AN INTERFACE BETWEEN A NEAR-FIELD ACQUISITION SYSTEM AND ACTIVE ARRAYS WITH DIGITAL BEAMFORMERS

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ABSTRACT

Phased-array antennas have always presented challenges in their interface to an acquisition system. Active arrays, especially those with a Digital Beam-Former (DBF), further complicate this interface. Whereas a passive phased array might be readily controlled with a simple digital code from the acquisition system, an active array tends to require more sophisticated communication to exercise the capabilities that must be tested. Furthermore, a DBF has receivers built into the array, and the simultaneous readings on these multiple receivers represent the data to be stored by the acquisition system vs. position and frequency.

The increased complexity of an active array's transmit beams by itself elevates the need for an interface between the array and the acquisition system. With the embedded receivers of a DBF, however, standard antenna testing of a DBF becomes nearly impossible without such an interface.

MI Technologies has developed a reasonably general interface between its acquisition system and active arrays with digital beamformers. MI has produced minor variations of this interface for multiple customers, and these customers will each use the interface to test multiple types of DBF active arrays. This paper discusses the challenges, capabilities, and architecture of this interface.

Keywords: Near-field, digital beamforming, active array, phased array, radar

1.0 Introduction

Testing active arrays, especially those with DBFs, presents numerous challenges [1]. Others have attempted to address these challenges [2,3], but those implementations are not evaluated here. MI Technologies was contracted to develop an interface for testing a particular DBF, and the facility with that initial interface has been previously described [4]. Since that time, MI has produced a similar interface for multiple customers, with minor modifications that have improved its generality and throughput. This paper discusses this interface between a commercial acquisition system and a generic active array with a DBF.

Requirements and/or goals of this interface included:

- Support three transmit modes. These are always treated as high-power modes, and pulsed CW is radiated with duty-cycle reduction employed to lower the average power.
  - One mode with conventional source and pulsed receiver. The source must provide pulsed RF, and those pulses must be synchronized with the high-power amplifier(s) within the array.
  - One mode with conventional pulsed receiver but using the exciter as the signal source. The receiver's sampling must be synchronized with the radiated pulses.
  - One mode with array components acting as both source and receiver
- Support two receive modes. These are low-power modes, and can be either pulsed or CW. Both use the element receivers to collect the data. Beamforming is performed after the acquisition and far-field transformation.
  - One mode with conventional RF source
  - One mode with an exciter as the source
- Provide control over the set of enabled elements
- Minimize restrictions on measurement throughput. The number of near-field aspects times the number of beam-frequency states typically desired can lead to a tremendous amount of data. An inefficient interface would turn that into a tremendous amount of time. Stopping the positioner at each near-field aspect could greatly simplify the interface, but the anticipated increase in test time is far too great. It is assumed that data for several hundred beam-frequency states might need to be acquired in the transmit modes.
- Provide a software interface that lets the MI-3000 operator, given appropriate input values by the test engineer, set up the array from the acquisition system

without having to make separate adjustments to the array. Further allow these entries to be made one time to support repeated production-mode tests.

- Populate the acquired data file so it looks like any other near-field data file with multiple frequencies, channels, and/or beams.
- Provide a generalized Ethernet interface to the array from the MI-3000 Sequencer.

2.0 Measurement Requirements

This Section lists the basic requirements of measuring an active array or DBF in the near field. Many of these requirements will seem remedial to those familiar with near-field testing, but might not be obvious to an antenna or firmware designer tasked with interfacing to the acquisition system.

- Near-field scanning begins with the need to obtain a single complex sample I + jQ for each beam-frequency state, on a prescribed grid, if far-field characteristics are desired [5]. This requirement applies whether testing the array in transmit or receive. The outputs of testing will normally be degraded if there is variable latency after reaching each record increment.
- The I-Q pairs at the several points on the grid must share a common phase reference. In other words, the measured phase at a particular grid point must be insensitive to the time at which it was measured. A 10 MHz reference is not sufficient to meet this requirement.
- Each complex I-Q pair will be computed from several A/D samples. The conversion from A/D samples to I and Q involves a digital downconversion for each of the signal and reference channels, a reduction of the down-converted stream to I and Q, and a subtraction of the reference phase from each element's data.
- Synchronization among synthesizer, array, receiver, and data storage must be maintained regarding the beam-frequency state that is being measured at a particular instant. If the acquisition system reverses the ordering of beam-frequency states during reverse scans, then the array must be aware of that reversal as it forms beams and/or applies calibration data.
- Any pulsed phenomena in the transmit chain must also be synchronized. Of particular interest are the pulse gating of a CW signal and a high-power amplifier that can only be enabled for brief periods of time. The receiver sampling must in turn be synchronized to the radiated pulses.
- The standard near-field transformations each process a single tone, or CW frequency, at a time [5]. Matched-filter response to a modulated waveform (other than pulsed CW) represents a non-zero bandwidth, and would therefore have questionable validity through the transform.
- Active arrays typically need to be tested in each of their transmit and receive modes. For a DBF, the multiple receivers within the array take the place of the antenna-measurement receiver in the range.
- Active arrays typically transmit at high power, and generally cannot be tested effectively unless peak power is radiated in each pulse. Duty-cycle reduction may therefore be required to protect the absorber and other equipment.

3.0 Architecture

The two sides of the interface are the acquisition system and the active array. It is expected, but not required, that each type of array will have some Special Test Equipment (STE) that interfaces to it during RF testing. It is then the STE that implements the fixed interface to the acquisition system, communicating the information to its active array in the form that its type of array expects. This partitioning of the interface minimizes integration risk, letting the individuals most knowledgeable about the array determine how best to do the low-level array interfacing.

The STE, perhaps assisted by the DBF in the array, is also expected to reduce the A/D sample stream from each receiver to a phase-referenced I-Q pair. This could be as simple as a digital down-conversion, followed by a weighted average, for each receiver (including the reference). The phase-referencing could then be as simple as a complex division of each receiver's I-Q by the reference I-Q.

The heart of the acquisition system when using this interface is the MI-788 Networked Acquisition Controller (NAC) and, in some modes, a multi-channel pulse generator. The MI-788 NAC provides the real-time sequencing of positions, multiplexer settings, frequencies and/or beam states during acquisition, as well as position capture and buffered-data retrieval from the receiver(s). The MI-788 NAC can work with several receiver types, including active-array receivers that conform to the specified interface via the STE. The pulse generator, when used, produces programmed streams of pulses in response to a single discrete pulse from the array or STE.

Ethernet is used in this interface to communicate the list of beam-frequency states prior to the acquisition, and when applicable to stream received data back to the acquisition system. The speed of the interface is not limited by the use of Ethernet or its bandwidth. All real-time traffic is handled by the four discrete lines that cross the interface. Data from the array, when applicable, are buffered within the STE and streamed to the acquisition system, which processes them as they become available. Acquisition timing is based on the completion of sampling, not on receipt of the data. Acquisition speed will typically be driven by the latency between discrete signals into the STE and the resulting action in the array. For arrays that already have appropriate discrete inputs, this might not be a limiting factor, and then sampling time, duty-cycle reduction, and/or positioner speed would drive the acquisition time.

In order to maximize the correlation of RF data to prescribed locations along a moving axis, and also to synchronize frequency changes and sampling, the acquisition system controls the acquisition timing.

Duty-cycle reduction in this interface is the responsibility of the STE. It is affected by holding off the STE's 'Beam State Set' discrete response by the amount of time required to ensure a safe long-term duty cycle.

4.0 Acquisition Modes

Up to five acquisition modes are explicitly supported within this interface, with three transmit and two receive modes. The names of the modes are defined as follows:

- 'Transmit' or 'Receive' describes what the array is doing in this mode. The 'Receive' modes always use the receivers within the array as range instrumentation.
- 'Conventional' indicates that conventional antenna-pattern instrumentation is being used throughout the acquisition system, and that the array is simply an amplified multi-beam antenna
- 'Hybrid' indicates that the source and receiver were not specifically designed to work together to measure antenna patterns
- 'CFE' indicates that both the source and receiver are part of the array, and are therefore customer-furnished equipment. While these would likely be designed to work together, they might or might not be suitable for near-field antenna measurements.

The block diagrams shown below leave out several features that are vital to the measurement but not relevant to the interface being discussed. For example, positioners will be present but are not depicted. The AUT might be mounted on a moving axis (spherical or cylindrical geometry), or might be stationary on the floor (planar geometry). Similarly, there are numerous interconnections among components on each side of the interface (which is the vertical dashed line in the diagrams) that have been left out to emphasize those that cross the interface.

4.1 Conventional Transmit Mode

The Conventional Transmit Mode most closely resembles a standard antenna-pattern measurement configuration. Its high-level block diagram is shown in Figure 1. The array's exciter is disconnected in this mode, and the acquisition system provides pulsed RF at the array's manifold port the exciter would normally feed.

One of the key challenges in this mode is to synchronize the pulsed-RF array input to the high-power amplifier in each of the array's T/R modules. When it is time to acquire data, the MI-788 sends the 'Activate Tx' discrete to turn on the T/R module amplifiers. When the amplifiers turn on, the STE (or array) responds with a 'Tx Active' discrete that triggers the chain of pulsed-RF synthesis and sampling within the acquisition system. At the end of that acquisition cycle, the beam-state-control pair of discretes is used to configure the array to the next beam-frequency state in the configured list.

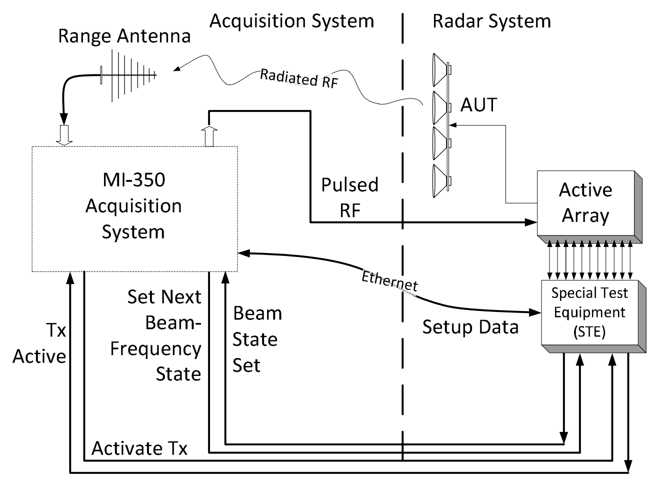

Figure 1 – Conventional Transmit Block Diagram

Figure 2 illustrates the acquisition timing in the Conventional Transmit Mode. Timing begins with record-increment detection within the acquisition system. At that time, the Activate Tx signal is sent to the array. When the Tx Active signal is returned indicating the transmit amplifier is on, the acquisition system produces the programmed burst of RF pulses and samples the MI-750 (or other) receiver while those pulses are radiating. This illustrates the required synchronization of amplification, pulse synthesis, and receiver sampling. When the sampling is completed, the MI-788 will then change frequencies and command the STE to form the next beam. When the beam is formed, and after any delay required to regulate the long-term duty cycle, the STE responds with the 'Beam Set' discrete. If the first beam in the sequence has been set again, then the acquisition system waits for the next record increment on the moving axis. Otherwise, the acquisition cycle repeats immediately for the current beam state.

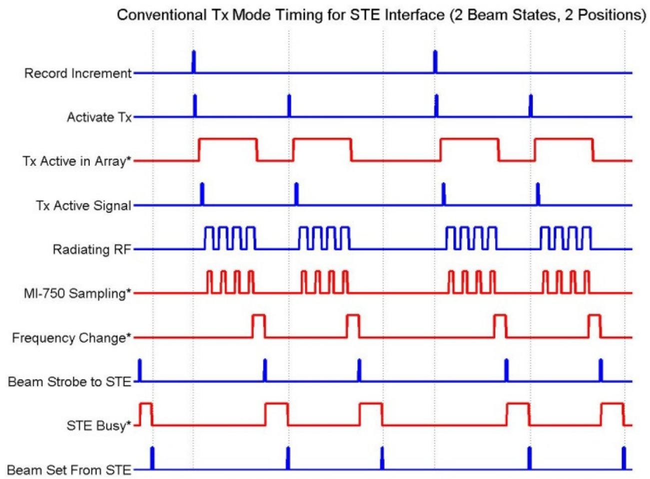

Figure 2 – Conventional Transmit Timing Diagram

4.2 Hybrid Transmit Mode

The Hybrid Transmit Mode uses the array's exciter rather than the acquisition system's source to synthesize the pulsed RF signal. The block diagram for this mode is shown in Figure 3. The primary difference between this and Figure 1 is that Conventional Transmit produces the pulsed RF and a coupled reference signal inside the acquisition system. Hybrid Transmit produces the pulsed RF within the array, and must pass a coupled copy (either CW or pulsed) across the interface in coax.

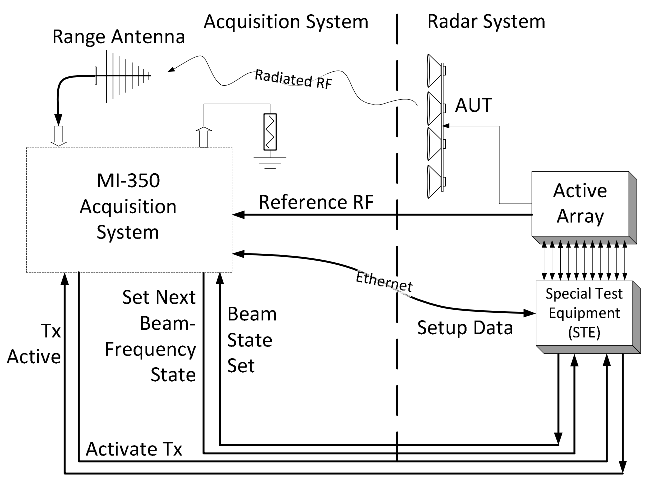

Figure 3 – Hybrid Transmit Block Diagram

The timing for Hybrid Transmit Mode is very similar to that in Figure 2. Since the transmit amplifier and the pulsed-RF synthesis are both in the array, that synchronization should be straightforward. All that remains is the synchronization of receiver sampling to the RF pulses. The 'Tx Active' signal in this mode is slightly different, indicating the start of each RF pulse.

4.3 Hybrid Receive Mode

Figure 4 shows the high-level block diagram for the Hybrid Receive Mode. In this mode, the receiver (including the LO) is contained within the array and STE, and is paired with the RF source from the acquisition system.

An 'extra element receiver' is used to measure a constant coupled copy of the RF signal. Its purpose is to provide a phase reference. This receiver is expected to use a coupled copy of the same LO and A/D clock as each of the element receivers.

An optional 10 MHz reference line crosses the interface to synchronize the RF and LO sources. The importance of this 10 MHz line depends on how the STE implements the phase referencing of the elements to the extra element receiver.

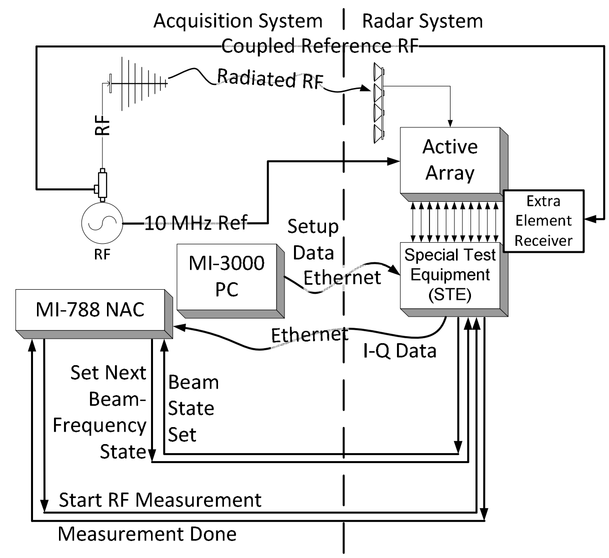

Figure 4 – Hybrid Receive Block Diagram

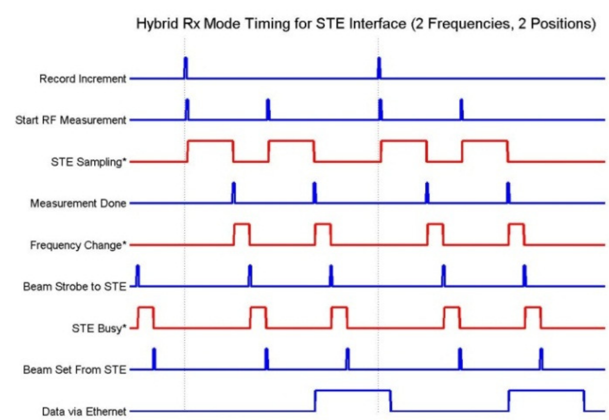

Figure 5 – Hybrid Receive Timing Diagram

The 'Activate Tx' and 'Tx Active' discretes have been replaced, at least in name, by a pair called 'Start RF Measurement' and 'Measurement Done'.

Figure 5 shows the timing diagram for the Hybrid Receive Mode. It shows the array/STE receivers sampling in response to the Start RF Measurement discrete and the subsequent Measurement Done return. It also shows the data for each record increment pushed onto the Ethernet.

4.4 CFE Transmit Mode

The CFE Transmit Mode uses array components for both the source and receiver in the set of range instrumentation. Its block diagram is shown in Figure 6.

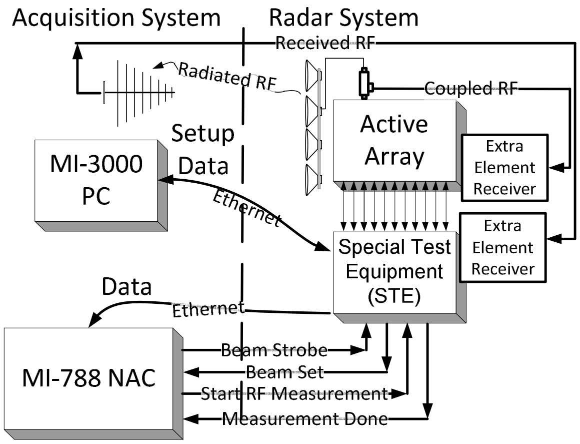

Figure 6 – CFE Transmit Block Diagram

The transmit portion of this mode is similar to the Hybrid Transmit Mode. The coupled RF that goes to the MI Receiver in the Hybrid Transmit Mode goes instead to an element receiver that provides the phase reference. The data received by the near-field probe goes to a second element receiver. The STE then combines the two receiver readings to provide a phase-referenced I-Q pair for each Start RF Measurement pulse received.

Note that the delay between pulse transmission and the required sampling in each receiver is very small compared to the typical delays seen when operating a ground-based radar. Note also that the two element receivers are fed RF via coax rather than an element. These notes might lead to the use of extra receiver modules that are not part of the array under test. They are both depicted close to the array and its STE because they need to share LO and sample clocks produced by the array.

4.5 CFE Receive Mode

The CFE Receive Mode again uses array components to measure the data, but this time the array is in receive mode. The block diagram is shown in Figure 7. New to this diagram is an 'extra array exciter' used to produce the RF signal, as well as a coupler to produce the signal for the reference receiver. The 'extra' exciter might or might not be part of the array under test.

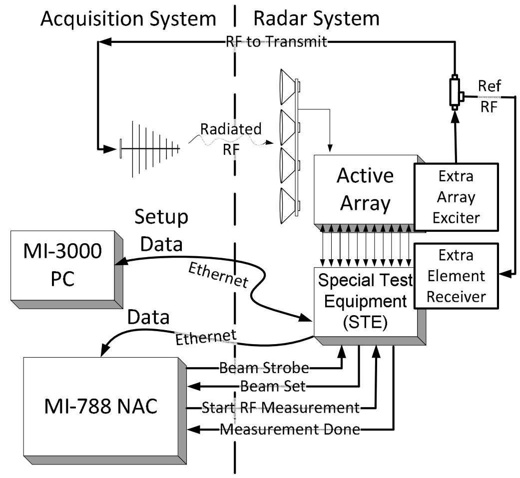

Figure 7 – CFE Receive Block Diagram

5.0 Operator Interface

This Section provides an overview of MI-3000 software operation when the array/STE is being used as the source and/or receiver. The MI-3000 permits the use of several vendors' sources and receivers. One of the options in each list is 'Active Antenna'. When that option is chosen and the button is pressed to configure the properties of that active-antenna instrument, a form similar to Figure 8 appears. This form primarily lets the user enter the number of rows and columns in the array, along with the set of elements present within that rectangular bound.

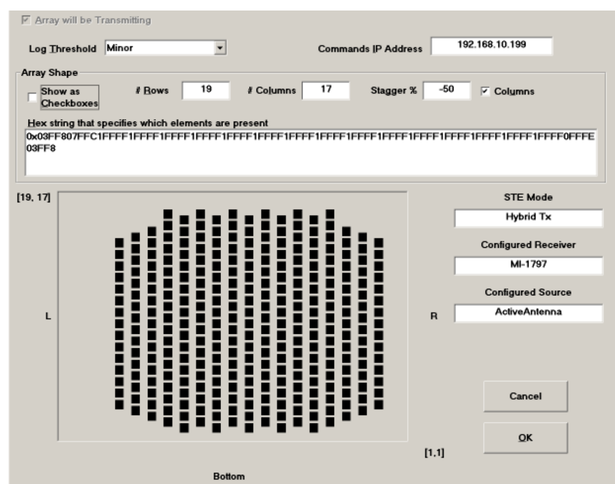

Figure 8 – Array Configuration Screen

For the transmit modes, an editor for the transmit beams becomes available in the acquisition definition editor. This form is shown in Figure 9. This form has three significant groups of entry:

- Set of enabled elements

- Two unconstrained double-precision floats. These are labeled 'Kx/K' and 'Ky/K', but the interface does not limit their use to beam pointing directions.
- Eight unconstrained long integers. These might be used to put the array into various modes, turn on or off calibration, specify null placements, or anything else that might need to be controlled during an acquisition sequence.

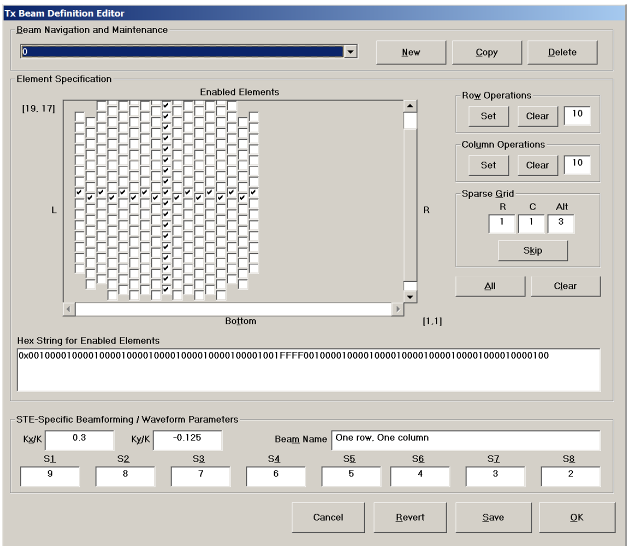

Figure 9 – Transmit Beam Editor

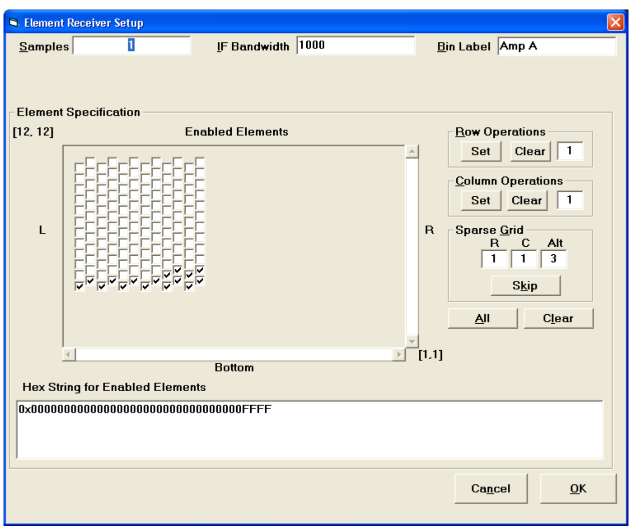

Figure 10 – Receive-Mode Editor

In the receive modes, there is a form in the acquisition definition editor to control the element receivers. This form is shown in Figure 10. Again, there are entries to control the set of enabled elements, which determines the number of I-Q values that will be returned. There are also two entries labeled 'Samples' and 'IF Bandwidth' that can be used to control the reduction of A/D samples to I-Q pairs or for other array-specific purposes.

6.0 Other Possibilities

The interface described above has five clearly defined modes. It is possible to test other configurations than those explicitly supported:

- Conventional Receive: The predefined receive modes always obtain data from the array's element receivers. If there is no DBF, but rather an RF coax port following a receive combiner, then the interface could simply be configured as Conventional Transmit but connected with the array receiving. One of the 'spare' Tx beam parameters could signal to the array that it is in receive mode, and suppress the transmit amplifier.
- Formed beams in receive mode: If the DBF serves as the receiver, then it could return one I-Q pair for each formed beam. The number of beams to form would be the number of 'enabled elements'.
- The generalized Ethernet I/O available through the MI-3000 Sequencer permits additional array setup beyond what this interface has defined. This can provide additional support for production-mode testing with minimal operator intervention.

7.0 Conclusions

MI Technologies has defined and implemented an interface specification enabling efficient high-speed testing of active arrays with DBFs. That testing includes the array's transmit and receive modes, and permits testing in various stages of AUT integration. The interface supports both developmental testing and automated production-mode testing. This interface, with minor modifications, has been successfully provided to multiple end users.

8.0 References

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