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Double Star-Shaped Wideband Patch Antenna for THz Applications

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Abstract: ***This work provides a dual star-shaped patch for terahertz frequency operations that is attached at the opposite upper edges of the antenna's feedline. It does a thorough examination of the antenna's execution, taking into account important factors including gain (dB), VSWR, directivity (dB, return loss (dB), along with total bandwidth coverage (THz). A 90 µm-thick polyimide substrate having a reduced dielectric constant (εr) about 3.5 is used in the structure of the antenna. The connection among the source to patch of the intended antenna is facilitated by a narrow microstrip line. The recommended antenna has an overall bandwidth about 0.250 THz and operates in the 1.011 THz to 1.262 THz frequency range. Resonance frequencies are found at 1.050, 1.126, and 1.198 THz across the whole operating band. It also achieves 8.10 dB of directivity as well as an overall gain about 7.09 dB throughout its frequency range.***

Keywords: Microstrip antenna, Terahertz (THz) antenna, Antenna parameters, Polyimide, CST

1. Introduction

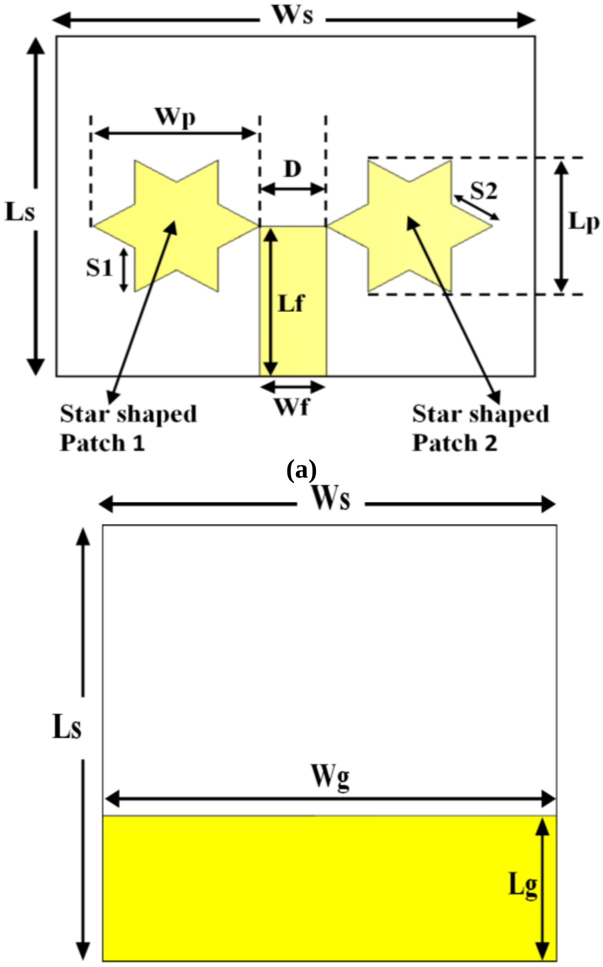
Within contemporary technology, wireless communication refers to a system or channel that facilitates the movement of data from one location to another via a wired or wireless route. These days, long-distance communications use the electromagnetic spectrum. The electromagnetic spectrum is completely employed in antenna applications because it is a naturally occurring resource. The utilization of wireless technologies has risen tremendously in the communication business during the past several years. Worldwide, the importance of cellular systems in our daily lives has increased dramatically. With billions of users worldwide, wireless communications are becoming a crucial component of cellular systems [1]. When a channel is implemented without the need of cables and a medium is provided for the transfer of significant data across multiple mobile systems or sites, that communication is known as wireless communication. In the context of modern communication, the term "wireless" essentially refers to a wireless emitter or receiver that provides convenience as well as connectivity to a large number of mobile broadband along with internet connection users. The term "wireless" additionally denotes an application type that uses the network as a whole without the need for cables. A few instances of wireless communication include various kinds of satellite, broadcast, and mobile television, global positioning system (GPS), wireless accessories for computers, inputting keys, headphones, as well as portable and transportable cell phones [2]. Satellite communication or antennas enable long-distance laptop as well as smartphone users to communicate overseas, among other services provided by wireless communication. Various wireless communication modes include: Cellular phones, communications via satellite mechanisms, radio and television broadcast stations, as well as duplex radio networks are examples of radio frequency connectivity. Within the electromagnetic (EM) spectrum, THz radiation is defined as having a frequency between 100 GHz and 10 THz, which falls between millimeter and infrared wavelengths. The THz band is also referred to as sub-millimeter wave, far infrared, as well as near-millimeter wave. THz waves are viewed as an extension of the millimeter wave as well as microwave bands, offering a wider communications bandwidth than microwave frequencies. Microwave and photonic sources undergo up and down conversion to produce THz waves. The various unique characteristics of THz radiation promote the expansion of the THz industry as a whole. The non-invasive, non-ionizing T-rays and waves pose no threat to people, pets, or plants. Because of its exceptional sensitivity for soft tissues and non-ionizing nature, T waves have consequently gained popularity in the biomedical field. The main problems for optical communication are absorption and scattering because of the worst air conditions. The fourth power of the wavelength has an opposite correlation with the scattering loss. Consequently, in contrast to optical transmissions, THz along with millimeter signals offer less loss. Another option to the optical link is THz communication [3]. Despite being attenuated, THz waves radiate efficiently in dust because of nano particles that are close to the wavelength [4].

As compared to microwave communications, THz waves have the following advantages: they can penetrate dense materials; they can respond quickly and across a wide spectrum; they are small, have a large bandwidth, and can transmit data at a high rate; they also don't require switching between different pieces of hardware, such as lasers for optical communications, and are inexpensive. THz radiation can reach deeper penetration levels with less dispersion. While they are opaque in the optical spectrum, dry and non-metallic materials are translucent in this range. X-ray photons have far higher energy than photons in the THz range, whereas T-rays do not ionize. Several molecules' intra- and inter-vibrational modes can be found in the THz spectrum [5, 6]. Many strategies, including the use of alternative antenna configurations as well as DGS (Defected Ground Structure) designs, have been researched in order to prevent mutual coupling between antennas [7]. In addition to producing a slow wave effect, DGS designs are quite successful at changing the antennas' current route [8, 9]. THz antennas have not been the subject of as many studies in the literature [10–17] as millimeter as well as microwave antennas have. This is a result of the computational complexity of simulation analyses and the challenges associated with experimental THz antenna observations. A silicon substrate-based flexible THz antenna was described in [10]. At the resonant frequency, good gain values were obtained when the antenna was examined at 0.65 THz. FR-4 is normally not favored used a material for the substrate since of its unstable nature at high frequencies; nonetheless, FR-4 was used in the construction of a microstrip antenna that was described in [11]. To create broadband with elevated gain THz antennas, Singhal used an elliptical design with a polyamide substrate in [12, 13]. Nonetheless, it is evident that the suggested antennas' gain values are low at lower THz frequencies.

However, given the limitations of the design, this is expected and applies to the majority of THz research. A sub-THz antenna with a bandwidth of 38.6%, ranging from 0.294 until 0.41 THz, was presented in [14]. In [15], a further microstrip array antenna was examined, utilizing liquid crystalline polymer as the substrate material. The investigation yielded findings with a narrow bandwidth along with relatively poor efficiency. It was alleged that the THz antenna created in [16] was utilized for wireless body-surface networks. This antenna has a low gain of 2.5 dB along with a narrow bandwidth of about 7 GHz. The low-profile and low fabrication cost of microstrip antennas make them a popular choice for a variety of antenna designs and frequency values. This study seeks to demonstrate a THz frequency range microstrip antenna with a basic unslotted design and a working bandwidth that spans 0.093 THz until 0.207 THz. The antenna is also compact, measuring 800 µm x 800 µm x 666 µm.

2. Antenna Design

The ideal antenna parameter values are given in Tables 1 and 2, and the geometry of the proposed antenna construction can be observed in Figures 1(a) along with (b). In the illustration, the substrate material is represented by the white section and the yellow section, respectively. The proposed antenna has minimal width and length values because it is intended to function at THz band. That means that the substrate should be as thin as feasible. Polyimide with a thickness of 90 µm has been selected as the substrate.

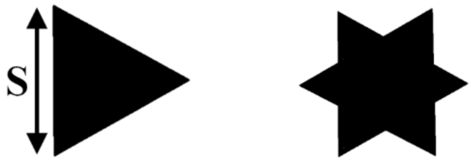


(a)

(b)

Figure 1: Proposed antenna view **(a)** Front view, **(b):** Rear view

It has a relative permittivity of 3.52 along with a loss tangent around 0.0027. Copper is used for the two metallic patches in the shape of stars, the ground, and the feed line. Additionally, the antenna's dimensions is 800 x 800 x 90 µm^3 overall and has a copper thickness of 18 µm.



(a) **(b)**

Figure 2(a): Triangular patch basic composition, **(b)** Triangle patch's initial iteration

Two-star patches are typically positioned at a distance of "D" from one another at the top corners of the feedline on the left and right, respectively, in the layout and structure of the star-shaped patch antenna. The star patch antenna depicted in Figure-2(b) is made using the triangle patch layout from figure 2(a). The following formula can be used to get the triangular patch's frequency of resonance [17].

$$f_r = \frac{2c}{3S_{eff}\sqrt{\varepsilon_{eff}}} \tag{1}$$

Where,

$$S_{eff} = S_1 + \frac{h}{\sqrt{\varepsilon_{eff}}}$$

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{4}\left(1 + \frac{12h}{S}\right)^{-1/2}$$

Table 1: Abbreviations and full terms.

Acronym	**Full term**
f_r	Resonant frequency (THz)
S_{eff}	Triangle's effective length of side (μm)
ε_r	Relative permittivity of substrate
h	The thickness of the substrate
ε_{eff}	Effective relative permittivity
S	The triangle's side length (μm)

Table 1 provides the acronyms and full term of Equation (1), and table 2 uses the standard antenna equation 1 to determine the antenna measurement. Where the substrate's width and length are portrayed by Ws and Ls. The microstrip feeding line's width and length are precisely measured to match the typical 50Ω impedance as closely as possible [18].

Table 2: Dimensions of the proposed antenna element.

Parameters	*Value (μm)*
Ws	800
Ls	800
Wf	80
Lf	300
Wp	280
Lp	259.8
D	80
S1	98.14
S2	63.5
Wg	800
Lg	300

Wf and Lf stand for the feedline's width and length, respectively. The width as well as the length of both star-shaped patches, Wp and Lp, are used to designate the two star-shaped resonators as radiating elements. D is the separation among the two-star patches as measured from the patches near edges. Additionally, to generates more resonance, which enhances the antenna's bandwidth, return loss, and gain DGS ground [19] is used, denoting the width and length of the ground, respectively, as Wg and Lg. The majority of THz research involves μm-sized slots, which are challenging to etch on an antenna using current technologies. The absence of holes or slits on the antenna's ground and radiator is a key component of the suggested design. The antenna varies from previous THz experiments in that all of the aforementioned aspects are intended to make fabrication easier.

3. Results and Discussion

With a frequency over 1.011 THz, or 1011 GHz, the nano antenna is suited for numerous terahertz applications and falls within the optical spectrum. Figure Return loss as well as VSWR of the proposed antenna are displayed, respectively, in figures 3 and 4. Return loss, sometimes referred to as S11, is the power that the antenna reflects and is sometimes called return loss [20]. S11 of 0 dB indicates that the antenna emits no radiation. This suggests that the radiation from an antenna increases with the negative value of S11.

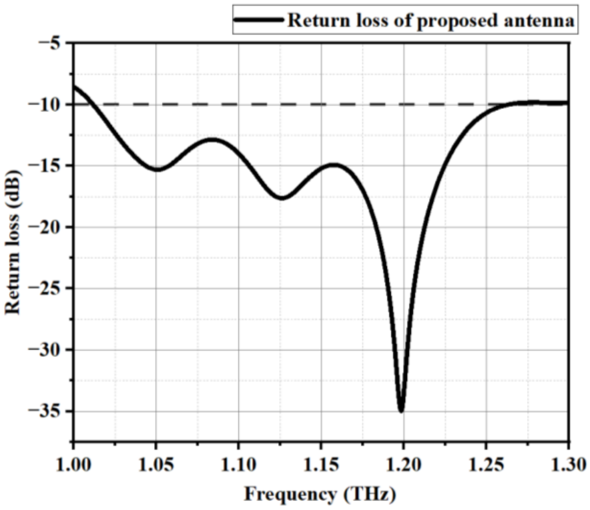


Figure 3: Return loss of proposed antenna.

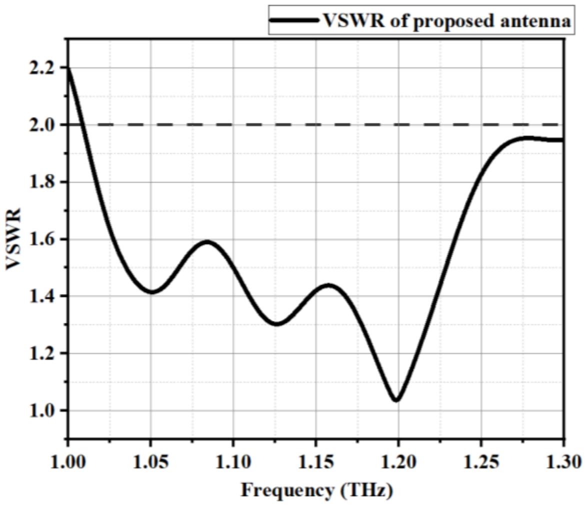


Figure 4: VSWR of proposed antenna

From return loss figure 3 it can be clearly seen that the total operating bandwidth of antenna is 0.251 THz or 251 GHz, which is from 1.011 to 1.262 THz. Also, Within its operating frequency the antenna resonates at three different frequencies of 1.050, 1.126 and 1.198 THz with their respective return loss of -15.29, -17.62 and -35 dB, which implies that it has the ability to transport data and radiate efficiently. In addition to defining the S11's function, Figure 4 depicts the VSWR of the antenna. VSWR is a true, positive value at all times. The VSWR need to be lower than 2 in order to provide the antenna with more power and to better match the antenna with the transmission line. It can be noticed from VSWR figure 4 that in antenna operating frequency, VSWR is less than 2 and as antenna has resonates at three different frequencies i.e. 1.050, 1.126 and 1.198 THz, the corresponding VSWR value is 1.41, 1.30 and 1.03.

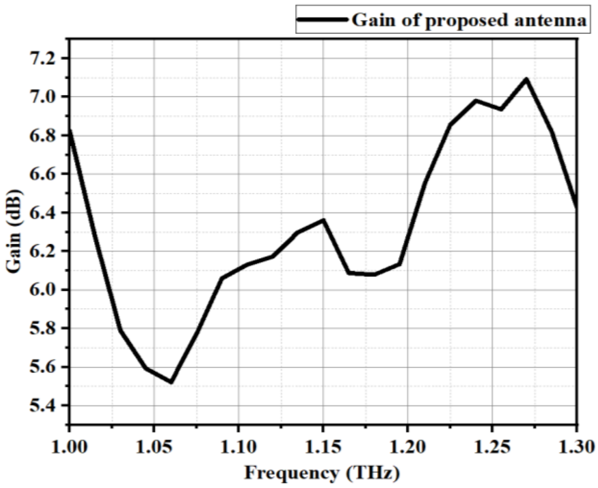


Figure 5: Gain of proposed antenna

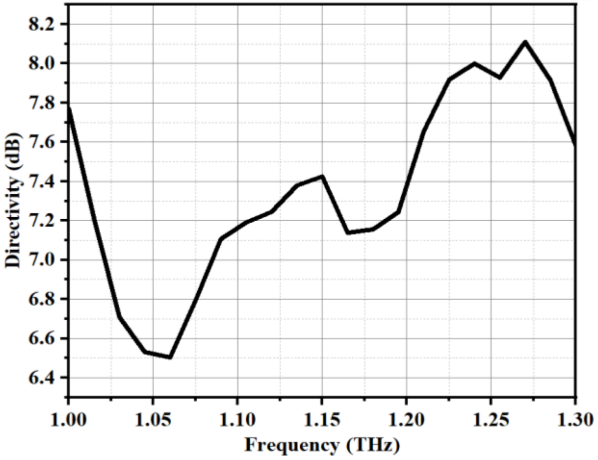


Figure 6: Directivity of proposed antenna

The figure 5 displays the plot of gain against all operational frequencies to confirm if the terahertz antenna is narrow-band or broad-band. The antenna exhibits a positive gain in its functional frequency that ranges from 1.011 through 1.262 THz, as illustrated in Figure 5, exhibiting a highest gain reaching 7.09 dB at 1.27 THz throughout the whole operational band. As a result, this micro-sized antenna offers satisfactory gain value. Also gain of value 5.56, 6.22 and 6.22 dB at antennas corresponding resonating frequencies of 1.05, 1.12 and 1.19 THz. The directionality, or directivity, of the planned antenna can be observed in figure 6.

Table 3: Evaluation of results of proposed antennas design in terms of different parameters

Antenna type	*Proposed antenna design*
Resonating frequencies (THz)	• 1.05 • 1.12 • 1.19
Return loss (dB)	• -15.29 • -17.62 • -35
VSWR	• 1.41 • 1.30 • 1.03
Gain (dB)	• 5.56 • 6.22 • 6.22
Directivity (dB)	• 6.52 • 7.29 • 7.33
Total operating bandwidth (GHz)	• 1.011 THz to 1.262 THz (Total bandwidth of 250 GHz)

It is also a crucial parameter to consider because If the antenna is not directional in the proper frequency band, its effectiveness is likely to be severely compromised. The directional nature of the antenna and its maximum directivity about 8.10 dB near 1.27 THz in its working band can be observed or noted from the figure 6. Also, value of directivity is 6.52, 7.29 and 7.33 dB at antenna resonating of 1.05, 1.12 and 1.19 THz respectively. Table 3 illustrates the assessment of proposed antenna, focusing on metrics such as resonant frequencies, Return loss, VSWR, gain, directivity along with total operating bandwidth.

4. Conclusion

This study describes a dual star-shaped patch intended for terahertz frequency applications, which attaches to the opposing top edges of the antenna's feedline. The construction uses polyimide as the substrate material, which has a dielectric constant of 3.5. The antenna exhibits an overall bandwidth of 0.251 THz when operating in the THz frequency band ranging from 1.011 THz to 1.262 THz. Three different THz frequencies are1.050, 1.126, along with 1.198 THz are where it resonates. The antenna shows lowest return loss values of -15.29 dB, 17.62 dB, along with -35 dB, respectively, within the operational THz spectrum. The antenna achieves a maximum gain of 7.09 dB along with directivity of 8.10 dB within its operational THz frequency band. Moreover, the VSWR value is always lower than 2 over the operational band. It does a thorough examination of the antenna's performance, taking into account important factors including gain (dB), VSWR, directivity (dB), return loss (dB), along with total bandwidth coverage (THz). The antenna's construction and performance study has been completed using CST Studio.

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