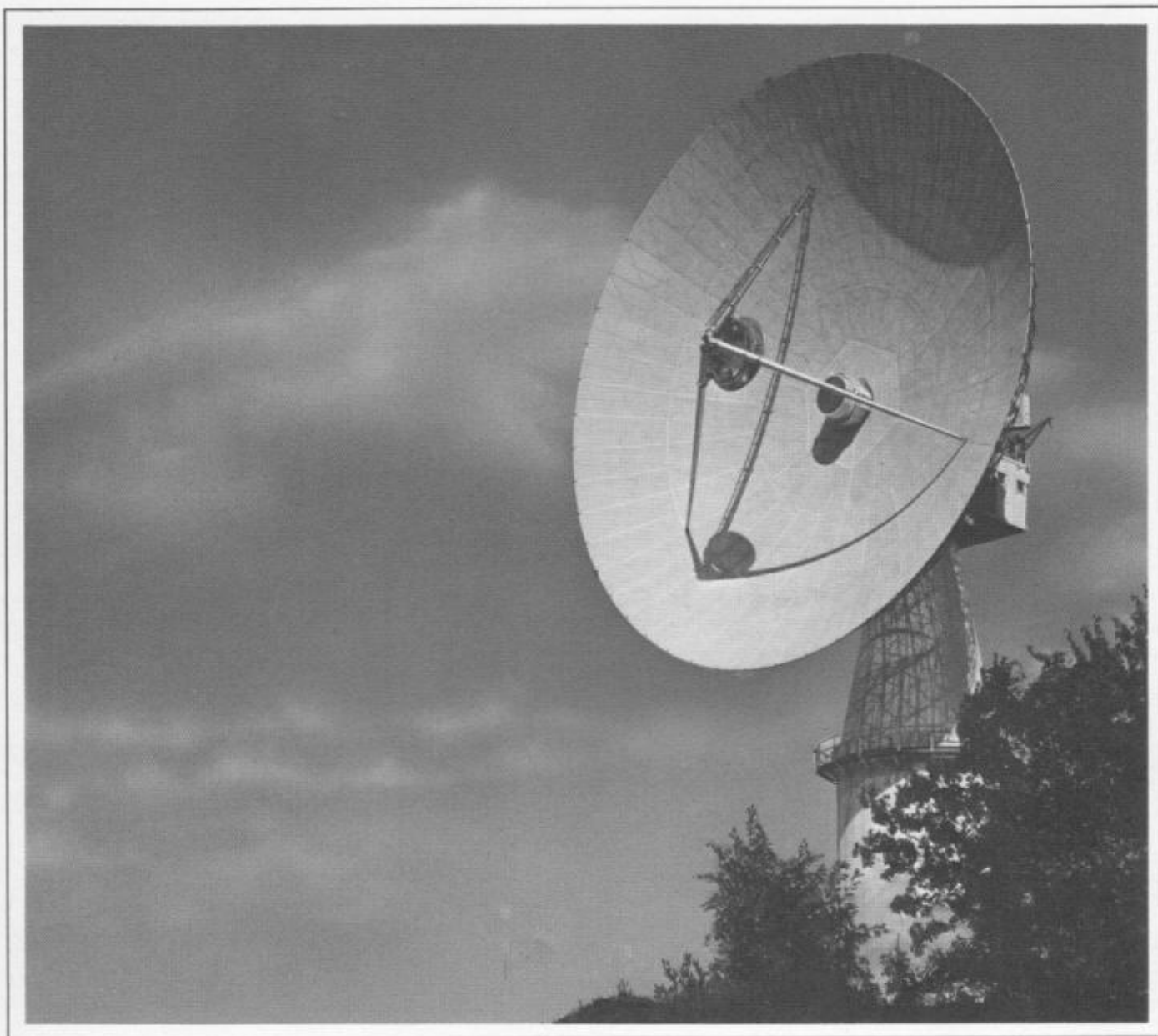


# Antenna/Radome Boresight Error Measurements



HEWLETT  PACKARD

APPLICATION NOTE 110

## ANTENNA/RADOME BORESIGHT ERROR MEASUREMENTS

A SIMPLIFIED ELECTRONIC BORESIGHT  
ERROR MEASURING SYSTEM

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## ABSTRACT

This paper describes a simplified and accurate method of automatically measuring radome induced antenna boresight and/or beamshift errors.

Because many types of antenna systems are enclosed in radomes which require testing, the radome test range facility must include many complex electronic test equipments. Three basic types of antenna measuring systems are discussed in this paper. They are:

- multiple beam (null seeking)
- phase sensing
- shaped beam antennas

The dominant boresight measuring method employed for phase sensing antennas has utilized complex and cumbersome waveguide phase sensing networks. Diode detection systems provide direct readout. Boresight and beamshift error measuring systems employed on multiple beam and shaped beam antennas utilize the diode detection system with a less complex waveguide network than that used in phase detection.

The system described herein eliminates the necessity for the waveguide network and the video detection system. It employs a Hewlett-Packard Model 8410A Network Analyzer which utilizes a harmonic frequency converter to provide all of the basic RF tuning and IF conversion functions. The phase and amplitude relationship between the input RF signals is maintained in two 20 MHz IF signals. The final output of the system is a dc voltage directly proportional to the amplitude and/or phase change experienced at the input to the harmonic frequency converter.

Boresight error measurements are described in detail for multiple beam (null seeking), beamseeking and phase sensing antennas at frequencies of 5.09 GHz, 13.325 GHz and 17.0 GHz respectively.

## INTRODUCTION

It is not uncommon to encounter a different boresight or beamshift error measuring system for each antenna-radome combination to be tested. Most of these systems are custom designed to fit the requirements of the particular test range and antenna-radome combination to be tested. One way power transmission loss, antenna pattern distortion and reflected power can be measured with existing shelf item test equipment. However, up to this time, no standard test equipment has been adaptable for automatic boresight and beamshift error measurements. While certain shelf item equipments can be employed in point to point boresight and beamshift measurements with limited accuracy and time consuming test techniques, such equipment has not been compatible with automatic scanning. When the antenna-radome test system engineer is confronted with the use of the custom designed measuring system, he is faced with the following primary problems.

- Limited production does not allow sufficient effort in design improvements.
- The equipment cost represents a major capital investment and often has no application in other areas of microwave testing.
- Such equipment employs a complex set-up and calibration procedure.
- Maintenance and procurement of repair parts are difficult due to the limited production.

The boresight and beamshift error measurement system discussed in this report is capable of testing most types of antenna-radome combinations with the following advantages:

- The measuring system utilizes only shelf item test equipment which can be employed in other areas of microwave testing.
- It maintains a simplified set-up and calibration procedure.
- It offers accurate automatic scanning capabilities.

The antenna-radome positioning fixture retains its custom designed characteristic due to the many unique antenna-radome combinations.

## ERROR DETECTION SYSTEM DESCRIPTION

The instrumentation employed in this test system is generally the same type as that employed on most antenna-radome test ranges with the exception of the boresight and beamshift error detection system. The error detection system consists of a Hewlett-Packard 8411A Harmonic Frequency Converter, a Hewlett-Packard 8410A Network Analyzer, and a Hewlett-Packard 8413A Phase Gain Indicator.

The harmonic frequency converter accepts two RF signals from the same frequency source, between 0.11 and 17.0 GHz, and converts them into 20 MHz IF signals. The IF signals are then fed to the network analyzer which contains the automatic frequency tuning circuit, IF amplifiers, and precision IF gain control. A front panel switch selects an octave range between 0.1 and 12.4 GHz. No further tuning is necessary for the detection system. Although the octave range switch indicates 12.4 GHz maximum input frequency, tests on the Lockheed unit indicate that it performs equally well to 18.0 GHz.

The system phase locks to the desired test frequency and follows even rapid sweep operation. It is capable of operating with either modulated or CW RF energy. The phase gain indicator plugs into the network analyzer main frame to provide meter readout of relative amplitude and phase shift between two input signals. The meter is calibrated in  $\pm 3$ , 10 and 30 dB amplitude and  $\pm 6$ , 18, 60 and 180 degrees phase. The meter function and range are selected by pushbutton switches. A phase offset switch, calibrated in precise 10 degree steps, allows any angle to be displayed on the  $\pm 6$  degree phase scale for  $0.1^\circ$  resolution. Separate dc outputs are provided to plot either amplitude or phase, or both amplitude and phase simultaneously on an auxiliary recorder. The above system has been successfully operated at a frequency of 18.0 GHz with an RF power input level of -15 dBm.

## ANTENNA-RADOME TEST RANGE

Boresight and beamshift error test ranges normally consist of a transmitting antenna and a receiving antenna or array of antennas. The receiving and transmitting antennas are separated on the test range by a minimum distance of  $2D^2/\lambda$ , where:

$D$  = diameter of the largest antenna aperture

$\lambda$  = freespace wavelength of the test frequency

The height of the receiving and transmitting apertures are selected to accommodate the test range terrain. It is advantageous that the radome test range designer include the capability of testing one-way power transmission loss simultaneously with the boresight error.

## BEAMSHIFT ERROR TEST RANGE SYSTEM

A typical beamshift error test range is shown in Figure 1. A shaped beam test antenna is employed as the transmitting aperture. The three antennas A, B and C make up the receiving array. Antennas A and C are the beamshift detection antennas while antenna B is utilized as the one-way power transmission loss detection antenna. The beamshift antennas A and C are separated vertically by a distance preferably equal to the 3 dB beamwidth of the test antenna aperture, although it is acceptable to separate them as little as the 1 dB beamwidth of the test antenna. The test antenna is electrically aligned with the array antenna B which is located in the same plane and in the center of antennas A and C. With the antennas aligned in this manner, antennas A and C will receive the radiated signal at equal amplitude and 1 to 3 dB less than antenna B, dependent upon the separation of A and C.

The amplitude decrease caused by losses due to the radome wall is undetected in the beamshift antennas since both antennas will experience the same amplitude decrease. It is the ability to detect the relative amplitude change between antennas A and C that is important in beamshift error measuring. With the test antenna properly aligned, the RF output of antenna A is fed into the test channel of the harmonic frequency converter and the RF output of antenna B is fed into the reference channel of the harmonic frequency converter. A null or 0 dB reference output is established on the phase gain indicator by means of the calibrated step attenuator on the network analyzer. The dc output on the phase gain indicator is coupled to the y-axis of a suitable recorder. The x-axis of the recorder is synchronized with the radome positioning fixture.

When the beam is shifted up, antenna A experiences a small increase in power and antenna C experiences a small decrease in power. A positive dc output will be detected on the y-axis of the recorder proportional to the upward beamshift error. A downward shift in the beam results in a converse reaction.

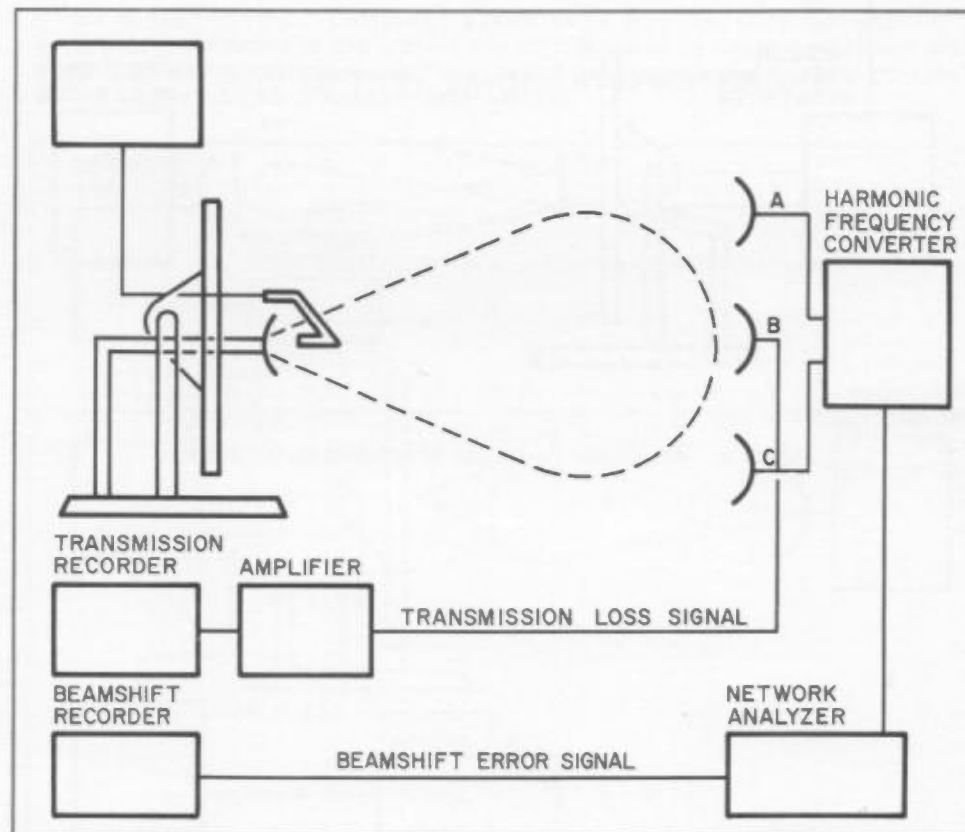


Figure 1. Beamshift Error Test System

## AMPLITUDE BORESIGHT ERROR TEST RANGE SYSTEM

A typical amplitude boresight (multiple beam antenna) measuring range is shown in Figure 2. In this case it is preferable to conduct one way power transmission and boresight error measurements separately unless a sum output of the multiple beams is provided on the test antenna. The test antenna is utilized as the receiving antenna and consists of two independent apertures which maintain a beam crossover between 1 and 3 dB down from the peak of the beam. The transmitting antenna is aligned electrically to the crossover of the multiple beams. The received signal amplitude is then monitored at its proper RF output ports; and when boresight error is induced by the radome, a change in the relative amplitude between the two ports on the test antenna is detected.

The amplitude boresight system operates on the same principle as the beamshift error system. The only changes necessary will be to physically relocate the test equipment to accommodate the antenna-radome system under test.

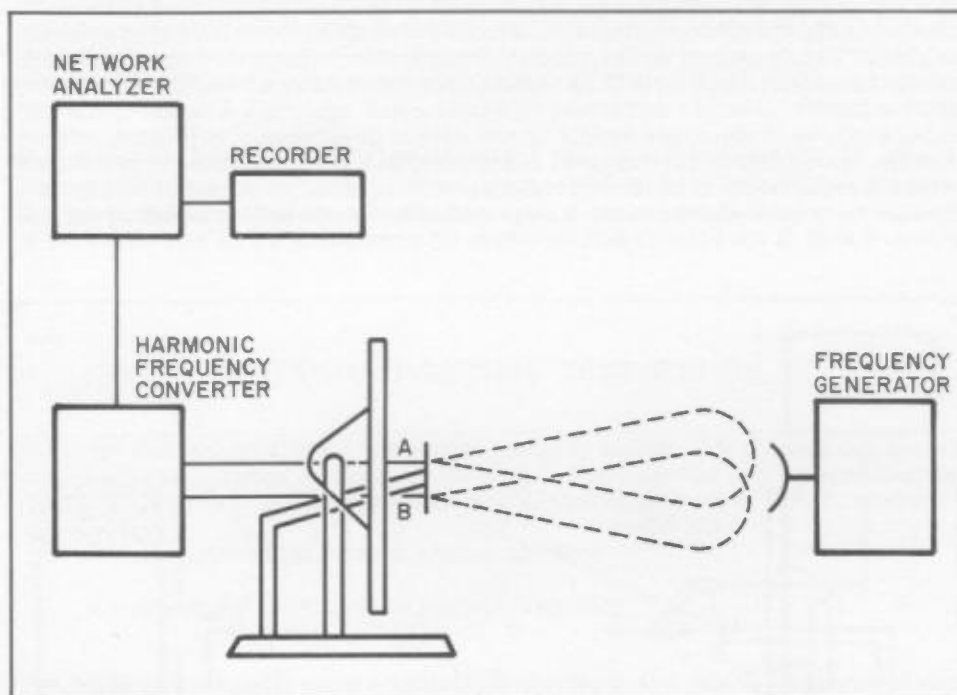


Figure 2. Amplitude Boresight Error Measuring System



## PHASED ARRAY BORESIGHT ERROR TEST RANGE SYSTEM

A typical phased array antenna boresight measuring range is shown in Figure 3. In this case the antenna under test is employed as the receiving antenna. Boresight error is detected as the relative phase change between the two arrays of the test antenna and is defined as:

$$\phi = \frac{d \sin \theta 360^\circ}{\lambda}$$

where

$\phi$  = phase change in RF degrees

$\theta$  = boresight error angle

$d$  = phase center separation between the two arrays

$\lambda$  = free-space wavelength

The relative phase shift between the two arrays is directly proportional to boresight error. The transmitting antenna is optically aligned with the phased array to establish electrical boresight. Any boresight error caused by the presence of the radome will be detected as a relative phase change between the two arrays. The RF output of port A on the test array is coupled to the test channel of the harmonic frequency converter. The RF output of port B on the test array is coupled to the reference channel of the harmonic frequency converter. The phase gain indicator is adjusted by means of the calibrated step phase shifter to indicate a null or  $0^\circ$  phase reference between array A and B. The dc output on the phase gain indicator is coupled to the y-axis of a suitable recorder. The x-axis of the recorder is synchronized with the radome-antenna positioning fixture.

When an upward boresight error is induced on the test antenna, port A of the phased array experiences a phase lead and port B experiences a phase lag. Thus, a positive dc output proportional to the upward boresight shift will be experienced on the y-axis of the recorder. Conversely a negative or downward boresight shift can be recorded. Calibration of the system can be confirmed by the self contained phase shifter, by an external phase shifter in one of the receive ports, or by physically displacing the antenna in known angular offsets.

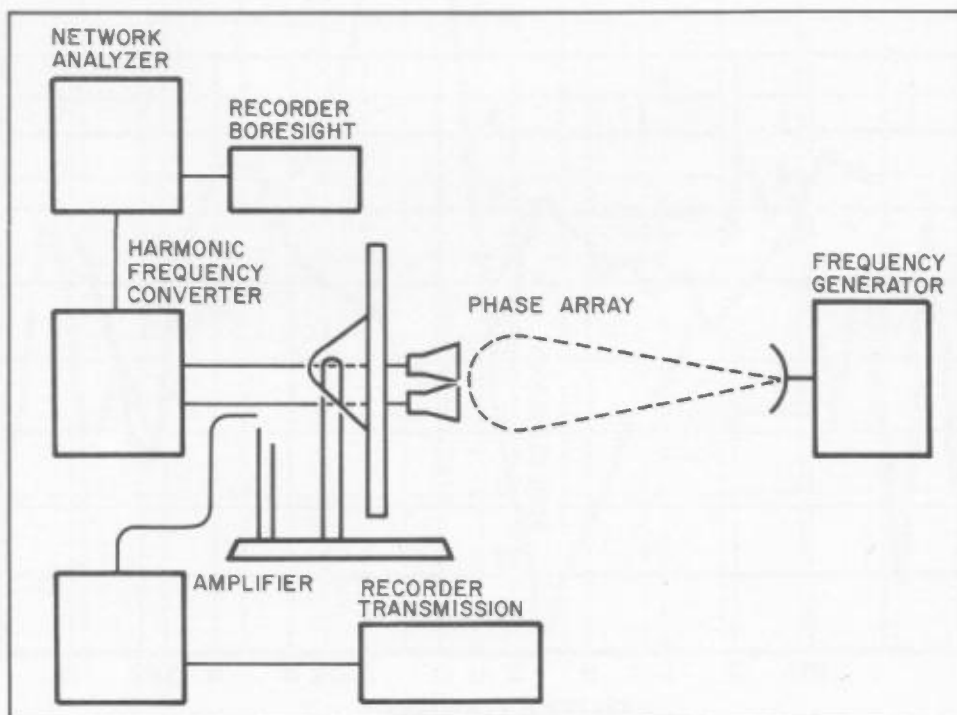


Figure 3. Phased Array Boresight Error Measuring System



## EXPERIMENTAL RESULTS

A typical beamshift error measurement system was setup and operated at a frequency of 13.325 GHz. Photographs of the antenna-radome positioner and the receiving array are shown in Figures 4 and 5 respectively. A typical beamshift error scan taken on this system is shown in Figure 6. The actual calibration utilized for this test is shown on the beamshift error curve. The calibration was obtained by angularly displacing the antenna in 1 milliradian increments.

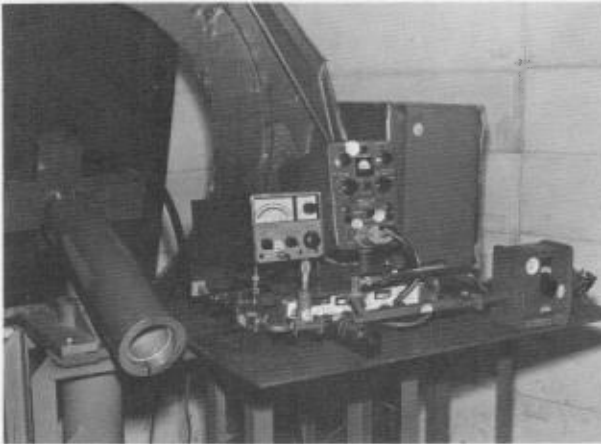


Figure 4.

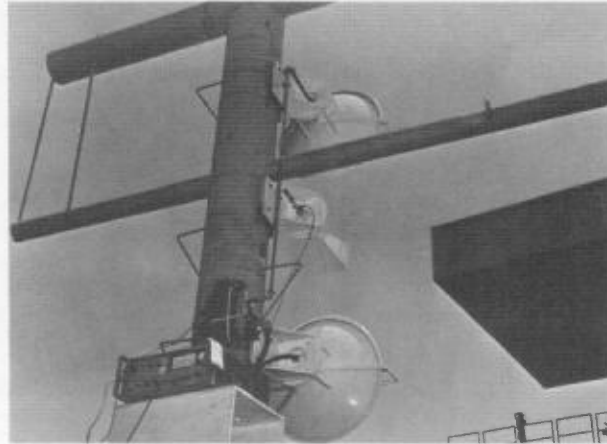


Figure 5.

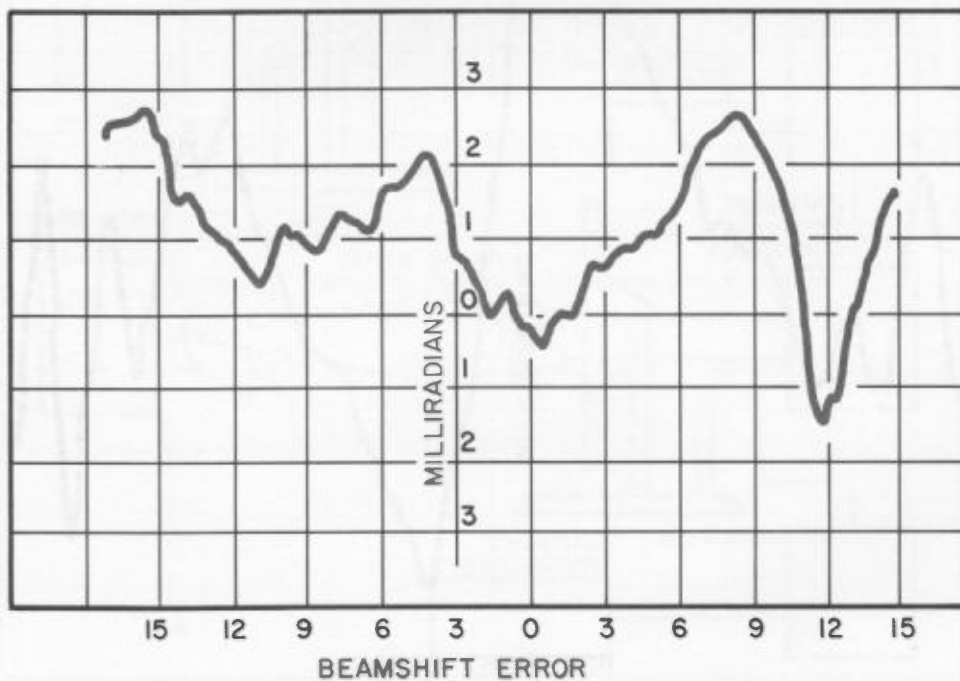


Figure 6.

A typical amplitude boresight error measurement system was setup and operated at a frequency of 5.09 GHz. Photographs of the antenna-radome positioner and the radome test range are shown in Figures 7 and 8 respectively. An experimental boresight error scan taken on this system is shown in Figure 9. The calibration data shown on the curve was obtained by angularly displacing the antenna in one milliradian increments. An experimental radome was employed to study the effectiveness of the measurement system for large errors.



Figure 7.



Figure 8.

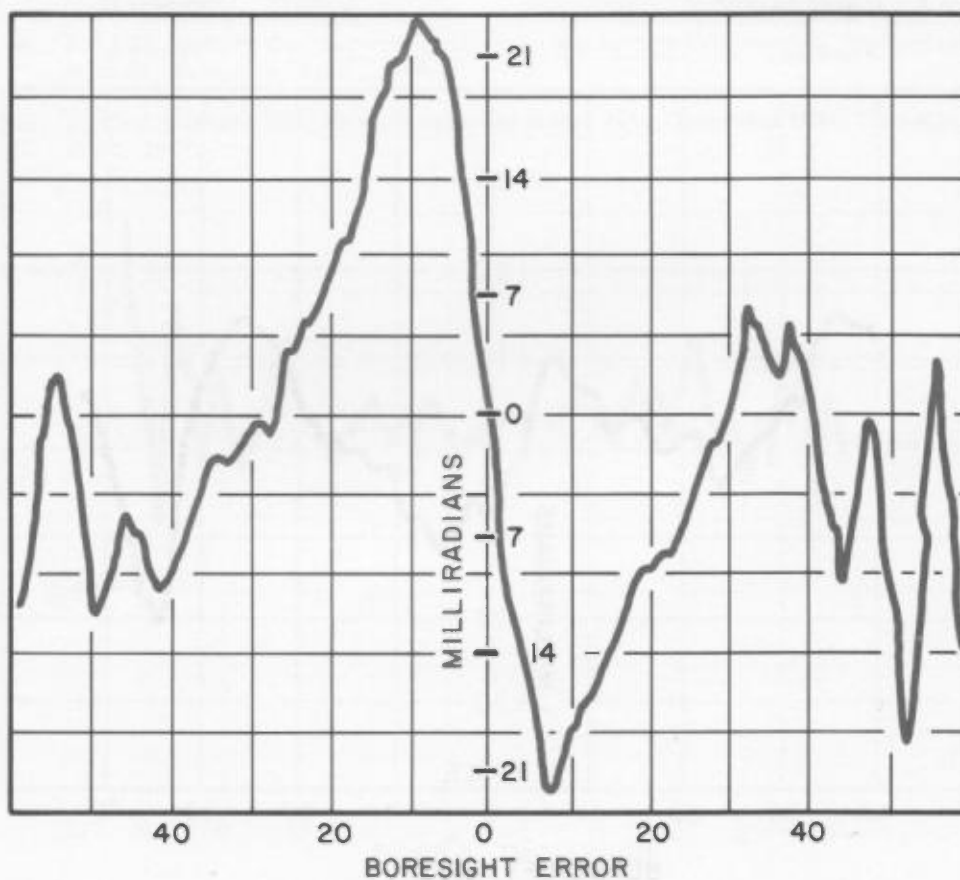


Figure 9.

A typical phase sensing boresight error measurement system was set up and operated at a frequency of 17.0 GHz. Photographs of the antenna-radome positioner and the radome test range are shown in Figures 10 and 11. An experimental boresight error scan taken on this system is shown in Figure 12. The calibration data shown on this curve was obtained by the use of a precision phase shifter inserted in one of the phased array ports. The calibration was confirmed by using the step phase shifter of the phase gain indicator and by angularly positioning the array in known increments. The directional coupler shown in one port of the phased array is to facilitate one way power transmission loss measurements simultaneously with the boresight error measurements.

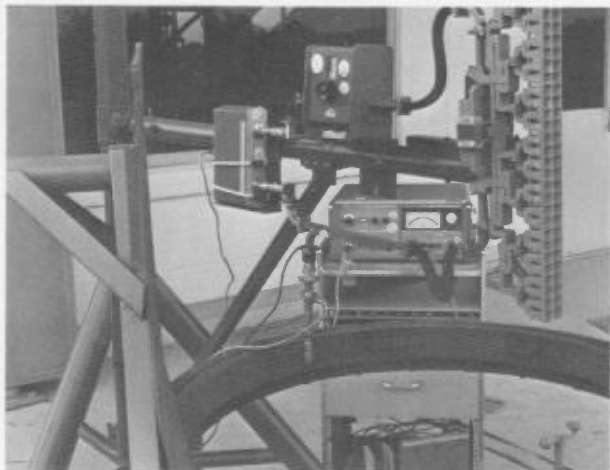


Figure 10.



Figure 11.

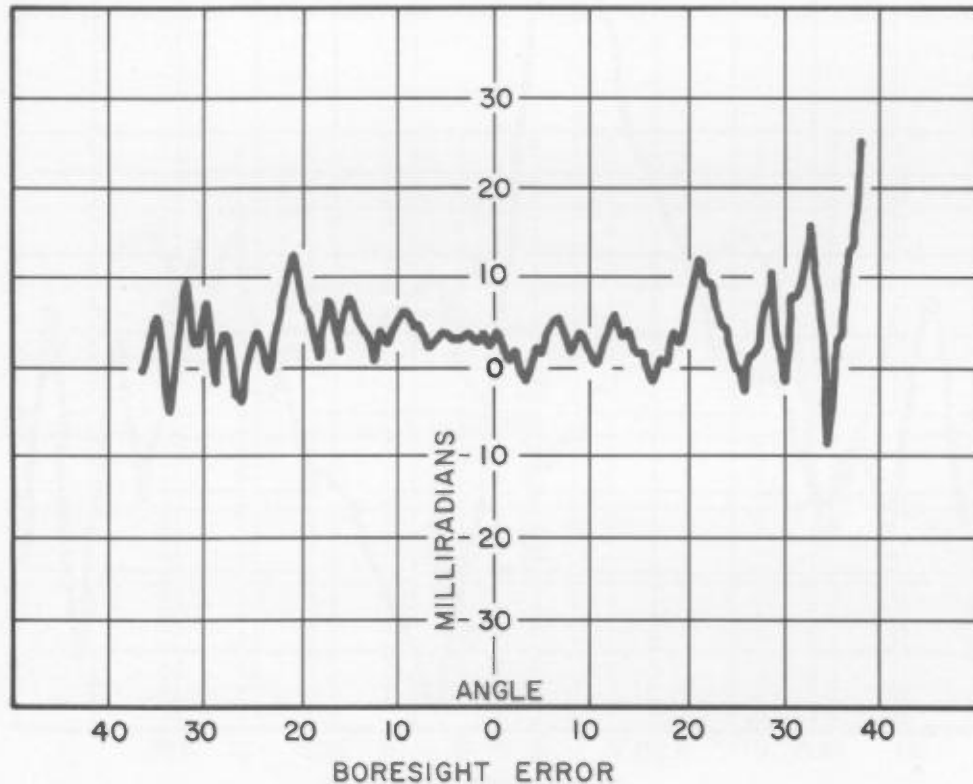


Figure 12.

## CONCLUSIONS

In view of the experimental results obtained, it is concluded that the boresight and beamshift error system described is superior to previously used systems in all respects. Accuracy of the beamshift and amplitude boresight error measurements were  $\pm 0.1$  milliradian. The accuracy of the experimental phase delay measurements was within  $\pm 0.2$  milliradian. The primary limitation to ultimate accuracy of this test system is the quality of the test range and radome-antenna positioning fixture. An ultra-stable frequency source also contributes toward a more accurate measurement system. Total electronic setup and calibration time is approximately 30 minutes after the equipment had been physically placed on the test range. Microwave technicians who were unfamiliar with the test system were capable of setup and calibration of the test range after a one hour training session.

Although this discussion has been principally on measuring single plane boresight or beamshift errors, dual plane errors may be realized by using an additional system in both the horizontal and vertical plane antenna channels.

Studies are also under way to extend the frequency capabilities of the unit.

## REFERENCES

1. Silver, S., Microwave Antenna Theory and Design, McGraw-Hill Book Co., Inc., New York, N. Y. 1949.
2. Hewlett-Packard Co., Network Analysis at Microwave Frequencies, Application Note 92, Palo Alto, Calif. 1968.
3. Hewlett-Packard Co., Network Analyzer Model 8410, Technical Data, Palo Alto, Calif. 1967.



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