Experimentation with Full-Duplex Wireless in the COSMOS Testbed

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***Abstract*—In order to support experimentation with full-duplex (FD) wireless, we integrated the FlexICoN Gen-2 wideband FD radio with the city-scale PAWR COSMOS testbed [1]. In particular, the implemented FD radio consists of an antenna, a customized Gen-2 RF self-interference (SI) canceller box, a USRP software-defined radio (SDR), and a compute node. The RF canceller box includes an RF SI canceller implemented using discrete components on a printed circuit board (PCB), which emulates its RFIC canceller counterpart. The Gen-2 RF SI canceller achieves 50 dB RF SI cancellation across 20 MHz bandwidth using the technique of frequency-domain equalization (FDE) [2]. In this abstract, we present the design and implementation of the remotely accessible Gen-2 wideband FD radio integrated with the COSMOS sandbox at Columbia University. We also present an example real-time wideband FD wireless link demonstration using the GNU Radio software.**

I. Introduction

Full-duplex (FD) wireless has drawn significant attention [3], [4] due to its potential to double data rate at the physical layer and to provide many benefits at different layers of the network stack. One of the major challenges associated with FD is the extremely powerful self-interference (SI) signal on top of the desired signal, which requires more than 90 dB of self-interference cancellation (SIC) across the antenna interface, and RF and digital domains.

Within the Columbia FlexICoN project [5], we focus on the design and experimentation with FD radios and systems grounded in integrated circuit (IC) implementations, which are suitable for hand-held and form-factor-constrained devices [4]. Since interfacing an RFIC canceller with software-defined radios (SDRs) presents numerous technical challenges, we implemented the RF SI canceller on a printed circuit board (PCB) to facilitate the cross-layered experiments with an SDR platform. In particular, we demonstrated the FlexICoN Gen-1 *narrowband* FD radio and an FD link in [6], where 40 dB RF SIC is achieved across 5 MHz bandwidth. The Gen-1 RF SI canceller implemented on a PCB emulates its RFIC counterpart that we presented in [7].

In order to allow the broader community to experiment with FD wireless, we recently integrated an improved version of the Gen-1 narrowband RF canceller presented in [6] with a USRP N210 SDR in the open-access ORBIT testbed. The implementation of the Gen-1 RF canceller box and the description of the open-access FD radio in the ORBIT testbed

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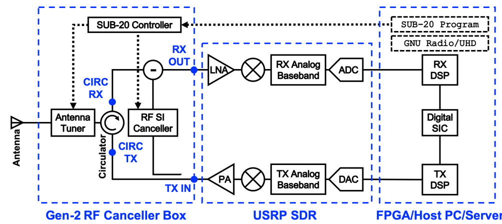


Fig. 1: Block diagram of the implemented Gen-2 wideband full-duplex (FD) radio consisting of a Gen-2 RF canceller box, a USRP software-defined radio (SDR), and a compute node (e.g., a host PC/server).

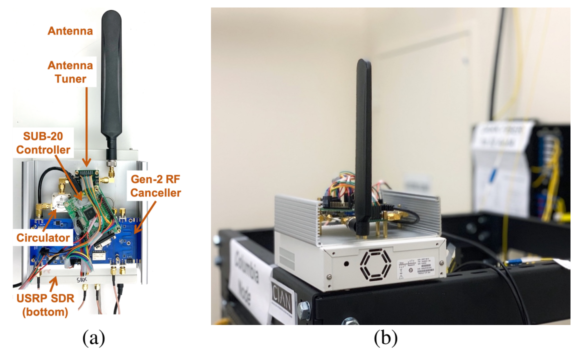
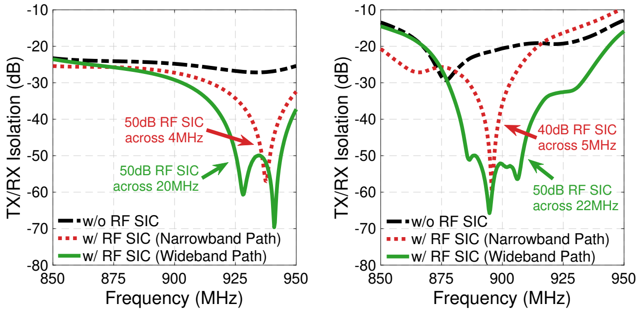


Fig. 2: (a) The implemented FlexICoN Gen-2 wideband FD radio, and (b) its integration with a COSMOS sandbox located at Columbia University, where the FD radio can be accessed and controlled by a COSMOS compute node (e.g., a host PC/server).

can be found in [8]. We also provided example remote FD experiments where 90 dB overall SIC is achieved across the antenna interface, and the RF and digital domains.[1]

More recently, in [2], we designed and experimented with the FlexICoN Gen-2 *wideband* FD radio based on the technique of frequency-domain equalization (FDE) [11], where 50 dB RF SIC is achieved across 20 MHz bandwidth. In this abstract, we present an improved version of the Gen-2 wideband RF SI canceller used in [2] and its integration with the USRP SDR platform using the GNU Radio software. We also discuss the integration of the Gen-2 wideband FD radio with the city-scale PAWR COSMOS testbed [1], [12] (the detailed tutorial can be found in [13]). We envision that the implemented FD radio and the example experiments, which can be further extended to more complicated communication and networking scenarios, can facilitate further hands-on research in the area of FD wireless, as discussed in [8].

[1]The detailed instructions and code of the open-access Gen-1 FD radio integrated in the ORBIT testbed are available at [9], [10].



(a) Ideal case w/ 50 Ω termination. (b) Practical case w/ a real antenna.

Fig. 3: Measured TX/RX isolation of the Gen-2 RF canceller without turning on the canceller, and with the narrowband (Gen-1)/wideband (FDE) path on, when the circulator antenna port is: (a) terminated by 50 Ω, and (b) connected to an antenna.

II. The Gen-2 Wideband Full-Duplex Radio

Figs. 1 and 2 show the diagram and implementation of the Gen-2 wideband FD radio, which is integrated with the COSMOS testbed sandbox at Columbia University. The implemented FD radio consists of an antenna, a Gen-2 RF canceller box, a USRP SDR, and a compute node (e.g., a laptop/PC or a server). The Gen-2 RF canceller box (see Fig. 2(a)) includes a customized antenna tuner, a coaxial circulator, a Gen-2 RF SI canceller, and a SUB-20 controller.

The Gen-2 RF SI Canceller. To alleviate the requirements on the RX front-end linearity and the analog-to-digital converter (ADC) dynamic range, an FD radio needs to achieve sufficient SI isolation and cancellation in the RF/analog domain before involving SIC in the digital domain. In particular, the Gen-2 RF canceller is implemented using discrete components on a PCB and is optimized around 900 MHz operating frequency.[2] To achieve RF SIC, a reference signal coupled from the RF canceller TX input is passed to the cancellation path. The implemented Gen-2 canceller includes two cancellation paths that can be selected through an RF switch: the Gen-1 (*narrowband*) path and the FDE (*wideband*) path. Then, RF SIC is performed at the RF canceller RX output. In particular, the implementation of the narrowband path is identical to the Gen-1 RF canceller implementation described in [8], and the detailed implementation of the FDE path can be found in [2].

Measured RF SIC. Fig. 3 shows two example measurements of the TX/RX isolation achieved by the Gen-2 RF canceller (measured between the TX input and RX output ports of the canceller using a vector network analyzer) when the circulator antenna port is terminated by 50 Ω (ideal), and is connected to a real antenna (practical), respectively.

The results show that in the ideal case, the circulator provides around -25 dB TX/RX isolation without turning on the Gen-2 RF canceller. When the canceller is turned on, the FDE path can achieve 40/50 dB RF SIC across 28/20 MHz bandwidth, which is a 2.5/5$\times$ improvement in bandwidth compared to that achieved by the Gen-1 path. In the practical case, due to the worse TX/RX isolation provided by the antenna interface, the Gen-1 path only achieves 40 dB RF SIC across 4 MHz, while the FDE path can still achieve 40/50 dB RF SIC across 28/22 MHz bandwidth.

[2] We select 900 MHz around the Region 2 902–928 MHz frequency but the design can be easily extended to other frequency bands (e.g., 2.4/5 GHz).

III. A Real-Time FD Link Demonstration

The demonstration setup contains two Gen-2 wideband FD radios that simultaneously transmit and receive OFDM packets at around 900 MHz carrier frequency with up to 20 MHz sampling rate. A laptop is used to remotely login into the COSMOS testbed to execute the example FD link experiment, where both FD radios are controlled by a COSMOS compute node (server). In order to achieve optimized performance, we implemented the RF canceller control and the digital SIC algorithm as customized GNU Radio out-of-tree modules in C++. Overall, the Gen-2 FD radio achieves a total amount of 90–95 dB SIC across up to 20 MHz bandwidth, where 50 dB and 40-45 dB SIC is achieved in the RF and digital domains, respectively. Through the GNU Radio graphical user interface (GUI), demo participants can observe: (i) the real-time signal received at the FD nodes after RF and digital SIC, (ii) the coefficients returned by the packet-level digital SIC algorithm, and (iii) the decoded OFDM packets at the FD radios and the corresponding packet error rate.

Acknowledgments

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