# Demo Abstract: Open-Access Full-Duplex Wireless in the ORBIT Testbed


Tingjun Chen*, Mahmood Baraani Dastjerdi*, Guy Farkash*, Jin Zhou†, Harish Krishnaswamy*, Gil Zussman*

*Electrical Engineering, Columbia University, New York, NY 10027, USA

†Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

{tingjun@ee., b.mahmood@, guy.farkash@, harish@ee., gil@ee.}columbia.edu, jinzhou@illinois.edu



***Abstract*—In order to support experimentation with full-duplex (FD) wireless, we integrated an open-access FD transceiver with the ORBIT testbed [1]. In particular, an ORBIT node with a National Instruments (NI)/Ettus Research Universal Software Radio Peripheral (USRP) N210 software-defined radio (SDR) was equipped with the Columbia FlexICoN Gen-1 customized RF self-interference (SI) canceller box. The RF canceller box includes an RF SI canceller that emulates an RFIC canceller, which is implemented using discrete components. It achieves $40\,\mathrm{dB}$ RF SI cancellation across $5\,\mathrm{MHz}$ bandwidth. This demonstration presents the design and implementation of the open-access FD transceiver and the baseline program, as well as an example of a remote FD experiment where $85\,\mathrm{dB}$ overall SI cancellation is achieved across both the RF and digital domains.**


## I. Introduction

Due to its potential to double network capacity at the physical layer and to provide many other benefits at higher layers, full-duplex (FD) wireless has drawn significant attention [2]. The major challenge associated with FD is the extremely strong self-interference (SI) on top of the desired signal, requiring powerful self-interference cancellation (SIC) across both the RF and digital domains.

Our work on FD transceivers/systems within the Columbia FlexICoN project [3] focuses on integrated circuit (IC) implementations that are appropriate for mobile and small-form-factor devices [4], [5]. We presented the FlexICoN Gen-1 FD transceiver and an FD wireless link in [6], featuring $40\,\mathrm{dB}$ RF SIC across $5\,\mathrm{MHz}$. The implemented Gen-1 RF SI canceller emulates its RFIC counterpart that we presented in [5].

There is no existing open-access wireless testbed with FD-capable nodes, which is crucial for experimental evaluations of FD-related algorithms at the higher layers. Therefore, to allow the broader community to experiment with FD wireless, we integrated an improved version of the Gen-1 RF canceller presented in [6] with a National Instruments (NI)/Ettus Research USRP N210 SDR in the open-access ORBIT testbed [1]. Since interfacing an RFIC canceller with an SDR presents numerous technical challenges, we implemented the RF canceller on a printed circuit board (PCB) to facilitate the cross-layered experiments with an SDR platform.

In this demonstration, we present our cross-layered (hardware and software) implementation of an open-access FD transceiver integrated with the ORBIT testbed, including the design and implementation of the Gen-1 RF canceller box and an FD transceiver baseline program. The detailed description

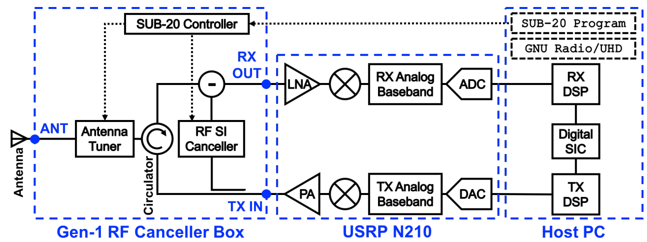
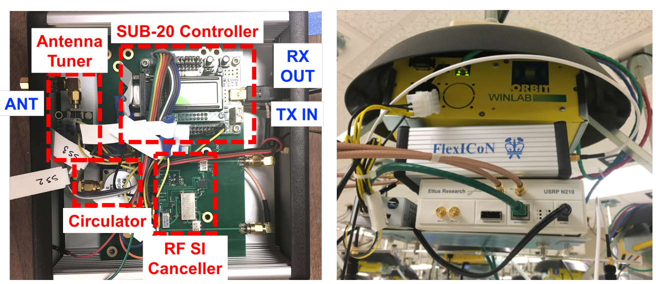



Fig. 1: Block diagram of the implemented FD transceiver.




(a) (b)

Fig. 2: (a) The Columbia FlexICoN Gen-1 RF canceller box, and (b) the open-access FD transceiver installed in the ORBIT testbed.

of RF canceller box and instructions of the baseline program can be found in [7]. We also demonstrate an example of a remote FD experiment, where $85\,\mathrm{dB}$ overall SIC is achieved across the RF and digital domains. The detailed instructions and code are available at [8], [9]. The implemented FD transceiver and the baseline program, 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 [7].

## II. Integration of the FlexICoN Gen-1 RF Canceller Box with an ORBIT Node

Fig. 1 shows the block diagram of the implemented FD transceiver, in which a Gen-1 RF canceller box (as depicted in Fig. 2(a)) is connected to an Apex II multi-band antenna (at the ANT port) and a USRP (at the TX IN and RX OUT ports). Fig. 2(b) shows the FD transceiver installed in the ORBIT testbed. The RF SI suppression is achieved by the circulator and the RF SI canceller in the Gen-1 RF canceller box, where the circulator has a TX/RX isolation of around $20\,\mathrm{dB}$ and the RF SI canceller can provide 20-30$\,\mathrm{dB}$ RF SIC.

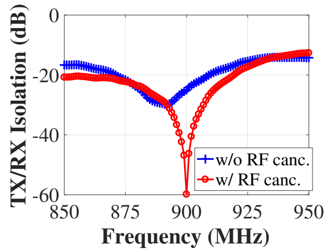
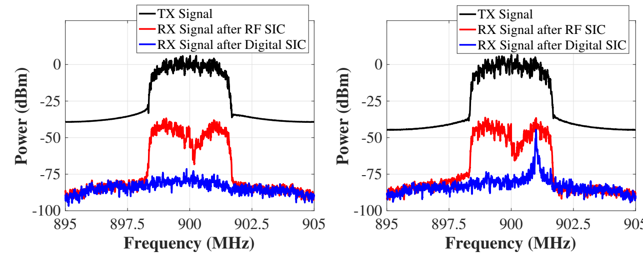



Fig. 3: Measured TX/RX isolation of the RF canceller box with and without turning on the RF canceller. The RF canceller box with the circulator and the RF canceller provides 40 dB RF SIC across 5 MHz bandwidth.




(a) (b)

Fig. 4: Power spectrum of the received signal at the FD transceiver with and without the desired signal. The TX power level is 0 dBm.

As Fig. 2(a) shows, the RF canceller box contains four components: (i) a frequency-flat amplitude- and phase-based RF canceller, which is an improved version of that presented in [6], (ii) a coaxial circulator, (iii) a custom-designed antenna tuner, and (iv) a SUB-20 controller. Fig. 3 shows an example of the measured TX/RX isolation (measured between TX IN and RX OUT ports of the RF canceller box), where 40 dB RF SIC is achieved across 5 MHz bandwidth.

Specifically, the RF canceller is implemented using discrete components on a PCB and is optimized around 900 MHz operating frequency. The RF canceller taps a reference signal from the output of the power amplifier (PA) at the TX side and adjusts its amplitude and phase. Then, SIC is performed at the input of the low-noise amplifier (LNA) at the RX side. For amplitude adjustment, a 7-bit SKY12343-364LF digital attenuator is used, in which the attenuation can be adjusted within a 31.75 dB range with a resolution of 0.25 dB. For phase adjustment, a Mini-Circuits passive SPHSA-152+ phase-shifter is used, which covers full 360 deg and is controlled by an 8-bit TI-DAC081S101 digital-to-analog converter (DAC). The attenuator and DAC are programmed through the SUB-20 controller serial-to-parallel interface (SPI).

We developed an FD transceiver baseline program containing two parts which runs on the host PC (i.e., the yellow box in Fig. 2(b)): (i) a GNU Radio program for the main SDR application, and (ii) a `C`-based SUB-20 program for configuring the RF canceller box. The digital SIC algorithm is based on Volterra series and a least squares problem and is similar to that presented in [10].

## III. Demonstration

The demonstration setup contains the FD transceiver that transmits and receives simultaneously at 900 MHz carrier frequency with 10 MHz sampling rate. A laptop is used to login into the ORBIT testbed through `ssh` to execute the example FD experiment. Demo participants can observe the real-time signal spectrum and the performance of RF SIC.

In the demonstration, the FD transceiver (`node11-10`) transmits a 2.5 MHz signal stream with QPSK modulation scheme at an average TX power level of 0 dBm. Fig. 4(a) shows the power spectrum of the received signal at the FD transceiver, where 85 dB overall SIC is achieved, where 43 dB is from the RF domain, 42 dB is from the digital SIC algorithm, and the SI signal is canceled to the receiver noise floor at $-85$ dBm.[1] In addition, another ORBIT node (`node13-8`) with a USRP serves as a second radio that transmits a single tone with frequency offset 1 MHz. Fig. 4(b) presents the power spectrum of the signal received at the FD node after RF and digital SIC. As Fig. 4(b) shows, the SI at the FD node, which transmits the 2.5 MHz QPSK signal, is canceled to the USRP receiver noise floor after SIC in the RF and digital domains, and the digital SIC algorithm introduces minimal SNR loss to the desired signal (with frequency offset 1 MHz).

## Acknowledgments

This work was supported in part by NSF grants ECCS-1547406 and CNS-1650685, DARPA RF-FPGA and SPAR programs, a Qualcomm Innovation Fellowship, Texas Instruments, and Intel. We thank Steven Alfano, Jelena Diakonikolas, Aishwarya Rajen, Jinhui Song, Mingyan Yu for their contributions to the project. We thank Ivan Seskar, Jakub Kolodziejski, and Prasanthi Maddala from WINLAB, Rutgers University, for their help on the integration with the ORBIT testbed. We also thank Kira Theuer and Kendall Ruiz from NI and the NI technical support team for their help.

## References

[1] "Open-access research testbed for next-generation wireless networks (ORBIT)," http://www.orbit-lab.org/.

[2] A. Sabharwal, P. Schniter, D. Guo, D. W. Bliss, S. Rangarajan, and R. Wichman, "In-band full-duplex wireless: Challenges and opportunities," *IEEE J. Sel. Areas Commun.*, vol. 32, no. 9, pp. 1637–1652, 2014.

[3] "The Columbia FlexICoN project," http://flexicon.ee.columbia.edu/.

[4] J. Zhou, N. Reiskarimian, J. Diakonikolas, T. Dinc, T. Chen, G. Zussman, and H. Krishnaswamy, "Integrated full duplex radios," *IEEE Commun. Mag.*, vol. 55, no. 4, pp. 142–151, 2017.

[5] 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*, vol. 49, no. 12, pp. 1–17, 2014.

[6] T. Chen, J. Zhou, N. Grimwood, R. Fogel, J. Marašević, H. Krishnaswamy, and G. Zussman, "Demo: Full-duplex wireless based on a small-form-factor analog self-interference canceller," in *Proc. ACM MobiHoc'16*, 2016.

[7] T. Chen, M. Baraani Dastjerdi, J. Zhou, H. Krishnaswamy, and G. Zussman, "Open-access full-duplex wireless in the ORBIT testbed," *arXiv preprint arXiv:1801.03069*, 2018.

[8] "Open-access full-duplex wireless in the ORBIT testbed: Instructions and code," https://github.com/Wimnet/flexicon_orbit.

[9] "Tutorial: Full-duplex wireless in the ORBIT testbed," http://www.orbit-lab.org/wiki/Tutorials/k0SDR/Tutorial25, 2017.

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

[1] This USRP receiver noise floor is limited by the existence of environmental interference at 900 MHz frequency. The USRP has a true noise floor of around $-95$ dBm at the same receiver gain setting, when not connected to an antenna.