# HOW TO SPECIFY AN RF SYSTEM FOR ANTENNA MEASUREMENTS

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## Abstract

Antenna measurement systems have unique requirements, which must be properly evaluated and understood in order for the antenna engineer to be successful in specifying an RF system that meets his needs. Antennas are characterized by specific operating and performance parameters that will determine the requirements for a measurement system. Aperture size, frequency range, bandwidth, side-lobe nulls, beamwidth, and polarization characteristics are a just few of the more important parameters. As with most engineering problems, system performance often requires a trade-off of equally important, but conflicting characteristics. Sensitivity and measurement time are well-known examples of this trade-off. Other examples include local vs remote mixers, receiver speed vs sensitivity, range size vs system dynamic range, and there are many others. The antenna engineer must be able to identify his most important system performance parameters in order to make compromises with confidence, since they are inevitably required. Once the system performance requirements have been determined, the antenna engineer can begin to select equipment, cables and components with the desired performance characteristics for his range.

This paper will describe the process for analyzing requirements, performing system trade-offs and specifying equipment and components for several antenna measurement system types.

Keywords: Antenna Measurements, Near-field, Far-field, Microwave Receiver, Microwave Synthesizer, Harmonic Mixers, Multipliers, Couplers, Attenuators, Isolations, Amplifiers, Dynamic Range, Sensitivity, Leakage, Crosstalk, Compression.

## 1.0 Introduction

This paper describes the process for specifying an RF system for antenna measurements, and includes the following sections:

- Identifying Requirements
- Analyzing Performance
- System Tradeoffs
- Equipment and Components
- Performance Verification
- Summary

## 2.0 Identifying Requirements

The type and size of the antenna under test (AUT) will largely determine the technique employed in the antenna measurement system. Common techniques include planar, cylindrical or spherical near-field and far-field or compact range systems [1]. Selection of the RF system may appear to be independent of the measurement technique used, since it is driven more by the frequency range, sidelobe levels, cross-polarization, and other electrical characteristics of the AUT. The choice of measurement technique, however, directly impacts the performance of the system by influencing the range length and, therefore, the RF cable lengths. Long RF cables increase the loss budget and detract from the overall ability of the system to measure low sidelobe levels [2]. Similarly, the electrical requirements may influence the measurement technique chosen. A very high frequency AUT may require a shorter range to minimize cable or wave-guide loss.

The above discussion illustrates one of the inter-dependencies involved in specifying an antenna measurement system, and highlights the need for a systematic approach to identifying and analyzing system requirements before settling on a particular measurement technique or a specific RF system configuration. Antenna parameters of interest, a few of which are shown in Figure 1, include gain, directivity, antenna pattern, sidelobes, polarization, VSWR, bandwidth, pointing accuracy and efficiency.

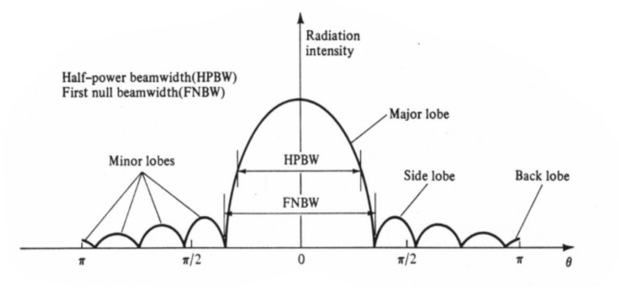


**Figure 1 Typical Antenna Parameters**

Before attempting to design a system to measure these parameters, an understanding of the measurement technique used and the performance characteristics of the components and equipment being considered must be attained.

Other than simply measuring antenna parameters, most RF systems will have additional requirements including accuracy, dynamic range, sensitivity, polarization, multiple AUT ports, multiple frequencies, pulse mode, receiver speed [3], synthesizer settling time, and overall test measurement time. Table 1 shows an example of a configuration form for identifying important system requirements.

**Table 1 AUT Configuration Form**

| | |
|---|---|
| Type of AUT: | *Circular phased array* |
| AUT height: | *1 m* |
| AUT width: | *1 m* |
| AUT weight: | *150 lbs* |
| AUT gain: | *30 dB* |
| AUT side-lobe levels | *-40 dB* |
| Frequency range: | *8 – 12 GHz* |
| Polarization (linear/CP): | *dual circular* |
| No. of AUT ports: | *4* |
| No. of polarization ports: | *2* |

Each of the system requirements should be ranked in order of importance to the overall goal and purpose of the measurement system. Understanding the relative importance of each requirement will greatly assist in determining how to proceed in analyzing performance, performing tradeoffs and selecting equipment, cables and components.

## 3.0 Analyzing Performance

Measurement system performance is determined by a combination of range configuration, equipment selection, cables and components. Each cable, coupler, attenuator and adapter in the RF signal path must be analyzed for its performance over the frequency range of interest. The weakest link in the chain will determine the performance, or degradation, of the entire system. Other parameters that should also be evaluated include VSWR, leakage and power handling characteristics. A block diagram, as shown in Figure 2, is a useful aid in illustrating the selection of equipment and the arrangement of components to maximize system performance.

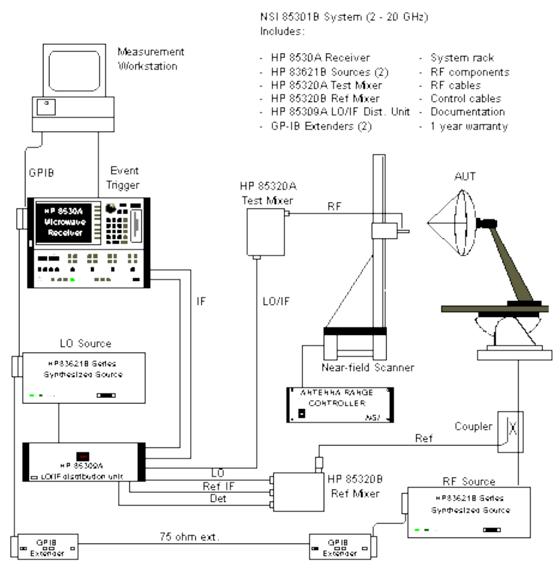


**Figure 2 Typical RF System Block Diagram**

A system power budget, as shown in Figure 3, is an essential tool in analyzing the effects of component and cable loss on overall system performance. Synthesizers, amplifiers and mixer compression levels can also be included in the analysis. Use of a spreadsheet or similar tool allows the system engineer to quickly test alternatives and determine the impact of changes on system performance. Error bounds and component power damage levels should also be included in the model.

| Freq. GHz >>> | 2.00 | 4.00 | 8.00 | 12.00 | 18.00 |
|---|---|---|---|---|---|
| Output power | +10.00 | +10.00 | +10.00 | +10.00 | +10.00 |
| 10 ft cable to coupler | -1.56 | -2.22 | -3.17 | -3.90 | -4.82 |
| coupler loss | -3.00 | -3.00 | -3.00 | -3.00 | -3.00 |
| 40 ft RF cable to Probe | -5.74 | -8.17 | -11.65 | -14.37 | -17.75 |
| Probe Gain | +6.00 | +6.00 | +6.00 | +6.00 | +6.00 |
| AUT Gain | +6.00 | +6.00 | +6.00 | +6.00 | +6.00 |
| Received Power at AUT | -0.30 | -3.39 | -7.82 | -11.27 | -15.56 |
| 40 ft RF cable to mixer | -5.74 | -8.17 | -11.65 | -14.37 | -17.75 |
| Attenuator at Input to test mixer | -20.00 | -20.00 | -10.00 | - | - |
| Power Level at Input to Test Mixer | -26.04 | -31.56 | -29.48 | -25.65 | -33.31 |
| Specified Noise Floor (10 KHz IF BW) | -110.00 | -110.00 | -110.00 | -110.00 | -110.00 |
| Specified 0.1 dB Comp. Power | -24.00 | -24.00 | -24.00 | -24.00 | -24.00 |
| **Measurement S/N Level, dB** | **84.0** | **78.4** | **80.5** | **84.4** | **76.7** |

**Figure 3 Typical RF System Power Budget**

For systems that cover a wide range of frequencies, connector compatibility is an issue that must be addressed. For example, SMA, 3.5mm and 2.9mm connectors are all compatible, but cover different frequency bands and have different mechanical tolerances and reliability characteristics. Figure 4 shows the frequency ranges covered by commonly used microwave coaxial connectors.

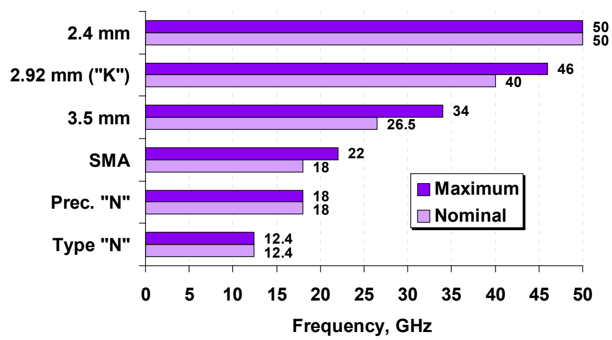


**Figure 4 Commonly Used Coaxial Connectors**

Figure 5 gives an idea of the compatibility between connector types. The asterisk shows the combinations that risk damage due to tolerance mismatch. In general, SMA connectors are low in cost, but 3.5mm connectors with higher precision tolerances have higher reliability and better repeatability.

Dynamic effects on components that move during test should also be analyzed to determine amplitude and phase stability. Rotary joints are commonly used to handle an RF signal path that must cross a moving rotary stage boundary. The rotary joints selected must have a high degree of amplitude and phase stability over the frequency range of the signal path.

| | Male (Plug) | | | | |
|---|---|---|---|---|---|
| **Female (Jack)** | **"N"** | **SMA** | **3.5 mm** | **2.92 mm** | **2.4 mm** |
| **"N"** | YES | NO | NO | NO | NO |
| **SMA** | NO | YES* | YES | YES | NO |
| **3.5 mm** | NO | YES* | YES | YES | NO |
| **2.92 mm** | NO | YES* | YES | YES | NO |
| **2.4 mm** | NO | NO | NO | NO | YES |

*Risk of Damage

**Figure 5 Coaxial Connector Compatibility**

Cable tracks are also used to handle RF cables that must be routed to a moving probe on a planar or cylindrical near-field scanner. The flex characteristics of an RF cable in motion must be well understood in order to expect a high degree of accuracy in the measurement. For example, a single cable is needed to carry a phase reference signal between a moving probe antenna and stationary RF equipment, irrespective of whether the probe is used for transmitting or receiving [1]. A variety of methods have been used to carry the phase reference cable including flexible cable, rotary joints, free-space RF, fiber-optic cable and measurement of the electrical cable length. Phase reference cables are discussed in reference 1.

Thermal stability should also be considered for the RF system. For large ranges, a small temperature change over the measurement time may result in a significant change in RF path length and resulting phase noise. Thermal stability of $\pm 1°$ F is often required for large ranges. Thermal stability is also discussed in reference 1.

Analyzing system performance is always an iterative process. A change in cables or components to improve flex characteristics, for example, may require one to reconsider a previous choice of synthesizer, mixer [4] or amplifier. The system analysis phase should be done very early in the system development process, since cost and delivery are also prime considerations. The process of determining the optimal selection of equipment involves a number of engineering tradeoffs that will be discussed in the following section.

## 4.0 System Tradeoffs

System tradeoffs are sometimes performed during the performance analysis phase, but the wrong choice can easily be made if all the data is not known, or if the analysis is not complete. Often decisions can be made without extensive analysis through the use of a simple decision tree, as shown in Figure 6.

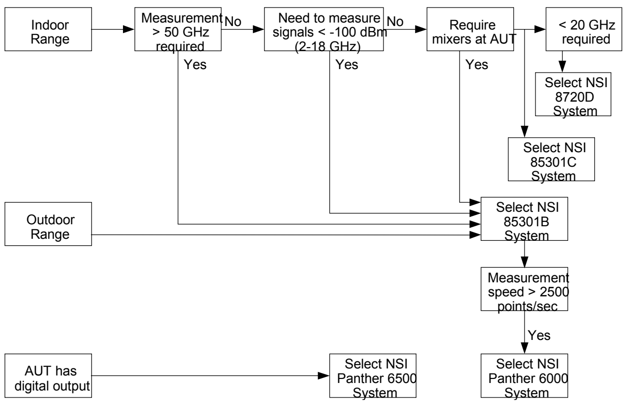


**Figure 6 System Decision Diagram (Example)**

Standard system configurations can also aid in the decision process. Figure 7 shows how a standard NSI 85301B can be adapted to cover a wide range of frequencies and also be upgraded to handle pulsed, millimeter wave and many other types of measurements.

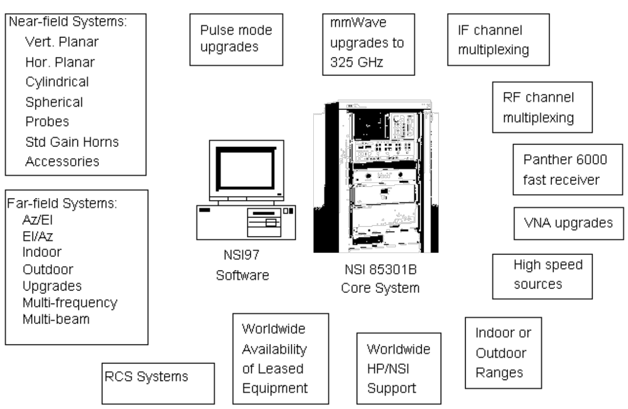


**Figure 7 Standard RF System Configuration**

Each addition or change to even a "standard" system configuration requires the system engineer to re-evaluate the impact on system performance. Figure 8 compares the performance specifications of a few of the standard NSI system configurations.

| Standard Configuration (1) | Sensitivity (S/N=1, avgs=0) dBm (2) | Dynamic Range dB | Measurement Speed, pts/sec (3) |
|---|---|---|---|
| NSI 8720D | -90 | 98 | 1200 |
| NSI 85301C | -98 | 88 | 5000 |
| NSI 85301B | -113 | 89 | 5000 |
| NSI 6000 Panther | -90 | 68 | 80,000 |

1. Specifications are typical, 8 - 18 GHz. Performance varies with configuration and frequency range of operation.
2. Sensitivity is defined as signal = noise. Averaging will improve sensitivity by 10 Log (No. Averages)
3. Panther speeds include beam setup time and assume high speed devices.

**Figure 8 RF System Performance Comparison**

Determining RF system performance is an important task, but one cannot ignore system automation, reliability, maintenance and supportability issues. With the advent of low cost PCs, system automation is almost taken for granted, however, the integration of reliable equipment drivers with the antenna measurement software should be examined closely. The ability to design custom software applications for production and test support is also important for a high quality, repeatable manufacturing environment.

Equipment reliability should be an assumed characteristic for offerings from the leading suppliers, however, make sure that the features that you are requesting for automated antenna tests are fully tested and dependable in the environment you require. Some equipment may be used primarily for bench-top testing in an R&D environment and could be under-validated for the automated production environment.

Maintenance and support are important issues that should be addressed during the requirements analysis phase. Providing spares for each element of the measurement system may be cost prohibitive, so the most reliable equipment available for the application should be selected. Spares of lower cost system components, especially those that degrade with use, i.e. rotary joints and flex cables, should definitely be required.

Support of equipment in the event of failure and for periodic calibration of primary equipment elements are requirements that should be considered. Support during system installation and critical system operations may also be required depending upon the capabilities of the operators.

Once the primary system requirements have been identified, analyzed and system tradeoffs have been completed, the engineer can begin to examine and select equipment, cables and components that will meet his requirements. A few of these are discussed in Section 5.0.

## 5.0 Equipment and Components

This section will discuss the primary considerations for selecting the receiver, synthesizer, mixers and cables for the RF system. A detailed discussion of microwave instrumentation is provided in references [1] and [4].

The microwave receiver is one of the primary components that determine the overall system performance. The ability of the receiver to provide highly accurate and linear amplitude and phase measurements over a wide dynamic range and down to very low signal levels is extremely important for many antenna measurement applications. The Agilent 8530A, shown in Figure 9, is an example of a high performance receiver that is used in many automated antenna applications.

**Figure 9 Agilent 8530A Microwave Receiver**

Recently developed for high-speed measurements, the NSI Panther 6000 receiver [3] is capable of 80,000 amplitude and phase measurements per second, compared with 2500 equivalent measurements per second for the Agilent 8530A. The Panther 6000 high-speed receiver, including the high-speed beam controller (HSBC) is shown in Figure 10.

**Figure 10 NSI Panther 6000 High Speed Receiver**

Synthesizers will determine the frequency range of operation, output power level and speed with which multiple frequency measurements can be performed. The Agilent 8360 series synthesizers provide direct frequency synthesis up to 50 GHz while providing a stepped frequency list mode that can switch between frequencies at approximately 5 ms + 5 ms/GHz. The Agilent E6432, shown in Figure 11, is a new VXI module that provides a very fast list mode of 400 microseconds over the full frequency range of 10 MHz to 20 GHz [7]. The VXI module can communicate with a measurement workstation using the IEEE 1394 Firewire interface at rates up to 400 Mbps.

**Figure 11 Agilent E6432A VXI Synthesizer Module**

Very high speed sources, i.e. the Comstron FS5000B, are available with 1.0 microsecond switching times, but are very expensive. A lower cost alternative is the Gigatronics 12000A series synthesizer, as shown in Figure 12, with switching times in the 2.0 msec range.

**Figure 12 Gigatronics 12000A Synthesizer**

Mixers are used in systems like the NSI 85301B to reduce the RF signal path by providing a remote mixer near the AUT or probe. This approach improves system performance for fundamental mixing up to a minimum frequency, typically 18 GHz, provided by the LO synthesizer or LO distribution unit. Mixer selection is based on frequency range and system performance requirements [5]. Harmonic mixing will extend the frequency range, but the additional conversion loss will reduce the overall dynamic range. LO/IF distribution systems like the Agilent 85310A, shown in Figure 13, provide an infrastructure for handling the local oscillator (LO) and intermediate frequency (IF) signals. The 85310A also provides a leveling loop for the LO output to insure adequate LO power and prevent starving the mixer over the frequency range.

**Figure 13 Agilent 85310A Distributed Frequency Converter**

Mixer placement and the selection of a stable low-loss phase reference cable is also very important in determining system performance. Mixer placement determines the length of the RF and LO path lengths and sets the maximum achievable fundamental frequency for the system.

## 6.0 Performance Verification

Performance verification tests should be run on the final system configuration to verify that design requirements are met, the system was configured correctly and all components are functioning properly. Agilent Technologies has developed a suite of automated performance verification tests that NSI is running as part of the RF system factory acceptance tests. The tests are run over the frequency band of interest and the results are compared to factory upper and lower limits, as applicable, to determine pass/fail criteria. The specs are shown for each test in Table 2 for an NSI 85301B system with standard mixers over the 2 to 18 GHz frequency range.

**Table 2 Performance Verification Tests**

| Tests | Spec Limits NSI 85301B |
|---|---|
| System Configuration | - |
| Calibrate RF Splitter | - |
| Conversion Efficiency | 6 dB |
| Gain Compression | -23 dBm |
| IF Noise | -100 dB |
| Crosstalk | -100 dB |
| Dynamic Range | 85 dB |
| Tracking | 5 dB |
| Sensitivity | -108 dBm |
| Isolation | -102 dB |

## 7.0 Summary

This paper has described the process for specifying an RF system for high quality antenna measurements. Unfortunately, there is no easy, 'cookbook' method of designing and configuring an RF system for antenna measurements. The system engineering approach of requirements identification and analysis is the key to the proper selection of equipment, cables and components. Finally, performance verification is essential to guarantee that the system actually performs as it was designed and meets its intended requirements.

## References


1. D. Slater, Near-field Antenna Measurements, Artech House, Norwood, MA, 1991.
2. J. Boyles, "Long Range Antenna Measurements With The HP 8510 Using Harmonic Mixers", AMTA 1986, p. 19.
3. D. Fooshe, D. Slater, "Digital Receiver Technology For High-Speed Near-field Antenna Measurements", AMTA 1999, p. 394-399.
4. B. Newton, N. Mott, "Application of the HP 85301A Antenna Measurement System To Receiver Pattern Measurements", AMTA 1992, p. 15-20.
5. J. Boyles, "Selecting A Mixer For Antenna Test Applications", AMTA 1987, p. 344.
6. J. Swanstrom, R. Shoulders, "Pulsed Antenna Measurements With The HP 8530A Microwave Receiver", AMTA 1994, p. 416.
7. J. Swanstrom, M. Flaherty, "Achieving Faster Measurement Throughput with a VXI-based Microwave Synthesizer", AMTA 1999, p. 406.