Optimization of a Small Lens for a Leaky-Wave Slit Dipole Antenna at the Terahertz Band

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Abstract - **In this paper, we optimized the small lens for a slit dipole antenna to behave as a leaky-wave antenna. An extended hemispherical silicon lens was attached at the back side of a slit dipole antenna and the antenna gain and radiation pattern characteristics were investigated over a frequency range from 200 to 400 GHz. The numerical results show that the antenna gain responses exhibit a higher level of sensitivity against lens size and increase linearly with increasing lens radius. A lens with a radius of 1.2 λ_o is identified as the smallest lens size for the slit dipole antenna on an extended hemispherical silicon lens.**

Index Terms—**Leaky-wave antennas, lens-coupled antennas, lens optimization, slit dipole antennas.**

1. Introduction

The terahertz band has attained significant importance recently due to the large bandwidth available to meet the demand for fast and high data rate communication systems. Compared to lower frequency bands, this band offers wider bandwidth and a less congested spectrum [1]. The terahertz band has found its place in many other attractive applications, such as radio astronomy, atmospheric research, chemical spectroscopy, medical imaging, security screening, and defense [2], [3].

Extensive research has been carried out to couple planar antennas and substrate lenses. Past studies have investigated lens-coupled antennas, including dipole antennas [4], folded-dipole antennas [5], bow-tie antennas [6], annular-slot antennas [7], and log-periodic antennas [8]. In this paper, we designed a slit antenna that is coupled to an extended hemispherical silicon lens, and we investigated the size and shape of the lens for lens optimization at a frequency of approximately 300 GHz. The investigation was carried out using the finite-integration time-domain simulator from CST Microwave Studio

2. Antenna Geometry

The detailed geometry of the slit dipole antenna backed by an extended hemispherical silicon lens (ε_r = 11.9) is shown in Fig. 1. The slit dipole antenna consists of an open-ended narrow slit of width $W_s=10$ µm, which is fed by a short dipole at the center. The short dipole has a width and gap of $W_d=10$ µm and $g=10$ µm, respectively. The silicon lens has an extension length and radius of T and R, respectively. The antenna is fed by a discrete port having 50 Ω characteristic impedance, placed at the center feed gap. The metal layer used in antenna has thickness of 0.35 µm and conductivity of 1.6×10^7 S/m. The lenses with different radii (R) were selected in the study to optimize the lens size and shape. The shape of the lens, determined by the T/R ratio, was optimized for each lens size by varying the T/R ratio. The lens shape optimization is very important because it plays a key role in maximizing antenna gain and radiation spectral bandwidth in lens-coupled antennas [9].

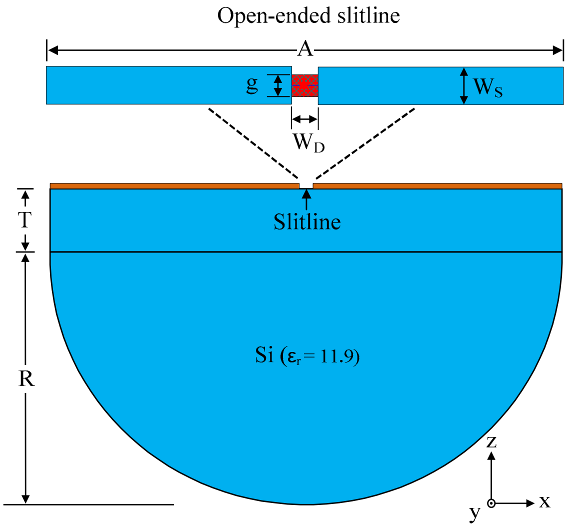

Fig. 1. Geometry of the slit dipole antenna coupled to the extended hemispherical silicon lens.

3. Antenna Characteristics

Three lenses having radius (R) of 0.8 λ_o (0.8 mm), 1.2 λ_o (1.2 mm), and 1.6 λ_o (1.6 mm) were selected for study, where λ_o is the wavelength of the central frequency of 300 GHz in free space. The optimized shape of each lens, determined by the T/R ratio, was obtained by changing the T/R ratio. The slit antenna showed the best gain curves for all lenses at T/R=0.34. Thus, we maintained this optimized ratio of T/R for each lens size in our study. The antenna gain responses with different lens sizes with the optimized shape (T/R=0.34) is shown in Fig. 2. The antenna gain increased

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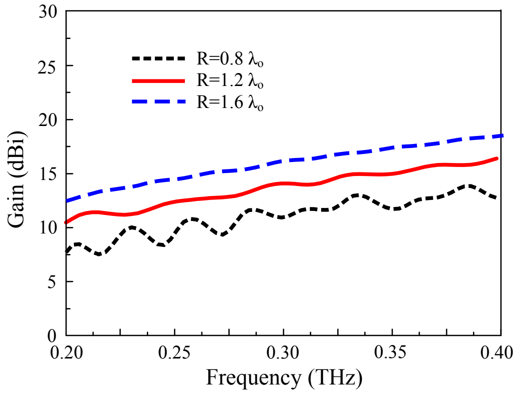
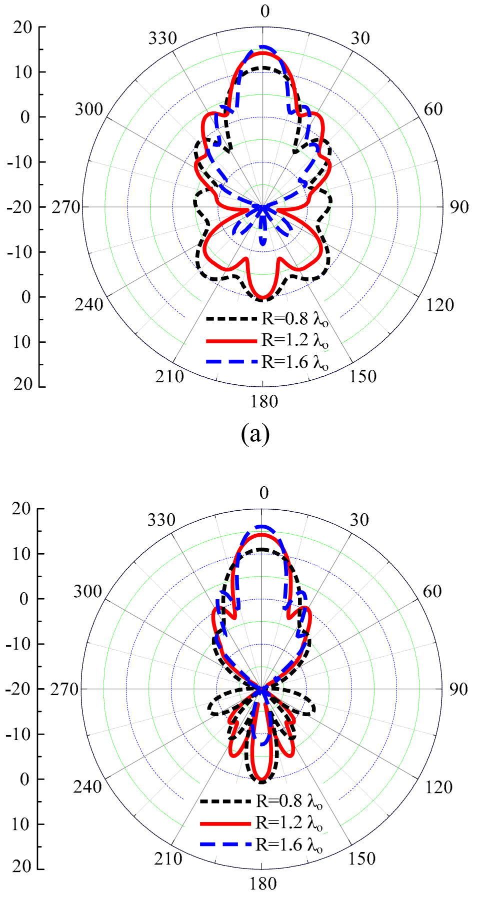


Fig. 2. Antenna gain performance for different lens radii with optimized lens shape (*T*/*R*=0.34).



(a)

(b)

Fig. 3. Radiation patterns of the antenna with different lens radii (*R*) and optimized lens shape (*T*/*R*=0.34) at 300 GHz: (a) xz-plane and (b) yz-plane.

with the increasing lens radius. Improvements in the gain level were obtained by increasing the lens radius from 0.8 λ₀ to 1.6 λ₀ with an increment of 0.4 λ₀. With the smaller lens, the antenna showed low and fluctuating gain behavior. The lens with the radius of 0.8 λ₀ also gave a low and fluctuating gain. The antenna gain noted at 200 GHz was 7.8 dBi and increased to 12.7 dBi at 400 GHz. The gain of the antenna with the lens radius of 1.2 λ₀ increased smoothly from 10.5 dBi to 16.5 dBi, with an increase in frequency from 200 GHz to 400 GHz. Similarly, the lens with a radius of 1.6 λ₀ produced a higher gain level of 12.5 dBi at 200 GHz, which increased up to 18.5 dBi at 400 GHz. Thus, each lens size gives a low gain at lower frequencies, and the antenna gain increases with frequency. This is because the effective size of the radiating element increases at higher frequencies.

Fig. 4 shows the radiation patterns of the antenna for the different lens radii at the center frequency of 300 GHz. Generally, the *yz*-plane patterns showed relatively clean profiles, with few back and side lobes, while the *xz*-plane showed more back and side lobes. The number of back and side lobes in both principal planes increased with an increase in lens radius. Furthermore, we saw a narrowing of the main beam and an increase in the gain level with increasing lens radius. This is because of the increasing aperture size of the lens and the resulting enhancement of the beam collimation.

4. Conclusion

The influence of lens shape and size on the characteristics of the slit dipole antenna was studied over a frequency range of approximately 300 GHz to optimize the extended hemispherical lens for slit dipole antenna. The results showed that the lens size and shape play an important role in determining the gain and radiation spectral bandwidth of the antenna. A lens with a radius of 1.2 λ₀ is found to be the best minimum lens size for a slit dipole antenna on an extended hemispherical silicon lens to behave as a leaky-wave antenna.

Acknowledgment

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