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ABSTRACT

The power pattern of a corrugated horn antenna designed for low-sidelobes was measured to levels 90 dB below the main beam maximum in both the E and H planes. The measured patterns were found to be in good agreement with theoretical predictions. It is demonstrated that a conducting ground plane shield may be employed to further reduce the effective sidelobes of the horn antenna.

INTRODUCTION

Antennas with high off-axis signal rejection have general application in communications, satellite-earth stations and radio astronomy. The present work was motivated by a requirement for an antenna with very low sidelobes to measure the cosmic microwave background radiation from a satellite. The particular application calls for horn antennas of approximately 7° beamwidth scanning the sky at frequencies in the range 20 GHz to 90 GHz to obtain a precise determination of the anisotropy of the diffuse background radiation. If current state-of-the-art antennas and pattern measurement techniques are assumed, then the precision obtainable in such a measurement is severely limited by stray earth or solar radiation which may enter through the far antenna sidelobes. To our knowledge, the sidelobes of horn antennas of this beamwidth have not been measured to levels lower than 75 dB below the main beam peak [1], [2], [3].

The present work demonstrates that the sidelobes of horn antennas can be measured to significantly lower levels. Our specific goal was to demonstrate the feasibility of obtaining an off-axis rejection on the order of 85 dB, relative to the main peak, at all angles beyond 60° from the axis. To meet this objective we have concentrated on the pattern measurement of an existing horn which was specifically designed for low-sidelobe performance. In addition we have investigated the effectiveness of a ground-plane shield in further reducing the sidelobes of this horn. The results should be of interest in both the measurement and further design of low-sidelobe antennas in other areas of application.

THE HORN ANTENNA

An existing horn antenna which was designed for low-sidelobe performance was employed for the measurements. The horn (Figure 1) is a corrugated conical horn of the scalar feed horn antenna type, possessing a beamwidth of approximately 7°. It was constructed under contract by TRG in Boston, Massachusetts, and has been employed in an airborne experiment to measure the anisotropy of the cosmic background radiation [4]. The design is based on pioneering studies by Kay [5] and Potter [6] of low-sidelobe antennas. Several authors, most notably Clarricoats and Saha [7], have investigated the theoretical properties of this type of antenna. The significant features of the present horn are its broad bandwidth, and the 10° flare angle and moderate groove spacing which permit compact and easy construction. Although the design frequency of the horn is 33 GHz, the pattern was not predicted to be significantly different at the present test frequency of 31.4 GHz. A transition section is employed to match the circular input port of the horn with rectangular waveguide.

THE MEASUREMENT TECHNIQUE

The horn pattern was measured at the Mesa Antenna Test Range Facility of the Jet Propulsion Laboratory in Pasadena, California. The antenna test range is located on a mesa north of the Laboratory. The measurement strategy was to eliminate as nearly as possible the main sources of extraneous signals which could confuse the far-sidelobe measurements, while a conventional pattern measurement technique was employed. The chief sources of background signal were anticipated to be radiation scattered into the main beam or near sidelobes from nearby objects, and RF leakage into the receiver behind the horn due to imperfect connectors and junctions. Particular care was taken to obtain a clean test geometry, while the RF portion of the receiver was made extremely compact and easy to shield.

The measurement geometry illustrated in Figure 2 was achieved by mounting a receiver with the test horn and transmitter on towers, illuminating the test horn on a horizontal path. The transmitter-receiver plane was thus removed 6 meters from the ground to isolate the test system from nearby sources of reflection. The receiver tower was located at the edge of the mesa, the terrain beyond falling off sharply. The transmitter employed an identical low-sidelobe horn to further reduce potential reflection paths. The test horn was rotated in a horizontal plane by rotating the receiver tower on an azimuth bearing located near ground level. The axis of azimuth rotation passed through the point where the horn axis intersects its aperture, so that the incident signal was uniformly sampled as the azimuth was rotated to measure the sidelobes. The mount holding the receiver and test horn also rotated around the test horn axis, allowing the test horn polarization to be set at any chosen angle. The transmitter and test horn were separated by 4 meters, giving a sufficiently uniform illumination of the test horn while maximizing signal strength.

Figure 3 gives a schematic of the test circuit. A fixed-frequency Gunn oscillator supplied a CW signal at the test frequency. A calibrated attenuator in the transmitter circuit allowed the transmitter power to be varied from its maximum of 10 milliwatts through a range of 50 dB. A series 1750 receiving system manufactured by Scientific-Atlanta Corporation was employed, and consists in essence of a narrow-band receiver which is phase-locked to the transmitter signal. The local oscillator employs a relatively low frequency signal

($\sim$2.6 GHz), the 12th harmonic of which is locked to the transmitter frequency. The advantage of this system is that the RF portion of the receiver is limited to the harmonic mixer, and is very compact. For the measurements the mixer was well wrapped with microwave-absorbing material in a small cylindrical volume behind the test horn. Although the receiving system was capable of obtaining phase as well as amplitude data, only amplitude information was retained in our measurements. The received signal power was recorded on a log-scale recorder chart, the second axis of which was synchronized with the horn rotation angle.

THE HORN PATTERN

After a series of measurements to guarantee proper alignment of the test system, the pattern of the test horn was measured in both the H and E planes. The results are shown in Figs. 4 and 5 respectively. Receiver linearity was checked by remeasuring the H-plane pattern with the transmitter power reduced in increments through a range of 50 dB. The patterns remained identical to within 1 dB over the region where the system noise is negligible, ensuring linearity over the dynamic range of the measurements. Receiver noise dominates the measurement below 90 dB. Taking into account the short time constant employed in the receiver, we estimate an upper limit to the signal of as low as 95 dB in the far sidelobes.

Variations in the test system such as varying the transmitter/receiver separation and rewrapping of the microwave-absorbing material around the receiver produced no noticeable changes in the measured pattern. Hence we conclude that the measurement is noise-limited, and find no apparent limitations which would not allow further improvement by increasing receiver sensitivity or transmitter power.

The dashed curves in Figures 4 and 5 show a theoretical calculation of the test horn pattern based on a computer program developed by Potter [2]. Although there are small deviations between the calculated and measured patterns, the overall agreement is excellent. The observed differences may be due to machining tolerances in the actual horn or to neglected contributions in the computation of the theoretical patterns.

THE EFFECT OF A GROUND-PLANE

In principle, a shield consisting of a conducting sheet which geometrically shadows the horn from radiation in a given direction may act to further suppress the effective sidelobes in this direction. To test this concept, a shield was constructed and attached to the horn (Figure 6). The intent was to simulate the simple case of a semi-infinite half-plane which geometrically shadows the horn aperture at angles beyond 30° from the horn axis in the direction normal to the shield plane. The horn-shield combination was mounted on the receiver tower such that the horn position remained the same as previously, with the shield plane vertical. Azimuth rotation then allowed the gain pattern of this combination to be measured in the direction normal to the shield plane.

Figs. 7 and 8 show the results of measurements in the H and E planes, rotating the horn with respect to the shield (which was maintained vertical) to obtain the respective polarizations. These results were compared with a simple diffraction calculation in which it was assumed that the incident radiation is a plane wave and that the shield acts as a perfectly conducting semi-infinite plane. The effective gain of the horn-shield combination is computed as the gain of the unshielded horn at the geometric shadowing angle of 30°, reduced by the relative loss of intensity of the diffracted wave in the shadow region.

The finite horn aperture is neglected. The intensity loss due to Fresnel diffraction by a semi-infinite plane is readily calculated [8] to give curve A of Figs. 7 and 8. This approximation may be physically justified by noting that the diffracted wave originates in a few narrow Fresnel zones at the edge of the shield, and at the horn aperture must approximate a plane wave incident at an angle very nearly equal to the geometric shadowing angle. Since the angle of incidence is slightly decreased from the shadowing angle, the above approximation tends to overestimate the reduction in gain.

The large discrepancy between this prediction and the measured pattern may be accounted for by considering the narrow beamwidth of the transmitter horn. In the pattern sweep the transmitter horn remained directed at the receiver horn, and at large angles of incidence the diffracting edge of the shield is illuminated by the edge of the beam. The loss of intensity is conservatively estimated by finding the transmitter horn gain at the intersection of the receiver rotation plane with the shield edge, taking into account the additional scattering angle due to the finite distance of the transmitter, and adjusting curve A accordingly downward to obtain curve B of Figs. 7 and 8. This gives better agreement with the measured pattern, and the remaining discrepancy is reasonably accounted for by noting that the average intensity in the first few Fresnel zones along the shield edge is somewhat less than given by this conservative estimate. Additionally, a more correct diffraction calculation must take the incident wave polarization and the appropriate boundary conditions at the shield edge into account. We believe that such refinement is unwarranted in the present case, although we note that the measured H-plane gain in Figure 7 is lower with respect to the polarization-independent Fresnel prediction than in the E-plane case of Figure 8.

CONCLUSIONS

It is demonstrated that horn antenna patterns are measureable to levels approaching 95 dB below the central peak with conventional range techniques. Since the present measurement is noise-limited, lower levels are possible with relatively straight-forward improvements in the sensitivity of the apparatus. Existing theory for the performance of corrugated scalar feeds appears to give excellent predictions at these low sidelobe levels.

The observed effect of the ground-plane shield is generally consistent with Fresnel diffraction theory,although the large apparent sidelobe reduction seen in Figs. 7 and 8 results in part from our test geometry. The theoretical curves (A) give a more correct estimate of the sidelobe performance of the present configuration for a uniform plane wave. This result may be more usefully generalized by noting that the antenna gain, modified by a semi-infinite ground plane shield, is well approximated in the far shadow region by the asymptotic expression

$$G(\theta) = G_o(\theta_s)\frac{\lambda D}{[2\pi\ s]^2}\ ,\ \theta \gg \theta_s$$

where θ is the angle of incidence in the plane perpendicular to the shield, and $G_o(\theta_s)$ is the gain of the unshielded horn at the geometric shadowing angle θ_s. D is the normal from the aperture to the wave front plane tangent to the shield edge, while s is the distance on this plane from the normal to the shield edge. This function decreases more slowly than the nearly exponential behavior exhibited by the present horn just off the central peak, and it is evident that a horn-shield combination must be carefully optimized for a given application in order to obtain the full benefit of shielding.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

1. The test horn - a corrugated, conical scalar feed horn antenna. The flare angle is 10°, and the groove spacing is approximately 0.5 wavelengths. Choke grooves on the rim face are to supress potential backlobe radiation.
2. Schematic of the pattern measurement geometry.
3. Test circuit schematic.
4. H-plane radiation pattern of test horn; ——— measured, ---- calculated. Receiver noise dominates below 90 dB.
5. E-plane radiation pattern of test horn; ——— measured, ----- calculated.
6. Ground-plane shield geometry.
7. H-plane radiation pattern of test horn with shield; ——— measured; curve A, predicted performance for a plane wave diffracted by a semi-infinite conducting plane shield; curve B, predicted performance for the shielded horn taking into account the finite beam of the transmitter horn and the test geometry.
8. E-plane radiation pattern of test horn with shield (refer to caption for Figure 7).

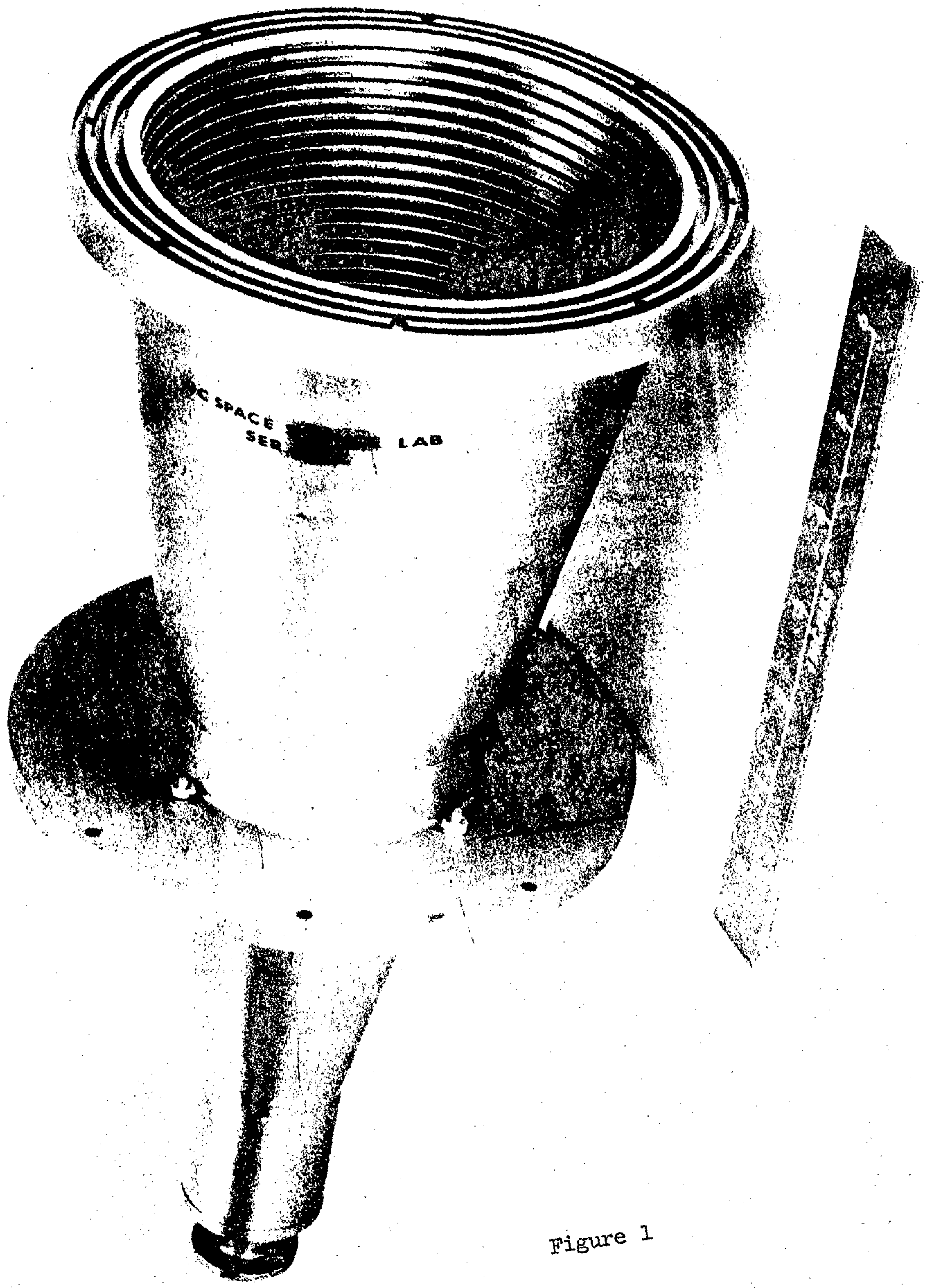


Figure 1

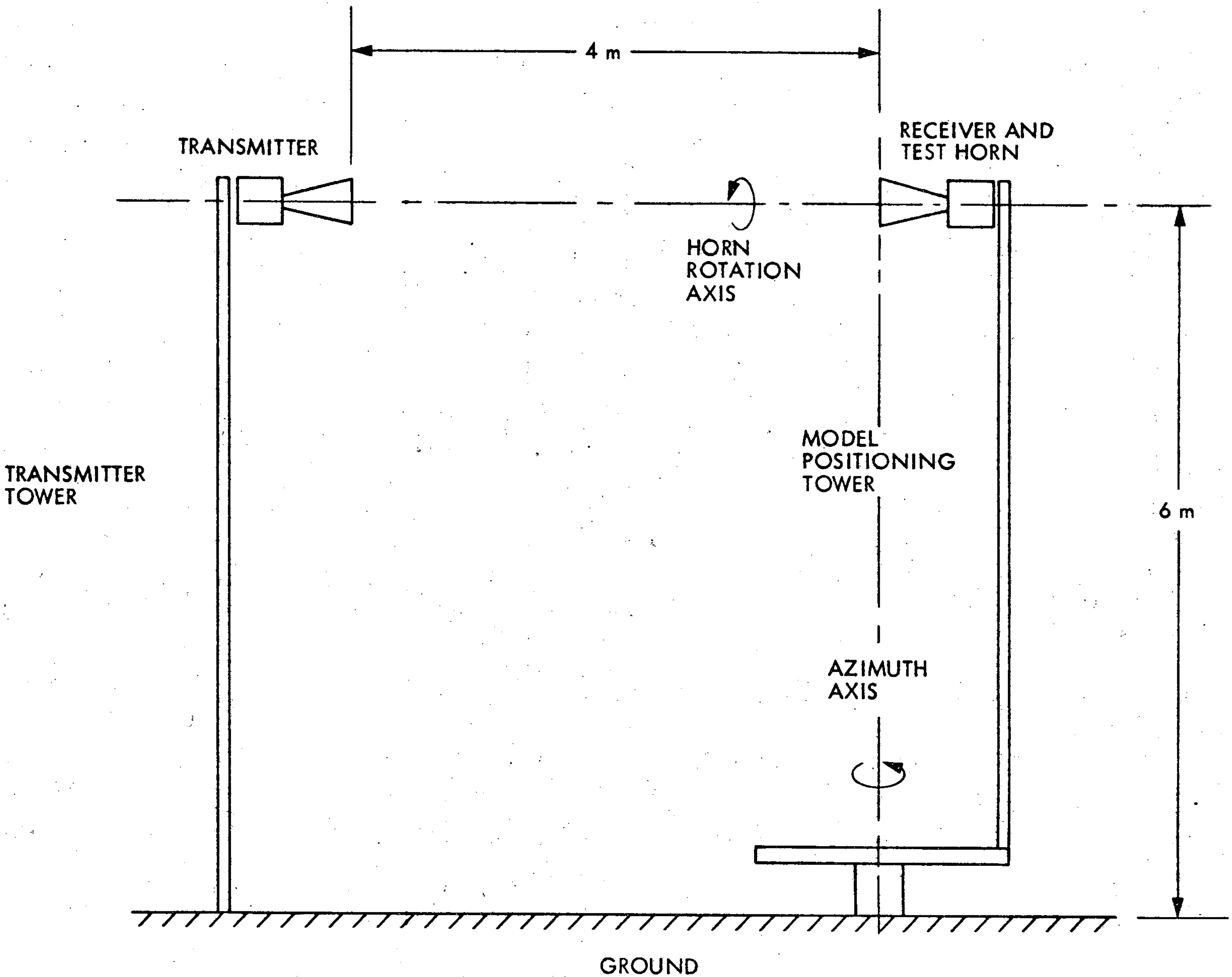

4 m
TRANSMITTER
RECEIVER AND TEST HORN
HORN ROTATION AXIS
TRANSMITTER TOWER
MODEL POSITIONING TOWER
6 m
AZIMUTH AXIS
GROUND

Figure 2

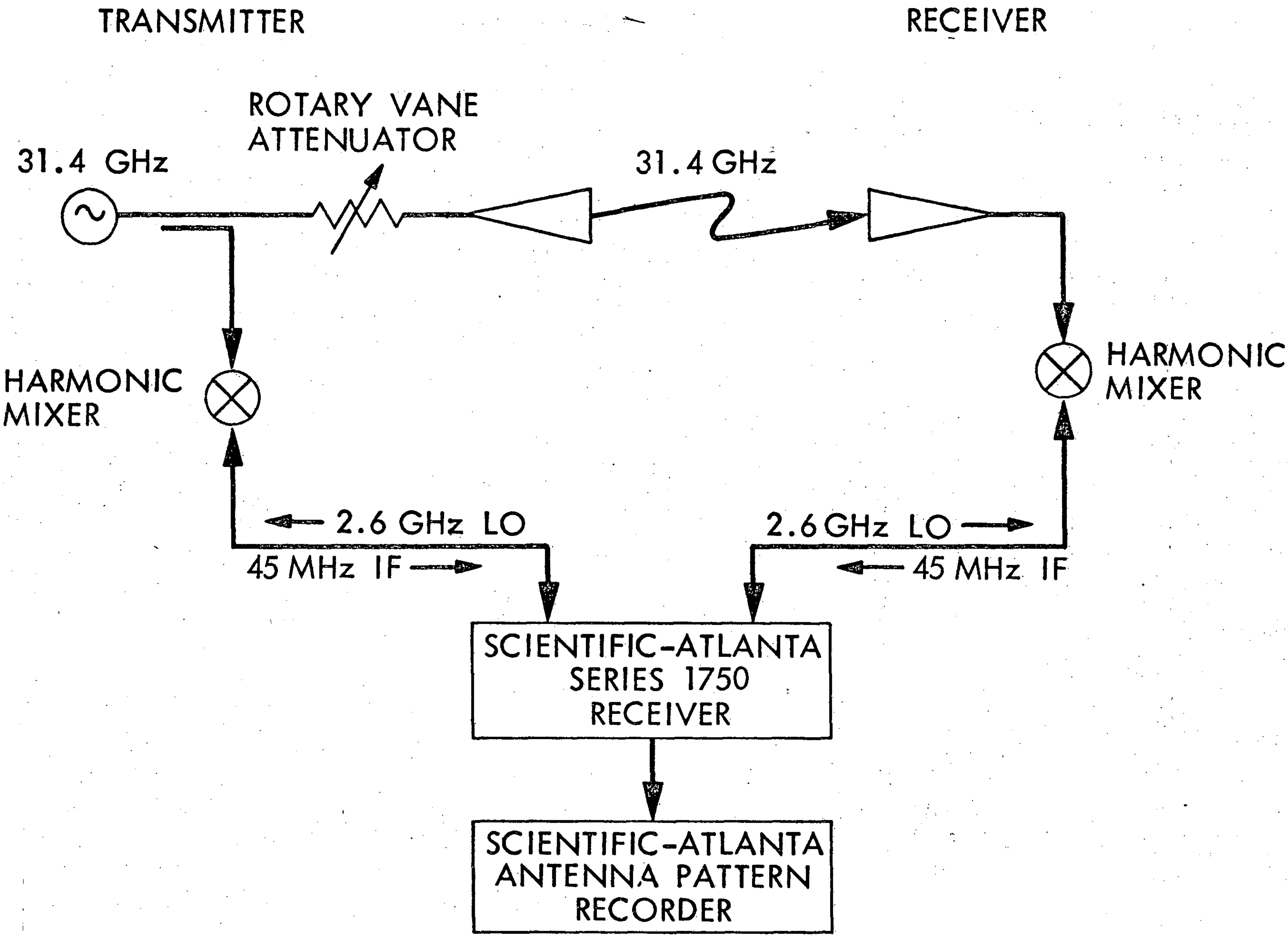
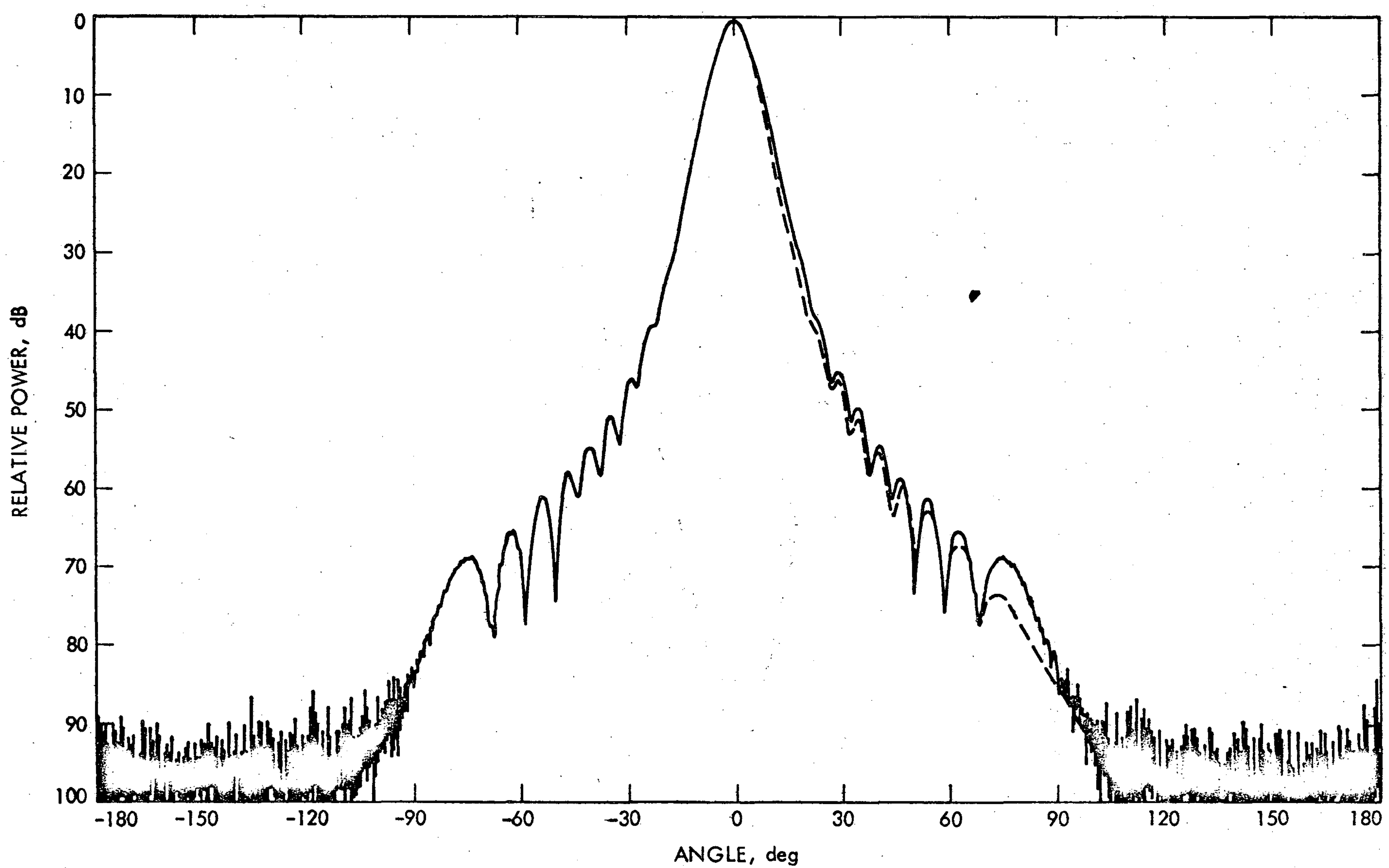
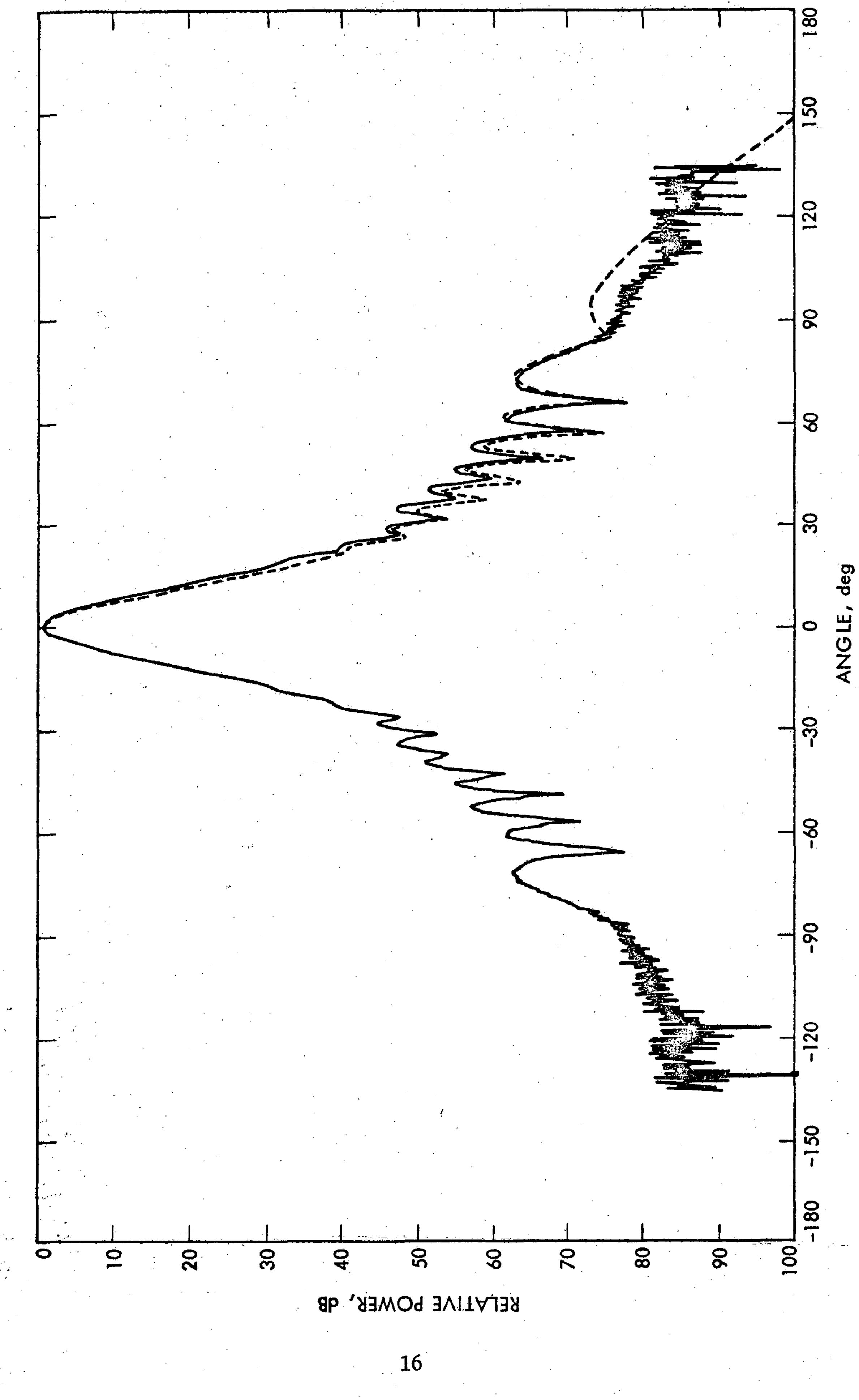

TRANSMITTER
RECEIVER
ROTARY VANE
ATTENUATOR
31.4 GHz
31.4 GHz
HARMONIC
MIXER
HARMONIC
MIXER
2.6 GHz LO
45 MHz IF
2.6 GHz LO
45 MHz IF
SCIENTIFIC-ATLANTA
SERIES 1750
RECEIVER
SCIENTIFIC-ATLANTA
ANTENNA PATTERN
RECORDER

Figure 3



0
10
20
30
40
50
60
70
80
90
100
RELATIVE POWER, dB
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
ANGLE, deg

Figure 4



RELATIVE POWER, dB
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ANGLE, deg
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-90
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0
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180

Figure 5

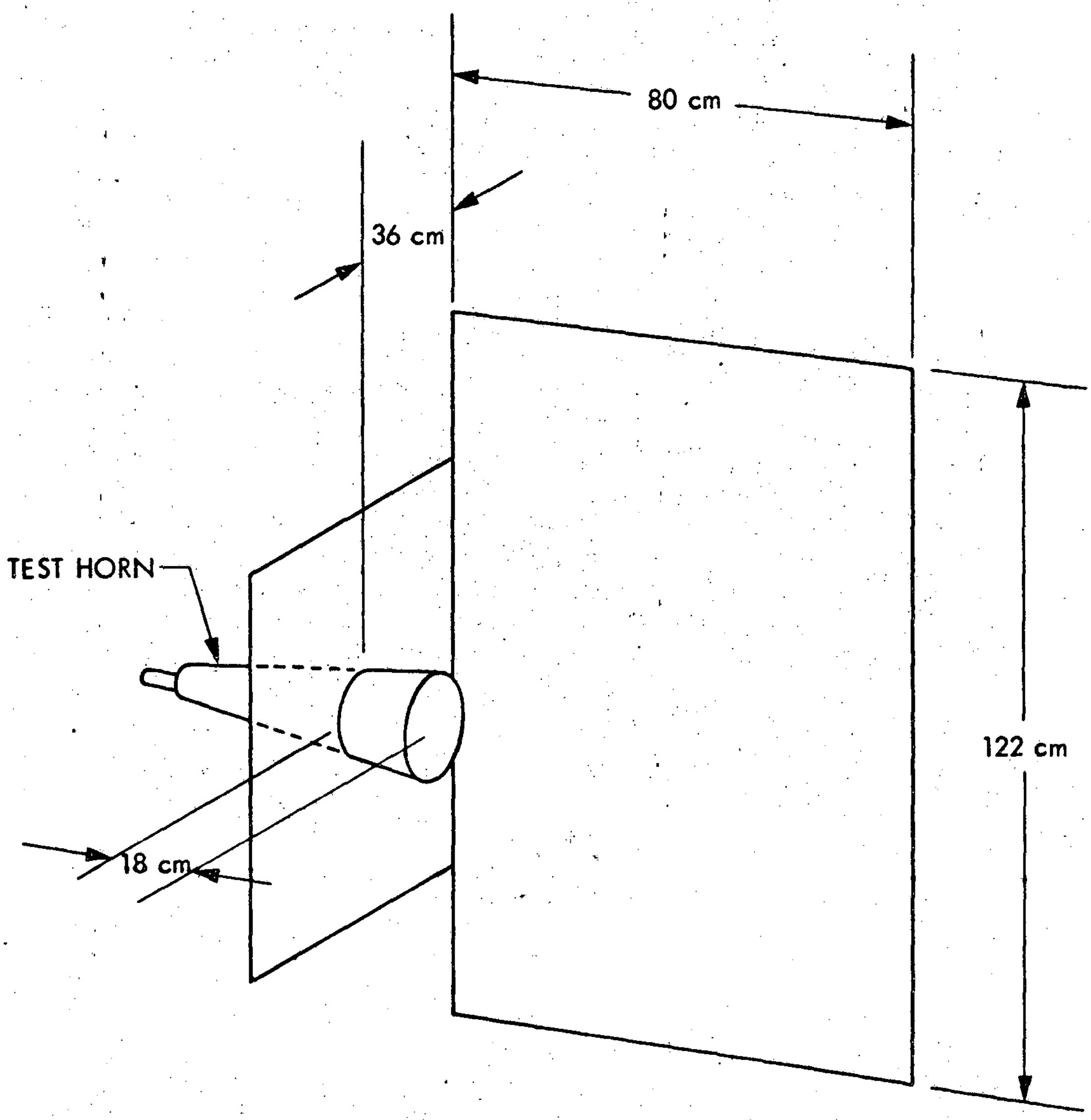

Figure 6

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