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A CERTIFICATION PLAN FOR A PLANAR NEAR-FIELD RANGE USED FOR HIGH-PERFORMANCE PHASED-ARRAY TESTING

Michael H. Francis
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Electromagnetic Fields Division
Electronics and Electrical Engineering Laboratory
National Institute of Standards and Technology
Boulder, Colorado 80303-3328

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The National Institute of Standards and Technology (NIST) has written a certification plan to ensure that a proposed planar near-field range is capable of measuring high-performance phased arrays. Generally for a complete plan, one must evaluate many aspects including scanner alignment, near-field probe alignment, alignment of the antenna under test, rf crosstalk, probe position errors, rf path variations, the receiver's dynamic range and linearity, leakage, probe-antenna multiple reflections, truncation effects, aliasing, system drift, room multipath, insertion loss measurements, noise, and software verification. In this report, we discuss the important aspects of a certification plan specifically written for the measurement of high-performance phased-array antennas. Further, we show how the requirements of each aspect depend on the measurement accuracies needed to verify the performance of the array under test.

Key words: antennas; antenna measurements; phased array; planar near field.

1. INTRODUCTION

Recently, NIST prepared a certification plan for a proposed planar near-field (PNF) range to be used in high-performance phased-array testing. This certification plan was drawn up based upon information supplied to NIST on the planned application. This information included required measurement accuracies for gain, main- and cross-polarization pattern, RMS sidelobe level, and beam steering. Each of these accuracy requirements affects various aspects of the range. For example, the sidelobe level to which one must make accurate measurements will determine how well the PNF scanner rails must be aligned and how well the probe must be positioned. The same sidelobe specification will also determine what levels of leakage and room scattering can be accepted.

In this report, we discuss those factors one must consider in demonstrating that a range is capable of making PNF measurements to the desired accuracy. The proposed PNF range to be tested (hereinafter called the Range) has the design shown in figure 1. The antenna under test (AUT) and the probe both can move in X and Z. This feature allows for easier determination of the effects of probe-AUT multiple reflections and room scattering on the AUT parameters.

In section 2 we discuss some policy considerations, and in section 3 we indicate the phased array measurement requirements that drive the specifications of the PNF Range. In sections 4 through 7, we discuss the tests required for certifying the PNF Range. Tests are divided into four categories: (1) tests performed by resident PNF Range personnel, (2) tests performed by or under the direct supervision of NIST personnel, (3) software comparison tests, and (4) measurement comparison tests. Section 8 contains a summary.

2. POLICY ISSUES

2.1. Purpose of Certification Process

NIST intends that the certification process, when successfully completed, will verify (1) that the planar near-field (PNF) technology has been successfully transferred, and (2) that the PNF Range and its personnel are capable of measuring antenna parameters of high- performance phased arrays of a specified size to the required accuracy over a specified frequency range.

One of the major goals of NIST is technology transfer. We hope therefore that any problems that become apparent during the certification process can be resolved so that the certification process can be successfully completed. Toward this end NIST will provide advice and consultation to a customer, whenever possible, to help resolve such problems. NIST certification does not guarantee that accurate measurements will be performed, and only indicates that accurate measurements are possible.

2.2. Certification Period

Planar near-field measurements are complex and involve detailed theory and complex measurement techniques. Accurate PNF measurements require both a good PNF range and qualified personnel to perform the measurements and process the data. For these reasons, the PNF range and its personnel are certified as a unit.

The average electronics engineer in industry changes jobs about every 5 to 7 years. Much of the equipment used on the PNF range requires a major repair or replacement in roughly the same time frame. Thus, it seems appropriate to make the certification valid for 7 years.

2.3. Certification Costs

Since NIST is required by law to recover the cost of its services, the cost will necessarily vary from range to range and will also depend on the PNF Range's required measurement accuracies.

3. AUT MEASUREMENT REQUIREMENTS

The PNF Range is required to measure the gain of a 4.5 m diameter phased array to an accuracy of 0.2 dB. The Range must also have the ability to measure -55 dB sidelobes to an accuracy of 5 dB and beam steering angles up to 60° to an accuracy of 20". This phased array will operate at frequencies up to 4 GHz.

To ensure that the above measured parameters meet the required accuracies, we need to evaluate the individual error sources and place limits on them so that their combinations meet the requirements. Preliminary error budgets for gain, sidelobe level, and beam steering are shown in tables 1 through 3. These error budgets come primarily as a result of NIST error analyses. These budgeted errors correspond to worst-case errors (3σ values for the random errors). Note that we have used a root sum square to combine the errors in each budget. In combining errors in this way, we have assumed that the errors are independent and therefore are not likely to all add in the same direction. From experience this is usually a valid assumption. However in a rigorous sense, the only way to guarantee that the total error is below a required value is by ensuring the arithmetic sum of the individual errors is less than the required total error.

The error budgets found in tables 1 through 3 will drive the specifications for the PNF measurement system either through the error equations of Newell [1] and Yaghjian [2] or through rules that are derived from NIST's expertise. These are discussed in the next section.

Table 1. Error budget for AUT gain measurement.

Error Source	Error (dB)
Probe relative pattern	0.00
Probe polarization ratio	0.00
Probe gain measurement	0.11
Probe alignment	0.02
Normalization constant	0.05
Impedance mismatch factor	0.04
AUT alignment	0.02
Data point spacing (aliasing)	0.00
Measurement area truncation	0.05
Probe position errors	0.02
Probe-AUT multiple reflections	0.10
Receiver nonlinearity	0.01
Receiver dynamic range	0.00
Flexing cables	0.01
Temperature effects	0.01
Room scattering	0.00
Leakage and crosstalk	0.00
Random errors	0.05
Root Sum Square	0.18

Table 2. Error budget for -55 dB sidelobe measurement.

Error Source	Error (dB)
Probe relative pattern	0.5
Probe polarization ratio	0.5
Probe gain measurement	0.0
Probe alignment	0.5
Normalization constant	0.0
Impedance mismatch factor	0.0
AUT alignment	0.5
Data point spacing (aliasing)	0.8
Measurement area truncation	0.5
Probe position errors	1.8
Probe-AUT multiple reflections	2.4
Receiver nonlinearity	0.2
Receiver dynamic range	0.5
Flexing cables	1.5
Temperature effects	1.5
Room scattering	1.4
Leakage and crosstalk	0.8
Random errors	0.8
Root Sum Square	4.4

Table 3. Beam steering measurement error budget.

Error Source	Error (")
Probe alignment	5
AUT alignment	5
Scanner alignment	5
Other[1]	10
Root sum square	14

4. TESTS BY RESIDENT PNF RANGE PERSONNEL

There are several major types of tests that resident Range personnel must perform to characterize the errors associated with measurements on the range. They include tests to determine alignment accuracy, errors caused by the instrumentation, and errors due to rf energy traveling undesired paths. In a rigorous sense, most of these tests should be performed for each unique probe-AUT combination. Because of the nature of these tests, they will demonstrate not only if the PNF range is capable of making measurements to the desired accuracies but also if resident Range personnel are able to determine the errors associated with a particular measurement.

[1] Currently, there are no equations or rules of thumb that predict how most error sources affect the measurement of the beam-steering angle. However, errors in the measurement of the beam-steering angle have been observed for probe-AUT multiple reflections, truncation, and aliasing.

4.1 Alignment Tests

For this particular AUT, the sidelobe measurement accuracy, the beam steering angle, and beam steering accuracy are the important conditions that drive the mechanical requirements of the scanner. Note that both translational and angular requirements apply to the alignment of the rails, rotators, scan plane mirror, the AUT, and the probe. Evaluation of these conditions leads to the scanner alignment requirements in table 4. All alignment tests shall be performed twice. The minimum time interval between performances of the same test shall be one week. This is necessary to ensure the stability and repeatability of the measurement system.

Specifically for the case of a steered beam, X-, Y-position errors cause errors in the sidelobe direction $\vec{K}$, given by eq (58), [1]

$$\left|\frac{D_e'(\vec{K})}{D'(\vec{K})}\right|_{dB} \leq \frac{13.5\ \Delta(\vec{K})}{\lambda} \sin\theta_b\ g(\vec{K}), \tag{1}$$

and Z-position errors cause errors in the sidelobe given by eq (61), [1]

$$\left|\frac{D_e'(\vec{K})}{D'(\vec{K})}\right|_{dB} \leq \frac{13.5\ \delta_z(\vec{K})}{\lambda} \cos\theta_b\ g(\vec{K}), \tag{2}$$

where $\Delta(\vec{K})$ and $\delta_z(\vec{K})$ are the Fourier transforms of the position errors $\Delta\vec{P}(\vec{P})$ and $\delta Z(\vec{P})$. $g(\vec{K})$ is the ratio $(D'(\vec{K}_0)/D'(\vec{K}))$ with $\vec{K}_0$ being the direction of the main beam, and θ_b is the beam-steering angle.

The largest errors occur for periodic errors in δZ and $\Delta\vec{P}$, see [1]. For example, using eq (2), assuming a wavelength of 7.5 cm, and a probe alignment error of 0.5 dB (table 2), then a Z-position error with a period in X of ℓ_x will cause errors in the directions corresponding to $K_x = \pm 2\pi/\ell_x$ with magnitudes (in decibels) of $(8.7\pi/2\lambda)\delta Z_{max} \cos\theta_b\ g(K_x = \pm 2\pi/\ell_x)$. In all other directions the error will be zero. The pattern errors caused by periodic position errors lead to the ΔX, ΔY, and ΔZ alignment requirements of table 4.

Angular alignment errors lead directly to errors in determining the beam-steering angle. Thus a 5" error in the scanner alignment will cause a 5" error in the location of the beam. This leads to the angular requirements of table 4.

4.1.1 Scanner Alignment

To meet the requirements of table 4, one may align the PNF range to satisfy the requirements discussed above or one may use software compensation to correct for any residual inadequacy (provided that it is much less than a half wavelength). If personnel cannot make alignments to the required accuracy, software compensation still requires the ability to measure alignment errors with sufficient precision. If the position errors are measured with sufficient accuracy, one can make corrections using the k-correction technique [3], or the technique of Muth and Lewis [4]. The accuracies given below can be met using one of these software compensation methods. It will be difficult to meet the mechanical requirements without software compensation, though it is possible.

Table 4. Scanner alignment requirements.

<u>Translation</u>	
ΔX vs. X1,X2,Y	0.01 mm
ΔY vs. X1,X2,Y	0.01 mm
ΔZ vs. X1,X2,Y	0.01 mm
<u>Angle</u>	
Z1 perpendicular to X1,X2	2"
Z2 perpendicular to X1,X2	2"
Y perpendicular to X1,X2	2"
X1 parallel to X2	2"

A file which is compatible with the computer system and which contains a digital map of all the alignment errors shall be saved for future use and for comparison with NIST alignment test results.

The alignment of the scanner shall be determined using the following procedure. First, the straightness accuracy of the front X1 rail (the rail closest to the AUT, see fig. 1) shall be measured using a laser measurement system with straightness interferometer optics and a separate laser position measurement system. The straightness interferometer optics, part of which is on the probe transport mechanism, should be located close to the X1 axis when the mechanism is at the bottom Y position. The laser straightness measurement system must be set up parallel to the average of the X1 axis and is used along with the laser position measurement system to measure the ΔZ1 versus X1 along this rail at intervals of 2 cm (about $\lambda/4$ at 4.0 GHz) or less in X1. This quantity we designate as ΔZ_H. Second, the laser straightness measurement system, the laser position measurement system, and an optical square which has an accuracy of 1" or better should be used at the mid-range, X_0, of the X1 rail to measure ΔZ1 along the Y rails at intervals of 2 cm or less. This quantity we designate as ΔZ_V. Third, the laser position measurement system and an electronic level are used to measure the rotation about the front X1 rail (i.e., the forward-backward tilt in the Y-Z1 plane with a tilt away from the AUT being positive) at intervals of 2 cm or less in X1. We designate this angle by ϵ_{TILT}. Fourth, the laser position measurement system and the electronic level shall be used to measure the rotation about the Z1 axis at intervals of 2 cm or less in X1. This angle is ϵ_{ROLL} and is measured in the X1-Y plane. As viewed from the AUT, ϵ_{ROLL} is positive when measured counterclockwise from Y toward X1. Note that in steps 3 and 4, the tilt and roll are measured with the level located on the probe transport mechanism and with the mechanism in the bottom Y position. Fifth, using this information we can determine ΔZ, ΔY, and ΔX as a functions of X1 and Y. These quantities are given by the following equations.

$$\Delta Z(X1,Y) = \Delta Z_H(X1,0) + \Delta Z_V(X_0,Y) + Y[SIN(\epsilon_{TILT}(X1)-\epsilon_{TILT}(X_0))], \tag{3}$$

$$\Delta Y(X1,Y) = -Y[2 - COS(\epsilon_{TILT}(X1)-\epsilon_{TILT}(X_0)) - COS(\epsilon_{ROLL}(X1)-\epsilon_{ROLL}(X_0))], \tag{4}$$

$$\Delta X(X1,Y) = Y[SIN(\epsilon_{ROLL}(X1)-\epsilon_{ROLL}(X_0))]. \tag{5}$$

A similar procedure is employed to determine the alignment for the X2 rails.

The parallelism of the X1 and X2 axes is measured using the laser straightness measurement system, the laser position measurement system, and two optical squares. The laser straightness is set up parallel to the X1 axis. One of the optical squares shall be used to turn the beam 90° toward the X2 rails. The second optical square shall be used to turn the beam another 90° so that it is anti-parallel with the X1 rails at one of the X2 rails. The straightness shall be measured at intervals of 2 cm or less in X2. A least squares line shall be fit to this data as a function of X2. The angular departure of X2 from a line parallel to X1 is given by the arctan of the slope of this least squares fit line.

The orthogonality of the X1, Y, and Z1 axes is measured using a procedure similar to that in the above paragraph but using only one optical square. The orthogonality of X2 and Z2 are likewise determined.

4.1.2 Scan Plane Mirror Alignment

A precision, optically flat mirror, capable of being adjusted in azimuth and elevation shall be installed on the seismic isolation slab provided in the Range facility. The face of the mirror shall be parallel to the face of the scan plane within ±2". This mirror shall look along the -Z axis. It shall be mounted 2 m (±10 cm) above the slab. The mirror face shall be accessible to a transit mounted behind and to one end of the X1 rails. The scan plane mirror shall be used to transfer the scan plane alignment to the probe and the AUT. The normal to the mirror shall be aligned parallel to the normal of the scan plane. The normal to this mirror shall be transferred to the probe which in turn shall be used to align the AUT.

The alignment of the mirror shall be set using the following collimation techniques. First, the azimuth alignment shall be done by aligning a transit with collimation optics along the X axis. Then an optical square shall be used to turn the collimation of the transit 90° to the face of the mirror. Last, the azimuth angle of the mirror shall be set parallel to the collimation. Second, the elevation alignment of the mirror shall be accomplished using the transit's level. This shall be done by setting the transit in front of the mirror, leveling the transit, and setting the mirror's elevation angle to that of the scan plane.

4.1.3 AUT Alignment

The AUT mount shall be capable of adjusting the antenna to within 0.05 mm in translations and 2" in rotations. Adjustment capabilities on the AUT in azimuth, elevation, and along the phi axis of the AUT (see fig. 1), shall be provided.

The AUT shall be aligned parallel to the scan plane mechanically by use of a depth gauge mounted in the probe aperture. A fixture will be made to adapt the depth gauge for the probe. A minimum of three alignment points will be defined on the AUT aperture face. The depth gauge will be capable of making linear displacement measurements to an accuracy of ± 0.01 mm or better. The phi axis of the AUT will be defined with an electronic level. After aligning the AUT, the PNF range personnel shall record the residual alignment errors for Z (depth gauge reading at the reference points), azimuth, elevation, and phi (electronic level reading) and provide them to NIST.

4.1.4 Probe Alignment

The flex (angular deviations) of the probe over its X, Y, and Z translation limits shall be less than 2" at the probe face. Angular gimbles will be provided to allow adjustment in elevation and azimuth (see fig. 1) of the probe in two separate and independent planes. The probe shall be rotatable in phi from 0 to 90° (to provide for both vertical and horizontal polarization measurements) within an accuracy of 0.05°. The probe face shall be perpendicular to the waveguide axis to an accuracy of ±0.5°. The probe face shall be aligned to the scanner to an accuracy of ±2".

The probe alignment shall be accomplished as follows:

* A collimation fixture shall be built that has three mirrors mounted on it in different orientations (fig. 2). This fixture shall have an adjustable mirror mounted on the face that has been aligned to the plug insert which defines the inside walls of the probe. It shall have an additional two mirrors mounted approximately 90° from each other on its sides. These two mirrors shall have been characterized so that the angle between them is known.

* The angular flex of the probe as it moves in X and Y shall be determined by using a collimation transit mounted to the side (along the X axis) of the probe. The collimation fixture shall be mounted with one mirror in the downward direction. The transit shall be collimated on the X mirror of the collimation fixture directly, and through an optical square for the Y mirror. The angular deviations as the probe moves in X and then in Y shall be characterized through the transit. The maximum magnitudes of these angular deviations shall be recorded.

* The linear translation of the probe as it moves along the Z1 axis shall be characterized by aligning a transit along that axis, by using the transit's crosshairs and the crosshairs of the face mirror on the collimation fixture. Measurements of the deviation in X and Y shall be taken every 2 cm along the entire probe travel.

* Measurements of the phi rotation error shall be accomplished with the probe at a desired Z1 position. The transit shall be collimated and fixed on the crosshairs of the face mirror of the collimation fixture. Another transit shall be collimated to the side mirror (along the X axis) of this fixture. The probe shall be rotated 90° in phi so that the other side mirror is rotated in view of the X transit. Collimation of this mirror shall be compared to the original collimation to determine the phi rotation error. The collimation on the face mirror shall be compared to its collimation in the initial orientation to determine the azimuth and elevation errors. Deviations in the crosshairs on the face mirror represent the X and Y translation errors.

* The probe face to waveguide error shall be measured by aligning a transit along the inside edge of the rectangular waveguide portion of the probe. A precision flat/parallel mirror shall be mounted on the face of the probe. Deviations in azimuth and elevation of this mirror represent this error.

* The probe's azimuth and elevation shall be compared to the azimuth and elevation of the scan plane mirror. A transit shall be collimated to the scan plane mirror. The probe, with the collimation fixture inserted in its aperture shall be moved in front of this transit. Differences in azimuth and elevation of the face mirror represent this error.

4.2 Rf Crosstalk

The rf isolation shall meet the requirements of table 5.

Mixer LO-to-rf port-to-port isolation, coaxial switch port-to-port isolation, the isolation of all isolators, and coupler directivity shall be measured using a network analyzer which has a calibration traceable to NIST.

Receiver reference channel to measurement channel isolation shall be measured using the following procedure. First a signal source shall be used to put a -25 dBm signal into the reference channel. Next all measurement channels shall be terminated with matched loads at the rf input ports. Then the reference channel shall be set to 0 dB. The attenuation in each measurement channel shall be set to the same value as that of the reference channel. An amplitude measurement shall be made at the rf output port of each measurement channel using the maximum available averaging. The resulting amplitudes shall be less than -90 dB.

The isolation between receiver measurement channels shall be measured using a procedure similar to that described above. A -25 dBm signal shall be fed into each measurement channel in turn and the amplitude out of each of the other measurement channels recorded.

Table 5. Isolation requirements.

	Isolation requirement (dB)	Isolation measurement accuracy requirement (dB)
Mixer LO-to-rf port-to-port isolation	≥ 25	within ±2
Receiver reference-channel to measurement-channel isolation	≥ 90	within ±5
Isolation between two receiver measurement channels	≥ 90	within ±5
Coupler directivity	≥ 30	within ±3
Isolation of isolators	≥ 30	within ±3
Coaxial-switch port-to-port isolation	≥ 80	within ±5

4.3 Rf Path Variation

The transmission line shall provide phase and amplitude stability of the rf signal during motion of the probe. The stability performance shall be less than ±0.02 dB and ±0.2° over the entire scan plane or sufficiently repeatable to allow for correction.

The rf path variation shall be determined using the following procedure illustrated in figure 3. A 20 dB coupler and tuner assembly shall be inserted at a point between the signal source and the probe where there is no cable flexing. A load shall be inserted in place of the probe and the tuner adjusted for a null. Then a short shall be inserted for the load. The signal reflected by the short shall be fed into the receiver. The short shall be positioned at the center of the scan area and the amplitude and phase set to zero. A full two dimensional scan of the entire available scan area shall be performed with $\Delta X = \Delta Y = 2.0$ cm and the amplitude and phase recorded. The recorded phase shall be divided by 2 and saved in a file along with the amplitude. This file now contains a map of the phase and amplitude variation over the entire scan plane.

4.4 Position Errors

The probe servo positioning system for X1 and Y shall be capable of placing the probe to within 0.01 cm or less of its commanded position. The AUT servo positioning system for X2 and Z2 shall be capable of placing the AUT to within 0.01 cm or less of the commanded position.

The positioning accuracy shall be determined by the following procedure.

a. For the X1 position accuracy, the probe shall be placed 10 cm above its bottom limit. Then the probe shall be commanded to go to X1 = 2.00 cm, 4.00 cm, and so forth until X1 = 900.00 cm is reached. This procedure shall be repeated at the central Y position and at 10 cm below the top limit. The actual X1 position shall be recorded using the laser measurement system. The difference between the commanded position and the actual position shall be 0.01 cm or less.

b. For the Y axis the probe shall be commanded to go to 10 cm from the right limit (as viewed facing the scanner). Then the probe shall be commanded to go to Y = 2.00 cm, 4.00 cm, and so forth until Y = 900.00 cm is reached. This procedure shall be repeated at the central X1 position and at 10 cm from the left limit. The actual position shall be recorded using the laser measurement system. The difference between the commanded and actual position shall be 0.01 cm or less.

c. For the X2 axis the AUT shall be placed at 10 cm from its forward position. Then the AUT shall be commanded to go to X2 = 2.00 cm, 4.00 cm, and so forth until X2 = 900.00 cm is reached. This procedure shall be repeated at the central Z2 position and 10 cm from the back limit. The actual position shall be recorded using the laser measurement system. The difference between the commanded position and the actual position shall be 0.01 cm or less.

d. For the Z2 axis the AUT shall be commanded to go to 10 cm from the right limit. Then the AUT shall be commanded to go to Z2 = 2.00 cm, 4.00 cm, and so forth until Z2 = 100 cm is reached. This procedure shall be repeated at the central X2 position and 10 cm from the left limit. The actual position shall be recorded using the laser measurement system. The difference between the commanded and actual position shall be 0.01 cm or less.

4.5 Rf System

The dynamic range of the system must be adequate to measure the low sidelobes and the cross polarization. The receiver dynamic range should be an order of magnitude better than the system dynamic range to ensure that the system meets the requirements. The system dynamic range is primarily limited by system noise.

4.5.1 System Dynamic Range

The system dynamic range shall be at least 75 dB relative to the near-field peak of the main component and shall be determined using a receiver averaging time of no more than 10 ms. The probe shall be placed at the main component near-field peak. The receiver shall be set to 0.0 dB. Then to determine the noise floor, at least 90 dB of attenuation shall be inserted in the measurement channel (at any convenient point along the rf line) using a rotary vane attenuator (RVA) or by inserting a fixed attenuator until the signal disappears in the noise. The receiver reading shall be recorded and the difference between this receiver reading and 0.0 dB is the system dynamic range.

4.5.2 Receiver Dynamic Range

The receiver dynamic range shall be at least 85 dB and shall be determined using a receiver averaging time of no more than 10 ms. The receiver dynamic range shall be determined by setting the input signal to the mixer at its maximum input level (as specified by the manufacturer, typically -20 to -30 dBm). The receiver reading shall be set to 0.0 dB. Then to determine the noise floor, at least 100 dB of attenuation shall be added to the rf line until the signal disappears in the noise. The receiver reading shall be recorded and the difference between this reading and 0.0 dB is the receiver dynamic range.

4.5.3 System Linearity

We can determine the requirements for system and receiver linearity by using eqs (64) and (67) of [1]. The system linearity shall be measured over a 75 dB dynamic range. The residual amplitude error shall be less than 0.001 dB/dB below the maximum signal level of this dynamic range and the residual phase error less than 0.1°/dB.

The system's amplitude linearity shall be determined with the probe at the near-field peak of the main component using the RVA calibrated by NIST. The RVA shall be inserted in the system between the signal source and the transmit antenna. The RVA shall initially be set to 0.00 dB and the receiver to 0.00 dB. The RVA shall be set to 2 dB, 4 dB, and so forth in 2 dB increments to 20 dB. Then the RVA shall be set to 25 dB, 30 dB, and so forth in 5 dB increments to 75 dB. At each RVA setting, the receiver reading (amplitude and phase) shall be recorded. This procedure shall be repeated 10 times and the average of the 10 measurements determined. The averages shall be compared to the calibrated values of the RVA to determine the system linearity correction.

4.5.4 Receiver Linearity

The receiver linearity shall be measured over an 85 dB dynamic range. The residual amplitude error shall be less than 0.001 dB/dB below the maximum signal level of this dynamic range and the residual phase error less than 0.1°/dB.

The receiver's amplitude and phase linearity shall be determined using an RVA calibrated by NIST for both amplitude and phase versus attenuation. The RVA shall be inserted in the system just prior to the rf input of the receiver. The RVA shall initially be set to 0.00 dB and the receiver to 0.00 dB. The RVA shall then be set to 2 dB, 4 dB, and so forth in 2 dB increments to 20 dB. Then the RVA shall be set to 25 dB, 30 dB, and so forth in 5 dB increments to 85 dB. At each RVA setting, the receiver reading (amplitude and phase) shall be recorded. This procedure shall be repeated 10 times and the average of the 10 measurements determined. These averages shall then be compared to the RVA calibration values to determine the receiver linearity correction.

4.6 Noise Level

The average noise level of the far field shall be less than -70 dB relative to the far-field peak of the AUT main component and shall be measured as follows. A full two=dimensional near-field scan of the AUT main component shall be made at 4 GHz using $\Delta X = \Delta Y = 2$ cm and the far-field determined. The average noise level shall be computed using the far-field amplitude at the points where

$$\frac{\sqrt{k_x^2 + k_y^2}}{k} > 1.1, \tag{6}$$

using the following equation.

$$\text{Average noise level} = \frac{\sqrt{\sum [\text{amplitude}(k_x, k_y)]^2}}{\sqrt{N}}, \tag{7}$$

where N is the number of data points in the average.

4.7 Leakage

The maximum leakage for the entire scan plane shall be 75 dB or more below the maximum measured near-field signal of the AUT main component.

Rf leakage shall be measured at 4 GHz using the following procedure. First, a complete scan shall be performed to determine the maximum near-field signal. Second, a complete scan shall be performed with the probe radiating normally, and with a matched load on the AUT-to-receiver transmission line where it normally connects to the AUT output ports. Third, a complete scan shall be performed with the AUT receiving normally, and a matched load on the probe-to-rf source transmission line where it normally connects to the input port(s) of the probe. No level of the second and third scans shall exceed -75 dB relative to the peak of the first scan.

4.8 Probe-AUT Multiple Reflections

The effects of the probe-AUT multiple reflections on the far field shall be no greater than the levels shown in table 6.

Table 6. Multiple reflection level.

Far-field pattern level relative to the main beam (dB)	Maximum multiple reflection error level relative to the main beam (dB)
0	-39
-55	-65

The effects of these multiple reflections shall be determined by using four full two dimensional planar near-field scans taken at Z_0, $Z_0 + \lambda/8$, $Z_0 + 2\lambda/8$, and $Z_0 + 3\lambda/8$, where Z_0 is established to optimize both the effects of probe-AUT multiple reflections and truncation. Then the far field for each scan shall be calculated and a phase adjustment applied to account for the differences in Z position. A complex average of the four adjusted far fields shall be made, and a complex difference between the average far field and each of the individual far fields shall be computed. These differences shall not exceed the values specified in the above table.

4.9 Room Multipath

The multipath, the signal due to the reflection of rf energy off the walls and other structures excluding only the probe-AUT multiple reflections, shall be no greater than -75 dB relative to the peak of the far-field signal.

The room multipath shall be verified as follows. A centerline y-scan of the AUT shall be measured at different x-positions relative to the scanner but the AUT and the probe shall have the same x-position relative to each other. These scans shall be measured 2 cm apart (relative to the scanner) at a frequency of 4 GHz and shall cover the entire X and Y scanning range. A complex average with respect to x shall be determined for each y-position so as to obtain an average y scan. The complex difference between this average scan and each individual scan shall be determined. This two dimensional near-field difference (multipath) pattern shall be transformed to obtain an error spectrum. This error spectrum shall be compared to the AUT far-field spectrum and no point in the error spectrum shall be greater than -75 dB relative to the mainbeam peak.

4.10 Truncation

We have found from our experience that the truncation error spectrum bears some resemblance to the true spectrum, e.g., the truncation error spectrum is higher in the mainbeam than in the sidelobe regions. For the normal X- and Y-scan dimensions of the AUT, the truncation error shall meet the requirements in table 7.

Table 7. Maximum truncation error.

Far-field pattern level relative to the main beam (dB)	Maximum truncation error level relative to the main beam (dB)
0	-45
-55	-80

The truncation error shall be determined using the following procedure. First, a normal two dimensional near-field scan shall be performed on the AUT and the far field calculated. Next, all the amplitudes of near-field data shall be set to zero except for the outer rectangular boundary. The far field of this resulting data is calculated to yield the truncation error spectrum.

4.11 Aliasing

The aliasing error shall not exceed -75 dB relative to the peak of the main beam for $|\theta| \leq 75°$. Aliasing errors shall be determined at 4 GHz by (1) making a two dimensional scan with $\lambda/8$ spacing in X and Y, (2) computing the far field for this full set of data, (3) computing the far field using every other data point in X and Y ($\lambda/4$ spacing), (4) computing the far field using every fourth data point in X and Y ($\lambda/2$ spacing), (5) performing a complex subtraction between the $\lambda/4$-spaced and $\lambda/8$-spaced far fields, and (6) performing a complex subtraction between the $\lambda/2$-spaced and $\lambda/8$-spaced far fields. The resulting differences obtained in (5) and (6) shall be compared to the aliasing error requirements and a sampling spacing determined. It should be noted that before the subtractions in (5) and (6), all three sets of near-field data must be zero-filled to the same array size.

4.12 System Drift

System drift, the variations in amplitude and phase read on the receiver as a function of time, shall be less than 0.1 dB in amplitude and 10° in phase over a four-hour period, and must be correctable to 0.01 dB and 0.1°.

The probe shall be set to the peak of the near-field amplitude. The receiver amplitude and phase shall initially be set to 0.0 dB and 0.0°. The amplitude and phase of the receiver shall be recorded every 2 min for the 4 h period.

4.13 Insertion Loss Amplitude and Phase Measurement

Insertion loss amplitude and phase measurement shall be repeatable to an accuracy of ± 0.05 dB in amplitude and ±2° in phase for the main component. For the cross component, the amplitude shall be repeatable to within ±0.2 dB in amplitude and ± 10° in phase. Ten repeated insertion loss amplitude and phase measurements shall be taken at four different times separated by a week.

5. TESTS BY NIST PERSONNEL AT THE PNF FACILITY

NIST will perform the following tests using the same procedures described in section 4. Their results will be used to verify those obtained by Range personnel.

1. Scanner Alignment (under 4.1).

2. Scan Plane Mirror Alignment (under 4.1).

3. Leakage (under 4.7).

4. Room Multipath (under 4.9).

5. Truncation (under 4.10).

6. NIST will perform at least three additional tests chosen from section 4 to verify the test results obtained by Range personnel.

6. SOFTWARE COMPARISON TESTS

The purpose of these tests is to ensure that the Range software works correctly. Results from data processed at the PNF range shall agree with NIST results to within the round-off error of the computers. The following apply.

6.1 Test Data

NIST will provide sample data from its PNF Data Library to Range personnel.

6.2 NIST Processing

NIST will process the sample data through its PNF software.

6.3 Range Data Processing

Range personnel shall process the sample data through its PNF software. All results shall be supplied to NIST on an appropriate medium.

6.4 Comparison of Results

NIST will compare the Range results to the NIST results and will provide the results of the software tests to Range personnel.

7. MEASUREMENT COMPARISONS

7.1 Transfer Test Antenna

A transfer test antenna will be measured on both the PNF Range and the NIST PNF range. The results from the Range shall agree with NIST results to within the combined uncertainties of both measurements. The antenna shall be transportable and measurable at both facilities. It shall have low sidelobes to properly test the low sidelobe measurement capability of the Range. The customer shall be responsible for acquiring an antenna that is acceptable to NIST for these measurements.

7.2 NIST Measurements

NIST will measure the gain, co-polarization pattern, and cross-polarization pattern of the transfer antenna over ± 75° in azimuth and elevation. NIST will determine the error budget for its measurements. Individual entries in the error budget will correspond to the 3σ value for random errors and the worst-case error for systematic errors.

7.3 Range Measurements

Range personnel shall measure the gain, co-polarization pattern, and cross-polarization pattern of the transfer antenna over ± 75° in azimuth and elevation. Range personnel will determine the error budget for its measurements. Individual entries in the error budget shall correspond to the 3σ value for random errors and the worst-case error for systematic errors. Range personnel shall provide all results to NIST.

7.4 Comparison

NIST will compare the results of the two sets of measurements. Range results shall agree with NIST results to within the combined errors of the two measurements. NIST will provide the results of the comparisons to the customer.

8. SUMMARY

This certification plan is based in part on information supplied by Range personnel regarding the types of antennas Range personnel will measure and the required measurement accuracies. Any significant changes or additions in measurement frequency, antenna size, or measurement accuracies will require modifications to the certification plan.

9. ACKNOWLEDGEMENTS

The authors thank the Naval Surface Warfare Center Crane Division for their contribution to this effort.

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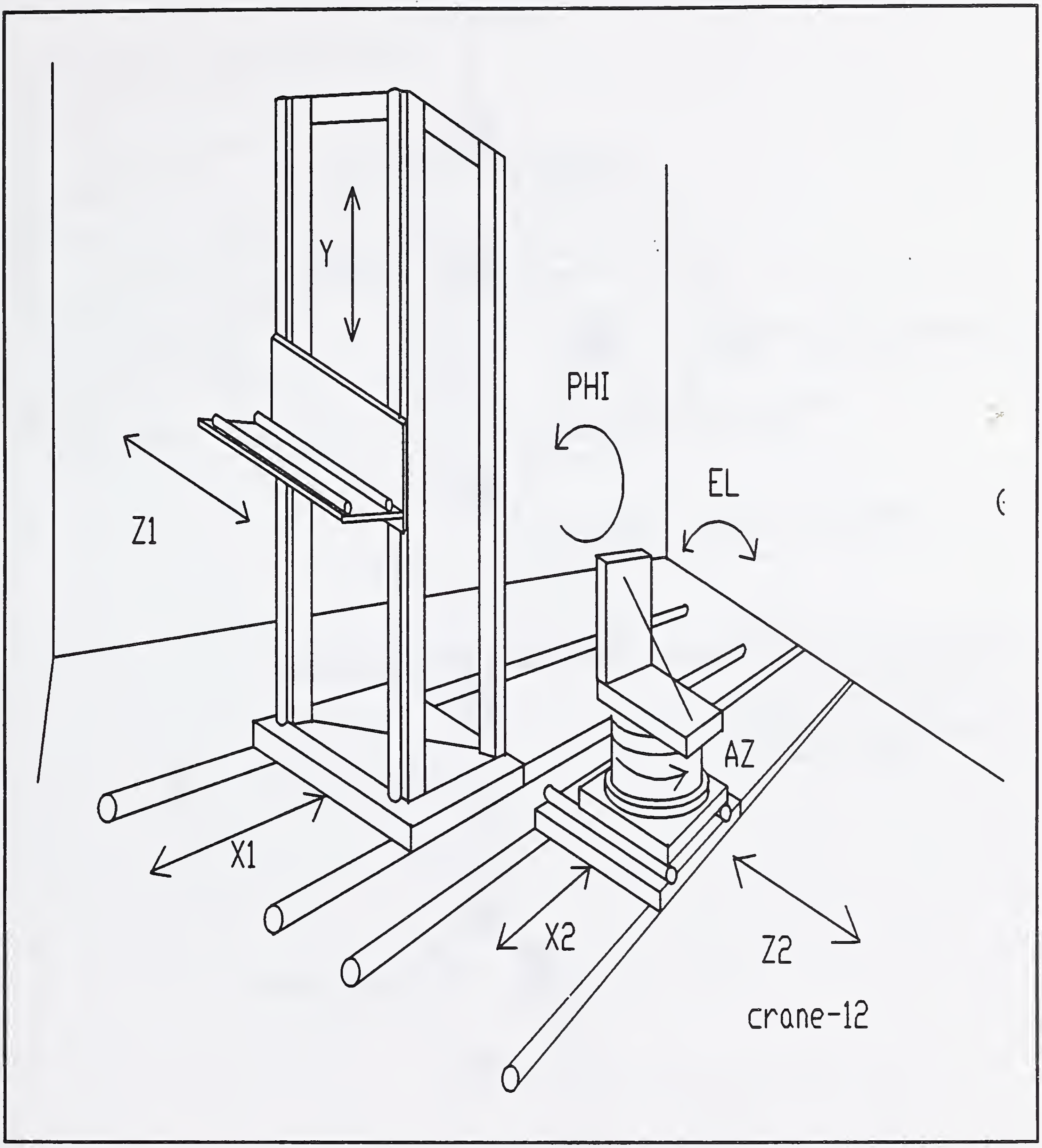

Figure 1. Coordinate axes for the proposed PNF range.

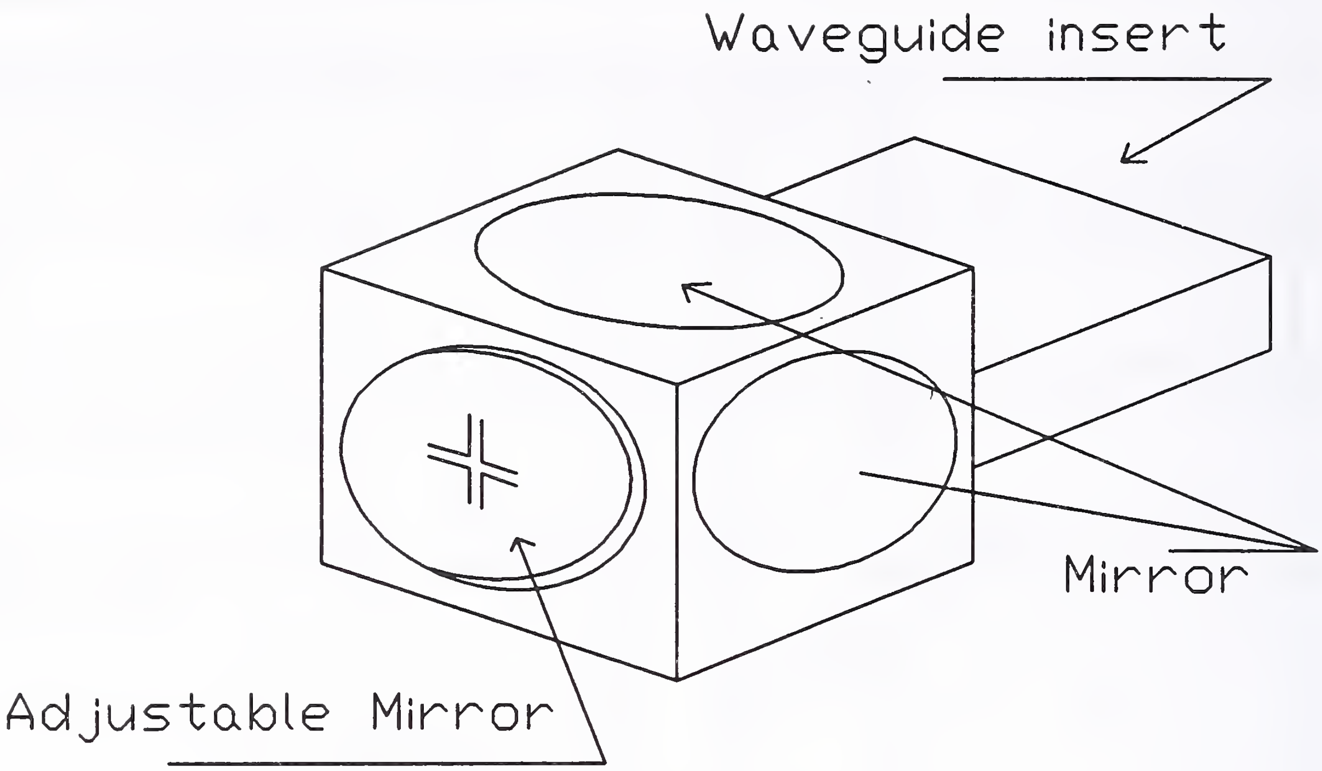

Figure 2. Schematic of collimation fixture.

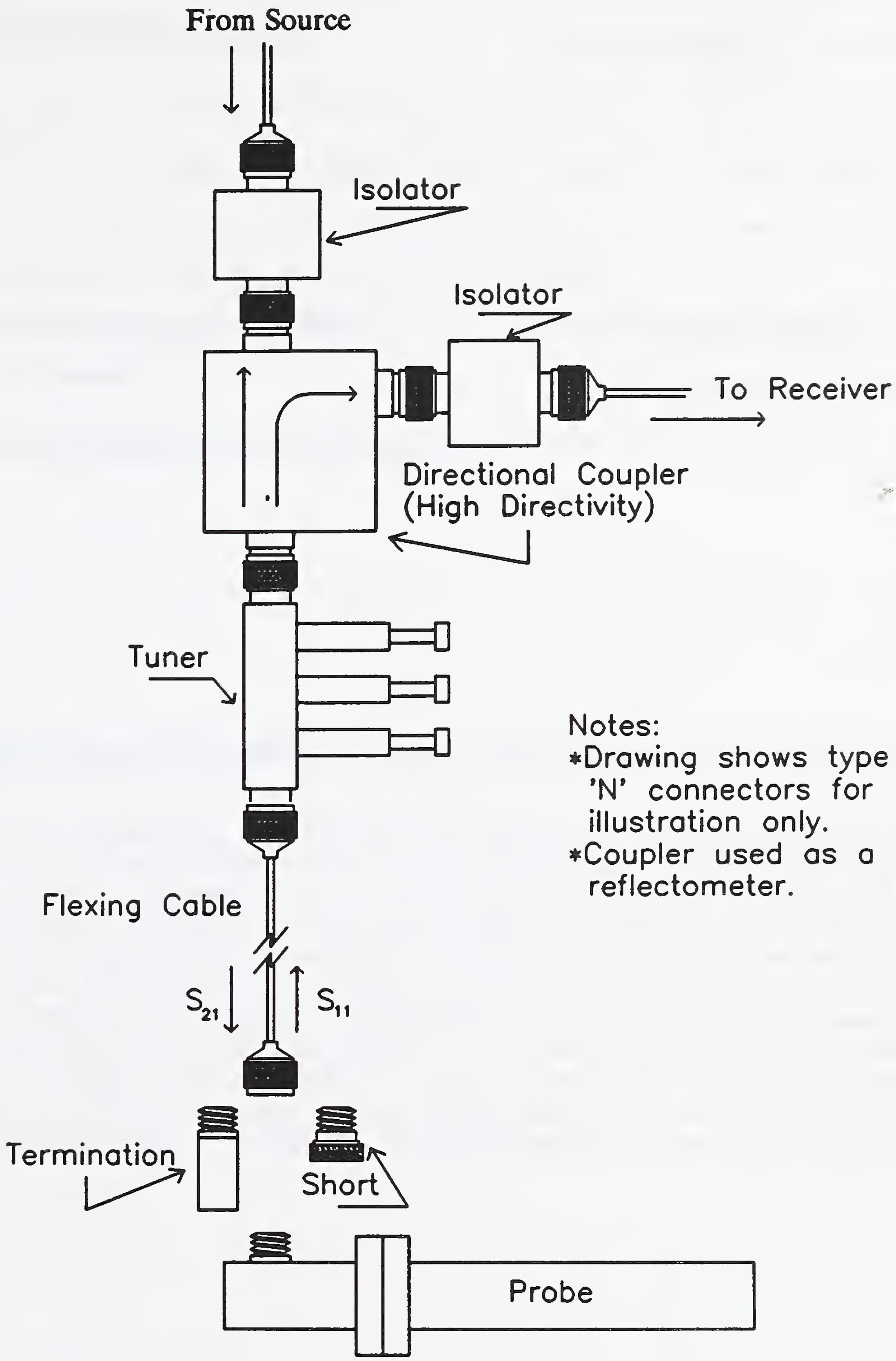

Figure 3. Schematic for testing rf amplitude and phase path variation.

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The National Institute of Standards and Technology (NIST) has written a certification plan to ensure that a proposed planar near-field range is capable of measuring high-performance phased arrays. Generally for a complete plan, one must evaluate many aspects including scanner alignment, near-field probe alignment, alignment of the antenna under test, rf crosstalk, probe position errors, rf path variations, the receiver's dynamic range and linearity, leakage, probe-antenna multiple reflections, truncation effects, aliasing, system drift, room multipath, insertion loss measurements noise, and software verification. In this report, we discuss the important aspects of a certification plan specifically written for the measurement of high-performance phased-array antennas. Further, we show how the requirements of each aspect depend on the measurement accuracies needed to verify the performance of the array under test.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

antennas; antenna measurements; phased array; planar near field

13. AVAILABILITY

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