

Elliptical Monopole Antenna on InP Substrate for Sub-THz RTD-based Oscillators

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Abstract—The high permittivity of InP substrates has been a limiting factor for the bandwidth and efficiency of antennas fabricated in this material. In this manuscript we propose an elliptical monopole, monolithically fabricated in InP, fed by a CPW line. The suggested topology was simulated using HFSS finite element method. Input reflection coefficient measurements were performed on the monopole to validate the proposed antenna. Simulated and measured -10 dB bandwidths of 27 and 24 GHz were obtained, respectively. The peak simulated efficiency and realized gain were 95.37% and 4.6 dBi.

I. INTRODUCTION

Antennas fabricated on high permittivity materials typically suffer from reduced bandwidth and degraded efficiencies. At sub-THz frequencies the permittivity of InP was measured to be $\epsilon_r = 12.33$ and the loss tangent $\tan \delta = 0.009$ [1]. Brown [2] stated that the ratio of radiation which goes in to the substrate and the one that escapes to free space is approximately $\epsilon_r^{3/2}$. Additionally, he concluded that, if the frequency is within the sub-THz range, substrate modes appear which distort the radiation pattern of antennas and lead to a guided wave being reflected in the top and bottom interfaces.

In 1993, Brown proposed a photonic crystal for GaAs to circumvent substrate modes and enhance the air to substrate radiation ratio. Nonetheless, Brown's work requires a well established but expensive fabrication process. In 2015 Choi proposed a wire array design using three layers of benzocyclobutene (BCB) on top of an InP substrate, which yielded a simulated gain of 5 dBi with a peak radiation efficiency of 70% [4]. Lee proposed a rectangular cavity antenna from which he attained a maximum radiation efficiency of 70% and a bandwidth of 41 GHz centred at 300 GHz [5]. In 2016 Choi designed a rectangular cavity antenna for operation at 280 GHz, albeit with a relatively low radiation efficiency of 52% and an impedance bandwidth of 20 GHz [6].

In 1992, Honda reasoned from the symmetry of the disk monopole that it should exhibit broadband omnidirectionality [7]. From this work onwards, planar topologies were proposed for low frequencies and omnidirectional ultra wide-band (UWB) applications, where ground plane shaping was used for impedance matching [8]. For sub-THz frequencies Li suggested the usage of the circular monopole in a photonic transmitter where the high permittivity GaAs substrate beneath the antenna was removed [9].

In this study we propose the usage of an elliptical monopole, monolithically fabricated in InP for easy integration with the resonant tunneling diode (RTD) oscillator. This antenna exhibits a wideband reflection response and is meant to be used as a radiating element for RTD-based oscillators to achieve air-side radiation. Shaping the ground plane of the feeding coplanar waveguide line enables one to attain better impedance matching, radiation pattern stability and satisfactory front-to-back ratio for the envisaged application. The paper is organized as follows: the next section addresses the proposed topology and preliminary design; section III focuses on the simulation of the antenna performance on the InP substrate and presentation of measurement results; in section IV the final conclusions and future work guidelines are given.

II. ANTENNA DESIGN

The model of the antenna is represented in Fig. 1. An InP substrate with a height of $100 \mu\text{m}$ and a 400 nm thick gold metallization were used for designing the monopole. We considered a permittivity of $\epsilon_r = 12.6$ for the design as given by the fabrication technology. An exponential shaping of the form $y = k \cdot e^{ax}$ was introduced in the ground-plane to improve the bandwidth when compared to a linear cut. The factors k and a are obtained from the (x, y) coordinates of the points that the exponential curve should intersect. The design variables were swept to achieve optimum performance and their final values were obtained as follows: $D = 190 \mu\text{m}$, $d = 120 \mu\text{m}$, $g = 6 \mu\text{m}$, $h = 137.5 \mu\text{m}$, $w = 51 \mu\text{m}$. An infinite reflector plane was considered below the substrate to obtain air-side radiation.

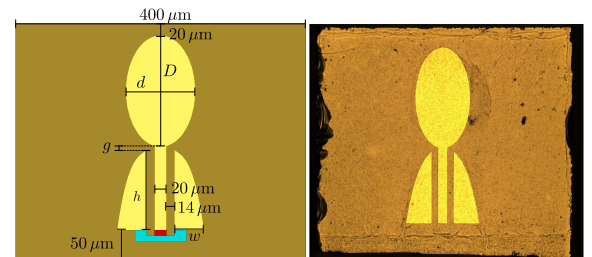


Fig. 1: Antenna model used for finite element method simulation in HFSS (left) and fabricated sample (right).

III. RESULTS AND DISCUSSION

The measurement setup depicted in Fig. 2 was used to characterize the reflection coefficient of the proposed antenna. The antenna sample was placed above a large copper reflector to mimic the simulation model where an infinite reflector plane was used.

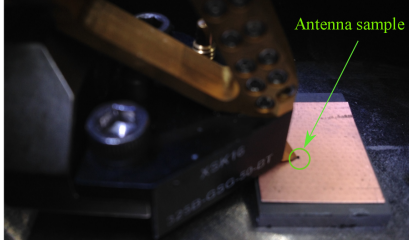


Fig. 2: Measurement setup with probing station, reflector plane and antenna sample.

In Figs. 3 and 4 the measured reflection coefficient magnitude and simulated radiation patterns are shown, respectively. A good agreement can be seen between the measured and the simulated $|S_{11}|$, despite the presence of some undesired reflections from the measurement setup and a slight offset in the resonant frequency, the latter most likely due to moisture absorption causing InP permittivity to fluctuate. The radiation patterns were verified to remain unaltered throughout the operating bandwidth of the antenna. The simulated peak realized gain and peak efficiency were 4.6 dBi and 95.37%, at 300 GHz, respectively.

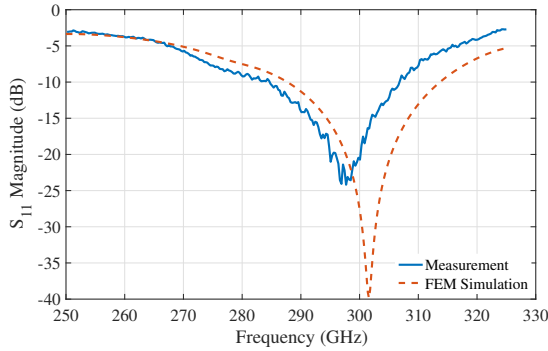


Fig. 3: Measured and simulated $|S_{11}|$ of elliptical monopole.

IV. CONCLUSION

In this work a successful implementation of an elliptical monopole in InP for sub-THz communications was shown. The good agreement between the measurements and the simulation results validated the proposed antenna, which was carefully designed to mitigate substrate modes and achieve air-side radiation. Nonetheless, some variations on the InP permittivity shall be considered on future designs.

The possibility of including this antenna as feeding element of a larger horn antenna is also interesting as the gain can be highly improved, thus increasing the distance at which high throughput communications can occur.

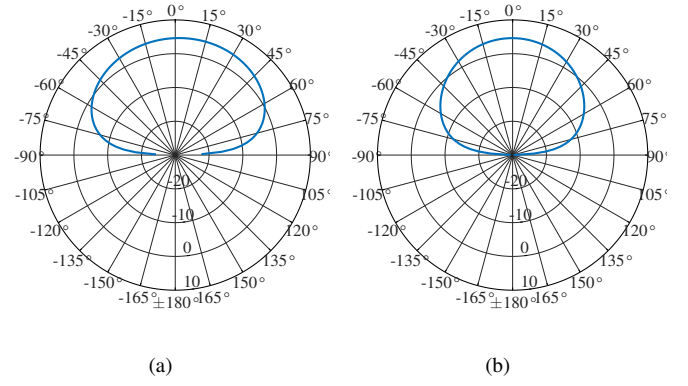


Fig. 4: Simulated E-plane (a) and H-plane (b) radiation patterns at 300 GHz.

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