Energy Efficient, Linear, and Wideband Mm-Wave Transceiver Front-End for Next-Generation Wireless Communication Systems

Tzu-Yuan Huang, *Student Member, IEEE*, and Hua Wang, *Fellow, IEEE*

***Abstract*— This report partially summarizes the research outcomes supported by the 2022 IEEE MTT-S Graduate Fellowship Program. In this report, we propose and implement a 23-37GHz autonomous 2D MIMO receiver (RX) array system with rapid full Field-of-View (FoV) spatial filtering and beamforming to manage interferences and signals from unknown Direction-of-Arrival (DoA). The implemented RX array system architecture can also provide multiple deep spatial notches to relax downstream ADC circuits' dynamic range requirement and extend to a larger 2D array.**

Keywords—MIMO Receiver, mm-Wave, 5G.

I. Introduction

The rapidly growing interest in mm-Wave spectrum for next-generation wireless technologies have stimulated an explosive wave of research on mm-Wave electronics and systems. While array beamforming enhances the wireless link budget and signal-to-noise-ratio (SNR), concurrent multi-beam systems have become a promising technology direction to further increase the channel capacity. The mm-Wave RX arrays are required to handle the complex and dynamic channel conditions and accommodate strong signals/blockers without compressions. Analog beamformers are reported to support spatial notches and reject the blocker signals, but they typically exhibit limited FoV and are restricted to multiple-input single-output (MISO) systems. In addition, multiple analog beamformers for true MIMO operations will add substantial complexity. On the other hand, digital beamforming arrays can support full FoV and true MIMO capabilities with multi-stream/beams to support concurrent multi-beam operations and improve spatial-spectral efficiency for multiple end users. With beamforming and spatial filtering all in the digital backend, digital beamforming arrays offer substantially more flexibility compared to their analog counterparts. In this report, we successfully demonstrate a scalable autonomous 2D 2×2 MIMO RX array with rapid full-FoV spatial filtering to suppress unknown interferences and to beamform desired signals under low latency.

II. 2D MIMO Receiver Array With Autonomous Beamformer and Spatial Filter

To address the aforementioned limitations of analog and digital beamforming, we demonstrated an autonomous 2-D 2x2 MIMO RX array with rapid full-FoV spatial filtering to suppress unknown interferences and to beamform the desired signals. The operation of the implemented RX array is demonstrated in Fig.1. Any 2D incident plane wave can be decomposed to two orthogonal plane wave-fronts in the X-/Y-directions. We use Ant#1 as the reference channel. The autonomous beamformer (AB) in two adjacent array elements (Ant#1 and Ant#2) detects the phase difference θ_X in the X-direction, and the AB in another two elements (Ant#1and Ant#3) detects the phase difference θ_Y in the Y-direction. 2-D autonomous beamforming requires two phase-domain negative feedback loops to track the two

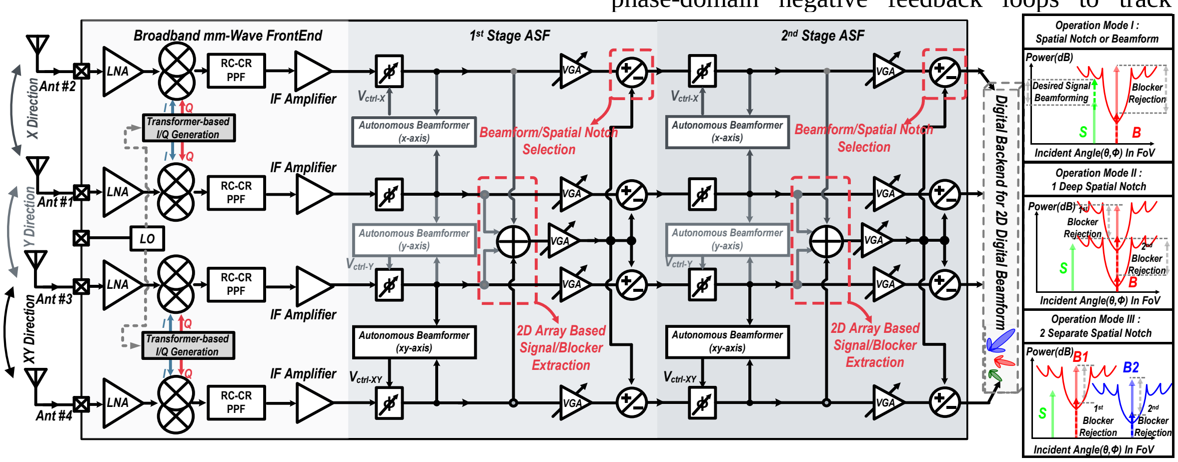

Fig. 1. Block diagram of the proposed 2D MIMO RX array with both autonomous beamforming and spatial filtering functionalities.

Tzu-Yuan Huang is with the School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA (e-mail: tyhuang@gatech.edu).

Hua Wang is with the School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA, and also with the School of Information Technology and Electrical Engineering, ETH Zürich, 8092 Zürich, Switzerland (e-mail: wanghua@ethz.ch).

orthogonal plane wave-fronts independently. Thus, the X-/Y-direction autonomous beamformers generate phase feedback DC control voltages Vctrl-X and Vctrl-Y. The control voltages are fed to the perspective phase-shifters, such that Ant#1 /Ant#2 are aligned to the X-direction plane wave-front, and Ant#1/Ant#3 are aligned for the Y-direction plane wave-front. Practical phase shifters suffer from mismatches and nonlinearity. To align Ant#4, an additional AB between Ant#3/Ant#4 is added to automatically generate control voltage Vctrl-XY. Therefore, the 2-D 2×2 channels are all precisely phase-aligned towards the strongest signal/blocker, which then can be accurately extracted as signal S by a 2×2 array summation in the Auxiliary (Aux.) path and fed to the feedforward path. The feedforward path can be configured as a subtraction ("-" sign) or addition ("+" sign) of S to each channel's Main path for spatial filtering or constructive beamforming and spatial filtering. The DC phase shifter controls and IF signal combining/subtraction enables scalable 2-D array operation. Therefore, a 2-D 2×2 Autonomous Spatial Filter (ASF) stage autonomously tracks the dominant unknown signal/blocker and performs feedforward spatial filtering or addition without losing full-FoV or MIMO capability. Moreover, multiple 2-D 2×2 ASF stages can be cascaded to track multiple unknown signals/blockers depending on their power level or provide a sharp spatial notch to a large blocker.

III. Measurment Result

The implemented RX is measured using concurrent multiple wideband modulated co-channel blockers and one desired signal (-47dBm) with different overlapping case (see Fig.2). All the desired signals and blockers are independently modulated, and various blocker/desired signal power level differences are assigned (3dBc to 5dBc) to produce a practical MIMO environment. The proposed design with the 2-stage ASFs for performing spatial filtering also successfully rejects the wideband modulated blockers and demodulates the desired signal with 2.4Gb/s 64QAM (high speed) and -22.02dB EVMrms (25% spectrum overlap) as shown in Fig.2. Furthermore, the case with two different blockers is also measured. With the 2-stage ASFs for performing spatial filtering, wideband modulated blockers are autonomously rejected, and the desired signal is demodulated for 0.6Gb/s 64QAM with -22.13dB EVMrms (0% spectrum overlap).

IV. Career Plan and Impact Statement

I am deeply honored and grateful to have been awarded the fellowship during my PhD journey. This opportunity allowed me to attend the IMS in person and be recognized at the Awards Banquet. Throughout the IMS week, I had the privilege of learning about the latest THz, mm-Wave, and microwave technologies through presentations and company showcases. This experience has given me greater confidence to tackle the challenges in my ongoing projects and future career, whether in academia or industry.

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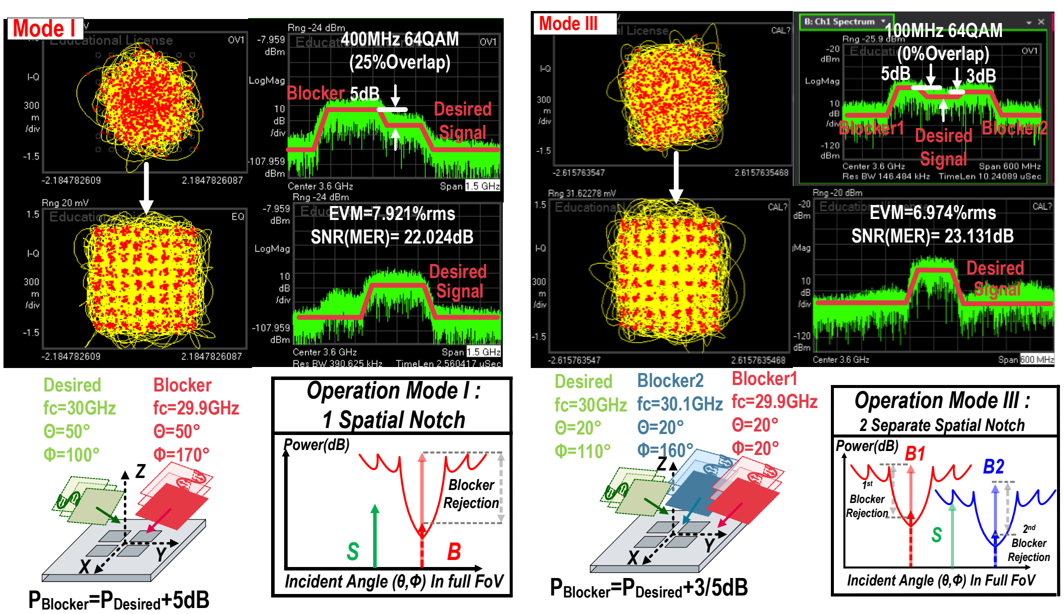

Fig. 2. The mm-Wave RX MIMO array with 2-stage ASFs demonstrate concurrent autonomous rejection of blockers and automatic desired signal beamforming. First test uses 400MHz (high speed) 64QAM complex modulated signals and 25% overlapping on desired signal/blockers. Second test uses 100MHz 64QAM complex modulated signals and no overlapping on desired signal and two blockers.