Novel Silicon Circuits and Systems for Terahertz Communication

Chen Jiang, *Member, IEEE*, and Ehsan Afshari, *Senior Member, IEEE*

I. Outcomes of the Project

In this project, three silicon chips are designed and tested to verify our proposed ideas. All of them achieve very good performances and push the state of the art forward. The results are also published in top conferences and journals [1-3].

A. A 300-GHz Source with Entirely On-Chip Feedback Loop for Frequency Stabilization

Harmonic oscillators are commonly used to generate THz signals; however, due to supply noise and ambient environment changes, free-running THz oscillators exhibit large spectral linewidth and frequency drift. As a result, frequency stabilization is required in many systems. Conventionally, PLLs are used for this purpose; however, major challenges exist when frequency goes into THz band. Since the division ratio (N) is large in THz PLLs (10^3 to 10^4) and the reference phase noise is multiplied by N^2 to the output, a high-quality off-chip crystal oscillator is needed to keep the noise contribution low enough. Moreover, the large N causes significant VCO-noise folding, potentially degrading the output in-band phase noise. Finally, injection-locking frequency dividers (ILFDs) in THz range provide insufficient locking range, which limits the achievable output frequency range. To boost the ILFD locking range, higher injection power or multiphase injection is needed, which significantly increases the power consumption.

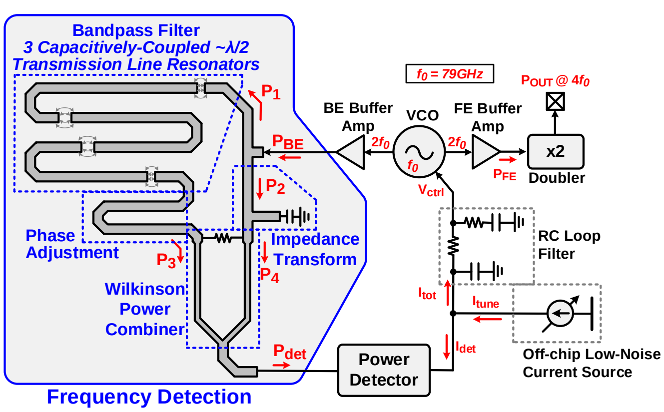

Fig. 1. Circuit Architecture of the proposed 300-GHz frequency-stabilized source.

Chen Jiang is with the Department of Electrical and Computer Engineering, Cornell University, Ithaca, NY 14853.

Ehsan Afshari was with the Department of Electrical and Computer Engineering, Cornell University, Ithaca, NY 14853, and now with the Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109.

In this work, an entirely-on-chip frequency-stabilization feedback loop for mm-wave/THz sources is presented. As shown in Fig. 1, a passive bandpass filter is used to sense the VCO output frequency and form a negative feedback. This scheme eliminates the need for both frequency dividers and off-chip crystal oscillators.

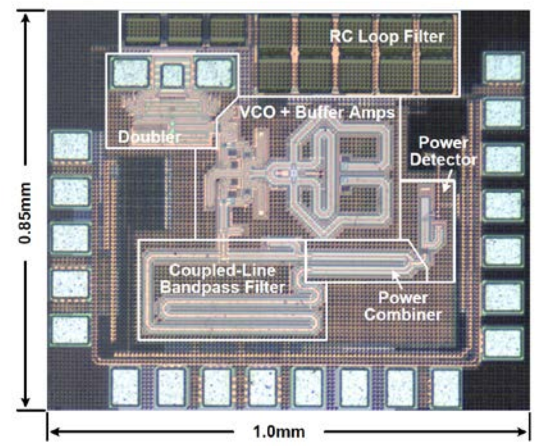

Fig. 2. Chip photo of the proposed 300-GHz source.

Using this mechanism, a 300-GHz source prototype is designed in a 0.13-µm SiGe:C BiCMOS technology [1]. According to the measurement, the source consumes a dc power of only 51.7 mW. The output phase noise is -71.1 and -75.2 dBc/Hz at 100 kHz and 1 MHz offset, respectively. A -13.9-dBm probed output power is also achieved. Overall, compared to other state-of-the-art works, it achieves the largest tuning range and lowest power consumption, as well as comparable phase noise and output power. It also eliminates the frequency reference, achieving much lower integration cost.

B. A 312GHz Source with 4.6-mW Peak Radiated Power and On-Chip Frequency-Stabilization Feedback

Using the same frequency stabilization mechanism, another design targeting at high output power radiation is designed [2]. The front-end of this source is a 6×4 radiator array. Each of the radiator cell is a harmonic oscillator, whose fundamental frequency is 156GHz and the second harmonic is extracted and radiated. Inside each row, the radiator cells are coupled together. Four mutually-coupled VCOs are also implemented, which have a fundamental frequency of 78GHz and their second harmonic is sent to 8 buffer amplifiers. Out of the 8 buffers, 6 of them are front-end buffers, whose output is used to inject lock one row of radiator cells. The other 2 are backend buffers, which send the output signal for frequency detection and VCO control feedback generation. The proposed source achieves a peak radiated power and EIRP of 4.6mW and 24.7dBm, respectively, with a total dc power consumption of 1.18W. The frequency tuning range is larger than 2.7%. The measured phase noise at 1MHz offset is -80.1dBc/Hz.

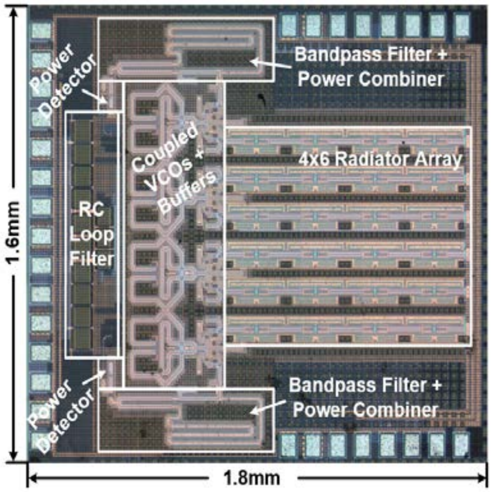

Fig. 3. Chip photo of the 312GHz radiating source.

C. A 220-GHz Spatial-Orthogonal ASK Transmitter with 24.4-Gb/s Capacity and 21.1-dBm/ch EIRP

Wireless communication using THz/sub-THz band can alleviate the spectrum scarcity in conventional RF bands and satisfy the drastically expanding demand for capacity. The line-of-sight nature can also provide higher security.

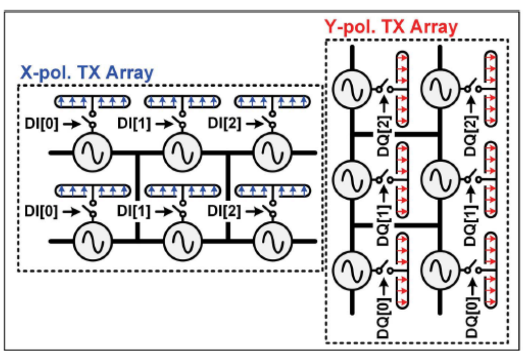

Fig. 4. The four-level SO-ASK transmitter with 2×3 array configuration inside each channel.

In this work, a spatial-orthogonal ASK transmitter architecture shown in Fig. 4 is presented. The self-sustaining oscillator-based transmitter architecture has an ultra-compact size and excellent power efficiency. With the proposed high-speed constant-load switch, significantly reduced modulation loss is achieved. Using polarization diversity and multi-level modulation, the throughput is largely enhanced. Array configuration is also adopted to enhance the link budget for higher signal quality and longer communication range.

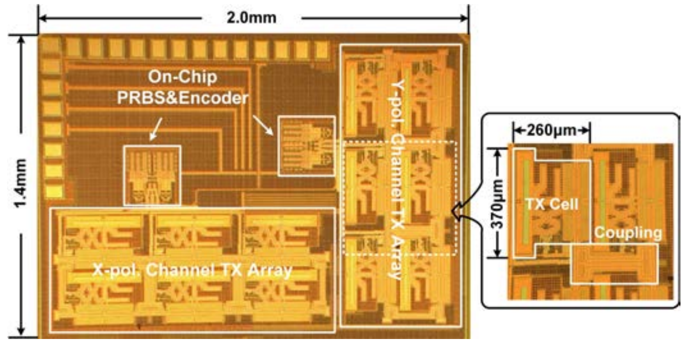

Fig. 5. Chip photo of the 220-GHz SO-ASK transmitter.

The transmitter is fabricated with a 0.13-μm SiGe:C BiCMOS technology [3]. It achieves an EIRP of 21 dBm and dc-to-THz-radiation efficiency of 0.7% in each spatial channel. A 24.4-Gb/s total data rate over a 10-cm communication range is demonstrated. With an external Teflon lens system, the demonstrated communication range is further extended to 52 cm. Even with demonstrated speed limited by the on-chip PRBS and encoder circuits as well as SNR drop caused by the receiver impedance mismatch, this work still shows much higher transmitter efficiency compared with prior art.

II. Future Plans

After getting my PhD degree, I plan to go to industry and continue to work on design of silicon chips for communication systems (5G/Wifi/BT).

I really appreciate the MTT-S society for granting me the fellowship award and sponsoring me to work on such interesting projects. Communication has been and will continue to be an important factor that changes people's way of living. The pursuit of higher data rates also never ends. I have learnt and gain a lot from working on these challenging projects.

References

[1] C. Jiang et al., "A 301.7-to-331.8GHz Source with Entirely On-Chip Feedback Loop for Frequency Stabilization in 0.13μm BiCMOS," in Proc. IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers, Feb. 2018, pp. 372–373.

[2] C. Jiang et al., "A 308-317GHz Source with 4.6mW Peak Radiated Power and On-Chip Frequency-Stabilization Feedback in 0.13μm BiCMOS," accepted and will be presented on IEEE Radio Freq. Integr. Circuits Symp., Jun. 2018.

[3] C. Jiang et al., "A high-speed efficient 220 GHz spatial-orthogonal ASK transmitter in 130 nm SiGe BiCMOS," IEEE Journal of Solid-State Circuit (JSSC), vol. 52, no. 9, pp. 2321-2334, 2017.