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Admittance Matching of 60 GHz Rectangular Dielectric Resonator Antennas for Integrated Impulse Radio

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Abstract—Methods to achieve admittance matching of rectangular dielectric resonator antennas intended for 60 GHz impulse radio are reported. The motivation is to find a suitable antenna that may be integrated in the V-band gated tunnel diode wavelet generator, replacing its tank circuit and forming a low complexity transmitter. Probed one- and two-port scattering parameter measurements have been performed to characterise the fabricated antennas. Changing the feed structure from a tapered dipole to an offset fed and tapered slot, a change from capacitive to inductive characteristics is observed, and the matching to the gated tunnel diode is improved. Deembedded admittance resonance frequencies of fabricated antennas were found at 53.6 and 52.2 GHz for dipole and slot fed antennas, respectively. Characterising the transmission link between dipole fed antennas, a maximum antenna gain of 10.5 dBi and a 3 dB power bandwidth of 1.5 GHz were found at 53.3 GHz.

I. INTRODUCTION

Wireless communication at 60 GHz is attractive for operation at high bit-rates and integrated impulse-based systems offer broadband low-power consumption transmitter solutions, requiring compact and energy efficient integrated antennas. Coplanar microstrip or waveguide antennas on electrically large semiconductor substrates are not feasible for impulse operation as they disperse the transmit signal into uncontrollable high order propagating modes [1]. High, V-band, operation frequency introduce the possibility to cut a dielectric resonator antenna (DRA) from the substrate and use an electrically small probe to feed it. DRAs have been studied for their effective radiation characteristics, small size and diversity of compatible feed methods. Placed on a mirror groundplane for increased directivity and compactness, a high performance and scalable antenna may be achieved.

We are targeting a rectangular DRA for our gated tunnel diode (GTD) wavelet generator, which is fabricated on 650 µm thick semi-insulating GaAs. Successful integration with an antenna that actively tunes the GTD to resonance at 60 GHz will produce an energy efficient wavelet transmitter operable in impulse mode by e.g. pulse position, frequency or binary phase shift keying [2], [3]. Constructing a transmitter using a matched antenna, without any matching network or buffer, has advantages such as low power loss and minimal integration complexity.

In this work, different antenna feed structures on rectangular DRAs are fabricated and the admittance matching to the GTD evaluated. Also, transmission measurements between dipole fed DRAs demonstrate the functionality of the fabricated antennas.

II. GTD WAVELET TRANSMITTER

A resonant tunnel diode (RTD) may be utilised as the active component in an oscillator circuit since it possesses the physical property of negative differential conductance [2], [4]. The GTD is fabricated through incorporation a third terminal in the form of a permeable gate adjacent to the double barrier heterostructure of an AlGaAs/GaAs RTD. This has been made possible through the method of epitaxial GaAs overgrowth over ultra-thin tungsten wires [5]. Since the magnitude and sign of the GTD output conductance is related to the electrostatically controlled RTD area, it may be tuned using the gate bias [6]. Loading the GTD output with a tank circuit, it is possible to rapidly gate the circuit into and out of an oscillating state, producing down to 33 ps long 60 GHz wavelets directly from a baseband signal [3].

The admittance of, and hence matching of an antenna to, the GTD output is dependent on the defined active device area and...
bias point. Deembedded output characteristics of a $10 \times 18 \mu m^2$ GTD measured at bias $V_{CE} = 0.94$ V and $V_{GE} = -0.50$ V is displayed in Figure 1, revealing a capacitive output admittance in the current implementation where $Y = -55 + 39j$ mS at 60 GHz. In the wavelet generator setup, the GTD is tuned to resonance by an inductive integrated coplanar short-circuit stub [2], [3]. Important in the selection of antenna is hence that it has an inductive and smooth susceptance which added to the GTD output yields a clean resonance condition at 60 GHz.

III. ANTENNA DESIGN

We treat the design of the DRAs as two separate problems. The dimensions of the resonator is assumed to be the main factor to determine the resonance frequency of the antenna, while the input admittance is tuned by the feed used to access the resonant mode, as will be discussed below.

A. Resonator

Rectangular dielectric resonators have non-confined TE-modes that efficiently radiate their energy to the surroundings. The principles of radiation from the fundamental mode in such a resonator have been reported together with design formula and experimental results [7], [8]. A schematic picture of a rectangular resonator geometry is presented in Figure 2, including a sketch of the electric and magnetic fields of the fundamental mode mirrored in the $xz$-groundplane.

The following design formulas of the dielectric waveguide model from [8] are used to obtain a preliminary design which is later refined using full wave simulations. In the $x$ and $y$ dimensions, the wavenumbers $k_x$ and $k_y$ of the fundamental resonant mode are simply fitted to the length $l$ and height $h$ of the mirrored resonator

\[ k_x = \frac{\pi}{l}, \]  
\[ k_y = \frac{\pi}{2h}. \]  

A more intricate expression is used to relate the width $w$ and wavenumber $k_z$ of the resonator in the $z$ direction

\[ k_z \tan \frac{k_z w}{2} = \sqrt{(\epsilon_r - 1)k_0^2 - k_z^2}, \]  

where $k_0 = 2\pi f_0/c$ is the wavenumber in free space. Applying the above expressions to the separation equation

\[ k_x^2 + k_y^2 + k_z^2 = \epsilon_r k_0^2, \]  

the width $w$ of a resonator with known length $l$ and electrical height $2h$ may be calculated for the desired resonance frequency $f_0$.

At 60 GHz, a mirrored $h = 650 \mu m$ high and $l = 1300 \mu m$ long GaAs resonator, $\epsilon_r = 12.9$, must then be $w = 450 \mu m$ wide. Early experimental results on dipole fed DRAs indicated that a width $w = 650 \mu m$ provides a better implementation at 60 GHz, although it according to theory would resonate at 56 GHz.

B. Feeds

Feeding of the rectangular resonator is done with an electrically small metallic structure positioned directly onto its side. Probes that mimic the fields of the targeted mode are desired in order to get a good electromagnetic coupling.

A dipole placed on top of and along the length of the resonator, to stimulate a parallel electric field, has been investigated previously through simulations [9]. This feeding solution turned out capacitive at the dielectric resonator resonance frequency as a dipole is an inherently capacitive structure below its resonance frequency. The antenna can be made inductive by shunting it with a small inductive strip, which corresponds to a simple matching network, which however will short circuit the radiation resistance. Here, we fabricated and studied dipole fed DRAs with tapered arms to increase their bandwidth, as shown on the optical micrograph in Figure 3.

A slot in an infinite groundplane is the complementary structure to a dipole, having qualitatively inverse impedances [10]. Feeding the resonator with a slot, oriented along the width of the resonator, should hence turn out as an inductive...
characterising the transmission between DRAs, a barrier of aluminum foil was inserted between adjacent antennas under test and a piece of Cu-plated printed circuit board was positioned above the antennas and used as a signal reflector. This setup blocks the direct path between the adjacent antennas and instead introduce a reflected link, allowing transmission measurements at broadside radiation over variable propagation distances $r = 83$ to 143 mm, corresponding to a few tens of free space wavelengths.

A. Reflection coefficient

Deembedded input reflection coefficient measurements on the dipole and slot fed DRAs in Figures 3 and 4 are presented in Figure 5, obtained with a 20 mS reference at a source power of -6 dBm. The dipole fed DRA have a relatively strong resonance peak, $|S_{11}| = -5.81$ dB at 57.3 GHz, while the slot fed DRA have two resonant peaks within the measurement interval, $|S_{11}| = -2.39$ dB at 48.6 GHz and $|S_{11}| = -3.41$ dB at 68.1 GHz, respectively.

B. Admittance

Admittance of the fabricated DRAs is extracted from the reflection coefficient measurements, showing the influence of dipole and slot feeding in Figures 6 and 7, respectively. Also shown are full wave simulation data from the method.
spine resonance undulations for all fabricated slot fed DRAs, independent on offset feeding of the electrically small feed slot. Dielectric waveguide design formulas were found to overestimate the resonance frequency of the fabricated DRAs. Inductive slot feeding of the DRA results in a resonance frequency close to simulations, while the capacitive dipole fed DRA resonate at higher frequencies, likely depending on the metal connectors to the input waveguide confining the mode further. A good susceptive match to the GTD may be performed with the tapered and offset fed slot DRA, although it need to be tuned to 60 GHz. Transmission experiments confirm the antenna functionality and show a maximum gain of 10.5 dBi for the dipole fed DRAs in the current measurement setup. Antenna gain can be further increased by combining several of the antennas considered in this paper as elements in an array antenna.

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REFERENCES