Microwave Photonic Self-Interference Cancellation System Using a Slow and Fast Light Delay Line

Matthew P. Chang¹, Joanna Wang¹, Monica Lu¹, Daniel Fisher², Brian Chen¹, and Paul R. Prucnal¹
¹Lightwave Communications Research Laboratory, Department of Electrical Engineering, Princeton University, Princeton NJ 08540
²Department of Electrical Engineering, The College of New Jersey (TCNJ), Ewing Township, NJ 08618
*mpchang@princeton.edu

Abstract: We demonstrate a microwave photonic system to perform wideband, radio-frequency self-interference cancellation. The tunable optical time delay is implemented using a novel semiconductor slow and fast light delay line that enables fast electrical control.

Introduction. By 2018, mobile data traffic is expected to increase by an enormous 1100% [1]. Such exponential growth in the demand for bandwidth requires, new, highly efficient methods to allocate and manage radio-frequency (RF) spectrum. Self-interference cancellation (SIC) is a method that not only recovers valuable spectrum real estate, but also has a tremendous impact on future wireless networks [2]. Self-interference occurs when a system simultaneously transmits and receives on the same channel; the system naturally and strongly interferes with itself. Cancelling self-interference enables key spectrum-saving technologies such as in-band full-duplex communications, which immediately doubles the throughput of half-duplex systems. SIC also alleviates pesky global spectrum management issues, and is essential in applications such as military jamming [2].

Most SIC systems are comprehensive, involving antenna, analog, and digital cancellation [3-6]. Electrical analog cancellation uses RF components and phase shifters, which are inherently frequency specific. As a result, electronic SIC typically has constrained bandwidths (~20 MHz) [3,4,6]. Microwave photonics is a natural alternative to bandwidth-limited RF electronics: optics is wideband, immune to noise, and precise [7]. Microwave photonic SIC systems have demonstrated >30 dB analog cancellation across 40 MHz bandwidth with widely tunable center frequency [8]. However, the lack of a fast (< ms) tunable optical delay has prevented optical SIC systems from being used in practical settings, which require quick adaptation to environmental fluctuations. In this paper, we demonstrate a microwave photonic SIC system, which uses a slow and fast light delay line as a quickly tunable and fully electrically controlled optical delay. Slow and fast light creates an optical delay by changing the group velocity of light within a material. We have previously demonstrated such a delay line with ~100 ps range [9]. We measure the system’s ability to perform SIC, and study the effects of the delay line on interference cancellation.

Experimental Setup. The microwave photonic SIC system subtracts self-interference from a corrupted signal in the optical domain. The system accepts two inputs: the corrupted signal and a tap of the transmitted interferer; it outputs the clean signal, as shown in Fig 1a. The system must not only subtract the interferer from the corrupted signal, but also model channel effects of the propagation medium between transmitter and receiver. These effects include attenuation and propagation delay, as well as more complicated effects such as multipath and nonlinear distortion.

The transmitted interferer and corrupted signal each modulate separate optical carriers of wavelength $\lambda_1 = 1550.55$ nm as shown in the schematic in Fig. 1b. The corrupted signal, consisting of both the signal of interest and the self-interference, propagates unperturbed along the left fiber branch. The transmitted interferer propagates in the

Figure 1. (a) Application of the microwave photonic SIC system in a full-duplex communication system. (b) Schematic of the system with a slow and fast light delay line, which uses an SOA as the slow and fast light medium. EAM = electro-absorption modulator, VOA = variable optical attenuator, LDC = laser diode controller, EDFA = erbium-doped fiber amplifier, PC = polarization controller.
right branch where it is delayed by a slow and fast light delay line, and attenuated by a tunable optical attenuator to model the channel. Slow and fast light is generated in a semiconductor optical amplifier (SOA) via coherent population oscillations (CPO) [10]. The effect is based on carrier dynamics, so the SOA takes about one carrier lifetime (~1 ns) to adjust to a new value. The group velocity, and hence the optical delay, is controlled by changing the input optical power and the SOA bias current using a variable optical attenuator and a laser diode controller, respectively, as shown in the right part of Fig. 1b. In addition to delaying the signal, the SOA inverts the signal and converts the wavelength to $\lambda_2 = 1553.33$ nm via cross-gain modulation. Finally, the delayed, attenuated, and inverted transmitted interferer is combined with the corrupted signal using a 50/50 optical coupler. The interference in the corrupted signal destructively interferes with the transmitted interferer, leaving behind the clean signal of interest.

**Experimental Results.** A network analyzer-generated RF interference signal is split, with one half used as the transmitted interferer and the other half used as the corrupted signal. Figure 2 is a demonstration of the system’s ability to cancel the interference, and shows how the slow and fast light delay is used to dynamically converge to an interference minimum. In Fig. 2a, interference cancellation centered at 810 MHz with a 400 MHz bandwidth, is measured under six different states of the delay line, each specified by the input optical power and the SOA bias current. As the delay is tuned across the six states, as shown in Fig. 2b, the system progressively cancels more interference, reaching a maximum of $\sim$40 dB cancellation across $\sim$40 MHz, equal to the bandwidth of one WiFi channel or two LTE channels. This exceeds the performance of typical RF SIC systems in both amount of cancellation and bandwidth. An important consideration is that the amplitude of the signal is not unintentionally affected while tuning the delay of the delay line. This is shown in Fig. 2c, where the signal amplitude deflects by less than .5 dB across 400 MHz in each of the different states. Therefore, the additional cancellation achieved in Fig. 2a is indeed caused by the delay shift, which induces more precise destructive interference of the interferer.

**Conclusion.** We demonstrate a microwave photonic self-interference cancellation system employing a slow and fast light delay line for quickly tunable optical delay. The system can achieve $\sim$40 dB interference cancellation across $\sim$40 MHz bandwidth. The slow and fast light delay line is electrically controlled, making it suitable for fast convergence and locking of the system to an interference minimum, neutralizing environmental fluctuations. In addition, because all the components are semiconductor based, such a system also has potential to be integrated.

**References**