DISTRIBUTED RF SYSTEMS FOR ANTENNA MEASUREMENTS

Bert Schluper and David S. Fooshe
Nearfield Systems Inc., 19730 Magellan Drive
Torrance, CA 90502 USA

ABSTRACT

It is well known that modern, high-performance antenna range instrumentation requires fast sources and receivers. What is often overlooked is that the locations of the components making up the RF subsystem need to be considered as well. RF sources and receivers that are controlled over a LAN interface can easily be located remotely, where they are closer to the transmitting and receiving antennas. In addition to using remote mixers, other components such as amplifiers and multipliers can be mounted remotely, on a positioner or probe carriage. This allows using lower-frequency cables with lower loss, and dramatically increases the available power level at the transmitting antenna. Use of fiber optics is also becoming an option for transmission of RF signals in distributed RF systems. Automated configuration control can be achieved using remotely controlled switches.

This paper will present comparisons of distributed and more traditional geometries, including performance and cost benefits.

Keywords: RF subsystem, RF sources, antenna range instrumentation, receivers, remote mixers, amplifiers, multipliers, fiber optics.

1.0 Introduction

Nearfield Systems has a long history of implementing distributed RF systems on large antenna ranges. As an example, the 33 m x 16 m vertical near-field scanner installed at Toshiba in 1998 was then considered the largest vertical near-field range in the world [1]. With cable lengths of 60 m distance from the control room to the scanner x-carriage and 26 m additional distance to the probe carriage, the system represents a unique implementation of a distributed RF system for antenna measurements. The Toshiba 50 GHz RF system includes remote mixers, control of remote RF sources, remote PIN switches and a remote frequency multiplier/amplifier unit.

At the other end of the spectrum is the small low frequency range that simply uses a vector network analyzer or integrated frequency converter in a central location or standalone configuration.

The type of RF system best suited for a particular antenna range depends upon a number of factors including the measurement technique, frequency range and antenna parameters of interest. The choice of measurement technique, i.e. planar, cylindrical or spherical near-field, far-field or compact range directly impacts the performance of the system by influencing the range dimensions and, therefore, the RF cable lengths. Long RF cables increase the loss budget and detract from the ability of the system to measure low side-lobe levels. Similarly, the electrical requirements may influence the measurement technique chosen. The inter-dependencies involved in specifying an antenna measurement system 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 [2].

The goal of this paper is to demonstrate the performance improvements that may be gained by implementing a distributed RF system. For example, how large should the antenna range be before one begins to consider a distributed RF system? A standalone system may work well up to 18 GHz for a 12 ft x12 ft near-field scanner, but it could operate to 40 GHz with a 6 ft x 6 ft scanner. How does this inverse relationship extend to spherical, far-field or combination ranges? Since the size of the range also determines the dynamic range of the measurement system, the antenna test requirements also become an important factor.

This paper will compare three different antenna range examples and show the differences in performance depending upon the choice of configuration. Instrumentation control, range automation and the use of fiber optics for RF transmission will also be discussed.

2.0 RF System Examples

In order to demonstrate the advantages of the distributed RF system approach, simplifying assumptions have been made in order to present three different antenna range examples for comparison. The assumptions include:

- An example 12 ft x 12 ft planar near-field scanner located inside a chamber with dimensions of 9 m x 5 m x 6 m was selected as an average size, typical of many existing ranges.
- A frequency range of 1 to 40 GHz was chosen, representative of many of today's antenna ranges.
- Cable length distance of 12 m from RF rack to AUT. Cable length distance of 20 m from RF rack to probe.
- Probe gain is 6 dB, AUT gain is 30 dB.

The following sections will show three different RF configurations while keeping the above parameters constant. This will provide a means of comparing the performance improvement that may be expected with a distributed RF system and also by using a remote frequency multiplier.

2.1 Standalone RF System

A standalone RF system is one that consists of a vector network analyzer (VNA or PNA) or a receiver with an integrated frequency converter (IFC) centrally located, typically in a control room adjacent to the antenna range. The standalone system consists of a length of RF cable from the network analyzer to the AUT and also from the probe back to the network analyzer. Figure 1 shows a simplified block diagram of a planar near-field scanner with a 40 GHz PNA RF system. The 40 GHz cables run directly from the PNA to the probe and AUT.

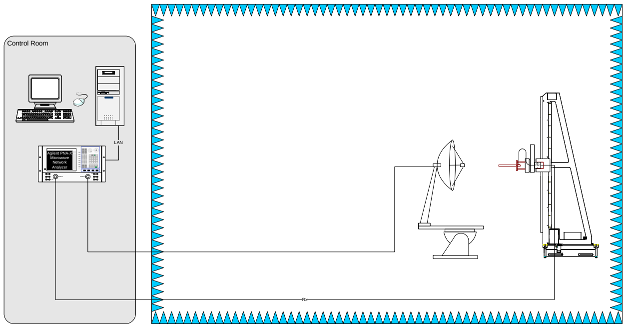

Figure 1 Standalone RF System Block Diagram

The power budget for the standalone system configuration consists of the components and cables shown in Table 1.

Table 1 Simplified RF Power Budget (Standalone)

Device/Cable	Power (dBm), Loss (dB) or Length (m)	Notes
40 GHz PNA	5 dBm @ 40 GHz	Varies with F
40 GHz AUT cable	12 m	
AUT/Probe loss	24 dB	
40 GHz probe cable	1 m	
40 GHz rotary joint	1.0 dB @ 40 GHz	Varies with F
40 GHz probe cable	20 m	

The results of the standalone system power losses are shown in the plot of Figure 2. Due primarily to cable loss and AUT/probe loss, the power at the input to the PNA is -39 dBm at 1 GHz and decreases with frequency to below -90 dBm above 25 GHz. This would not be considered an acceptable level of performance and would likely result in the re-arrangement of equipment to shorten the cables. An external amplifier could be added, however, its noise figure would reduce the RF system sensitivity, since it could not be placed in a position common to both test and reference paths.

2.2 Remote Mixer System

The remote mixer RF system uses a distributed frequency converter (DFC) with mixers located at the probe and near the AUT. In the AUT Tx configuration the RF cable runs from the frequency source to the AUT, but the mixer on the receiving end is located near the probe, thereby, reducing the total RF cable length requirement. Figure 3 shows the addition of the DFC and remote mixers. The 40 GHz cable runs from the PNA to the coupler then to the AUT. A reference mixer is located near the AUT. A test mixer is located near the probe, thereby reducing the 40 GHz probe path from 20 m to 2 m.

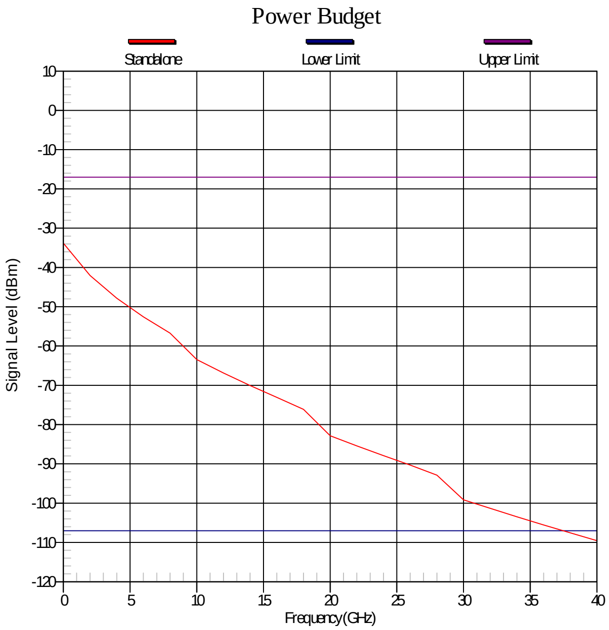

Figure 2 Standalone RF System Power Plot

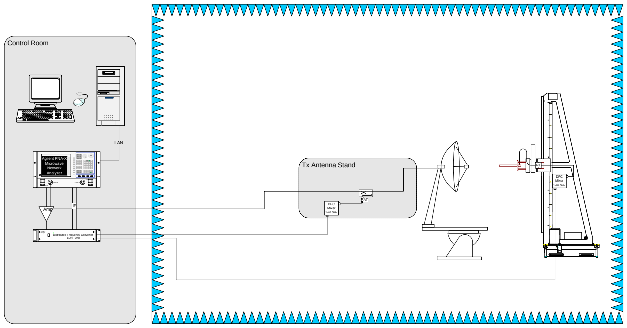

Figure 3 Remote Mixer RF System

The NSI-RF-5940 Distributed Frequency Converter can support long LO cables with up to 30 dB of loss. This allows LO cable lengths of over 100 ft while still using fundamental mixing to 18 GHz.

The power budget for the remote mixer system configuration consists of the components and cables shown in Table 2.

The results of the remote mixer system power losses are shown in the plot of Figure 4. The power at the input to the PNA is -30 dBm at 1 GHz and decreases to -70 dBm at 40 GHz. This represents a significant improvement over the standalone case.

Table 2 Simplified RF Power Budget (Remote Mixer)

Device/Cable	Power (dBm), Loss (dB) or Length (m)	Notes
40 GHz PNA	5 dBm @ 40 GHz	Varies with F
40 GHz AUT cable	12 m	
40 GHz coupler	1.5 dB	Varies with F
40 GHz AUT cable	1 m	
AUT/Probe loss	24 dB	
40 GHz probe cable	1 m	
40 GHz RJ	1.0 dB @ 40 GHz	Varies with F
40 GHz probe cable	1 m	

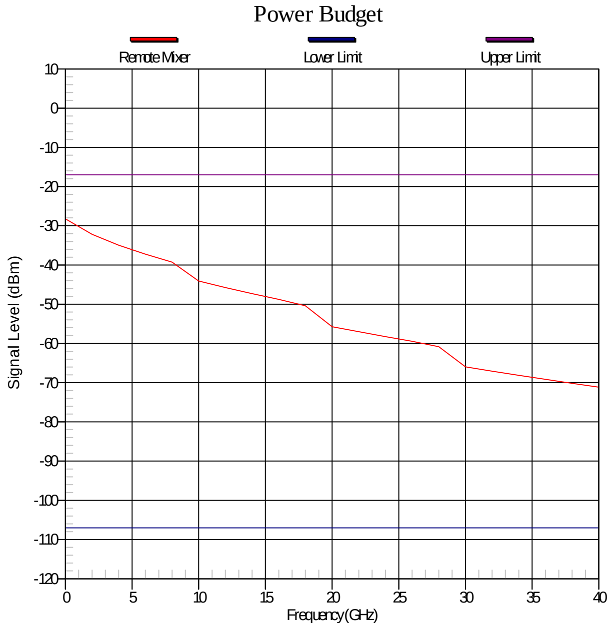

Figure 4 Remote Mixer RF System Power Plot

2.3 Remote Multiplier System

The third example enhances the remote mixer RF system by locating a frequency multiplier near the AUT. This reduces the frequency of the RF cable from the source to the AUT to 20 GHz instead of the more expensive and higher loss 40 GHz cable. This system may also be implemented using the lower cost 20 GHz PNA. The NSI-RF-5994 RF Multiplier-Amplifier-Coupler Plate, 1-40 GHz provides an amplifier, multiplier and coupler near the AUT. The amplifier alone may be used below 20 GHz when the multiplier is not required. The amplifier and multiplier are located prior to the coupler resulting in cancellation of noise in the S21 signal due to the common test and reference path. Figure 5 shows a simplified block diagram.

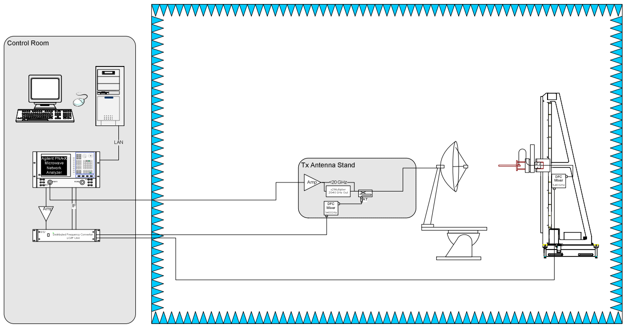

Figure 5 Remote Multiplier RF System

The power budget for the remote multiplier system configuration consists of the components and cables shown in Table 3.

The results of the remote multiplier system power losses are shown in the plot of Figure 6. The power at the input to the PNA is -11 dBm at 1 GHz and decreases to -24 dBm at 40 GHz. Although manual reconfiguration is required going above or below 20 GHz, this represents a significant improvement over the either of the prior cases. In this case, attenuation may be required at the lower frequencies to avoid mixer or receiver saturation.

Table 3 RF Power Budget (Remote Multiplier)

Device/Cable	**Power (dBm), Loss (dB) or Length (m)**	**Notes**
20 GHz PNA	5 dBm @ 40 GHz	Varies with F
20 GHz AUT cable	12 m	
Amplifier	P1dB=+18 dBm Gain = 36 dB	1 – 20 GHz
Multiplier	P1dB=+17 dBm	20 – 40 GHz
40 GHz coupler	1.5 dB	Varies with F
40 GHz AUT cable	1 m	
AUT/Probe loss	24 dB	
40 GHz probe cable	1 m	
40 GHz rotary joint	1.0 dB @ 40 GHz	Varies with F
40 GHz probe cable	1 m	

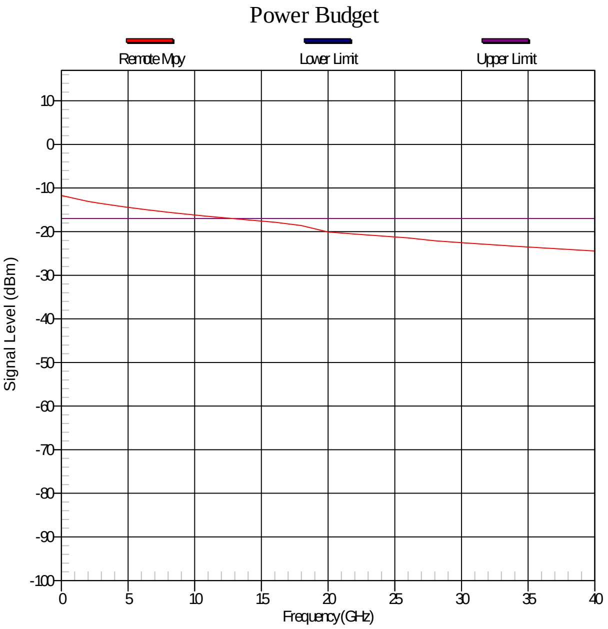

Figure 6 Remote Multiplier RF System Power Plot

3.0 Remote Instrumentation

Additional performance can often be gained by remotely locating an RF source or network analyzer near the probe or AUT. GPIB extenders have been used for this purpose, however, many of today's instruments are equipped with a LAN interface. The LAN interface provides a very easy means of interfacing to the data acquisition computer and is capable of controlling equipment at distances of 100 m [3].

The remote source mitigates the RF cable loss problem; however, for multiple frequency measurements the source must be triggered by the system controller. This is not easily done over the LAN interface. LAN triggering of the source adds timing uncertainty and reduces speed. It is possible to remote the system controller near the source [4], but requires multiple distributed system controllers in order to be an effective solution. Long trigger cables require close attention to signal timing, but are a common solution. The Panther 9000 receiver, however, with its support for multiple distributed high speed beam controllers may be an attractive option for timing and sequence control of distributed instrumentation [5].

4.0 Fiber Optic Links

Fiber optic links have been used in various ways on the antenna range including control of instrumentation and distribution of time base, LO and RF signals [6]. The low loss and extremely wide bandwidth of fiber optic cable make it an attractive alternative to coax for the transmission of LO and RF signals; however, until recently the maximum frequency of RF transmission over fiber was limited to 10 GHz [7]. Fiber optic links are now available that are capable of transmitting RF signals in the 0.1 GHz to 18 GHz frequency range, making them more broadly applicable to antenna range applications.

NSI is currently developing an RF system for a far-field application, which uses a 700 m fiber optic link to transmit the RF signal received from the AUT by the far-end range antenna back to the test mixer in the control room. The fiber optic link contributes approximately 1 dB of additional system noise, but offers advantages such as low loss, high isolation and fundamental mixing.

Further work is required to determine the performance of fiber optic links in other applications such as flex cable or LO distribution.

5.0 Range Automation

Distributed RF systems often require manual reconfiguration of remote cables and components resulting in a logistics and configuration control challenge for antenna range operators. Test repeatability may also be adversely impacted by manual configuration changes.

To automate the configuration of remote components in a distributed RF system, NSI has developed the Range Transition Manager (RTM) and Transmit/Receive Unit (TRU). The RTM and TRU were developed specifically for the antenna range and include a family of RF modules with built-in RF switches, mixers, amplifiers, attenuators and other components to facilitate the automation of the antenna range configuration [8]. Figure 8 shows an RTM and TRU used with a Panther 9000 RF system. The RTM and TRU are controlled over a LAN interface to allow the range operator or control program to easily reconfigure a very complex distributed RF system in a matter of seconds. While automation may result in lower power levels due to the added switches and attenuators, the tradeoff is one that many range operators are willing to make.

An application of the TRU in a standalone RF system for phased array measurements was presented at the 2008 AMTA [9]. RTMs and TRUs are currently being used to automate distributed RF systems on a number of planar near-field ranges, the largest of which is 60 ft x 40 ft.

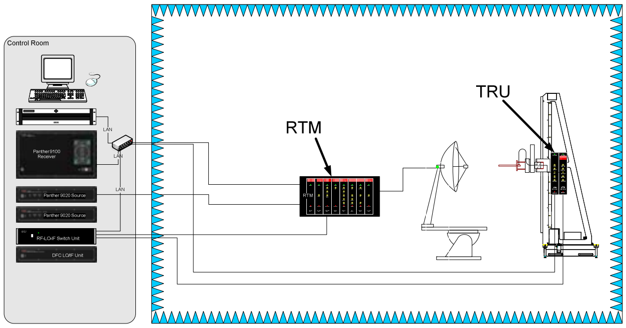

Figure 8 Automation of Distributed RF System

6.0 Summary

Distributed RF systems are a necessity for many large high frequency antenna ranges, but any range can benefit from a performance analysis and tradeoff to determine if a distributed RF system would improve performance or measurement efficiency. This paper has attempted to compare the performance of three different range configurations in order to show the advantages of a distributed RF system. Figure 9 compares the performance of the three configuration examples presented in this paper.

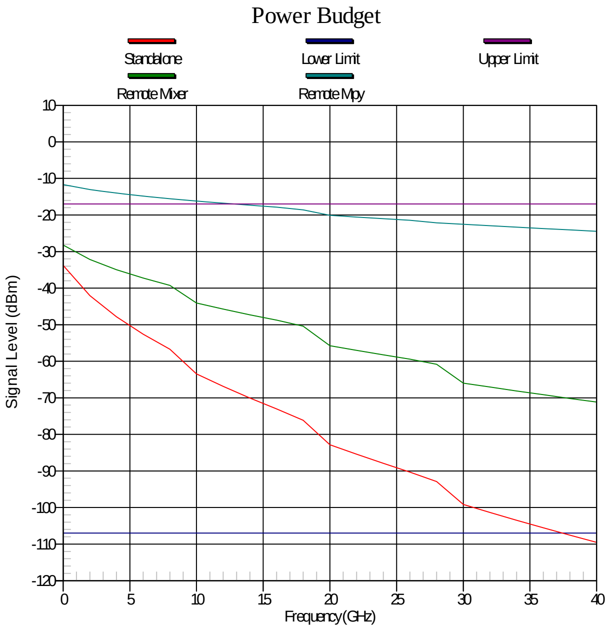

Figure 9 Comparison of the three configurations

Fiber optic solutions and remote instrumentation are other options currently being considered in distributed RF system design. For production systems and those that require automated configuration control, the RTM and TRU offer techniques to automate the distributed RF system.

7.0 References

[1] T. Speicher, S. Sapmaz, M. Niwata, “33m x 16m Near-field Measurement System, AMTA Proceedings 1998,

[2] D. S. Fooshe, M.J. Schultz, How to Specify An RF System for Antenna Measurements”, AMTA Proceedings 2000.

[3] M.C. Baggett, “The Impact of Local Area Networks on Antenna Measurement Range Design”, AMTA Proceedings 2006, p. 333, Austin, TX, Oct 2006.

[4] M.C. Baggett, “An Ethernet Based Controller for Managing Complex Antenna Measurements with a Vector Network Analyzer”, AMTA Proceedings 2008, p. 519, Boston, MA, Nov 2008.

[5] D. Slater, “Next Generation Phase Coherent Instrumentation Receiver”, AMTA Proceedings 2007, p. 302, St. Louis, MO, Nov 2007.

[6] G.J. Matyas, “High Speed Fiber Optic Remote Receiver Link for Improved Antenna Measurements”, AMTA Proceedings 1992, p. 14-4.

[7] C. Carlsson, A. Larsson, A. Alping, “RF transmission over multimode fibers using VCSELs-comparing standard and high-bandwidth multimode fibers”, IEEE/OSA Journal of Lightwave Technology, Volume 22, Issue 7, p. 1694, July 2004.

[8] D.S. Fooshe, “Improving Automation for Antenna Ranges”, AMTA Proceedings 2006, p. 339, Austin, TX, Oct 2006.

[9] D.S. Fooshe, Nearfield Systems Inc., Chris Smith, Lockheed Martin Corp., “A Standalone RF System for Solid-State Phased Array Antenna Measurements”, AMTA proceedings 2008, Boston, MA, Nov 2008.