New Network Analyzer Methodologies in Antenna/RCS Measurements

White Paper

Agilent Technologies

ABSTRACT

This paper is designed to illustrate the technical advances in network analyzers and how they can be effectively utilized in an RCS test range. The Hewlett-Packard 8530A [1 - 4] has been utilized in antenna test ranges since the 1980's and will be used as a reference comparison. Advances in network analyzer hardware and software provide increased functionality, speed and accuracy for RCS measurements. A typical RCS full polarization matrix imaging measurement will be used to illustrate these advances in technology. Range gating, digital and down-range resolution and alias-free range topics will be discussed illustrating the technical advances that can be utilized in an RCS test range. Flexibility of network analyzer hardware will also illustrate the effectiveness of reducing measurement hardware complexity resulting in an increase in measurement speed and accuracy.

1.0 RCS Full Polarization Matrix Imaging Measurement

A typical RCS range is illustrated in Figure 1. This measurement consists of a test chamber, network analyzer, feed horns, and target. We will illustrate a full polarization matrix imaging example where the vertical and horizontal components of the electric field will be transmitted and measured independently as shown in Table 1. This will require two transmit and receive polarizations, vertical (V) and horizontal (H).

Tx	Rx1	Rx2
Vertical Polarization	Vertical Polarization	Horizontal Polarization
Horizontal Polarization	Vertical Polarization	Horizontal Polarization

Table 1. RCS full polarization matrix

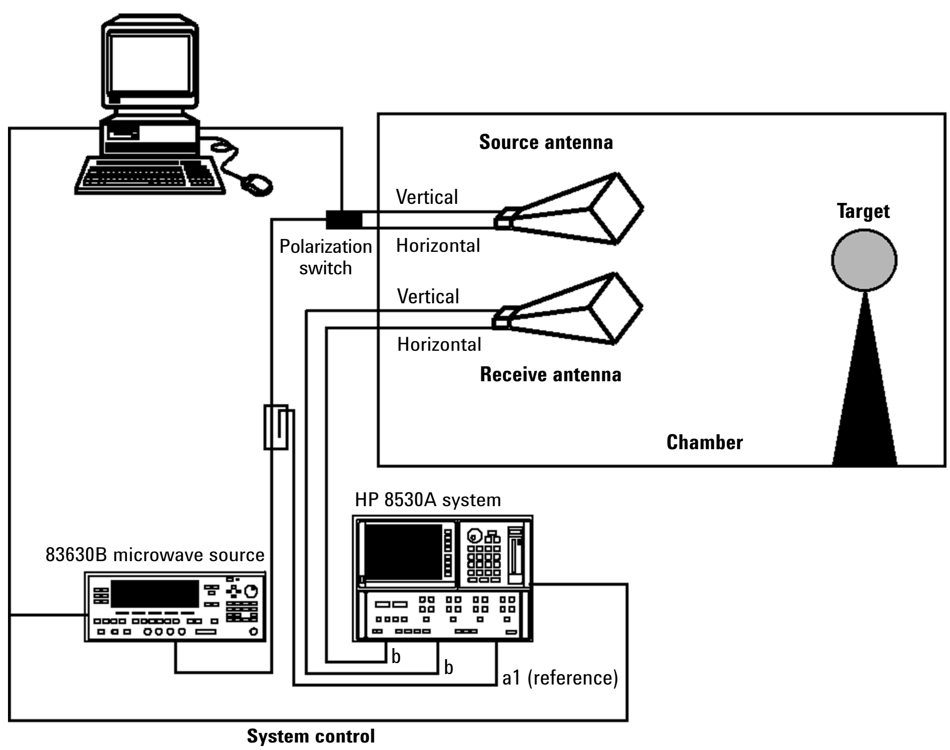


Figure 1. RCS full polarization matrix range with the HP 8530A

2.0 RCS Measurement Resolution Enhancements

When performing RCS measurements utilizing a network analyzer there are three resolution terms to be concerned with, cross-range, down-range and digital resolutions.

Cross-range resolution depends on the incremental angle of rotation of the target and is independent of the network analyzer hardware utilized.

RCS down-range resolution refers to the minimum separation between target scatters that can be resolved in the time domain impulse of the test system. The RCS down-range resolution depends on the measurement frequency span and the window that is selected on the network analyzer. The windowing feature is used to modify the frequency domain data before time domain transform. Utilizing different window shapes provides the user flexibility in modifying the resulting time domain impulse. Maximizing down-range resolution can be obtained by increasing the frequency span on the network analyzer in conjunction with the chosen window that is applied to the requency domain data prior to transforming into the time domain.

Digital resolution is defined as the ability to locate a single response in time. In other words, if only one response is present, this is how closely you can pinpoint the peak of that response. The digital response of the time domain trace is determined by the number of points measured in the frequency domain and by the time span that is displayed. One can therefore increase the digital resolution by reducing the displayed time span. This was the method commonly used on the HP 8530A because the maximum number of points that could be used was 801. On newer network analyzer platforms, such as the Agilent PNA [5 - 8], the number of points can be increased to 16,001. Therefore, digital resolution on the PNA can be increased while still maintaining the displayed time span by increasing the number of points for up to 20 times increase in digital resolution

3.0 RCS Alias-Free Range Enhancements

Alias-free range is the length of time that a measurement can be made without encountering a repetition of the desired response in the time domain. The repetition of the time domain response occurs at regular intervals and is a consequence of the frequency domain response being measured at discrete frequency intervals. To prevent aliasing during RCS measurements the alias-free range should be greater than twice the RCS chamber length. The alias free range is given by:

$$\text{Alias free range} = \frac{1}{\Delta F} = \frac{(\text{Number of points} - 1)}{\text{Frequency span}}$$

On the HP 8530A a typical measurement scenario would be:

801 points
8.2 GHz to 12.4 GHz

$$\text{Alias free range} = \frac{(801 - 1)}{(12.4 - 8{,}2)^* 10^{9}} = 190 \text{ ns or } 57 \text{ meters}$$

The length of the RCS range from the range antennas to the chamber back wall must be 28.5 meters or less (one half of alias free range). To increase the alias free range one can either increase the number of points or decrease the frequency span. Reducing the frequency span also reduces the down-range resolution which is undesirable. This was a common tradeoff when using the HP 8530A because of it's limitation of 801 points. The Agilent PNA Series network analyzer can have a maximum[1] of 16,001 points per trace providing up to 20 times increase in alias-free range at an equivalent frequency span thus not affecting the down-range resolution. In this example the length of the RCS test range could be increased to 570 meters while still maintaining an alias-free zone and maintaining the down-range resolution. RCS ranges that do not require this large alias-free range but require improved down-range resolution can increase the frequency span that is swept while utilizing the full 16,001 points. For example, if 57 meters is the desired alias-free range, the frequency span may be increased in this example from 4.2 GHz to 84 GHz again a 20 times improvement. Large frequency spans may require the utilization of multiple banded antennas.

Alias free range = 190 ns or 57 meters

$$\text{Frequency span} = \frac{(16001 - 1)}{190^* 10^{-9}} = 84 \text{ GHz}$$

1. Minimum number of points is 2.

4.0 RCS Test System Hardware Enhancements Utilizing Synthetic Time Domain

RCS measurements are made in the time domain by gathering frequency domain data and applying Fourier techniques to generate a synthetic pulse in time using a chirp-z transform. Figure 1 illustrated a typical RCS test range using an HP 8530A system. Figure 2 illustrates a similar setup but utilizing an Agilent PNA network analyzer.

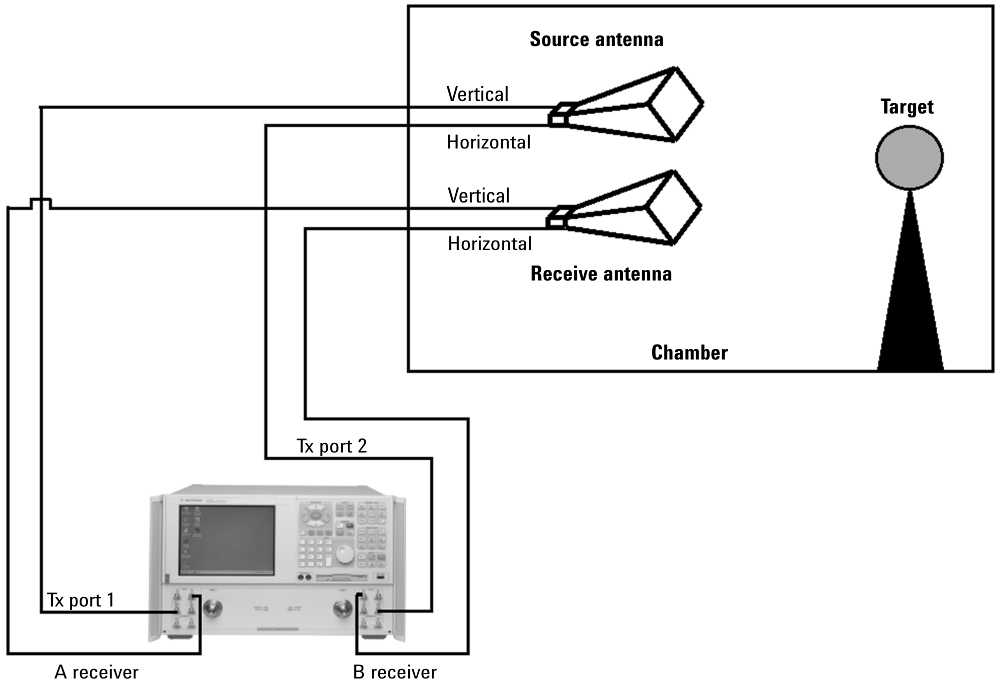


Figure 2. RCS full polarization matrix range with PNA

This newer analyzer platform has the ability to directly access various components within the analyzer as illustrated in the system block diagram of Figure 3. In our RCS example we require the source to transmit vertical and horizontal polarized fields and measure the cross and co-polarization as shown in Table 1. The analyzers, receivers and source can be independently controlled in such a way that the analyzers internal transfer switch can be used as the transmit feed polarization switch while the receive feeds are connected directly to the analyzers internal receivers. The RCS test system is configured with the vertical polarized receive antenna connected to the analyzer internal A receiver and the horizontal polarized receive antenna connected to the analyzers internal B receiver. The vertical polarized transmit feed is connected to the analyzers internal source through the source output connector on the port 1 side of the analyzers internal transfer switch while the horizontal transmit feed is connected through the source output on the port 2 side of the internal transfer switch. This configuration has eliminated the external transmit feed polarization switch and control. Also the cross and co-polarizations can be simultaneously measured during each transmit polarization because the analyzer measures the A and B receivers at the same time. Table 2 illustrates the RCS matrix and the associated measurements on the PNA.

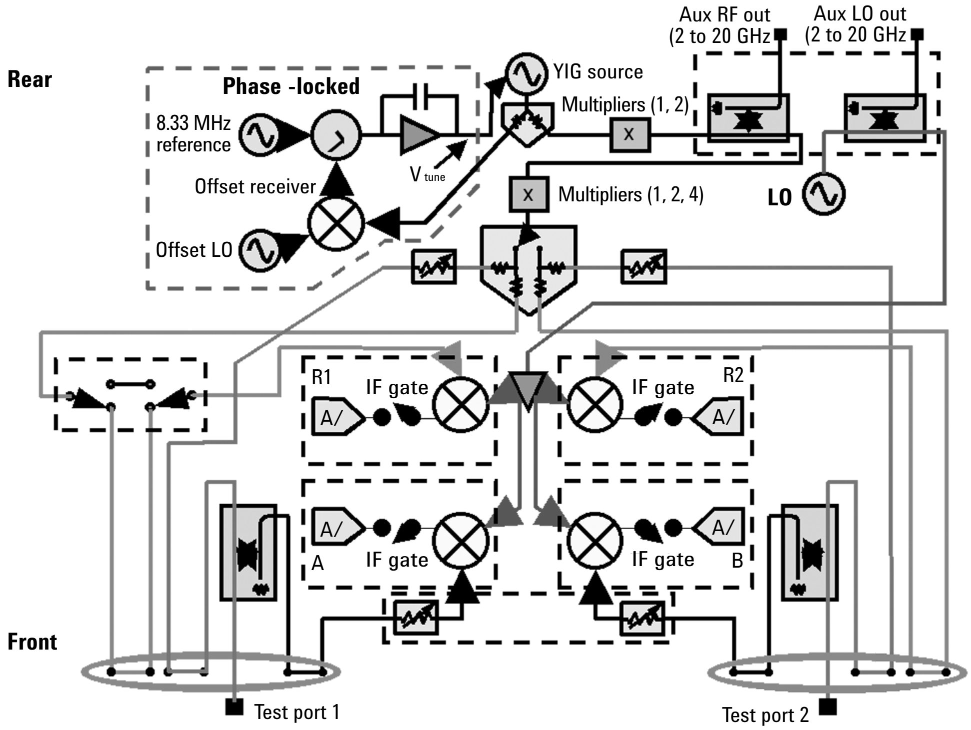


Figure 3. PNA internal block diagram (Option H11)

The PNA can simultaneously measure and display (buffer) these 4 traces with up to 16,001 points for each trace for 64,004 data points on a single display and in conjunction with its exceptional data acquisition speed has a total measurement time of 6.3 seconds or 98 us[1] per point. The network analyzers internal transfer switch isolation of better than 90 dB and receiver sensitivity of better than -120 dBm [7] provide excellent performance in RCS measurements. Table 3 summarizes a number of RCS measurement configurations comparing the HP 85301B/C systems to the PNA clearly illustrating the advantages of the PNA in advanced RCS measurements. These measurement times were measured by writing a program that ran on the PNA measuring the total sweep time for all the acquired points. This includes all components of the analyzer data acquisition [9] and is a realistic number that can be obtained in an actual RCS range configuration (includes band-crossings, external triggering, stepped mode, and transfer switch settling time).

Range gating allows the user to selectively view portions of the time domain response thus removing their effects in the time and frequency domains. The gates utilized in synthetic gating have a tradeoff between the minimum allowable gate span and the corresponding passband ripple and sidelobe levels. One must choose the appropriate gate shape that will provide the needed resolution while minimizing the sidelobe levels. This is an inherent issue when using synthetic gates.

1. 35 kHz IFBW.

Tx	Rx1	Rx2
Vertical Polarization (Source port 1)	Vertical Polarization (A/R1 trace)	Horizontal Polarization (B/R1 trace)
Horizontal Polarization (Source port 2)	Vertical Polarization (A/R2 trace)	Horizontal Polarization (B/R2 trace)

Table 2. RCS full polarization matrix utilizing PNA

Down ange resolution per polarization (points)		801	801	1601	1601	4000	16001
Cross range resolution (degrees)		±30, .25 incr. 241 scans	±30, .1 incr. 601 scans	±30, .25 incr. 241 scans	±30, .1 incr. 601 scans	±30, .1 incr. 601 scans	±30, .1 incr. 601 scans
Total number of measurement points		772,164	1,925,604	1,543,364	3,848,804	9,616,000	38,466,404
~ –98 dBm sensitivity	**PNA total measurement time 10 kHz IFBW**	3.2 min	8.1 min	5.3 min	13.1 min	27.7 min	96 min
	85301C total measurement time Ramp sweep	9.5 min	24 min	Not available	Not available	Not available	Not available
~ –113 dBm sensitivity	**PNA total measurement time 300 Hz IFBW**	21 min	54.1 min	42.2 min	105.3 min	4.3 hrs	16.9 hrs
	85301B total measurement time Step sweep	72 min	3 hrs	Not available	Not available	Not available	Not available

Table 3. RCS full polarization matrix measurement times (8.2 – 12.4 GHz)

5.0 RCS Test System Hardware Enhancements Utilizing Natural Time Domain

The Agilent PNA can be configured such that the source signal can be pulsed and the receiver's hardware gated in the time domain providing hardware gated RCS measurements. The corresponding time domain response is not derived by utilizing Fourier techniques, rather a 'natural' or 'real' pulse in time is transmitted by modulating the source signal. There are no aliasing or windowing concerns when using a non-synthetic pulse because no Fourier techniques are used. Figure 4 illustrates a typical setup where an external modulator is used to pulse the analyzers source signal. Hardware gates are placed in front of the receivers (Figure 3) providing the ability to offset the received energy from the transmit energy. By varying the time delay between the source modulator and the analyzers internal gates, a time domain plot can be created at a particular CW frequency.

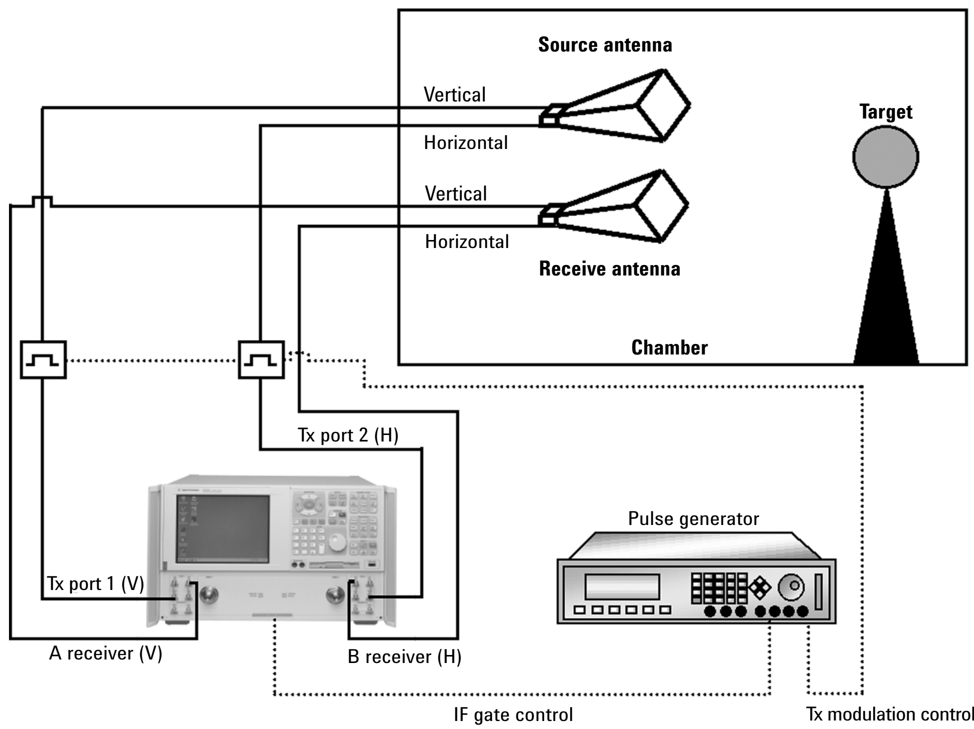
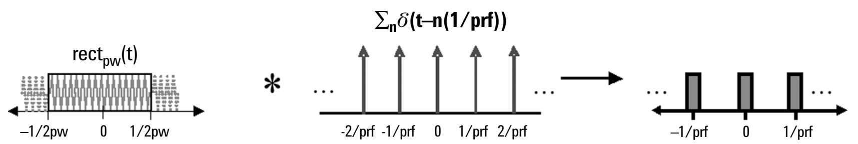


Figure 4. PNA RCS configuration utilizing hardware gating

A pulsed signal in the time domain is represented in Figure 5 illustrating the resulting frequency domain response consisting of a series of periodic tones separated n*PRF (Pulse Repetition Frequency) away from the main carrier. To accurately measure this pulsed signal utilizing a narrowband receiver architecture requires that the PRF tones are eliminated before final processing by the analyzer. One must also be aware that the 'mirror' image of the pulsed spectrum also exists mathematically in the negative frequency plane. This in conjunction with certain pulse repetition frequencies and pulse widths may cause a negative frequency plane PRF component push into the positive plane which may fall within the analyzers filter bandwidth during measurement. This will cause errors in the measurement that are undesirable. The PNA (with pulse mode option) utilizes an adaptive filter (Figure 6) that accounts for the main PRF tones as well as the negative plane crossover and any other mixing products ensuring a stable and accurate measurement [10, 11].

$$y(t) = (\mathrm{rect}_{pw}(t) \cdot x(t)) * \mathrm{shah}_{\frac{1}{prf}}(t)$$



$$Y(s) = (pw \cdot \mathrm{sinc}(pw \cdot s) * X(s)) \cdot (prf \cdot \mathrm{shah}(prf \cdot s))$$
$$Y(s) = (pw \cdot \mathrm{sinc}(pw \cdot s) \cdot (prf \cdot \mathrm{shah}(prf \cdot s))$$
$$Y(s) = \mathrm{DutyCycle} \cdot \mathrm{sinc}(pw \cdot s) \cdot \mathrm{shah}(prf \cdot s)$$

Figure 5. Time domain view of pulsed signal

Utilizing the analyzers internal gates provides up to 20 ns of resolution. If more resolution is required then external gates can be applied that provide better time resolution. Range gating can be accomplished by using the internal hardware gates to selectively gate in the time domain. Hardware gating has the added benefit over synthetic gating of no tradeoff between minimum gate span and sidelobe levels. Thus very narrow gates with very high rejection ratios can be utilized to remove unwanted RCS responses from the time and frequency domain measurements.

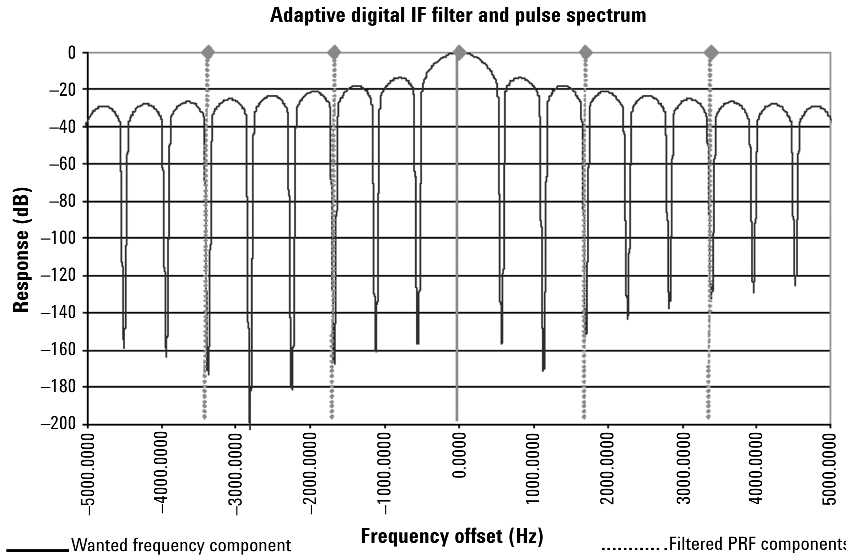


Figure 6. PNA adaptive filtering of PRF components

Conclusion

It has been shown that newer network analyzer platforms offer more flexibility, speed and accuracy for effective RCS measurements. Increasing the number of points in conjunction with advances in digital receiving hardware provides the RCS user the ability to increase accuracy while maintaining high measurement speeds. Natural and Synthetic time domain measurements and gating have been discussed and offer the RCS users maximum flexibility in RCS measurements.

10. References

[1] R. Balaberta, and Shatnu R. Mishra, *On the use of the HP 8510 Network Analyzer for Antenna Pattern Measurements,* 1986 AMTA proceedings.

[2] Dan Slater, and Greg Hindman, Nearfield Systems, Inc. *"A Low-cost, Portable Near-field Antenna Measurement System,"* 1989 AMTA proceedings.

[3] John Swanstrom and Robert Shoulders, *Pulsed Antenna Measurements with the HP 8530A Microwave Receiver,* 1994 AMTA proceedings.

[4] *85301B/C Antenna Measurement System Configuration Guide*, literature number 5967-6042E.

[5] *Antenna Test Solutions Catalog,* literature number 5968-6759E.

[6] *PNA Series RF and Microwave Network Analyzer,* brochure, literature number 5968-8472EN.

[7] A*gilent PNA Series Microwave Network Analyzers Data Sheet*, literature number 5988-7988EN.

[8] *Triggering the PNA Series Network Analyzer for Antenna Measurements,* White paper, literature number 5988-9518EN.

[9] Swanstrom, J., Puri, J., Anderson, K., Kwan, B., *Antenna and RCS Measurement Configurations Using Agilent's New PNA Network Analyzers,* 2003 AMTA Symposium.

[10] *Accurate Pulsed Measurements, Agilent PNA Microwave Network Analyzers,* literature number 5988-0563EN.

[11] Betts, L., *Make Accurate Pulsed S-Parameter Measurements*, Microwaves & RF, November 2003, Vol. 42, No. 11.

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