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Case Study of Sample Spacing in Planar Near-Field Measurement of High Gain Antennas

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CASE STUDY OF SAMPLE SPACING IN PLANAR NEAR-FIELD MEASUREMENT OF HIGH GAIN ANTENNAS

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SUMMARY

Far-field antenna patterns can be reconstructed from planar near-field measurements acquired at a sample spacing of $\lambda/2$ or less. For electrically large antennas, sampling at the Nyquist rate may result in errors due to system electronic drift over long data acquisition times. Furthermore, the computer capacity may limit the largest size of the near-field data set. The requirement to sample at the Nyquist rate can be relaxed for high gain antennas which concentrate most of the radiated energy into a small angular region of the far-field. The criteria for sample spacing at greater than $\lambda/2$ through the use of a priori information of the antenna radiation characteristics are presented. Far-field patterns of a 30 GHz dual offset reflector system with a 2.7 m parabolic main reflector are computed from near-field data obtained at sample spacings ranging from 0.1 λ to 10 λ. The effects of sampling interval and spectrum cut-off on the far-field patterns are discussed.

INTRODUCTION

The near-field measurement technique has been used extensively for electrically large antennas which can not be easily tested on a far-field range. In reconstructing the far-field antenna patterns from the near-field measurements, a planar configuration may be used with a computation based on the Fast Fourier Transform (FFT). The near-field data are generally sampled over a planar grid at the Nyquist sampling rate of $\lambda_0/2$ spacing or less. For electrically large antennas, sampling at the Nyquist rate requires long data acquisition times over which significant system electronic drift may occur. Furthermore, the computer capacity may limit the largest size of the data set. Special data filtering techniques for large data sets have been reported (ref. 1). However, these techniques still require sampling at $\lambda_0/2$ spacing.

E. B. Joy (ref. 2) discussed how the sampling spacing may be increased through the use of a priori information on the antenna under test. In this paper, the criterion of sample spacing greater than $\lambda_0/2$ is examined and demonstrated using data obtained with an offset Cassegrain configuration.

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FORMULATION

It is well known that the electric field may be represented as a plane wave spectrum (ref. 3)

$$\bar{E}(x,y,z) = \frac{1}{4\pi^2} \iint_{-\infty}^{\infty} \bar{F}(K_x,K_y)\, e^{-j\bar{K}\cdot\bar{r}}\, dK_x dK_y$$

where

$$\bar{K} = K_x\hat{x} + K_y\hat{y} + (K_o^2 - K_x^2 - K_y^2)^{1/2}\,\hat{z}$$

$$K_o = 2\pi/\lambda_o$$

$\bar{F}(K_x,K_y)$ is the wave-number spectrum function which may be expressed as the Fourier transform of the aperture field, $\bar{E}(x,y,o)$, in the x-y plane as follows:

$$\bar{F}(K_x,K_y) = \iint_S \bar{E}(x,y,o)\, e^{jK_x x + jK_y y}\, dx\,dy$$

As $\bar{\gamma}$ tends to infinity, an asymptotic value of $\bar{E}(x,y,z)$ may be found by the method of steepest descent, namely,

$$\bar{E}(\bar{r}) \sim \frac{jK_o \cos\theta}{2\pi r}\, e^{iK_o r}\, \bar{F}(K_o \sin\theta\cos\phi,\ K_o \sin\theta\sin\phi)$$

For plane wave propagating away from the aperture plane at $z = o$, the propagation constant in the z direction is

$$K_z = \left[K_o^2 - K_x^2 - K_y^2\right]^{1/2} \geq 0$$

Thus, radiating modes exist only in the visible region of the real k-space defined by

$$K_x^2 + K_y^2 \leq K_o^2$$

while evanescent modes exist in its complement space. According to the Nyquist sampling theorem, a function whose spectrum exists and is nonvanishing over finite region of wave-number space may be exactly reproduced from its sample values taken on a periodic lattice at a rate of at least two times the maximum frequency, or in terms of wave number, $2k_{max}$. Since the maximum wave-numbers

$k_{x_{max}}$ and $k_{y_{max}}$ which define the boundary of the visible k space is $2\pi/\lambda_o$, the Nyquist sample spacing is given by

$$2K_{x_{max}} \Delta X \leq 2\pi$$

or

$$\Delta x \leq \lambda_o/2$$

Similarly,

$$\Delta y \leq \lambda_o/2$$

For a broad spectrum, the radiated power extends over the entire visible region and a sample spacing of $\lambda_o/2$ is required. However, for high gain antennas such as large reflector systems used on communication satellites at geosynchronous orbit, most of the spectral components are concentrated in the central region of the visible space. Consequently, data acquisition at a sample rate greater $\lambda_o/2$ is possible.

If only the spectrum within the region bounded by $(\pm K_x, \pm K_y)$ is of significance, the sample spacing may then be increased by $k_{x_{max}}/K_x$ and $k_{y_{max}}/K_y$. That is

$$\Delta x = \pi/K_x$$

$$\Delta y = \pi/K_y$$

where $K_x < K_{x_{max}}$ and $K_y < k_{y_{max}}$.

By expressing the wave-number, k_{max}, in spherical coordinate, i.e., $k_{max} = 2\pi/\lambda_0 \sin\theta_{max}$, the maximum elevation angle of coverage, θ_{max}, as a function of sample spacing, Δ, can be computed from

$$\theta_{max} = \sin^{-1}(\lambda_o/2\Delta)$$

For illustration, a few computations of θ_{max} versus Δ are tabulated below

Δ	$\lambda_o/2$	λ_o	$2\lambda_o$	$3\lambda_o$	$5\lambda_o$	$20\lambda_o$
θ_{max}	90°	30°	15°	10°	6°	3°

As indicated above when the sample spacing is increased, only a small angular sector of the far-field can be accurately computed by the FFT. For antennas with broader beams sample spacings approaching $\lambda_0/2$ are required.

DISCUSSION AND RESULT

The effects of sampling at greater than the Nyquist rate were studied experimentally for a dual offset Cassegrain Configuration designed by TRW for NASA Lewis Research Center (ref. 4). The main reflector is parabolic with the following characteristics:

Dish diameter = 257.89 λ_0
Focal length = 318.74 λ_0
Offset length = 135.51 λ_0
Centerfrequency f = 28.5 GHz (λ_0 = 1.05 cm)

The reflector is illuminated by a linearly polarized feed at the focus with a 18 db edge taper. The hyperboloidal subreflector has a magnification factor of 2. The antenna was tested with the planar near-field range currently in operation at the NASA Lewis Research Center, Near-field Centerline data were acquired at $\lambda_0/2$ spacing. The radiation patterns were reconstructed from the centerline near-field data set with a one-dimensional FFT algorithm. For sample spacing greater than $\lambda_0/2$ appropriate subsets were selected from the original data set. The effects of the sample spacings are illustrated in the antenna patterns shown in figures 1(a) to (e).

This antenna patterns showed no perceptible changes from data taken at 0.5, 1, and $2\lambda_0$ spacing. Sidelobe degradation starts to occur at approximately $4\lambda_0$ spacing. The main beam is slightly modified by a sample spacing of up to $8\lambda_0$. For antennas used in space communication application where the beam widths are in the order of 0.3° are often desired, a good choice of sample spacing will be between 2 to $4\lambda_0$.

Spectrum characteristics with cut-off power levels at -30, -40, and -50 dB are shown in figures 2(a) to (c). These spectrum plots were obtained with near-field data taken at a $\lambda_0/2$ spacing. As shown, spectral components with higher cut-off power level occupies a smaller visible region of the K-space, and thus a smaller wave number limit K_x and K_y. This corresponds to sample spacing greater than $\lambda_0/2$.

Figures 3(a) to (c) compares far-field antenna pattern from near-field data taken at $\lambda_0/2$ spacing (dotted line) and spacings implied by the spectrum cut-off plots (solid line). From these figures we can conclude that neglecting data below -40 dB is consistent with sample spacing.

In general, desired pattern accuracy, desired angular range, and available instrumentation dynamic range must be taken into consideration when selecting sample spacing.

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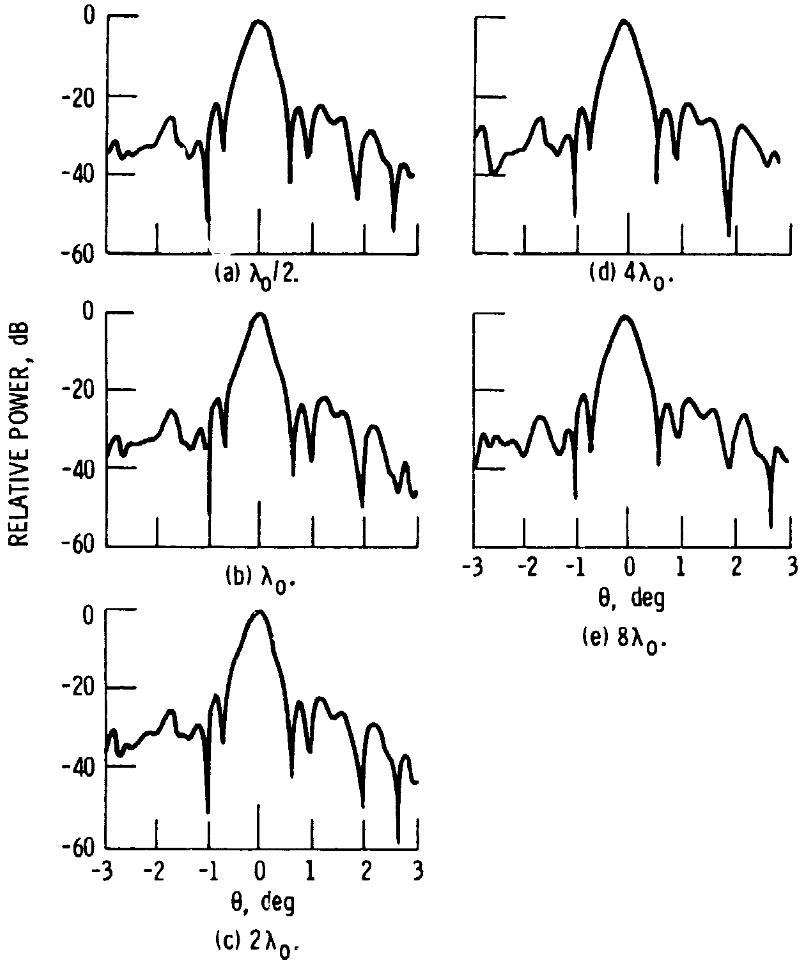

Figure 1. - Relative power pattern as a function of elevation angle for different sample spacing.

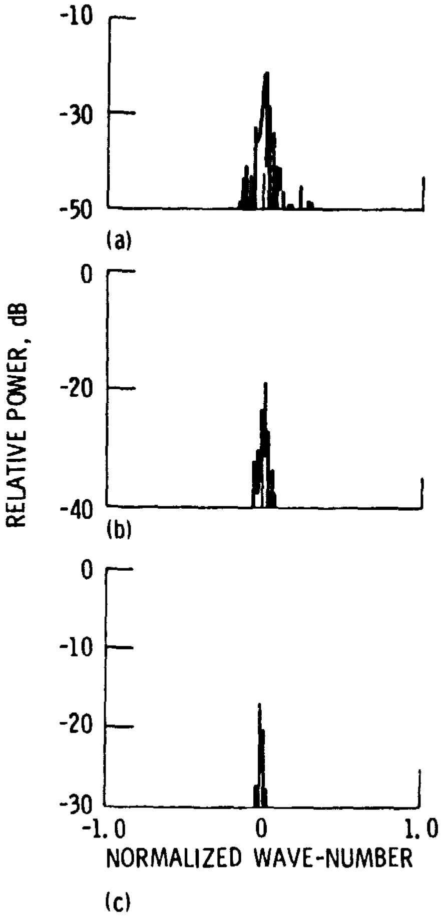

Figure 2. - Power spectrum.

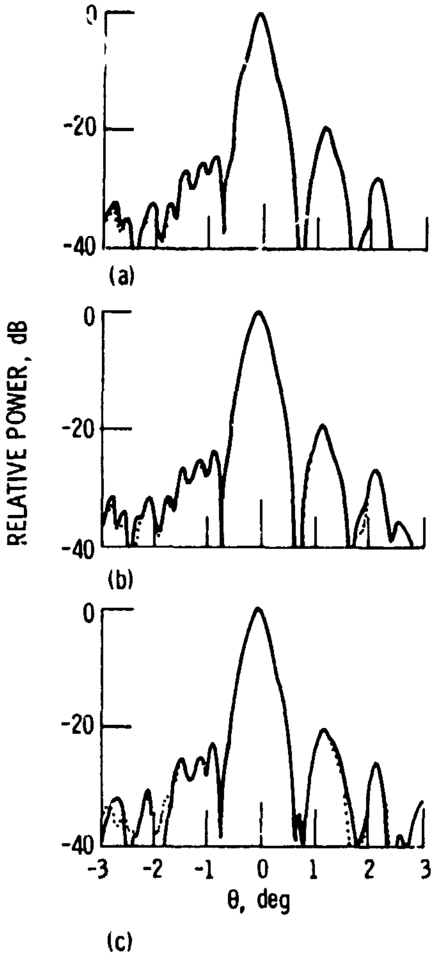

Figure 3. - Relative power pattern as a function of elecation angle.