AUTOMATIC BORESIGHT MEASURING EQUIPMENT

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ABSTRACT

The high fineness ratio required by modern boresight radomes has reduced present day radome design to an art rather than a science. The radome designer must have at his disposal some means of rapidly collecting boresight shift data, which he can employ to improve or control a given radome design.

This paper describes an automatic boresight measuring system, consisting of a radome mounting fixture, a radar tracking antenna and a null seeking mechanism, which can be employed to provide such data. The automatic boresight measuring equipment is able to automatically collect and record boresight data, cross talk data, and the vector sum of these two as a function of the angle of look. The accuracy of these measurements is better than 0.25 mils.

This particular set of automatic boresight measuring equipment can also be employed as a radiation pattern measuring device.

INTRODUCTION

"A chain is no stronger than its weakest link." Two links of particular importance to the aeronautical electronics engineer are the radar antenna and the radome. The tracking radar antenna is responsible for detecting the target of interest and then accurately determining its relative angular position and range. The radome is responsible for enclosing and protecting the radar antenna during flight, introducing little or no error in the location of the target of interest (boresight error).

With the advent of supersonic aircraft, nose radomes have assumed conical shapes with high-fineness ratios, rather than the hemispherical radomes formerly used with subsonic aircraft. This change to high-fineness ratio conical radomes has greatly increased the radome designer's problem, especially in connection with boresight shift for various angles of look. Radome design is presently at a state where it is more of an art than a science, and therefore the radome designer must have some tool that will allow him to evaluate just how good a radome may be, and just how its characteristics vary as small changes are made in radome construction.

The purpose of this paper is to describe such a tool -- an automatic boresight measuring instrument. This particular set of boresight equipment consists of:

a) a radar tracking antenna and a beam shift recording mechanism which together establish a radar line of sight, and

b) a radome mounting fixture which supports the test radome associated with the tracking antenna and rotates in such a manner that all points on the radome may be explored.

Basically, the equipment is capable of simultaneously measuring and recording the boresight error, the cross talk error, and the vector sum of these two, over angular cuts of 100° with a measurement accuracy of the order of 0.2 milliradians.

MECHANICAL DESIGN

The problem of designing a radome mounting fixture such that we may conveniently explore any desired portion of a given radome, at first sounds like a straightforward design procedure. However, we must be careful that whatever scanning motion is employed truly reproduces the scanning motion that takes place in the actual installation. Consider, for example, an aircraft installation of a tracking antenna and a radome where the antenna executes an azimuth sweep for an elevation angle of -10°. The intersection of the radar line of sight with the radome is a curve, parabolic in form, that lies in a plane parallel to the axis of the radome. If we were to install the radome about the tracking antenna on the pattern range, and if we were to take an azimuth cut by rotating the radome for the radome tilted relative to the fixed tracking antenna to simulate -10° in elevation at dead ahead, the intersection of the line of sight with the radome in this case is a curve parabolic in form, but lying in a plane that intersects the axis of the radome. These two cuts are not equivalent. Figure 1 indicates just how the various azimuth and elevation sweeps intersect the radome. It can be shown that if we wish to accurately duplicate the boresight errors encountered in an actual installation, that the test radome must be mounted with its azimuth and elevation axes interchanged. The mechanical design philosophy of the radome mounting fixture is based on this premise. Briefly, it may be described as follows:

The positioning mechanism shown in Figure 2 consists of a "vertical axis" turntable on which is mounted the half-yoke support for the "horizontal axis" scanning mechanism. The "horizontal axis" scanning mechanism is mounted on the half-yoke with large diameter bearings and supports the radome ring bearings. It is motor driven throughout its operating range. The radome support ring is mounted on roller bearings to permit rotation of the radome on its own axis through 360°. A suitable clamp is provided to lock the radome support ring at any desired setting. The support ring inside diameter is 46" and will accomodate radomes up to 42" in diameter. The equipment can be modified to accomodate larger radomes. Maximum great circle angular motion permitted by the 46" ring is approximately 100°. A mounting plate is provided at the upper end of the antenna support bracket for mounting the particular radar tracking antenna associated with the radome under test. A boresight telescope bracket is mounted on the "horizontal axis" scanning mechanism parallel to the radome axis and normal to the radome support ring. This boresight telescope mounting enables the operator to calibrate the test equipment and to check its accuracy. The antenna support bracket is rigidly attached to the base of the radome mounting fixture for boresight error measurements. It can be employed in conjunction with the turntable for radiation pattern measurements.

The other end of the boresight measuring equipment consists of a null seeking system. This system includes a microwave shaping device and a positioning mechanism mounted on a pedestal which utilizes a biplaner parallelogram linkage to position the microwave shaping device. This particular piece of automatic boresight measuring equipment was designed for a 1,000" boresight range and the null seeking mechanism is designed to search a 30 x 30 milliradian sector.

ELECTRICAL DESIGN

Electrically, the automatic boresight measuring equipment operates somewhat as follows: a microwave source of energy supplies energy via a flexible coaxial cable to a parabolic antenna mounted on the null seeking mechanism. This antenna transmits a pencil beam in the direction of the radome and radar tracking antenna mounted at the other end of the 1,000" boresight range. The radar tracking antenna receives this energy as modified by the radome and develops a tracking error signal proportional to the apparent location of the null seeker source of energy. These tracking error signals are resolved into azimuth and elevation components and are fed back to motors that control the null seeker, which in turn drives the null seeker in such a manner as to reduce the tracking error signal to zero. As the radome is rotated through some desired cut, the effect of the radome changes and the apparent location of the null changes, thereby changing the relative position of the null seeker. The position of the null seeker is transmitted to a graphic recorder where boresight error, cross talk error and the vector sum of these two are available for analysis.

A block diagram of the boresight servo amplifier is shown in Figure 3, and its operation may be described as follows:

Energy is accepted by the tracking radar antenna system which, in this particular case, is a conical scanning antenna operating at a spin rate of 35 cycles per second. This signal is detected by a crystal video detector and is applied to a two-stage video amplifier. The output of this amplifier is detected by means of a simple "box-car" type of detector using a keyed detection scheme. This method of detection is useful in reducing the 1,000 cycle noise in the amplifier and it also helps to alleviate certain overloading and blocking conditions that might exist under extreme transient errors. This detector extracts the spin frequency modulation and amplifies it. The 1,000 cycle carrier frequency is rejected by a series filter arrangement and the smoothed output is applied to a narrow band, 35 cycle amplifier filter, which discriminates against spin frequency second harmonic noise. The resulting signal is phase detected, using as a reference two voltages derived from the scanner spin generator which are indicative of the azimuth and elevation beam position. The two DC outputs of the phase sensitive detectors are fed through servo compensated networks, and then chopped at 60 cycles before being applied to their respective motor drive amplifiers. Two feed back loops are provided around the motor drive amplifiers. The first loop is employed to reduce the output impedance to prevent single phasing of the servo motors. The second loop employs tachometer feed back to reduce the motor time constant and therefore allows a higher loop gain with a resulting improved static accuracy. Tachometer feed back also improves the high frequency response thereby reducing the effects of wind loading.

Typical response curves for such a system are shown in Figure 4. These curves indicate that the dynamic error, as limited by servo response, for a ramp boresight shift pattern with a slope of 3 mils per degree, is somewhat less than 0.3 mils for a rotational rate of 180° per 10 minutes. If tachometer feed back is employed, the maximum error can be reduced to less than 0.2 mils for a rotational rate of 180° per 5 minutes, and to less than 0.1 mil for a rotational rate of 180° per 10 minutes.

The factors which ultimately determine the accuracy of the boresight measurement can be conveniently divided into static and dynamic system accuracies. The static errors include such factors as motor sensitivity, noise due to spin frequency second harmonic and carrier demodulation, drift of balance, wind loading, mechanical stiction and magnetron instabilities. The sum total of these errors is relatively small, probably of the order of 0.075 milliradians.

The dynamic inaccuracies include such factors as servo system response, reference generator phasing and wind loading. As described above, the servo response depends somewhat on the slope of the boresight error; for an extremely poor radome (boresight shift rate of 3 milliradians per degree) with a 3 minute data collection period, the maximum error due to servo response was less than 0.2 mils. The proper adjustment of the reference generator phasing is important in reducing cross talk. Experiments to date indicate that small inaccuracies in spin generator phasing do not materially affect the overall accuracy. Wind loading is a problem that must be considered on an individual site basis. The frequency spectrum of most wind gusts is sufficiently high to cause jitter in the tracking system unless extremely high servo frequency response is obtained. The use of a high gain, rapid response tachometer feed back loop immediately around the motor and its driving amplifier has been instrumental in reducing wind gust effects to a tolerable minimum. On an overall basis, the boresight measurement equipment is able to operatewith an accuracy of better than ± 0.25 mils. On the average, the accuracy of the system is probably better than 0.2 mils. Obviously, the accuracy of the system will depend in a large measure on the boresight rate of the radome and the speed with which the boresight data is collected.

DATA COLLECTION RATES

The automatic boresight measuring equipment described above provides the radome designer with a tool that will quickly and accurately determine the boresight shift characteristics of a given radome. The various points on the radome may be explored by taking azimuth cuts, elevation cuts and/or circumferential (roll) cuts. The data collection rates depend on the maximum boresight shift slope likely to be encountered and the required measurement accuracy. For a rather poor boresight radome (maximum shift slope of 3 mils/degree) and a measurement accuracy of ± 0.25 mils, a 100° azimuth or elevation cut would require 2.8 minutes. For a reasonably good boresight radome (maximum shift slope of 0.5 mils/degree) and a measurement accuracy of ± 0.25 mils, a 100° azimuth and elevation cut would require 0.5 minutes. For radomes with small boresight shift rates, one can employ a long data collection period and possibly realize boresight accuracies of 0.1 mil.

CONCLUSIONS

1) The high-fineness ratio required by modern boresight radomes reduces present day radome design to an art rather than a science.

2) A radome designer must have at his disposal some means of rapidly collecting boresight shift data which he can employ to improve or control a given radome design.

3) An automatic boresight measuring system consisting of a radome mounting fixture, a radar tracking antenna, and a null seeking mechanism, can be employed to provide such data.

4) The automatic boresight measuring equipment is able to automatically collect and record boresight data, cross talk data, and the vector sum of these two as a function of angle of look. The accuracy of these measurements is better than 0.25 mils.

5) The automatic boresight measuring equipment can also be employed as a radiation pattern measuring device.

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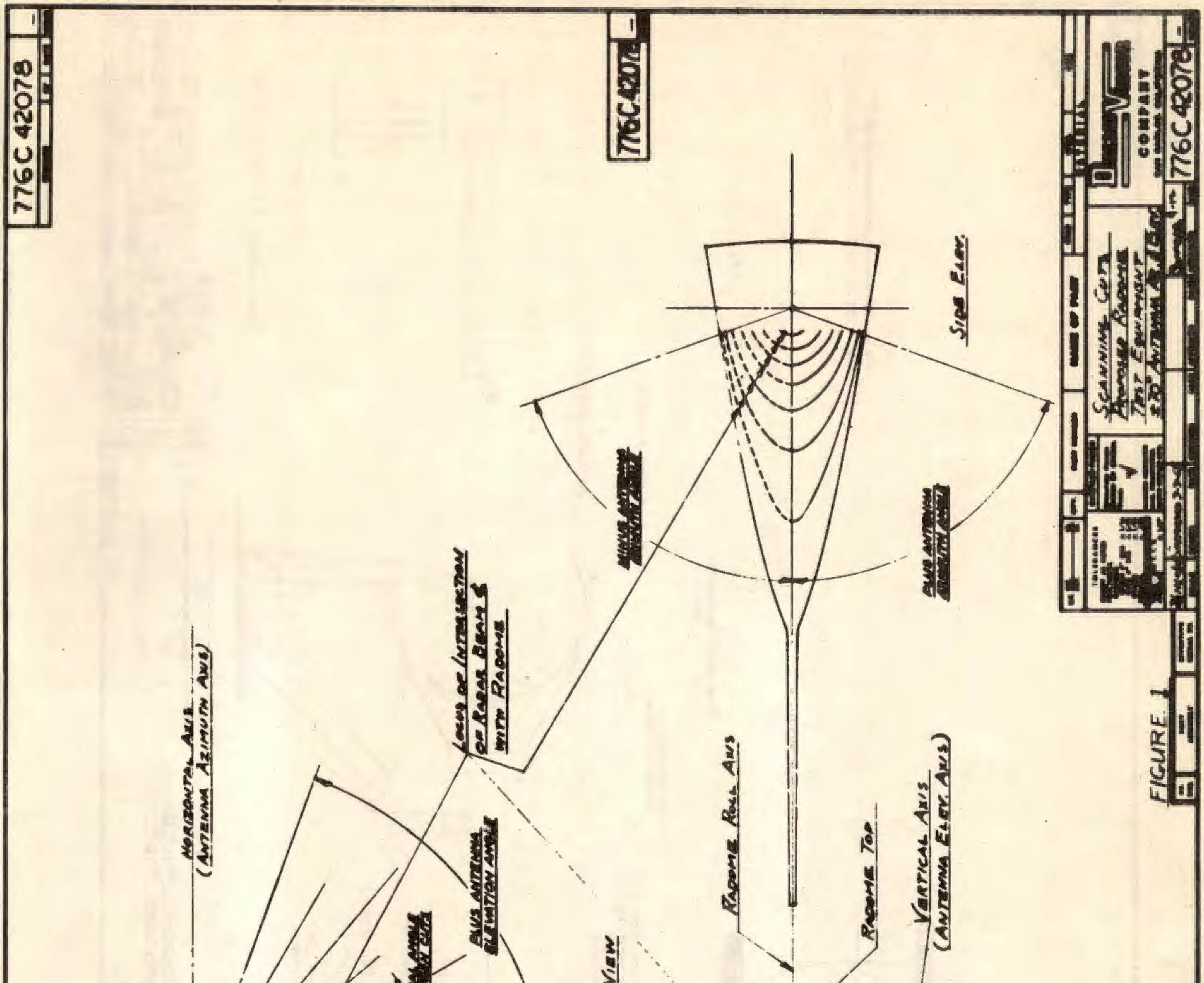
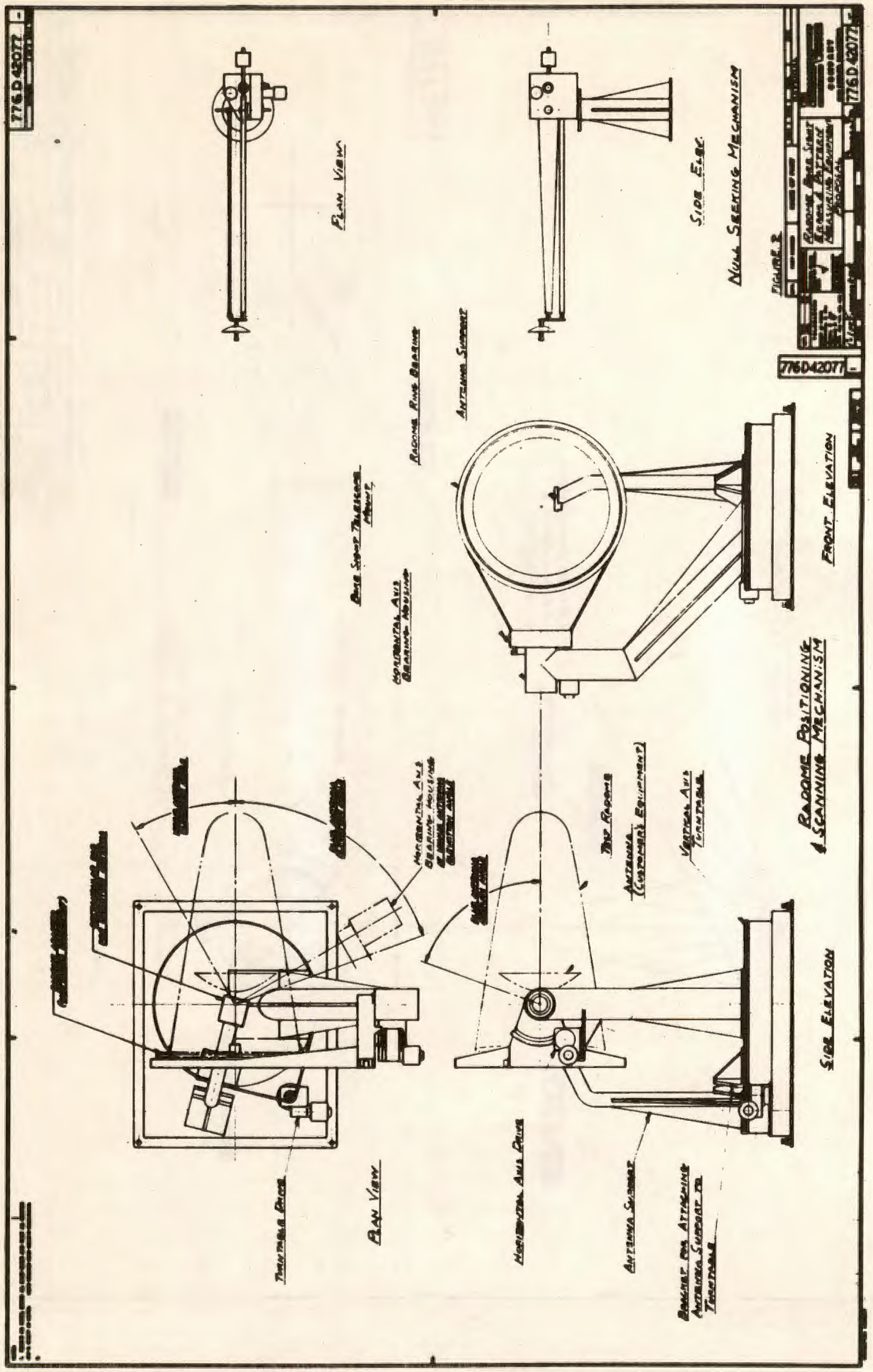
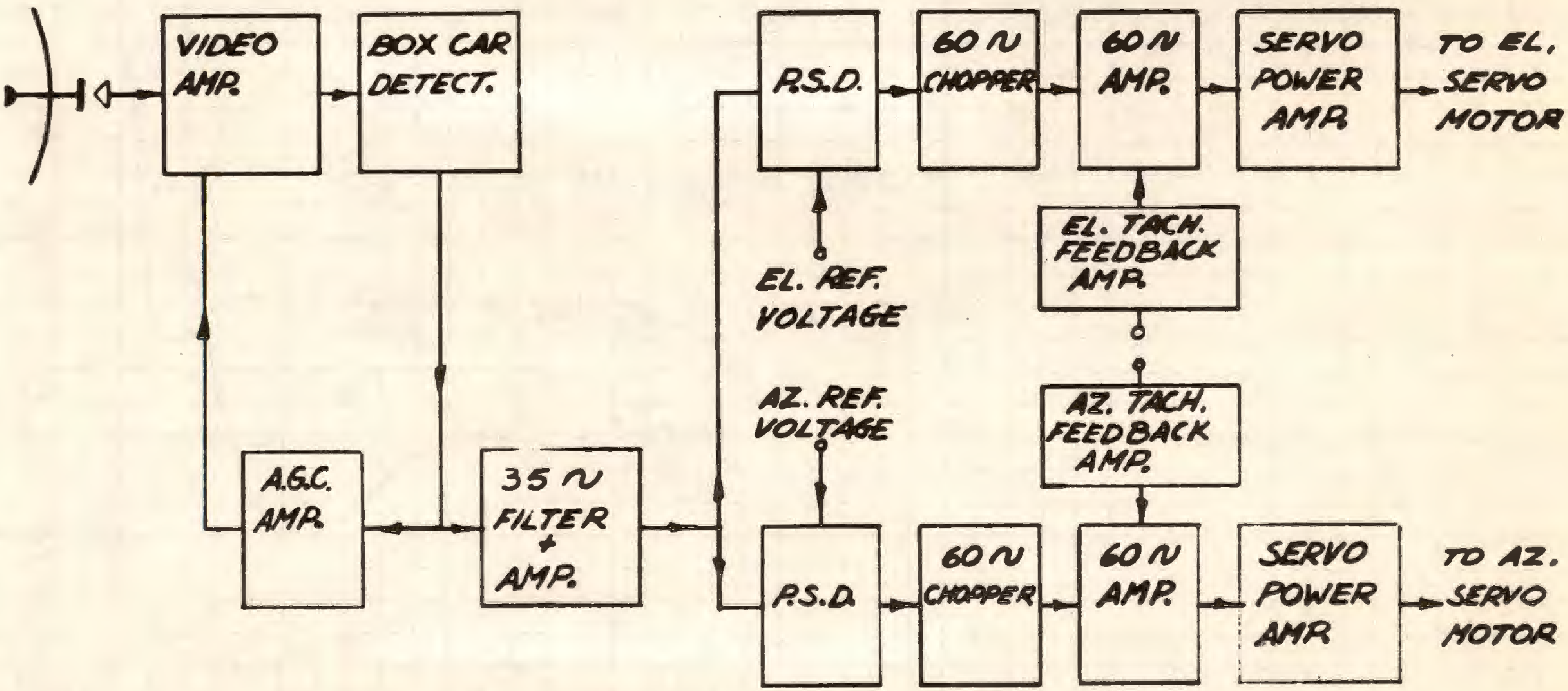

776C 42078
HORIZONTAL AXIS
(ANTENNA AZIMUTH AXIS)
LOCUS OF INTERSECTION OF RADAR BEAM ℄ WITH RADOME
PLUS ANTENNA ELEVATION ANGLE
MINUS ANTENNA ELEVATION ANGLE
PLAN VIEW
RADOME ROLL AXIS
RADOME TOP
VERTICAL AXIS
(ANTENNA ELEV. AXIS)
RIGHT
LEFT
FRONT ELEV.
RADOME BOTTOM
MINUS ANTENNA AZIMUTH ANGLE
PLUS ANTENNA AZIMUTH ANGLE
SIDE ELEV.
SCANNING CUTS
PROPOSED RADOME
TEST EQUIPMENT
COMPANY

FIGURE 1


776D42077
PLAN VIEW
SIDE ELEV.
NULL SEEKING MECHANISM
ANTENNA SUPPORT
FRONT ELEVATION
RADOME POSITIONING
& SCANNING MECHANISM
TEST RADOME
VERTICAL AXIS
TURNTABLE
PLAN VIEW
SIDE ELEVATION
TURNTABLE DRIVE
HORIZONTAL AXIS DRIVE
ANTENNA SUPPORT
BRACKET FOR ATTACHING
ANTENNA SUPPORT TO
TURNTABLE

NOTES:



QTY	PART NUMBER	NAME OF PART	KIND	TYPE	SPEC.	SIZE
			MATERIAL			

BLOCK DIAGRAM FOR SERVO AMPLIFIER FOR RADOME ERROR MEASURING EQUIP.

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NO. REQ	NEXT ASSEMBLY	EFFECTIVE SERIAL NO.	SCALE	DRAWN	DATE	CHECKED	DATE	APPROVED	DATE	APPROVED	DATE		ISSUE
			—	Abestuno	9/6/56							FIGURE 3	

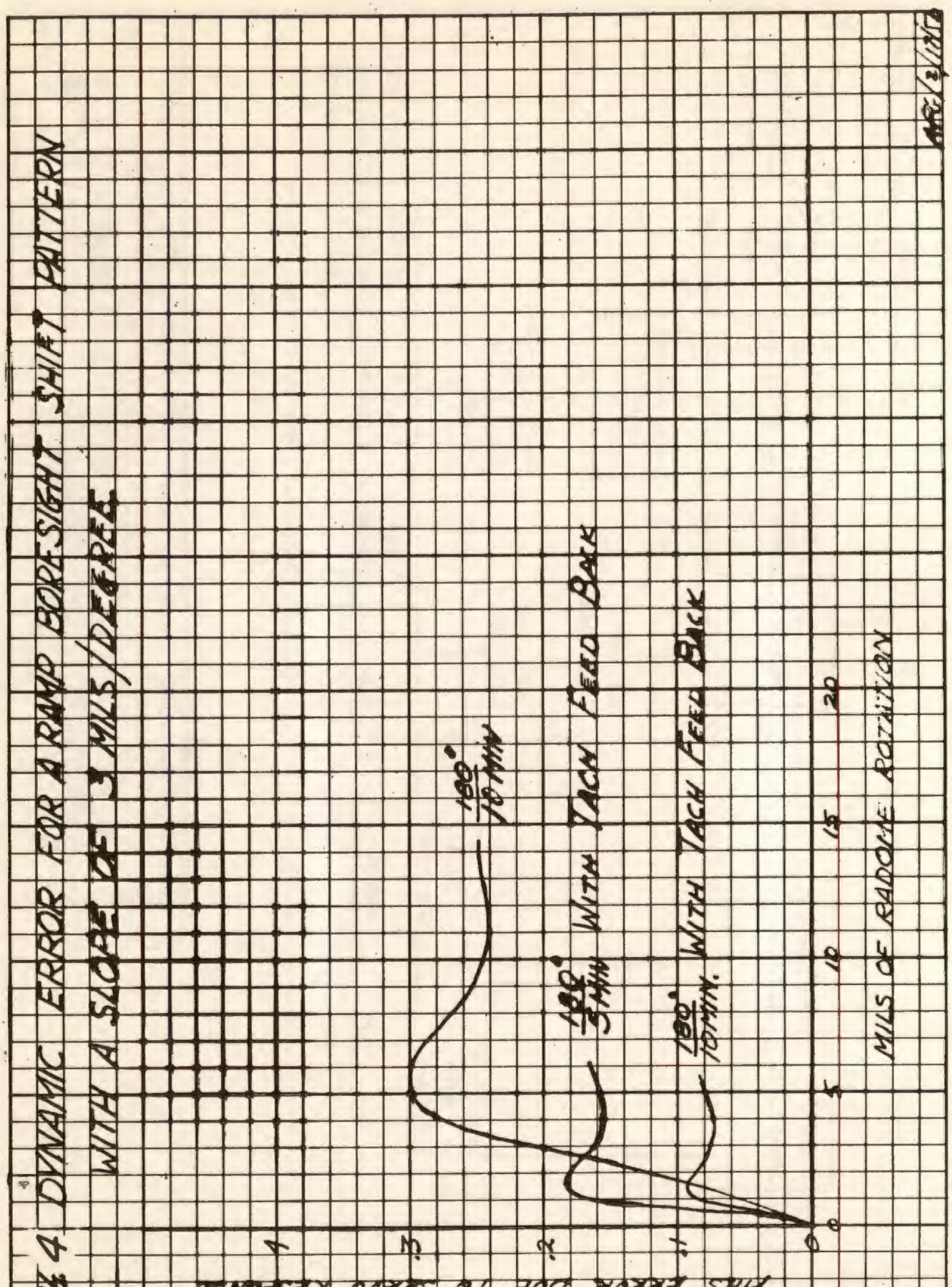

FIG 4 DYNAMIC ERROR FOR A RAMP BORESIGHT SHIFT PATTERN WITH A SLOPE OF 3 MILS/DEGREE