ORBIT/FR

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Microwave Test and Measurement Solutions for a Wireless World

Application Note

"Using Software Gating to Enhance Antenna Pattern Measurement Accuracy"

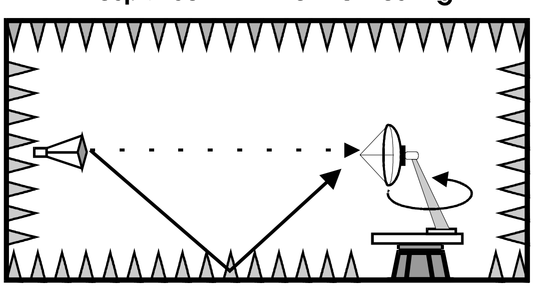
Software Gating Can Help Correct These Problems:

- Asymmetric Sidelobes & Backlobes
- The Inability to Accurately Measure Monopulse Antenna Null
- Poor Sidelobe Accuracy from Near Field Measurements
- Excessive Measurement Ripple on Patterns
- Inaccurate Axial Ratio Measurements on CP Antennas
- Poor Phase Data Off Boresight.

What is a Software Gate?

A software gate is simply a digital filter which is applied to the measured test data after the data is collected and stored. This filter isolates the desired signal from the antenna under test (AUT) while rejecting unwanted signals which arrive before and after the AUT response. Examples of these undesired signals include ground-bounce, wall, ceiling & floor reflections in chambers, and other multipath responses.

Typical Undesired Multipath Response in Antenna Testing



How is a Software Gate Used?

To use a software gate, the AUT is measured at multiple, equally spaced frequencies. This allows the gating algorithm to determine the relative separation of each measured response. The user then selects the desired response by placing a bandpass filter (i.e., gate) over the appropriate span of time. Because the gate is a bandpass function, responses located both before and after this gate are attenuated significantly. The selected gate is applied to the multi-frequency data collected at each measurement angle. The resulting gated data is then plotted versus angle by choosing one or more frequencies from the gated dataset.

This process is illustrated in Figure 1. First, the data is measured at multiple frequencies and angles. Typical Gain versus Frequency plots are shown with the ripple caused by the indicated multipath responses. The frequency domain data is transformed to the time domain. Here, the user can identify the desired AUT response and then gate out the undesired multipath responses. Finally, the gated data is displayed in a Gain versus Azimuth format, but without the multipath errors.

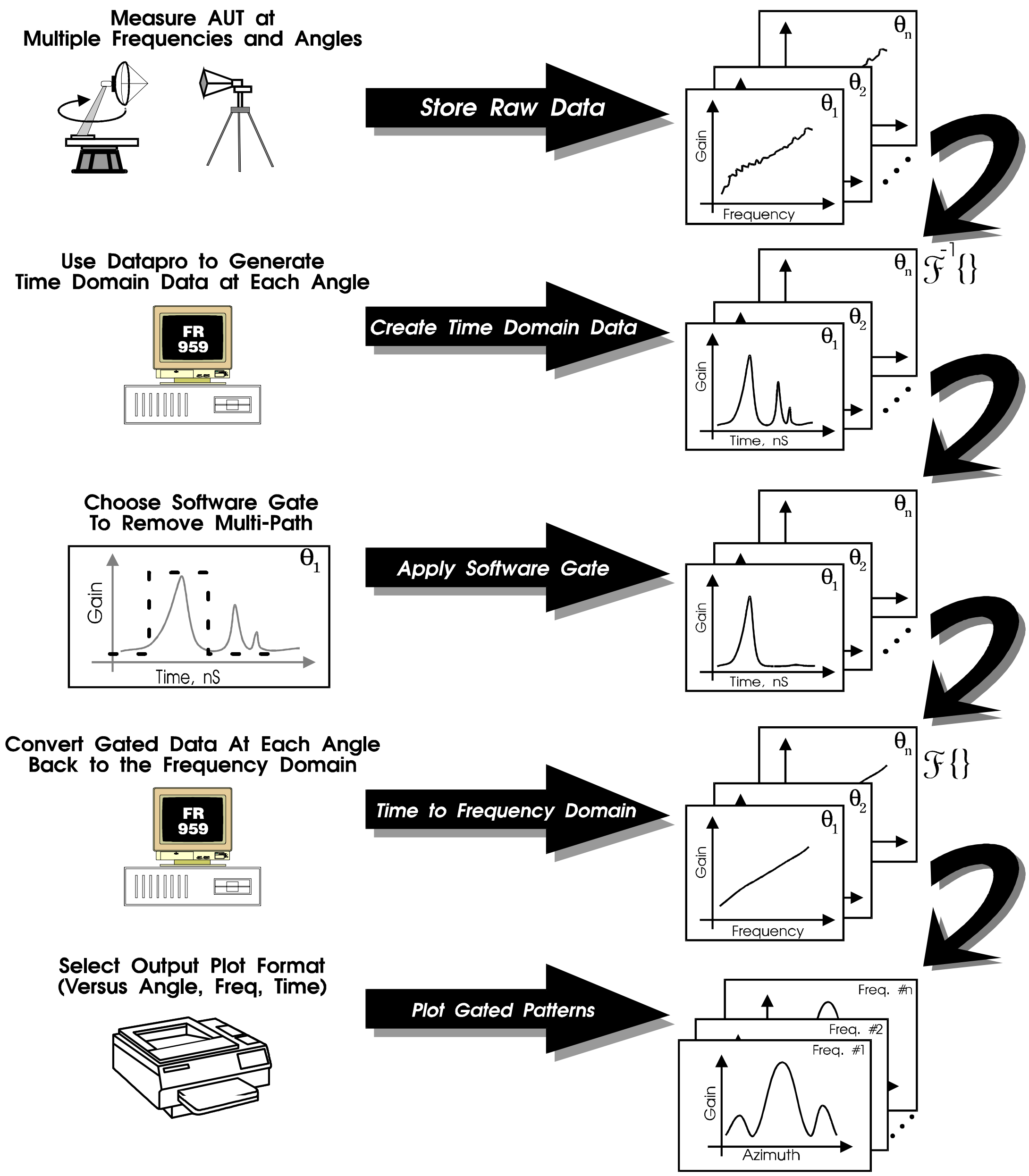


Figure 1. A Conceptual View of the Software Gating Process.

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When using the FR959 Antenna Measurement Workstation, the original, un-gated data is *always* retained in the data file. The gating mathematics is performed during post-processing. This means that the measured data can be analyzed with a variety of gates to determine the best gate size, shape, and location to produce the best pattern accuracy.

As with any signal processing algorithm, software gating has certain limitations, data requirements, and restrictions. These factors are covered in more detail in the following sections.

Software Gating Performance & Data Requirements

The ability of a software gate to improve data accuracy is affected by these three factors:

1. The number of measurement frequencies at each angle (i.e., the frequency increment),
2. The measurement bandwidth, and
3. The separation between the desired test antenna response and the undesired responses.

Each of these factors combine in different ways to affect the performance of the software gate, the accuracy of the data, and the measurement time. The first important parameter to understand in software gating is the impact of *alias-free range*.

Alias-Free Range

When planning an antenna test using software gating, it is important to achieve a sufficient *alias-free range* with the measured data. Alias-free range is the maximum separation which exists between two responses and still be able to unambiguously locate the responses in time. Too small of an alias free range may result in undesired responses appearing at the same time domain location as a desired antenna response. Alias free range is calculated as:

$$Alias\,Free\,Range\,(nS) = \frac{No.Frequencies - 1}{Bandwidth\,(in\,GHz)}$$

Note

In antenna measurements, 1 nS of time roughly corresponds to 1 foot (0.3048 meters) of distance. For example, if you were to move your antenna down-range by 5 feet, you would expect the time domain location of the AUT response to move down-range by approximately 5 nS.

Planning your data collection for a sufficient alias-free range is important. Collecting too many frequencies for an excessively large alias-free range unnecessarily increases the measurement time. Applying a software gate when there is an insufficient alias-free range can severely corrupt the resulting gated pattern data.

Note

Insufficient alias-free range will not affect the quality of the data unless a software gate is applied.

Example:
Planning the Proper Alias-Free Range

For this example, assume the test range is a direct illumination type. This means that the first response from the system must be the desired AUT response (it's the shortest path). Now determine the longest path length associated with the last ***significant*** *multipath response. If this is an indoor range, it may be the backwall response. If the backwall is 15 feet behind the AUT, then the maximum additional path length is 15 feet from the AUT to the backwall plus an additional 15 feet from the backwall to the AUT, or 30 feet total. This means that the number of test frequencies should be chosen to produce an alias-free range of at least 30 nS. Some margin on this number should be provided, so we'll choose an alias free range of 50 nS. If we are measuring an AUT over a 2 GHz frequency bandwidth, this means we'll need 101 frequencies:*

The calculations for the above example are shown here:

$$50\,nS = \frac{Number\ of\ Frequencies - 1}{2\,GHz}$$

therefore,

$$Number\ of\ Frequencies = 101$$

Figure 2. Alias-Free Range (in Meters).

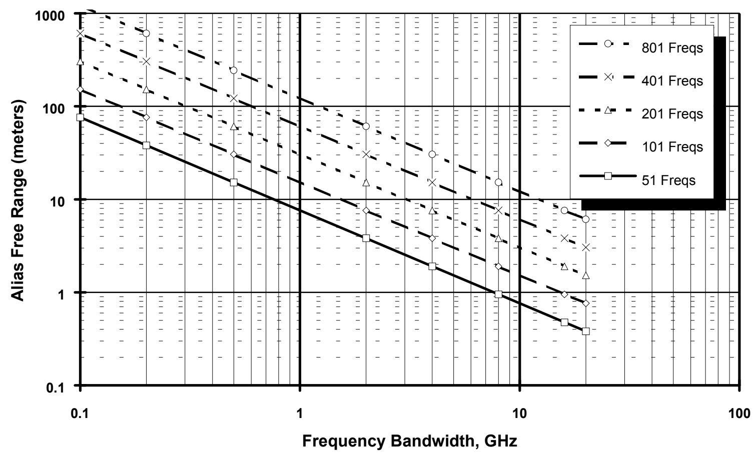
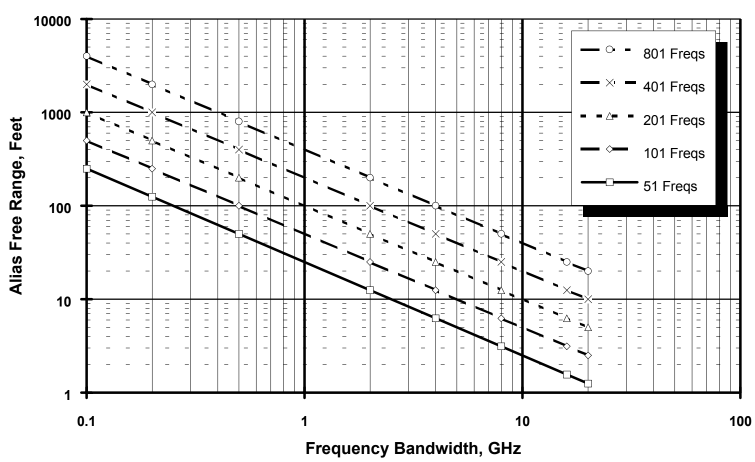


Figure 3. Alias-Free Range (in Feet).



For your particular range, it may be useful to make a scale drawing of the possible multipath responses, and then determine the last significant response which can corrupt your pattern data. Remember, the multipath responses can vary *significantly* as the AUT rotates. This is especially true for high gain antennas.

An alternative method for verifying a sufficient alias-free range is look at the gain vs. frequency plot. If you have at least one full cycle of ripple, you typically have a sufficient alias-free range to perform gating.

Figures 2 and 3 are provided to assist you in quickly determining the minimum number of test frequencies for a given alias free range and measurement bandwidth.

Gate Rise and Fall Time

The gate rise and fall times (they are equal) are determined by two factors: 1) the selected gate 'shape', and 2) the measurement bandwidth. Table 1 provides equations for determining the approximate rise and fall times for each of the supported gate shapes in the HP 8510 & 8530 (with Opt. 010), and the FR959 Datapro processing package (with option 959-AN6).

Figure 4 graphically illustrates the relationship between the gate rise/fall time (between the 0 dB point and the gate stopband) and the measurement bandwidth. Keep in mind that relying on the absolute limit in gate rise/fall time leaves no margin for error in the setting of the gate or displacement of the AUT during rotation.

From Table 1 and Figure 4, three important relationships are apparent:

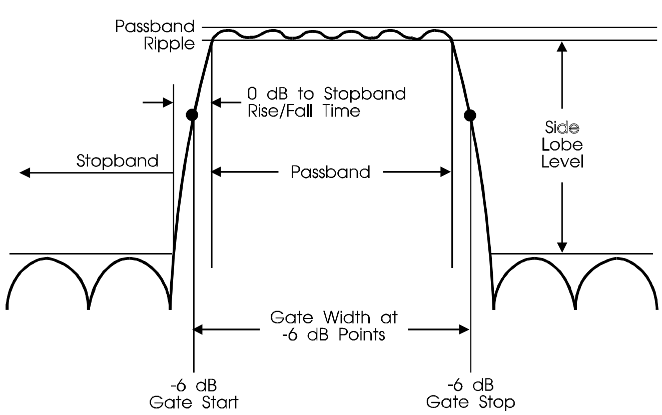
1. As the measurement bandwidth increases, the software gate is better able to reject unwanted responses which fall closer to the desired AUT response.
2. The 'narrower' the selected gate shape, the faster the gate's rise and fall time (all other factors being equal). However, selecting the narrower gate shapes causes more gate ripple and also yields reduced stopband rejection capability.
3. The 'wider' gate shapes produce less time domain ripple but the stopband rejection of wider gate shapes is greater.

Here are some general 'rules-of-thumb' regarding the selection of a software gate shape:

1. Start with the 'Normal' gate shape.
2. If the undesired response is very close to the AUT response and is not large relative to the AUT response, choose the 'Minimum' gate shape.
3. If the undesired response is not close to the AUT (easily resolved in the time domain plot), stay with the 'Normal' gate shape.
4. If the undesired response is still affecting data accuracy with the 'Normal' gate shape, switch to the 'Wide' or 'Maximum' gate shapes. However, be careful about interpreting plots at frequencies near the band-edges of the measurement band (see the

Table 1.
Approximate Time Domain Software Gate Characteristics.
BW is the Measurement Bandwidth, in GHz.
The Result is in Units of Nanoseconds.

Gate Shape	Minimum Gate Width (-6 dB Points)	0 dB to -6 dB Rise/Fall Time	0 dB to Stopband Rise/Fall Time	Passband Ripple	Maximum Stopband Sidelobe Level
Minimum	1.2/BW	0.6/BW	1.2/BW	±0.40 dB	-24 dB
Normal	2.8/BW	1.4/BW	2.8/BW	±0.04 dB	-45 dB
Wide	8.0/BW	4.0/BW	8.0/BW	±0.02 dB	-52 dB
Maximum	22.4/BW	11.2/BW	22.4/BW	±0.01 dB	-80 dB



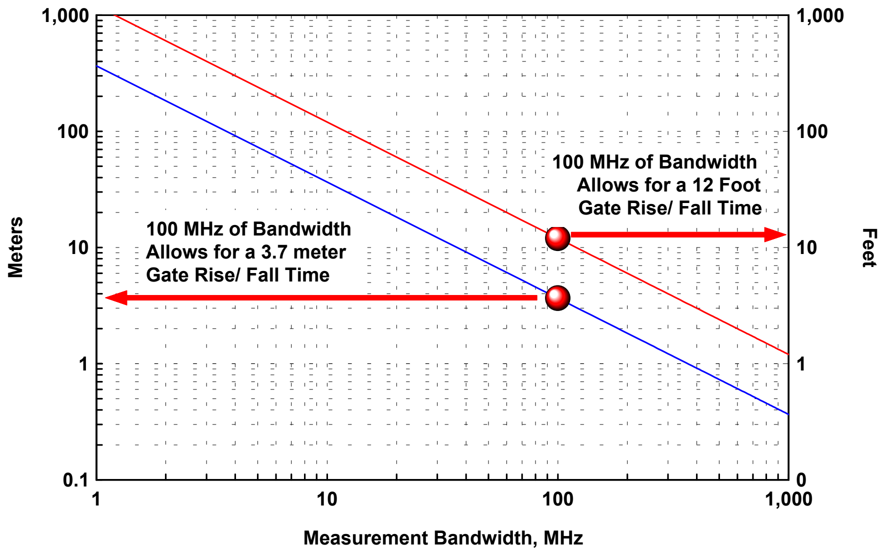


Figure 4. Absolute Minimum Gate Rise and Fall Times Achievable With the 'Normal' Gate Shape.

"Data at Band Edges" section for more information on this caution).

Applications Limitations Associated with Software Gating

A software gate is simply a digital filter. Because the data is sampled over finite frequency increments and with a finite bandwidth, the signal processing introduces some degree of error in the measured data. Typically, this added error is very small relative to the other measurement errors (less than 0.05 dB). However, there are circumstances where prudent judgment must be exercised by the analyst to ensure the errors produced by software gating do not outweigh the benefits.

Data at Band Edges

Following the application of a software gate, the data at the band-edges is less accurate than the data over the central portions of the frequency sweep. As a rule of thumb, do not utilize pattern data from the upper and lower *'x'* percent of the frequency band, where *'x'* is defined in Table 2 below.

Table 2. Band-Edge Data to Avoid When Software Gating.

Gate 'Shape'	*'x'* Percent of Frequency Sweep to Avoid
Minimum	1%
Normal	5%
Wide	10%
Maximum	20%

These percentages are estimates based on experience in using various shapes of software gates. In general, the data will be less corrupted at the band edges if the data within the frequency sweep is well behaved. Frequency domain data which varies significantly over the measured bandwidth may produce larger errors at the band edges following the application of a software gate.

When planning a test, it may be useful to 'over-sweep' the desired test frequencies slightly so that the corrupted data is outside the band of interest. Use caution, however, in measuring outside of the antenna's VSWR bandwidth as erratic time domain displays may result.

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Non-Stationary Reference/Test Antenna

When using software gating, calibrating with, or testing an antenna whose phase center moves with frequency can present problems. If the phase center of *either* the reference or test antenna moves significantly, the antenna's time domain response can move outside of the software gate at some frequencies and/or angles.

Consider one example: The gain standard used to calibrate the range is an 0.2 to 1.1 GHz Log Periodic Dipole Array (LPDA). The test antenna is a dual-ridged horn. When the calibration mathematics performs the complex normalization of the test data by the gain standard data, the phase center of the horn will appear to move away from the source antenna much farther than would be expected for this type of antenna. This is because the phase center of the LPDA moves towards the source with increasing frequency. When complex division is used to normalize the test antenna by the reference antenna, the 'reference plane' established by the LPDA moves towards the source. This makes the calibrated horn antenna response appear to move away from the range source antenna, even though it actually moves only a very small distance, if at all. If the user were to set a very narrow gate over the horn response, the non-stationary reference measurement would cause the horn antenna response to fall outside the gate at some frequencies and angles.

There are two techniques which should be considered when calibrating or measuring antennas whose phase centers move a significant distance across the measurement band:

1. *Incorporate the phase center movement of the gain standard in the Standard Gain Table.* This will result in a true phase center measurement on any test antenna at each calibration frequency. This capability is fully supported by the FR959 Measurement System.
2. *Set the Software Gate wide enough to allow for phase center movement with frequency and angle.* If it is anticipated that the test antenna phase center will move with frequency, set the software gates wide enough so that the entire test antenna response will be within the passband of the gate for all frequencies and angles.

Non-Linear Test Antenna Behavior

Test antennas which incorporate certain types of magnetic material or active devices require special attention when using software gating. The software gating process relies upon the linearity of both the gain standard and the test antenna data. If one of these measurements is non-linear, the application of a software gate can result in severely corrupted data.

Here are some critical factors to consider when measuring non-linear antennas:

- Ensure any active devices incorporated within the antenna remain well within their 1 dB compression points.
- Ensure any frequency translation devices within the antenna under test are free from undesired images and spurious responses. This includes such items as LO-RF leakage, harmonic distortion, and spectral foldover which can produce undesired signals in the first IF of the receiver.
- Ensure any T/R devices, circulators, and isolators are being operated well within their design limits during the test and at all test frequencies.

Comparing a Software Gate to a Hardware Gate

A hardware gate provides an alternative means for rejecting unwanted range responses during an antenna pattern test.

A hardware gate works by transmitting a pulse down the antenna range. When this pulse is received by the test antenna, a receive gate (i.e., switch) is briefly opened which accepts only the energy from the source antenna. Energy from the ground-bounce or other undesired path is rejected by a closed gate. A central timing unit controls the opening and closing of the transmit and receive switches.

Typically, many hundreds of pulses are sent for each data point. These pulses are integrated within the receiver, and then filtered so that only the carrier frequency (which is the test frequency) is measured by the final detection stages of the receiver.

There are significant advantages and disadvantages with a hardware gate relative to a software gate. Some of the more important distinctions are discussed below.

A Hardware Gate Allows for Gated Patterns from Measurements at Arbitrarily Spaced Frequencies

With a hardware gate, one or more frequencies which are arbitrarily spaced can be measured while still achieving the advantages of gating. This can, depending upon the instrumentation and range conditions, significantly improve the measurement time relative to software gating.

A Hardware Gate Still Requires Test and Source Antenna Bandwidth

Even though a single frequency, gated measurement can be performed with a hardware gate, the test antenna *and* the range source antenna must still have enough physical bandwidth (both pattern and VSWR bandwidth) to support the majority of the transmit pulse bandwidth. This means that the source and test antennas must have at least 50 to 100 MHz of bandwidth under standard operating conditions.

This restriction may be relaxed somewhat by utilizing extended transmit pulse widths and allowing the test antenna to ‘ring down’ prior to sampling with the receive gate. Using this technique decreases the rejection ability of the hardware gate on close-in and undesired range responses. Please contact ORBIT/FR for more information on using this technique.

Data Collected With An Incorrectly Set Hardware Gate Can’t Be Fixed!

A software gate is a post-measurement signal processing technique. This allows multiple software gates to be tried without affecting the original, undated data. A hardware gate is different.

With a hardware gate, the receiver collects only the gated data. If the hardware gate is set incorrectly, the data cannot be re-constructed. It must be re-collected. For this reason, it is important that the correct setting of the hardware gate be verified prior to performing any pattern tests.

Although Potentially Faster, a Hardware Gate is Initially More Expensive

A hardware gate requires a significant addition to the standard complement of antenna test RF equipment. Available in bands from 0.1 to 2 GHz (FR Model 8205) and 2 to 18 GHz (FR Model 8105B), a hardware gate typically requires the installation of RF hardware at both the transmit and receive ends of the antenna range.

This additional hardware increases the initial cost of the range instrumentation. However, when evaluating the time and associated costs to collect multiple, equally-spaced frequencies for a software gate, a hardware gate can prove more cost-effective over the life of the range.

Measurement Time Considerations

When using a software gate with antenna pattern measurements, you must measure multiple, equally-spaced frequencies. Even if you only want the antenna pattern at a single frequency, you must still measure multiple frequencies to collect the time domain information necessary to separate the desired from the undesired responses. This can increase the measurement time, depending upon the maximum speed of your positioning system.

Note

A 51 frequency pattern measurement for software gating does not necessarily mean a 51-fold measurement time increase over a single frequency pattern measurement!

The time required to perform the data collection at a single frequency is typically limited by the maximum positioner speed. That is, data at more than one frequency can be collected without any penalty in speed. There is a point, however, at which collecting more frequencies will result in a decrease in measurement speed. To determine the speed impact of making multiple frequency measurements, determine the rotation rate which will be used for a multi-frequency measurement by following these three steps:

Step 1) Determine (through calculations or measurement) the total time required for your measurement system to collect the desired data at all frequencies for a single angle. This time will be called $\mathbf{T}_{sweep}$ and has units of seconds.

Step 2) Using the desired number of degrees per sample (θ_{inc}), determine the maximum allowable rotation rate ($\mathbf{V}_{rotation}$) to collect antenna patterns at each of the required frequencies:

$$V_{rotation}\left(\frac{\textbf{deg}}{\textbf{sec}}\right)=\frac{\theta_{inc}\left(\textbf{deg}/\,sample\right)}{T_{sweep}\left(\textbf{sec}/\,sample\right)}$$

Step 3) Compare this number to the maximum rotation rate capability for your positioner. The data collection will use the smaller of these two numbers.

Depending upon the value of T_{sweep}, the additional time required to perform a software gated antenna measurement can vary significantly. A very large value of T_{sweep} (slow frequency switch times or large amounts of averaging) can require very slow rotation rates and hence, long measurement times as compared to single frequency pattern cuts.

A Measurement Example

To demonstrate the power of software gating, a simple test is performed. Using the FR959 Antenna Measurement Workstation and any receiver capable of I and Q (real and imaginary) data output, a conventional antenna test is configured. For this test, a simulated multipath signal is achieved by connecting a fixed receive antenna through a delay line into the normal test antenna signal path. This multipath signal is simply added, through a power combiner, to the normal test antenna signal. This setup is illustrated in Figure 5.

Figure 5. Software Gating Demonstration Block Diagram.

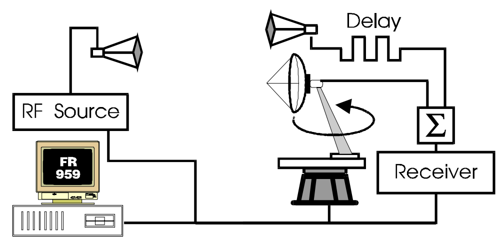


Figure 6 shows the measured antenna pattern both with, and without the multipath channel connected. The multipath signal is severely corrupting the true antenna pattern in this measurement.

Figure 7 shows the time domain response at the zero-degree position (azimuth = 0 degrees). The measurement bandwidth is 4 GHz (6 to 10 GHz) using 81 Frequencies. The alias-free range is 20 nS. The multipath signal responsible for corrupting the pattern is clearly identified. Using the FR959/Datapro package, this response is removed with a software gate after the measurement is completed. The bold line in Figure 7 shows the time domain response following the application of the software gate starting at -10 nS and stopping at

Figure 6. Measured Antenna Pattern with and Without Multipath Errors.

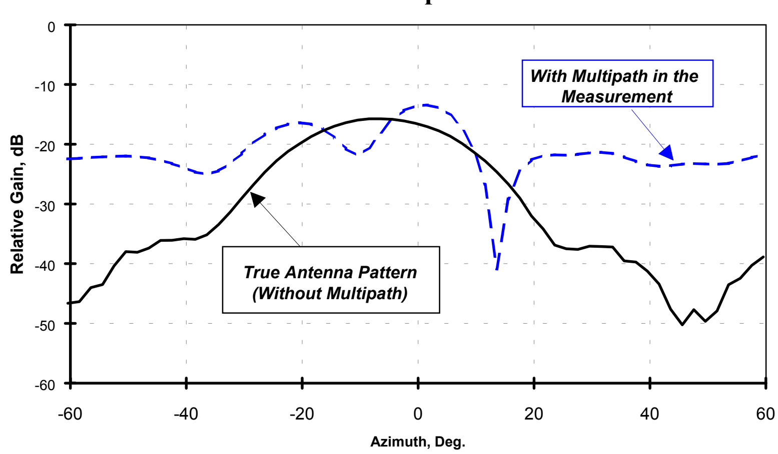
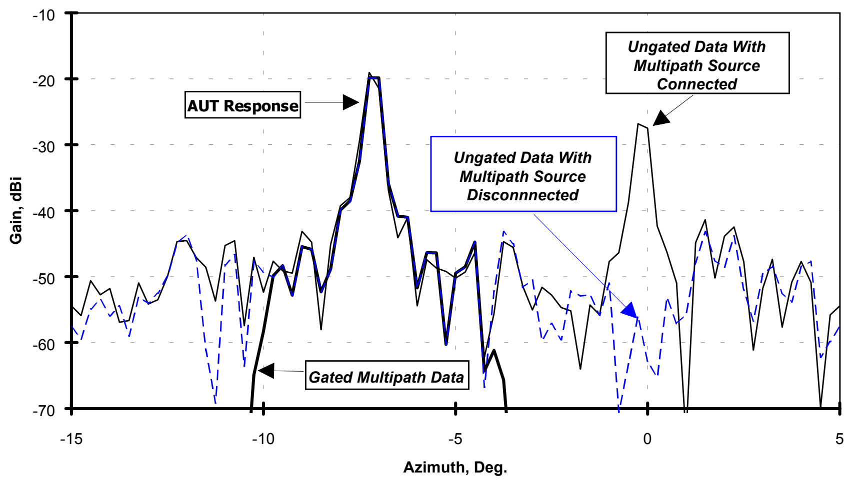


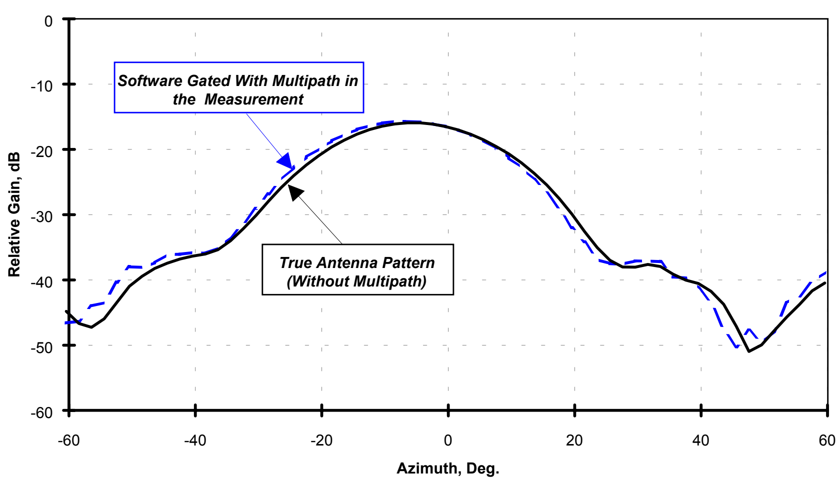
Figure 7. Time Domain Data Responses at 0 Degrees for the Data Both With and Without Multipath Signals, and the Response Following Software Gating.



-4 nS (-6 dB points).

Once gated, the pattern data can again be plotted versus azimuth. The gated pattern is shown in Figure 8 along with the original pattern measured without multipath. The agreement is quite close, despite the presence of severe multipath in the original, un-gated pattern measurement.

Figure 8. Measured Antenna without Multipath Compared to Software Gated Data Which Includes Multipath.



Notes: