Synopsis of FIU's RAND-Lab Current Research on Spectrum Utilization (FR1 up to D-Band)

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STAR Front-End using Two Circulators in A Differential Connection

The In-Band Full Duplex (IBFD) communication system attracts the research interests due to its ability to double the spectral efficiency by achieving receiving and transmitting simultaneously. As there is a rapid development of the communication technologies and an increasing demand of high traffic over transmission, considerable capacity of the communication channel is expected. Shannon-Hartley law says the capacity, in bits per second, is given by

$$C_c = W log_2(1 + SNR)$$

In order to increase the capacity of the channel, we can either increase the bandwidth or the SNR. However, the issue regarding to the IBFD system is the inherent Self-interference (SI) component, which leaks directly from the Tx to Rx, and deteriorates the performance, thus lowering capacity. Self-Interference Cancellation (SIC) is required in the IBFD system to increase the SNR and therein increase capacity of the channel.

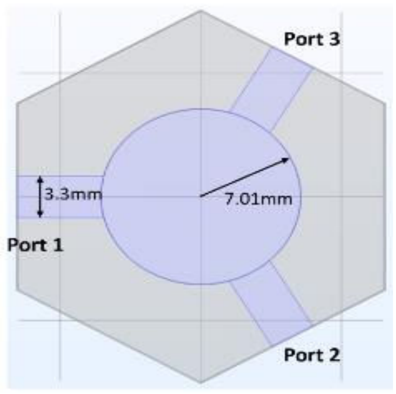


Fig. 01 : Ferrite based circulator.

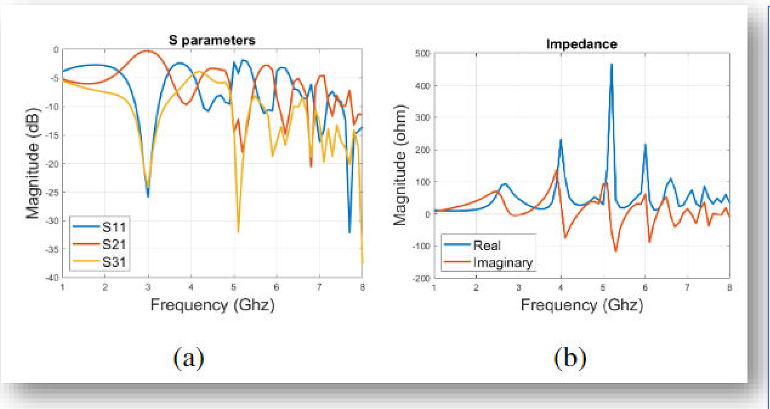


Fig. 03 : Ferrite circulator without the matching network simulation result: (a) S-parameters (b) Impedance

- The real part of the impedance within the band of interest running from 3 to 7 GHz maintains within 30 to 80 ohm, and the imaginary part of the impedance maintains within -20 to 20 ohm after adding the impedance matching network and optimization. Therefore, the optimized circulator can achieve a wide bandwidth from 3 to 7 GHz.

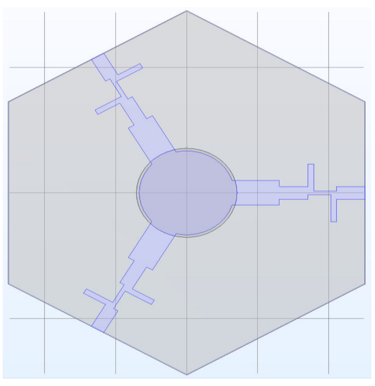


Fig. 02: Optimized ferrite based circulator design.

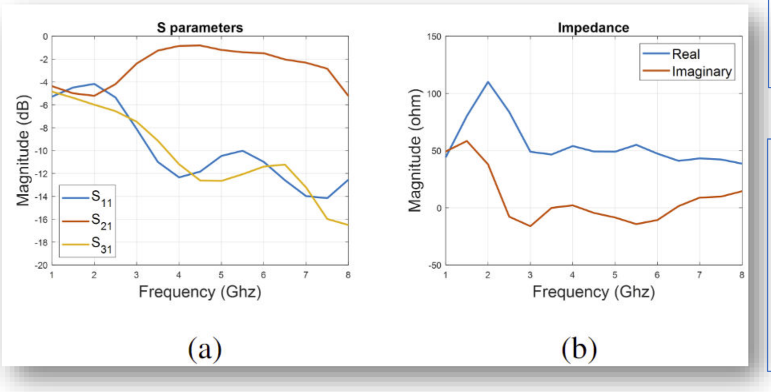


Fig. 04: Ferrite circulator with the matching network simulation result: (a) S-parameters (b) Impedance

- Compared with the ferrite before impedance matching, the designed ferrite circulator obtains a broader bandwidth across 3 to 7 GHz.

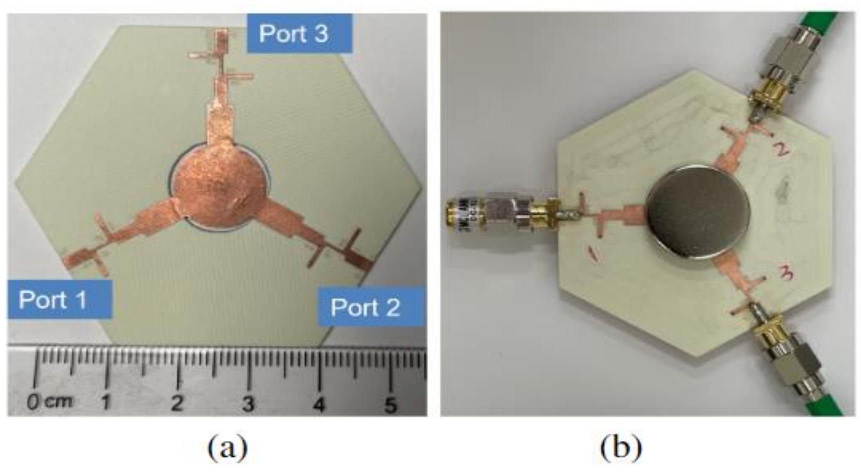


Fig. 06: Proposed circulator design: (a) Copper conductor (b) Circulator with ferrite inserted and magnets.

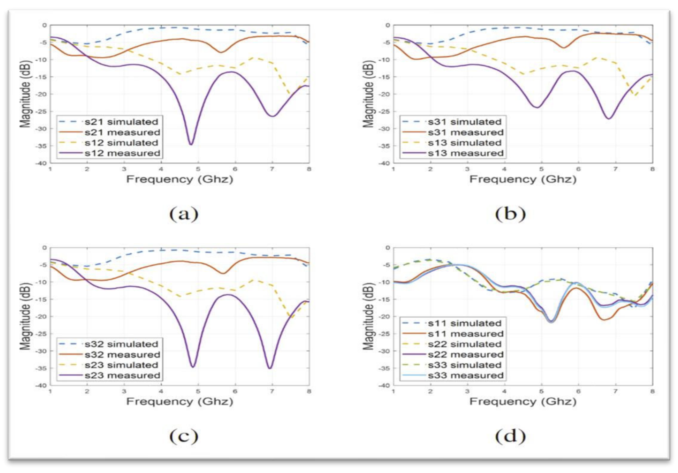


Fig. 07: Ferrite circulator with the matching network measurement and simulation result.

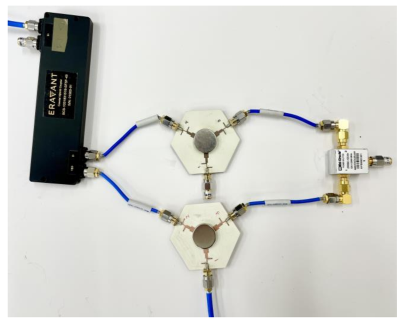


Fig. 08: Proposed SIC architecture.

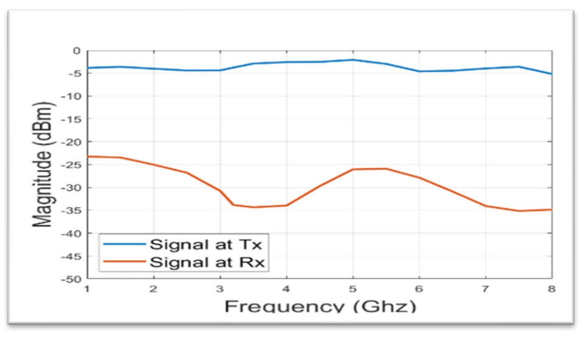


Fig. 09: Frequency domain measurement of signal levels. The transmit signal undergoes about 3 dB of loss as measured at the Tx port. The residual self-interference at the Rx is better than -30 ∓ 4 dB.

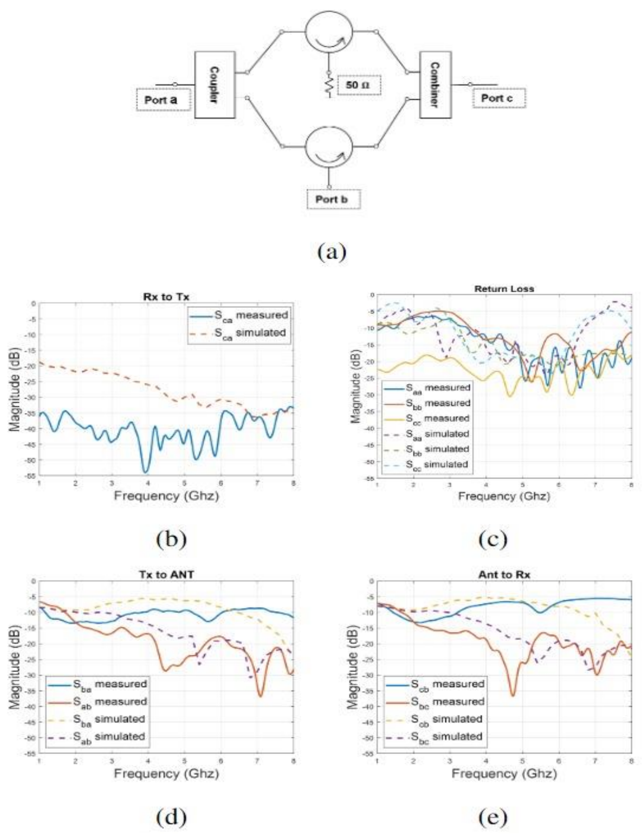


Fig. 10: Measurement for a 50 ohm termination: (a) Designed SIC architecture (b) Interference level at the receiver side (c) Return loss measured at all the ports of the proposed system (d) Signal at the transmit port showing about 10±3 dB off loss. (e) Signal at the receive port showing about 5±2 dB off loss.

- The measured signal at the transmit side (Tx) is marked in blue curve, and the leaking signal at the interference port (Rx) is marked in red.
- The best isolation performance for the proposed system is from 3 to 8 GHz due to the best operating frequency range of the circulator. The measured transmitted signal at the transmit port is about -3 dBm to -2 dBm, and the measured interfering signal at the receiver side is around -33 dBm that keeps the system isolation, also known as self-interference cancellation is better than 30 dB over a wide bandwidth from 1 to 8 GHz.

Publications

- Y. Zhao, U. De Silva, S. B. Venkatakrishnan, D. Psychogiou, G. Larkins and A. Madanayake, "STAR Front-End Using Two Circulators in a Differential Connection," in IEEE Journal of Microwaves, vol. 4, no. 2, pp. 253-263, April 2024, doi: 10.1109/JMW.2024.3372855.

Differential Arrays for Butler Multi-Beam STAR

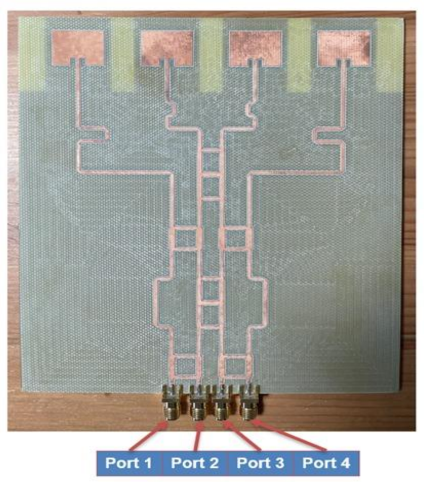


Fig. 01: Butler Matrix.

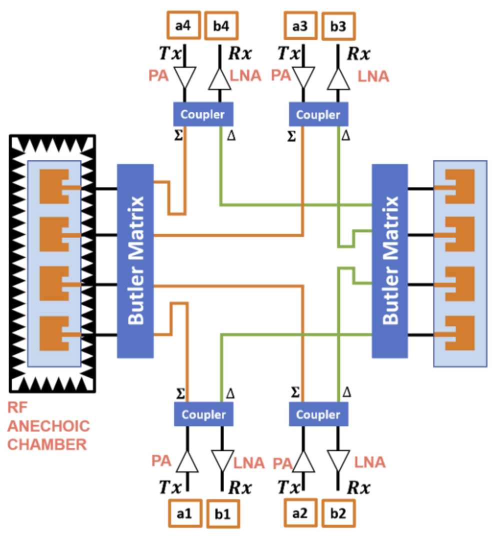


Fig. 02: Proposed full-duplex system.

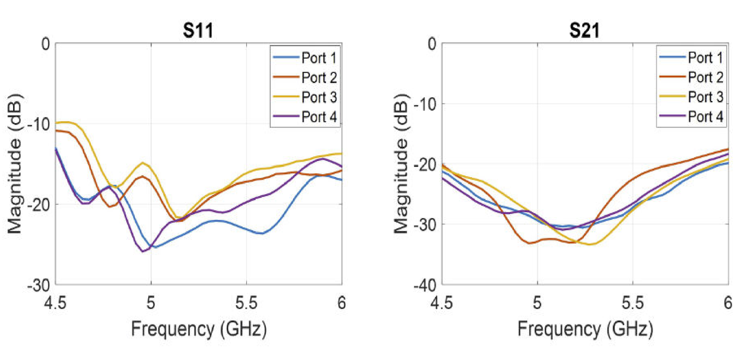
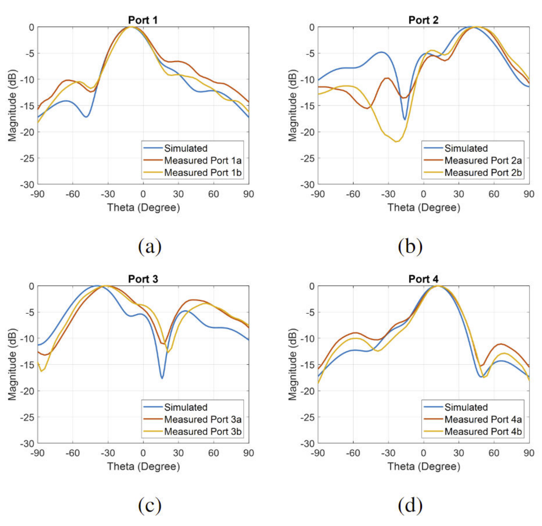


Fig. 03: Self-coupling for the full-duplex system.



- The proposed method combines a passive multi-beam beam-former matrix realized using passive microwave circuits with the twin-array concept.
- The result indicates that the system achieves an isolation between Tx and Rx that is below −30 dB across the entire 5 GHz to 5.5 GHz frequency range.

Publications

- Y. Zhao, S. B. Venkatakrishnan, Constantinos L. Zekios, Soumyajit Mandal, and A. Madanayake, "Differential Arrays for Butler Multi-Beam STAR ", in 2024 International Applied Computational Electromagnetics Society (ACES) Symposium, IEEE, 2024 (paper accepted) .

Terahertz Communication

Sub-Terahertz communication system was implemented :

- Design experimentation of an SDR operating in the 130-150 GHz band, with ASK/BPSK/QPSK modulation on I/Q channels, at a maximum data rate of 128Mbps.
- Developing realistic THz channel model based on measurements, estimating, and clustering the channel parameters using advanced signal processing, ML/DL techniques.

Applications: ultra capacity wireless back haul in cellular networks, high speed satellite communication, inter/intra chip communication and more.

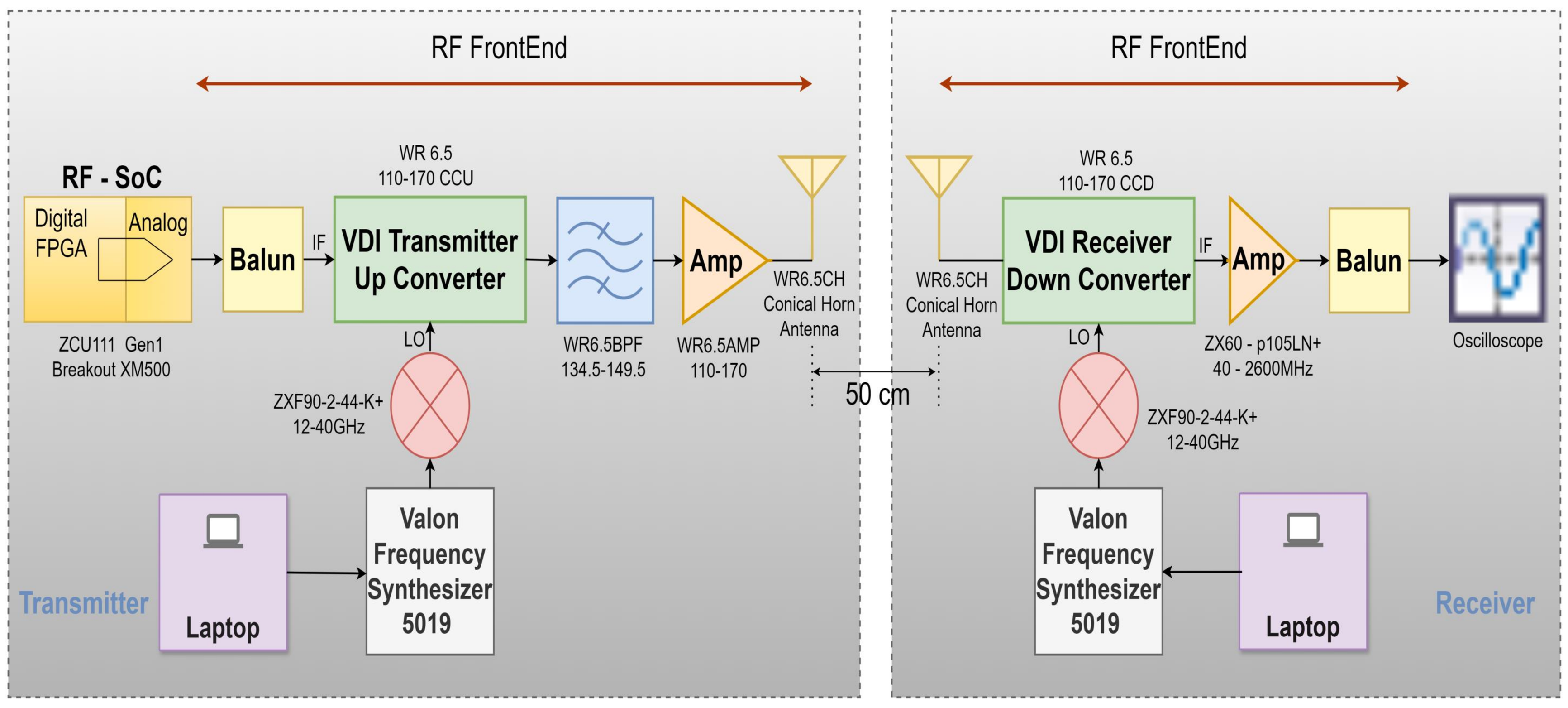


Figure 1: Real-time BPSK/ASK waveforms monitored on oscilloscope, 40 dB SNR and 32 samples/symbol, ADC sample rate 4 GS/s with 8 phases.

Transmitting and Receiving Signal

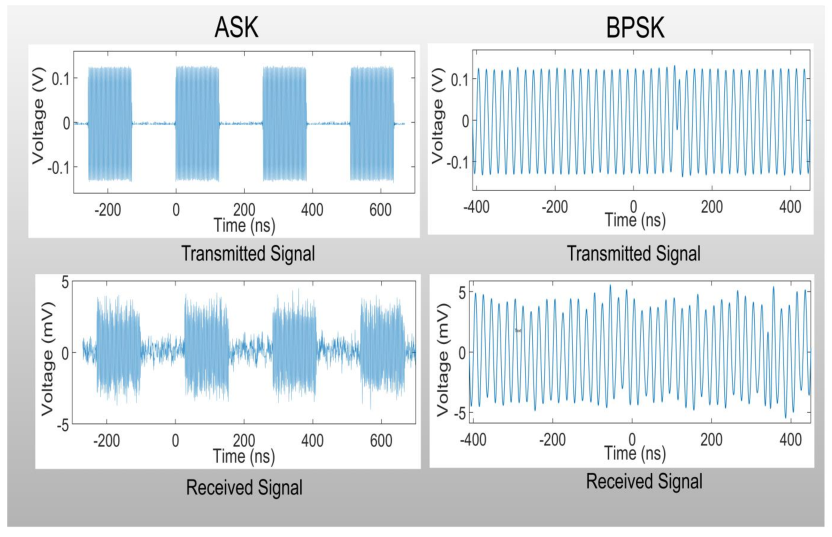


Figure 02: Time domain modulated signals; data ...-1-0-1-0-1.... IF at 500 MHz, a) Tx ASK, b) Rx ASK, c) Tx BPSK (zoomed), and d) Rx BPSK (zoomed).

Front End:	Back End :
•WR 6.5 Conical antenna 110 – 170 GHz •WR 6.5 Amplifier 110 – 170 GHz •WR 6.5 VDI CCU and CCD 110 - 170 GHz	•Xilinx RF SoC ZCU 111 •Includes ADC/DAC sampling frequencies of 4.096 GSPS

Transfer Function of system

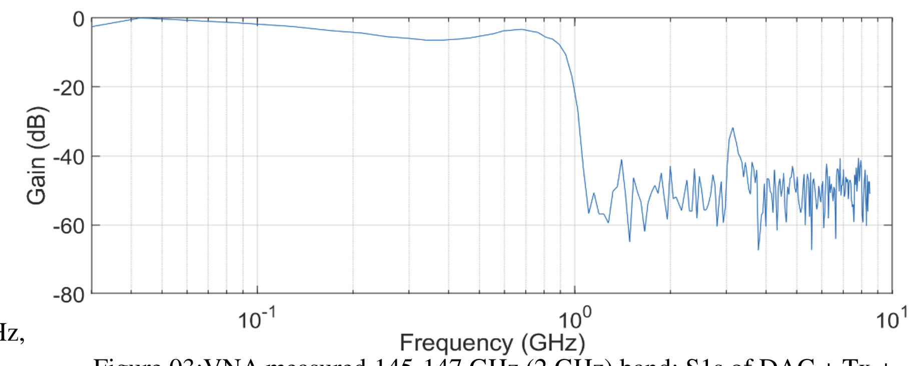


Figure 03:VNA measured 145-147 GHz (2 GHz) band: S1s of DAC + Tx + Channel + Rx + ADC sampled at 4 GS/s and 8/16 ADC/DAC clock phases.

Publications

- K. Karunanayke, H. Weerasooriya, G. Rathnasekara, A. Singh, T. S. Rappaport, J. M. Jornet, and A. Madanayake, "Design of 145 GHz BPSK Modem on RF-SoC", in 2024 International Applied Computational Electromagnetics Society (ACES) Symposium, IEEE, 2024 (paper accepted).
- H. Abdellatif, V. Ariyarathna, S. Petrushkevich, A. Madanayake, and J. M. Jornet, "A real-time ultra-broadband software-defined radio platform for terahertz communications," in IEEE INFOCOM 2022 – IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), 2022, pp. 1–2.

Multichannel Spectrum Intelligence Systems Using ADFT for Antenna Array based spectrum perception

Fast sensing across multiple directions using array processors for sensing and perception of the waveforms

- First, the captured signal is amplified using an LNA. Then it is band pass filtered to filter out the 5.8-GHz signals
- The amplified and filtered signal is then fed to the mixer with local oscillator(LO) signal to obtain the down converted signals.
- The mixer output is then low-pass filtered and again amplified to boost the filtered baseband signal.

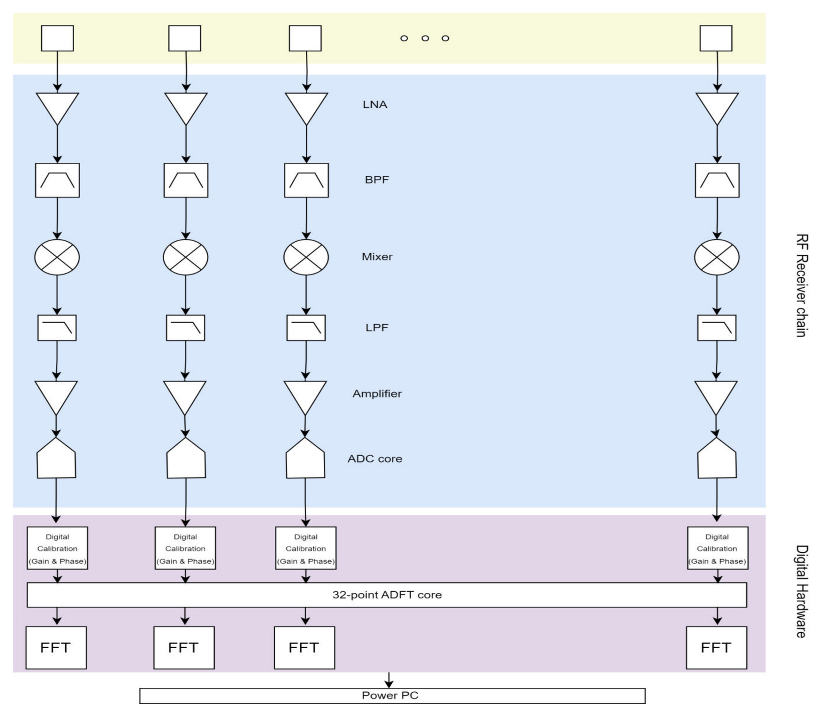


Fig. 1: The system architecture.

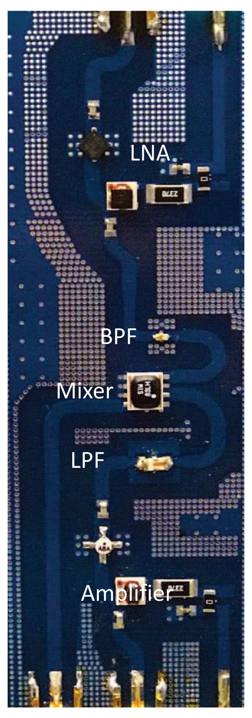


Fig. 2: RF receiver chain.

Fig. 3: 5.8 GHz 32-beam array receiver.

FPGA Designs for Multi-Beamforming

- The ADFT is used to create a wideband multi-beam RF digital beam former and temporal spectrum-based attention unit which monitors 32 discrete directions across 32 sub-bands in real-time using a multiplier-less algorithm having low compute complexity. The digital designs for performing multi-beamforming using the ADFT were designed using Xilinx tools.
- CASPER Reconfigurable Open Architecture Computing Hardware (ROACH) has been used in our systems to sample the intermediate frequency (IF) signal and perform the digital beamforming.
- ROACH-2 is based on a Xilinx Virtex-6 FPGA chip, It also includes an integrated on-board processor that handles communications and control functions with the FPGA. Also, it has two ZDOK interfaces.

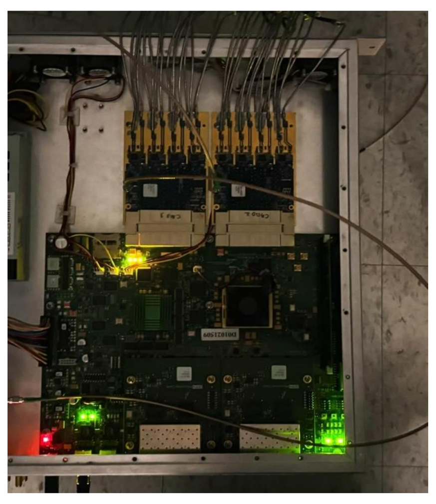


Fig. 4: ROACH-2 Platform.

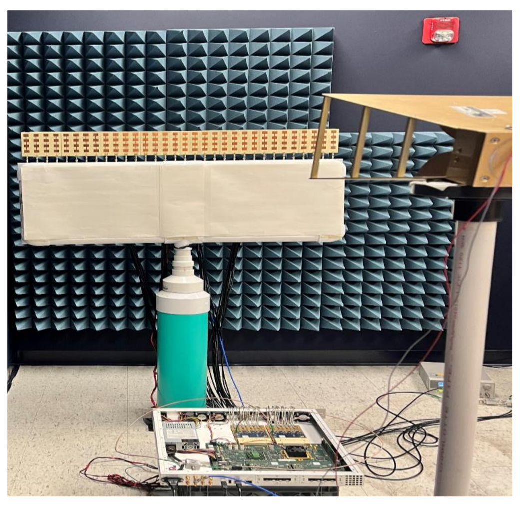


Fig. 5: Full experimental setup.

Publications

- V. A. Coutinho et al., "A Low-SWaP 16-Beam 2.4 GHz Digital Phased Array Receiver Using DFT Approximation," in IEEE Transactions on Aerospace and Electronic Systems, vol. 56, no. 5, pp. 3645-3654, Oct. 2020, doi: 10.1109/TAES.2020.2987094.
- V. Ariyarathna et al., "Multibeam Digital Array Receiver Using a 16-Point Multiplierless DFT Approximation," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 2, pp. 925-933, Feb. 2019, doi: 10.1109/TAP.2018.2882629.

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