# A High-Speed, Fully-Integrated, 180/195 GHz FSK Transmitter Using Coupled Oscillators

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***Abstract*—A novel design for a high-data rate, 180/195 GHz transmitter is described. The transmitter is based on a coupled oscillator topology, and is predicted to provide 15 Gbps communication over a 10cm channel. The topology exploits the fast-settling frequency modulation of mutually coupled oscillators. The system was designed and fabricated on a 65nm CMOS technology. Measurement results are pending. The total chip area for the fully-integrated transmitter is 0.6825mm$^2$.**

***Index Terms*—coupled oscillators, mm-wave circuits, integrated transmitter**

## I. Introduction

As communication systems edge closer and closer to Shannon's limit in conventional RF bands, new approaches must be taken to accommodate the increased demand for wireless communication throughput. In contrast to the scarcity of bandwidth in RF bands, millimeter-wave frequencies have vast amounts of unallocated spectrum available for high data-rate communication. Millimeter-wave transmitters have already been demonstrated on CMOS processes in several works, but suffer from either high-SNR requirements, [1], or high modulation loss, [2].

To solve the issue of modulation loss in low-SNR modulation schemes, it is advantageous to consider frequency-shift-keying modulation (FSK). FSK has not been used for high data-rate communication due to the long transient settling time of the oscillator during frequency modulation, as well as the power loss due to frequency tuning at mm-wave frequencies. Frequency tuning with minimal power loss can be accomplished, however, by using coupled oscillator schemes—making the topology an attractive high-power source for array structures [3]. This project aims to design a 180/195 GHz FSK transmitter using coupled oscillators, resulting in a scalable, high-power, 15 Gbps transmitter with low SNR requirements and low modulation loss.

## II. System Design and Implementation

To take advantage of the fast frequency settling time of the topology in Fig. 1, a direct-modulation FSK transmitter was designed. The transmitter consisted of three major blocks: the core oscillators, the phase shifters, and the antennas. All components were designed and fabricated on a 65nm CMOS technology.

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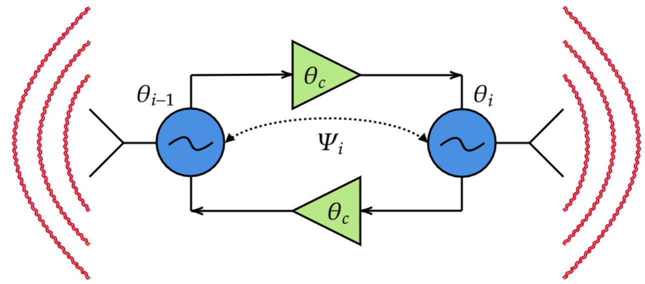


Fig. 1. Two mutually coupled oscillators. The frequency of the oscillators is varied via the phase shift imposed on the injecting currents $\theta_c$. The phase difference, $\Psi$ between the two oscillator waveforms is deterministic and fixed via frequency shift. The modulated data is transmitted via on-chip antennas.

### *A. Harmonic Oscillator Design*

To achieve high-power out of each oscillator core at 190 GHz, an oscillator design that is optimized for second harmonic generation was used. Fundamental limits for second harmonic generation in CMOS oscillators are approximated in [4], and the design principles used there are adapted for this work. An oscillator core with roughly +1 dBm output power at the second harmonic (180/195 GHz) was designed.

### *B. Fast-settling Phase Shifter Design*

The transient settling time of the topology in Fig. 1 is limited by the speed at which the phase shifter can settle during modulation. A resonant-amplifier phase shifter has been designed, where tunable varactors change the resonant frequency of the amplifier. A control voltage signal carriers the data that is to be transmitted, and modulates the frequency of the entire loop in Fig. 1 via the phase-shifters. The control signal varies the capacitance in the tank, and provides a different phase shift for a given frequency. Varactors were sized to provide a large enough phase shift—$\approx 140°$ between the two modes. Since the phase shifter needs to settle as fast as possible, the quality factor of the amplifier is intentionally degraded to make the phase shift large as well as decrease the settling time, since settling time is inversely proportional to tank $Q$.

### *C. Wideband Antenna Design*

Each oscillator core is connected to an antenna for the transmitted signal to be radiated and for spatial power combining

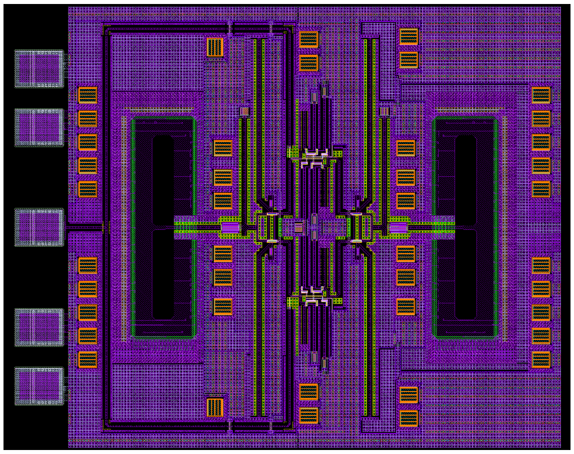

Fig. 2. The final layout of the fully-integrated transmitter. The total chip area including pads is $0.6825\text{mm}^2$.

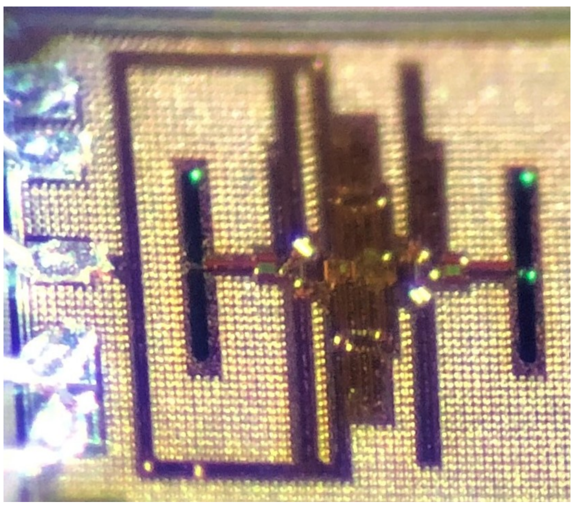

Fig. 3. Die photo of the fabricated transmitter including pads.

to occur. To accommodate high-data rate communications, a wideband antenna is required. The antenna also needs to have a high-directivity to enable point-to-point communications. A slot antenna is used for its good broadband characteristics as well as high gain. The gain of the antenna is 6-8 dBi across the band.

The layout of the designed transmitter is shown in Fig. 2. The antennas are spaced at $0.7\lambda$, which will result in grating lobes that need to be addressed. The fabricated chip is shown in Fig. 3. The total chip area for the fully-integrated transmitter is $0.6825\text{mm}^2$.

## III. Results

Measured results have yet to be conducted. The simulated performance of the current FSK system is shown in the frequency eye-diagram of Fig. 4. The system is capable of 15 Gbps communication—which can be increased to 30 Gbps if spatial orthogonality is used.

## IV. Conclusion

A 180/195 GHz FSK transmitter based on mutually coupled oscillators is presented. The transmitter exploits the fast-

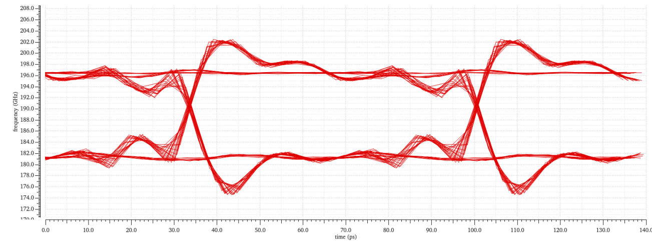


Fig. 4. Frequency eye diagram for 15 Gbps data modulation at the fundamental frequency. Note that this is not the actual eye diagram of bits but rather the eye diagram of the modulated frequency. Frequency carriers are separated by 7.5 GHz at the fundamental, which corresponds to 15 GHz at the second harmonic.

settling frequency characteristic of mutually coupled oscillators. The transmitter is predicted to be capable of 15 Gbps communication over a 10cm channel and can be extended to 30 Gbps by using spatial orthogonality. The chip was designed on a 65nm CMOS technology and is yet to be measured.

## V. Future Plans

The undergraduate scholarship from IEEE MTT-S helped me complete this project and solidified my interest in the field of high-frequency integrated circuits and systems. The award has also given me the opportunity to attend a MTT-S sponsored conference. After finishing my B.S.E last year, I began a Ph.D program in electrical engineering with a focus on integrated circuits. I look forward to being part of the MTT-S community throughout the duration of my studies and beyond, and am grateful for their support.

## References

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