A Study of Sampling Sizes Greater than 0.5λ on Planar Near Field Ranges for Electrically Large Antennas

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***Abstract* - This paper presents a study on near-field sampling intervals larger than the conventional λ/2 spacing and evaluates their impact on the reconstructed far-field radiation patterns of electrically large antennas. Measurements were performed on a 2.4-m-diameter Q/V-band Cassegrain reflector antenna operating from 37 to 51.5 GHz using a 3.5 m × 3.5 m planar near-field range. Results demonstrate that sampling intervals up to 6λ can be employed to rapidly characterize electrically large antennas with minimal degradation in the far-field radiation patterns, thereby reducing measurement time by many hours.**

***Index Terms* — Near-field, Antenna range, Q/V-band, Cassegrain Reflector Antenna, Sampling size**

I. Introduction

The Q/V-band spectrum (37.5–42.5 GHz, 47.2–52.4 GHz) has experienced rapid development in recent years, driven by high-throughput ground-to-space satellite communication applications such as satellite internet services and broadband cellular networks [1], [2]. To support these applications, many companies have developed and deployed large Cassegrain reflector antennas with aperture sizes ranging from 2.4 m to 13.5 m in diameter [3], [4]. These antennas are considered *electrically large* because their physical dimensions are much greater than the operating wavelengths.

Characterizing such antennas in traditional far-field ranges is impractical due to the large distances required. For example, a 13.5-m-diameter antenna operating at 52 GHz has a calculated far-field distance exceeding 63,000 m (39.5 miles or more than 200,000 ft), as determined by (1), where the far-field distance R is related to the antenna aperture diameter D and wavelength λ. In contrast, most commercial far-field test chambers are less than 40 ft in length, and the largest anechoic chamber worldwide is only 260 ft [5].

$$R \geq \frac{2D^2}{\lambda} \tag{1}$$

Consequently, the most suitable approaches for testing these large reflector antennas are compact antenna test ranges (CATRs) or planar near-field (PNF) ranges. Commercial CATRs provide quiet zones up to 12 m in diameter, while PNF ranges are available in sizes up to 50 m×25 m (vertical) or 30 m×25 m (horizontal). Compared with CATRs, PNF ranges offer several practical advantages for measuring large reflector antennas, as summarized in Table I based on [6].

TABLE I
PNF vs CATR Comparison

	Planar Near Field	**Compact Range**
Zero G Effects	Excellent (Horizontal)	Poor
Facility Cost	Low	Very High
Speed	Excellent	Fair
Complexity	Moderate	High
Antenna Access	Excellent	Fair
Antenna Alignment	Easy	Difficult

Although [6] notes that planar near-field (PNF) ranges can acquire measurements faster than compact ranges, the characterization of electrically large antennas can still require many hours or even days. The total measurement time depends primarily on the probe scan plane size and the sampling step. Larger scanning planes and smaller sampling steps significantly increase acquisition time. The scanning plane dimensions are determined by several factors, including the antenna under test (AUT) diameter, probe-to-AUT separation, and desired far-field angular coverage. The sampling step is typically chosen to be less than λ/2 to avoid aliasing in the reconstructed radiation pattern [7].

This paper investigates the impact of using sampling steps larger than the conventional λ/2 criterion on both measurement time and radiation pattern accuracy for an electrically large reflector antenna. A step size of 0.48λ was chosen as the baseline for comparison since it falls slightly under the recommended λ/2 criteria. Experimental results show that sampling intervals can be relaxed up to 6λ without introducing significant changes in the far-field radiation patterns, thereby enabling substantial reductions in test time for electrically large antennas.

II. Test Setup

The electrically large antenna used for the study was a 2.4 m diameter Cassegrain reflector antenna operating from 37 to 51.5 GHz with a typical gain of 58 dBi and typical beamwidth of 0.2 degrees. The D/λ ratio for this antenna is approximately 296 at 37 GHz, 400 at 50 GHz, and 412 at 51.5 GHz. The antenna was installed in a 3.5 m x 3.5 m vertical planar near-field range as shown in Figure 1. The antenna range can measure electrically large antennas with diameters up to 3.0 m and frequencies up to 110 GHz. The probe selected was a standard WR-22 rectangular open-ended waveguide probe (OEWG) with a typical gain of 6.5 dBi.

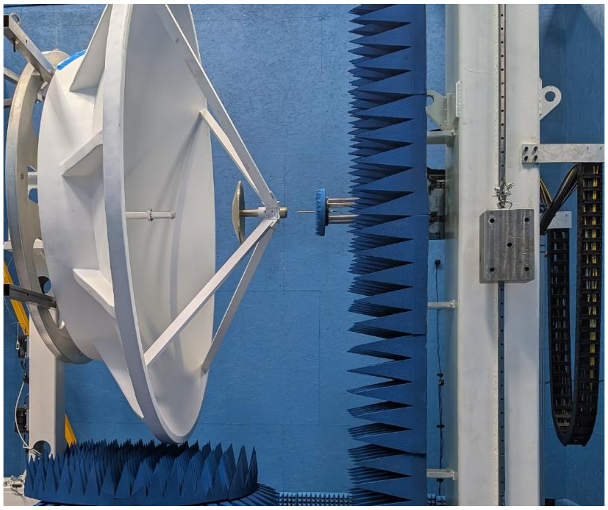

Fig. 1. Test Setup of the 2.4 m Antenna on the PNF

After the mechanical setup and alignment of the antenna on the PNF was completed, the scan plane size and sampling step sizes were defined in the near-field control software. The scan plane was calculated using Figure 2 and (2), where L is the probe travel in X or Y, D is the diameter of the AUT, P is the diameter of the near-field probe, Z is the probe-to-AUT separation, and θ is the desired far-field angular coverage.

$$L = D + P + 2ZTan(\theta) \quad (2)$$

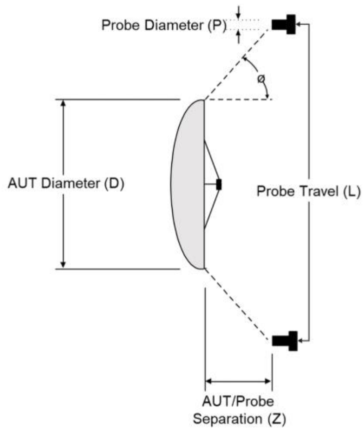

Fig. 2. Supplementary diagram for (2). Source: NSI-MI [8]

Due to the high gain and narrow beamwidth of the antenna, the main lobe and major sidelobes all occur within ± 5 degrees of the boresight, so 5 degrees was selected as the desired angular coverage for the far-field patterns. The recommended probe-to-AUT separation is typically within 3λ to 5λ of the highest operating frequency. At 50 GHz, this means the probe ideally should be 18 mm to 30 mm from the AUT. However, this is not mechanically feasible due to the presence of the spars and collar that hold the sub reflector. These structures extend past the main aperture of the antenna and would interfere with the probe if it were to be positioned within 3λ to 5λ. The closest mechanically feasible probe-to-AUT separation was determined to be 613 mm, or over 100λ, 20 times the recommended criteria. The rest of the selected parameters are summarized in Table 2 below. The final calculated probe travel length in X and Y was around 2.55 m, thus making the recommended scan plane size 2.55 m x 2.55 m. To give some margin and to coincide with the 0.48λ step size at 50 GHz, the scan plane size was increased to 2.9 m x 2.9 m during the actual testing.

TABLE II.
VALUES USED TO CALCULATE X-Y PROBE TRAVEL LENGTH

Parameter	Value
D	2.4 m (96”)
P	6.35 mm (0.25”)
Z	613 mm (24.14”)
θ	0.0873 rad (5°)

Six different step sizes (0.48λ, 2λ, 3λ, 4λ, 5λ, and 6λ) were chosen and calculated at 50 GHz. This was the highest operating frequency that the WR-22 OEWG had calibrated data for. The calculated step sizes and number of samples taken in X and Y for the 2.9 m x 2.9 m scan plane are shown in Table 3.

TABLE III.
SAMPLING STEP SIZES AND NUMBER OF SAMPLES

	Step Size @ 50 GHz (X, Y)	Number of Samples (X, Y)
0.48λ	2.9 mm (0.114”)	1000
2λ	12 mm (0.472”)	242
3λ	18 mm (0.709”)	162
4λ	24 mm (0.944”)	121
5λ	30 mm (1.181”)	97
6λ	36 mm (1.417”)	81

III. TEST RESULTS

The testing was done over a course of two days. The total measurement time to complete the test at each step size is summarized in Table 4. As shown in Table 4, testing the 2.4 m antenna at 0.48λ step size for 50 GHz took almost an entire day to complete. Increasing the step size to 2λ reduced the testing time to around 2 hours, which is about an 87% reduction in the testing time compared to 0.48λ. Further increasing the step size to 3λ results in savings of an extra hour, but further step size increases result in diminishing returns that save only a few extra minutes at a time.

TABLE IV.
TOTAL MEASUREMENT TIME FOR EACH SAMPLING STEP SIZE

	Step Size @ 50 GHz	Time (hrs)	Time (minutes)
0.48λ	2.9 mm (0.114”)	17.38	1043
2λ	12 mm (0.472”)	2.18	131
3λ	18 mm (0.709”)	1.07	64
4λ	24 mm (0.944”)	0.68	41
5λ	30 mm (1.181”)	0.53	32
6λ	36 mm (1.417”)	0.47	28

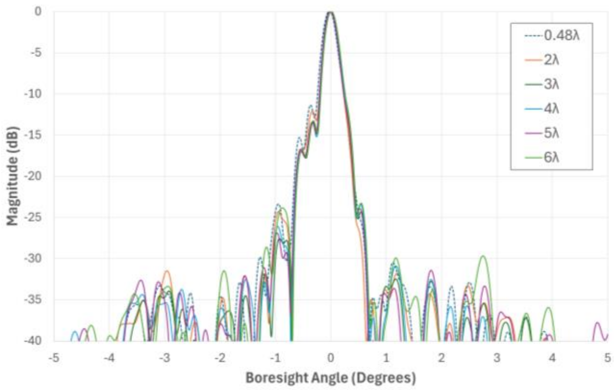

Fig. 3. Azimuth Patterns @ 37 GHz for the 2.4 m Antenna

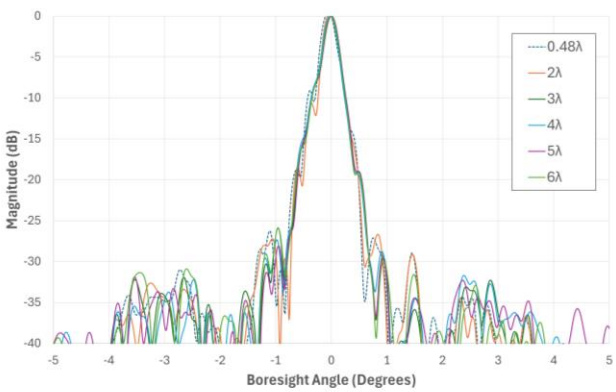

Fig. 4. Elevation Patterns @ 37 GHz for the 2.4 m Antenna

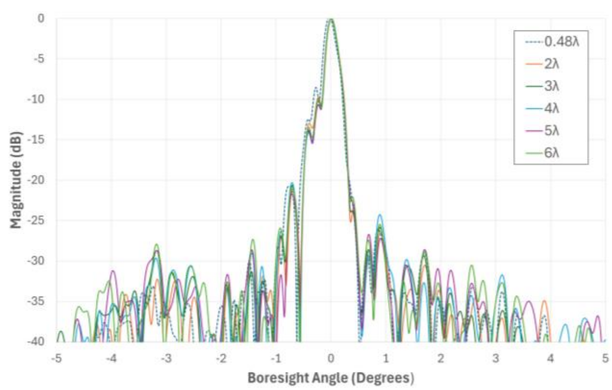

Fig. 5. Azimuth Patterns @ 50 GHz for the 2.4 m Antenna

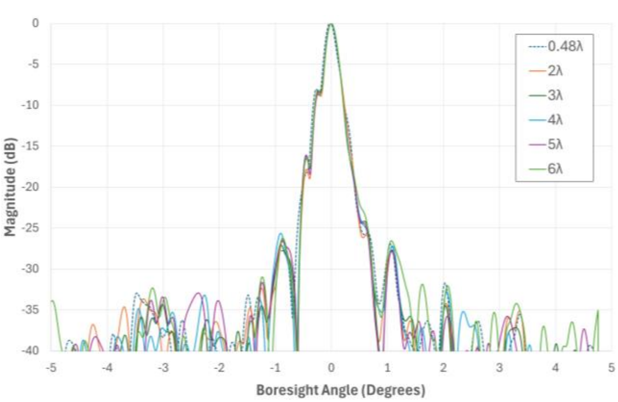

Fig. 6. Elevation Patterns @ 50 GHz for the 2.4 m Antenna

The radiation patterns at 37 GHz and 50 GHz for each step size were plotted and overlaid in Figures 3 through 6. As can be seen from the plots presented, the results for 3λ to 6λ show basically no changes in the main lobe and 1st sidelobes. The results for 0.48λ compared to 2λ show minor differences within 1 to 2 dB in the 1st sidelobes except for the elevation cut at 50 GHz, but otherwise there are no changes in the main lobe. The patterns taken at 2λ compared to 3λ to 6λ show no changes in the main lobe and very minor changes that are around 1 dB in magnitude for the 1st sidelobes. The most pronounced change can be seen in the elevation cut at 37 GHz, where the nulls of the 1st sidelobe disappear and appear smoothed out when the step size increases from 2λ to 3λ. Otherwise, the basic 1st sidelobe shape and null definitions are preserved from 0.48λ to 6λ for all other patterns.

The asymmetricity of the patterns was because the antenna had not been tuned yet. In fact, one of the primary motivations for conducting this study was to find a way to significantly reduce the time it takes to tune the antenna. For Cassegrain reflector antennas, the traditional way to tune the antenna is to adjust the phase center of the feed horn relative to the main reflector's focal point and the sub reflector angular tilt and offset relative to the feed and main reflector. After the adjustments are made, the antenna undergoes testing in the near field range. If further tuning is needed, the feed horn and sub reflector are adjusted again based on the test results and the antenna is tested once more. The tuning and testing process continues until satisfactory performance of the antenna is achieved.

As described in Table 4, each test using 0.48λ step size takes 17 hours for a 2.4 m antenna at 50 GHz. If five test cycles are needed to properly tune this antenna, that would take a total of 85 hours, or almost 4 days, of pure testing time, not including the time it takes to adjust the antenna feed and sub reflector in between test cycles. In addition, the monetary costs for testing such an electrically large antenna at 0.48λ step size increases with each additional day needed, assuming the user is being charged a daily rate to test the antenna at a third-party antenna measurement facility. Such scenarios are not uncommon, as there are very few locations with readily available test equipment to handle such electrically large antennas.

In contrast, for a 2λ step size, only 11 hours are needed to complete five test cycles. For a 6λ step size, only 2.33 hours are needed to complete five test cycles. Because the tuning process is primarily focused on reducing and balancing the sidelobe levels of the antenna, it is entirely feasible to perform all the tuning and sanity-check testing using 6λ step size for an electrically large antenna within a normal 8-hr workday. If desired, the 0.48λ step size can still be used at the end for final acceptance testing when no further adjustments need to be made to the antenna.

IV. Conclusion

A study was performed on different near-field sampling sizes ranging from 0.48λ up to 6λ and the resultant effects on the radiation patterns for an electrically large antenna. The testing was conducted on a 2.4 m Cassegrain reflector antenna at frequencies of 37 and 50 GHz. The results indicate that there are some small differences in the far-field patterns when comparing results taken from 0.48λ to 2λ step sizes and almost no differences when comparing results taken from 3λ up to 6λ step sizes. Such minor changes in the patterns may be acceptable to save significant amounts of time and money during the tuning and testing stage of electrically large reflector antennas. Further study into near-field sampling sizes can be conducted on different sized reflector antennas operating at higher and lower frequencies to establish a concrete threshold for when an antenna can be considered "electrically large" such that the sampling size can be increased to 2λ and greater without severely affecting the far-field radiation patterns.

Acknowledgement

The authors would like to thank Craig Roberts, Dhanraj Doshi, and Dayong Yang from Eravant for assistance in setting up the 2.4 m antenna on the planar near-field range.

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