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Power Efficient RF Self-Interference Cancellation System for Simultaneous Transmit and Receive

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***Abstract*—Mono-static full duplex systems employ a single antenna and a circulator to provide isolation between the transmit (Tx) and the receive (Rx) radio chains. As much as 50 dB isolation is required to avoid receiver desensitization due to leakage of high power transmit signal. However, available circulators are typically designed to provide ~20-30 dB Tx/Rx port isolation. Therefore, additional cancellation circuits are required to enable simultaneous transmission and reception (STAR). In this paper, we present a novel STAR system that incorporates two circulators, a hybrid coupler, and a Self-Interference Cancellation (SIC) circuit based on a hybrid Finite Impulse Response (FIR) and a resonator topology. Preliminary simulations show promising results with an average Tx/Rx port isolation of 55 dB across a 20 MHz bandwidth.**

Keywords*— *Full-duplex, self-interference, FIR resonator, bandwidth.

I. Introduction

A Full Duplex (FD) system with high-suppression and considerable isolation is needed to achieve Simultaneous Transmission and Reception (STAR) and double spectral efficiency. Currently, the uplink and downlink of communication systems have operated in a mutually exclusive manner, requiring either two frequency bands to operate simultaneously (i.e., Frequency Division Duplexing, FDD) or two time slots to operate on the same band (i.e., Time Division Duplexing, TDD). Although these methods waste time-frequency resources, they guarantee interference-free transmit and receive chains—unlike FD systems that suffer from high Self-Interference (SI). Nevertheless, the development of these duplex technologies is of priority to meet the requirements for the next-generation communication systems, such as 5G and 6G technologies [1]. As wireless communication and advanced technologies continue to grow exponentially at unprecedented rates, these improvements and advancements are needed on the radio frequency (RF) front-end to relieve the overcrowded spectrum. Otherwise, the spectrum will continue to become vulnerable to signal fratricide and interference and unable to accommodate the expanding user demands of humans and connected machines.

FD systems can be designed either monostatic or bistatic. Monostatic designs employ the same antenna for transmit (Tx) and receive (Rx), relying mainly on circulators and antennas with high-isolation capabilities to cancel the SI. On the other hand, bistatic designs need

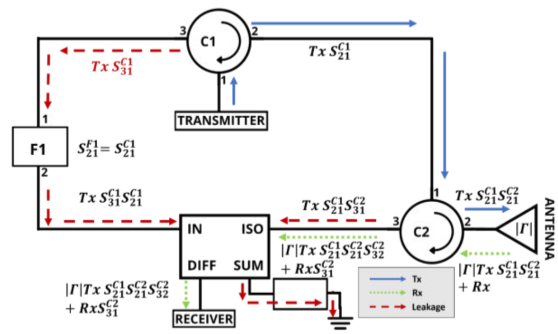

Figure 1. STAR system using a combination of two circulators (C1 and C2) and a SIC filter (F1).

separate antennas and achieve their cancellation through spacing, polarization, beam squint diversity, and other methods. In general, for both FD designs, relevant research work shows that multiple cancellation stages, in the analog and digital domains, are required to achieve the desired isolation levels. The main stages targeted with SIC techniques in most research papers [2]- [3] are: 1) the antenna stage by making space or design alterations to the physical antenna to reduce the coupling between the transmit and receive antenna; 2) the RF stage by implementing RF SIC circuits; and 3) the digital stage using probabilistic channel models. To minimize the coupling at the antenna stage, a convenient method is to use a bistatic system design, with at least one Rx and one Tx antenna, since the spacing between the Tx and Rx can be modified to achieve a higher isolation. However, this configuration requires large distance between the Tx and Rx antennas for acceptable isolation, which is impractical for many applications.

Alternatively, monostatic FD systems are the appropriate design for applications with these space constraints. However, monostatic designs pose their own disadvantages due to poor isolation as they rely on circulators and other components with internal leakage and power loss. In [4], a wideband monostatic configuration with a Wilkinson power divider, two circulators, and a balun is presented. The design achieves 5 dB isolation across 2-4 GHz. Nevertheless, half of the Tx signal is lost in the creation of the identical leakage signal. Similarly, half of the Tx power is lost in the circulator-free design realized with 180° coupler and power splitters in [5]. In [6], two lumped element circulators and a 3 dB quadrature coupler are used to reduce the SI signal. However, this technique was able to achieve only 40 dB isolation across 25 MHz bandwidth.

The above-mentioned STAR topologies suffer from a 3 dB power loss of either the Tx or Rx signal or both, as a result of the equal-signal split done for cancelling the leakage. In this effort, we present power efficient monostatic RFSIC system based on two circulators and filter topology, as depicted in Fig. 1. Additing a second circulator and a filter enables the creation of a quasi-replica of the leaked transmitted signal to achieve high isolation with a minimal power loss of the Tx signal.

II. RF SELF-INTERFERENCE CANCELLATION SYSTEM

In the STAR configuration shown in Fig. 1, most of the Tx signal goes through circulator C1 as TxS_{21}^{C1} and only a small fraction leaks (TxS_{31}^{C1}) due the circulator's mismatches. On the left side of the system, the leaked signal is passes through the filter F1, designed to have $S_{21}^{F1} = S_{21}^{C1}$. We note that the filter design is based on a hybrid Finite Impulse response (FIR) and resonator circuit. The design and implementation of such filter are detailed in [3] and will not be elaborated in this paper. At the output of the filter, the signal becomes $TxS_{31}^{C1}\,S_{21}^{F1} = TxS_{31}^{C1}\,S_{21}^{C1}$. On the right path of the system, the signal TxS_{21}^{C1} is sent to the antenna via circulator 2 (C2). Here also, some of the Tx signal leaks through port 3 of C2, adding to the Rx signal, making the total signal equal to $TxS_{21}^{C1}\,S_{31}^{C2} + Rx\,S_{32}^{C2}$. Given that both circulators are equivalent ($viz. S\,_{31}^{C1} = S\,_{31}^{C2}$), the leaked Tx signals on the left and right side are practically identical. As a result, the received signal, $Rx\,S_{32}^{C2}$, is isolated in the difference port of the 180º hybrid coupler where $TxS_{21}^{C1}\,S_{31}^{C2}$ cancels out with the filtered quasi-replica, $TxS_{31}^{C1}\,S_{21}^{C1}$. Using our method, the 3dB loss in Tx signal is avoided, allowing us to maintain a satisfactory power level.

III. RESULTS

Fig. 2 shows the simulated Tx-Rx isolation achieved using our two circulators configuration with a Hybrid FIR-resonator circuit, and compares it to a single circulator configuration. We note that our system is designed to operate in the UHF band. Results show that a single circulator can provide only 24 dB across 20 MHz, whereas, using two circulators and a hybrid FIR-resonator achieves an average Tx-Rx isolation of 55 dB across the operational bandwidth. Notably, the FIR-resonator circuit [3] provides a secondary cancellation stage to further improve Tx-Rx isolation .

IV. CONCLUSION

In this paper, a new STAR design is presented using two circulators with a hybrid FIR-resonator circuit. Our configuration achieves an average isolation of 55 dB between the Tx and Rx radio chain, across a 20 MHz bandwidth. In summary, adding an FIR-resonator between two circulators provides improved secondary matching to approximate the channel coupling for further SIC. Our future work includes prototype fabrication and testing.

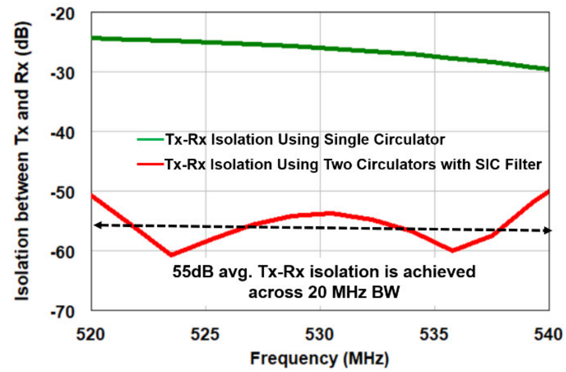

Figure 2. Simulated self interference cancellation showing an average of ~55 dB cancellation between Tx and Rx ports

V. ACKNOWLEDGMENTS

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