Demo: Full-Duplex Wireless based on a Small-Form-Factor Analog Self-Interference Canceller

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ABSTRACT

A demonstration of a real-time full-duplex wireless link is presented, in which a pair of full-duplex transceivers perform simultaneous transmission and reception on the same frequency channel. A full-duplex transceiver is composed of a custom-designed small-form-factor analog self-interference canceller, and a digital self-interference cancellation implementation is integrated with the National Instruments Universal Software Radio Peripheral (USRP). An adaptive analog self-interference canceller tuning mechanism adjusts to environmental changes. We demonstrate the practicality and robustness of the full-duplex wireless link through the National Instruments LabVIEW interface.

Keywords: Full-Duplex Communications; Self-Interference Cancellation; Software Defined Radio

1. INTRODUCTION

Full-duplex (FD) communication, simultaneous transmission and reception on the same frequency channel, has the potential to substantially increase the throughput in wireless networks. The main challenge hindering the implementation of practical FD devices is the high self-interference (SI) caused by signal leakage from the transmitter into the receiver circuit. The SI signal is usually many orders of magnitude higher than the desired signal at the receiver's input, requiring 90 dB-110 dB of self-interference cancellation (SIC).

Recent work focused on the development of laboratory bench-top FD transceivers using off-the-shelf components [3]. Integrated circuit (IC) implementations that are more appropriate for mobile and small-form-factor devices were presented in [6, 7, 8]. Related work also investigated the possible rate gains assuming perfect SIC [2] and non-negligible SI [4, 5], where the latter also takes into account realistic FD circuit parameters.

In this demonstration, we present a cross-layered (software and hardware) implementation of an FD wireless link composed of two FD transceivers. Each transceiver consists of an antenna, a circulator, a custom-designed RF SI canceller, and a National Instruments (NI) USRP software defined radio (SDR) [1]. Figs. 1 and 2(a) show the diagram and the implementation of a transceiver. The SI signal is canceled to the noise floor by applying both RF SIC and a digital SIC algorithm. Specifically, our frequency-flat amplitude and phase-based RF SI canceller emulates the behavior of an IC RF canceller that we presented in [6], which has a smaller form factor than [3] at the expense of narrower cancellation bandwidth. To dynamically adjust the amplitude and phase of our RF SI canceller, an adaptive control mechanism is implemented.

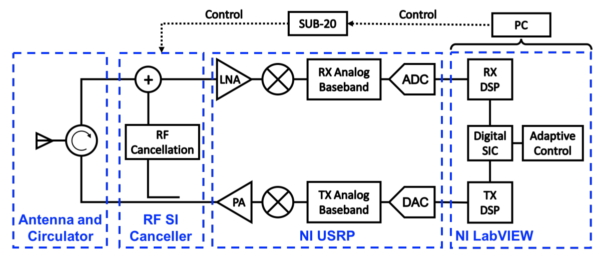
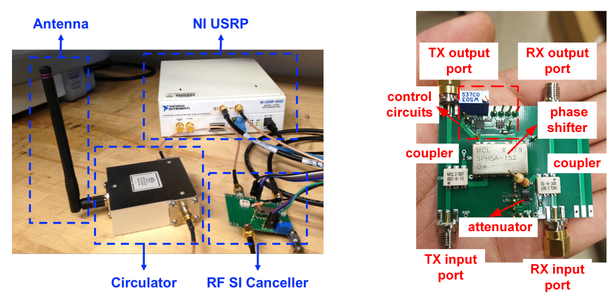


Figure 1: Block diagram of the presented FD transceiver.



(a) (b)

Figure 2: (a) An FD transceiver composed of an antenna, a circulator, a custom-designed RF SI canceller, and an NI USRP, and (b) The 0.8 GHz to 1.3 GHz frequency-flat amplitude and phase-based RF SI canceller.

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2. SI CANCELLATION

Our RF SI canceller taps a reference signal at the output of the power amplifier (PA) and performs SIC at the input of the low-noise amplifier (LNA) at the RX side. The implemented RF SI canceller depicted in Fig. 2(b) operates from 0.8 GHz to 1.3 GHz. The TX input and output ports of the canceller connect to the PA output and the circulator's TX port, respectively. The RX input and output ports of the canceller connect to the circulator's RX port and RX input, respectively. A portion of the TX signal is coupled from the PA output through a 6 dB directional coupler. The TX reference signal is then adjusted in amplitude and phase by using a passive phase shifter and an attenuator, which are software-controlled from a PC (see Fig. 1). The passive phase shifter covers full 360° range and is controlled by a control circuit that consists of an 8-bit digital-to-analog converter (DAC), resulting in a resolution of about 1.5°. The attenuator provides an attenuation range from 0 dB to 15.5 dB with a 0.5 dB resolution.

An adaptive control mechanism is implemented on the PC to automatically adjust the amplitude and phase of the RF SI canceller based on the amount of RF SIC achieved, so that the RF SI canceller adapts quickly to environmental changes. The RF SIC is critical to alleviate the RX linearity and the analog-to-digital converter (ADC) dynamic range requirements. Then, digital SIC further cancels the linear SI as well as the non-linear distortion products generated by the RX and the RF canceller. The digital SIC is implemented based on a nonlinear tapped delay line. Given the transmitted and received pilot sequence, the non-linear coefficient sequence is found by solving the least-square problem.

3. DEMONSTRATION

We implemented the digital SIC algorithm using the NI USRP SDR. The NI USRP can operate at a carrier frequency between 50 MHz and 4.4 GHz and can provide a maximum output power around 20 dBm. The operating frequency of the FD transceivers is 0.9 GHz, which is the same as the operating frequency of both the circulator and the RF SI canceller. The USRP is controlled from a PC that runs NI LabVIEW, which both performs digital signal processing and provides a graphical user interface.

The demonstration setup contains two FD transceivers that transmit and receive simultaneously on the same frequency channel. Through the panel of NI LabVIEW (Fig. 3), demo participants can observe the visualized transmitted and received signals in both time and frequency domains. Furthermore, the amount of SIC in each domain is constantly updated and displayed. The transmitted multi-tone signal has a bandwidth of 5 MHz with a peak output power of 10 dBm and an average output power of 0 dBm. The received signal is shown after each SIC phase (analog and digital). Without performing SIC, the SI signal is too strong for the desired signal to be detected. Once the SI signal is suppressed close to the −90 dBm noise floor, the desired signal is revealed. The circulator and the RF SI canceller together provide 40 dB SIC before the USRP RX, of which around 20 dB is obtained from the RF SI canceller. The additional 50 dB suppression comes from the digital SIC which eventually allows us to detect the desired signal under the powerful SI.

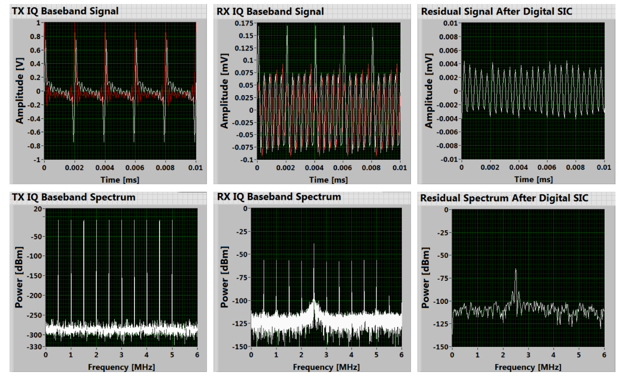

Figure 3: NI LabVIEW user interface showing the transmitted signal (left column), received signal with desired signal after RF SI canceller (middle column), and recovered desired signal after digital SIC (right column).

4. ACKNOWLEDGMENTS

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5. REFERENCES

[1] NI USRP-292x/293x Datasheet. http://www.ni.com/datasheet/pdf/en/ds-355.

[2] J. Bai and A. Sabharwal. Distributed full-duplex via wireless side-channels: Bounds and protocols. *IEEE Trans. Wireless Commun.*, 12(8):4162–4173, 2013.

[3] D. Bharadia, E. McMilin, and S. Katti. Full duplex radios. In *Proc. ACM SIGCOMM'13*, 2013.

[4] J. Marašević, J. Zhou, H. Krishnaswamy, Y. Zhong, and G. Zussman. Resource allocation and rate gains in practical full-duplex systems. In *Proc. ACM SIGMETRICS'15*, 2015.

[5] J. Marašević and G. Zussman. On the capacity regions of single-channel and multi-channel full-duplex links. In *Proc. ACM MobiHoc'16*, 2016.

[6] J. Zhou, A. Chakrabarti, P. Kinget, and H. Krishnaswamy. Low-noise active cancellation of transmitter leakage and transmitter noise in broadband wireless receivers for FDD/co-existence. *IEEE J. Solid-State Circuits*, 49(12):1–17, Dec. 2014.

[7] J. Zhou, T. H. Chuang, T. Dinc, and H. Krishnaswamy. Integrated wideband self-interference cancellation in the RF domain for FDD and full-duplex wireless. *IEEE J. Solid-State Circuits*, 50(12):3015–3031, Dec. 2015.

[8] J. Zhou, N. Reiskarimian, and H. Krishnaswamy. Receiver with integrated magnetic-free N-path-filter-based non-reciprocal circulator and baseband self-interference cancellation for full-duplex wireless. In *Proc. IEEE ISSCC'16*, 2016.