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Wideband hemispherical dielectric lens antenna with stabile radiation pattern for advanced wideband terahertz communications

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ABSTRACT

This paper demonstrates a terahertz wideband antenna with Quartz hemisphere lens. The antenna has wide impedance bandwidth of 100%, −58.7 dB minimum return loss, high average radiation and total efficiencies of 89.7% and 88.4% respectively. Maximum gain of 13.2 dB is achieved at 1120 GHz. The antenna radiation pattern is shown at nine frequencies which represents steady pattern and main lobe direction. Finally we provide a comparison between the antenna and some main previous works.

1. Introduction

Terahertz (THz) or tremendously high frequency [1] is known as electromagnetic spectrum between 0.1 THz to 10 THz and lies in frequency gap between microwave and infrared. The THz high frequency and huge unlicensed bandwidth pave the way for having high speed communications such as data rate of over 64 Gbit/s [2] for satisfying unprecedented demand for higher data rate wireless communications in the recent decade. The THz data transmission speed is much higher than microwave and even than 60 GHz [3] and 120 GHz [4] bands millimeter-wave links.

Medical imaging is one of the interesting THz applications which because of higher THz operation frequency compare to microwave, THz images have better resolutions [5,6]. This THz advantage is very interesting in some medical applications, for example in cancer tumor detection higher resolution means detecting smaller tumor in earlier stage and having more chance and time to cure it. Meanwhile, THz radiation is non-ionizing and has low photon energy which compare to dangerous X-Ray radiation, is safer for patients and medical staff.

In industry and commercial applications THz frequency has potential for inspecting products [7]. THz radiation can pass through nonpolar substances like conductive wire coating and this property makes THz an appropriate candidate for Non-Destructive (NDT) inspecting of electric wires [8].

Due to interesting and various THz applications in different areas, designing THz antennas which is one of the most important components of wireless THz systems has been attracted many researches [9–11] such as rectangular patch antenna based on 20 μm polyimide substrate [12], graphene nanoribbon based antenna [13].

On the other hand, because of high atmospheric losses in the THz frequency region designing high gain and directive THz antenna is valuable. Using dielectric lens is one of the popular and useful methods for increasing antenna gain. Novel antenna with silicon lens fed by a leaky wave enhanced waveguide is developed [14] and authors in [15] present ring-resonator

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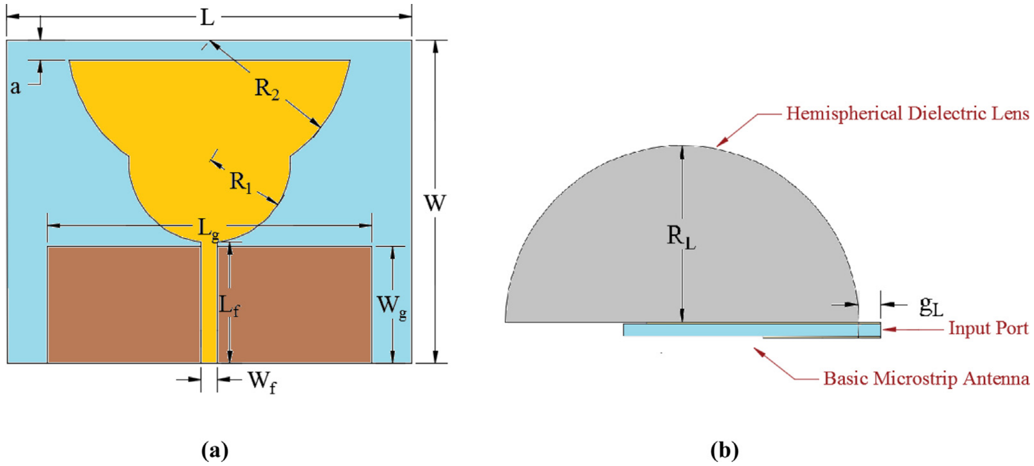

Fig. 1. Antenna view, (a) Basic microstrip antenna and (b) Proposed lens antenna.

integrated hemi-elliptical lens for 600 GHz applications. In [16] antennas on extended hemispherical and elliptical silicon dielectric lenses, [17] silicon micromachined lens and [18] low-cost discrete dielectric lens based on 3D printing technology are provided.

In the previous work [19] we coated top of a small copper reflector by 40 μm Quartz layer which led to increase 35.4% Maximum gain. In this work we get benefit from hemisphere Quartz that is used as dielectric lens for increasing antenna gain.

Having simple structure is always suitable regardless of antenna operation frequencies and applications. But in the THz frequency region due to small size of antenna becomes very important. Therefore, one of our focuses on designing the antenna in this paper, is to have simple structure. We design simple shape of lens that is hemispherical instead of hemi-elliptical [15], the extension length for matching antenna and lens is eliminated and a wideband hemispherical dielectric lens antenna for THz application is presented. First a basic single layer THz microstrip antenna is designed and in the next step the antenna is equipped with dielectric lens. The proposed lens antenna is studied in 400–1200 GHz frequency region.

In this paper, Section 2 describes the antenna structure. The results are demonstrated in Section 3 and finally the paper is concluded in Section 4.

2. Antenna design

An input signal is transferred by a microstrip feed line which has $W_f = 20\ \mu m$ width and $L_f = 300\ \mu m$ length for exciting antenna radiation patch. The patch is derived by merging two minor and major circles with $R_1 = 200\ \mu m$ and $R_2 = 350\ \mu m$ radiuses, respectively. The antenna is based on $L = 1000 \times W = 800 \times h = 10\ \mu m^3$ Rogers RT5880LZ substrate that have dielectric constant of 1.96 and loss tangent of 0.0019.

The basic microstrip antenna is shown in Fig. 1(a), for increasing the antenna gain, we get benefit from dielectric lens. Therefore, the antenna is equipped with a hemisphere Quartz lens as displayed in Fig. 1(b). The lens has radius of $R_L = 480\ \mu m$, 3.75 dielectric constant and 0.0004 loss tangent. Another antenna parameters are: $L_g = 800\ \mu m$, $W_g = 290\ \mu m$, $g_L = 80\ \mu m$ and $a = 50\ \mu m$.

3. Results and discussions

The basic microstrip antenna gain plot shows by green solid color in Fig. 2. The antenna has Maximum gain of 6.1 dB at 1180 GHz and minimum of 2.9 dB at 400 GHz.

Adding Quartz hemisphere lens to the basic antenna structure leads to increase antenna gain in whole bandwidth. The antenna Max gain goes up to 13.2 dB (116.4% increasing) at 1120 GHz and Min to 8.7 dB (200% increasing) at 400 GHz. Average gain increases 161.4%, from 4.4 dB to 11.5 dB.

However the basic antenna is equipped with dielectric lens which generally leads to decrease efficiency due to reflection and loss inside dielectric lens [20,21] but the proposed antenna has high efficiency. The Maximum amount of total and radiation efficiencies are 94.8% at 445 GHz and 94.9% at 400 GHz with averages of 88.4% and 89.7%, respectively.

The efficiency decreases by increasing operation frequencies because of having higher loss at upper operation frequency in dielectrics, Rogers and Quartz. Therefore, a downtrend is observed in the efficiency plots, as shown in Fig. 3.

The proposed antenna provides an impedance bandwidth from 400 GHz to 1200 GHz. It is noticeable that 400–1003.9 GHz frequency region is covered by return loss lower than −15 dB. The antenna has minimum return loss of −58.7 dB at 590.4 GHz and six resonant frequencies with return losses lower than −25 dB, as illustrated in Fig. 4.