An 8-Element 23–40GHz Continuously Auto Link-Tracking Phased-Array Transceiver with Time Division Modulator for 5G NR

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***Abstract*—In this report, the motivation, concept, implementation, and measured results of an 8-element 23–40GHz continuously auto link-tracking phased-array transceiver with time division modulator is presented. Firstly, the concept of three-step link-tracking procedure is introduce to auto-establish transmit/receive (T/R) link with communication target at unknown direction. Secondly, the time division modulator is utilized, which can tune the LO power for RX gain flatness improvement and provide a baseband-to-RF direct conversion in TX mode. Based on aforementioned structure, an 8-channel phased-array transceiver is designed and implemented using 40-nm CMOS technology. The measured link-tracking time is 7s and peak TX system efficiency is 25.3%, which can support 4.8Gb/s 64-QAM and 8Gb/s 16-QAM transmission.**

***Index Terms*—CMOS, link-tracking, millimeter-wave, phased-array, transceiver**

I. Introduction

INCREASING demands on high-data-rate and low-latency wireless communication drives the development of millimeter-wave (mm-wave) phased-array transceivers (TRXs), which utilizes large-scale array to improve the link budget and coverage range for modern wideband wireless applications, especially 5G NR in 24, 28, 37, and 39GHz bands [1], [2]. Meanwhile, in multiple high-speed systems (e.g., indoor AR/VR, drone, and vehicle), the communication targets are moving quickly and randomly, which results in a rapid-changing transmit/receive (T/R) links. The beam-steering of conventional TRX arrays are controlled by open-loop phase shifters. Establishing stable T/R links with a fast-moving target requires a complex phase shifting algorithm and power-hungered digital processor. Therefore, the array systems that can support fast beam-tracking are demanded in those scenarios [3], [4]. However, the reported beam-tracking techniques are only implemented in RX array. Therefore, the broadband TRX array that can support fast beam-tracking to achieve high-data-rate and low-latency wireless link is highly demanded in those scenarios.

In this report, an 8-element 23–40GHz continuously auto link-tracking TRX array with time division modulator (TDM) is introduced to support auto-beam-steering for fast tracking of moving target in both RX and TX modes [5]. Meanwhile, the integrated TDM can improve the RX gain flatness and the TXs achieve a peak system efficiency (SE) of 25.3% supporting 8Gb/s transmission.

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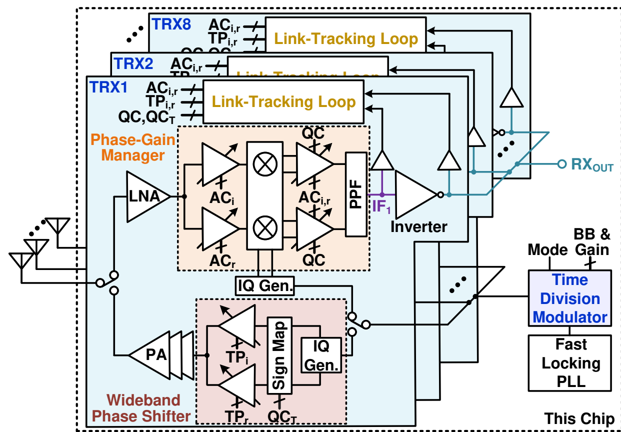

Fig. 1. Architecture of the proposed phased-array transceiver.

II. Project Outcome

Fig. 1 shows the configuration of the proposed phased-array TRX. Each RX element consists of an LNA, a phase and gain tuner, a mixer, and an IF inverter, while a three-stage PA and a phase shifter form each TX element. A TDM is used to control the gain of the single tone LO signal in RX mode, and modulated RF signal in RX, and generate directly digital modulated RF signal in TX mode, respectively. A power divider loaded with switches distributes the output signal from TDM for each TRX element, while the TDM is driven by an on-chip wide-band PLL. Fig. 2 exhibits the three-step operation of continuously auto link-tracking. Firstly, the phased array TRX receives a signal from unknow target direction. Initialized phase settings are equal in all RXs, and the IF signals (i.e., IF_m, m=1,2,...n) are generated with different phases in each RX. An inverter is utilized in each RX before combining the IF signals into a single array output (i.e., RX_{OUT}). Thus, the RX_{OUT} phase is the inverse of combined IF signals. Secondly, the link-tracking loop in each RX element detects the phase difference between the RX_{OUT} and IF_m. The RX link tracking is performed by equalizing the phase of each IF signal, which is achieved by shifting the phase of each IF signal to the inverse of RX_{OUT}. By tracking to the target direction, the power of RX_{OUT} is enlarged. Each TRX element shares a single antenna interface with a switch. Therefore, to steer the TX beam toward the target direction for establishing TX link, the phase shifting of each TX element (i.e., φ_{TXm}) equals to the minus of φ_{RXm}.

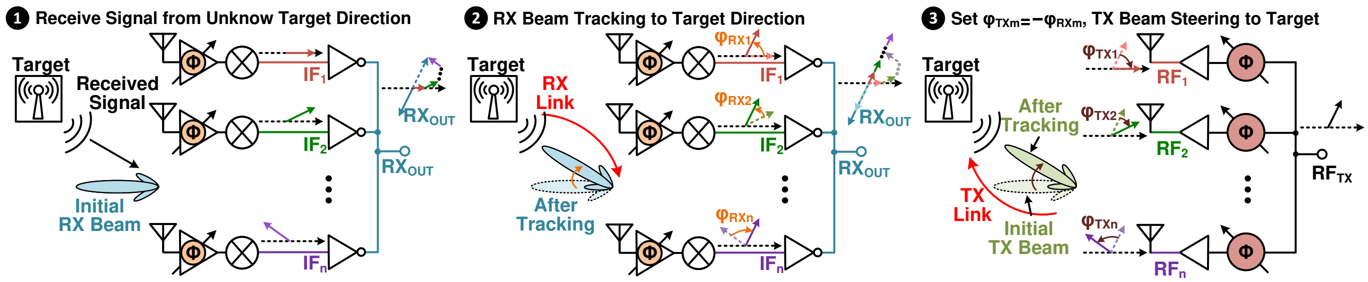

Fig. 2. Three-step link-tracking operation.

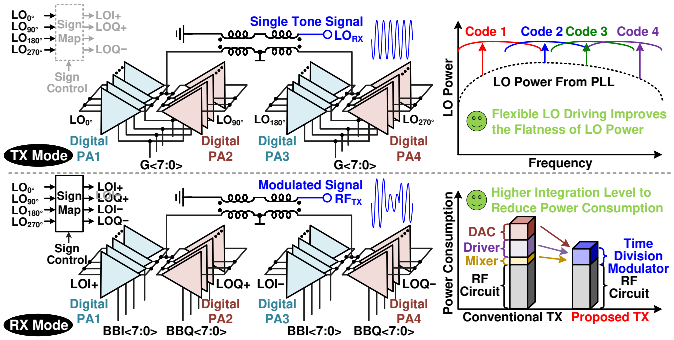

Fig. 3. Concept and operation principle of the TDM in RX- and TX-modes.

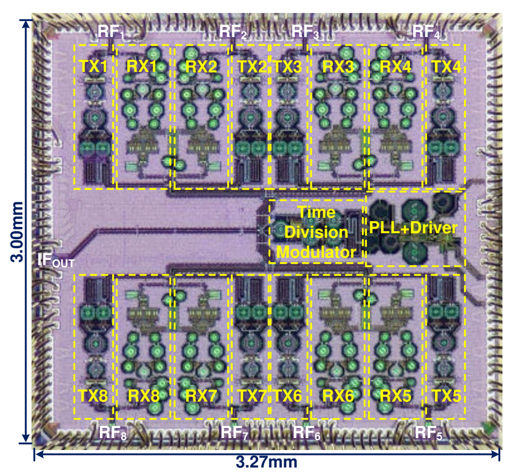

Fig. 4. Chip micrography.

Fig. 3 exhibits the configuration of TDM in RX- and TX-modes. The main part of TDM is consisted of a sign-map circuit, four digital power amplifier (PA) arrays, and an output transformer. The sign-map circuit generates quadrature LO signals with equivalent amplitude (i.e., LOI+, LOQ+, LOI−, LOQ−) according to the sign-control code. In RX mode, TDM is a LO driver, four digital PAs are controlled by $G < 7:0 >$ for a variable gain. Therefore, a flexible LO driving capability is achieved to improve the flatness of LO power within a wideband. In TX mode, TDM is configured to operate as a RF DAC. The digital PAs are controlled by baseband signals $BBI < 7:0 >$ or $BBQ < 7:0 >$, while the output quadrant is reconfigured by the sign-map circuit. The modulated RF signal is generated according to baseband signals directly. Thus, the proposed TDM integrates multiple functions of the mixer, driver, and DAC into a single module, which increases the integration level and reduces the overall power consumption.

The proposed phased-array TRX is implemented and fabricated using a conventional 40-nm CMOS technology, as shown in Fig. 4. It consumes 86mW in PLL, 209mW in TDM (Psat), 75mW in each RX element, and 179mW (at P_{sat}) in each TX element. The maximum RX conversion gain is 39dB with 3dB bandwidth of 23–40GHz. The measured NF is lower than 5.3dB within the operation frequency range and the minimal NF is 3.9dB at 25GHz. The P_{sat} of the TX is 14.0–17.1dBm at 23–40GHz, while the peak PA efficiency and peak TX SE are 30.4% and 25.3%, respectively. Both the TX and RX array support 4.8Gb/s, 64-QAM, and 8Gb/s 16-QAM modulation. With a 10MHz external clock triggering the link-tracking loop, the tracking time is about 7μs once the target direction changed from 0 to 30 degree.

III. Fellowship Impact and Career Plan

It is a great honor for me to receive the 2022 IEEE MTT-s Graduate Fellowship Award, which supports my research work and will encourage me in the future academic career. I plan to make my research benefit for the life of human being after I finish my Ph. D project. Finally, I would like to thank my supervisor prof. Dr. Xun Luo for the guidance and encouragement during my research.

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