CHEETAH PNA RCS AND ANTENNA MEASUREMENT SYSTEM

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ABSTRACT

System Planning Corporation (SPC) is pleased to announce our new instrumentation radar measurement system denoted the Cheetah radar line. This radar system is based around the new Agilent PNA series of network analyzers. The PNA operates from 0.1 to 67 GHz and is utilized for making gated CW or CW RCS and Antenna measurements. The PNA has a built in synthesizer that allows the unit to be used without costly external synthesizers and external mixers. The PNA also has four identical receiving channels, two signal and two reference, that permit simultaneous co and cross pol measurements to be made. PNA IF bandwidth is selectable from 1 Hz to 40 kHz to optimize measurement sensitivity, dynamic range and speed. Using the segmented sweep feature of the PNA a single frequency sweep can be broken into segments, to further optimize the sensitivity, dynamic range, and speed. Each segment can have its own start and stop frequency, frequency step size, IF BW and power level. SPC has developed the high speed RF gating, low noise RF preamplifiers and high speed digital timing system, which allow maximum sensitivity, full up gated CW or CW radar measurements using the PNA. SPC has coupled the system to the CompuQuest 1541 RCS and Antenna Data Acquisition and Data Analysis Processing Software. This exciting new product line offers reduced cost and improved performance over current network analyzer based systems using the HP 8530, 8510, etc. Performance improvements are in the reduced noise figure, sensitivity, dynamic range and measurement speed. Measurement speeds are increased by at least a magnitude of order over the older systems and in some cases a couple of orders of magnitude.

Keywords: RCS Measurements, Antenna Measurements, Radar Cross Section, Performance Network Analyzer

1.0 Introduction

This paper describes the latest development in low cost gated CW and CW RCS and Antenna Measurement Systems. The system is based around the new Agilent Performance Network Analyzer (PNA), which operates from 0.1-67 GHz. Hardware gating is derived using a high-speed pulse modulator switch after a high power solid state or TWT amplifier or by grid modulation of a TWT. T/R switching or circulators are provided to allow for a monostatic RCS antenna configuration if it is required. The receive side of the system provides a high speed reverberation/isolation switch, low noise preamplifier (LNA), range gate switch, and a second LNA if the line losses from the antenna to the PNA are too great. The software control is provided by the CompuQuest Quest 1541 Data Acquisition and Data Analysis Processing system.

Low cost RCS and Antenna measurement systems in the past have relied on network analyzers such as the HP8510, HP8530, and other earlier analyzers. In addition, custom solutions have been provided by multiple vendors. Typically these solutions led to costly implementations due to the fact that the analyzers do not have built in frequency synthesizers. The PNA has a built in synthesizer that greatly reduces the switching time between frequencies, thus allowing faster measurements and a lower cost. Also no external mixers are required for a typical installation. A picture of the PNA is shown in Figure 1.

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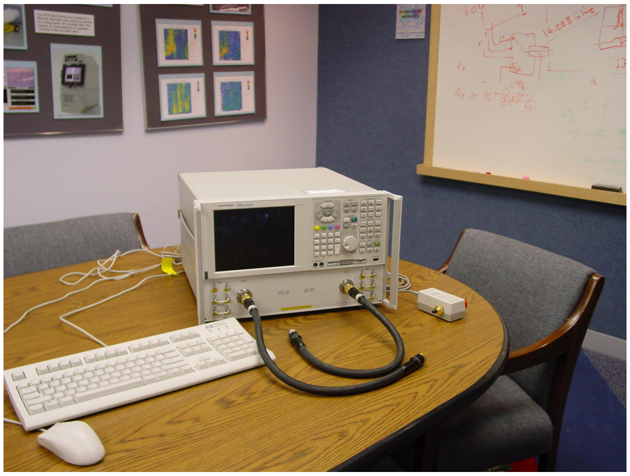

Figure 1 Agilent PNA Unit

The Quest 1541 Data Acquisition and Data Analysis Processing system provides the operator complete control of the radar. Eight real-time plots are available for RCS and Antenna measurements ranging from simple line plots to full 3-D images.

SPC entered into the Agilent Channel Partner Program in February of 2003. This program allows SPC direct access to Agilent engineers to acquire detailed engineering information regarding the PNA. In addition, it allows SPC to pass back to Agilent suggestions for upgrades and changes that might be required to support this product line and customer requirements.

2.0 What Is The Cheetah Radar System

The Cheetah radar system is a customized use of the PNA system for making RCS and Antenna measurements. A typical configuration is shown in Figure 2. As can be seen in the figure, the system consists of a Data Collection and Processing Computer, the PNA, a RF Electronics Head, a Digital Pulse Generator, and transmit/receive antennas. The PNA is configured for the final RF frequencies required in the measurements as are the components in the RF Electronic Head. The Digital Pulse Generator can operate up to 5 MHz PRF with pulsewidths as low as a few nanoseconds.

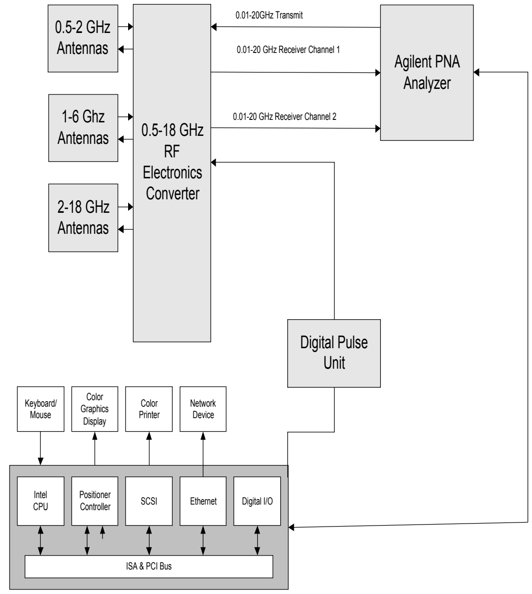

Figure 2 – Cheetah Radar System

The standard digital pulse timing unit provides up to 4 timing signals that can be used to control the transmit pulse switch, the T/R switch and the range gate switch. If more than 4 timing signals are required, a second unit can be installed to provide up to 8 signals. The unit is under IEEE-488 control from the computer system. All of the timing signals are independent with control of both the delay and width. This unit provides all of the high speed timing requirements in a typical system. For slow speed timing, e.g., polarization switching, antenna switching, a DIO card is installed in the control computer, which then tells these switches what position to be in at the appropriate time. The RF high power amplifiers can be configured in a variety of ways to meet the specific customer requirements. Typically from 2-18 GHz a single amplifier can provide +23 dBm, and if broken into standard bands (2-4, 4-8, and 8-18) up to 10 watts can be provided in solid-state amplifiers. For very high power systems, TWT amplifiers can be used.

3. The Agilent PNA Network Analyzer

In approximately 2001, Agilent introduced the PNA as the 'A' model. The system has the following options for frequency coverage: 10 MHz to 20 GHz. 10 MHz to 40 GHz, 10 MHz to 50 GHz, and 10 MHz to 67 GHz. In 2002, the 'B' version was introduced, which allowed its use as the basis for RCS and Antenna Measurement Systems. The PNA will be discussed from a number of system level specifications that impact these types of measurements. These include: (1) Dynamic Range, (2) Noise Floor, (3) Timing, and (4) the built in synthesizer.

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In order to maximize the units' performance, Option 014 – Configurable test set is provided. This allows direct independent access to the 4 identical PNA test signal and reference receivers by bypassing the normal couplers in the PNA front end, which eliminates the coupling loss of 12-15 dB, and increases dynamic range by 12–15 dB.

The Dynamic Range achievable with the receiver is then based on examination of the performance with Option 14. This performance with 10 Hz IF bandwidth and no averaging (coherent integration) is shown in the following table as measured at the direct receiver access input ports.

Frequency Range	Dynamic Range (Typical dB)[1]
10 MHz to 45 MHz	118
45 to 500 MHz	117
500 MHz to 2 GHz	123
2 to 10 GHz	122
10 to 20 GHz	124
20 to 40 GHz	110
40 to 45 GHz	107
45 to 50 GHz	105

Next the specified PNA noise floor is shown at the same 10 Hz IF Bandwidth with no averaging.

Frequency Range	Direct Receiver Access Input Noise Floor (Typical dBm)[1]
10 MHz to 45 MHz	<128
45 to 500 MHz	<127
500 MHz to 2 GHz	<133
2 to 10 GHz	<132
10 to 20 GHz	<134
20 to 40 GHz	<125
40 to 50 GHz	<123

For RCS and Antenna Measurements, the ultimate Cheetah system dynamic range and noise floor sensitivity are limited by the high noise figure of the PNA. This is overcome by the use of low noise amplifiers (LNA's) preceding the input of the PNA. The Cheetah receiver Noise Figure is held to within a few tenths of a dB of the low noise RF preamp NF for the best possible sensitivity. The PNA Timing is defined in three categories: (1) IF Bandwidth, (2) Synthesizer, and (3) Data transfer time.

The IF Bandwidth (IFBW) is provided by digital filters in the instrument and range from 1 Hz to 40 kHz in 28 steps. This is a major departure from the previous analyzers in that this was provided by an analog filter and only a single choice was provided. The PNA utilizes a relatively high speed A/D converter to sample the signal at a high data rate for input into the digital filter, which then creates a 'single sample' for the operator. For most practical purposes, 1/IFBW computes the time required for the filter to provide this sample.

The built-in synthesizer is another major change in the PNA from previous units. This synthesizer is fast compared to the older HP and Agilent units, but not as fast as the more expensive units offered from other vendors. The time for the synthesizer is comprised of a number of factors that all sum into the final calculation. These factors are: frequency stepping time, settling time, band crossings, and retrace. The frequency stepping time in step mode is a fixed value based on the PNA source rate times the frequency step size. The settling time is approximately equal to the stepping time. Band crossings require a longer amount of time. There are 25 bands up to 50 GHz. Retrace occurs with about the same speed as the frequency stepping.

The last factor in the PNA timing is the Data Transfer time. There are four different options available in the PNA: SCPI over GPIB, SCPI, COM, and DCOM over LAN. For 201 data points, the numbers range from 1ms to 7 ms. One area of note, the PNA must be read on a sweep by sweep basis. If the data is not read prior to the start of the next sweep, then the previous sweeps data will be overwritten. Double buffering can be setup to avoid this happening assuming that the data from sweep N can be read by the time sweep N+1 is complete.

The built-in synthesizer provides the following characteristics[1].

Phase Noise (10 kHz offset from center frequency, nominal power)	
10 MHz to 45 MHz	-70 dBc typical
45 MHz to 10 GHz	-70 dBc typical
10 to 20 GHz	-65 dBc typical
20 to 40 GHz	-55 dBc typical
40 to 50 GHz	-55 dBc typical
Harmonics (2nd or 3rd)	-23 dBc typical at max power
Non-harmonic spurious (at nominal output power)	For offset frequency >1 kHz
10 MHz to 45 MHz	-50 dBc typical
45 MHz to 20 GHz	-50 dBc typical
20 to 40 GHz	-30 dBc typical
40 to 50 GHz	-30 dBc typical

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Certainly the advantageous aspect of the built-in synthesizer is that the PNA does not require an external synthesizer in order to speed up the measurements. For extended antenna measurements, their may be the desire to use an external synthesizer for remote mixing to allow for long cable runs that do not need to operate over the RF bandwidth that may be required. The Cheetah system allows for this configuration.

4. Cheetah Noise Figure Measurements

This section discusses the means of achieving a low noise figure with the Cheetah system. As noted in section 3, the PNA has a relatively high noise figure as a stand-alone instrument. No sensitive RCS measurement configurations using network analyzers like the PNA use the analyzer input directly, low noise preamplifier(s) are always provided. The following discussion assumes a high sensitivity Receiver is required for RCS and/or Antenna measurements. Typically the RF front end of the Cheetah may contain the following items: Polarization select switch, reverberation switch, LNA, receive gate switch, and line amplifier. All of these components add to the total system noise figure plus loss front end calculation. These parts may have high RF bandwidth, say 2-18 GHz, and ultimately set the noise figure of the Cheetah. A good choice for an LNA is a unit manufactured by Miteq. This amplifier has a 2.3 dB noise figure from 100 MHz to 18 GHz.

In order to calculate the expected noise figure of the system, a spreadsheet is used to calculate the noise figure of the Cheetah receiver. The Cheetah receiver configuration consists of a low noise preamplifier (LNA) followed by the receiver range gate and a 2nd LNA if required to overcome line losses to the PNA receiver input. A well designed gated-CW system like Cheetah provides a low noise preamplifier and the necessary front-end gain so that the Cheetah receiver NF is nearly equal to the NF of the preamplifier. This provides the maximum theoretical receiver sensitivity achievable. This is fully analyzed and described in Ref 2.

SPC configured the PNA as a typical demonstration Cheetah receiver system. with a LNA , the receive gate switch, a line amplifier and simulated cable loss in order to make and verify noise figure measurements, verify noise floor sensitivity and verify gated CW noise floor performance A calibrated noise diode source was used to drive the LNA. In addition, in order to measure the noise floor in dBm, the PNA needs to be calibrated utilizing the Agilent recommended procedure. This was done. Next the measurements were taken utilizing the "Y" factor method to measure and compute the noise figure of the system. In this case the PNA, LNAs, receive gate and cable losses that were used resulted in a theoretical noise figure of 1.87dB. Based on this, the measured Cheetah receiver noise figure was 1.94 dB on one measurement and 2.13 dB on a second measurement. This demonstration system verified that near theoretical NF improvement can be achieved using low noise preamps with the PNA. The PNA IF bandwidth was set at 700 Hz. The absolute measured noise floor on the calibrated PNA output display was –143 dBm. This was within a half dB of the theoretical expected results using a nominal 2 dB for the measured Cheetah NF. A PRF of 5 MHz and receive gated pulse width of 28 nsec were used. This is a duty factor of 0.14 or –8.54 dB. When the receive gate was turned on the Cheetah receiver noise floor dropped –8.5 db as it should theoretically.

During this demonstration angle triggers from an azimuth positioner were simulated in real time from a pulse generator and used to trigger the external input trigger on the PNA to initiate a stepped frequency segmented sweep type waveform. Several bandwidths were used during each 2 to 18 GHz sweep. Calculated and measured measurement times agreed closely.

System sensitivity results are not presented in this paper due to the fact that they are based on the final transmit powers, xmit/receive/antenna cable losses, T/R, reverberation switch, antenna gains, and range to the target etc. These are computed based on a particular range configuration.

5. Cheetah System Measurement Timing

In order to calculate the Cheetah timing, a typical RCS measurement scenario is generated below. This scenario is as follows:
Azimuth Span: 360 degrees, at fixed elevation angle
Azimuth Increment: 0.1 degrees steps
Frequency Span: 2 to 18 GHz
Frequency Increment: 50 MHz steps
IF Bandwidth: 10 KHz from 2 - 5.8 GHz; 2KHz from 5.8- 18 GHz. Use segmented sweep.
Averaging: None
Full Polarization Matrix HH, HV, VV, VH
Simultaneous Dual Receiver Channels
Measurement Channels; CH 1: HH & HV; CH 2: VV & VH.

Therefore, there will be 16 GHz/50 MHz = 321 frequency steps times 2 pols = 642 steps at each azimuth increment and 360/0.1 +1 = 3601 azimuth steps.

Expected Measurement Times

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One Single 2-18 GHz Frequency Sweep = .35 seconds
Total Scenario Time for 360 degree azimuth sweep = 41.7 minutes.

6. Cheetah Control and Processing Software

For the Cheetah system, SPC selected CompuQuest for providing the control and processing software. This is due to the fact that they have provided the Quest 1541 software package for numerous network analyzer (HP 8510, HP 8530, HP 8720, HP 8757, and HP 8566) applications and other radars (SA2090 and SA1790) systems. The Quest 1541 provides RCS and Antenna measurements in real-time as well as post processing of the data. The Quest 1541 software provides up to eight (8) separate real-time displays for data monitoring during a data acquisition. Each plot is individually defined and can be displayed either in its own window (grid) or overplotted onto an existing grid. The overplot window can be from the current acquisition or a previous acquisition or a post processing analysis for comparisons with archive data. The available plot types for any given acquisition is dependent on the data that is being acquired (stationary, rotating, single frequency, multi-frequency, etc.). The list of possibilities include:

RCS /Antenna Gain vs. Azimuth or Elevation

RCS/Antenna Gain vs. Frequency

RCS/Antenna Gain vs. Downrange (1D FFT)

RCS/Antenna Gain vs. Frequency vs. Azimuth or Elevation

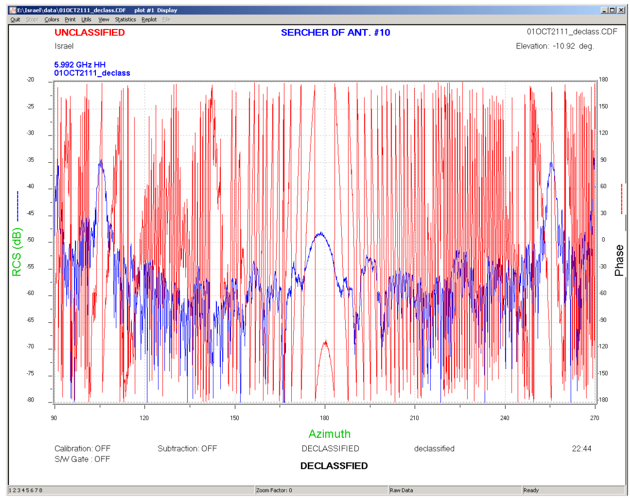
RCS/Antenna Gain vs. Downrange vs. Azimuth or Elevation

RCS/Antenna Gain vs. Azimuth vs. Elevation

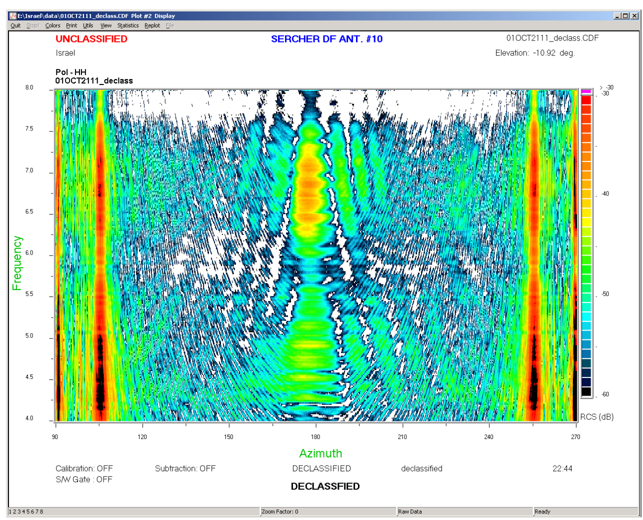
ISAR Image

In addition to RCS returns for the real-time displays, the operator can choose to monitor the phase returns instead. If only a single plot is enabled and 2D ISAR Image is selected for the plot type, the operator can use to either define an angle to perform the image at, or to continuously create non-overlapping images as fast as an aperture of data becomes available. If multiple plots are enabled for an acquisition, and 2D ISAR Images are selected as the plot types, the operator can only define single angles for each of the plots (images). This does allow for overlapping images as each plot is independent of the others and has an image angle separately defined.

When a data acquisition ends, the real-time displays can be printed to the attached hardcopy device or saved to disk as a BMP or JPEG graphics file. Each plot is fully annotated with user-defined labels. A line plot showing antenna gain and phase on the same plot is shown in the following figure. Following this figure is a pixel plot showing a 3D plot.



Antenna Gain and Phase vs. Azimuth Plot Format



Pixel Format for 3D Plot

The Quest 1541 controls the PNA using the DCOM LAN connection. This provides the fastest possible communication path to the PNA from the control computer. Communication to the high-speed digital pulse unit is via the IEEE-488 bus. Slow switches are controlled via a DIO card residing in the computer. Target Positioning Control is implemented through the IEEE-488 bus. Typical controllers are the Orbit 4806 series and Scientific Atlanta units.

The Quest 1541 allows for triggering either from the Positioner Controller or by examination of the target position data. The Cheetah Radar Control Software includes a series of built-in test (BIT) diagnostics that can be used to verify the proper functioning of the radar system. A list of those diagnostics that can be operator initiated and no changes need to be made to the Cheetah system are as follows:

Transmit Pulse Diagnostic

HPA Loop Mode Diagnostic

RF Switch Timing Diagnostic

Stability Test

A/D Converter Diagnostic

Pulsewidth Diagnostic

Noise Floor Diagnostic

PNA Status

- Phase Unlock
- Unleveled
- Overpower
- EE Write Failed
- YIG Cal Failed
- Ramp Cal Failed
- Over Temp

The second list shows diagnostics that can be operator initiated, but require changes to the Cheetah hardware configuration with test equipment and/or RF parts.

Noise Floor Calibration

Linearity

Transmit Power

PNA Diagnostics.

If there is a problem with the PNA, then the standard diagnostics of the PNA may be exercised to locate the problem.

The data displayed in real-time can be either calibrated or uncalibrated. The collection software provides for calibration against standard type targets, or from custom targets where the response is known as RCS versus frequency or as a lambda dependency.

Background subtraction is provided via two methods. (1) Chamber background data can be applied in the real-time processing or background blocks can be collected and optionally contain background subtraction vectors for post-processing of data. (2) A real-time loop mode is provided that allows monitoring of the RF front end and can be applied to the data in real-time. This allows for system background subtraction of 40 dB or greater in real-time.

7. Reliability

The mean-time-between-failure (MTBF) for the Cheetah is predicted to be excellent. This is based on the following information.

MTBF for PNA: 40,000 hours (Agilent prediction)
MTBF for Digital Pulse Unit: No specific data is available, but the company states that the reliability is great and that they have very few service calls on a few thousand units that have been sold.

MTBF for RF: Again very good. The parts are either like or similar to parts used in the SPC MkV system. Over the last 5 years, there have been two failures on 17 systems, which equates to an approximate MTBF of 21,900 hours.
Thus, the total MTBF is predicted to be on the order of 14,152 hours. This number is pessimistic and should get better as systems are delivered and utilized such that we can analyze the data.

7. Summary

With the introduction of the Agilent PNA network analyzer, new faster RCS and Antenna Measurement systems can be fielded, which greatly increase the current capabilities of this market arena. SPC has taken the steps required to design and produce high power transmit and low noise receiving RF and high speed timing system front end heads that take advantage of these new capabilities. Coupling to the CompuQuest Quest 1541 Real Time Data Acquisition and Analysis software package allows the user to collect, display and process the data into meaningful plots.

The PNA provides numerous new capabilities that were not available with the previous network analyzer configurations. Flexible IF Bandwidth allows more custom implementations for achieving sensitivity without sacrificing as much time. Flexible IF Bandwidth coupled with PNA segmented frequency sweep modes and independent measurement channels allow the optimization of frequency sampling, sensitivity, dynamic range, and measurement times. The instrument has high dynamic range over a very broad frequency coverage. Most significant is the new built-in synthesizer, which

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allows for reasonably fast measurements without the need for an external synthesizer.

Custom Cheetah configurations can be easily implemented for frequency coverage, transmit power, antenna selection, and polarization select. Predicted reliability is much higher than existing systems due to the new RF components available as well as the high reliability of the PNA. All of these factors lead to a low cost, high capability RCS and Antenna Measurement System.

SPC as the system designer, integrator and installer will also provide long term support for the Cheetah systems. The standard warranty for the system is one year with extension to three years. SPC 's field support group then maintains the system based on the type of service required. Software maintenance is provided through CompuQuest.

8. REFERENCES

[1] Agilent PNA Series Microwave Network Analyzers, Data Sheet 5988-7988EN, 16 September 2002, Agilent Technologies Inc., PO Box 4026, Englewood Co (800)-452-4844

[2] Sensitivity Performance Analysis, Pulsed Wideband IF Versus Gated-CW Radars, circa 1991. Thomas Thompson and Andreas Schultheis. System Planning Corporation, 3601 Wilson Blvd., Arlington, VA. 22201, (703) 351-8656

9. ACKNOWLEDGMENTS

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