Co-design of Full-duplex RFIC and Resource Allocation Algorithms

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Full-duplex (FD) wireless -- simultaneous transmission and reception at the same frequency -- is an emerging wireless duplexing scheme that has the potential to significantly improve wireless network performance [1-2]. However, the biggest challenge associated with FD wireless is the tremendous amount of self-interference (SI) on top of the desired signal. The SI has to be suppressed below the receiver noise floor through isolation and cancellation as filtering the SI is not an option. An integrated CMOS implementation imposes constraints that render SI cancellation (SIC) techniques proposed in prior discrete-component-based implementations (e.g. [3]) nonviable. Moreover, to fully utilize the benefits of FD communication, wireless systems will require a careful redesign of both the physical layer and the medium access control (MAC) layer.

RF SIC at the receiver input can be accomplished using passive or active circuitry. Active RF cancellers are compact, widely tunable and reconfigurable. A fundamental challenge associated with active RF SIC is the noise and distortion of the cancellation circuitry, which can limit the receiver's performance. A second challenge with active RF SIC is the cancellation bandwidth (BW), which is typically limited by the frequency selectivity of the antenna interface. We have developed fully-integrated reconfigurable wireless receivers with widely-tunable SIC at RF that addresses these two challenges. The first receiver addresses the challenges associated with the noise and distortion of the active RF SIC circuitry [4, 5]. This is accomplished by embedding the active RF SIC in a noise-cancelling low-noise transconductance amplifier (LNTA) so that the noise and the distortion of the cancellation circuitry are cancelled as well (Fig. 1), resulting in a noise-cancelling, self-interference-cancelling receiver (NC-SIC RX). The second receiver addresses the RF SIC bandwidth challenge associated with fully-integrated RFIC implementations by employing widely-tunable bandpass filters (BPFs) in RF canceller [6]. A 2nd-order BPF combined with amplitude and phase scaling features four degrees of freedom, namely center frequency, Q factor, absolute amplitude, and absolute phase. These can be leveraged for the replication of not just the amplitude and phase at a frequency point, but also the slope of the amplitude and the slope of the phase (i.e. group delay), enhancing cancellation bandwidth. A bank of such filters with independently controllable parameters enables such replication at multiple points in different sub-bands, further enhancing cancellation bandwidth (Fig. 2). Essentially, this is frequency-domain equalization (FDE) in the RF domain.

To provide insight into the design of a MAC layer, there is a need to evaluate the achievable throughput gains resulting from the use of SIC receivers in OFDM wireless systems (e.g., Wi-Fi and cellular). Hence, we performed a thorough analytical study [2], grounded in realistic models of the receivers for a base station (BS) or an access point (AP) [3] and a mobile station (MS) [4-6]. Our throughput gain metric is the increase in uplink and downlink rates resulting from the use of FD, compared to the use of time division duplex (TDD), when the sum of uplink and downlink rates over OFDM channels is maximized. We limit the maximum irradiated transmission power, complying with existing standards. We obtained a number of insightful and surprising structural results for the sum of the rates as a function of transmission power levels at the BS and at the MS [2]. Our results lead to a near-optimal power allocation algorithm that maximizes the sum of the rates. We also design an efficient algorithm that maximizes the rates under the high SINR approximation. The power allocation at the MS and at the BS and achievable throughput gains for the conventional frequency-flat canceller, one-filter FDE canceller, and two-filters FDE canceller at the MS are shown in Figs. 3, 4, and 5, respectively, for different values of average SNR (received signal quality) over channels. Interestingly, the results suggest that the algorithm designed for the high SINR approximation is near-optimal whenever the throughput gains exceed 50%. This is an encouraging result, since it is simple to compute in real time the power allocation for the high SINR approximation. On the other hand, for the high SINR approximation to be near-optimal at low values of received signal SNR (which translates into high throughput gains over wider ranges of SNR), the SIC receiver must be reasonably broadband, thus demonstrating the advantage of the FDE-based receivers over the conventional ones.

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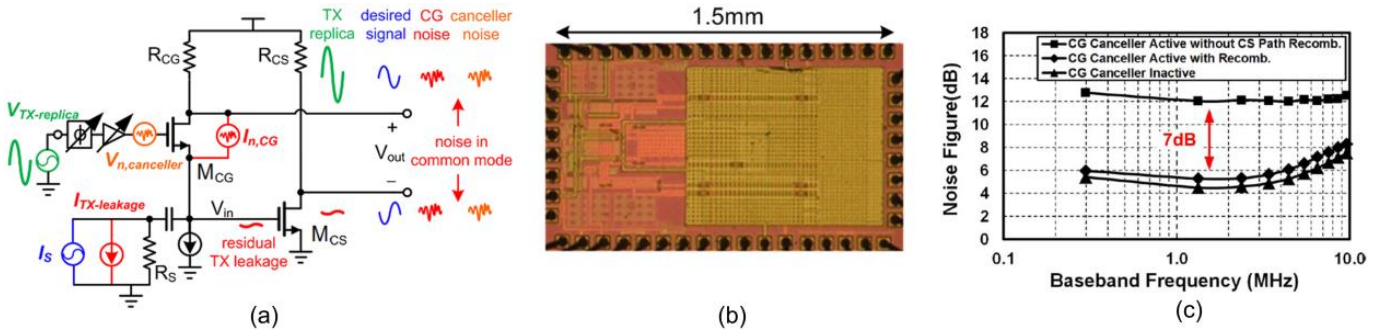

Fig.1 (a) Noise-cancelling, SI cancelling concept. (b) 0.3-1.7GHz NC-SIC RX in 65nm CMOS. (c) The associated increase in RX NF is only 0.8dB. When noise cancelling is disabled, the NF increase is as much as 7dB.

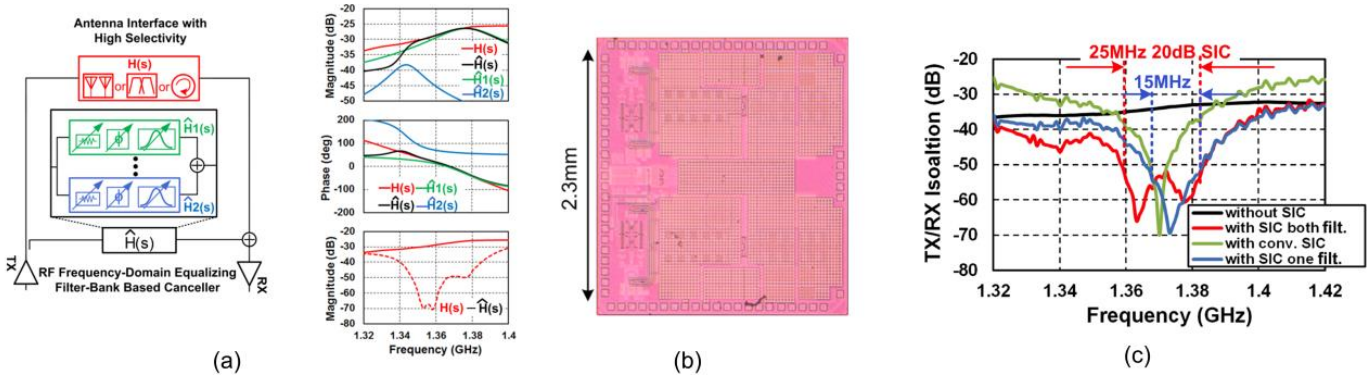

Fig.2 (a) Frequency-domain equalization based wideband RF SIC concept. (b) 0.8-1.4GHz SIC RX based FDE in 65nm CMOS. (c) RF SIC measurements across the 1.4GHz antenna pair demonstrate nearly 10 times improvement over a conventional RF canceller.

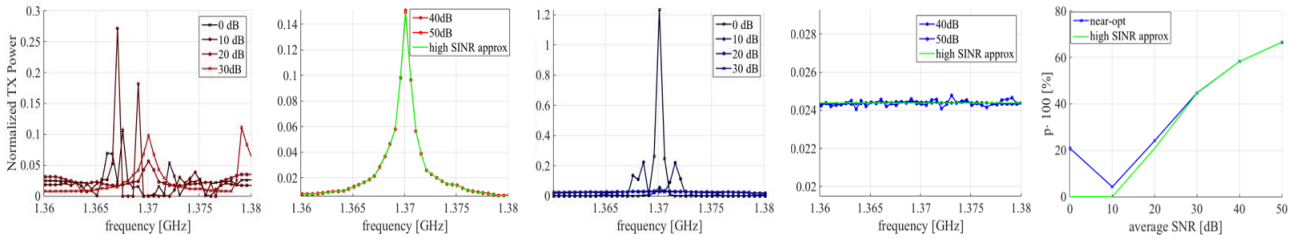

Fig.3 Power allocation at the (a), (b) MS and (c), (d) BS and achievable (e) throughput gains for the conventional compact canceller at the MS and a discrete canceller with very wideband frequency-independent cancellation [3] at the BS.

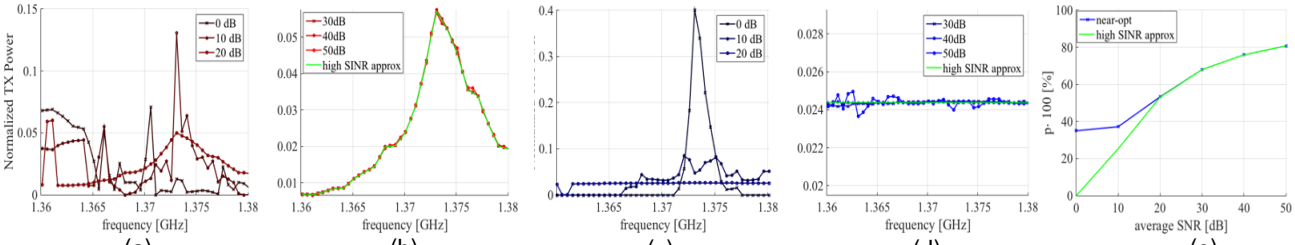

Fig.4 Power allocation at the (a), (b) MS and (c), (d) BS and achievable (e) throughput gains for the one-filter FDE canceller at the MS and a discrete canceller with very wideband frequency-independent cancellation [3] at the BS.

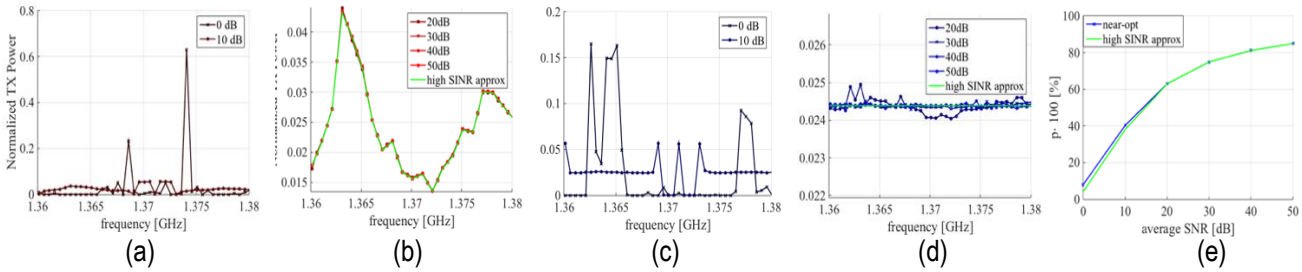

Fig.5 Power allocation at the (a), (b) MS and (c), (d) BS and achievable (e) throughput gains for the two-filters FDE canceller at the MS and a discrete canceller with very wideband frequency-independent cancellation [3] at the BS.