Multi-Probe Spherical Near-Field Antenna Test System for an Aircraft Rotodome

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Abstract—A multi-probe array (MPA) spherical near-field antenna measurement system, comprised of COTS equipment, has been developed for testing UHF antennas mounted of an aircraft rotodome. The spherical probe radius is 5 meters, which accommodates a 24 ft. diameter rotodome. The probe array, arranged in a circular arc about the test zone center, provides rapid time multiplexed samples of dual polarized spherical theta angle measurements. These measurements are collected at incremental steps of spherical phi angles, provided by a floor azimuth turntable. The rotodome is mounted on the azimuth turntable, and is rotated 360 degrees during a data collection. During one azimuth rotation, completed in a few minutes, a full set of 3D, dual polarized, multi-frequency near-field pattern data is collected. The data is transformed to full 3D far-field patterns in another minute, providing a complete rotodome test time within 15 minutes. The entire system is contained within a room 42' x 42' x 25'.

This paper will describe the test requirements, physical requirements of the DUT, size constraints of the facility, and measurement speed goals. Alternate solutions and range geometries will be discussed, along with why the MPA solution is best given the requirements and size constraints. The system will be described in detail, including discussion of the room design, RF instrumentation, multi-probe array, positioning equipment, and controllers. Measurement results will be presented for test antennas of known pattern characteristics, along with other performance metrics, such as test times.

I. Introduction

Multi-probe arrays (MPA) for spherical near-field Measurements have been have been successfully applied for a range of applications in the past [1,2]. This paper describes a MPA spherical near-field antenna measurement system developed for testing UHF antennas mounted in an aircraft rotodome. The system also has capability for testing up to frequencies of 18 GHz. The following subsections briefly describe key requirements and the rational for selecting an MPA spherical system.

A. Requirements

The following are key system requirements.

- Frequency Range: 0.4 to 18 GHz
- Test Time: 15 minutes for 100 frequencies, 3D pattern, 2.5 degree theta/phi step size (no over sampling)
- Chamber Size: 42' x 42' x 25' high
- AUT Size Radius: As large as 24 ft. diameter

B. Why a Near-Field System is Best Choice

The facility size is restricted to 42' x 42' x 25' (length, width, height). This rules out alternate test range configurations, such as far-field and compact range.

The far-field criteria for a test object (1) suggests that for an

$$R_{ff} > \frac{2D^2}{\lambda} \tag{1}$$

AUT of 24 ft. (7.3 m) diameter, at 400 MHz, the range must be a length of at least 142 meters. This is much larger than the room available in the facility.

Similarly, a compact range will require a reflector more than twice the size of the AUT quiet zone, 48 ft. in this case. Again, the room size does not allow for this. In addition, the cost of a UHF compact reflector are prohibitive.

The small room size, relative to the AUT size, suggests that a near-field system is best. A spherical system was chosen because of the round symmetry of the test rotodomes and because a number of the test antenna elements within the rotodome are low gain, broad beam devices.

II. Description of System

A. System Block Diagram

Figure 1 shows a simplified diagram of the multi-probe spherical near-field system.

The RF Source and receiver are implemented with a Keysigh network analyzer. An azimuth positioner, controlled by the Orbit 4164 controller, is used to scan the AUT over the phi spherical direction. The MVG multi-probe array (MPA) contains low band and high band dual polarized probe antennas, covering a theta range from 45 to 135 degrees, at 2.5 degree angle increments. Smaller increment sampling is achievable via 'over-sampling' (discussed in a later section).

All instrumentation is controlled via the 959 Spectrum computer controller. A full set of spherical near-field data, over all test frequencies, is collected during one 360 degree azimuth rotation.

B. Description of the MPA

The MPA contains an interleaved array of low band and high band dual polarized probe antennas. The low band antennas operate from 400 MHz to 6 GHz. The high band antennas operate from 6 to 18 GHz. All antenna outputs pass through a high speed switch matrix and selected one antenna at a time to the network analyzer receiver. With a reasonable receiver bandwidth (10 kHz or larger), all probes within one band can be cycled through, per measurement frequency, over a very short time period. This allows for the azimuth positioner to rotate at full speed (3 deg/s) during the data collection while collecting all elevation positions during one azimuth sweep.

A probe increment spacing of 2.5 degrees is sufficient for satisfying the spherical Nyquist criteria, given by (2).

$$\theta_{\mathrm{inc}} < \frac{\lambda}{2R_{AUT}} \tag{2}$$

A consequence of Equation (2) is that the physical 2.5 degrees angle increments is more than enough to test 12 ft. radius AUTs at frequencies in the 400 – 500 MHz range, and thus no oversampling is required.

C. MPA Calibration

The probes in the MPA are calibrated on boresight for both amplitude, phase, and polarization errors. For each probe, a set of frequency dependent coefficients are derived from data collected with a horn pointing at each probe. Equation 3 shows how calibrated V,H polarization components are obtained for a probe k from measured raw M1,M2 polarizations through a polarimetric calibration matrix (Zmn).

$$\begin{bmatrix} V(f) \\ H(f) \end{bmatrix}_k = \begin{bmatrix} z_{11}(f) & z_{12}(f) \\ z_{21}(f) & z_{22}(f) \end{bmatrix}_k \begin{bmatrix} M_1(f) \\ M_2(f) \end{bmatrix}_k \tag{3}$$

D. MPA Over-Sampling

For higher frequencies, when 2.5 degree angle increments do not satisfy the Nyquist criteria, over-sampling is utilized by adding and AZ/EL positioner on top the AUT tower at the quiet zone center.

Multiple azimuth sweeps are collected, with the elevation axis stepping small increments between each azimuth sweep. Because the elevation axis is aligned with the MPA center, rotation of the elevation axis is equivalent to the MPA array rotating about its center. Note that the upper azimuth, not lower azimuth axis must be used for the phi scan, because the elevation positioner must remain aligned with the MPA.

This allows for smaller angle step sizes, at the cost of increased collection time. This provides a test capability for smaller test antennas up to 18 GHz. An 18 GHz test antenna radius as large as 1.8 m can be tested at 0.25 degree angles steps (x10 over-sampling).

E. Theta Truncation

Because of limited room height, the MPA only covers a theta angle range from 45 to 135 degrees. This will result in measurement truncation in the theta region from 0 to 45 degrees and 135 to 180 degrees. For broad beam antennas, this can cause significant ripple error in the patterns.

Fortunately, this is not usually a problem because for the primary antennas, the truncation will be in the sidelobe region. There is little energy content in the theta region outside the 45° - 135° range.

F. Echo Reduction

A powerful post-processing tool is Echo Reduction. This provides the ability to achieve the benefits of modal filtering even when the test antenna is significantly offset from the spherical quiet zone center.

The number of spherical modes required is dependent on the total AUT radius with respect to the spherical center. Even with a small AUT, if it is offset by a large difference, a larger number of spherical modes is required to properly transform the NF data to a far-field pattern.

Echo reduction is done by the following steps:

- Generate FF pattern via spherical transform
- Translate FF pattern to the spherical center, effectively lowering the AUT radius
- Generate another FF pattern, using a lower number of modes, based on the smaller AUT radius,
- Translate the filtered FF pattern back to the original position

The benefit of this process is a reduction in noise and ripple uncertainty, caused by random reflections and other error terms.

III. Performance

The following is a discussion of performance results.

A. Measurement Time

Table 1 summarizes total data collection times and NF-FF transform times for a spherical data collection over various numbers of frequencies.

These results are for a receiver bandwidth of 10 kHz and Theta/Phi angle step sizes of 2.5 degrees. At UHF frequencies, these parameters are more than sufficient for achieving best performance.

Table 1: Test Times for Various Number of Frequencies

10 kHz Receiver Bandwidth, 2.5 Deg. Theta/Phi Steps, No Secondary Over-Sampling			
# Frequencies	Test Time (min:sec)	Transform Time	Total Time
21	2:06	0:35	2:41
51	3:08	1:20	4:28
101	4:13	2:40	6:53
201	8:14	5:10	13:24

It is seen that for as many as 201 frequencies, the total process takes less than 15 minutes.

B. Measurement Accuracy

An uncertainty analysis was done at the UHF band, and yielded a 2σ measurement peak gain uncertainty of 1.4 dB. This analysis was done assuming a gain replacement method of calibration, and includes a gain standard 2σ uncertainty of 0.88 dB.

Actual testing for several different SGA horn antennas was conducted, computing directivity instead of gain. When utilizing post processing tools, such as Echo Reduction and Pattern Stitching (discussed below), 2σ peak pattern uncertainties of 0.25 dB were commonly achieved.

C. Effects of Echo Reduction

Various antennas were tested at significant radius from the rotation center. When transforming the NF measurement to the FF, there is some ripple in the resulting patterns. Echo reduction[3] has been applied to the patterns and shown to improve the results.

Figure 2 and Figure 3 show results for a Narda 644 horn mounted 2 meters offset from the center of rotation. Comparison plots are shown, with and without echo reduction, for phi and theta patterns. It can be seen that the blue traces (echo reduction) have much less ripple than the green traces.

D. Stitching Data Sets

In cases where truncation in the theta axis causes significant pattern errors, it is possible to 'stitch together' multiple patterns collected at different theta ranges.

For example, by using the AZ/EL positioning system, two separate pattern measurements can be made, with identical test parameters, except that the elevation positioner is tilted up and down 30 degrees. The two resulting pattern measurements will have different theta angular ranges, 15 to 105 degrees and 75 to 165 degrees. In post processing, these patterns can be 'stitched together' to create a single pattern with theta ranging from 15 to 165 degrees.

This has proven to be a useful technique for low gain AUTs that have broad patterns susceptible to measurement truncation. Figure 4 and Figure 5 show phi and theta pattern comparisons for an A-Info LB-2100-10 horn antenna (410 MHz). The red traces are FEKO simulation results, the green traces are measured and processed results for theta ranging from 45 to 135 degrees, and the blue traces are measured and processed (with stitching) results for theta ranging from 15 to 165 degrees

The stitched results match the FEKO traces better, particularly for the theta patterns.

Figure 6 shows an example of how stitching improves gain accuracy. The gain of the pattern resulting from truncation is about 0.5 dB too small. The stitched pattern gain is 11.28 dB, only 0.03 dB larger than the gain data from the A Info datasheet.

With significant truncation, there is ripple in the main peak of the pattern, which results in gain error. Stitching greatly improves the gain accuracy.

IV. Conclusion

A multi-probe array (MPA) spherical near-field antenna measurement system has been developed for testing UHF antennas mounted of an aircraft rotodome, as well as higher frequency antennas, up to 18 GHz. Within a very short period of time, a full pattern set of 3D, dual polarized, multi-frequency data is collected and processed to far-field patterns. The entire system is contained within a moderately small facility.

Measurement accuracy has been verified with uncertainty analysis and pattern measurements of known gain standard antennas. Improvements in accuracy have been achieved with post processing techniques, such as Echo Reduction and Pattern Stitching.

References

[1] P.O. Iversen et al, "Real-Time Spherical Near-Field Antenna Test Range for Wireless Applications" AMTA Symposium, November 1999, Monterrey, Californima

[2] Graham, J. and Iversen, P., "Rapid Spherical Near-Field Antenna Measurements for Vehicle Applications," SAE 2005 Transactions Journal of Passenger Cars: Electronic and Electrical Systems - Technical Paper 2005-01-0569

[3] L. J. Foged, L. Scialacqua, F. Mioc, F. Saccardi, P. O. Iversen, L. Shmidov, R. Braun, J. L. Araque Quijano, G. Vecchi, "Echo Suppression by Spatial Filtering Techniques in Advanced Planar and Spherical NF antenna Measurements", 34th Annual Symposium of the Antenna Measurement Techniques Association, AMTA, October 2012, Seattle, Washington, USA

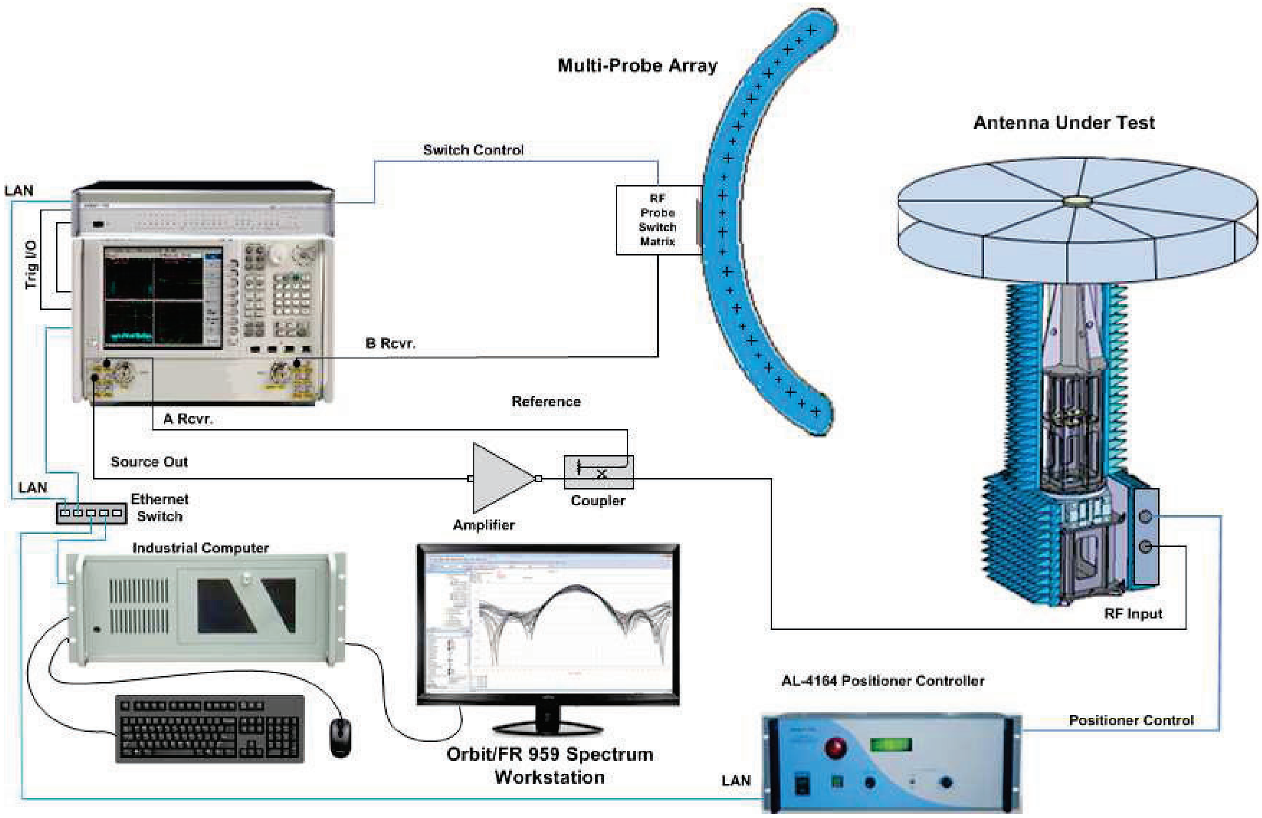

Figure 1: Simplified System Diagram of Multi-Probe Spherical Near-Field Antenna Test Facility

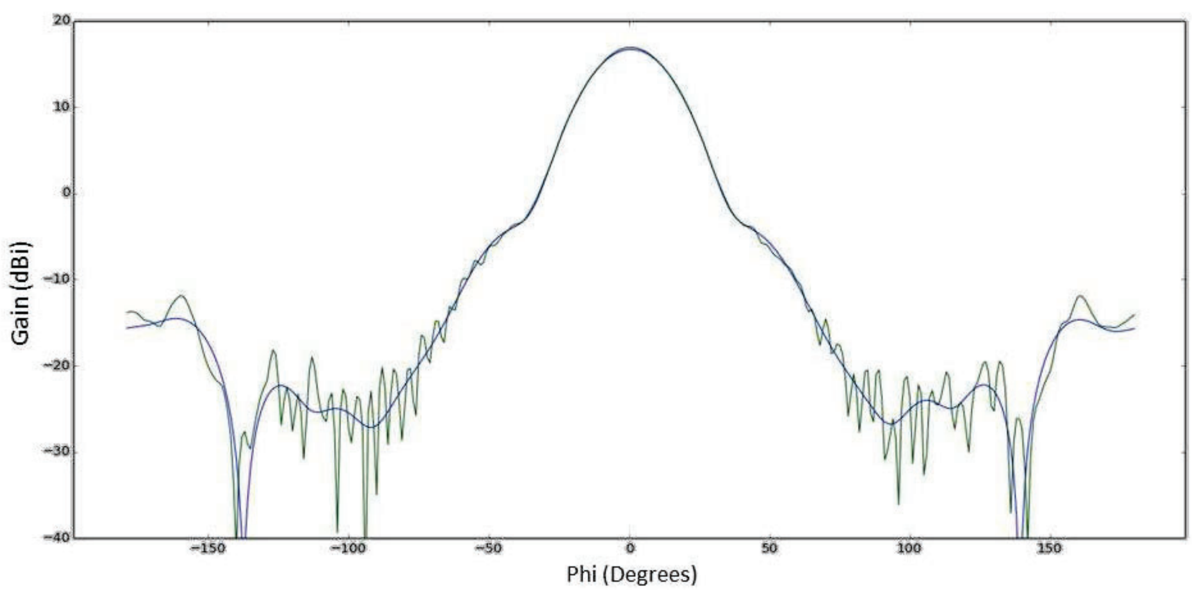

Figure 2: Narda 644 Phi Pattern w/ and wo/ Echo Reduction

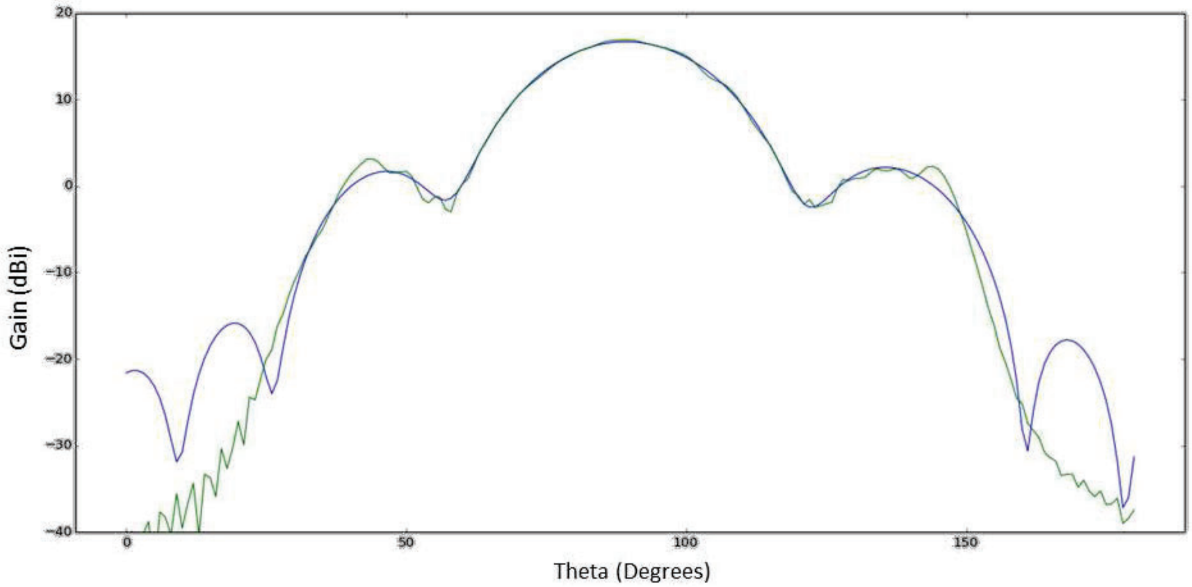

Figure 3: Narda 644 Theta Pattern w/ and wo/ Echo Reduction

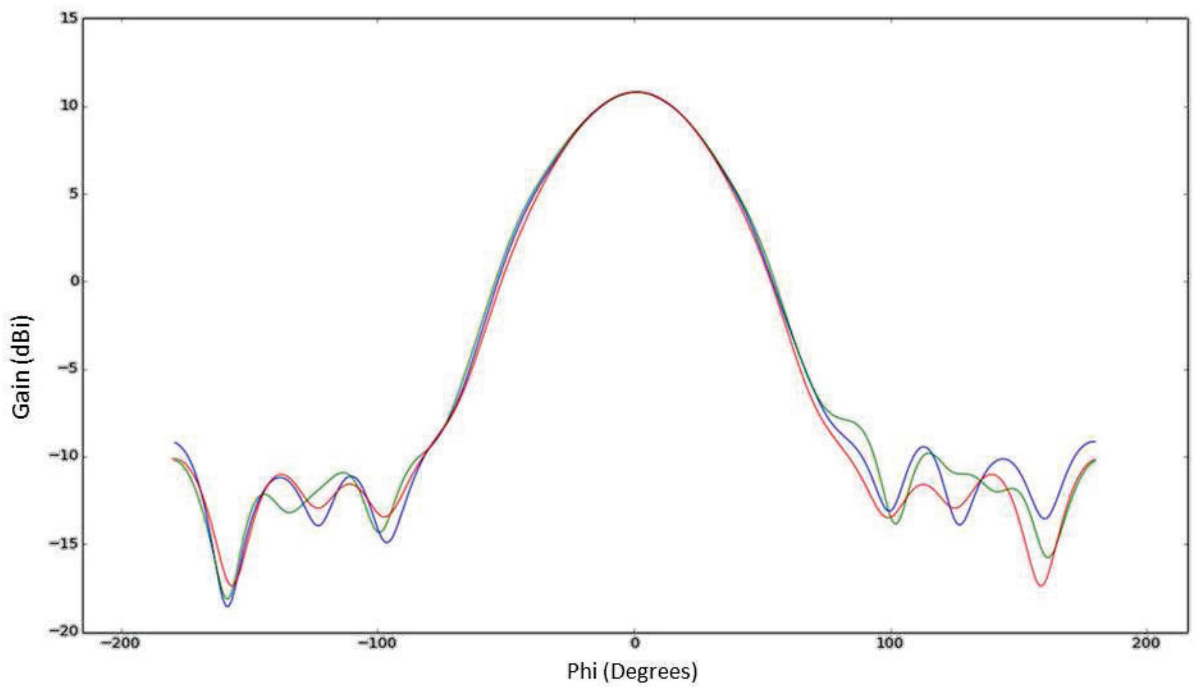

Figure 4: Phi cut, H-pol, of A-Info LB-2100-10, 410 MHz, FEKO model (red), FF Pattern of Truncated NF Data (green), and FF Pattern of Stitched NF Data (blue)

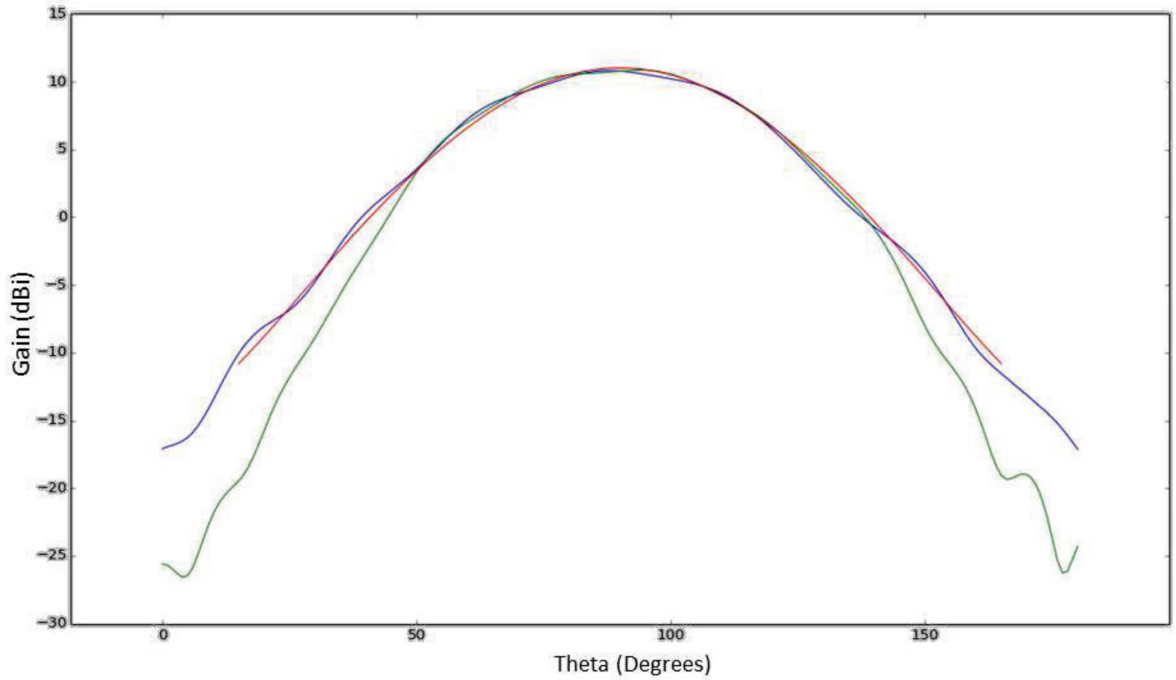

Figure 5: Theta cut, H-pol, of A-Info LB-2100-10, 410 MHz, FEKO model (red), FF Pattern of Truncated NF Data (green), and FF Pattern of Stitched NF Data (blue)

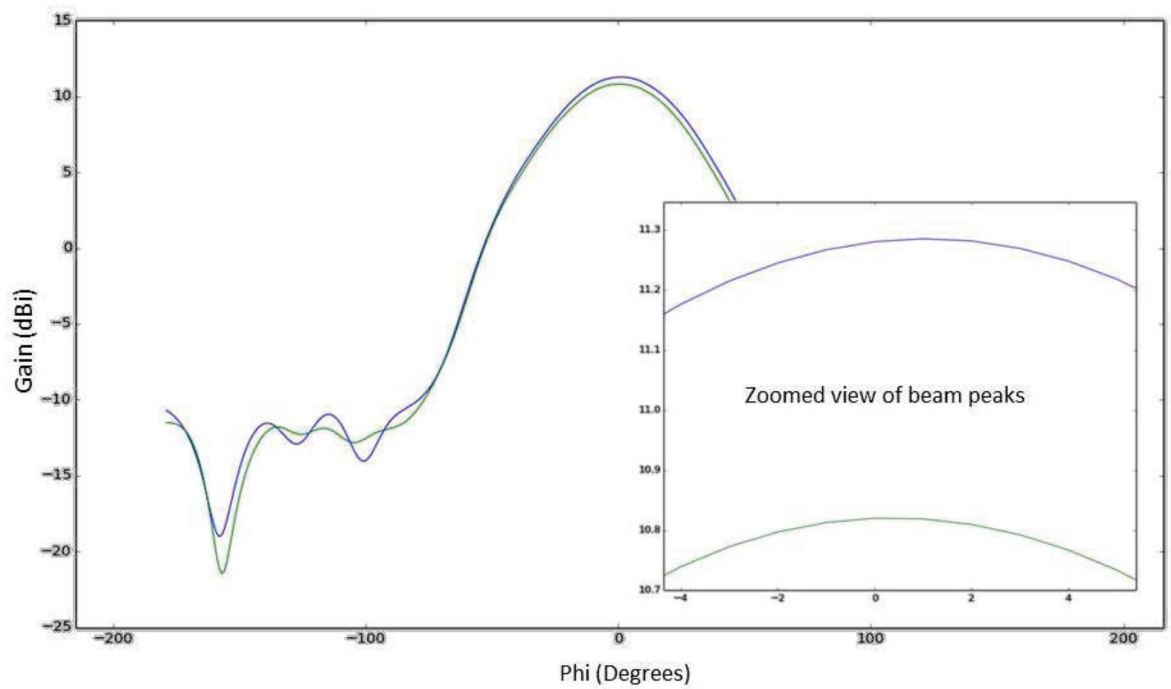

Figure 6: Phi cut, H-pol, of A-Info LB-2100-10, 420 MHz, FF Pattern of Truncated NF Data (green), and FF Pattern of Stitched NF Data (blue)