Tech Notes

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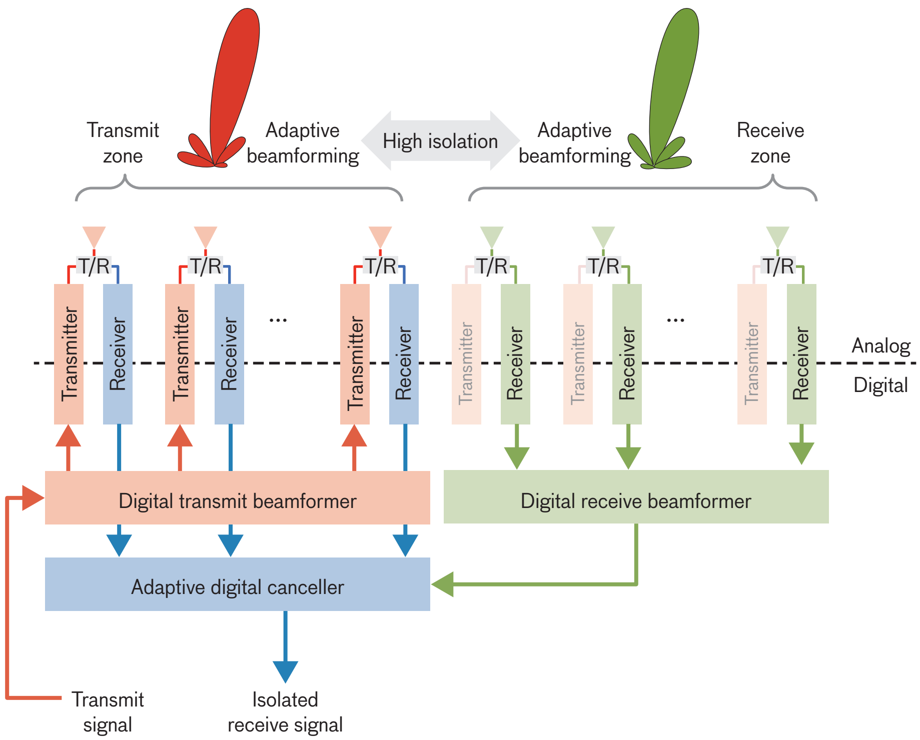
Simultaneous Transmit and Receive Phased Arrays

A proposed new architecture may enable simultaneous transmit and receive within a digital phased array.



This block diagram illustrates how digital beamforming and cancellation are applied in the Aperture-Level Simultaneous Transmit and Receive (ALSTAR) phased array. Transmit and receive digital beamforming provides spatial isolation between two adjacent subarrays, while digital receivers provide a measured reference for each transmitter to enable digital cancellation of residual signal and noise from the receive beam.

A longstanding limitation of radio-frequency (RF) systems has been the inability of collocated transmitters and in-band receivers to operate concurrently because of strong self-interference. This limitation restricts the capabilities and performance of wireless communication networks, radars, spectral sensing, and electronic warfare systems. Simultaneous transmit and receive (STAR) is an emerging capability that seeks to overcome these constraints by engineering extremely high isolation between the transmitter and receiver.

Any STAR system must attenuate or cancel its own significant self-interference without adversely impacting the sensitivity of its receiver(s). Achieving sufficient isolation improvement typically requires the combination of multiple technologies, such as high-isolation antennas, tunable analog filters, and adaptive digital cancellation. Although these techniques have been successfully integrated to enable single-channel STAR radios, the development of a phased array capable of STAR has remained a significant challenge because the many coupling paths between the multiple transmitting and receiving elements must each be cancelled individually.

Many of the advantages offered by recent advances in digital beamforming can also be leveraged to achieve STAR capability in a digital phased array. Adaptive digital beamforming allows high isolation to be maintained between simultaneous transmit and receive beams. Additional digital signal processing can then be applied to further remove the residual transmitted signal and noise from the received waveform. By using only digital-domain techniques, a fully STAR-capable array can be implemented without custom radiators or front-end cancelling circuits, both of which can increase front-end losses and add significant size, weight, and cost to the array.

Aperture-Level Simultaneous Transmit and Receive Array

MIT Lincoln Laboratory has developed a new digital phased array architecture to support simultaneous transmit and receive operation. This proposed approach uses element-level digital beamforming with a dedicated digital transceiver at each element. The aperture is partitioned into a transmitting subarray and an adjacent receiving subarray. This approach is called the Aperture-Level Simultaneous Transmit and Receive (ALSTAR) to distinguish it from other architectures that might support high transmit and receive isolation at the element level. Each element in the array may be assigned to either function, and the size and geometry of the transmit and receive zones can be dynamically modified as needed to support various antenna patterns and functions required by the overall system. If all elements in the array are either transmitting or receiving, the array operates in the traditional manner without performance degradation.

Transmit digital beamforming is used to minimize the total coupled power incident at each receiving element while approximating the desired beam pattern in the far field. With sufficient isolation, high receiver sensitivity can be maintained without overloading the receiver front-ends. Likewise, receive beamforming is used to minimize the coupled self-interference accepted from each transmitter while maximizing gain in the direction of an external signal of interest.

Even after the spatial isolation improvement provided by digital beamforming, a significant amount of residual transmitted signal and noise will remain in the received signal. With traditional digital cancellation techniques, cancellation of the transmitted signal is possible, but cancellation of nondeterministic noise is not. To solve this problem, the output of each active transmit channel is coupled to the (otherwise unused) receive channel for that element. With a measured reference copy of the physically transmitted waveform, the transmit signal, distortion, and noise can all be effectively removed by using adaptive digital cancellation. The amount of cancellation is then limited not by transmitter noise but by the dynamic range of the reference receiver. Because a receiver can generally be implemented with significantly greater dynamic range than that of a high-power transmitter, this approach represents a significant improvement in overall isolation versus traditional digital cancellation.

The linear phased array and eight-channel digital transceiver chassis (above) were developed to demonstrate ALSTAR, which operates at 2.45 GHz with up to 125 MHz instantaneous bandwidth.

Impact of STAR Phased Arrays

The ALSTAR phased array architecture uses entirely digital-domain techniques to achieve extremely high isolation between concurrent transmit and receive functions. It does not require custom radiating elements, feed networks, analog cancellers, or other additional front-end hardware. Moreover, the performance of standard array (non-STAR) functionality is not reduced or compromised by the ALSTAR architecture. The ALSTAR approach, therefore, represents a straightforward method for augmenting any digital phased array with STAR capability.

To further explore and implement practical phased arrays capable of STAR, Lincoln Laboratory designed and built an eight-channel element-level digital phased array capable of supporting the ALSTAR architecture. By combining the performance of high-gain and high-power directional phased arrays with the flexibility of STAR, Lincoln Laboratory is enabling new capabilities in RF technology:

- Full-duplex directional networking with increased throughput and improved spectral efficiency
- Capability for radars to support multiple simultaneous modes and pulse repetition intervals, and low probability of intercept/ low probability of detection waveforms
- Uninterrupted spectral sensing and persistent situational awareness
- Continuous responsive jamming without “look-through” breaks (i.e., periods in which jamming is paused in order to track a signal of interest)
- Multifunctional arrays that simultaneously support multiple federated client systems ■

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