A 260 GHz Fully Integrated CMOS Transceiver for Wireless Chip-to-Chip Communication

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Abstract

A fully integrated 260GHz OOK transceiver is demonstrated in 65nm CMOS. Communication at 10Gb/s has been verified over a range of 40 mm. The Tx/Rx dual on-chip antenna array is implemented with half-width leaky wave antennas. Each Tx consists of a quadrupler driven by a class-D^{-1} PA with a distributed OOK modulator, and outputs +5 dBm of EIRP. The Rx uses a double balanced mixer to down-convert to a V-band IF signal that is amplified with a wideband IF driver and demoduated on-chip.

Introduction

A short range wireless link is proposed for chip-to-chip communication. To serve this functionality, such a link, or wireless bus, should have low latency, high data rate, and reasonable power consumption. This wireless bus can fulfill many roles, especially routing between chips when a physical interconnection is difficult. Sub-THz frequencies are interesting in these applications to enable high data rates without incurring a large area penalty. For example, at 260GHz, the dimensions of on-chip antennas become comparable to a few pads, and antenna inefficiency is comparable to signal loss through the pads and the package, making a fully integrated solution the preferred choice. However, realization of fully integrated (sub) THz transceivers is challenging because the performance of CMOS devices is severely limited at these frequencies. This paper demonstrates a sub-THz wireless OOK transceiver operating beyond the device cut-off frequency (f_T) by utilizing quadruplers and spatial power combining with a leaky-wave on-chip antenna array.

0.26THz Fully Integrated Transceiver

A. Transceiver Architecture

Given a communication range of cm's, the limited device performance of 65nm GP CMOS at sub-THz frequencies, and the additional complexity incurred by quadrature up and down-conversion, this design relies on non-coherent OOK modulation. The choice of this simple modulation scheme provides enhanced robustness to carrier frequency shift as well as simple front-end elements, which is a critical consideration given the need for spatial power combining to achieve sufficient link budget. As shown in Fig. 1, in this design two Tx/Rx unit elements are spatially combined with half-width leaky-wave on-chip antennas.

B. Half-width Leaky-wave On-chip Antenna

At (sub-)THz frequencies, on-chip antennas are essential considering the high cost and loss associated with external antennas. We modify a wideband half-width leaky-wave (LW) antenna[1] so that it can simultaneously serves as Tx and Rx dual antenna having two inputs by designing its termination port is matched to the input impedance of the off-state counterparts. By placing a metal wall attached to one side of the edge, a microstrip-line with $\lambda_g/4$ width excites the 1^{st} higher mode (EH_1) as the radiation mode (Fig.2). This design achieves comparable radiation efficiency to a patch antenna while achieving 5-6 times wider bandwidth. As the Tx and Rx share the LW antenna array, aperture size restrictions due to the chip area constraint are relieved while obviating the need for an explicit TR switch. By arraying four elements, the antenna-array achieves 4.5dBi of gain with more than 30GHz of BW and 26.3% of radiation efficiency in HFSS. The detailed antenna structure, radiation pattern, and input BW of the LW antenna is shown in Fig. 2.

C. Transmitter with Distributed OOK Modulator

Fig. 1-(a) presents the architecture of the CMOS wireless transceiver. A V-band balanced signal ({0°,180°}) is generated from the Tx VCO with a differential cascode buffer (Fig.3-(b)). Two branch-line hybrids take each of the differential outputs of the Tx VCO and produce I/Q output signals for each Tx chain. Coplanar Strip-line (CPS) is widely used as a balanced transmission-line for the chain. The OOK modulator is implemented in a distributed fashion to overcome transient signal ringing caused by the resonant matching networks in the Tx chain. Dummy loads mask the switching action propagation to the preceding stages (Fig.3-(a)). A capacitance-loaded hybrid is implemented with four meandered microstrip-lines to reduce the size. A transformer balun converts single to differential signals. The amplifier chain followed by the balun consists of a class-A driving amplifier, 1^{st} modulation switch, a class-D^{-1} PA, and a 2^{nd} modulation switch followed by a quadrupler utilizing the quadrature push-push structure (Fig.3-(c)) [2]. Using a stacked transformer, the class-D^{-1} PA achieves 25% PAE with +13dBm of output power. An on-chip 20Gb/s interleaved 2^7 - 1 PRBS generator using CML latches and buffers provides the digital data to the distributed OOK modulator which has a switching isolation larger than +28dB at 20Gb/s in simuation. The total power consumption of the Tx chain is 688mW.

D. Receiver with Quadrature Push-Push Demodulator.

Without a sub-THz LNA in the Rx front-end, it is essential to minimize the NF of the down converting mixer (Fig.1-(b)). A double-balanced passive mixer is used for down conversion to achieve high LO to IF isolation (Fig.4-(a)). To minimize the NF of the mixer, a strong LO signal is necessary. +0dBm of 3^{rd} harmonic balanced IQ LO signals are generated from two triplers biased in class-C (Fig.4-(b)). The triplers are driven by a V-band LO chain consisting of a class-D^{-1} PA, an I/Q hybrid, and Rx VCO. The down-converted I/Q IF signals from the two respective mixers are amplified by a wide-band IF driving amplifier utilizing loosely coupled IF transformers to achieve pole-separation (Fig.4-(c)). The simulated gain of the Rx chain is 17dB with 15GHz of bandwidth and the NF is 19dB. The IF output I/Q signals are combined and demodulated with a quadrature push-push circuit. The demodulated signal is amplified by an IF buffer which drives an external instrument. The Rx chain consumes a total power of 485mW.

Measurement

The 65nm GP test-chip integrating the proposed transceiver measures 4×1.5mm^2 (Fig.5). Using a calorimeter, WR3.4 horn antenna, and a waveguide transition, we measured +5 dBm of EIRP at 260GHz. Comparing the measured and simulated antenna pattern, it is clear that the 3rd harmonic

affected the radiation pattern measurement since the waveguide cutoff is at f_c =174GHz (Fig.2). Fig.6 shows the spectrum of the *in-situ* modulated V-band signal at 14Gb/s. A wireless data-link was verified over a 40mm range as shown in Fig.7, and the spectrum of the 6Gb/s demodulated toggling signal is shown in the Fig. 8.

Conclusion

A 260GHz fully integrated non-coherent OOK transceiver is presented in 65nm CMOS. The spatially combined arrayed transceiver structure with Tx/Rx dual antenna demonstrates the feasibility of sub-THz systems operating beyond the cut-off frequency of CMOS transistors.

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[2] J.-D. Park et al., "A 0.38THz fully integrated transceiver utilizing quadrature push-push circuitry," *VLSI Circuits ,* 2011.

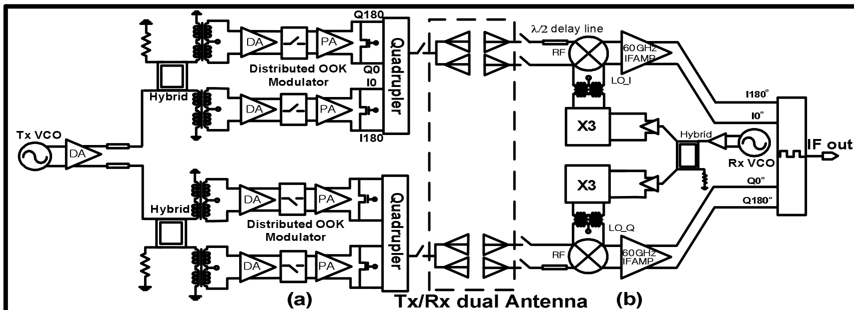

Fig.1 Tx/Rx front-end Architecture

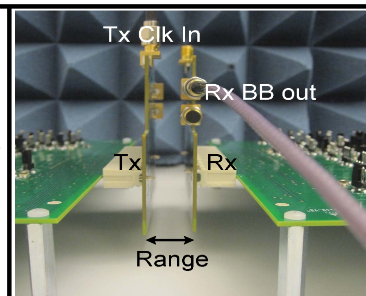

Fig.7 Sub-THz wireless data-link setup

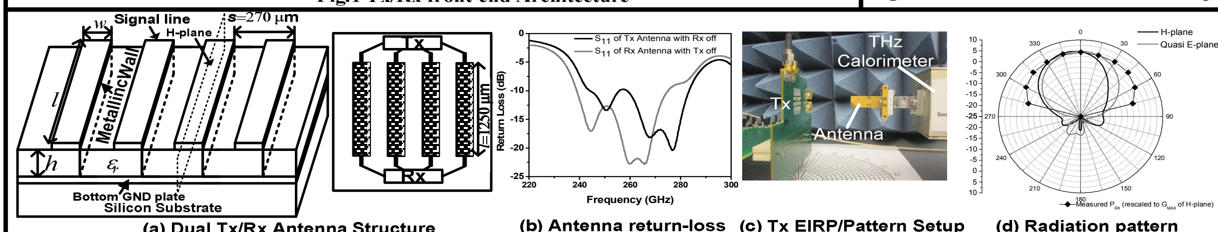

Fig.2 Tx/Rx dual leaky-wave antenna array

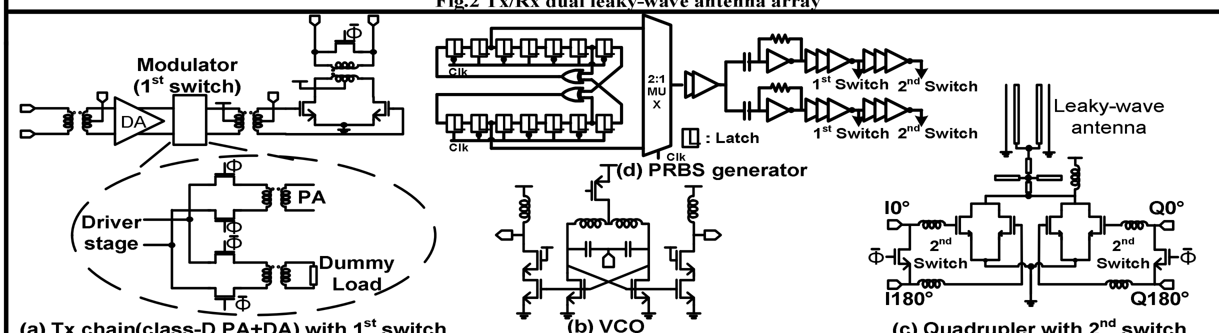

Fig.3 Transmitter with a distributed OOK modulator

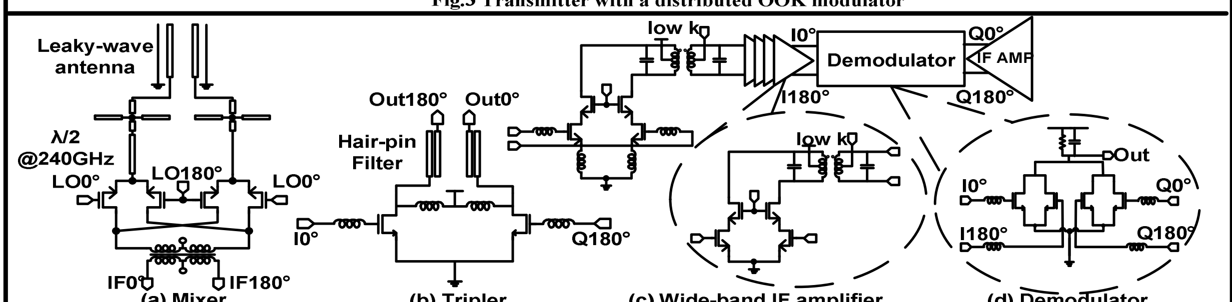

Fig.4 Receiver with a wide-band IF chain

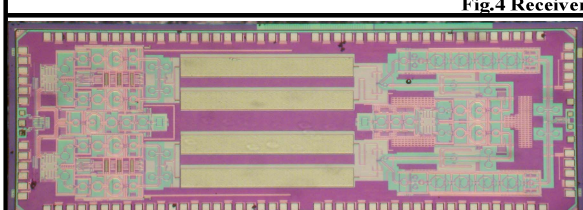
Fig.5 Chip microphotograph (4.0mmx1.5mm)

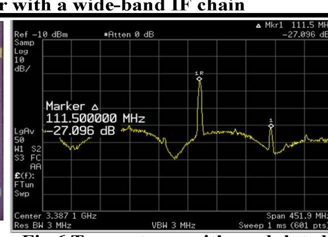

Fig.6 Tx spectrum with modulated 14Gb/s PRBS

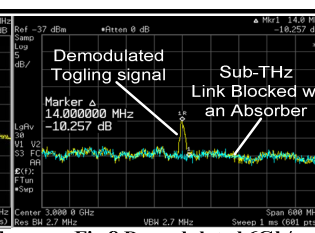

Fig.8 Demodulated 6Gb/s toggling signal