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A Real-Time Ultra-broadband Software-Defined Radio Platform for Terahertz Communications

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Abstract—**Wireless communication in the terahertz band (100 GHz to 10 THz) is envisioned as a critical building block of 6G wireless systems, due to the very large available channel bandwidth above 100 GHz. Thanks to the narrowing of the so-called terahertz technology gap, several platforms for experimental terahertz communication research have been recently developed. However, these are mostly channel sounding or physical layer testbeds that rely on off-line signal processing. In order to research and develop upper networking layers, it is necessary to have a real-time platform that can process bandwidths of at least a few gigahertz. In this paper, a software-defined radio platform that is able to operate in real-time with up to 8 GHz of bandwidth at 130 GHz is demonstrated for the first time.**

I. INTRODUCTION

Due to increasing demands for high data-rate and low latency links for both consumer and backhaul communications, it is necessary to move up in the frequency spectrum to the sub-terahertz and terahertz bands and thereby, leveraging its available broad bandwidth [1]. For many years, terahertz communication research was limited to theoretical and numerical studies due to the lack of experimental platforms. More recently, experiments in the sub-terahertz and terahertz bands with multi-gigahertz bandwidth have demonstrated that such links are feasible and reliable for wireless communication [2], [3]. Current experimental platforms for systems above 100 GHz are mostly channel sounders or physical layer testbeds that rely on off-line processing [3]. Although extensive research has been done on the physical layer for systems above 100 GHz, there has been a slow progress on the upper layers due to hardware limitations in enabling real-time systems.

With the goal to develop and test upper layer protocols for above 100 GHz systems, it is crucial to develop a software defined radio (SDR) that operates at above 100 GHz and can process multi-GHz of bandwidth in real-time. Developing such system has many challenges, which include the need of high-speed interfaces to move data in/out of the programmable digital logic; the high noise introduced by the high frequency wide bandwidth commercial analog components; the high conversion losses of the IQ mixers; power handling and high phase noise introduced by the frequency synthesizers used to upconvert and downconvert the generated signals to/from the carrier frequencies, among others. Existing real-time platforms, including those developed for millimeter-wave systems [4], cannot exploit the large bandwidth offered by the terahertz channel.

In this demonstration, we will show a programmable SDR able to process in real-time up to four multiplexed 2-GHz-wide channels, each supporting an Orthogonal Frequency Division Multiplexing (OFDM) based physical layer. The demonstration will be conducted in the 120-140 GHz band, but the target frequency can be changed by replacing the frequency of the up and down-converters. As of today, this is the only SDR platform with largest real-time bandwidth demonstrated to the best of the authors' knowledge.

II. SYSTEM DESIGN AND IMPLEMENTATION

Our developed fully functional SDR operating at 8 GHz of bandwidth integrates the following components: a high-speed DSP engine, high-speed data converters, an analog combining network, and 120–140 GHz front-ends. Our approach utilizes Xilinx Radio Frequency System on Chip (RF-SoC) which contains multiple data-converters alongside the programmable logic fabric which realizes the DSP engine [5]. At the transmitter side, a total of eight DACs (two per channel) are utilized operating at 4.096 Giga-samples-per-second (GSps). Each pair of DACs supports one complex baseband channel bearing 2.048GHz of bandwidth. Each channel is then up converted to different IF carriers using IQ mixers driven with a unique LO frequency. Finally, the channels are combined and sent out through the 120–140 GHz front-ends. Similarly, at the receiver the signal is down-converted by the 120–140 GHz front-end and passed to a splitter that separates four copies of the received signal, each down-converted with a unique LO frequency based on the channel. Finally, by utilizing the eight ADCs available, the eight streams of in-phase and quadrature components are sampled at 4.096 GSps. In the subsequent Secs. II-A, II-B, and II-C, the physical layer, analog system, and RF front-ends are briefly described.

A. Physical Layer Implementation

An OFDM based physical layer is implemented on the programmable logic, largely based on the IEEE802.11a standard due to its simplicity and, thus, adequateness for high-speed operation. The OFDM implementation uses 64 subcarriers such that frequency response is flat across the subcarrier bandwidth [5]. The digital cores have been designed to support the conventional modulation schemes, namely, BPSK, QPSK, 16-QAM, and 64 QAM. The following crucial blocks necessary for a communication system have been implemented

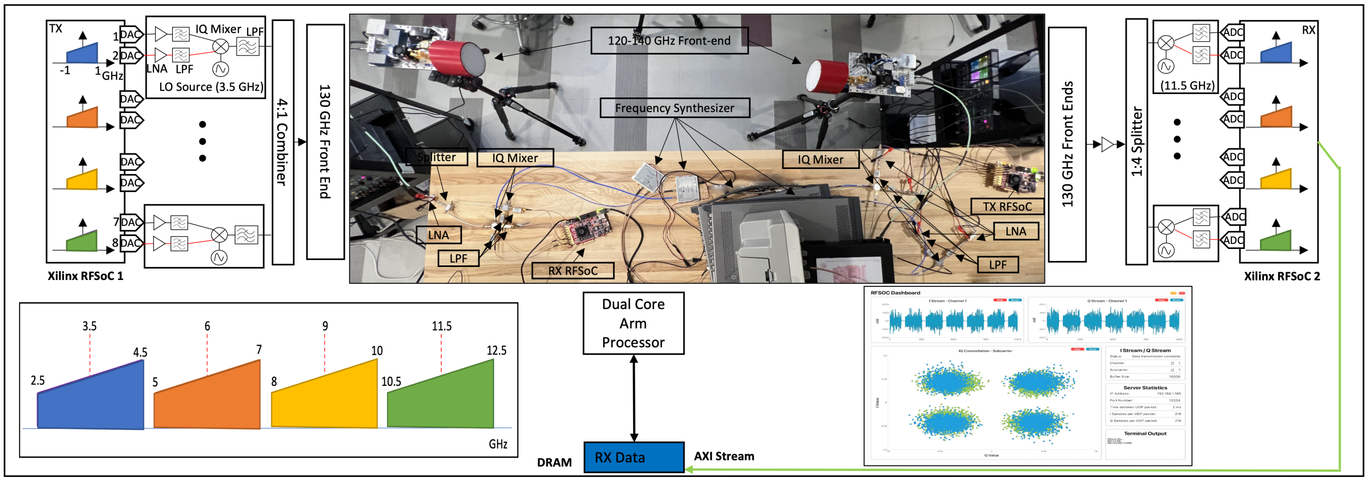

Fig. 1. Overview architecture of our 130 GHz SDR including the RFSoC, IF analog network, 130–140 GHz front-ends, and custom dashboard showing received constellation of the two-channels running real-time.

on the digital cores: header insertion, symbol mapping, IFFT, CP insertion, packet detection, frequency offset estimation and correction, timing acquisition, FFT, CP removal, and channel estimation and equalization. When all four channels are utilized at the highest modulation scheme supported (64-QAM), an effective data-rate of 48 Gbps can be achieved.

B. Analog IF Network

IQ mixing is performed in analog in order to obtain the maximum baseband bandwidth per channel from digital while 2x interpolation/decimation is performed the relax analog filtering requirements. The signal coming out of the DACs is first amplified then filtered with a low pass filter to remove the digital images. This signal is then upconverted by a IQ mixer driven with a unique LO based on the channel. At the output of the mixer, we utilize a low pass filter with a cut-off frequency close to our highest channel frequency. Ideally, we would like to utilize a 2.048 GHz band-pass filter, but off-the-shelf filters that match our frequencies and bandwidth do not exit. Finally, all the four outputs of the IQ mixer are combined and fed to the IF input of the 120–140 GHz front-end. At the receiver, the signal is amplified and then split into four. Each split output will go through a separate IQ mixer that is driven by an LO (determined based on the channel number and the LO frequency utilized at the front-ends). The IQ mixer will downconvert to complex baseband and the individual complex streams are then low pass filtered and finally sampled.

C. RF Front Ends

The 120-140 GHz front-ends utilized in this demo are custom-designed by Virginia Diodes Inc. (VDI) which are based on Schottky diode technology [6]. At RF, a maximum output power of 13 dBm is achieved by an RF power amplifier with 20 dB gain. At the transmitter and receiver 38 dBi antennas are used.

III. DEMO DESCRIPTION

We will demonstrate a fully functional real-time wireless communication system operating at 130 GHz. The demonstration will include two active channels of 2.048 GHz bandwidth each with QPSK modulation. We will show IQ constellations at the receiver by exporting the OFDM demodulated IQ samples in each channel to the ARM host through AXI Stream and illustrating them on a custom GUI as shown in Fig. 1. This will validate the platform's ability to run in real-time a multi-channel OFDM-based physical layer carrying data at several Gbps at sub-terahertz frequencies.

IV. CONCLUSION

A SDR platform able to process ultra-broadband signals in real-time is needed to develop and test innovative networking solutions for future 6G networks in the terahertz band. In this demonstration, we have shown the first operational testbed that meets this requirement, based on a RFSoC and able to manipulate up to four 2 GHz-wide channels in real-time. While an OFDM-based physical layer is shown, this is a fully programmable platform able to support any multi-channel waveform. This platform will be utilized to test medium access control protocols, neighbor discovery strategies, multi-hop relaying and routing solutions tailored to terahertz networks.

REFERENCES

[1] I. F. Akyildiz, J. M. Jornet, and C. Han, "Teranets: Ultra-broadband communication networks in the terahertz band," *IEEE Wireless Communications*, vol. 21, no. 4, pp. 130–135, 2014.

[2] P. Sen and J. M. Jornet, "Experimental demonstration of ultra-broadband wireless communications at true terahertz frequencies," in *2019 IEEE 20th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, 2019, pp. 1–5.

[3] T. S. Rappaport, Y. Xing, O. Kanhere, S. Ju, A. Madanayake, S. Mandal, A. Alkhateeb, and G. C. Trichopoulos, "Wireless communications and applications above 100 ghz: Opportunities and challenges for 6g and beyond," *IEEE Access*, vol. 7, pp. 78 729–78 757, 2019.

[4] R. Zhao, T. Woodford, T. Wei, K. Qian, and X. Zhang, *M-Cube: A Millimeter-Wave Massive MIMO Software Radio*. New York, NY, USA: Association for Computing Machinery, 2020.

[5] V. Ariyarathna, A. Madanayake, and J. M. Jornet, "Real-time digital baseband system for ultra-broadband thz communication," in *2020 45th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, 2020, pp. 1–2.

[6] P. Sen, V. Ariyarathna, A. Madanayake, and J. M. Jornet, "A versatile experimental testbed for ultrabroadband communication networks above 100 ghz," *Computer Networks*, vol. 193, p. 108092, 2021.