feed. The obtained values of return loss, gain and directivity of the designed model are -64.304dB (S11), 14.218 dB and 14.54 dBi respectively which show an improvement as compared to those of a conventional patch antenna without PBG substrate. Hence the use of designed antenna has its advantages in various wireless applications such as aircraft collision avoidance system, telemetry, on-vehicle satellite links, missile radars, inter and intra orbital communications, communications inside space vehicles, GPS systems and other space based applications.

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