A High Power 910 GHz 24 Element Radiator Array Based on a Novel CMOS Oscillator and Coupling Network

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***Abstract*—This project presents a high-power radiator capable of radiating at 910 GHz. The proposed radiator comprises of 24 elements which are phase and frequency locked, to boost the total radiated power. A cross-coupled oscillator stacking technique is used to increase the -gm and adjacent elements are coupled through on-chip double-fed coupled monopole antennas. A high resistivity silicon lens is used to improve radiation efficiency and directivity. Designed in 45 nm SOI CMOS, the simulations show a -15 dBm radiated power with an EIRP of 0 dBm at 910 GHz with 1.1 W DC power consumption.**

***Index Terms*— mm-wave, THz, CMOS, antenna**

I. Introduction

The THz spectrum, defined between 300 GHz and 3 THz, provides frequencies with exciting applications. Absorption windows of several molecules fall in this range, enabling spectroscopy. Moreover, THz-based imagers and radars provide much better resolution than their RF counterparts and suffer from less attenuation than their optical counterparts. The wide bandwidth offered by these THz frequencies enables high-speed (>100Gbps) short-range communication links [1]. However, it is not easy to generate THz frequencies through electronics and optics. The cutoff frequencies of silicon transistors fall around 350 GHz. Generating frequencies <3THz is tough using optical techniques, and these solutions are often bulky. A compact silicon-based solution is hence necessary.

This project aims to radiate > -15dBm power with >0dBm EIRP above 900 GHz using CMOS. Multiple individual oscillators are phase and frequency-locked to enable free-space lossless power combining.

II. Circuit Design

Transistors cannot provide power gain beyond ‘Fmax’. Even for the best CMOS process, the Fmax falls below 350 GHz. Hence, to generate power at 900 GHz, we require harmonic oscillators. Basically, we design a strong fundamental oscillator and extract its harmonics. Here, we design fundamental oscillators at 225 GHz and extract its 4th harmonic at 900 GHz. Since we require an even harmonic, we can extract the signal from the common-mode of a differential oscillator. This provides inherent odd harmonic cancellation.

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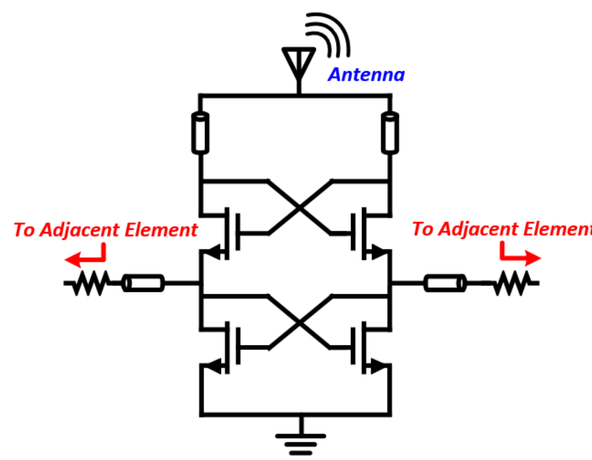

Fig. 1. Oscillator unit cell

Conventional oscillator structures need a negative resistance cell and a resonance tank. An LC network acts as the tank, while a cross-coupled transistor pair typically provides the required negative resistance. However, this negative resistance drops sharply as the oscillation frequency approaches 50% of Fmax. We adopt the stacked cross-coupled structure introduced in [2]. Fig. 1 shows the schematic. This architecture provides a boosted negative resistance, along with a negative capacitance component. Thus, strong fundamental oscillations can be generated. Since the transistors are inherently non-linear, a strong fundamental oscillation can also generate strong higher-order harmonics.

Designing an array of locked oscillators can provide further improvement in power and EIRP and even enable beam-steering. However, these oscillators need to be phase and frequency locked. Active-based locking networks cannot be used at 900 GHz. Thus passive locking networks are used in this work.

The transmission-line and the resistor shown in Fig. 1 ensure that the adjacent horizontally coupled elements remain in-phase. This is because if the oscillators go out-of-phase, the resistor will de-Q the oscillator tank and quench the oscillation. To ensure locking along vertical dimension, we use a novel dual-feed monopole antenna. Fig. 2 shows the structure of this antenna. When excited out-of-phase, this structure behaves like a twin lead transmission line. When fed in-phase, it behaves like two monopoles which are placed exactly adjacent to each other. We connect this antenna to the

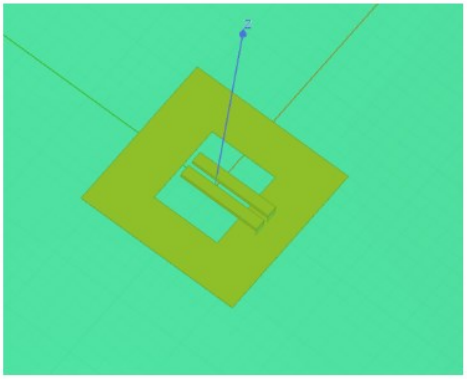

Fig. 2. Dual-feed monopole antenna

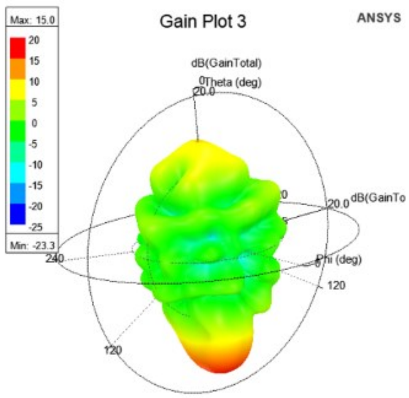

Fig. 3. Simulated radiation pattern.

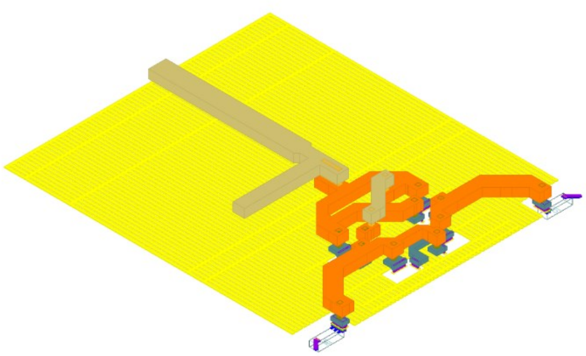

Fig. 4. EM simulation testbench for a single oscillator cell

common mode of the oscillator (as shown in Fig. 1). Only even harmonic, 2 and 4, flow through this node. The vertically adjacent oscillators lock out-of-phase at 2^{nd} harmonic through the antenna and in-phase at 4^{th} harmonic. Thus the 4^{th} harmonic signal gets selectively radiated. The antenna is EM simulated along with a hyper-hemispherical silicon lens. The lens ensures that the substrate modes are cancelled and it also boosts the directivity. The simulated radiation pattern for a single antenna element is shown in Fig. 3.

The GlobalFoundries 45RFSOI process is chosen for this project. All the passive networks described here are rigorously EM simulated. The transistor parasitic are also EM simulated for accuracy. The circuits and EM structures are co-designed, and the antenna is designed and simulated in a 3D EM solver (Fig. 4). The overall 24 element coupling network is shown in Fig. 5. Simulations results show -15 dBm total power with an EIRP of 0 dBm at 910 GHz with 1.1 W DC power consumption.

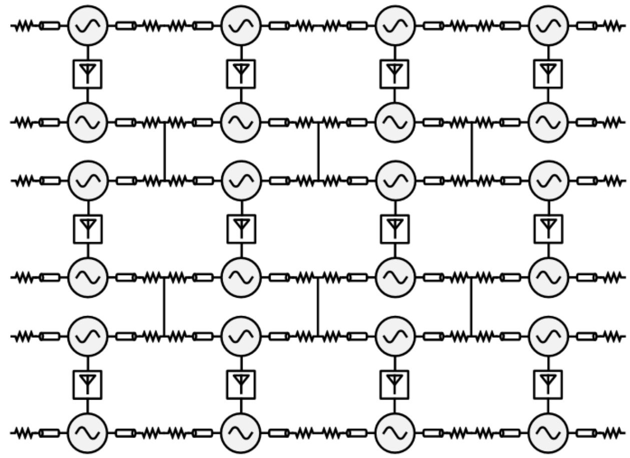

Fig. 5. 24 element 910 GHz radiator array

III. Conclusion

This work presents a 910 GHz CMOS radiator array. Twenty-four cross oscillator cells are coupled in-phase to boost the radiated power and EIRP. A cross-coupled oscillator stacking technique is used to boost the negative -gm for each individual oscillator cell. A dual-fed monopole antenna structure is introduced which can simultaneously function as as a transmission line or as an antenna based on how it is excited. Simulation results show -15 dBm total radiated power and an EIRP of 0 dBm at 910 GHz, while consuming 1.1 W DC power in GlobalFoundries 45nm SOI process.

IV. Acknowledgment and Career plans

The IEEE MTT-S Scholarship program has been instrumental in my electrical engineering graduate school education. This scholarship made it possible for me to involve in a tape-out. It increased my depth of understanding in microwave engineering and IC design. This scholarship has deeply increased my interest in research. Presently I am pursuing a Ph.D. degree in THz IC design under the guidance of Prof. Aydin Babakhani at UCLA.

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