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Review of Microstrip Patch Antenna Performance for Terahertz Frequency Range Application

[1]Vaishali Deshmukh, [2]Dr. Shruti Dixit
[1]M.Tech Scholar, [2]Associate Professor
[1&2]Department of Electronics and Communication Engineering
[1]School of Engineering and Technology, Bhopal, India
[2]Sagar Institute of Research and Technology, Bhopal, India

Abstract : Terahertz antenna is an indispensable part of detecting terahertz wave, and the performance of the terahertz antenna directly affects the quality of the entire detection system. Terahertz frequencies share some properties of both microwave and infrared (IR) radiations. THz waves travel in LOS (Line of Sight) and they are non-ionizing like IR/microwave waves. Moreover similar to microwave, THz frequency waves penetrate wide variety of non-conducting materials such as clothes, wood, paper, plastic, cardboard, ceramics and so on. Terahertz radiation is highly reflected by metals. In the modern edge world, there is diverse sort of antennas accessible for remote correspondence. With the progression in the antenna innovation some framework like military and business media transmission framework requires scaling down, ultra wideband, multiband and savvy antennas. Fractal antenna has appealing sort of properties that are particular from different antennas. So as to accomplish wanted properties like scaling down, multiband various shapes fractals are utilized. Microstrip antenna has confinement of restricted bandwidth that can be conquered utilizing fractal opening. This Paper presents the designing and performance of Microstrip patch antenna for Terahertz Frequency range application.

***IndexTerms* – Terahertz Frequency, Wideband wireless Fractal Microstrip Patch Antenna.**

I. INTRODUCTION

With the increase in services and users of wireless communication day-by-day, the demand for utilizing Terahertz (THz) and Sub-terahertz (S-THz) spectrum in the foreseeable future is growing specifically for preventing congestion and traffic in microwave and radio frequency spectrum. From the past certain decades, the vast demands of communication systems with high spectral efficacies, huge data rates, efficient information transmission/reception and robust fading mitigation along wideband in highly mobile situations have enhanced briskly. For satisfying these necessities, wireless communication experts in both industry and universities started working at frequencies greater than microwave region but lower than infrared range. Majority of this frequency band is covered by the THz and S-THz spectrum. This band provides 100 Gbps data rate that is indispensable for new generation communication operations [1]. The THz and S-THz band is roughly defined as a section of the electromagnetic spectrum extending from 0.1 THz to 10 THz, occupying a mega regime of spectrum between the microwave and infrared bands. This band shows rich potentials in imaging, communication, screening and sensing applications [2]. Due to these notable and profitable features of this band, antenna engineers have come up with various antenna designs for THz systems.

Terahertz (THz)-band (0.1-10 THz) communication is envisioned as a key wireless technology of the next decade, able to support wireless Terabit-per-second links in 6G systems. THz communication exhibits an extremely large bandwidth (tens to hundreds of GHz) at the cost of a very high path loss (>100 dB for distances beyond a few meters). Therefore, highly directional antennas (DAs) are needed simultaneously in transmission and reception at all times to establish reliable communication links. The application of highly DAs introduces new challenges in the neighbor discovery process [6]. There is an increasing demand for large format detector arrays with large bandwidths and high antenna efficiencies for future THz astronomical radiometric applications. For direct detection instruments, it is also desired to have antennas with dual polarization reception in order to increase the received power from incoherent sources, thereby improving the observing speed of the instrument. The main goal of this work is the validation of the incoherent detection of two orthogonal polarizations by a leaky lens antenna, coupled to a single microwave kinetic inductance detector (MKID). The resonant frequency of the MKID changes depending on the absorbed power over a distributed transmission line. The proposed antenna is composed of two crossed leaky wave slots feeding a silicon extended hemispherical lens. The slots are coupled to four aluminum (Al) coplanar waveguide (CPW) lines that incoherently absorb the incoming THz radiation. The antenna and the power absorbing CPW lines are embedded inside the MKID, allowing efficient radiation detection at THz frequencies where no lossless superconductors are available [10]. A new terahertz (THz) photoconductive photomixer/antenna device is presented. A continuous-wave THz signal is generated in a dc-biased photoconductive film by employing optical heterodyne scheme, and at the same time, the size of the film on the grounded dielectric substrate is designed to have an efficient broadside radiation. Incorporating the photoconductive film as the photo-mixing media and the radiation element not only eliminates source to antenna coupling problem but also makes the proposed device attractive for THz array source configurations. Analytical expressions for the photocurrent and the radiation power are derived under high dc bias condition, and the effects of the device configuration on its performance are studied [24]. The different wireless applications require distinct antenna, whereas, a multipurpose antenna is always a prime requirement of the market. Due to less weight, small size, ease of fabrication, low profile, multiband/wideband characteristics, Microstrip Patch Antenna (MPA) and Fractal Antennas are gaining huge popularity.

Such fractal antennas are also referred to as multilevel and space filling curves, but the key aspect lies in their repetition of a motif over two or more scale sizes, or "iterations". For this reason, fractal antennas are very compact, multiband or wideband, and have useful applications in cellular telephone and microwave communications. A fractal antenna's response differs markedly from traditional antenna designs, in that it is capable of operating with good-to-excellent performance at many different frequencies simultaneously. Normally standard antennas have to be "cut" for the frequency for which they are to be used and thus the standard antennas only work well at that frequency.

This makes the fractal antenna an excellent choice for wideband and multiband applications. In addition the fractal nature of the antenna shrinks its size, without the use of any components, such as inductors or capacitors.

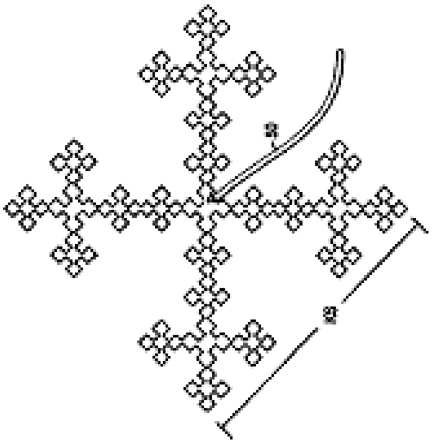

Figure 1: Fractal antenna

A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale. There are many mathematical structures that are fractals; e.g. Sierpinski’s gasket, Cantor’s comb, von Koch’s snowflake, the Mandelbrot set, the Lorenz attractor, et al. Fractals also describe many real-world objects, such as clouds, mountains, turbulence, and coastlines that do not correspond to simple geometric shapes.

To meet the requirement of inter connects, waveguides and varieties of planar transmission line can be designed and implemented in the terahertz wireless communication system. The most versatile interconnect is a waveguide, which can be used up to 1.0 THz. At the terahertz frequency, to combat the path-loss, it is necessary to improve the directivity and gain of the antenna so that it could play a crucial role in the successful implementation of the wireless communication system. In the microwave frequency regime, various researchers have used high dielectric permittivity or thick substrate material to improve the electrical performance of the microstrip antenna. However, the application of high dielectric permittivity material leads to shock wave at the air-substrate interface in the millimeter or terahertz regime of the spectrum. Further, the application of thick substrate leads to surface wave loss due to the trapping of energy within the substrate and reduction in the substrate thickness reduces the performance and mechanical strength of the antenna.

II. LITERATURE SURVEY

Y. Shi et al.,[1] in this work the fractal butterfly antenna is constructed by independent fractal unit groups on butterfly antenna, which simplifies the antenna manufacturing process and reduces the manufacturing cost. The antenna can operate in the 0.1-10 THz frequency band, with impedance bandwidth of 85% resonated at 4.9 THz, return loss of as small as -33.59 dB, and maximum gain of 16.95 dB. Among the antenna with 3 to 4 fractal unit groups, the best operation band of the antenna is 6.2-6.4 THz.

T. -Y. Chiu et al.,[2] proposed heterogeneously-integrated THz imager can provide measured effective R V and NEP of 0.967 MV/W and 0.18 nW/Hz 0.5 at 328 GHz, respectively, as f mod is 1 kHz. The measured antenna directivity and HPBW can be 30 dB and 4° at 340 GHz, respectively. Such a THz imager with advantages of high antenna directivity and narrow HPBW can be employed to realize a simple, low-cost, and lensless THz imaging system.

M. Ferreras et al.,[3] this research paper presents the frequency-dependent complex impedance for optimum matching, the technology restrictions to ensure proper chip fabrication, and the overall detection efficiency after backing the device with a silicon lens. Calibrated detector measurements for 7777 Hz modulation frequency yielded minimum optical noise-equivalent power (NEP) of 25 pW/ √ Hz at 1 THz, with NEP values below 50 pW/√Hz in the 0.84-1.29 THz frequency range.

G. -B. et al.,[4] in this work dielectric post is employed as the element of the DDL, whose height is tuned from pixel to pixel to realize the required aperture phase distribution. 3-D printing technology was utilized to fabricate the two DDLs aiming at simplifying the manufacturing process and reducing the cost. The theoretically calculated, simulated, and measured results reveal that the designed THz DDL can generate 2-D scanning nondiffractive Bessel beam with a large field of view (FoV) of 86.2° and full azimuth coverage.

J. Grzyb et al.,[5] proposed a silicon lens-coupled dual-polarization on-chip ring antenna for THz direct detection in 0.13 μm SiGe hetero junction bipolar transistor (HBT) technology is presented. In particular, various circuit-antenna co-design aspects are addressed, including the detector frequency-dependent driving impedance and responsivity, and the necessity of accommodating multiple dc signal lines in the antenna layout.

Q. Xia et al.,[6] presents, a time-efficient neighbor discovery protocol for THz-band communication networks is proposed. The protocol expedites the neighbor discovery process by leveraging the full antenna radiation pattern to detect a series of effective signals and map them to the universal signal patterns, which indicate the potential direction of the signal source.

Z. Shen et al.,[7] in this work the Resonant antennas have garnered considerable interest in terahertz and visible regimes owing to its extraordinary localized field concentration capability. In this work, we experimentally demonstrate a novel metal-free terahertz detector, which is fashioned by heavily doped polysilicon using standard CMOS process. The computational results show that the incident field can be largely enhanced within the antenna gap area at the resonance of 650 GHz.

M. Bauer et al.,[8] proposed Many emerging applications in the terahertz (THz) frequency range demand highly sensitive, broadband detectors for room-temperature operation. Field-effect transistors with integrated antennas for THz detection (TeraFETs) have proven to meet these requirements, at the same time offering great potential for scalability, high-speed operation, and functional integrability.

A. Schmid et al.,[9] this research work conducted electromagnetic simulations and performed experiments at a synchrotron light source and with a photomixing setup as sources for short THz pulses. In this paper, we evaluate a narrow-band double-slot antenna as well as a broadband log-spiral antenna design.

O. Yurduseven et al.,[10] proposed dual-polarized device absorbs power incrementally over four different CPWs incoherently and is therefore simulated in reception (deriving a plane-wave response) similarly to what is done in distributed absorbers.

G. P. Szakmany et al.,[11] present a terahertz (THz) wave detector based on antenna-coupled single-metal nanoscale thermocouples. The dipole antenna is tuned to receive 600-GHz electromagnetic waves, and the nanoscale thermoelectric converter (NTEC) converts the heat, generated by the dissipated antenna currents to electrical signals. The measured polarization- and thermopile-length-dependent responses of these THz detectors, configured in thermopiles with various lengths, confirms that the measured signal is the result of the heating caused by the radiation-induced antenna currents and detected by the NTEC.

P. Zhao et al.,[12] this work presents the terahertz (THz) waveguide-fed circularly polarized double-fan-shaped slot antenna (DFSSA) based on a silicon micromachining technology is proposed. The antenna is fed by a WR1.9 waveguide. Optimized rotation angle of the double-fan-shaped slot can realize left-hand circular polarization or right-hand circular polarization.

Z. Thacker et al.,[13] presents the utilization of terahertz time-domain spectroscopy (THz-TDS) to measure the complex dielectric function of NiO, ZnO, Ta 2 O 5 , and Nb 2 O 5 . These oxides were chosen for their efficacy as the tunneling insulator layer in a metal-insulator-metal (MIM) diode rectifier coupled to an antenna designed for high-frequency absorption.

M. Jarrahi et al.,[14] in this work the photoconductive terahertz sources and detectors has proven to offer significantly higher terahertz radiation powers and detection sensitivities by enhancing photoconductor quantum efficiency while maintaining its ultrafast operation.

Y. Shang,et al.,[15] in this work circular- polarize d substrate-integrated-waveguide (SIW) antenna is demonstrated in CMOS 65 nm process with high spectrum resolution and high sensitivity for sub-THz spectroscopy imaging system with consideration of depolarization effects. The sub-THz imager is a receiver that consists of a circular polarized substrate integrated waveguide (SIW) antenna, down-conversion mixer and power gain amplifier (PGA).

V. Varlamava et al.,[16] presents the structure is designed to be combined with a rectifying junction, realized just below the whisker base, which produces the direct conversion of terahertz electromagnetic field into dc current. The figure of merit of the structure is the electric field enhancement factor at the metallic whisker/semiconductor interface

A. Rolland et al.,[17] in this research paper THz signal radiated by a transverse-electromagnetic-horn antenna. The THz signal is detected and analyzed by a subharmonic mixer coupled to an electrical spectrum analyzer. All components involved in this experiment operate at room temperature without phase locking the beatnote. So far, the dynamic range evolves from 58 dB at 282 GHz to 15 dB at 1.026 THz, and the measured linewidth is better than 30 kHz.

S. R. Kasjoo et al.,[18] presents the report on the low-temperature detection of free-space radiation at 1.5 THz using a unipolar nanodiode, known as the self-switching diode (SSD), coupled with a spiral microantenna. The SSD, based on an asymmetric nanochannel, has a diode-like characteristic that can be utilized in rectifying high-frequency electrical signals. The truly planar structure of the SSD not only provides intrinsically low parasitic capacitance that enables rectification at ultrahigh speed, but also allows the fabrication of a large SSD array in parallel without the need for interconnection layers.

N. Khiabani et al.,[19] this research paper examines the factors which affect the radiated power and optical-to-THz power conversion efficiency of the antenna. A novel equivalent circuit model using lumped elements is developed for analyzing the performance of these antennas. In this model, whilst keeping the simplicity of the lumped element approach, the underlying physical behavior of the device is taken into account when calculating the circuit elements.

J. W. Bowen et al.,[20] proposed methodology is generic and should be useful across the wider sensing community, e.g., in single detector acoustic imaging or in adaptive imaging array applications. Furthermore, it is applicable across other frequencies of the EM spectrum, provided adequate spatial and temporal phase stability of the source can be maintained throughout the measurement process.

I. Kostakis et al.,[21] in this work the Photoconductive antennas fabricated on novel low temperature (LT) beryllium (Be) doped InGaAs-InAlAs multi-quantum-well structures have been evaluated as THz emitters and detectors in a time-domain spectroscopy (TDS) system. This work present the system responses with THz pulses having spectral range up to 3 THz and power to noise ratio of 60 dB, making them competitive with LT-GaAs excited at 800 nm and among the highest reported to date for this material system.

S. Liu et al.,[22] this research work characterize a dipole antenna structure that allows for coherent detection of narrowband terahertz radiation with enhanced sensitivity at the resonant frequency. The antenna incorporates a corrugated metal structure that surrounds the dipole. Each periodically spaced groove in the corrugation couples an approximate replica of the incident THz pulse to a surface Plasmon pulse, which then propagates towards and is detected by the dipole.

M. Bareib et al.,[23] this research paper designed to be sensitive to the IR range and work at room temperature without cooling or biasing. In order to achieve large arrays of ACMOMDs, nano transfer printing have been used to cover a large area with metal-oxide-metal (MOM) diodes and with antenna structures. The printed antenna structures consist of gold and aluminum and exhibit a low electrical resistivity.

D. Saeedkia et al.,[24] proposed two possible photo mixer configurations, namely longitudinal and transversal, are introduced and their photo-mixing efficiencies and radiation power are compared. The typical nW output power is achievable by mW laser pump power for frequencies up to 10 THz.

N. Karpowicz et al.,[25] this research paper presents the recent progress in the use of continuous wave THz imaging for nondestructive testing applications. These results demonstrating the use of hyperbolic lenses to achieve diffraction-limited resolution in a CW system and show applications of the technology while discussing its strengths and limitations.

Table 1: Summary of Literature review

Sr No.	Author Name & Year	Work	Outcome
1	Y. Shi et al., IEEE 2021	Design of Terahertz Detection Antenna With Fractal Butterfly Structure	THz, return loss of as small as -33.59 dB, and maximum gain of 16.95 dB.
2	T. -Y. Chiu et al., IEEE 2021	340-GHz Heterogeneously-Integrated THz Antenna Array for Lensless Terahertz Imaging Applications	The measured antenna directivity and HPBW can be 30 dB and 4° at 340 GHz.
3	M. Ferreras et al., IEEE 2021	Broadband Sensing Around 1 THz Via a Novel Biquad-Antenna-Coupled Low-NEP Detector	Best reported narrowband devices close to 1 THz.
4	G. –B et al., IEEE 2020	A 2-D Beam-Scanning Bessel Launcher for Terahertz	Proposed 2-D scanning THz Bessel beam launcher can find

		Applications	widespread applications
5	J. Grzyb et al., IEEE 2019	A Lens-Coupled On-Chip Antenna for Dual-Polarization SiGe HBT THz Direct Detector	THz fractional bandwidth with consistent radiation patterns up to 1 THz
6	Q. Xia et al., IEEE 2019	Expedited Neighbor Discovery in Directional Terahertz Communication Networks Enhanced by Antenna Side-Lobe Information	THz communication exhibits an extremely large bandwidth (tens to hundreds of GHz) at the cost of a very high path loss.

A. Advantages

- It offers greater bandwidth than microwave frequencies. The data bandwidth exceeds wireless protocols e.g. 802.11b.
- THz radiation waves can easily pass through non-conducting materials as mentioned above.
- It can be used in image sensing and higher bandwidth wireless networking systems for distances of about 10 to 100 meters.
- It has minimum effects on human body as it is non-ionizing in nature.

B. Disadvantages

- It does not support long range communication due to scattering and absorption by cloud, dust, rain etc.
- It supports less penetration depth than microwave radiation. Moreover it has limited penetration through clouds and fog. THz waves can't penetrate liquid water or metal.
- It is difficult to detect terahertz frequencies as black body radiation at room temperatures is very strong at these frequencies.
- Sources, detectors, modulators are not available at affordable prices which lead to hinderances in its commercial availability as communication system.

III. FRACTAL ELEMENT ANTENNAS AND CHALLENGES

Many fractal element antennas use the fractal structure as a virtual combination of capacitors and inductors. This makes the antenna so that it has many different resonances which can be chosen and adjusted by choosing the proper fractal design. This complexity arises because the current on the structure has a complex arrangement caused by the inductance and self capacitance. In general, although their effective electrical length is longer, the fractal element antennas are themselves physically smaller, again due to this reactive loading.

Thus fractal element antennas are shrunken compared to conventional designs, and do not need additional components, assuming the structure happens to have the desired resonant input impedance. In general the fractal dimension of a fractal antenna is a poor predictor of its performance and application. Not all fractal antennas work well for a given application or set of applications. Computer search methods and antenna simulations are commonly used to identify which fractal antenna designs best meet the need of the application.

Although the first validation of the technology was published as early as 1995, recent independent studies show advantages of the fractal element technology in real-life applications, such as RFID and cell phones.

One researcher has stated to the contrary that fractals do not perform any better than "meandering line" (essentially, fractals with only one size scale, repeating in translation) antennas. Specifically quoting researcher Steven Best: "Differing antenna geometries, fractal or otherwise, do not, in a manner different than other geometries, uniquely determine the EM behavior of the antenna. However, in the last few years, dozens of studies have shown superior performance with fractals, and the below reference of frequency invariance conclusively demonstrates that geometry is a key aspect in uniquely determining the EM behavior of frequency independent antennas.

A. CHALLENGES

1. Designing Calculations

One of the important parts of antenna designing is the selection of substrate which has particular dielectric constant and should not change its characteristics in any circumstances.

2. Simulation Process

Even a small change in dimensions of patch affects the fringing fields from the edges. It affects the effective length, thereby changing the resonance frequency. In the simulation process assigning of waveport is very important. The feed is fed with coaxial cable with proper calibration of antenna with short circuit and open circuit current and proper termination of transmission line whereas there is no such concept of feeding through cable present in the HFSS software. So, the energy is provided with the help of a sheet called as waveport, placed at the beginning of the feedline to provide excitation to the waveport. Assigning proper boundary conditions in simulation process is most critical parameter. A boundary can be assigned to any two-dimensional area such as a plane, a face of an object or an interface between two objects. Most boundary conditions are used to define electromagnetic characteristics such as conductivity or resistivity. This also includes exciting the structure, and hence any error can result in inaccurate results.

B. Fabrication and Testing Process

There is a little variation in the parameters studied in simulation process and results obtained after fabrication process. After fabrication of antenna, antenna radiates in the atmosphere. At the time of radiation of antenna, there are many metallic objects present in the environment which affects the propagation of electromagnetic waves. Due to these objects, reflections of EM waves take place. This leads to the variation in radiation pattern of antenna. Thus, we get variation in the antenna characteristics. The differences in the results after fabrication can also have a reason of manufacturing defects. It may contain impurities present in the material used for antenna fabrication. Also the environmental conditions like humidity; high temperature affects the charge distribution of patch which affects the characteristics of an antenna.

IV. CONCLUSION

The conventional microstrip patch antenna dimensions shrink to a few microns when operating at such terahertz frequencies. Thus, the design of the patch and its feeding network will be miniaturized extremely, and their fabrications would be extremely difficult. Various new antenna geometry and techniques make antenna efficient for terahertz frequency range. Although fractal shape is very challenging to design and simulate due to its complexity, but there are lot of wireless application. This paper present the reviews of previous research work and comparative study of terahertz frequency range applications. Computer simulation technology software is used to design microstrip patch antenna. Further we make a novel design and enhance parameter performance for THz frequency range, which can be used in the 5G wireless communication application.

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