TIME-GATING OF ANTENNA MEASUREMENTS II

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ABSTRACT

Currently many new compact range facilities are being constructed for making antenna pattern measurements indoors. Limited suppression of stray signals -- due to range layout, confined surroundings and residual absorbing material reflectivity -- represents a limitation on the accuracy of the measurements made in these facilities. Time-gating of the compact range signal appears to be very attractive technique to reduce unwanted reflections.

The authors have carried out an experimental investigation of time gating in a compact range. It is demonstrated that time-gating can improve the uniformity of the aperture field by removing the feed backlobe radiation; and, it is demonstrated that time-gating can remove the effects on a pattern of certain room reflections and on feed backlobes.

When compared to conventional methods of reducing reflections based on placement of absorber, time gating appears equivalent. It does not appear however that time gating improves the conventional methods, except for measuring wide beamwidth antennas.

Keywords: Time Gating, Time-Gated Antenna Measurements, Compact Range.

1. INTRODUCTION

Time-gated antenna measurements are based on the principle of differentiation of signals according to their time of arrival. The purpose of time-gated measurements is to discriminate against unwanted extraneous signals that contaminate a typical antenna range because of the presence of surrounding objects. Since reflections off of objects removed from the line of sight of a range travel longer distances between the range source and test zone than the direct path signal travels, time gating can be useful in improving pattern measurements.

To implement time-gated measurements, one needs a pulse modulator at the transmitter, a pulse gate at the receiver and a means of controlling the pulse width, gate width and gate delay. The measurement of an antenna pattern under time gated conditions proceeds identically to the CW case except for the addition of these features.

The transmitted pulse waveform is characterized by a pulse width \( W_T \) and rise- and fall-times. The timing of the receive gate is characterized similarly -- by its width in time \( W_R \) and by rise- and fall-times. The spectrum of the transmitted pulse is spread over a group of frequencies centered on a central test frequency of interest. After the desired signal is gated it is filtered and detected for the received amplitude and phase of the center frequency. The result ideally is the single frequency pattern rid of extraneous signal contamination.

Pulse-gated measurements can suffer a loss of sensitivity or dynamic range because of the duty factor and the spread of frequencies used. For a given peak power transmitted, the gated CW receiver sees less signal than for the same CW case with no gating. This works as a detriment to the method.

In this paper we show several cases where the pulse-gating method has been applied to measurements made on a compact range to reduce extraneous signal effects.

There is a limitation on which signals can be gated out. It is related to how narrow in time one can make the pulse and the relative delay (or advance) between the wanted and unwanted signals: Generally for an antenna of dimension \( D \) one must meet the following requirements:

\[
W_T < |L_X - L_D|
\]

(1)

\[
W_T = W_R + 2D
\]

(2)

where \( L_X \) and \( L_D \) are the extraneous and direct path lengths. Here time quantities are measured as lengths, with the speed of light being the conversion factor. These relations combine to give the general relation

\[
2D < W_T < |L_X - L_D|
\]

Extraneous signal path lengths \( L_X \) which differ little from the direct path length \( L_D \) will not be discriminated against by pulse gating unless the pulse width \( W_T \) is narrow enough to meet the
above criterion. On the other hand, antennas of dimension D tend to smear pulse excitation over a time width of several D. Thus larger antennas require wider pulses and larger differential path lengths to be measured under pulse gated conditions.

2. EXTRANEOUS SIGNAL PATH DELAY
FOR A COMPACT RANGE

Consider a generic paraboloidal-reflector compact range with a point-source feed, shown in Figure 2, set up in conventional geometry. The main reflector is one focal length in dimension. The test zone is one-half a focal length in diameter. The center of the test zone is 1-1/4 focal length behind the feed. The ceiling is just above the top of the reflector. The rear wall is 3/4 of a focal length behind the center of the test zone.

The direct path from the feed to the center of the test zone via the reflector is a distance of 3.36 focal lengths. The extraneous signal path from the feed to the center of the test zone along a backlobe ray is 1.35 focal lengths. The extraneous signal path from the feed to the center of the test zone via the reflector and the rear wall is 4.86 focal lengths. The extraneous signal path from the feed to the center of the test zone via the ceiling is 1.95 focal lengths.

For all three of the extraneous signal paths mentioned above the differential delay \( |L_2 - L_0| \) is greater two test zone dimensions — i.e., greater than one focal length. It should be possible to gate out their effects. It does not appear that side wall reflections are separable from the direct path.

Feed backlobes, ceiling reflections and rear wall reflections can be removed from the compact range composite signal provided the transmit pulse width \( W_p \) is less than the smallest differential delay which is one focal length. See Table 1.

In the next section we discuss experimental measurements where \( W_p \) is 10 nanoseconds and the focal length is 3.66m (144 inches). A pulse width of ten nanoseconds is equivalent to a distance of 3.0m (118 inches). Therefore these effects can be removed. Evidence is given for two of the three cases.

3. RESULTS FROM TIME-GATED FIELD PROBE MEASUREMENTS

Evaluation of a compact range test zone for amplitude taper, amplitude ripple and phase variation can be done with the field probe technique. In this method, a probe horn that receives excitation from the plane wave signal transmitted by the compact range, is moved across the test zone as the amplitude or phase of its received signal is measured. The amplitude or phase is usually plotted as a function of transverse position in the test zone.

For an ideal compact range, the amplitude and phase are constant within a transverse plane throughout the zone. Deviations from a uniform plane wave character serve to quantify the performance of the range. Smaller deviations connote superior performance. Extraneous signals from feed backlobes, certain wall and ceiling reflections, and signal source leakage, cause ripples to appear in the field probe plots. These types of ripples can be reduced or eliminated by time-gating.

Evidence that this is true was gathered for the case of a Scientific-Atlanta Model 5752 compact range. The results confirm an earlier demonstration of this by Burnside and his coworkers.

The compact range-reflector used for these tests has a 3.65m (12 foot) paraboloidal reflector fed by a point source feed. The range has a test zone approximately 1.22 to 1.83m (4 to 6 feet) in diameter. The room in which the measurements were done is 6m x 3.5m x 1m (20 feet wide by 17 feet high by 36 feet long).

The gating unit used for these tests was comprised of three modules: a pulse modulator, a gate and a remote control. The transmit pulses and receive gate could be varied in width over the range 10 to 99 ns in 1 ns increments. The relative delay between them could be varied between 30 and 200 ns; extra cabling was used to adjust the true delay to be appropriate for the distances within the range.

This set of electronics was a special implementation of a gating instrument designed for RCS measurements. Antenna measurements require that the transmitter and receiver be separately located. Radar systems typically have the transmitter and receiver colocated — i.e. in the monostatic configuration. To avoid routing microwave signals over large distances, the transmit modulator and receiver gate must be separately packaged with timing signals connecting their operation.

The effects of time-gating on field probe tests of amplitude uniformity are shown in Figure 3. A series of four field probe traces is shown. The traces are all vertical cuts in vertical polarization at 5.2 GHz. The probe horn is a pyramidal standard gain horn for X-band; the feed for the range is an X-band feed — round waveguide operation with choke rings. The low end of the band is chosen, since that is where feed backlobes are the worst.

The first of the four traces is a normal trace with no gating whatsoever. The ripple amplitude is approximately 0.1 dB. To provide a test of gating the feed was exposed. It was modified by deliberately removing the features which control backlobes — the choke rings and the top portion of the absorber baffle. The induced ripple for
the CW case is thus approximately 0.2 dB, as shown in the second trace.

After the modulator and gate are installed on the range the same test can be run with a very wide -- 90 ns pulse and gate. As shown in the third trace the results are identical to the CW version with the feed exposed.

The fourth trace shows the effect of a 10 ns pulse and gate width -- short enough to eliminate the effect of feed backlobes. It is identical to the CW case with the feed in its usual state, with choke rings and absorber installed.

These results clearly show that feed backlobe contamination can be reduced by time gating. On the other hand, the usual measures taken to reduce feed backlobes are almost equivalent in effectiveness to time gating, as judged by these field probe results. Tests with a broad beam probe horn shown the same trend. This indicates that time gating is warranted only for the most sensitive tests with broad beam test antennas.

4. ASSESSMENT OF EXTRANEOUS SIGNALS
   BY LONGITUDINAL PATTERN COMPARISON

Evaluation of the stray signals present in the compact range test zone can be performed by two different means: field probing and longitudinal pattern comparison. The field probe method is best for extraneous signals entering the test zone from forward directions. The longitudinal pattern comparison method shows up stray signals entering at angles far off axis or to the side or rear.

The method of longitudinal pattern comparison (LPC) is based on the translation invariance of a planar wave: For an ideal plane wave illuminator, the test antenna's pattern is the same at all distances from the source. The extent to which the pattern varies as a function of distance from the source, is evidence that the field is not a planar wave. Stray signals arriving from off axis directions partially destroy the plane wave character of the compact range field. By comparing patterns made at different longitudinal positions in the test zone, one can find evidence for the presence of extraneous reflected signals.

Longitudinal pattern comparison, then, entails making a series of nearly identical patterns at stepped positions along the longitudinal axis of the range. Sufficient distances must be transversed to significantly alter the relative phase between the extraneous signal at the port of the test antenna and the direct path signal at the port. The phase difference shows up as a slightly different amplitude on the pattern.

The successive patterns are usually plotted as overlays on the same page. The width of the envelope of discrepant patterns can be analyzed for the equivalent stray signal level. The discrepancies found in the set of patterns are dependent upon the particular test antennas used -- even for the same range. Large discrepancies are evidence of significant stray signals present. For an ideal range, no discrepancies would occur among the set of patterns.

In the following section the LPC technique is used to evaluate the effectiveness of time-gating. If time gating were fully successful in eliminating all extraneous signals from the port of the test antenna, the LPC technique would show no discrepancies. If time gating is partially successful the degree of discrepancy should be reduced.

The test of the effectiveness of time gating used for patterns is to look for reduction of LPC discrepancies when time-gating is applied.

5. RESULTS FROM TIME-GATING
   LONGITUDINAL PATTERN COMPARISONS

To demonstrate that time gating can reduce the effects of stray signals on patterns, several test antennas were mounted on the compact range positioner and LPC tests were run with and without gating, with the compact range in different configurations.

To show that reflections from the rear of the room can be removed by gating a large reflecting mast was left uncovered near the back wall. Without gating the mast showed up as a major discrepancy, using a small pyramidal horn mounted in the test zone. See Figure 4A. When time-gating was applied the pattern discrepancy disappeared. See Figure 4B.

Notice in Figure 4C that the LPC test when repeated with long pulses but with the mast covered shows little evidence of the mast. Thus time-gating is equivalent to the conventional use of microwave absorbing material in reducing signals. This pattern test was made with signals not far from the noise floor. The reduction of sensitivity when time gating is applied is apparent in the data.

Another series of tests was run to ascertain how effective time gating can be to reduce the effects on patterns of feed backlobes, a significant contributor to stray signals in a compact range. A standard gain pyramidal horn was mounted and the LPC was run with CW excitation, and the compact range in its standard configuration. See Figure 5A. Then a 10 nanosecond gate was applied with 10 nanosecond pulse width, and the LPC test was repeated. See Figure 5B. No significant difference is apparent, for this rather ordinary measurement, between the gated and ungated tests. Time-gating does not appear to improve conventional measurements significantly on this compact range.

To look more closely for evidence of the effects of gating on feed backlobe contamination of pattern measurements an open ended waveguide was
mounted as the test antenna. The feed was deliberately modified to enhance its backlobe levels by removing the choke flange from the feed aperture and removing the portion of the baffling absorber. The elevation axis was tilted over to cause the broad beam test antenna to "look down" in the direction of the feed. Then LPC tests were made both with and without gating. The results are shown in Figure 6A and B.

The main beam discrepancies are reduced by time gating from approximately 0.5 dB down to 0.2 dB. Time gating clearly helps to improve feed backlobe rejection.

Time gating does not remove all extraneous signals, however. It can't, for example, eliminate the effects of reflector edge diffraction or feed support diffraction from the collimated signal. Time gating is clearly not a panacea providing complete elimination of stray signals. Notice the residual discrepancy in the gated LPC test.

We conclude from these cases that time gating can be a useful tool in reducing stray signal effects on pattern measurements but it does not completely eliminate these effects.

6. SUMMARY

Time-gating has been shown to be effective at reducing stray signal levels on a compact range due to

1. Feed backlobe radiation
2. Certain room reflections

When compared to conventional methods based on placement and selection of absorber, time gating appears to give equivalent results. No evidence has yet been found that shows time gating significantly improves the conventional method. It does not appear that time gating will supplant the use of absorbing material for reflection signal reduction, based on measurements made so far.

Time-gating is most easily demonstrated with broad beamwidth antennas, and from this we conclude that time-gating should be applied in the future to that challenging problem.

Figure 1. Schematic of Extraneous Signals in a Compact Range
Figure 2. Schematic of Generic Compact Range Layout including the Chamber Walls

Table 1
Differential Delay for Configuration of Figure 2
For Primary Ray Path $L_D = 3.36F$

| Ray Type            | $L_X$     | $|L_X - L_D| $ |
|---------------------|-----------|---------------|
| Direct Backlobe Ray | 1.35F     | 2.01F         |
| Ceiling Ray         | 1.95F     | 1.41F         |
| Rear Wall Ray       | 4.86F     | 1.5F          |
Figure 3. Vertical Compact Range Field Probe Traces at 8 GHz Made Under Different Conditions

A. No Time Gating Used - CW Signals
B. No Time Gating Used and with Feed Backlobes Deliberately Worsened
C. Long Pulse Time Gating Used with Feed Backlobes Deliberately Worsened
D. Short Pulse Time Gating Used with Feed Backlobes Deliberately Worsened

The horizontal scale is 1.82m (72 inches) of travel of the field probe carriage.
The vertical scale is 0.1 dB per smallest division.
Figure 4. Longitudinal Pattern Comparison Test. Three range configurations with a small pyramidal horn test antenna.

A. Long Pulse Case (60 ns) with Uncovered Metal
B. Short Pulse Case (10 ns) with Uncovered Metal
C. Long Pulse Case with Metal Covered by Absorber

The horizontal scale is -140° to +180°; the vertical scale is 70 dB.
Figure 5. Comparison of LPC Test with Standard Gain Horn Patterns Made on a Compact Range at 10 GHz.

A. No Time-Delay Gating Used - CW Case
B. With Time-Gating - 10 ns Pulses

No significant improvement occurs when time-gating is applied, under normal conditions.
Vertical Scale is 80 dB, Full Scale
Horizontal Scale is ±180°, Full Scale
Figure 6. Comparison of LPC Test with Open Ended Waveguide at 10 GHz
A. No Time-Gating Used - CW Case
B. With Time-Gating - 10 ns Pulses

The effect of feed backlobes has been deliberately enhanced to demonstrate the use of time gating. Note the improvement in the LPC test when time gating is applied. The width of the envelope is reduced from 0.5 dB down to 0.2 dB.

The Vertical Scale is 20 dB, Full Scale, not 40 dB. The Horizontal Scale is ±90°.