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SAR ANTENNA CALIBRATION TECHNIQUES

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SUMMARY

Calibration of SAR antennas requires a measurement of gain, elevation and azimuth pattern shape, boresight error, cross-polarization levels, and phase vs. angle and frequency. For spaceborne SAR antennas of SEASAT size operating at C-band or higher, some of these measurements can become extremely difficult using conventional far-field antenna test ranges. Near-field scanning techniques offer an alternative approach and for C-band or X-band SARs, give much improved accuracy and precision as compared to that obtainable with a far-field approach.

1.0 INTRODUCTION

1.1 RATIONALE FOR ANTENNA CALIBRATION

Focused SAR antennas have a two-way synthetic power gain pattern given by

$$G(\theta) = \frac{\left| \sum_{n=1}^{N} A_n e^{j(\beta n \sin\theta + \phi_n)} \right|^2}{\left| \sum_{n=1}^{N} A_n \right|^2} G_r^2(\theta) \qquad (1)$$

where N is the number of elements in the synthetic array, A_n is the processor-controlled amplitude weighting factor, $\beta = 4\pi VT/\lambda$, V = velocity, VT = distance between elements, θ is the angle from beam center, and ϕ_n is the residual uncompensated phase error from the n^{th} element. $G_r^2(\theta)$ is the two-way pattern of the real aperture. This relationship assumes that the return amplitude of a reflector is essentially constant during the integration time NT. Equation (1) is normalized so that the synthetic aperture gain is equal to the real aperture gain if there are no uncompensated phase errors ϕ_n.

Calibration of the real-aperture antenna pattern is necessary to predict image quality and also to determine the minimum detectable σ^0. Such a calibration requires the measurement of antenna gain, sidelobe levels, cross-polarization levels, boresight errors, and far-field phase behavior. For example, the signal-to-noise ratio is proportional to the gain and thus the minimum detectable σ^0 is directly related to the gain. As another example, random phase errors in the far-field pattern are equivalent to the uncompensated phase errors ϕ_n in (1) above; large values of ϕ_n cause synthetic beam broadening and gain reduction, along with beam tilt and increased sidelobe levels. Table 1 is a partial list of measured antenna pattern characteristics and their principal effect on SAR system performance. Specific cause-effect relationships are to be found in the literature on SAR technology.

TABLE 1

SAR ANTENNA CALIBRATION FACTORS

Pattern Characteristics	Effect on SAR System Performance
1. Peak gain	1. SNR; minimum detectable σ^0
2. Pattern shape (amplitude)	2. Ambiguities
a. range sidelobe level	a. range ambiguity level
b. azimuth sidelobe level	b. azimuth ambiguity level
3. Cross-polarization level	3. Ability to cleanly differentiate between σ^0_{hh} and σ^0_{hv}
4. Boresight error	4. Position of antenna beam relative to zero Doppler plane; rate of change of that position
5. Far-field phase pattern deviation from spherical	5. Beam broadening and tilt; gain reduction; increased sidelobes and ambiguity levels

This relationship of antenna pattern characteristics to SAR system performance requires attention to accuracy in measured antenna gain, sidelobe level, cross-polarization level, and boresight error and emphasis on precision in the measurement of phase.

1.2 CALIBRATION TECHNIQUES FOR SPACEBORNE SAR ANTENNAS

Large spaceborne SAR antennas pose special calibration problems not encountered with other antenna systems, primarily as a result of increased measurement accuracy and precision required for these electrically large radiators. For example, as the SAR frequency is increased to C-band, X-band or higher, the range length required can increase to considerably more than a mile so that very few far-field test facilities qualify for an adequate measurement. Moreover, spaceborne SAR antenna support structures are designed for deployment in a 0 G environment so that earth-bound ranges produce handling problems including static stresses, wind, etc.

An alternative test approach makes use of near-field planar scanning techniques and circumvents nearly all of the problems encountered with far-field ranges. The measurement accuracy for nearly every electrical performance parameter is improved with near-field test techniques and antenna handling becomes greatly simplified. The principal disadvantage is psychological, since the method is relatively new and requires numerical inversion of the raw data to produce far-field patterns.

2.0 FAR-FIELD TEST TECHNIQUES

2.1 CANDIDATE FAR-FIELD TEST RANGES

Typical far-field antenna test ranges use two towers separated by distances ranging from 10 m to 2000 m; a transmitting antenna, usually a paraboloidal dish, is mounted on one tower and is used to provide an incident quasi-plane wave illuminating the test antenna which is operated in the receive mode on the other tower. The test antenna is normally exposed to the wind and weather, although it is possible to cover the test zone with a large thin inflated rubberized airdome which then protects the test antenna from environmental effects. Antenna test engineers often use the rule-of-thumb relation $R = 2\, D^2/\lambda$, although this is quite arbitrary; this rule, which corresponds to a 22.5^{o} quadratic phase taper over the test aperture, is inadequate for pattern measurements in connection with spaceborne SAR antennas.

Both the SEASAT and SIR-A antennas are planar arrays approximately 10 m x 3 m in size; Table 2 compares various range separation criteria for a 10 m

TABLE 2

FAR-FIELD RANGE DISTANCES FOR 10 m APERTURE

FREQUENCY	RANGE DISTANCE $2D^2/\lambda$ (22.5^o)	$4D^2/\lambda$ (11.25^o)	$8D^2/\lambda$ (5.63^o)
L-band (1.275 GHz)	850.00 m (2788')	1700.01 m (5576')	3400.02 m (2.11 mi)
C-band (5.000 GHz)	3333.33 m (2.07 mi)	6666.71 m (4.14 mi)	13,333.41 m (8.28 mi)
X-band (9.700 GHz)	6466.67 m (4.02 mi)	12,933.41 m (8.03 mi)	25,866.82 m (16.07 mi)

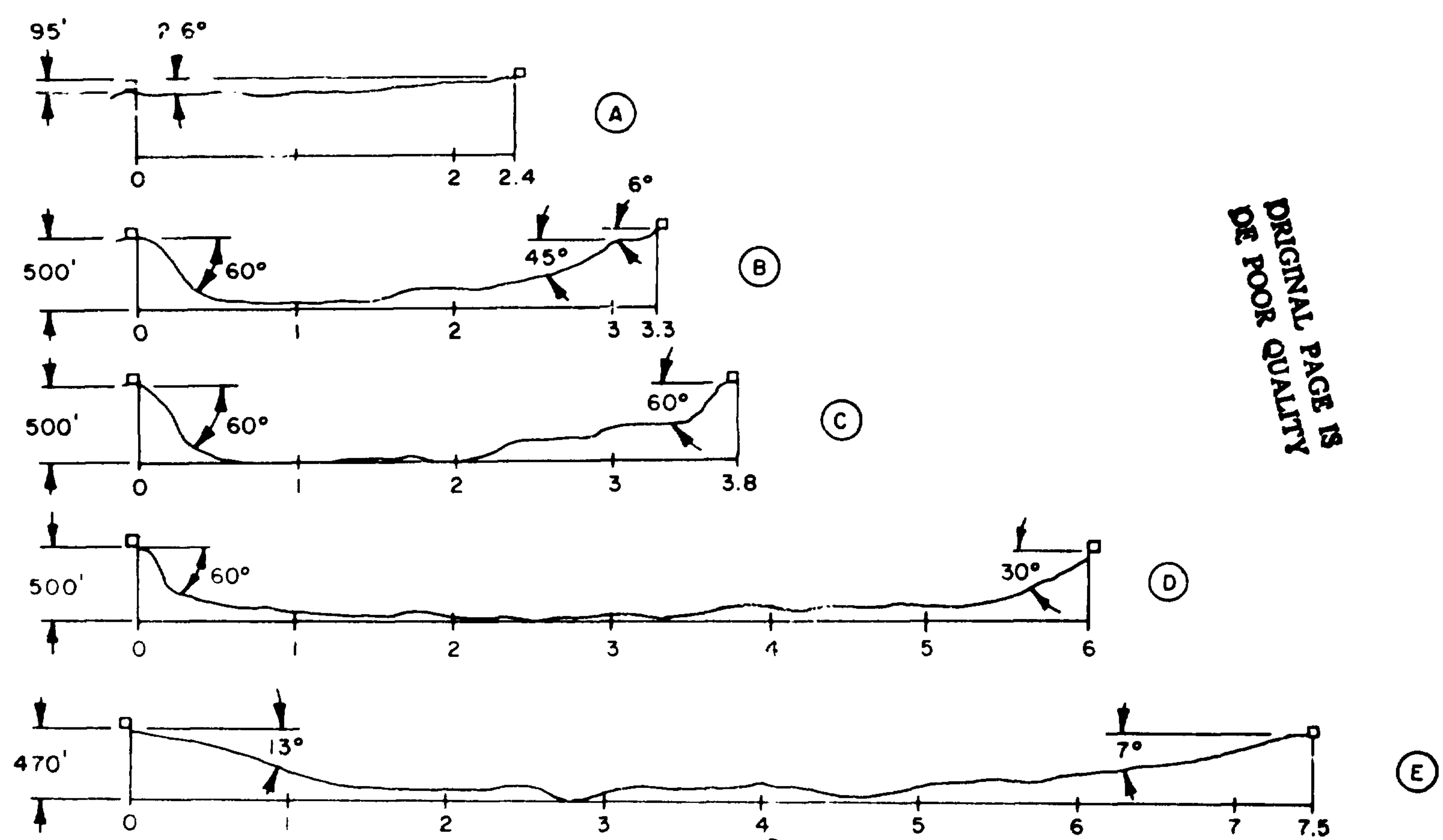
aperture length at L-band, C-band, and X-band. It is useful to compare these distances with some existing well-known far-field antenna test ranges; the characteristics of these ranges are summarized in Table 3 and Fig. 1.

TABLE 3

SOME EXISTING LONG FAR-FIELD TEST RANGES

Name	Location	Range Length	Comment
1. PSL, New Mexico State University	Las Cruces, N. M.	732 m	too short for SEASAT, SIR-A
2. JPL, West Mesa Range	Pasadena, Calif.	1007 m	marginal length for phase test
3. Hughes Aircraft Co. Carbon Canyon Range	Fullerton, Calif.	1156 m	marginal length for phase test
4. Lockheed Santa Cruz	Santa Cruz, Calif.	1829 m	used for SEASAT-A antenna test (air-dome protection)
5. Rome Air Development Center Range	Newport, N. Y.	2287 m	weather can be a problem

The 1829 m Lockheed Santa Cruz range has been used for far-field amplitude pattern tests of the SEASAT L-band SAR antenna, and offers protection from wind and weather by means of a large inflatable airdome which covers the



(A) – PSL/NMSU, TORTUGAS MT. AUX RANGE, LAS CRUCES, N.M.

(B) – JPL/CIT, WEST MESA LONG RANGE, PASADENA, CA.

(C) – HUGHES A/C CO., CARBON CANYON RANGE, FULLERTON, CA.

(D) LOCKHEED SANTA CRUZ RANGE, SANTA CRUZ, CA.

(E) – ROME ADC/USAF RANGE, NEWPORT, N.Y.

Figure 1. Vertical profiles of long baselength far-field antenna ranges.

positioner, test antenna, etc. This range is slightly longer than $4D^2/\lambda$ at L-band.

2.2 REQUIRED MEASUREMENT ACCURACY FOR SIR-A ANTENNA

As an example of typical spaceborne SAR antenna performance parameters and specified measurement uncertainties, consider the 10 m x 3 m SIR-A antenna with specifications as listed in Table 4 (1).

TABLE 4

SIR-A ANTENNA PERFORMANCE SPECIFICATIONS
AND MEASUREMENT UNCERTAINTY
FREQUENCY = 1.27 GHz

Parameter	Nominal Value	Measurement Uncertainty
Gain	33 dBi	± 0.7 dB
Elevation Sidelobe Level	-14.5 dB	± 0.4 dB
Azimuth Sidelobe Level	-14.5 dB	± 0.4 dB
Cross-Polarization Level	-25 dB	unspecified
Azimuth Far-field Phase	***	3.5° rms over -8 dB beamwidth
Maximum Total Boresight Error	± 2.0°	0.1°
Voltage Amplitude vs. Freq. (over 7 MHz bandwidth)	***	8% rms w.r.t. best linear fit
Voltage Phase Delay vs. Freq. (over 7 MHz bandwidth)	***	5° rms w.r.t. best quadratic fit
VSWR	1.5 max	unspecified
Payload Bay RFI	$2\ V\ m^{-1}$	unspecified

2.3 PERFORMANCE CRITERIA FOR FAR-FIELD RANGES

From Table 4, the principal SAR antenna parameters to be measured are (1) gain, (2) pattern shape and sidelobe level, (3) cross-polarized level, (4) boresight, (5) phase vs. angle over azimuth pattern to - 8 dB, (6) phase vs. frequency over the bandwidth, and (7) amplitude vs. frequency over the bandwidth.

2.3.1 GAIN MEASUREMENT ERROR BUDGET: FAR-FIELD TECHNIQUES

In a far-field gain measurement made by comparison to a standard antenna, there are nine principal sources of error; these are briefly discussed here.

1. Accuracy of gain standard

Using extrapolation techniques developed by NBS (Boulder) it is possible to measure the gain of a reference standard horn to $\pm$ 0.10 dB. This is discussed further in Section 3.3.1.

2. Range reflections

Reflections from specular zones on the terrain between towers and from antenna support structures cause multipathing and therefore a variation of the field over the region occupied by the test SAR antenna. If the ratio of maximum to minimum field is R, then the reflectivity is given by

$$F = 20 \log \; (R - 1)/(R + 1) \qquad (2)$$

A reflectivity of -39 dB corresponds to R = 1.023 or a 0.20 dB excursion in incident power density levels over the quiet zone. At L-band, and for a 10 m x 3 m quiet area, this $\pm$ 0.20 dB value can be considered to typify a good far-field range.

3. Cross-polarized return error

Cross-polarized incident waves resulting either from the source antenna or from depolarized multipath signals can cause errors in the measured gain. Assuming an intrinsic range cross-polarized level of - 35 dB and a test SAR antenna cross-polarized level of -30 dB (with respect to beam peak principal-polarization level), the equivalent cross-polarized component is -65 dB with respect to the beam peak. Using a relation similar to that in (1), we can show that this produces a gain error of $\pm$ 0.01 dB in the gain of the principal-polarization component.

4. Boresight inaccuracy

By examining the slope sensitivity of the azimuth pattern of the SIR-A antenna to angle, it can be shown that an error of 0.1^{0} in positioning angle will cause the pattern to roll off by 0.05 dB at L-band.

5. Detector nonlinearity

If a 17 dBi standard-gain horn is used for gain comparison, this is 16 dB below the peak gain of the SIR-A antenna. If an attenuator-compensation technique is used, nonlinearity errors can be reduced to $\pm$ 0.05 dB.

6. Detector-antenna mismatch

Assuming that the VSWR into the antenna or into the detector does not exceed 1.1, it can be shown that the gain error due to mismatch is $\pm$ 0.049 dB. This can be reduced if the phase of the reflection coefficients is known.

7. Short-term instabilities : $\pm$ 0.01 dB, estimated

8. Inadequate receiver-transmitter separation

A finite length range produces a quadratic phase taper of the illuminating wave with respect to plane, and thus causes a reduction in apparent gain over that obtained with a truly plane wave. The reduction in gain can be estimated by

$$\Delta G = 10 \log e^{-(\delta/2)^2} \tag{3}$$

where δ is the maximum quadratic phase error, given by

$$\delta = (2\pi/\lambda)(D^2/8R) \tag{4}$$

For a range length of 1829 m (e.g., Lockheed Santa Cruz range) and a 10 m aperture dimension, this corresponds to a gain reduction of 0.036 dB at L-band and 2.115 dB at X-band.

9. Roll-off of source antenna pattern

By an appropriate choice of source antenna diameter, this source of error can be reduced to less than 0.001 dB; this dictates that a sufficiently small diameter dish be used and must be balanced with the additional requirement that the source antenna beamwidth be large enough to keep the range reflectivity to the order of -39 dB.

2.3.2 GAIN MEASUREMENT ERROR SUMMARY FOR FAR-FIELD TECHNIQUE

Table 5 summarizes the principal sources of gain error and the RSS net error.

2.3.3 CROSS-POLARIZATION LEVEL

Assuming a -35 dB residual range cross-polarization level, the error in measuring a nominal -30 dB SAR antenna cross-polarization component would be (+3.9 dB, -7.2 dB); if the nominal antenna cross-polarization level were -20 dB, the measurement error would then decrease to $\pm$ 0.27 dB.

2.3.4 SIDELOBE LEVEL

Assuming a range reflectivity of -39 dB, the error in measurement of a first sidelobe level at a -15 dB nominal value would be $\pm$ 1.10 dB.

TABLE 5

ESTIMATES OF ERROR IN ON-AXIS GAIN USING FAR-FIELD TECHNIQUES

Source of Error	Error in Gain at L-band
1. Accuracy of gain standard	± 0.10 dB
2. Range reflections	± 0.20 dB
3. Cross-polarized returns	± 0.01 dB
4. Boresight inaccuracy	- 0.05 dB
5. Detector nonlinearity	± 0.05 dB
6. Detector-antenna mismatch	± 0.05 dB
7. Short-term instabilities	± 0.01 dB
8. Finite range-length	- 0.04 dB
9. Roll-off of source pattern	0.00 dB
RSS uncertainty	± 0.24 dB

2.3.5 PHASE VS. ANGLE

In a far-field range measurement of phase, the test ante ıa is positioned so as to rotate about the apparent phase center. This point of rotation minimizes the variation of phase vs. angle over the main beam. For an ideal antenna with a fixed point phase center, the phase fronts are spherical so that in principle there is no variation of phase with angle as the antenna is rotated about the phase center. In practice, however, the apparent phase center wanders as the look angle is changed.

Errors in the phase measurement result from (1) an inadequate range separation distance (vide Table 2) and (2) interference effects caused by range reflections. Consider, for example, the Lockheed Santa Cruz range (Table 3) of 1829 m length; for the 10 m dimension of SIR-A, this finite length would introduce a quadratic phase taper over the test aperture with a maximum of 10.4^{o} at the aperture edges. Assuming a -40 dB range reflectivity (equivalent spurious field is 0.01 times direct-wave field), the additional phase error incurred is $\pm 0.57^{o}$ maximum on the beam peak. At the -8 dB level on the main beam the effective reflectivity is -32 dB, and the range reflectivity contribution to the phase error increases to $\pm 1.44^{o}$. Under these conditions, the worst-case phase error over the -8 dB beamwidth is therefore $\pm 11.8^{o}$.

This is about three times the phase error tolerance specified in the Functional Requirements Document for the SIR-A antenna (Table 4). If the range length is increased in order to reduce the quadratic phase taper error, the ground scatter will increase and thus will begin to dominate the phase error budget. It appears that no available far-field range can measure the phase pattern to within 3.5^{o} rms error for the SIR-A antenna.

2.4 SUMMARY OF FAR-FIELD RANGE REQUIREMENTS FOR SIR-A

Table 6 summarizes the performance required of far-field ranges in order to meet the error limits discussed previously. Although these are specifically for SIR-A, they may be taken as representative of other spaceborne SAR antenna range calibration requirements.

TABLE 6

FAR-FIELD TEST RANGE REQUIREMENTS FOR SIR-A

Characteristic	Performance Level
1. Frequency range	1264 - 1286 MHz
2. Minimum range length	1800 m
3. Range reflectivity	-39 dB over test volume
4. Gain accuracy	±0.7 dB (worst case)
5. Boresight accuracy	$\pm 0.1^{o}$
6. Mechanical stability	wind below 2 mph

3.0 PLANAR NEAR-FIELD TEST TECHNIQUES

3.1 ADVANTAGES OF NEAR-FIELD MEASUREMENTS FOR SIR-A

Because of the special problems posed in the calibration of an electrically large SAR antenna, planar near-field (PNF) measurement techniques offer an attractive alternative to conventional far-field measurements. The required accuracies can be achieved in a measurement environment that is more compatible with the large lightweight antenna designed to operate in zero gravity. It is not subject to the effects of wind, weather, or motion of the antenna during measurement which can cause distortion in the antenna surface and, therefore, degrade the reliability and accuracy of the results.

In PNF measurements the antenna under test (AUT) remains stationary while a probe moves over a plane area very close to the aperture. Measurements are made approximately every half wavelength in both x- and y-directions of the amplitude and phase of the signal received by the probe. The resulting matrix of data, $B_1(x,y)$ is recorded on magnetic tape or disc for future processing. Normally the probe is essentially polarization matched to the AUT during the above measurement, and in order to obtain complete polarization results, a second measurement is performed with an independent probe, usually the original probe rotated about its axis by 90^o. The two data arrays $B_1(x,y)$ and $B_2(x,y)$ are computer processed to obtain the angular spectra, correct for the directive and polarization patterns of the probe, and calculate the usual far-field parameters for the AUT. It should be emphasized that in the measurements and data processing, the only approximations are that multiple reflections between the probe and AUT are small enough to neglect, and the measurement area is truncated to a finite size. Neither the AUT or probe need possess special pattern/polarization properties, or be reciprocal, and the numerical techniques involved do not introduce small angle or other approximations. In short, the technique is based on a very general and powerful theory, and is capable of producing high accuracy results. This capability has been demonstrated in a number of ways on a large variety of antennas.

3.2 SPECIAL TECHNIQUES REQUIRED FOR SIR-A

Because of the large dimensions of the SIR-A antenna, the usual PNF measurement techniques must be modified slightly in order to use existing facilities. In general, measurements must be made over an area somewhat larger than the dimensions of the AUT. The length of the scan in the x-direction L_x, the corresponding antenna dimension a_x, and the probe-to-AUT distance D, determine the maximum angle for which the computed results are reliable through the relationship

$$\theta_s = \arctan \frac{L_x - a_x}{2d} \qquad (5)$$

A similar relation holds for the y-direction. Assuming d = 40 cm, a_x = 10 m, a_y = 3 m, and $\theta_s = 60^o$ requires a scan length of approximately 11.4 m by 4.4 m. The largest planar scanner presently in operation is shown in Fig. 2 and has a measurement area of 3.85 m by 4.5 m. To accomodate the SIR-A

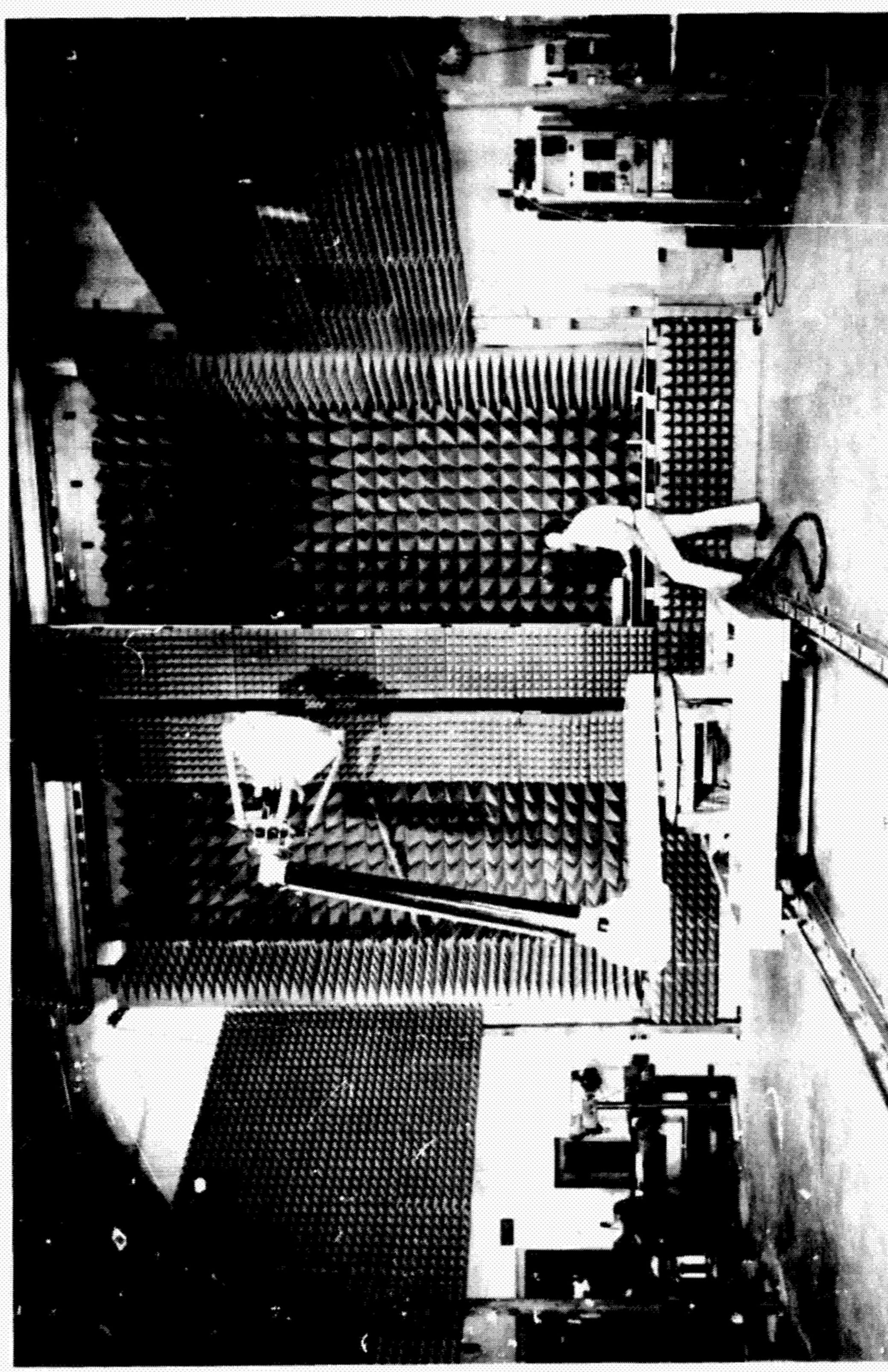


Figure 2. Planar near-field measurement facility at the National Bureau of Standards.

antennas, the measurement must be performed in three parts with the antenna translated in the x-direction in increments of 3.8 m between each scan as shown in Fig. 3. This requires careful angular and translational indexing to maintain the SIR-A in the same measurement plane after translation and re-establish the correct x- and y-positions. Similar realignments have been done in the past using an optical autocollimator for angular rotation sensing, and a laser interferometer for translation measurement, and the requirements here do not appear to be unreasonable.

3.3 ESTIMATES OF ERROR IN RESULTS FROM PNF MEASUREMENTS

Extensive work has been done to study the effect of errors in the measured near-field data upon the calculated results. This has included comparisons with other measurement techniques, computer simulation of var ypes of errors, and mathematical analysis. The mathematical analysis most general application because it provides equations in terms of simple antenna parameters and estimes of error in the PNF system from which upper bound errors may be determined. For instance, the error in dB in on-axis gain due to maximum probe position errors of Δ_x, Δ_y, and Δ_z respectively in the x-, y-, and z-directions is given by

$$\Delta G = \frac{8.7}{\eta}\left[\frac{\Delta_x}{L_x} + \frac{\Delta_y}{L_y}\right] + \frac{43}{\sqrt{\eta}}\left[\frac{\Delta_z}{\lambda}\right]^2 \qquad (6)$$

In the above, η is the antenna aperture efficiency, λ the wavelength, L_x and L_y the antenna dimensions. Similar expressions have been derived for errors in sidelobe level, monopulse difference null, bearwidth, boresight direction, main beam phase, and cross-polarization level in terms of the above position errors as well as errors arising from receiver nonlinearity, multiple reflections, measurement area truncation, probe pattern uncertainty, and amplitude normalization.

In the following estimates, we have used the uncertainties associated with the National Bureau of Standards near-field measurement facility. The maximum probe position errors in all three directions are $\pm$ 0.013 cm, the receiver amplitude error is $\pm$0.005 dB/dB, and the receiver phase error is $\pm$ 5 degrees. Multiple reflections produce a ripple in the measured data of

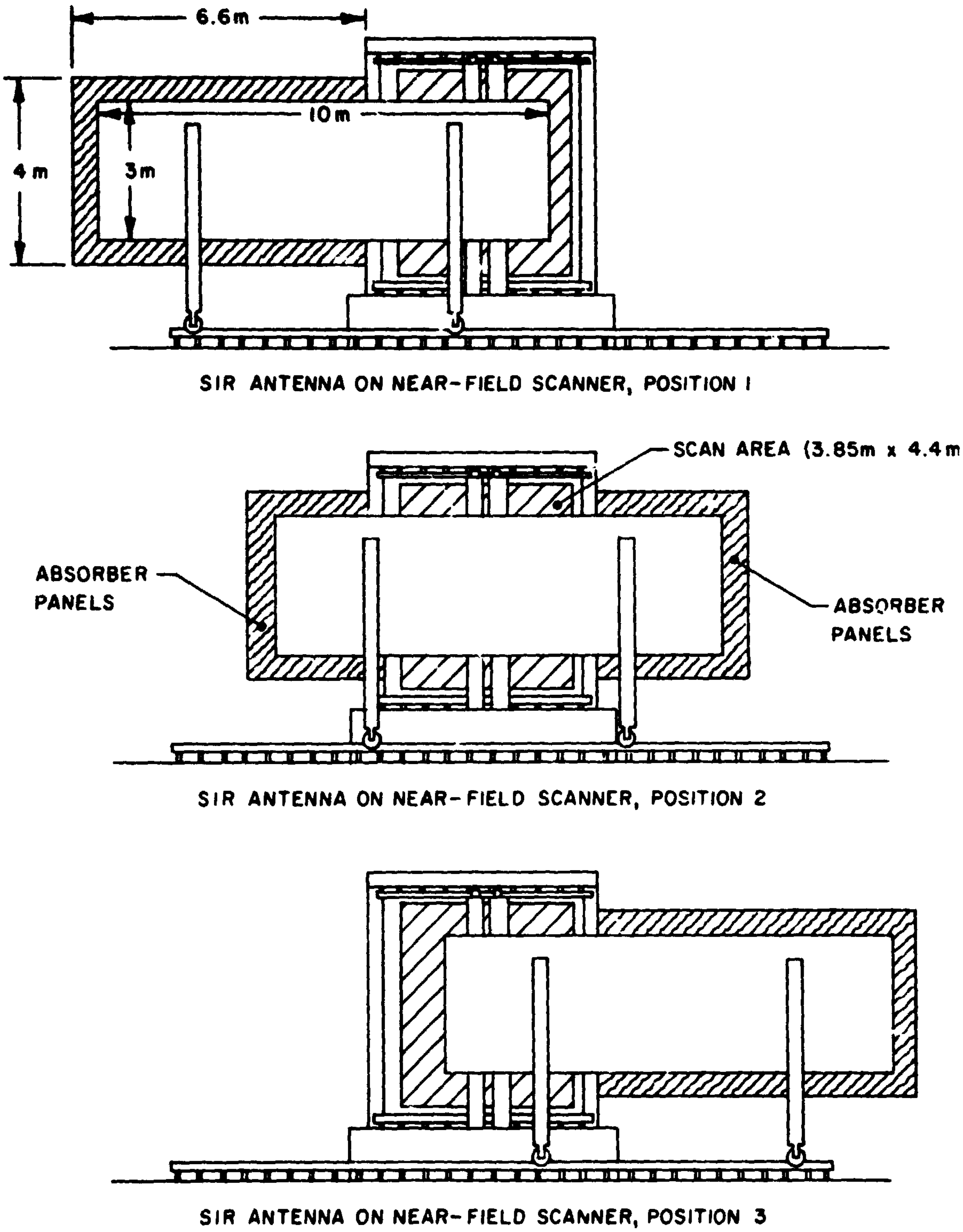


Figure 3. Schematic of SIR antenna in three positions for PNF measurement.

±0.1 dB, the probe gain is accurate to within ± 0.10 dB, and the amplitude normalization uncertainty is ± 0.05 dB. It is further assumed for estimating the effect of area truncation that the measured amplitude at the extremes of the scan area is at least 30 dB below the peak near-field amplitude.

3.3.1 GAIN MEASUREMENT ERROR BUDGET: NEAR-FIELD TECHNIQUES

Table 7 below summarizes the errors in on-axis gain for both the L-band and X-band of a 10 m x 3 m SAR planar array.

TABLE 7

ESTIMATES OF ERROR IN ON-AXIS GAIN USING PLANAR NEAR-FIELD TECHNIQUES

Source of Error	Error in Gain in dB L-Band	Error in Gain in dB X-Band
1. Amplitudes nonlinearity	± 0.12	± 0.12
2. Probe gain uncertainty	± 0.10	± 0.10
3. Multiple reflections	± 0.05	± 0.05
4. Normalization amplitude	± 0.05	± 0.05
5. Area truncation	± 0.02	± 0.003
6. Receiver phase	± 0.01	± 0.02
7. _-position	< 0.001	< 0.001
8. x-position	< 0.001	< 0.001
9. y-position	< 0.001	< 0.001
RSS uncertainty	± 0.17 dB	± 0.17 dB

3.3.2 CROSS POLARIZATION UNCERTAINTIES

All of the above sources of error contribute to the error in cross polarization with the exception of the probe gain. The absolute gain of the probe does not enter into the polarization calculation, but the probe polarization does in much the same way that the polarization of the source antenna enters into far-field measurements. Usually the polarization of the probe is measured along with its gain in a generalized 3-antenna measurement to an uncertainty of approximately ± 0.05 d er dB of axial ratio. The net effect of all sources of error is that the cross polarizat of the AUT is uncertain to ± 1.1, ± 3.3, and ± 10.2 dB for cross component levels of -20, -30 and -40 dB below the main component. These values are for both on-axis and sidelobe regions.

3.3.3 SIDELOBE LEVEL UNCERTAINTIES

In this case, it is the probe gain and normalization amplitude uncertainties which do not effect sidelobe levels, but a knowledge of the relative probe pattern is important as it enters into the probe correction of the measured data. When all sources of error are considered, the uncertainties in sidelobe pattern levels are, respectively, ± 0.6, ± 1.2, and ± 2.7 dB for -20, -30, and -40 dB sidelobes.

3.3.4 PHASE VERSUS ANGLE

In the mathematical error analysis, the relative change in the amplitude of the far-field $\Delta E/E$ has been computed for various sources of error in the measured near-field data. If ΔE is in phase with E, the amplitude change will be a maximum, while if ΔE is 90^o out of phase with E, the effect will be to alter the phase of the computed far-field. Errors in far-field phase may, therefore, be obtained from the amplitude error equations by

$$\Delta\phi = \arctan \frac{\Delta E}{E} = \frac{180}{\pi} \frac{\Delta E}{E} \qquad (7)$$

Using this modification in the error equations, one finds that the most serious errors are due to receiver amplitude and phase nonlinearity and to a lesser extent, multiple reflections and z-position errors. The net effect is to produce an error in the phase at the -6 dB level on the main beam of about 4 degrees.

3.3.5 PHASE AND AMPLITUDE VERSUS FREQUENCY

This requirement implies a swept-frequency measurement of the antenna response in the on-axis or maximum gain direction and is one measurement where near-field techniques are more difficult than far-field measurements. Near-field measurements are by nature fixed frequency measurements, and swept-frequency results must be obtained from a series of near-field measurements made at closely spaced frequencies. These measurements can be accomplished during one physical scan if the source and receiver are stepped through the frequencies as the probe moves between data points.

4.0 COMPARISON OF FAR-FIELD AND NEAR-FIELD MEASUREMENT UNCERTAINTIES

Table 8 compares the uncertainties obtained through far-field and near-field approaches to a measurement of an L-band SAR antenna which is 10 m x 3 m in area. A far-field range reflectivity of -39 dB over the quiet zone is assumed.

TABLE 8

COMPARISON OF FAR-FIELD AND NEAR-FIELD MEASUREMENT UNCERTAINTIES

Parameter	Uncertainty Far-field	Uncertainty Near-field
1. Gain	± 0.24 dB	± 0.17 dB
2. Sidelobe Level (-15 dB)	± 1.10 dB	
(-20 dB)	± 1.96 dB	± 0.60 dB
(-30 dB)	± 6.44 dB	± 1.20 dB
3. Cross-polarization level (-30 dB)	+ 3.9 dB - 7.2 dB	± 0.15 dB
4. Phase vs. angle over -6 dB beamwidth	$\pm 11^{o}$	$\pm 4^{o}$
5. Phase/amplitude vs. freq.	?	?

It is seen from this table that the near-field measurement is generally superior from an electrical parameter measurement uncertainty viewpoint. Also, it should be emphasized that the handling of large SAR antennas designed for zero gravity environments is greatly simplified with the near-field approach.

5.0 REFERENCE

1. Elachi, C., J. M. Vickers, R. Jordan, and J. Granger, "Space Shuttle Functional Requirements for SIR-A," Spec. FM511174, Rev. A, Jet Propulsion Laboratory, Pasadena, California, Nov. 23, 1977.