International Journal of Future Generation Communication and Networking
Vol. 13, No. 2, 2020 pp.1012-1017

Terahertz Micro Strip Slot Antenna On 3-D Printable Substrate Loaded With Photonic Crystals

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Abstract

The paper investigates a 3-D printable substrate with photonic crystals (3-D printed photonic bandgap structure) to support microstrip slot antenna at the terahertz frequency band. A microstrip slot antenna operating at 0.6THz has been presented. The proposed antenna presents an approximate radiation efficiency of 91.6%_. Further, antenna efficiency and gain have been enhanced with the help of a photonic band gap structure.

Keywords: *Terahertz Antenna, Photonic Crystal, Photonic Band Gap Structures*

1. Introduction

With the recent introduction of new technologies like the internet of things and vehicle to vehicle communications, there is a rising demand for higher data-rates and larger bandwidths. With almost everything around us connecting to a wireless network, the present sub-3GHz band is overcrowded and new areas of the electromagnetic spectrum are being explored throughout the world.

Ranging from 100GHz to 10THz, the terahertz frequency band in the electromagnetic spectrum has been gaining great interest recently because of its applications in imaging, biotechnology, radio sensing, satellite communication, wireless communication, radio astronomy and many more. Being shorter in wavelength (in micrometers), the terahertz band exhibits new challenges compared to that of microwave and millimeter waves. There has been significant work done in the area of Terahertz waves to understand its applications in wireless communications [1], medical imaging [2], satellite communication [3], and screening for security applications [4].

Antennas are the most important tool in any wireless communication system. There has been a lot of work focused on the development of antennas at the THz band. Some of the recent work includes multi-layered substrates for controlling the permittivity of the substrate material [5,6]. Another interesting work on the terahertz antenna includes the use of superstrates to improve the radiation efficiency of the antenna [7]. Materials like electromagnetic bandgap and photonic crystals (or photonic bandgap) substrates are of great interest in designing the antennas in the terahertz band.

An adding photonic crystal changes the current distribution on the surface of the antenna and hence improves the electrical performance in the microwave and terahertz bands. A lot of work has been presented on micro strip antennas designed using photonic crystals at terahertz bands [8-10]. But, due to the extremely small size (dimensions being in micrometers), it is difficult to fabricate such antennas at a fixed frequency band and test them. However, with the introduction of new technologies like 3-D micro-additive manufacturing [11], it has become possible to fabricate antennas with much higher precision.

This paper presents a microstrip slot antenna at 0.6THz band on a 3-D printable polylactic acid-based substrate (Dk = 2.7) loaded with photonic crystals. The paper describes the measurement of material properties with loaded photonic crystals along with the effects of photonic crystals on the antenna, followed by the design procedure for the antenna. Later, the radiation properties of the antenna are discussed in detail concluding that a 3-D printable photonic bandgap structure is a

ISSN: 2233-7857 IJFGCN

potential candidate to use the terahertz band for wireless communication and similar other applications in the future.

2. Material Characteristics

As described earlier, photonic crystals are seemed to be an ideal candidate for designing antennas at the terahertz frequency band. Photonic crystals as a substrate help in reducing the surface wave in the antenna and redistributes current density throughout the patch.

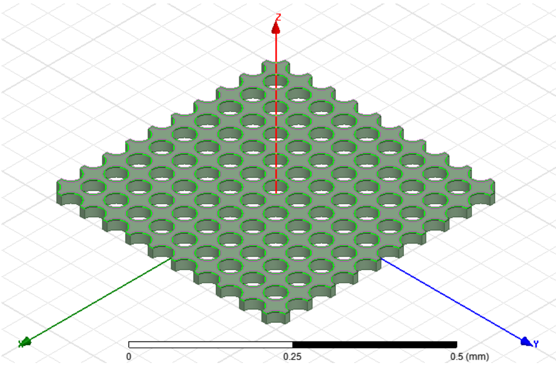
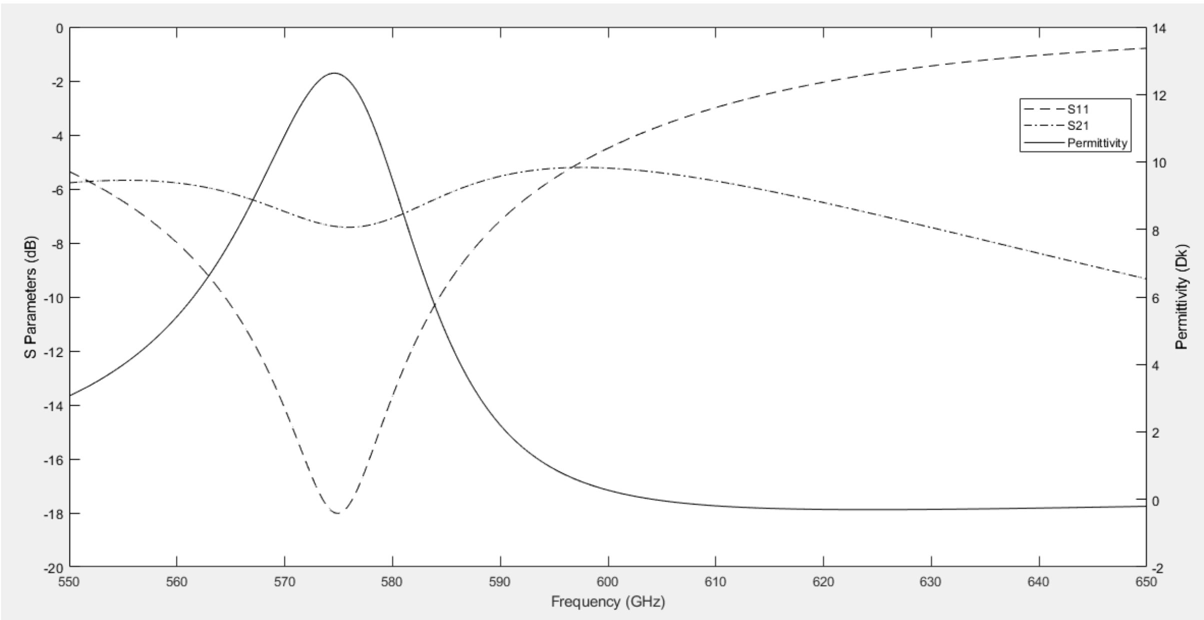


Figure 1: PLA substrate with air gaps of radius = 20um and pitch = 60um in x and y-direction

For this design, a 600x600x20 um slab of polylactic acid (PLA) material is taken. PLA is a very commonly used material for 3-D printing and has a dielectric constant (ε_r) of 2.7 and a loss tangent of 0.008. With a slightly higher conductivity compared to the generally preferred materials, the dielectric constant of the material is reduced further with the help of photonic crystals. To add photonic crystals, an 11x11 array of cylindrical air gaps of radius 20um are introduced in the material with a pitch of 60um in both x and y directions. Figure 1 presents the substrate with loaded photonic crystals.



The new effective dielectric constant of the substrate is calculated using the technique proposed by Kim and Jarvis in [12], using the S11 and S21 calculated through two ports across the element, the effective dielectric constant of the material is calculated and plotted in figure 2. The relative effective permittivity of the photonic bandgap material is calculated to be 0.257 (as shown in figure 2). The

Figure 2: S Parameters (S11 and S21) for the photonic bandgap material and calculated relative effective permittivity.

ISSN: 2233-7857 IJFGCN

measurements are done using Ansoft High-Frequency Simulation Software (HFSS) and MATLAB.

The radius of the cylindrical photonic crystal has been optimized to get the suitable performance. With the help of 3-D micro-additive manufacturing techniques discussed in [11], it is possible to print such materials for antenna designing. Further, a copper ground has been given to the material with the patch on top. The final antenna design is discussed in the next section.

3. Antenna Design

The dimensions of the patch antenna are calculated using the process mentioned in [13]. The width, W of the patch is dependent on the frequency of operation and effective permittivity of the material and is defined by the equation,

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_{reff} + 1}}$$

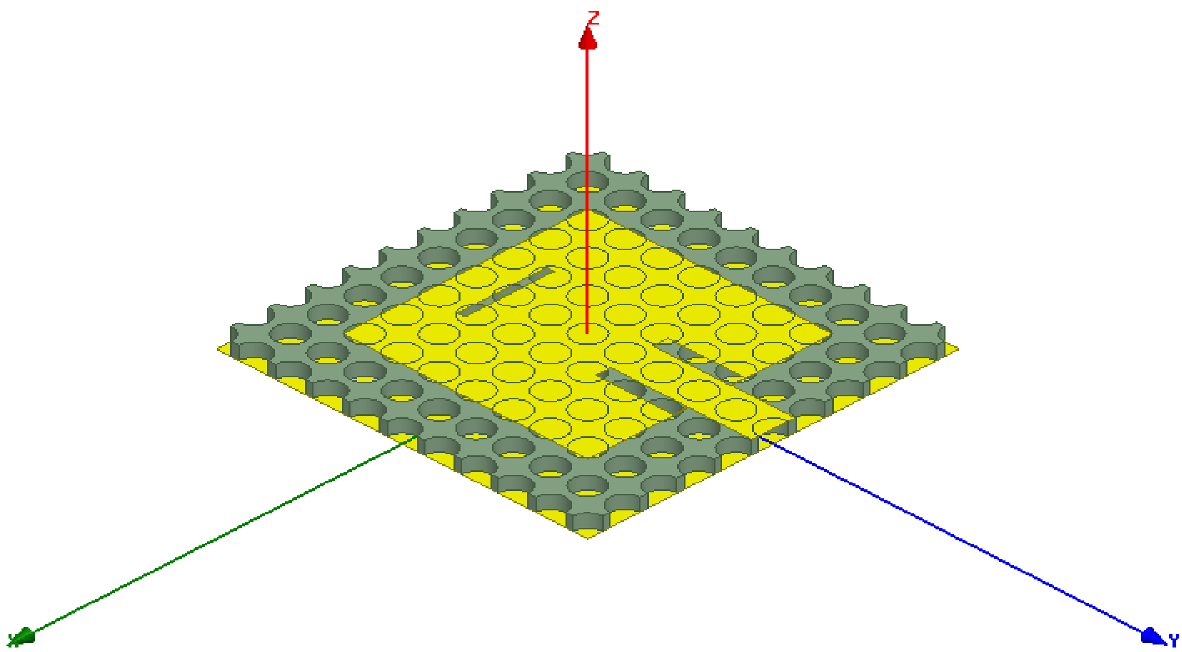
Where c is the speed of light, f is the frequency of operation and ε_{reff} is the relative effective permittivity of the substrate. Length of the patch is calculated as,

$$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Where $\Delta L$the additional electric length due to fringing is waves and is calculated by the equation,

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

Using the above equations, all the parameters of the antenna are calculated and are shown in table 1. Further, the proposed antenna design is shown in figure 3.



A slot of length equivalent to one wavelength is placed on the top of the patch to redistribute the current density and enhance the radiation pattern of the antenna. A simple inset-fed feeding technique

Figure 3: Micro strip Patch Antenna Design with a Slot at the Top

is used to feed the antenna through a lumped port with a characteristic impedance of 50 ohms.

The width of the feedline (wf) is dependent on the height of the substrate and effective permittivity, and is calculated using the equation,

$$Wf = 7.48h\, e^{\frac{Z_0\sqrt{\varepsilon_{reff}+1.41}}{87}} - 1.25t$$

Where, Z_0 is the characteristic impedance and is kept at 50 ohms, and t is the thickness of copper cladding of the patch antenna. Table 1 shows all the calculated values for the parameter that describes the patch design of the antenna.

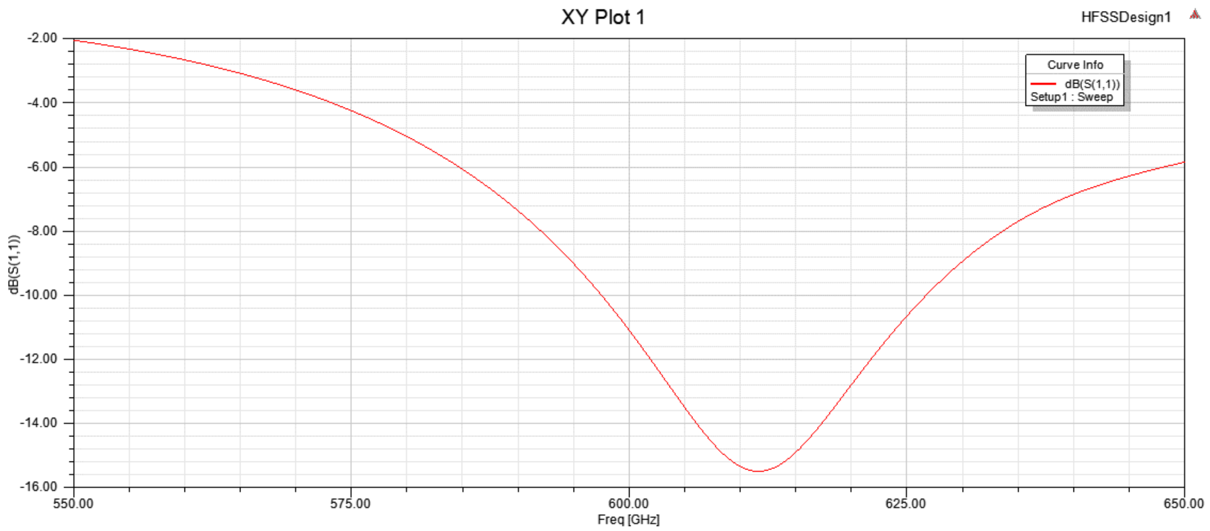


Table 1: Calculated Parameters for the Patch Design

Parameter	Value	Description
W	328um	Width of Patch
L	324um	Length of Patch
Wf	58um	Feedline Width
h	20um	Height of Substrate
t	10um	Thickness of Copper
Ls	200um	Length of Slot

Figure 4: Simulated Return Loss of the Microstrip Slot Antenna

Figure 4 shows the simulated return loss of the antenna using the Ansoft HFSS. It can be seen that the antenna has a resonance at a frequency of 0.595THz with a 10dB bandwidth of almost 30 GHz. One of the advantages of using the terahertz band is even a 5% bandwidth gives large enough bandwidth to the operator, allowing more data to travel at the same time, and hence increasing the data-rates.

ISSN: 2233-7857 IJFGCN

Figure 5 presents the radiation pattern for the proposed antenna. The antenna has a directivity of 8.01dBi with a reported efficiency of 91.6%_. The main beam of the antenna is tilted at 40deg and has a half-power beamwidth (HPBW) of 46deg. A significant circularly polarized beam can be observed for a single slot antenna proposed in the paper.

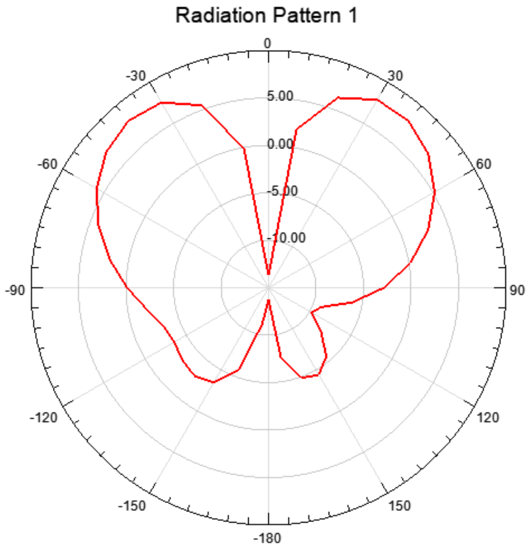


Figure 5: Radiation Pattern Phi = 90deg

4. Conclusion

The paper proposed a novel microstrip slot antenna using a 3D printable PLA substrate with photonic crystal loading. The paper shows that the new resultant material has a significantly lower effective permittivity and hence can be used to design a patch antenna. A microstrip slot antenna has been presented using the material at 0.6THz which demonstrates a high radiation efficiency of 91.6%_ with directivity of 8.01dBi. Further progress is being done in improving the antenna design and creating a reconfigurable array of antennas to present more applications in the terahertz band of the electromagnetic spectrum.

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ISSN: 2233-7857 IJFGCN