Performance Comparison of the Bowtie and Hexagonal Bowtie Terahertz Photoconductive Antennas

E. Rahmati
Department of Electrical Engineering
Sharif University of Technology
c_rahmati@ec.sharif.edu

M. Ahmadi-Boroujeni
Department of Electrical Engineering
Sharif University of Technology
ahmadi@sharif.edu

Abstract— One of the most common devices for terahertz (THz) wave generation and detection is a THz photoconductive antenna. This paper presents a numerical study of Hexagonal bowtie antenna and bowtie antenna on the LT-GaAs substrate employed as emitter in THz pulse systems. The performance of Hexagonal bowtie antenna has been examined from several aspects (radiation efficiency, directivity, impedance matching and total efficiency) and compared to that of bowtie antenna via the use of a full-wave electromagnetic solver (CST). The results show that the Hexagonal bowtie antenna has better performance than the bowtie antenna.

Keywords-component: Pulse systems; THz photoconductive antenna; Hexagonal bowtie antenna; Bowtie antenna

I. INTRODUCTION

Terahertz (THz) technology has recently become one of the most active research areas and has received much attention with technological advances such as high-power THz generation, THz imaging and THz time-domain spectroscopy (THz-TDS) [1], [2]. Among the various types of sources, photoconductive (PC) antennas with ultrashort pulse laser excitation are widely used as THz emission sources and bowtie antenna is a typical PC antenna in these systems. However, low achievable THz output power is a major challenge restricting THz systems from wider commercial application, especially for applications in which broadband THz pulses are required.

The principle of generation of THz wave from the photoconductive antenna is based on accelerating photo-carriers in a semiconductor and coupling the resultant field to free-space via a printed antenna structure. In a THz photoconductive antenna, with the illumination of femtosecond laser pulses, electron-hole pairs are created in photoconductive material provided that the photon energy exceeds the band-gap of the PC material. Using the metallic structure of the antenna, one can apply a DC bias voltage across the illuminated region. The applied bias voltage accelerates the photo-excited carriers. The quick change in electric field at the gap, when laser signal has a sufficiently short time period, i.e., roughly 100 fs, results in a transient current and finally an electromagnetic pulse in the THz frequency range is radiated [3], [4].

Having wideband characteristics, bowtie antennas are a common choice for pulsed THz PC antennas. Quadrangular bowtie antenna is proposed as a UWB antenna in the microwaves regime [5], [6]. A revised version of these antennas is the Hexagonal bowtie antenna. In this paper, we present an optimized bowtie antenna which has high radiation efficiency and directivity and show that by using hexagonal bowtie antenna in THz PC structures, one can obtain not only high directivity and radiation efficiency but also higher total efficiency and better impedance matching compared with the optimized bowtie antenna.

II. STRUCTURE OF THz PHOTOCONDUCTIVE ANTENNA

A. Optimized Bowtie Antenna

The structure of photoconductive optimized bowtie antenna is shown in Fig.1. A 0.35μm-thick Ti-Au bowtie antenna with width of d=15 μm, flare angle of θ=60° and length of 100 μm was used as a main radiator. The antenna is printed on a thin layer of LT-GaAs. As shown in Fig.2, the LT-GaAs substrate with a thickness of 1μm is placed on the top of a GaAs (lossy) substrate of 35-μm height. The GaAs substrate is also backed by a 0.35 μm-thick Ti-Au layer as the ground plane.

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For the back-excitation configuration, a vertical cylinder with a height of 32-µm and a radius of 10- µm is cut through the ground plane and the GaAs substrate. This cylinder creates a light path from the illumination source toward the feeding area of the bowtie antenna [7].

B. Hexagonal Bowtie Antenna

When operating in pulsed mode, since the terahertz radiating antenna is being driven by a broadband pulse of electrical current, the ideal antenna should be chosen to offer a broadband radiation resistance while maintaining a reactance value near 0 Ω [8]. For this purpose, a revised version of optimized bowtie antenna i.e., the Hexagonal bowtie antenna, is designed. The Hexagonal bowtie antenna is designed to offer a broadband radiation resistance of 30–120 Ω and a relatively low reactance level.

As shown in Fig.3, Hexagonal bowtie antenna is formed by truncating the outer edges of a bowtie antenna and converting its shape to a kite-shaped polygon. Two antennas are designed and simulated with the same flare angle, length and width dimensions for the sake of comparison. In order to demonstrate the effective performance of presented configuration in THz band, both the bowtie planar antenna and the hexagonal bowtie antenna are analyzed by the finite-difference time domain (FDTD) method and the obtained results are compared.

III. RESULTS AND COMPARISON

In this section, results of the numerical study of the hexagonal bowtie antenna are compared with those of the bowtie antenna. The CST Microwave Studio is used for numerical analyses. Fig.4 shows the simulated impedance versus frequency for designed Hexagonal bowtie antenna in comparison with bowtie antenna over 0.4-0.8 THz. It can be seen that by using Hexagonal bowtie antenna, impedance characteristics of the antenna for impedance matching is improved. As shown in Fig. 5, the improved impedance characteristics of the Hexagonal structure enhances the total efficiency of the antenna while the directivity remains unchanged. In the antenna design, the reflection coefficient Γ is determined by Eq. 1. The total efficiency ηtotal the product of the radiation efficiency ηradiation and matching efficiency ηmatching is expressed by Eq. 2 [9].

![Figure 1. Bowtie antenna (top view)](image1)

![Figure 2. Bowtie antenna (side view)](image2)

![Figure 3. (a)Hexagonal Bowtie antenna, (b) Bowtie antenna.](image3)

![Figure 4. Real and imaginary parts of antennas impedance](image4)
The third Iranian Conference on
Engineering Electromagnetic
(ICEEM 2014),
Dec. 3-4, 2014

\[
\Gamma = \frac{z_{\text{antenna}} - z_{\text{photoconductive}}}{z_{\text{antenna}} + z_{\text{photoconductive}}}
\]  

\[
\eta_{\text{total}} = \eta_{\text{radiation}} \times \eta_{\text{matching}} = \eta_{\text{radiation}} \times \left(1 - |\Gamma|^2\right)
\]

Finally, we investigated the directivity and the radiation pattern of the antennas. Fig. 6 shows the simulated directivity versus frequency at boresight direction of antenna (\(\theta=0^\circ\)). As can be seen in this figure, both structures have the same directivity in 0.4-0.8 THz. Fig. 7 shows radiation pattern of the antennas. It is evident that both antennas have also similar radiation patterns over the mentioned frequency range.

Impedance of a photoconductive semiconductor illuminated by a femtosecond laser commonly varies between 10 and 100 depending on the quality of the material and the laser power [4]. Hereafter, the matching efficiency is calculated by assuming a photoconductive impedance of 50 \(\Omega\) and the corresponding total efficiency is calculated using Eq. 2. As shown in Fig. 5, both antennas have same radiation efficiency of nearly 95\%, but the total efficiency is increased by about 20\% in the Hexagonal bowtie antenna.

![Figure 5. Efficiency of Bowtie and Hexagonal bowtie antennas](image1)

![Figure 6. Directivity of Bowtie and Hexagonal bowtie antennas](image2)

![Figure 7. Simulated radiation pattern of antennas at 0.7 (THz)](image3)
IV. CONCLUSION

In this paper, we present an optimized Bowtie terahertz photoconductive matching antenna. In order to obtain a wideband impedance matching, Hexagonal bowtie antenna is proposed in THz band and its performance including radiation efficiency, directivity, impedance matching and total efficiency are compared with those of a conventional bowtie antenna. The analysis results show that due to better impedance characteristics the Hexagonal bowtie structure can outperform the bowtie structure in photoconductive antennas for THz pulse generation.

REFERENCES


