Multiplexed Pulsed Transmit and Receive RF Measurement System for Active Phased Array Testing

Kim Hassett & Bruce Williams
Nearfield System, Inc., 19730 Magellan Drive, Torrance, CA 90502, USA
khassett@nearfield.com and bwilliams@nearfield.com

***Abstract* - Radar antennas are typically required to operate in using various transmit and receive conditions, depending on the particular radar mode. In active antenna applications, these modes may require different antenna operating parameters, which currently dictate testing the antenna independently in transmit and receive using different test system configurations. In testing highly-integrated active arrays, electrical and thermal considerations make it desirable to test the antenna in its nominal Tx/Rx (Transmit/Receive) operating mode as opposed to transmit-only or receive-only. An extension to the NSI Panther 9100 RF measurement system has been developed to support multiplexed transmit and receive, pulse-mode measurements with different measurement parameters during the course of a single data acquisition. This capability allows pulsed transmit and receive tests to be interleaved using a single measurement setup, reducing overall test time and improving the real-world accuracy of the test results.**

Keywords: phased array, pulse measurement, T/R, transmit

I. INTRODUCTION

Passive antennas, which are reciprocal in nature, are traditionally tested using CW (continuous wave) RF signal measurement techniques. Modern antennas, such as Active Electronically Scanned Arrays (AESAs) used in radar applications, are architected using T/R modules designed to switch between transmit and receive on a pulse to pulse basis. The T/R module contains variable RF components that allow the antenna to be configured with different transmit and receive operating parameters, making it no longer reciprocal. As a result, separate measurement system configurations are required to test both transmit and receive. Many of these antennas have output transmit power levels which exceed normal test facility power handling capabilities, dictating that they be tested using a low duty cycle pulsed RF signal. These restrictions all bear longer test measurement times.

Figure 1 shows a two-channel pulsed RF measurement system consisting of a measurement receiver, RF and LO sources, downconverter, and pulse generator, and is representative of the type of system typically used to test an active phase array antenna. There are various different methods for creating a modulated RF signal. In the configuration shown, the modulated RF pulse signal is being generated by the NSI 7020 sources with internal pulse modulation support, resulting in the RF input to the reference (REF) mixer also being modulated. For this given case, care must be taken to match the delays in the Test and Reference paths so that the pulsed IF inputs to the receiver are not significantly skewed. Alternatively, the RF modulation may also be generated using an external device such as a pulse modulator or RF PIN switch.

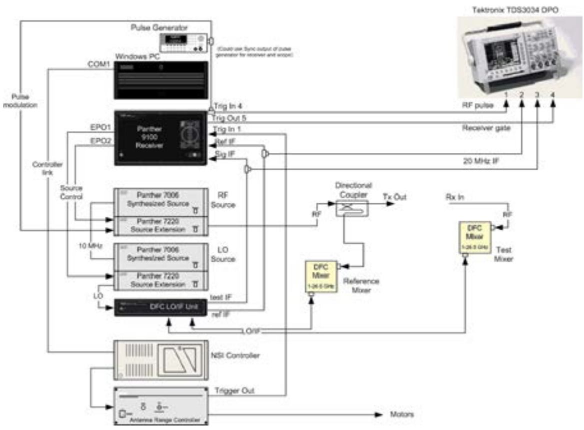

Figure 1 - NSI Panther 9100 Pulsed RF System Using Internal Source Modulation

II. PULSE SIGNAL PARAMATERS

Pulsed signals are defined by pulse width, Δt, and pulse period, T, or pulse repetition interval (PRI). The reciprocal of the PRI is referred to as the pulse repetition frequency (PRF). The duty cycle is the ratio of the pulse width to the pulse period, and represents the percentage of the pulse “ON” time. For antennas that transmit high pulsed power, the average output power may be reduced by decreasing the duty cycle as illustrated by the equations shown in Figure 2. The minimum pulse width is often limited by either the antenna or the measurement system so that the only means available for decreasing the duty cycle is by increasing the pulse period. The result is an increase in the PRI, which translates to longer measurement times.

$$P_{avg} = P_{peak} * \Delta t/T$$

$$P_{avg} = P_{peak} * \text{Duty Cycle}$$

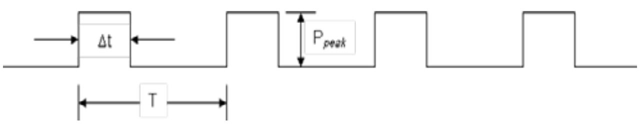

Figure 2 - Pulse Signal Parameters

Active phased array antennas used in radar applications switch between transmit and receive modes during pulse transitions. This transmit/receive mode switching is controlled by a pulsed digital signal, designated as “TR” in the timing diagram shown in Figure 3. The antenna transmits during the TR high state, and receives during the low state. The timing diagram below shows two additional pulsed signals: RF, representing the modulated RF signal; and RcvrMeas, representing the actual receiver integration time. A third additional pulse signal (not shown) is supplied to the receiver and used to trigger the receiver integration for each pulse.

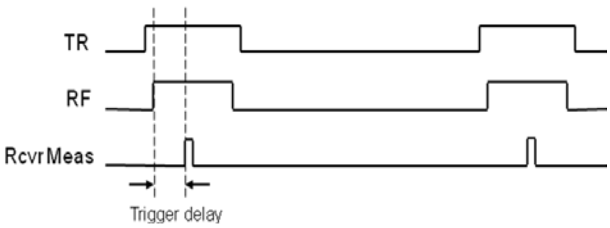

Figure 3 - Transmit Single Pulse Measurement Timing

III. SINGLE PULSE MEASUREMENT

The timing diagram shown in Figure 3 illustrates the signal timing for a pulsed transmit measurement where the RF signal is modulated ON only during the transmit interval of the TR signal. In this example, the RF signal will also be used as the receiver pulse gate and is shown to be slightly inside of the TR pulse to avoid pulse transients that may occur during the pulse transition. The same digital signal can be used for both the RF and receiver pulse gate keeping in mind that there may be some latency of the propagated RF signal due to path length. In the NSI Panther 9100 receiver, this latency can be accommodated by setting a trigger delay which will hold off the receiver measurement for a specified amount of time from the leading edge of the receiver pulse gate. Conversely, the same setup could be used for making a receive measurement by adding an additional delay to the RF pulse so that it occurs during the TR receive interval.

The advantage of this single pulse measurement case is that it requires configuring the test measurement setup for only one operating mode, either transmit or receive, and uses a fairly simple timing scheme. The disadvantage of this measurement can be easily seen from the timing diagram - only a single measurement is being made per pulse, which results in the measurement time being driven by the PRI.

IV. MULTI-PULSE MEASURMENT

For measurements with poor SNR, measurement accuracy can be improved by applying averaging. In the pulse measurement scenario presented in section 3, only a single receiver sample is being made per PRI. Applying averaging in this case requires collecting multiple pulses for the specified number of averages, N_{avgs}, and results in an increase in measurement time by a factor of N_{avgs}. If the pulse width is greater than the receiver integration time, the measurement time can effectively be reduced by collecting multiple receiver samples per pulse. The NSI Panther receiver has the ability to integrate multiple receiver samples within a single pulse and integrates across multiple PRIs in order to achieve the specified averaging in as few PRIs as possible. Using this technique, the number of pulses now required is reduced to:

$$N_{pulses} = PW / T_{rxint}$$

where

N_{pulses} = Number of pulses required for measurement

PW = Pulse width (seconds)

T_{rxint} = receiver integration time (seconds)

In the NSI Panther RF measurement system, this capability is referred to as Intra-Pulse Averaging and is depicted in the timing diagram shown in Figure 4. In this example, ten averages are being effectively collected using two pulses instead of ten. The RcvrMeas signal depicts the individual receiver samples per pulse.

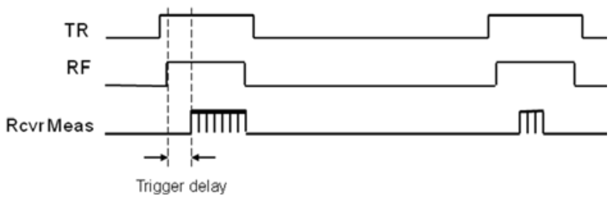

Figure 4 - Transmit Multi-Pulse Measurement Timing using Intra-Pulse Averaging

V. T/R SINGLE BEAM MEASUREMENT

On examination of the timing diagram in Figure 4, it can be surmised that a fair amount of time is still being wasted between pulse measurements and driven by the PRI. For active phased array transmit testing, where the duty cycle must often be limited due to radiating power restrictions, this can adversely affect test measurement time. The pulse measurement example presented above can be further optimized by making measurements during both transmit and receive pulse intervals, as illustrated in the timing diagram shown in Figure 5. In this example, the RF signal is being modulated “ON” during both transmit and receive pulse intervals and turned “OFF” during the TR pulse transitions. Two different averaging and trigger delays are used for transmit and receive to further optimize the measurement time between pulses. The trigger delay for the transmit measurement is applied relative to the TR pulse rising edge, and an independent delay for the receive measurement is applied relative to the TR falling edge.

The resulting transmit and receive measurement times are represented by the Tx and Rx signals respectively shown.

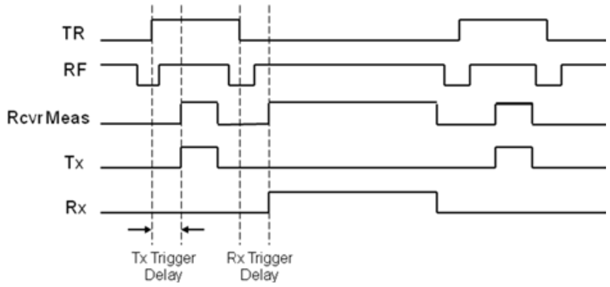

Figure 5 – Interleaved T/R, Single Beam Measurement Timing

This timing scheme provides a much more effective use of the available measurement time. However, it requires a bi-directional range that can be quickly reconfigured between transmit and receive modes at the TR pulse rate. In addition, we must now have some mechanism for keeping track of "transmit" and "receive" samples separately. Furthermore, it would also be desirable to apply different averaging for each mode.

VI. T/R MULTI-BEAM MEASUREMENT

Taking our T/R multi-pulse measurement one step further, the timing diagram in Figure 6 illustrates a measurement scenario that accommodates multiple antenna states during transmit and receive intervals. In the example shown, a single transmit measurement occurs during the transmit interval, and three receive measurements occur during the receive interval. As in our previous example, different receiver sampling averages and measurement delays may be applied for each transmit and receive measurement.

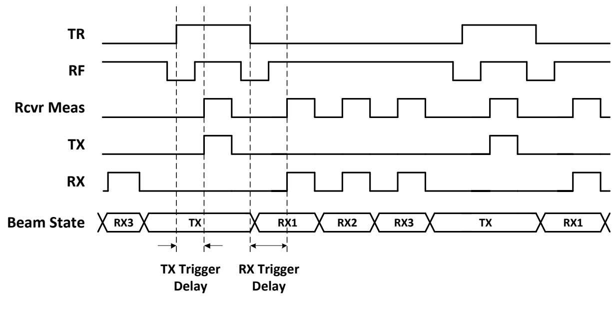

Figure 6 - TR Multi-Beam Measurement Timing

VII. IMPLEMENTATION

To collect both transmit and receive measurements within the same data acquisition requires a bi-directional measurement configuration that can switch between transmit and receive modes at the same rate as the antenna. In the NSI Panther Pulsed RF Measurement System, this is accomplished using the addition of the T/R Modulator circuitry shown in Figure 7. The T/R Modulator employs fast switching PIN-diode RF switches to redirect the RF signals to and from the AUT and RF probe or source antenna at the AUT TR signal rate. RF terminations on the switch outputs are used to blank the RF signal during the T/R transitions. Since the RF power levels will most likely be different between transmit and receive modes, programmable step attenuators are provided in each RF path to optimize the RF power separately for each mode.

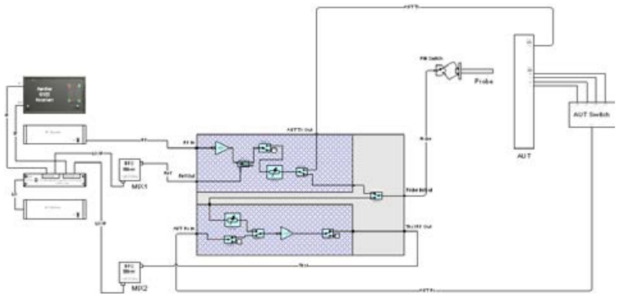

Figure 7 - NSI Panther 9100 Pulsed RF System with T/R Modulator

In addition to automatic range configuration switching, a software modification to the NSI2000 Antenna Measurement Software beam table was developed to accommodate both transmit and receive measurement states within the same data acquisition measurement. The resulting NSI2000 Advanced Beam Table (ABT) accommodates various user-defined, multiplexed measurement states to be measured during a single data acquisition. A new column, *TR Sync*, was added to the NSI beam table to identify each measurement beam as a "transmit," "receive," or "normal" measurement state. A transmit or receive state indicates a TR pulse transition is occurring in conjunction with the measurement and the test configuration mode is also changing state. A normal state indicates no TR transition is occurring for that particular measurement beam and the receiver measurement is triggered normally. An additional ABT column, *Samples*, allows the operator to specify the number of receiver averages on a per-beam basis. The ABT measurement is initiated by a major position trigger from the positioning system and starts on the next occurring TR transition. Prior to the start of the measurement, the NSI2000 software validates the ABT timing against the pulse parameters defined by the operator in the Panther Pulse Mode Setup menu in ensure that the measurement can be accommodated for the specified pulse parameters.

The example shown in Figure 8 illustrates an ABT implementation of a T/R multi-beam pulsed measurement for four independent measurement states, all occurring at a single data acquisition position. The four measurement states (three during receive, and one during transmit) are defined as follows:

Beam 1: RX1 with a 4 µs dwell and 10 averages
Beam 2: RX2 with a 1 µs dwell and 10 averages
Beam 3: RX3 with a 1 µs dwell and 10 averages
Beam 4: TX with a 1.5 µs dwell and 1 average

A TR signal with a 5 microsecond pulse width and 20% duty cycle, and a RF pulse width of 3 microseconds is used for this example. The first beam in the ABT is designated as a "receive" measurement based on the TR Sync value of (2), and will occur on the next TR low going transition. Once the TR transition is detected, the receiver will hold off for the specified dwell time of 4 microseconds before making the measurement. Dwell times are defined by the operator and set based on the time required for the range configuration and AUT to change state. The next two beams have a TR Sync value of zero, designating them as "normal" measurements in which no TR transition occurs; the receiver will be triggered normally based on the specified dwell time. Since the configuration state has not changed since the initial beam, both of these beams will also be receive measurements. For each of the receive beams, ten receiver samples will be integrated as designated by the ABT Sample value. The final beam has a TR Sync value of (1), which identifies it as a "transmit" measurement to occur on the next TR rising edge after a dwell time of 1.5 microseconds. This measurement is specified to have only a single receiver sample. The BeamSet time shown Figure 8 designates the total measurement time required for all four states from receipt of the major position trigger.

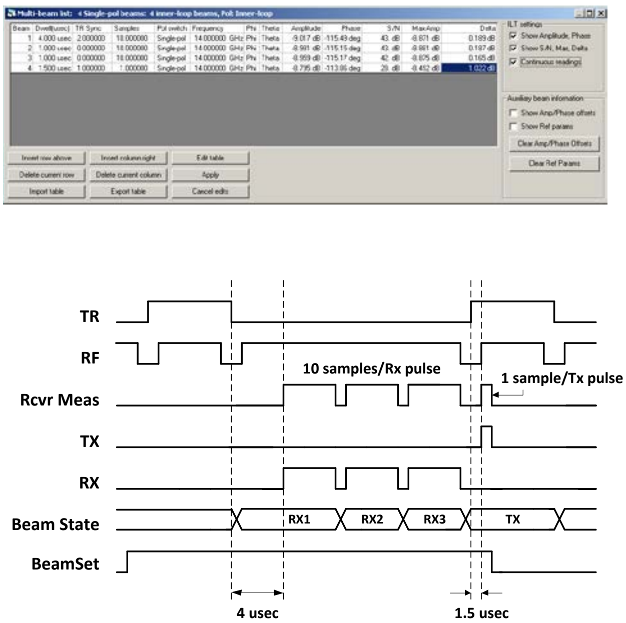

Figure 8 - NSI Advanced Beam Table T/R Multi-Beam Measurement Example

VIII. TEST CASE STUDY

Several test case studies were used to evaluate the potential measurement time reductions achievable using the T/R multiplexed beam implementation described above. The following test case studies are theoretical and are used to illustrate the test setups and test times for the various pulse measurement scenarios presented earlier in this paper

AUT #1 is an active radar antenna with one transmit port and four receive ports; the receive ports will be selected using a RF PIN diode switch. The antenna is to be tested at five X-band frequencies in both receive and transmit modes. The transmit duty cycle for this antenna is 5%, and the PRF is 10 kHz. This antenna is to be measured using a 36 inch by 36 inch near field scan plane with data point spacing (sampling interval) of 0.5 inch.

AUT #2 is an active phased array radar antenna with one transmit port and one receive port. The receive section of the antenna can be commanded into any of 64 beam positions. Commands are provided to the AUT as simple TTL parallel bits, and 10 µs must be allowed for the antenna's state to change once the command is issued. This antenna is to be tested at twenty-five X-band frequencies in both receive and transmit modes. The transmit duty cycle for this antenna is 5%, and the PRF is 10 kHz. This antenna is to be measured using a 36 inch by 36 inch near field scan plane with a data point spacing (sampling interval) of 0.5 inch.

The planar near-field scanner used for this study is modeled after the NSI 300V series scanner with a maximum X-axis velocity of 10 inches per second and a maximum Y-axis velocity of 15 inches per second. The receiver for all three cases is a NSI Panther 9100 with a sampling interval of 320 nanoseconds, and the RF sources are high-speed devices that can switch frequencies within 5 microseconds. The PIN switch used with AUT #1 is assumed to change state within 5 microseconds. TX beams will be measured with a 3.2 microsecond integration time. RX beams will be measured with a 10.2 microsecond integration time. In the "Interleaved T/R, Single Beam" case, both TX and RX beams must be measured with the same integration time, assumed here to be 3.2 microseconds. In the tables below, the scan time refers to a dual-pol data acquisition with separate Co- and Cross-Pol measurements made using a typical OEWG probe.

Table 1 - AUT #1 Test Times

AUT #1 – 5 ports, 5 frequencies				
Method	**Beam Set Time (ms)[1]**	**Scan Time (mins)[2]**	**# Scans**	**Total Test Time (mins)[3]**
1: Separate T/R Measurements	0.6	12	5	60
2: Interleaved T/R, Single Beam	0.6	12	4	48
3: Advanced Beam Table	0.6	12	1	12

[1] Includes pulse re-synchronization
[2] Limited by mechanical speed of scanner
[3] Not including setup time

Table 2 – AUT #2 Test Times

AUT #2 – 2 ports, 25 frequencies, 65 beams				
Method	**Beam Set Time (ms)[1]**	**Scan Time (mins)[2]**	**# Scans**	**Total Test Time (hrs)[3]**
1: Separate T/R Measurements	2.6	13.2	65	14.3
2: Interleaved T/R, Single Beam	2.6	13.2	64	14.1
3: Advanced Beam Table	60	60	1	1

[1] Includes pulse re-synchronization
[2] Limited by RF/computer subsystem
[3] Not including setup time

The results shown in the tables above clearly illustrate that a large reduction in test time is to be gained using the Advanced Beam Table to make interleaved T/R multi-state measurements as described in Sections 6 and 7. The actual time savings is dependent on a number of variables, but in some cases the test time can be reduced by a factor of ten or more as illustrated in the AUT #2 example. The test cases presented also indicate that very little test time reduction is to be gained by just doing interleaved T/R measurements alone (i.e. single transmit and receive measurements per PRI).

IX. SUMMARY

This paper presents various pulsed measurement scenarios for testing of an active phased array radar antenna, and a test methodology that can be employed to significantly decrease test times for these types of antennas. The NSI Panther 9100 Pulsed RF System with T/R Modulator, used in conjunction with the NSI2000 Antenna Measurement Software's Advanced Beam Table, offers a solution for making interleaved T/R multi-beam state measurements that can reduce test times by a factor of ten or more in some cases. This capability also allows radar antennas to be tested under their nominal operating conditions, which improves the real-world accuracy of the test results. Inherent features of the Panther 9100 Measurement Receiver, such as multi-pulse averaging and variable pulse trigger delays, can also be employed for further optimization of pulsed measurements.

REFERENCES

J. Swanstrom and R. Shoulders, "Pulsed Antenna Measurements with the HP8530A Microwave Receiver", AMTA Proceedings 1994.

C. Barnett and D. Dunn, "Practical Considerations for Making Pulsed Antenna Measurements", AMTA Proceedings 1997.

D. Fooshe, "Performance Considerations for Pulsed Antenna Measurements", AMTA Proceedings 2008.

NSI Panther 9100 Receiver System Pulse Mode User's Guide, April 2011.