PERFORMANCE CONSIDERATIONS FOR PULSED ANTENNA MEASUREMENTS

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ABSTRACT

Previous AMTA papers have discussed pulsed antenna measurements and the importance of parameters such as pulse width, pulse repetition frequency (PRF) and receiver dynamic range in determining the appropriate technique for performing pulsed measurements. Typically, the pulse width and PRF determine the IF bandwidth required of the instrumentation receiver to achieve a specific level of receiver performance. Less emphasis has been given to the receiver timing and synchronization required to achieve optimum performance for a full pulsed antenna measurement scenario.

This paper will discuss receiver timing considerations and show examples of scan time performance during high-speed pulsed measurements. Inter-pulse and intra-pulse measurements will be compared with respect to their impact on measurement time. Pulse profile measurements will be examined to show the importance of a fast synchronous receiver for sub-microsecond pulse characterization. Pulsed antenna pattern results will also be presented and compared with CW measurements.

Keywords: pulsed antenna measurements, pulse width, PRF, instrumentation receiver, phased array, IF bandwidth.

1.0 Introduction

This paper discusses performance considerations involved in making near-field antenna measurements using a microwave receiver operating in pulse mode.

Pulsed operation can affect the performance of an antenna measurement in several ways; therefore, attention must be paid to the choice of receiver and measurement technique. Previous papers [1] [2] [4] described narrowband pulse measurements and how the dynamic range decreases with increased pulse repetition interval (PRI). In a narrowband system, the receiver is not synchronized to the pulse and must average over an adequate number of pulses in order to detect the desired CW component. Since narrowband receiver operation requires no synchronization to the pulse, less control over the measurement process is available. For this reason, only wideband synchronous pulse mode operation is considered in this paper.

In a wideband system, the receiver is synchronized to the pulse and must wait for the RF pulse in order to make a measurement. This delay can affect the measurement and must be taken into consideration when planning the test. In a wideband pulsed system dynamic range is limited by the pulse width, but not affected by the PRF. To maximize the measurement efficiency, the receiver integration period should be equal to or less than the desired pulse width for the measurement.

A primary consideration when designing a measurement system for pulsed antenna measurements is the synchronization of the system with the RF pulse. Radar systems are designed for rapid transition between transmit and receive states often switching from a high power output to high sensitivity input. Testing the radar antenna as a separate subsystem without the transmit/receive electronics presents a unique challenge to the antenna measurement system.

The measurement system must be capable of simulating the control and timing of the radar system in a manner that provides a realistic test of the antenna while maintaining control over the measurement process. As an example, radar systems often require an advance pulse to arm or turn-on the amplifiers and electronics prior to the transmission of the RF pulse. If the antenna-under-test (AUT) is an active antenna, then this arm pulse must be generated by the measurement system in the proper sequence with the RF pulse.

Similarly, an active antenna may require a beam-steering computer (BSC) to compute the phase for each element in order to properly steer the beam. The computation is typically done in real-time during the measurement process and is often initiated by the measurement computer or beam controller.

In order to provide the resources necessary to address the demands of pulsed antenna measurements, the measurement system should include a high-speed receiver with wideband IF inputs, be capable of synchronous triggered measurements and allow the flexibility to increase integration time for increased signal-to-noise performance. The system should also include a high-speed beam controller capable of being synchronized to the scanner or positioner while providing a wide range of control over various devices and instruments used during the measurement process, including frequency synthesizers, high-speed PIN switches, beam-steering computers and pulse generators. For pulsed antenna measurements, the beam-controller should also be capable of synchronizing the receiver and the RF pulse.

This paper will review receiver pulse parameters and performance, discuss pulsed near-field considerations including pulse synchronization, pulse timing vs. scan speed, positional accuracy in pulse mode, and intra-pulse averaging. Pulse profile measurements will be discussed and a comparison of CW and pulse measurements will be presented.

2.0 Pulse Parameters and Performance

A convenient means of evaluating receiver pulse performance is the pulse performance diagram. The pulse performance diagram shows PRF as a function of pulse width and outlines the allowable regions of operation for the receiver. The lower region where pulse width is greater than PRI is, of course, CW. Operation with pulse widths greater than the receiver settling time is considered to fall within the full pulse performance region of operation, as shown in Figure 1. This is the desired region of operation for a synchronous wideband receiver. The older Panther 6000 receiver [3] has been tested over a variety of pulse parameters and exhibits full Signal/Noise performance with a minimum pulse width of 7 µs with a pulse trigger delay of no less than 2 µs.

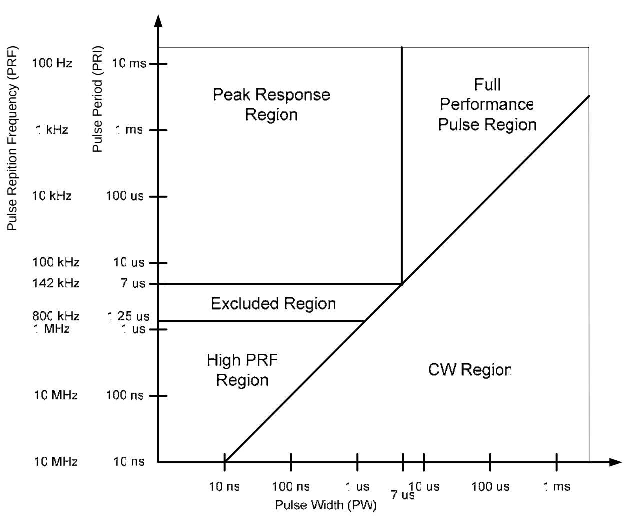

Figure 1 Panther 6000 Pulse Performance Diagram

The newer Panther 9000 receiver [5] with its faster integration time has expanded regions for peak response and full performance allowing full performance measurements of pulses less than 1 microsecond.

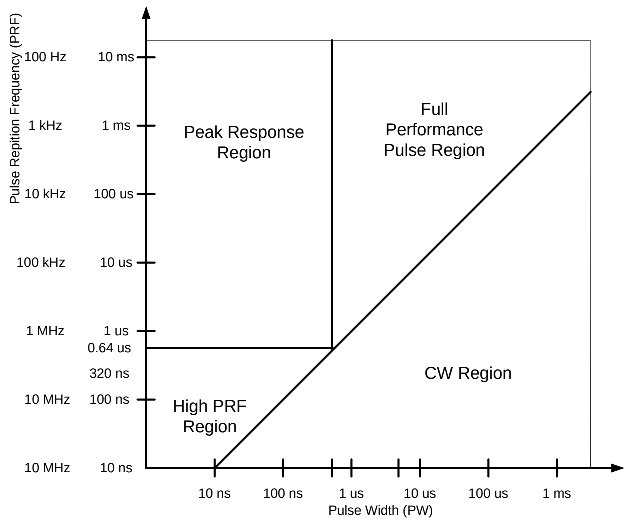

Figure 2 Panther 9000 Pulse Performance Diagram

Once the receiver operating region has been determined, system timing and synchronization must be evaluated. These will be considered for near-field measurements in the following sections.

3.0 Pulsed Near-field Measurements

CW near-field measurements [6] are well-understood and have been extensively covered in the literature. Pulsed near-field antenna measurements require the same level of understanding as CW, but with a few additional considerations, including the following.

- Pulse synchronization and timing must be considered when choosing a receiver for pulsed measurements.
- The near-field scan speed may need to be reduced to match the pulse rate, possibly increasing the overall test time.
- Positional accuracy may be affected by the pulse timing. A comparison test can be made to check for this.
- Intra-pulse averaging may be needed to maximize the receiver utilization and possibly reduce the test time.

3.1 Pulse Synchronization

Pulsed near-field measurements require synchronization between the pulse and the measurement system. Figure 3 shows a typical scope trace of signals in a pulsed measurement.

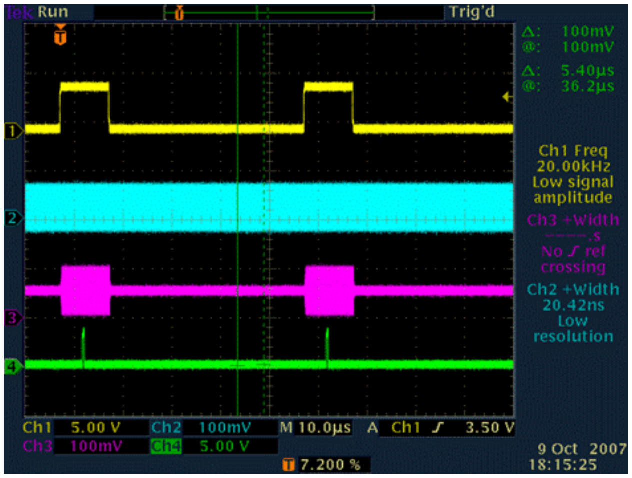

Figure 3 Pulse Timing - Simple

In Figure 3,

- Trace 1 is the 20 kHz PRF pulse (50 us PRI) with 10 µs pulse width,
- Trace 2 is the CW IF signal into reference channel A,
- Trace 3 is the pulsed IF signal into test channel B,
- Trace 4 is the 'receiver trigger' or gate signal, delayed by about 5 µs from leading edge of pulse.

Complex multi-frequency, multi-beam pulsed near-field measurements require synchronization of the scanner or positioner, beam controller and receiver with the pulse to insure accurate measurements.

To manage the measurement process, the NSI2000 antenna measurement software's beam table is used to specify the parameters to be measured between major position triggers. A major position trigger is generated by the motion controller, typically at one-half lambda spacing, i.e. for planar near-field measurements.

Both the Panther 6000 and Panther 9000 receivers use the beam table to specify timing. A beam is defined as a single parameter, i.e. frequency, port, beam-steer, etc, to be measured. Each beam has two timing parameters: dwell time, and measurement time. The dwell time initiates the beam. During dwell time the system is being prepared for an impending measurement by setting the states of switches, frequency sources, etc. At the end of the dwell time, the measurement time begins. The receiver is active during the entire measurement time, averaging continuously (in CW mode) until the measurement time ends.

In the Panther 9000, a "receiver window" signal tells the receiver when to start and stop a measurement, to a quantizing accuracy of 10 ns. Unlike the Panther 6000 in which software timing loops could produce several microseconds of jitter, the Panther 9000 with its hardware synchronization exhibits no such jitter. Receiver timing jitter is an important consideration for pulsed measurements and determines the accuracy to which the receiver can be triggered relative to the leading edge of the pulse.

3.2 Pulse Timing vs. Scan Speed

In a pulsed system the scan speed is required to accommodate the pulse rate so that all beams may be measured between position triggers, typically ½ lambda apart. Relevant factors to consider include the frequency of operation, scan speed, receiver speed and the number of frequencies and beams to be measured.

For an X-band system with ½ lambda spacing of approximately 0.5 inch, a 20 inch per second (ips) scan speed requires 0.029 seconds between major position triggers. All measurements for all beams and pulses must be completed within this time. Assuming a PRF of 10 kHz and receiver averaging of 10 pulses to meet dynamic range requirements, approximately 28 beams may be measured in the allotted ½ lambda interval.

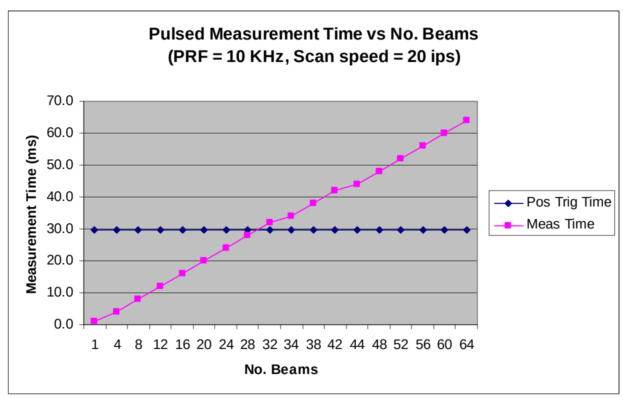

Figure 4 Measurement Time vs. No. of Beams (PRF=10 kHz, scan speed = 20 ips)

If the PRF is increased to 20 kHz, the number of possible beams is increased by x2. Slowing the scan speed from 20 ips to 10 ips also results in doubling the number of possible beams, but for a different reason. In this case, the ½ lambda time has doubled, as shown in Figure 5, allowing twice the time for multi-beam measurements.

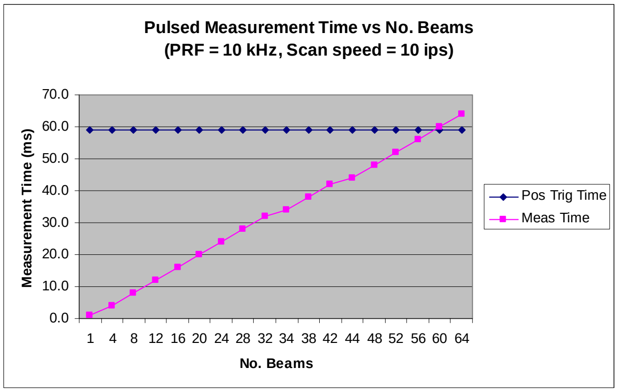

Figure 5 Measurement Time vs. No. of Beams (PRF=10 kHz, Scan speed = 10 ips)

The above examples are simplified to illustrate the affect of changing one or two parameters. Pulsed measurement complexity must be managed, however, when considering the full range of possible parameters including scan speed, RF frequency, PRF, pulse width, receiver speed, receiver averaging, dynamic range, etc. For multi-frequency pulsed measurements, the RF source speed may also be a factor if the source switching time is a significant percentage of the PRI. In this case, extra pulses must be considered for the source settling time resulting in fewer beams possible.

3.3 Positional Accuracy in Pulse Mode

Pulsed RF tests are subject to a probe positional uncertainty due to the fact that the receiver trigger signal must be delayed to be synchronized with the pulse modulation signal. This effect is commonly referred to as pulse jitter. Note that this is a different form of jitter from that discussed earlier. To assess the impact of this pulse jitter on measurement accuracy a continuous motion data acquisition (which will suffer from this effect) and a stop motion data acquisition (where there is no probe positional uncertainty) can be compared. In Figure 6 these two cases are compared and these results demonstrate the negligible effect of pulse jitter in this case. Note that the error depicted here is due to both repeatability and pulse jitter. The case shown is for a Y-axis scanning speed of 4 ips (0.1 m/s), a PRF of 3.33 kHz, 7 discrete frequencies, 2 probe polarizations and 2 AUT ports. A lower PRF may lead to higher error levels and in such a case the scan speed may have to be reduced.

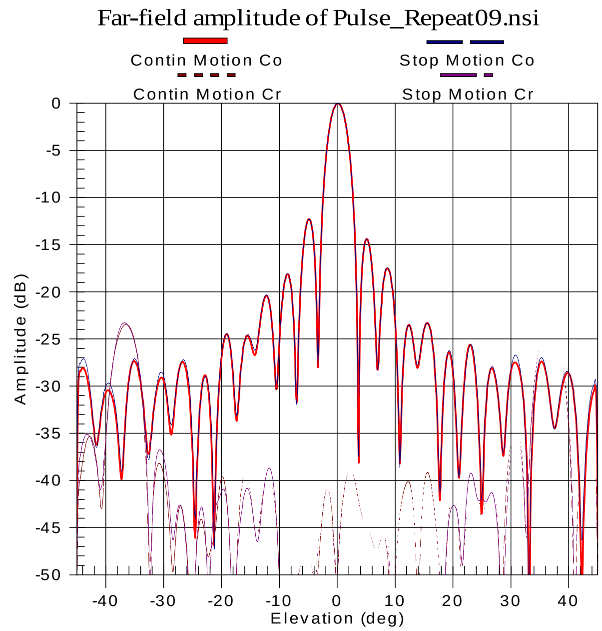

Figure 6 Positional Accuracy Comparison

3.4 Intra-Pulse Averaging

Intra-pulse averaging is a capability that allows the receiver to perform averaging within a pulse. Prior to the introduction of this feature, the Panther 6000 receiver acquired a single 3.55 μs sample per pulse. A single receiver measurement using a specified number of receiver averages required an equivalent number of pulses to be acquired. This resulted in receiver measurement times that were highly dependent on the PRF and inefficient in the cases of large pulse widths. With the intra-pulse averaging feature, multiple receiver samples may be collected within a single RF pulse to provide an increase in receiver measurement speed performance for cases where the RF pulse length is 10 μs or greater. With intra-pulse averaging the measurement may still require multiple pulses, but fewer will be needed to complete the measurement.

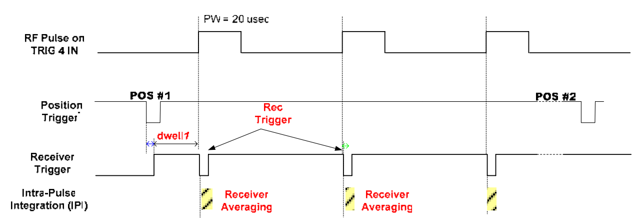

Figure 7 Pulse Timing (No Intra-Pulse Averaging)

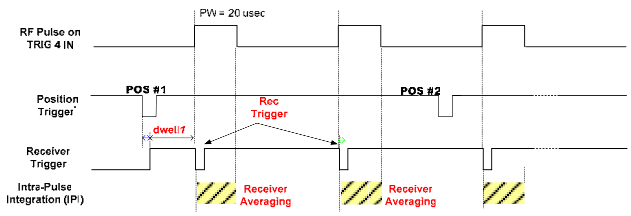

Figure 8 Pulse Timing (Intra-Pulse Averaging)

Note that in Figure 8 with intra-pulse averaging, fewer pulses are required to complete the measurement, i.e. before next position trigger (Pos #2).

4.0 Pulse Profile

Often pulse profile measurements are required in order to characterize the antenna or to better understand the pulse performance of the antenna system. By varying the trigger delay of the receiver, a pulse profile plot may be generated. A fast synchronous receiver is needed for accurate pulse profile measurements. Figure 9 shows a pulse profile measurement of a 10 microsecond pulse using the Panther 9100 receiver.

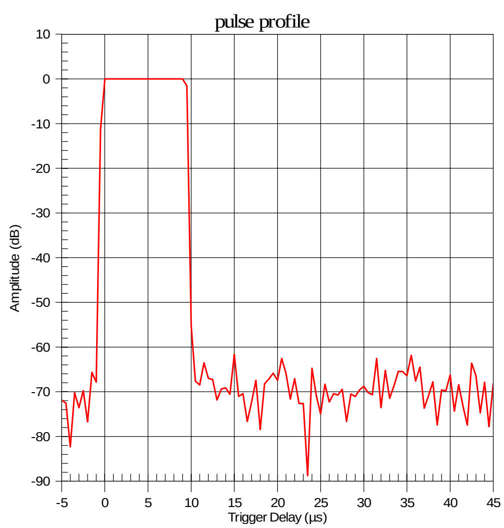

Figure 9 Panther 9100 Pulse Profile Measurement

5.0 CW vs. Pulsed Comparison

To verify the timing accuracy of a pulsed antenna measurement, it is often useful to compare pulsed and CW measurements. If an active antenna is used, CW measurements are not always possible, in which case a passive antenna should be considered to compare pulsed and CW measurements and validate the beam and pulse timing. Once the measurement system is validated with the passive antenna, the active AUT testing may begin.

Figure 10 shows good comparison between CW and three different pulsed measurements. An actual measurement was made on a gain horn using a spherical near-field scanner in the NSI booth at AMTA 2007. The demo system included the Panther 9100 receiver with 100 averages, the Panther 9020 sources switching 100 frequencies and 2 polarizations with a high-speed PIN switch. A 20 kHz PRF pulsed antenna measurement was performed using intra-pulse averaging with the following pulse widths.

- CW
- Pulsed, 10 µs pulse width
- Pulsed, 5 µs pulse width
- Pulsed, 2 µs pulse width

The plot in Figure 10 shows an overlay comparison of far-field azimuth cuts of the four scans.

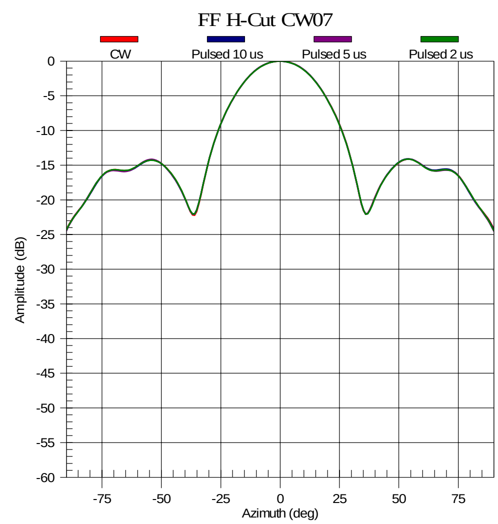

Figure 10 Pulse vs. CW Comparison

6.0 Summary

This paper has presented timing and performance considerations for high-speed pulsed antenna measurements including scan time considerations for near-field measurements, inter-pulse and intra-pulse comparisons, pulse profile measurements and a comparison between CW and pulsed antenna measurements. Emphasis was given to wideband synchronous pulse measurements, since this mode of operation provides the best opportunity for optimizing the performance of the pulsed measurement. Examples were provided to illustrate the importance of a fast synchronous receiver and a versatile beam controller for high performance pulsed antenna measurements.

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7.0 References

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