A Microwave Photonic Canceller for Improved Interference Rejection in Full Duplex Radio

Matthew P Chang*, Jingyi (Jenny) Sun*, Eric C. Blow*, Yue-Kai Huang† and Paul R. Prucnal*

*Lightwave Communications Research Laboratory, Electrical Engineering Department
Princeton University, Princeton, New Jersey 08540

†NEC Laboratories America, Inc., 4 Independence Way, Princeton NJ 08540 USA
e-mail: mpchang@princeton.edu

Abstract—A same-channel full duplex radio demonstrated >22 dB of interference rejection improvement with the addition of a microwave photonic self-interference canceller in the RF front end. The radio was operated at both 2.2 GHz and 2.46 GHz while using the same microwave photonic canceller.

I. INTRODUCTION

Microwave photonics has captivated researchers with the promise of infusing the enormous bandwidth and reconfigurability of optics into radio-frequency (RF) systems, which are in contrast narrowband and fixed [1], [2]. These advantages of optics are becoming particularly attractive as both the bandwidth and the number of bands in commercial wireless systems continue to grow to meet capacity demands.

In this paper, we present our work on a microwave photonic self-interference canceller, which is inserted into the RF front end of a software-defined radio (SDR) operating in same-channel full duplex mode. A same-channel full duplex radio transmits and receives on the same frequency at the same time with the lucrative reward of using half as much RF spectrum as a half-duplex radio. Modern radios cannot operate in same-channel full duplex mode because the receiver is completely exposed to the transmitter, a problem known as self-interference [3]. Digital cancellers exist but they have limited dynamic range and cannot handle strong interferers.

A microwave photonic canceller is advantageous because it has both a large dynamic range and the ability to operate over a wide span of RF frequencies. The functional goal of the microwave photonic canceller is to reduce the self-interference to a level where receiver can function in the presence of the strong transmitted signal. Previous works have demonstrated standalone optical cancellers [4]–[6], but never together with an actual radio. Therefore, it is unclear how much a microwave photonic canceller can positively (or negatively) affect radio operation and what tradeoffs can be made.

The objective of this work was to study the effects of the microwave photonic canceller on the operation of an SDR, particularly the receiver, and its ability to reject self-interference. Here, we elaborate on the experimental setup and present our preliminary results. In depth RF analysis and further results will be presented at the conference.

II. EXPERIMENTAL DESCRIPTION

The setup shown in Fig. 1 was constructed to study the effect of the microwave photonic canceller on a radio receiver. The experiment used two X310 Universal Software Radio Peripherals (USRP) from Ettus Research; one was operated in full duplex mode while the other transmitted a signal of interest (SOI) for the full duplex radio to receive. The full duplex radio used a single directional antenna, which was duplexed via an RF circulator, while the SOI radio transmitted through an omnidirectional antenna. The USRPs can operate from DC-4.4 GHz; however, the external RF components limited the operational frequency to 2.0-2.5 GHz.

The full duplex radio suffered self-interference from three primary sources: antenna return loss (S11), circulator leakage, and multipath backscatter. Of these sources, the first two were the strongest, as each of them underwent only about 20 dB of attenuation prior to entering the receiver. To cancel these sources of self-interference, the microwave photonic canceller was inserted directly before the full duplex receiver input.

Architecturally, the canceller consisted of three taps: one for the received signal arriving from the antenna, and one for each of the dominant sources of interference. For clarity, we refer to the latter two taps as cancellation taps. The received signal was modulated onto a 1550 nm optical carrier by an electroabsorption modulator (EAM); it propagated through a
fixed length of fiber to the positive port of a balanced photodetector. A reference copy of the full duplex radio’s transmitted signal was tapped by an RF splitter at the transmitter output and modulated onto the optical carriers of the cancellation taps (1550 nm and 1552 nm, respectively) by separate EAMs. The two cancellation taps required different optical wavelengths to avoid coherent beating upon combination. Each of the two cancellation tap signals were subsequently attenuated and delayed using variable optical attenuators (VOA) and tunable delay lines (TDL) to simulate the channel that the self-interference propagates through prior to entering the receiver. Finally, the cancellation taps were combined by a 50/50 optical coupler and detected by the negative port of a balanced photodetector. The balanced photodetector output photocurrent was proportional to the difference between the receiver tap’s and the cancellation taps’ optical intensities, subtracting the self-interference from the received signal.

To characterize the microwave photonic canceller, both radios were programmed to simultaneously transmit, at the same frequency, different pseudo-random binary sequences (PRBS) using OFDM with a QPSK modulation format. The bit-error rate (BER) of the SOI and the self-interference were measured from the point of view of the full duplex radio receiver as a function of the SOI-to-interference ratio (SIR).

III. RESULTS

The results of the BER measurements are shown in Fig. 2, both with and without the canceller active for comparison. The experiments were performed at 2.21 GHz and 2.46 GHz center frequency to demonstrate the wide tunability of the microwave photonic canceller. The VOAs and the TDLs were used to account for frequency response differences in the self-interference channel between the two frequencies. The BER plots show that the full duplex receiver exhibits significantly more interference rejection, >22 dB at both frequencies, with the canceller active. Normally, the receiver requires about +10 dB of SIR to operate reliably. The canceller enables the full-duplex receiver to operate even with negative SIR, indicating that the self-interference is being canceled. Further investigation revealed that the 22 dB limit was caused by high transmit powers pushing the modulators of the cancellation taps into the nonlinear regime of operation, degrading cancellation performance. This limit can be lifted by using a smaller RF splitting ratio to tap the transmitter output; a 50/50 splitter was used in this experiment. The BERs were artificially limited to $10^{-6}$ because the PRBS streams were only $10^6$ bits long.

Because the self-interference itself is an OFDM signal, we gained additional insight by measuring the self-interference BER from the point of view of the full duplex receiver. These measurements, not displayed here for brevity, show that the self-interference always has a BER of .5 when the canceller is active, regardless of the self-interference powers tested. This further corroborates the hypothesis that it is interference cancellation that is improving the receiver interference rejection.

IV. CONCLUSION

A microwave photonic canceller inserted into the RF front end of a full duplex radio receiver improved the receiver’s self-interference rejection by >22 dB. The canceller is able to operate over a wide range of RF frequencies. The full duplex radio will be characterized in terms of its RF figures of merit, and digital cancellation will be implemented to account for multipath backscatter.

REFERENCES