Sub-Terahertz Microstrip antenna array for future communication

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***Abstract*—In this article, a microstrip patch antenna array has been designed for sub-terahertz application. The designed antenna array consists of four rectangular-shaped radiating patches which are fed using the microstrip line feeding technique. The dielectric material utilized as a substrate is Roger RO3010 which has an epsilon value of 11.2, responsible for compact antenna size, it also exhibits minimal energy absorption and dissipation. The designed antenna has achieved acceptable simulated results of important parameters which include radiation pattern, Gain, and return loss, Bandwidth, current distribution, and impedance matching of the antenna. The designed antenna array offers increased bandwidth, enabling higher data rates and ultra-low latency. The proposed Sub-terahertz antenna array can support the deployment of high-speed, low-latency wireless networks for applications such as virtual reality (VR), augmented reality (AR), autonomous vehicles, and smart cities.**

Keywords— Microstrip, Array, RO3010, Sub-terahertz, Antenna, microstrip-line.

I. INTRODUCTION

The increasing demand for high-speed wireless communication, advanced imaging systems, and emerging technologies such as 6G networks and terahertz spectroscopy has sparked a growing interest in the sub-THz frequency range. Researchers have started thinking about the sub-terahertz frequency to be utilized for the upcoming generation era which includes AI-operated devices, these autonomous devices need a high data rate for real-time performance. Sub-terahertz range is believed to provide a high data rate and gain for fulfilling the requirements of the upcoming generation. Sub-terahertz (sub-THz) antennas offer numerous advantages in various applications due to the unique characteristics of the sub-THz frequency range. Sub-THz frequencies provide the potential for ultra-high data rates in wireless communication systems. Compared to lower frequency bands, sub-THz antennas can support significantly higher data throughput, making them suitable for future high-speed communication networks, such as 6G, similarly, Sub-THz antennas offer wide bandwidth capabilities, enabling the transmission and reception of signals across a broad frequency range. This wide bandwidth facilitates the transmission of large amounts of data and supports multi-frequency operation in applications such as high-definition video streaming and data-intensive communications [1]. The shorter wavelengths associated with sub-THz frequencies allow for compact antenna designs. Sub-THz antennas can be miniaturized, making them suitable for integration into small and portable devices, including smartphones, wearables, and IoT devices. Sub-THz antennas can be utilized in wireless sensor networks (WSNs) for IoT applications. WSNs consist of small, low-power sensors deployed in various environments to monitor and collect data. Sub-THz antennas enable high-speed wireless communication between the sensors, facilitating efficient data transmission and enabling real-time monitoring of environmental parameters, such as temperature, humidity, and air quality. In [2] a novel multi-layered microstrip line with built-in parallel-plate capacitors is proposed for DC-blocking applications, with its transmission characteristics. In addition to this researchers have proposed a design for terahertz frequency in [3], the antenna consists of a circular loop covering a volume of 47x92 µm. In another approach reported in [4] which a substrate with multilayers has been utilized to design an antenna for the sub-terahertz frequency range, the designed model has achieved a high gain whereas the size of the design is compromised. An antenna with a thicker substrate is difficult to integrate into compact devices. A multi-membrane-supported and polymer-cavity-backed planar monopole antenna consisting of a 2× 1 radiating antenna array is presented in [5]. The designed antenna operates at a frequency of 135GHz. The designed antenna offers a Gain of 6.51dBi, which is suitable for high bandwidth applications, the antenna offers a bandwidth of 12GHz. The compact size and miniaturization of sub-THz antennas can be challenging. Designing efficient sub-THz antennas with a small form factor for integration into compact IoT devices or mobile devices can be technically complex. Sub-THz frequencies suffer from higher propagation losses compared to lower frequency bands. The higher frequencies result in increased atmospheric absorption, scattering, and penetration losses, limiting the range and coverage area of sub-THz signals. To cover up this, an antenna can be utilized to fulfill the gap. Antenna arrays can achieve higher gain compared to single-element antennas. The combined radiated power of multiple elements in the array results in an increased effective aperture, which improves the antenna's ability to concentrate the radiated energy in the desired direction. Higher gain leads to improved signal strength, increased range, and better overall performance [5]. In an antenna array, the radiating patches are placed at a distance to achieve constructive interference. In this article, a microstrip patch antenna array is presented capable of working in the sub-terahertz frequency range. The introduction is described in section I, antenna design and methodology have been illustrated in section II whereas section III comprises Analysis and discussions, and section IV drivers towards the conclusion.

II. Antenna design and development

The Microstrip patch antenna has been designed which consists of four rectangular-shaped radiating patches. The radiating patches are placed at a specific distance to obtain constructive interference and can achieve high performance in a compact size. By combining multiple antenna elements into a single structure, the array has provided enhanced functionality without significantly increasing the physical structure. This makes microstrip antenna arrays suitable for integration into various devices, including mobile phones, IoT devices, and small wireless systems. The designed antenna radiating patches are placed above the substrate, these radiating patches are connected using a think transmission line responsible for the interception of current from the transmission line to the radiating patches. The radiating elements, Ground plan, microstrip feedline, and transmission line between the radiating elements are comprised of copper whereas the antenna dielectric material consists of single-layered RO3010 having an epsilon value of 11.2, the substrate covers a thickness of 50µm inserted between the radiating elements and ground plan. Roger RO3010 has a low dielectric loss tangent of 0.0022, which means it exhibits minimal energy absorption and dissipation. This characteristic allows for efficient signal transmission and reception, leading to high antenna performance and low signal loss. Roger RO3010 has a relatively high dielectric constant which helps in miniaturizing the antenna size. The high dielectric constant 11.2 is suitable for compact antenna designs, reducing the overall dimensions of the microstrip patch antenna array while maintaining the desired operating frequency [6]. Moreover, Roger RO3010 stays stable in different environmental conditions. Roger RO3010 exhibits excellent thermal stability, making it suitable for applications that involve high-temperature environments or temperature variations. The substrate material can withstand elevated temperatures without significant changes in its electrical properties, ensuring the antenna's performance remains consistent [7]. The designed antenna is fed using a microstrip line feeding technique, Microstrip line feeding allows the ease of integration in the circuit. This integration simplifies the overall antenna design and manufacturing process, as the feed network and antenna elements can be fabricated on the same PCB or substrate. Microstrip line feeding enables the design of low-profile and compact antennas [8]. The dimensions of the patch elements and the spacing between them are influenced by the operating frequency, which is related to the wavelength in the substrate. Higher permittivity leads to a shorter wavelength, which, in turn, reduces the physical dimensions of the antenna elements and spacing in the array [9]. The microstrip feed line is designed to have a small width and thickness, resulting in a low-profile structure. The designed microstrip line dimensions

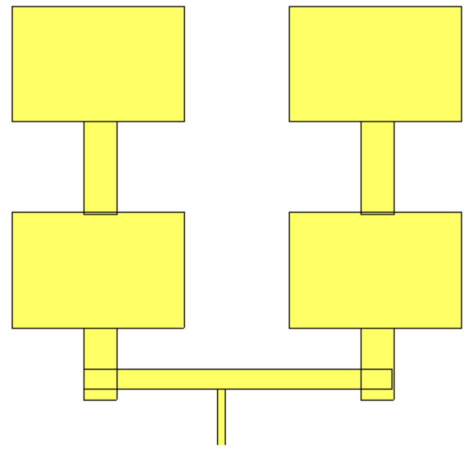

Figure 1 Structure of the MPA

are 2x3µm which is exactly matched at 50Ω impedance matching and responsible for delivering the current through the port to the radiating patches. The dimensions of the antenna are computed using the equations given below. The width of the radiating patch was determined using the equation.

$$Wp = \frac{C}{2fo}\sqrt{\frac{2}{\mathcal{E}r+1}} \quad (1)$$

The radiating patch length was calculated using equation.

$$Lp = Leff + \Delta L \quad (2)$$

Effective dielectric Constant of the antenna.

$$\mathcal{E}eff = \frac{\mathcal{E}r+1}{2} + \frac{\mathcal{E}r-1}{2}\frac{1}{\sqrt{1+12\frac{h}{Wp}}} \quad (3)$$

Extension in the length ΔL:

$$\Delta L = 0.415h\left[\frac{(\mathcal{E}eff+0.3)\left(\frac{Wp}{h}+0.264\right)}{(\mathcal{E}eff-0.258)\left(\frac{Wp}{h}+0.8\right)}\right] \quad (4)$$

The effective length of the antenna is calculated:

$$Leff = \frac{c}{2fo\sqrt{\mathcal{E}reff}} \quad (5)$$

Length of substrate:

$$Ls = 6h + Lp \quad (6)$$

Width of substrate:

$$Ws = 6h + Wp \quad (7)$$

The designed structure of the microstrip patch antenna array is shown in Figure 1 while the geometry of the antenna array is illustrated in Table 1. The antenna model is simulated in the CST Microwave Studio®. because of its friendly interference and wide material library CST Microwave Studio® was preferred [10].

III. Results and Analysis

The simulated results of the designed antenna are analyzed based on several parameters to evaluate its performance. These parameters include radiation pattern, Gain, and return loss. Bandwidth, current distribution, and impedance matching of the antenna.

A. *Return loss*

Return loss is a measure of the reflected power from the antenna. It indicates the level of impedance matching between the antenna and the transmission line. Analysing the return loss helps ensure efficient power transfer between the antennas. The designed antenna return loss is below -10dB at the resonant frequency of 134GHz. The simulated results in Figure 2 indicate the bandwidth at the resonant frequency which is acceptable for the sub-terahertz frequency application.

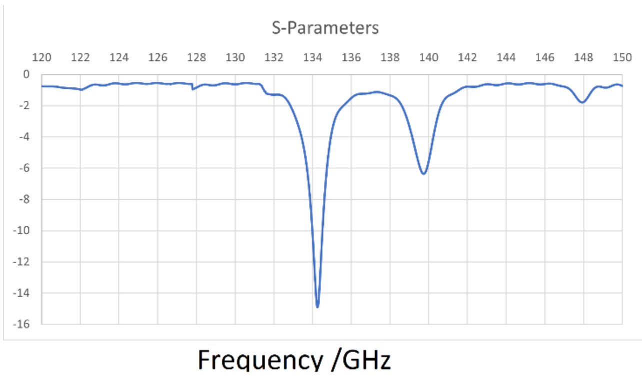

Figure 2 Return loss of the designed MPA.

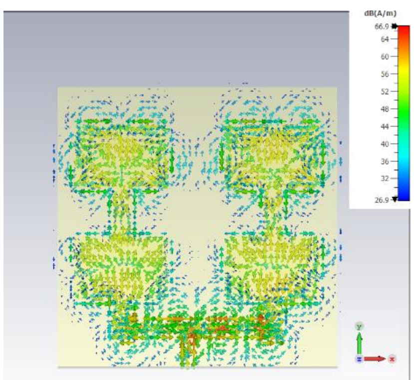

Figure 3 Current Distribution over the MPA

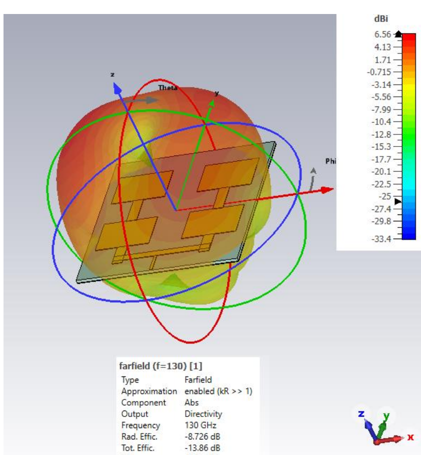

Figure 4Far-field Radiation Pattern

B. *Impedance matching*

Impedance matching ensures maximum power transfer from the source to the radiating patches. When the impedance of the microstrip line is matched perfectly to the antenna radiating patches. There is a minimal reflection of the signal, and the maximum amount of power is delivered to the radiating patches via the transmission line. This maximizes the efficiency of the propagated signal. The designed microstrip line is perfectly matched at 50Ω which minimizes signal loss along the microstrip line. When the line is mismatched, reflections occur, causing a portion of the signal to be reflected to the source [11]. These reflections result in signal loss and can degrade the overall system performance. By achieving 50Ω impedance matching, the amount of signal loss is minimized, leading to improved signal integrity, and achieving a higher gain which is 6.7dBi. similarly, Impedance matching allows for a broader bandwidth of operation. When the microstrip line is well-matched, it can support a wider range of frequencies. The designed antenna has achieved a higher bandwidth of 0.55GHz at the sub-terahertz frequency range.

C. *Current Distribution*

The current distribution directly influences the radiation pattern of the antenna. By analyzing the current distribution, it can be observed to gain insights into the shape, direction, and characteristics of the radiation pattern. Moreover, the current distribution analysis helps evaluate the performance of the antenna, the designed antenna current is distributed all over the antenna. It is directly coming from the feeding port and gets equally distributed over the radiating patches which are explicit in Figure 3. The simulated result of the current distribution allows us to assess parameters such as gain, directivity, efficiency, impedance matching, and bandwidth. the current distribution to the antenna's radiation pattern. Areas with higher current density tend to contribute more to the directivity of the main lobe of the radiation pattern. The analysis of current distribution assisted in optimizing the antenna design. By studying the current flow in the antenna elements and feed network, the area was identified where uneven current distribution occurred. On these bases, the antenna design was optimized to obtain acceptable performance.

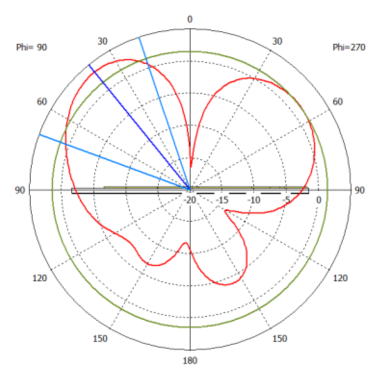

Figure 5 2-D Radiation Pattern of the proposed antenna ϕ = 0°

Table I

Antenna	Elements	Dimensions (μm)
Patch	Length (L)	560
	Width (W)	840
Ground	Length (L)	2500
	Width (W)	2500
Substrate	Length (L)	2500
	Width (W)	2500
	Thickness (t)	1.574
	Permittivity (Ɛ)	11.2
Transmission line	Length (TL)	300
	Width (Tw)	60

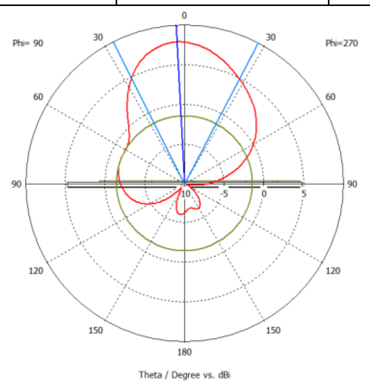

Figure 6 2-D Radiation Pattern of the proposed antenna ϕ = 90°

D. Far-field Radiation pattern

The far-field radiation pattern is illustrated in Figure 4 which provides essential information about the antenna's performance. It allows for the evaluation of important parameters such as beamwidth, directivity, gain, sidelobe levels, and polarization characteristics. The designed antenna far-field polar graph for E-field and H-field is illustrated in Figure 5 and Figure 6 respectively, it is evident from the figure that the antenna has some minimal side lobes of -9.3dB whereas the magnitude of the main lobe is 7.88dBi. The designed antenna offers a 3dB angular width of 54.2°. Analysing these parameters helps assess the antenna's ability to radiate energy efficiently in the desired direction and shape the coverage. These characteristics determine that the designed antenna's coverage is acceptable for operations in the terahertz frequency range and can focus the radiation in the desired direction.

IV. Conclusion

In this paper, a microstrip patch antenna array has been presented, which consists of four radiating patches. The patches are designed using pure copper whereas the dielectric material Roger RO3010 is utilized as a substrate material, because of the higher epsilon value the substrate material affects patch elements, and spacing between them is influenced by the operating frequency, which is related to the wavelength in the substrate. Higher permittivity leads to a shorter wavelength, which, in turn, reduces the physical dimensions of the antenna elements and spacing in the array. The designed antenna has achieved acceptable important parameters like reference impedance, current distribution, return loss, and far-field which makes it suitable for the sub-terahertz applications.

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