Demonstration of a Single-aperture, Full-duplex Communication System

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***Abstract* — The ability to simultaneously transmit and receive (STAR) through the *same* aperture is a key capability that will enable full duplex use of communications channels. We report the first demonstration of a single-aperture STAR system, which was enabled by a recent advance in microwave photonics: a new type of optical link that has high transmit–to–receive (T/R) isolation over a broad bandwidth. We measured 14 key performance metrics on a prototype system; key among these was T/R isolation. T/R isolation > 100 dB is projected for the technique; isolation as high as 85 dB was measured, which is the highest reported to date.**

***Index Terms* — simultaneous transmit and receive, full-duplex communication, single-aperture STAR, microwave photonics**

I. INTRODUCTION

It is universally taken as a given in communications that it is not possible to simultaneously transmit and receive (STAR) in the same frequency band. Recently this basic tenet has begun to be challenged by several groups that have reported prototype STAR systems. Workers at Purdue [1] and Stanford [2] Universities, for example, have used arrangements of multiple antenna elements in which the receive antenna is located in a null of the transmit antenna pattern to realize ~40 dB of transmit-to-receive (T/R) isolation. Signal processing was then used to extend the T/R isolation to ~60 – 70 dB. A group at Rice University [3], using single, separate transmit and receive antennas, computed the required cancelling signal and used it to cancel the transmit signal before it reached the analog-to-digital converter; this group reported up to 79 dB suppression. A key limitation of these approaches is the limited bandwidth over which sufficient T/R isolation can be achieved.

Several years ago at Photonic Systems, we began to investigate an even more challenging yet potentially more widely applicable STAR configuration: STAR via the *same* antenna element and in the same polarization. Further, we wanted to significantly extend the bandwidth over which sufficient T/R isolation could be achieved.

For decades there existed only one means to simultaneously connect the transmit and receive paths to a common antenna: a microwave circulator, which is a *passive* component with 3 ports arranged in a waveguide ring around a ferrite disk that induces a direction-dependent phase shift, causing the two counter-circulating halves of the wave to add up constructively at the next port in one circumferential direction along the ring but destructively at the next port in the other direction. Since it depends on summing and differencing the RF phase of two waves, a ferrite circulator is an inherently narrow-band device. Designers have found ways to widen a ferrite circulator's bandwidth in exchange for some loss of its perfect unidirectionality at its center design frequency, such that one can now purchase ferrite circulators from multiple vendors with ~20 dB of port 1 – 3 isolation over an octave-wide band.

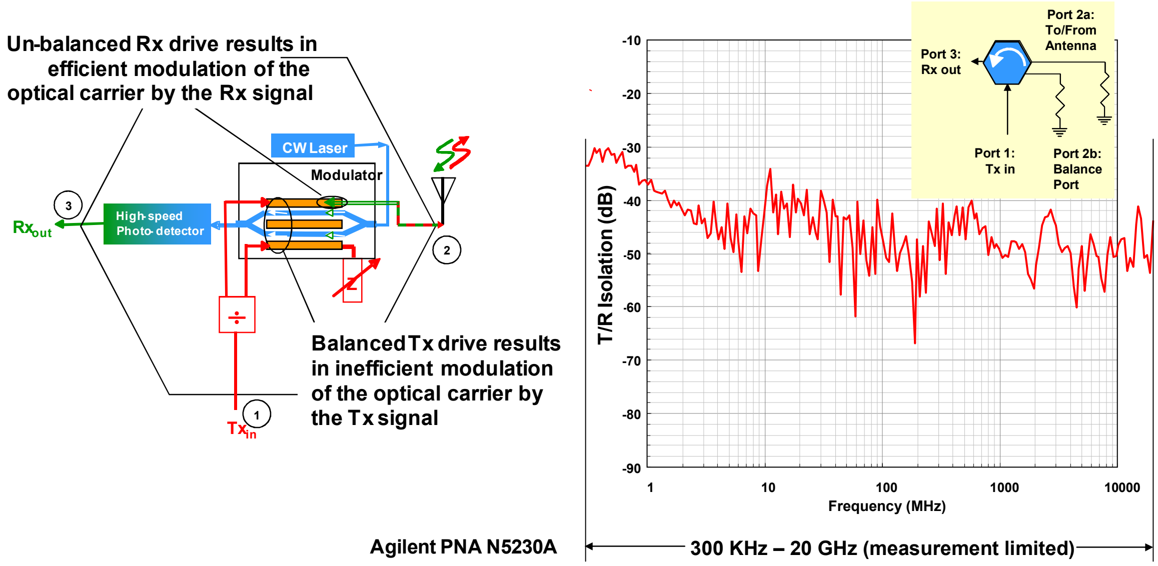
II. OVERVIEW OF THE NEW TIPRX LINK

To enable single-aperture STAR applications, separate groups of researchers recently hit upon two *active* circulator designs. An electronic circulator has achieved up to 40 dB T/R isolation, albeit over only about 10% bandwidth at X-band. A description of the electronic circulator's principle of operation is provided elsewhere [4].

The second new type of device is based on *photonics* and hence one might be tempted to refer to it as a photonic circulator. As we will present below, this new photonic component performs two additional functions beyond those of a conventional ferrite circulator. For this reason we refer to the new photonic component as a TIPRx, for Transmit-Isolating Photonic Receiver.

The operation and initial performance of the circulator function of a TIPRx can be understood with reference to Fig. 1. Figure 1(a) outlines the key operational principle. To achieve broad bandwidth isolation, we employ a balanced drive optical modulator (for a discussion of the principle of operation of an optical modulator, see [5]). In a balanced drive modulator, applying the same signal to both electrodes results in the same optical phase modulation being applied to each arm of the modulator. Hence when these two arms recombine, the result is – at least ideally – no intensity modulation of the optical carrier. To implement a TIPRx, we apply the transmit signal to both of the TIPRx drive ports, which results in no modulation of the light by the transmit signal being conveyed to the TIPRx receive output port, as desired.

Since the balanced drive operation extends "from dc to daylight", we have – at least in principle – a mechanism for achieving high isolation over extremely broad bandwidth. The measured data in Fig. 1(b) is a plot of TIPRx T/R isolation vs. frequency; the isolation is ~40 dB or better over 4 decades of bandwidth!



(a) (b)

Fig. 1. (a) Theory of operation of the Transmit Isolating Photonic Receive (TIPRxs) link; (b) Measured T/R isolation of a TIPRx with a 50 ohm load at the antenna port.

II. Overview of the Single-Aperture STAR System

It is reasonably straightforward to show that to achieve STAR will require 100 dB or more of T/R isolation. Hence as impressive as the 40 dB isolation we achieved with a TIPRx link is, we will require additional isolation to reach the 100 dB goal. Although it may be possible to achieve the required isolation from the TIPRx alone – we have achieved TIPRx isolations > 60 dB by concentrating on a fractional bandwidth of < 2 decades – we feel a more immediate path to 100 dB isolation is to augment the TIPRx isolation with digital signal processing.

Figure 2 is a block diagram of a prototype system that we assembled to demonstrate the ability to achieve single-aperture STAR using a TIPRx link, followed by signal processing. The prototype system was connected to an antenna, which was located in an anechoic chamber. We used two additional antennas (not shown in Fig. 2) to send signals to, and receive signals from, the STAR system. The transmit power was + 33 dBm.

Transmit power reflected by the antenna – which can have a return loss of –10 dB or worse – degrades the T/R isolation of the TIPRx to about the level as the return loss. Fortunately, the TIPRx has a 4th "balance" port, which can be used to compensate for the antenna return loss. Figure 1(a) shows this 4th port terminated in a tunable impedance.

Figure 3 is a plot of measured T/R isolation for a TIPRx optimized for 1 MHz – 6 GHz receive and simultaneous 150 MHz – 6 GHz transmit operation. The green plot shows the T/R isolation with 50 Ω loads connected to the antenna and balance ports. For comparison, we also show that isolation of a TIPRx is comparable to the range of typical isolations that can be achieved with broad-bandwidth PIN diode switches in non-STAR systems.

The blue plot in Fig. 3 shows the T/R isolation at the output of the signal processing, with TIPRx port 2 connected to an antenna whose return loss was as poor as –7 dB. It is important to note that the signal processing introduces an instantaneous bandwidth (IBW) constraint. In the case of the measurement shown by the blue plot, the IBW was 100 KHz. Broader IBWs are possible by using more powerful signal processing than was used in this initial demonstration system.

The performance of the prototype single-aperture STAR system was extensively measured using 14 figures of merit. A sampling of data from these additional measurements will be presented in the talk.

III. Summary

Simultaneous transmit and receive (STAR) has been extended to operate via a single aperture, for what is as far as the authors are aware the first time. The technology that enabled this breakthrough capability is a new type of photonic link called TIPRx (Transmit-Isolating Photonic Receiver). The TIPRx combines T/R performance that is superior to a ferrite circulator in both isolation and bandwidth with the gain and low-noise performance of an LNA. To confirm the single-aperture STAR capability enabled by the TIPRx, a proof-of-concept system was designed, assembled and tested. Measurements against 14 metrics indicated a level of performance sufficient for initial single-aperture STAR applications.

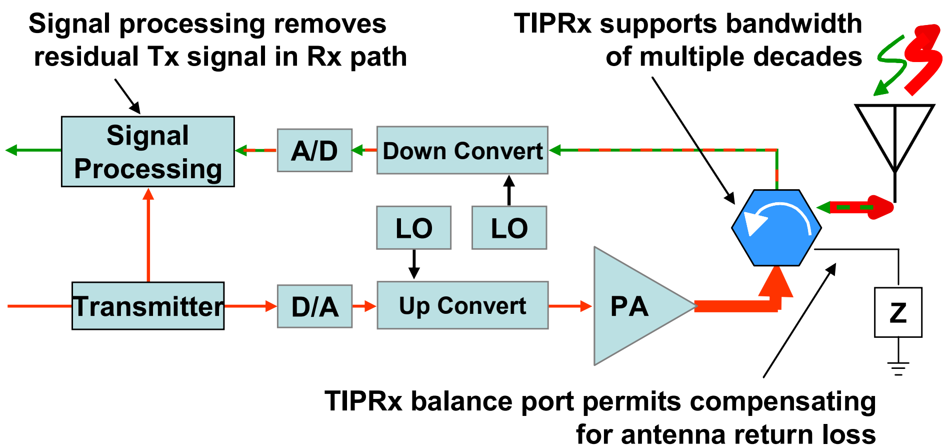


Fig. 2. Block diagram of single-aperture system capable of simultaneous transmit and receive (STAR).

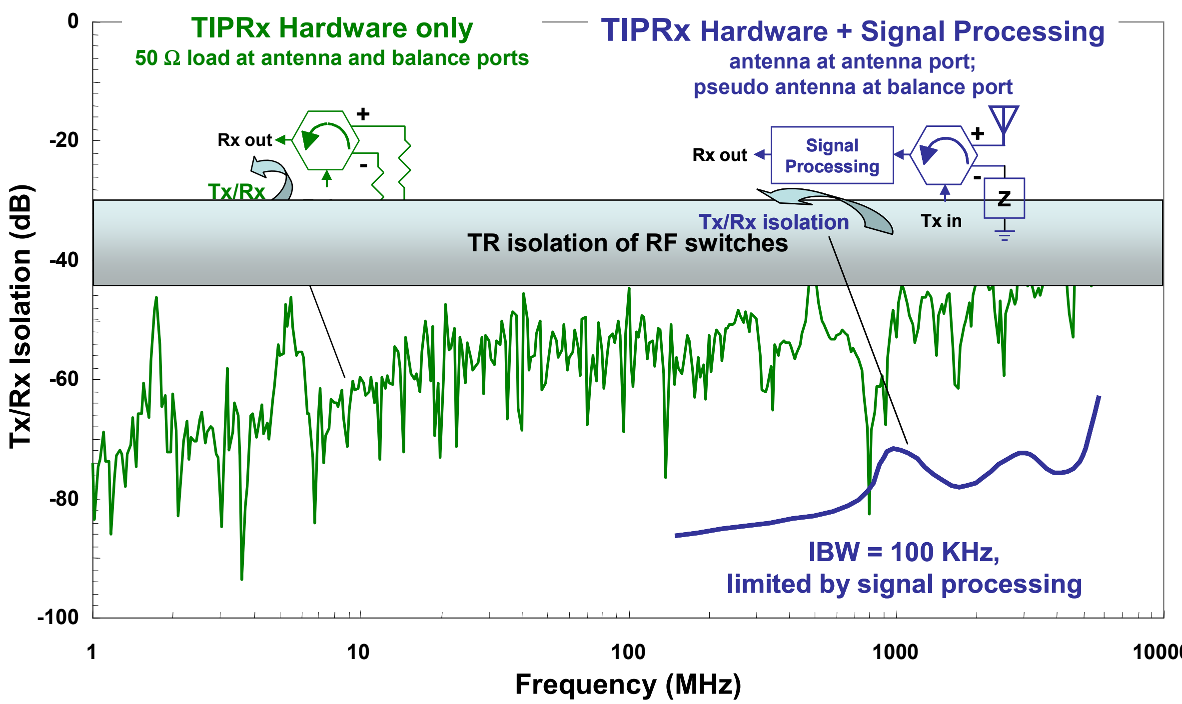


Fig. 3. Plot of T/R isolation vs. frequency for: TIPRx terminated with 50 Ω loads at the antenna and balance ports (green curve); TIPRx + signal processing (blue curve) and; the typical range of isolations from broadband PIN diode switches (grey band).

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