# Simultaneous Transmit and Receive Performance of an 8-channel Digital Phased Array

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***Abstract*—The Aperture-Level Simultaneous Transmit and Receive (ALSTAR) architecture enables extremely high isolation between adjacent transmitting and receiving sub-arrays in a digital phased array without analog cancellers or other complex front-end hardware. An 8-channel ALSTAR array prototype was constructed and demonstrated to achieve 125.5 dB effective isotropic isolation between broadside transmit and receive beams over a 100 MHz instantaneous band centered at 2.45 GHz.**

## I. Introduction

A phased array capable of Simultaneous Transmit and Receive (STAR) could provide significant benefits for many applications including communications, radar, spectral sensing, and multifunctional systems. In [1], the Aperture-Level Simultaneous Transmit and Receive (ALSTAR) architecture was proposed for achieving STAR using a fully digital phased array with a digital transceiver at every element. The ALSTAR array partitions the aperture into transmitting and receiving sub-arrays and maintains isolation through digital beamforming and digital cancellation. The size and shape of the transmit and receive regions can be dynamically allocated as needed to support various missions and scenarios. Because the isolation improvement techniques are digital, the array does not require custom radiators, analog cancelling circuitry, or other complex front-end hardware and there is no reduction in front-end sensitivity or efficiency. Moreover, the array can operate in the traditional (non-STAR) manner without performance degradation.

A simplified ALSTAR block diagram is shown in Fig. 1. Transmit digital beamforming is used to reduce the total power incident at each receive element, allowing the receive array to maintain full sensitivity in the presence of significant self-interference (SI) without clipping or saturation. Likewise, adaptive receive beamforming is applied to reduce the coupled SI from each of the transmitting elements. Because transmit beamforming alone cannot mitigate uncorrelated transmitter noise, and receive beamforming is vulnerable to front-end saturation, these techniques are complimentary and optimization of both beamformers is critical for maintaining high isolation.

Once the beamformers have been optimized, the residual SI can be further removed from the received beam with adaptive digital filtering and cancellation. The effectiveness of traditional digital cancellation is typically limited by channel noise and distortion. A unique aspect of the ALSTAR digital canceller is the use of auxiliary receivers to sample the output of each transmitter, enabling the canceller to remove random transmit noise and distortion along with the SI signal. This is implemented with a switchable coupling path from the output of each transmitter to the input of the corresponding receiver as shown in Fig. 1.

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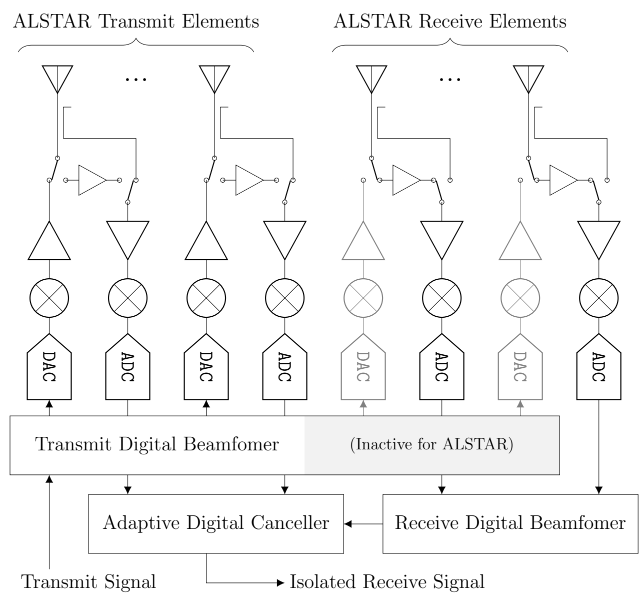


Fig. 1. Simplified block diagram of a digital phased array in ALSTAR configuration. Isolation between transmit and receive beams is maintained via digital beamforming and cancellation. For transmitting elements the corresponding receiver samples the radiated waveform, enabling digital cancellation of transmit distortion and noise.

## II. Prototype ALSTAR Array

A prototype 8-channel ALSTAR array was constructed from modular off-the-shelf components, and is shown in Fig. 2. The array contains four digital transceivers and four receivers, enabling an ALSTAR configuration with 4 transmitting elements and 4 receiving elements. The radiating aperture is a 9-element linear patch antenna array with the central element terminated. The RF center frequency is 2.45 GHz with 100 MHz band-


Fig. 2. ALSTAR prototype consists of a linear patch array with 4 transmitting and 4 receiving elements, and an 8-channel digital transceiver chassis.

width which is mixed to an IF center frequency of 187.5 MHz, supporting digital sampling in the second Nyquist zone at 250 Msps. Each transmit channel operates at 27 dBm nominal power, and the receive channels saturate at -16 dBm peak power with an SFDR of 65 dB. The digital interface consists of a Xilinx VC707 board with a Virtex-7 FGPA, a 4DSP FMC168 card with eight 16-bit ADCs, and a 4DSP FMC204 card with four 16-bit DACs. All of the digital signal processing was performed offline using MATLAB.

Probe waveforms were used to estimate the array channel response and optimize the transmit and receive digital beamformers. Table II shows the power at each element for a broadside beam under both uniform and adaptive transmit beamforming. At roughly the same total transmit power, the adaptive transmit beamformer reduced the worst-case receiver incident power from -10.6 dBm to -22.7 dBm, which is sufficient to maintain receiver linearity. Using a uniform broadside receive beamformer, the received beam had an interference-to-noise ratio (INR) of 57.8 dB, as seen in Fig. 3. Under adaptive receive beamforming the INR was reduced to 45 dB. The sampled transmit waveforms were then adaptively filtered and combined with the receive beam to achieve cancellation, yielding a final INR of 7.4 dB. The total self-interference cancellation (the ratio of total transmitted power to residual self-interference plus noise) is 111.0 dB. The effective isotropic isolation (self-interference cancellation plus transmit and receive antenna gain) was found to be 125.5 dB.

## III. Conclusion

The Aperture-Level Simultaneous Transmit and Receive (ALSTAR) architecture enables STAR functionality in a digital phased array without the use of specialized radiating elements or analog cancelling circuits. By applying digital beamforming

TABLE I
Measured Transmitted and Incident Power per Element under Uniform and Adaptive Transmit Beamforming

| | Uniform Tx Beam | Adaptive Tx Beam |
|---|---|---|
| Transmitted Power, Tx 1 | 27 dBm | 22 dBm |
| Transmitted Power, Tx 2 | 27 dBm | 30 dBm |
| Transmitted Power, Tx 3 | 27 dBm | 24.5 dBm |
| Transmitted Power, Tx 4 | 27 dBm | 25.6 dBm |
| Total Transmitted Power | 33 dBm | 32.6 dBm |
| Incident Power, Rx 1 | -13 dBm | -25.9 dBm |
| Incident Power, Rx 2 | -10.6 dBm | -22.7 dBm |
| Incident Power, Rx 3 | -21.5 dBm | -26.1 dBm |
| Incident Power, Rx 4 | -24 dBm | -27.7 dBm |

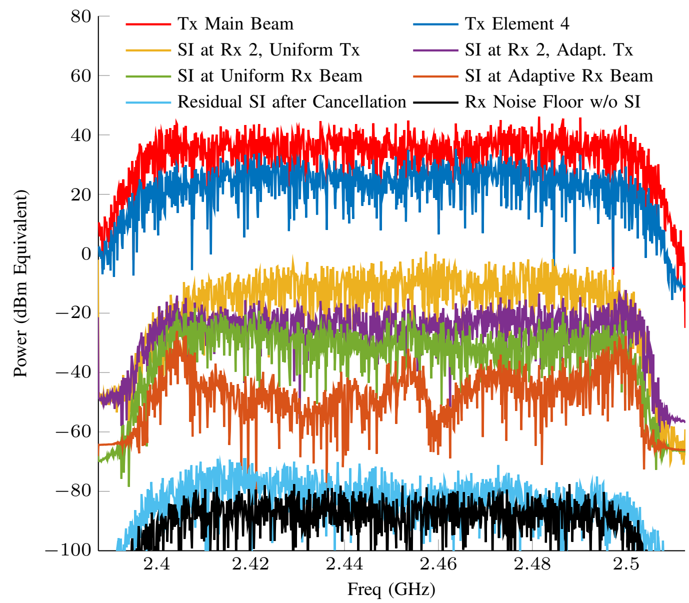


Fig. 3. Measured spectrum of wideband transmitted waveform and resulting self-interference (SI) for the prototype ALSTAR array of Fig. 2. After adaptive beamforming and cancellation, self-interference is suppressed to within 7.4 dB of the noise floor for a total effective isotropic cancellation of 125.5 dB.

and cancellation it is possible to maintain significant isolation between transmit and receive beams. The ALSTAR architecture enables a highly flexible digital array that can be dynamically reconfigured as needed to support multiple modes and applications.

In this work we measured the performance of a small 8-channel ALSTAR array. The results of [1] suggest that for larger arrays the additional degrees of freedom and increased average distance between transmit and receiving elements will enable even greater isolation. Future work will consider issues of computational complexity and convergence behavior when scaling to larger ALSTAR arrays, as well as the effects of scanning the transmit and receive beams.

## References

[1] J. P. Doane, K. E. Kolodziej, and B. T. Perry, "Simultaneous transmit and receive with digital phased arrays," in *IEEE International Symposium on Phased Array Systems and Technology*, Oct. 2016, pp. 1–6.