THREE-ANTENNA GAIN METHOD ON A NEAR-FIELD RANGE

W.G. Scott
Space Systems/Loral
G.F. Masters
Nearfield Systems, Inc.
1330 E. 223rd Street Bldg. 524
Carson, CA 90745 USA
(310) 518-4277

ABSTRACT

The Three-Antenna gain method is commonly used on far-field ranges to determine an antenna's absolute gain. This is especially true when no other calibrated antenna is available. This method has been used for years by calibration laboratories such as NIST to calibrate probes and gain standards for far and near-field ranges. In some cases the calibration is too costly or does not meet the schedule requirements of the near-field test range. An alternative is to calibrate the probe or gain standards directly on the near-field range. In this paper we present the results of a study done to show the accuracy of the Three-antenna gain method when used on a near-field range. An extensive error analysis is presented validating the utility of this method.

Keywords: Gain, Three antenna, Near-field, Scanner, Probe, Error

1. INTRODUCTION

We at the SS/Loral near-field range were approached by our compact range staff to perform a gain calibration for them on a linearly polarized 4- foot diameter S-band antenna (approximately 28 dBi). The antenna would be used as a gain standard for the compact range and had to be very accurately measured. A dual circularly polarized range probe was available which had been pre-calibrated at NIST, as to complex patterns, polarization ratios, and gains. Since this polarization combination was not optimum for best gain measurement accuracy we chose to use two different near field range gain measurement methods to provide increased confidence, namely the direct gain method and the three antenna method (1).

Our new 22 foot by 22 foot planar near-field scanner was designed and implemented by NSI (Nearfield Systems Inc.) as a state of the art facility (2). The scanner, shown in Figure 1 is horizontally mounted on a 25-foot tall steel frame built by SS/Loral, in a 40-foot tall, temperature-controlled anechoic chamber. It is instrumented with an HP8530A high-speed, antenna range receiver with operation form 2 to 40 Ghz. The probe's position (X,Y,Z) is measured and servo controlled by a laser subsystem to an accuracy of 0.002 inches RMS. Some pertinent range specifications are shown in Table 1 at Ku-band where much of the near-field measurements were performed.

2. DIRECT NEAR-FIELD GAIN MEASURMENTS

The near-field range direct-gain method is analogous to a far-field direct gain test wherein a pre-calibrated gain standard source transmit over a known far-field distance to the AUT (antenna-under-test). In the far-field technique the ratio of power transmitted to power received is measured. In addition, the transmit-to-receive distance is used with the pre-calibrated source gain and the Friis-transmission equation to solve for the gain of the AUT.

On the near-field range, the scanning probe measures the AUT's near-field power density and it is converted to the far-field via a Fourier transform. The far-field gain is then determined by knowing the probe gain, and the network insertion loss leading up to the

AUT and probe (1). In both the near-field and far-field gain methods, the gains are further corrected by impedance mismatch measurements at all appropriate junctions.

3. THREE-ANTENNA NEAR-FIELD GAIN MEASUREMENTS

The Three-antenna near-field gain method is an extension of the direct gain method except that the probe gain is not known. The gain of each antenna is determined by solving a set of three equations describing the direct gain measurements of three antennas. The three antennas for this test were a 15 dBi scalar horn developed by Comsat Laboratories, an open-ended waveguide (OEWG), and the 4-foot dish. The characteristics of these antennas are shown in Table 2. The three measurements were:

1.) Scalar horn (probe) - 4-foot dish (AUT)
2.) OEWG (probe) - 4-foot dish (AUT)
3.) OEWG (probe) - Scalar horn (AUT).

The probes of scans 1 and 3 are considered non-optimum from a mutual coupling stand point because their gain values are so similar to each AUT. From a series id self-comparison scans, using a pair of scans separated by one quarter wavelength probe-to-AUT and AUT-to-ceiling spacing, we found an acceptable test position which minimized mutual coupling, room scattering, and scan size truncation errors. Because if the relatively large probe we found that the probe-to-AUT spacing which minimized mutual coupling was also large, approximately 48 inches. This required a large scan area to control truncation effects.

The measurements for each of the three antenna combinations was made and the gain of the 4-foot dish was calculated. The results are shown in Table 3 and compared with the direct gain results. In both cases, extensive gain uncertainty estimates were derived through analysis of computation and measurement.

4. NEAR-FIELD GAIN ERROR ANALYSIS

Table 4 consists of as set of 18 terms developed by the National Institute of Standards and Technology (NIST) (3) to encompass all possible planar near-field error sources. The terms marked "none" do not apply to gain measurements. The table shows the direct gain error budget for the reflector/scalar horn gain measurements.

Numerous direct gain scan accuracy self-comparison tests were performed on the near-field range with the reflector and scalar horn in place. Some of this data was used initially to adjust near-field range test parameters to maximize the gain accuracy. Analysis was then performed on a final version of such data to derive the terms of the direct gain error summation of Table 4.

Each error term is based in special self-comparison test data and/or analysis for the term. In many cases, two tests of each type are performed, a "baseline" scan of the AUT and another scan after some physical changes is made. If the near-field range were ideal, the two scans should yield identical far-field transformed results. For example, if no scattered field existed between the AUT and probe, then a change in probe-to-AUT spacing should result in no change in the transformed far-field pattern. However, finite mutual coupling always exists, and small changes were found.

The differences in these two patterns identify the measurement uncertainty. The uncertainty can be used directly or converted to an error-to-signal ratio. The error-to-signal ratios of all 18 terms can be quadrature summed (RSS) and converted to an overall gain accuracy. The direct gain accuracy in Table 4 is ±0.16 dB. This accuracy would have been somewhat better had the probe and AUT been co-polarized. For example, in term 3 for the NIST pre-calibrated gains we have RSS combined the calibration uncertainties of ±0.10dB for each probe port yielding ±0.14 dB. Similar combinations of increased error were incorporated in other appropriate terms.

Table 5 summarizes the development of the error budget of the three-antenna near-field range methods. Error-to-signal ratios are first developed for each of scans 1, 2 and 3 by self-comparison tests and analysis. Next, for each of the 18 terms, the three error-to-signal ratios are RSS combined in the fourth column of Table 5. Finally, the 18 combined equivalent error signal terms are themselves RSS combined and converted to a total error term at the bottom of column five (±0.23 dB.). Note that the dominant error term is room scatter in scan 3 and is due to the very broad pattern of the OEWG probe. It may be feasible to reduce this error somewhat by coherent averaging of multiple scans at various heights of the AUT and probe above the floor (4).

It should be noted that even though the horn used is the Three-antenna method is the NIST-calibrated scalar horn, its calibrated gain accuracy is irrelevant and thus set to zero (None in item 3 of Table 5). The Three-antenna method measured gains for this horn are compared with the NIST measured values in Table 6. The agreement is very good and within the joint error bounds.

5.CONCLUSIONS

The near-field range, Three-antenna gain method was tried and found to be a practical method of gain measurement. Gain accuracy for this method is ±0.23 dB as compared to ±0.16 dB achieved using the direct gain near-field method with a NIST pre-calibrated probe. This method has been shown to be useful in reducing the need for a pre-calibrated probe or gain reference antenna when doing gain measurements on a near-field measurements on a near-field range.

6. REFERENCES

1. A.C. Newell, R.D Ward, and E.J. Mcfarlane; "Gain and Power Parameter Measurements Using Planar Near-field Techniques", IEEE Trans. A/P; Vol. AP-36, No. 6, June 1988.

2. G. Hindman and G. Masters, "Implementations of a 22' by 22' Planar Near-field System for Satellite Antenna Measurements", AMTA Proceedings, Dallas, Tx; 1993

3. A.C. Newell, "Error Analysis Techniques for Planar Near-field Measurements", IEEE Trans, A/P, Vol. AP-36, No. 6, June 1988.

4. G.E. Hindman and D. Slater; "Error Suppression Techniques for Near-field Measurements", AMTA Proceedings, Monterey, Ca; 1989.