Real-Time RF Self-Interference Cancellation for In-Band Full Duplex

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***Abstract*—We demonstrate a real-time RF self-interference cancellation scheme for in-band full duplex using an electrical balance duplexer. The balance network in the duplexer has four 8-bit tunable capacitor banks, creating a four dimensional optimization space with over 4 billion settings. We present a particle swarm optimizer that is able to find a close to optimal solution within 1 ms. The goal of this demo is to show a self-interference cancellation scheme for very dynamic environments. More specifically our demo is able to mitigate instantaneous changes in the antenna impedance in order to keep the self-interference below the threshold.**

I. Introduction

In-band full duplex (IBFD) [1] is an upcoming technology, which allows wireless nodes to transmit and receive data at the same time and on the same frequency. This technology potentially doubles the bidirectional physical layer throughput [2], and can also improve dynamic spectrum sharing and contention on the higher layers. As a full duplex transmitter is also a receiver, it enables true cognitive radio protocols like listen-and-talk [3] as opposed to regular listen-before-talk protocols. A full duplex receiver is also a transmitter, meaning that it can always be heard and this eliminates the hidden and exposed node problems [4].

Full duplex is hence an ideal technology to simplify the dynamic sharing of a single channel by multiple contending nodes. While the higher layer improvements have been discussed in literature, there are no experiments yet that confirm this. The main challenge is the availability of a full duplex prototype that allows sufficient performance, is fast enough to be used in real networks, and is based on technology that can be scaled to large numbers.

The goal of this demo is to present a full duplex prototype which allows real-time self-interference (SI) cancellation, even in changing environments. We use an electrical balance duplexer (EBD), which is controlled by a particle swarm optimizer (PSO) that can find a close to optimal solution in less than 1 ms starting from a random point. The PSO is implemented on an FPGA inside a software defined radio. Together they form a platform, able to test listen-and-talk or other IBFD protocols in networked environments.

II. In-Band Full duplex

The biggest challenge that IBFD-capable transceivers have to cope with is the magnitude difference between the local transmitted (self-interference) signal and the useful received signal. To solve this problem the self-interference needs to be sufficiently canceled. Typically this is done both in the analog and digital domain. Especially analog cancellation is important as it is needed to allow sufficient dynamic range for subsequent digital cancellation [5].

Doing analog self-interference cancellation (SIC) directly at RF frequencies is possible using an electrical-balance duplexer, which enables > 50 dB average TX-RX isolation through cancellation by equalizing the magnitude and phase of a TX signal copy intrinsically generated within the balance network [5]–[7]. In this particular SIC-embodiment, real-time automated tuning is critical to maintain a high SIC level by tracking environmental impedance variations naturally exhibited by any real antenna.

To our best knowledge, this is the first time that an automated EBD tuning solution is demonstrated in real-time. E.g. [7] uses MATLAB in the loop, which does not meet timing requirements. A small impedance change of the antenna is enough to change the cancellation performance, making it unusable for real-world environments. To enable real-time self-interference cancellation, an algorithm that can tune the EBD fast enough needs to be developed.

III. Demonstrator overview

The demo setup (Fig. 1) consists of three main components: (1) an EBD, (2) a software defined radio (SDR) and (3) a custom control interface PCB for high-speed programming of the EBD. A block diagram is shown in Fig. 2.

A. Electrical-balance duplexer

The EBD used in this demo [6] consists of a hybrid transformer and a balance network (Fig. 2). The transformer serves to enable signal cancellation through signal splitting and recombining. There are two signal paths from Tx→Rx in the EBD. When the magnitude and phase of these two paths are tuned properly, they will cancel each other and prevent the Tx signal from appearing at the Rx port. It consists of 2 fixed inductors, a fixed $50\ \Omega$ termination, and four 8-bit tunable capacitor banks, each of which enable the impedance of the balance network to be set such that a perfect inverse-phase current can be generated, even when the antenna impedance

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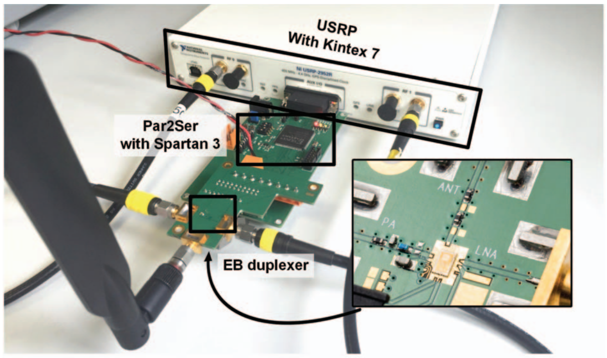

Fig. 1. Hardware overview showing the USRP, interfacing PCB and EBD

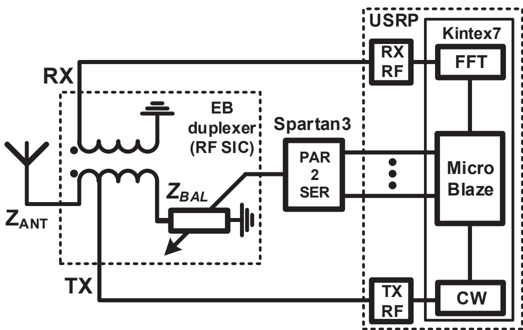

Fig. 2. Platform block diagram

changes. These four tunable capacitor banks create a four dimensional optimization space with over 4 billion settings.

B. Software defined radio

The SDR is a NI USRP RIO with a Kintex 7 FPGA onboard. The USRP has a front-end which ranges from 400 MHz to 4.4 GHz and samples at 120 MSamples/s. On the FPGA, a MicroBlaze softcore is implemented running at 150 MHz. It runs our optimization algorithm which controls the tunable capacitors of the EBD. A constant sine wave is transmitted from the TX port. The RX port receives the remaining signal and an FFT is obtained before sending it to the MicroBlaze.

C. Optimization algorithm and interface

The MicroBlaze (MB) is interfaced with the EBD using a custom PCB with a Spartan 3 onboard to convert the parallel outputs of the MB to the serial input of the EBD. The softcore runs a particle swarm optimizer [8], which minimizes the power in a certain frequency band. The algorithm releases randomly distributed particles in the four dimensional space of the EBD. Based on the input from the FFT, it calculates the direction the particles need to go, to find a close to optimal solution. The algorithm is able to find this solution in less than 1 ms. It is fully implemented in C and uses less than 20 KB.

IV. Results

Fig. 3 shows the remaining self-interference over time for a

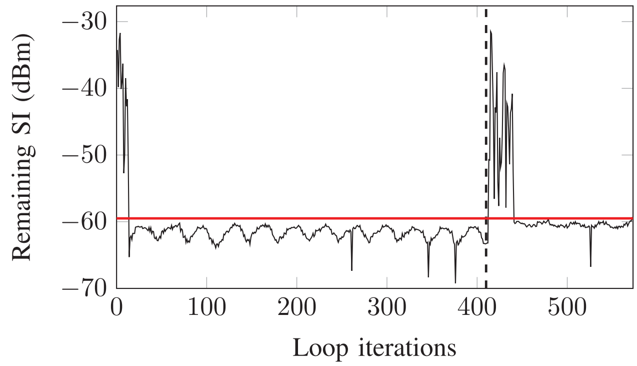

Fig. 3. Remaining SI after EBD cancellation. (——) is the threshold of the PSO algorithm and (- - -) indicates when the antenna impedance changes.

transmit power of 0 dB. The threshold of the algorithm is set just above −60 dB peak cancellation. First the algorithm finds a solution below −60 dB, after some time (at iteration 410 in the case of Fig. 3) we change the impedance of the antenna by moving a metal object close to the antenna. The algorithm detects the change in remaining SI and starts to optimize the EBD again. In both cases a solution around −60 dB is found.

V. Conclusion

In this demo we present a real-time RF self-interference cancellation scheme, capable of coping with instantaneous changes in antenna impedance.

Acknowledgements

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