A Ring Slot Excited Dielectric Rod Antenna for Terahertz Imaging

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Introduction

Terahertz radiation has many unique properties that lends itself to applications not possible elsewhere in the electromagnetic spectrum. The radiation passes through many materials that are opaque in the visible spectrum and can be used to form sub-millimeter resolution images. Potential applications for terahertz imaging technology range from skin cancer detection to concealed weapon detection.

Current terahertz imaging systems are limited to acquiring one or a few pixels simultaneously leading to impractically long image acquisition times. Large terahertz imaging arrays are required to realize practical systems and real-time imaging frame rates. Improved performance of existing imaging systems and better fabrication methods are also desired. To address these needs we are investigating an integrated focal plane array of terahertz antennas. We present the theory and simulation results for terahertz dielectric rod antennas excited by a ring slot source, as well as some early fabrication results.

Integrated THz Antenna Arrays

A number of different antennas have been built for terahertz frequencies which perform well as isolated elements, such as those described in [1,2]. For an antenna imaging array we require elements that can be closely packed, perform well in an array environment and be easily integrated with the detector electronics. From a fabrication perspective we want the process to be scalable to large array element sizes. Candidate elements to meet these requirements include dielectric rod antennas. These end-fire surface wave antennas have been shown to perform well in focal-plane arrays [3].

A Ring Slot Excited Dielectric Rod Antenna

The geometry of the antenna is shown in Fig. 1. The antenna consists of a profiled axially-symmetric cylinder (a linear taper is a special case) made from a high permittivity ε_r material with the radius starting from $\rho = \rho_{start}$ and terminating with $\rho = \rho_{term}$ and length ℓ. A ground plane with a ring slot is located at the start of the rod. The high permittivity of the rod material ensures

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the majority of the power radiated from the ring slot is in the positive z direction.

Cylindrical dielectric rod antennas can be excited in a number of different ways, most commonly by a circular waveguide and horn [4]. In this paper we consider the case of a ring slot antenna exciting the HE_{11} surface wave on the rod. High excitation efficiency is considered important for broadband operation of the rod with the intention that the gain is determined primarily by the termination radiation rather than the interaction between the feed and termination radiation.

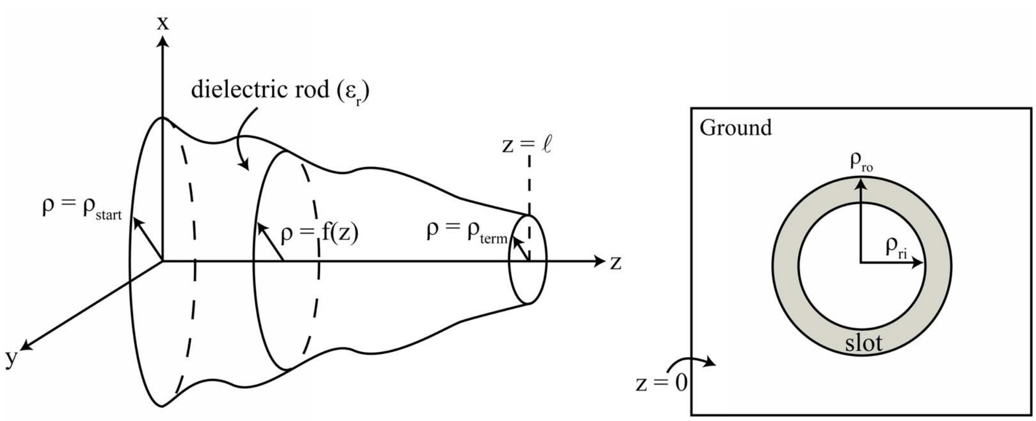


Figure 1: a) Cylindrical dielectric rod antenna b) exciting ring slot

The ring slot antenna is excited in its first resonant mode where the guided wavelength equals the average ring circumference. Fig. 2 shows the computed excitation efficiency of the HE_{11} surface wave for a range of rod diameters with $\varepsilon_r = 9.65$. From Fig. 2 we can see that 90% excitation efficiency is possible with a $0.31\lambda_0$ rod diameter. The excitation efficiency decreases for thicker diameters because of the increasing excitation of the HE_{12} mode. This mode is a leaky wave for diameters less than approximately $0.42\lambda_0$ and has an undesirable impact on the antenna radiation pattern. From this we conclude that a high excitation efficiency of the HE_{11} surface wave is possible; however, the value of $\rho = \rho_{start}$ is critical for determining this. The rod diameter must be thick enough at the input to ensure efficient slow wave excitation but should be thin enough to prevent the excitation of high order leaky modes.

A ring slot excited dielectric rod antenna was simulated using CST Microwave Studio with the parameters shown in Table 1, which are compatible with our fabrication process. Fig. 3a shows the computed return loss of the antenna. From this we can see that the antenna provides a good impedance match from 540GHz to 660GHz. This frequency range was chosen to fall within the band of our backward wave oscillator source. Fig. 3b shows the simulated radiation pattern.

Parameter	Value
ρ_{start}	180 (μm)
ρ_{term}	50 (μm)
ℓ	1500 (μm)
ε_r	9.65
ρ_{ri}	37.6 (μm)
ρ_{ro}	47.6 (μm)

Table 1: Dielectric rod antenna parameters

Fabrication Results

The length of the dielectric rod and the surface tolerances preclude the use of conventional milling or photolithographic fabrication techniques for forming the rod. To overcome these limitations a fabrication process using laser ablation has been developed. The dielectric rods were formed by removing material from the dielectric substrate to leave free standing rods. The process was adapted to allow a gentle taper to be formed on the rods allowing for broadband operation and greater gain. Magnesium oxide (MgO) was chosen as the substrate material because of its low absorption in the terahertz region, its suitability for laser ablation and compatibility with superconducting detectors. Laser ablation was carried out using a frequency quadrupled Nd:YAG system (266nm) with 200μJ pulses at a 1kHz pulse repetition rate. Fig. 4a shows a scanning electron microscope (SEM) image of a short prototype rod which has been ejected from the substrate and Fig. 4b shows a rod still connected to the substrate. The fabrication process is thought to be scalable to large array sizes.

Conclusion

We have evaluated the use of dielectric rod antennas for a terahertz imaging array. It was shown that a ring slot can excite the HE_{11} surface wave of a cylindrical rod antenna with high efficiency provided the combination of the starting diameter of the rod and permittivity are selected correctly. Early fabrication results were presented for a dielectric rod with a linear profile.

References

[1] D. Rutledge, “Substrate-lens coupled antennas for millimeter and submillimeter waves,” *Antennas and Propagat. Society Newsletter, IEEE,* vol. 27, pp. 4-8, 1985.

[2] D. Rabanus, C. Granet, A. Murk and T. Tils, “Measurement of properties of a smooth-walled spline-profile feed horn around 840GHz,” *Infrared Physics & Technology,* vol. 48, pp. 181-186, 2006.

[3] Richter, J., Schmidt, L.P., "Dielectric rod antennas as optimized feed elements for focal plane arrays," in *Antennas and Propagation Society International Symposium,* 2005, vol. 3A, pp. 667- 670, 3-8 July 2005.

[4] T. Ando, I. Ohba, S. Numata, J. Yamauchi and H. Nakano, “Linearly and curvilinearly tapered cylindrical dielectric-rod antennas,” *IEEE Trans. Antennas & Propagat.*, vol. 53, pp. 2827-2833, 2005.

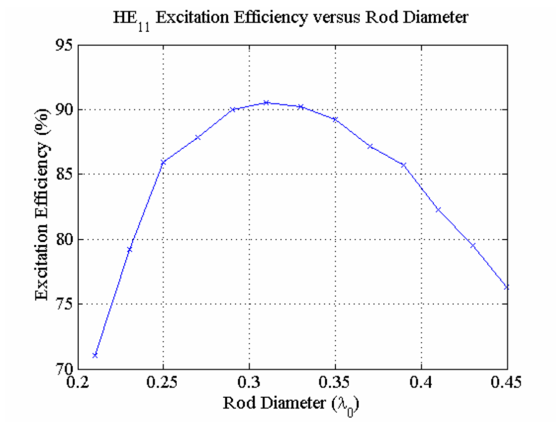
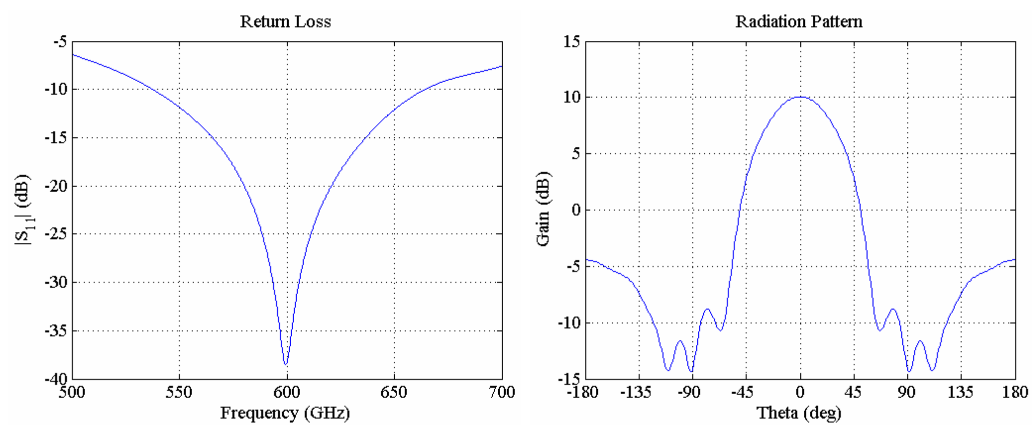
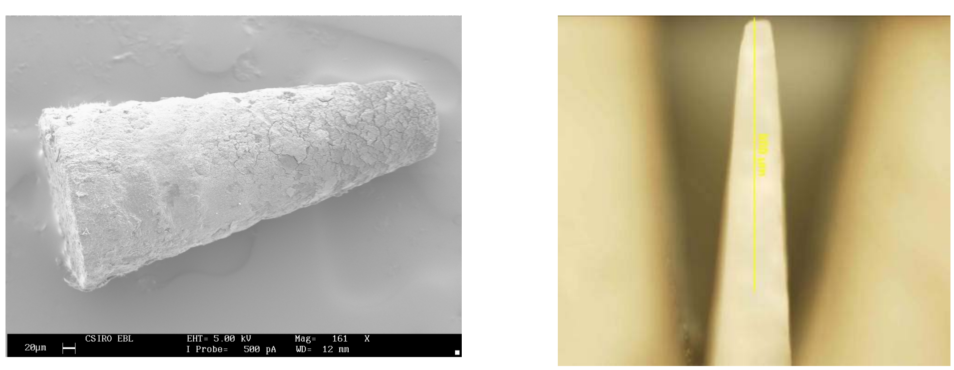


Figure 2: HE_{11} guided surface-wave excitation efficiency for a ring slot antenna



a) b)

Figure 3: Computed a) return loss and b) radiation pattern at 600 GHz



a) b)

Figure 4: a) SEM picture of an ejected rod and b) cross-section of rod with surrounding substrate removed