TERAHERTZ TECHNOLOGY– A NEW DIRECTION

Pradeep Kumar, Ajay K. Singh, G. Singh,
T. Chakravarty,*Member,IEEE,* S. Bhooshan
Department of Electronics and Communication Engineering
Jaypee University of Information Technology, Solan-173 215, India
E-mail: erpradeep_tiet@yahoo.co.in

Abstract

In this article, we have presented an innovative design of the THz microstrip antenna on a lossless dielectric membrane for detection and imaging of the cancer cells. The antenna design utilizes microstrip antenna technique of an annular-ring loaded circular-disk fed by a short microstrip line. Optimization of design leads to a broadband antenna from 300 GHz to 1THz with high radiation efficiency. The antenna yields end-fire beam pattern and can be utilized for pencil like probe on human body.
Keywords: THz radiation, annular ring, circular disk, loaded antenna.

1. Introduction

The THz frequency band (100 GHz - 10 THz) of the electromagnetic spectrum lies in the transition region between the electronics and photonics, which is scientifically rich with emerging possibilities in spectroscopy, sensing, imaging and broadband communication with unique applications in screening for weapons, explosives and biohazards, and concealed objects, but yet unexplored. This gap usually refers to the paucity of the technology – especially sources and detectors of electromagnetic radiation. The photon energies of THz radiation for aforementioned frequency range correspond to the fundamental energies associated with changes between molecular energy levels.

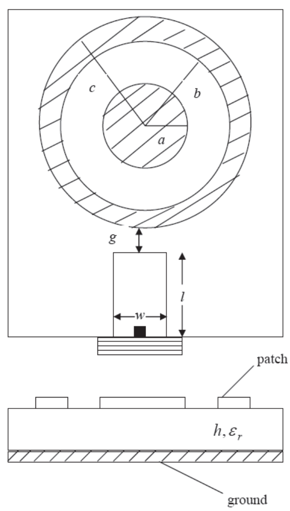

Fig. 1. Schematic of annular-ring loaded circular-patch antenna using microstrip line feed.

The absorption of THz photons is likely to produce changes in the rotational or even vibrational energy states of molecules, and therefore, THz technology have many potential applications as mentioned above. It is readily transmitted through most non-metallic and non polar mediums, thus enabling THz radiation poses either no or minimal health risk to either a suspect being scanned by a THz system or the system's operator [1], [2], [3]. Despite the increasing use of THz technology in many research areas, the virtual absence of practical compact THz sources has limited widespread use of this technology. A microstrip patch antenna is an attractive THz source and detector but it has major disadvantages such as narrow bandwidth and low efficiency. The bandwidth of the antenna can be increased by using various techniques such as by using a thicker substrate or by loading a patch. The use of thicker substrate causes spurious radiation [4-6]. Loading can be done by use of various forms like stub loading, slots, shorting posts, parasitic couplings, substrate loading, superstrate cover, resistors, capacitors, diodes, by gap coupling patches with slightly different resonant frequencies etc [4].

In this paper, the design of circular patch microstrip antenna loaded with an annular-ring and fed through the short microstrip-line has been proposed. The proposed antenna is a broadband antenna from 300GHz to 1 THz. It provides high radiation efficiency and yields end-fire pattern.

2. Antenna Configuration and Theory

The basic geometry of annular ring loaded circular patch antenna is shown in Fig.1. A circular patch of radius 'a' is mounted on a substrate of dielectric constant ε_r and height h. The inner radius of the ring is 'b'and the outer radius is 'c'. Initially, considering the gap to be narrow and the structure as probe free, it is safe to assume that the ring slot, located between outer boundary of the circle and the inner boundary of the annular ring, of width s ($s = b - a$) divides an entire disk of radius 'c' into two regions: the region 1 ($0 < r < r'$) and region 2 ($r' < r < c$), where $r' = \dfrac{b+a}{2}$.

For TM_{np} modes, the field expressions in the two regions are as follows [4]:

For region 1:

$$E_z^{(1)} = -j\omega_{np}\mu C_n^{(1)} F_n^{(1)}(k_{np}r)\cos n\phi \quad \text{.....(1)}$$

$$H_r^{(1)} = -\left(\frac{n}{r}\right) C_n^{(1)} F_n^{(1)}(k_{np}r)\sin n\phi \quad \text{.....(2)}$$

$$H_\phi^{(1)} = -k_{np} C_n^{(1)} F_n^{(1)\prime}(k_{np}r)\cos n\phi \quad \text{.....(3)}$$

where $C_n^{(1)}$ is the amplitude constant for region 1 and

$$F_n^{(1)}(k_{np}r) = J_n(k_{np}r)$$

$$F_n^{(1)\prime}(k_{np}r) = J_n'(k_{np}r)$$

For region 2:

$$E_z^{(2)} = -j\omega_{np}\mu C_n^{(2)} F_n^{(2)}(k_{np}r)\cos n\phi \quad \text{.....(4)}$$

$$H_r^{(2)} = -\left(\frac{n}{r}\right) C_n^{(2)} F_n^{(2)}(k_{np} r) \sin n\phi \quad \text{.....................................(5)}$$

$$H_\phi^{(2)} = -k_{np} C_n^{(2)} F_n^{(2)}{}'(k_{np} r) \cos n\phi \quad \text{.....................................(6)}$$

where $C_n^{(2)}$ is the amplitude constant for region 2 and

$$F_n^{(2)}(k_{np} r) = J_n(k_{np} r) N_n'(k_{np} r_e) - J_n'(k_{np} r_e) N_n(k_{np} r)$$

$$F_n^{(2)}{}'(k_{np} r) = J_n'(k_{np} r) N_n'(k_{np} r_e) - J_n'(k_{np} r_e) N_n'(k_{np} r)$$

$J_n(X)$ is Bessel function of first kind of order n, $N_n(X)$ is Bessel function of second kind of order n, ω_{np} and k_{np} are the angular frequency and propagation constant for TM_{np} mode, respectively.

These expressions are deduced by considering the magnetic wall model. Here r_e is the effective radius of the disk and is given as [4]:

$$r_e = c\left[1 + \frac{2h}{\pi c \varepsilon_r}\left(\ln \frac{\pi c}{2h} + 1.7726\right)\right]^{1/2} \quad \text{.......................................(7)}$$

The field expressions given by equations (1) - (6) have been solved for a transcendental relation by application of boundary conditions. The gap between circular disk and annular ring is represented as in Fig. 2. The resonant frequencies are obtained as [4]:

$$a \frac{F_n^{(1)}{}'(k_{np} a)}{F_n^{(1)}(k_{np} r')} - b \frac{F_n^{(2)}{}'(k_{np} b)}{F_n^{(2)}(k_{np} r')} = X_{np} \quad \text{.....................................(8)}$$

where

$$X_{np} = -\mathrm{Re}\left\{ j \frac{\omega_{np} \mu F_n^{(2)}(k_{np} b)}{k_{np} F_n^{(2)}(k_{np} r')} Y_2 \right\} - \mathrm{Re}\left\{ j \frac{\omega_{np} \mu F_n^{(1)}(k_{np} a)}{k_{np} F_n^{(1)}(k_{np} r')} Y_1 \right\}$$

where

$$Y_1 = y_n^w(a) + y_n^m(b,a), \quad Y_2 = y_n^w(a) - y_n^m(a,b)$$

Solution of expression (8) for given 'n' gives the resonant frequency for TM_{np} mode.

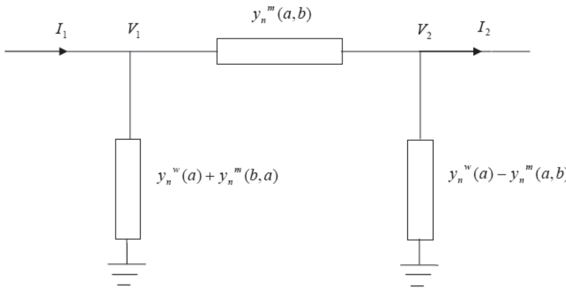

Fig. *2. Equivalent circuit for gap.*

3. Results and Discussion

In the present antenna the configuration is chosen such that the center disk is of radius a = 0.1 mm, annular ring of inner radius b = 0.11 mm and outer radius c = 0.2 mm. The substrate used is 'RT Duroid 5880' of dielectric constant ε_r = 2.2, and the thickness of the substrate is h = 0.125 mm. The computed resonant frequencies using expression (8) are shown in table -1.

Table-1 resonant frequency for different modes

Modes	TM_{11}	TM_{21}	TM_{31}	TM_{41}	TM_{51}	TM_{61}
Frequency(GHz)	172	341	507	665	824	975

The feed has been optimized in such a way that higher order modes radiate efficiently. For applications in medical imaging it is suitable that the antenna radiates in end-fire direction so that the probe can be placed close to the body. This is achieved by using higher order modes. Since the substrate is electrically thick, the bandwidth obtained is large. The simulated return loss is shown in Fig. 3. The 2:1 VSWR bandwidth extends from 480 GHz to 1 THz. The simulated beam pattern is at 850 GHz shown in Fig. 4. In this figure it is seen that maximum radiation occurs at 90^o from zenith or at origin. The cross polar level is at 12 dB down with respect to co-polar. The directivity is seen to be higher than a single patch (5-6 dB). The directivities and gain are given in table -2.

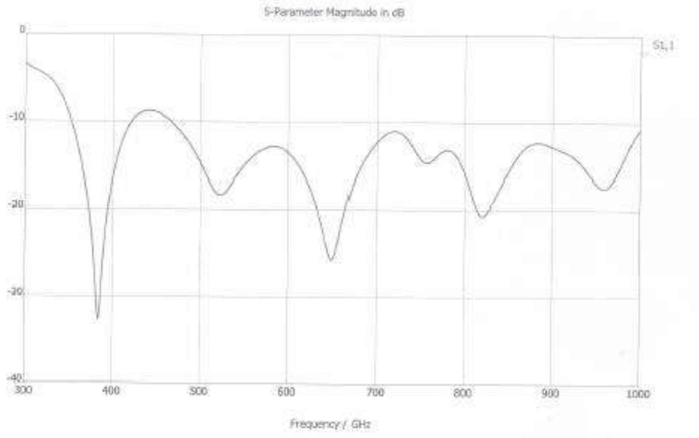

Fig. 3. Return loss of antenna versus frequency.

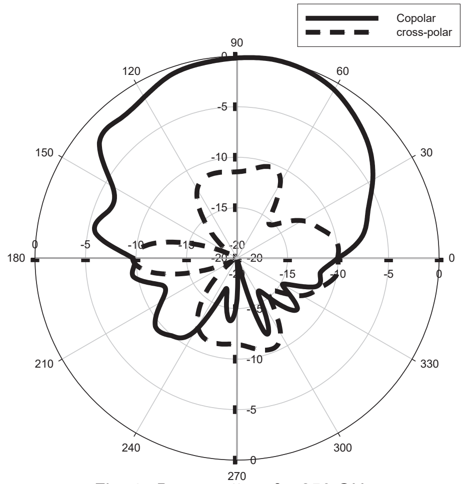

Fig. 4. Beam pattern for 850 GHz.

Table-2 antenna parameters**.**

Frequency (GHz)	Directivity (dBi)	Radiation Efficiency (%)	Gain (dBi)
550	7.518	92.6	7.247
850	8.67	94.5	8.42

4. Conclusion

In this paper, a simple approach of annular ring loaded circular disk microstrip antenna technology has presented for end applications in THz imaging. The low profile antenna utilizes higher order modes for end-fire radiation. The simple theoretical approach is fully supported by simulated results. With techniques now available very small antenna structures can be fabricated making THz antenna feasible.

References

[1] Siegel, P. H., "Terahertz Technology". *IEEE Trans. Microwave Theory and Techniques,* vol. 50, no. 3, pp. 910-928, 2002.

[2] Danil M. Mittleman, Rune H. Jacobsen, Martin C. Nuss, "T-Ray Imaging", *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 2, No. 3, pp. 679-692, 1996.

[3] Arnone, D. D., et al. "Application of Terahertz (THz) Technology to Medical Imaging." In *Proc. SPIE Terahertz Spectroscopy Applications II; International Society for Optical Engineering*: Bellingham, WA, pp. 209–219, 1999.

[4] Tapas Chakravarty, Sushamay Biswas, Arjit Majumdar and Asok De, "Computation of Resonant Frequency of Annular-Ring-Loaded Circular Patch", *Microwave and Optical Technology Letters*, vol. 48, no. 3, pp. 622-626, 2006.

[5] Constantine A. Balanis, "Antenna Theory: Analysis and Design", Wiley, 2005.

[6] David M. Pozar, "Microstrip Antennas" Proceedings of the IEEE, vol. 80, no 1,pp. 79-91, January 1992.

Author Info

Pradeep Kumar: Born in 1981 at Bijnor (UP), graduated in Electronics and Commnication Engineering from Institute of Engineering & Technology, Rohilkhand University Campus, Bareilly-India in 2003 and M.E. from Thapar Institute of Engineering & Technology (Deemed University), Patiala-India in 2005.
He was with Mody Institute of Technology and Science (Deemed University), Lakshmangarh (Sikar)-India for 2005-06. Currently working with Jaypee University of Information Technology, Waknaghat, Solan, India. He is also pursuing his Ph.D from JUIT, Solan. Image Processing, THz radiations & Antenna are the area of specialization.

Ajay K. Singh: Born in 1974 at Dhanbad, graduated in Computer Engg from Kumaon Engg College, Dwarahat (Alamora) in 1998 & M.Tech. from Allahabad Agricultural Institute (Deemed University), Allahabad in 2005. He has worked in the teaching field for over eight years with SSI, DIT, NIT Kurushetra, MITS, Lakshmangarh.
Currently working as Senior Lecturer with Jaypee University of Information Technology, Solan, India. He is also pursuing his Ph.D from JUIT,

Waknaghat, Solan. IVRS, DBMS, THz radiations and Signal processing are the area of specialization.

G. Singh: received M.Sc. degree in physics with specialization in electronics from Purvanchal University, Jaunpur, India, in 1995 and Ph.D. in electronics engineering from Institute of Technology, Banaras Hindu University, Varanasi, India, in 2000. He was associated with Central Electronics Engineering Research Institute, Pilani, and Institute for Plasma Research, Gandhinagar, India, respectively, where he was Research Scientist. He was also an Asst Professor with Nirma University of Science and Tech, Ahmedanad, India. He was a Visiting Researcher at the School of Physics, Seoul National University, Seoul, Korea. At present, he is an Asst Professor with Jaypee University of Information Technology, Solan, India. His research interests include relativistic electronics, cathodes for GW-class microwave sources, plasma physics, surface plasmons, electromagnetics, nanophotonics, THz radiation devices and antenna.

T. Chakravarty: obtained M.Sc. (Electronics Science) from Delhi University in 1988 and Ph.D from Jadavpur University in 2004. He worked as Scientific Officer in SAMEER Mumbai from 1988 to 1993. There he participated in development of MST radar in Gadanki. From 1993, he continued in SAMEER, Kolkata. He was director of Durgapur Institute of Advanced Technology and Management, Rajbandh, Durgapur (India) for 2005-06. Presently he is working as professor with Jaypee University of Information Technology, Solan. His present interests include Microwave passive circuits and Microstrip Antenna.

S. Bhooshan: obtained B. Tech from IIT. Delhi, M.S. from University of Illinois at Urbana-Champaign and Ph.D from University of Illinois at Urbana-Champaign. He joined Hewlett-Packard at their Network and Measurement Division at Santa Rosa California where he worked on a number of measurement related projects. Briefly he joined IIT, Kanpur as Assistant Professor. Thereafter he set up his own consultancy at New Delhi producing a number of products for the television related industry. He has worked in the teaching field for over ten years. Presently, he is working as professor and head, Electronics and Comm. Engineering Dept, Jaypee University of Information Technology, Solan. His interests lie in the areas of Microwaves, Radiation and Propagation, and Digital Communication.