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An Experimental Investigation of Wide-Angle Sidelobe Suppression in a Pyramidal Horn-Reflector Antenna

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An experimental investigation into the suppression of wide-angle radiation from a pyramidal horn-reflector antenna is reported in this study. We show that lining the sidewalls or diffracting edges of this antenna with microwave absorber in the region of the visible aperture can lead to a marked reduction in sidelobe energy when the antenna is transversely polarized. Specifically, sidelobe reductions of as much as 10 dB are attainable over angular regions 40 degrees or more from the main beam. Though the described absorber treatment reduces wide-angle radiation, it can simultaneously increase and distinctly modify the character of near-in sidelobe structure. Data reported in this study are related to those of a recently published paper on selective near-in sidelobe reduction for a pyramidal horn-reflector antenna.

I. INTRODUCTION

The judicious application of microwave absorber as a method to modify reflector antenna sidelobe levels is a well-known and powerful technique. The approach is especially useful in the design of large-aperture antennas for terrestrial radio communications, where RF interference into or from other radio links is of paramount and increasing concern.

In a recent paper, R. A. Semplak[1] presented data from an experimental investigation of selective near-in sidelobe reduction of a pyram-

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idal horn-reflector antenna. That work is especially important for those interference situations occurring at small angles from the antenna beam, where the antenna discrimination is naturally less than that at large angles. On the other hand, wide-angle antenna radiation often limits the number of converging routes into a microwave radio station, a potentially acute situation at metropolitan junctions. For the pyramidal horn-reflector antenna, this latter problem was ameliorated for longitudinal polarization* by modifying radome attachment methods[3] and for transverse polarization by attaching multiple-edge blinders to the sidewalls of the antenna.[4,5] This paper is related to Semplak's, in that we also report the results of an experimental investigation into sidelobe suppression in a pyramidal horn-reflector. Unlike Semplak's investigation, however, our focus is on broadband, wide-angle sidelobe suppression. We show, as Semplak did, that sidelobe suppression is dependent on where the absorber is specifically situated, some locations being preferable to others. Additionally, our findings highlight the fact that radiation from this antenna is not completely modeled in prior analytic studies, since they fail to completely predict the radiation patterns of this antenna.

Pyramidal horn-reflector antennas, one generic type in a family of horn-reflectors, are of considerable practical significance.[6] They are widely deployed throughout the world, with domestic use alone exceeding more than 10,000. In Semplak's study a scaled-down precision antenna was measured at 30 GHz. For this study we used a precision, fiberglass antenna specifically designed for line-of-sight operation in the 4-, 6-, and 11-GHz common carrier bands.[7] This antenna stands approximately 16 feet high, has a 70-inch offset paraboloid illuminated by a 29-degree radial pyramidal horn, and is equipped (for a portion of this study) with 17-edge blinders.[8] A photograph of this antenna appears in Fig. 1. Though this fiberglass antenna has an aperture area only 60 percent that of the standard pyramidal antenna used in the AT&T Communications network (with a 90-inch focal length), it affords uncommonly good wide-angle sidelobe suppression. Indeed, in some cases this antenna provides far-out sidelobe levels lower than that of the larger pyramidal horn-reflector. These last observations are noteworthy since we demonstrate in this paper that the wide-angle radiation can be further suppressed by as much as 10 dB using absorber on the sidewalls of the antenna aperture. Unfortunately, this absorber

* We use the conventional definitions for longitudinal and transverse polarizations for this antenna.[2] For terrestrial applications, the pyramidal horn axis is perpendicular to the local plane of the earth, and longitudinal polarization corresponds to aperture electric fields perpendicular to that horizontal plane, while transverse polarization corresponds to electric fields parallel to the earth's surface. All patterns are measured in the transverse plane, an azimuthal plane parallel to the earth's surface.

Fig. 1—Fiberglass, pyramidal, horn-reflector antenna equipped with multiple-edge blinders.

treatment simultaneously increases the near-in radiation lobes. It may well be that a combination of Semplak's methods, with selected microwave absorber placement like that described herein, could suppress sidelobe energy throughout major regions of the antenna's azimuthal radiation plane.

II. EXPERIMENTAL MEASUREMENTS AND INTERPRETATION

The experimental measurements reported in this study were carried out in two phases. In the first phase the antenna was equipped with 17-edge blinders, and the interior sidewalls in the region of the visible aperture were covered with 2-inch-thick, hair-type absorber. This absorber has a near-normal, specular power reflection coefficient less than 0.01 at 4 GHz, with an even smaller reflection at the higher frequencies used for part of this study. Absorber installation in the antenna is schematically illustrated in Fig. 2, where the multiple-edge blinders are omitted for clarity. In the second phase of the study, the blinders were removed, and a 3.5-inch strip of 2-inch-thick absorber was recessed and placed adjacent to the side diffracting edges. This situation, illustrated in Fig. 3, will be deferred for subsequent discussion.

2.1 Absorber-lined antenna interior

For this first phase of the investigation, complete principal and cross-polarized patterns were measured at a single frequency in each

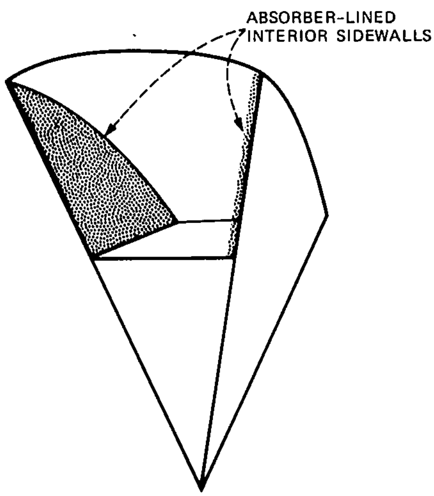

Fig. 2—Absorber installation on sidewalls of antenna. Edge blinders omitted for clarity.

of the 4-, 6-, and 11-GHz common carrier bands. Typical radiation pattern measurements, with and without absorber modification, are presented in Figs. 4 and 5, respectively. Complete 360-degree azimuthal plane patterns are measured in two stages. For radiation near the main beam, a 30-dB RF attenuator is used to limit power into the RF receiver. In the vicinity of 10 degrees, where the power is significantly lower, the attenuator is removed and the remainder of the pattern is measured. Patterns like those in Figs. 4 and 5, therefore, appear

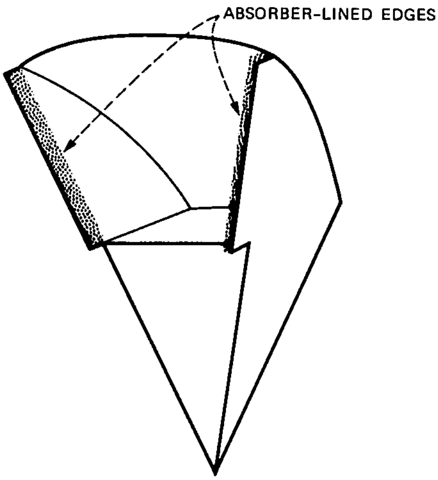

Fig. 3—Absorber installation along exterior, recessed, side diffracting edges. Edge blinders omitted for this portion of study.

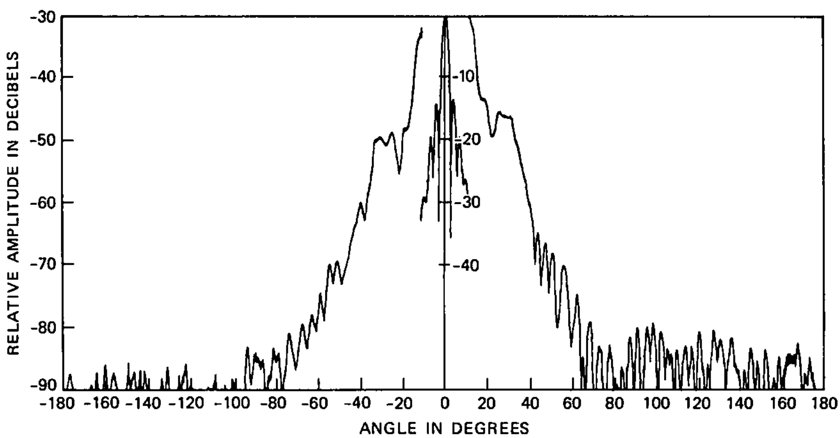

Fig. 4—Radiation pattern of antenna equipped with sidewall absorber and multiple-edge blinders. Transverse polarization, transverse (azimuthal) measurement plane; 3.95 GHz. (Note 30-dB change in ordinate scale near ±10 degrees.)

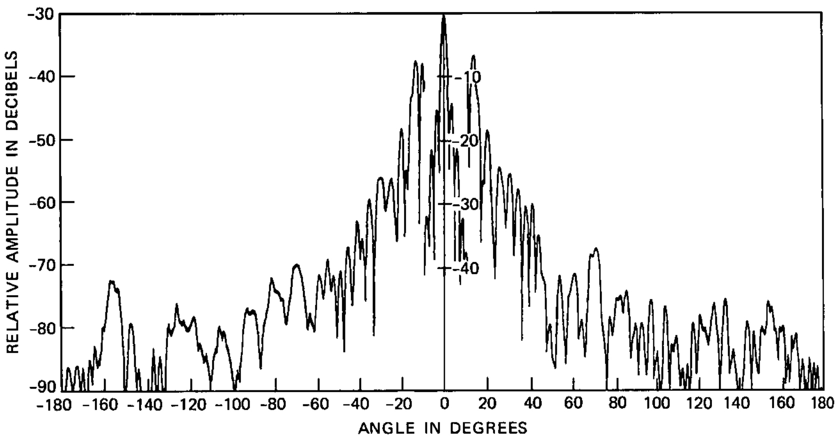

Fig. 5—Radiation pattern of antenna equipped with multiple-edge blinders but without absorber. Transverse polarization, transverse measurement plane; 3.95 GHz. (Note 30-dB change in ordinate scale near ±10 degrees.)

discontinuous with a corresponding 30-dB change in the ordinate. Because the absorber differentially affects near-in and wide-angle radiation sidelobes, results are most conveniently presented in separate subsections.

2.1.1 Absorber-lined antenna interior: effect on near-in sidelobes

Figures 6 and 7 present typical near-in sidelobe performance for 3.95-GHz longitudinal and transverse polarization. These figures also include comparative patterns for the antenna without absorber. The presence of absorber has little effect for longitudinal polarization (Fig. 6), while it notably raises the sidelobe levels and changes the character of sidelobe structure for transverse polarization (Fig. 7).

It will be remembered that the projected aperture fields for this antenna correspond closely to the illumination provided by dominant mode square waveguide. For longitudinal polarization, aperture fields are tangent to, and therefore vanish at, the antenna sides. Thus, for this polarization state, the aperture fields are unperturbed and hardly affect the near-in pattern except for a very slight decrease in aperture width (approximately 5.4 percent).

For transverse polarization, aperture electric fields are normal to the sidewalls and are greatly affected by the presence of absorber. Though one might initially think that the absorber attenuates and, therefore, acts to taper the aperture field, giving rise to reduced near-in sidelobes, Fig. 7 indicates this is not the case. This somewhat unexpected result could be attributable to aperture phase errors or blockage. Aperture phase errors tend to dominantly fill in the first

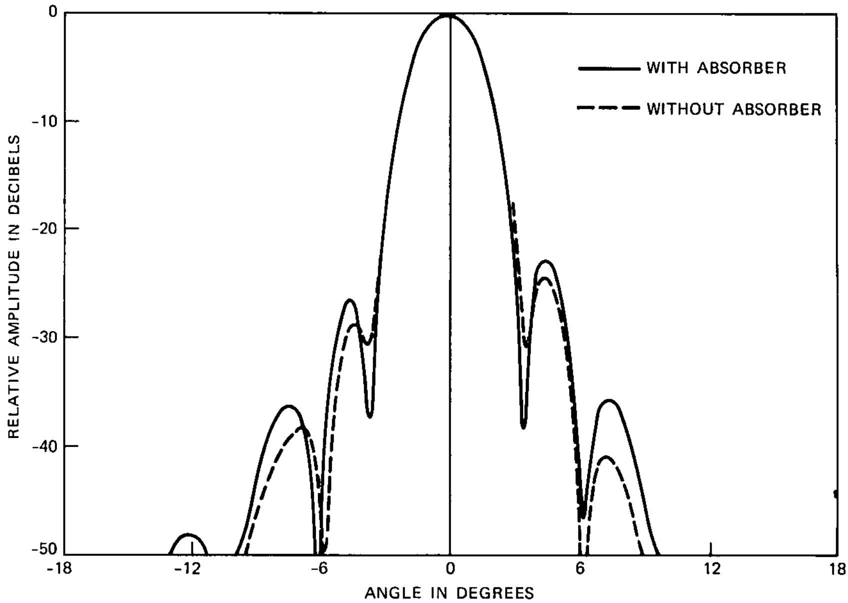

Fig. 6—Near-in radiation pattern. Antenna equipped with multiple-edge blinders. Longitudinal polarization, transverse measurement plane; 3.95 GHz.

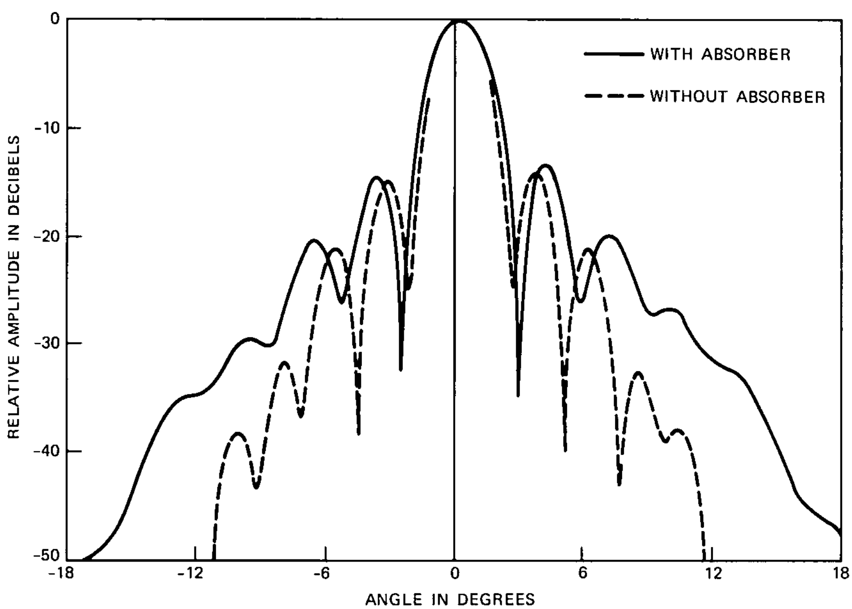

Fig. 7—Near-in radiation pattern. Antenna equipped with multiple-edge blinders. Transverse polarization, transverse measurement plane; 3.95 GHz.

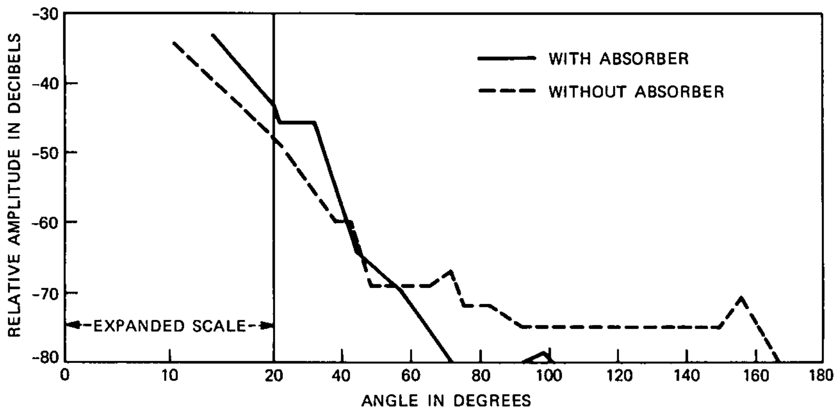

Fig. 8—Smoothed radiation pattern. Antenna equipped with blinders. Transverse polarization, transverse measurement plane; 3.95 GHz.

radiation null, with secondary nulls only secondarily affected.[9] Our measurements indicate that the first null is invariably preserved, with filling in occurring beyond that point. Moreover, phase errors could cause beam shifting in the longitudinal (vertical) plane, an effect not observed in these measurements. A more likely explanation is the excitation of certain higher-order modes, since the absorber was not recessed but partially blocked the aperture. (This effect would be minimal for longitudinal polarization since the fields are already low along the antenna sides.) This hypothesis is difficult to confirm without recessing the absorber, an impossibility in this particular design and an almost intractable problem from an analytic standpoint. It is worth noting though, that even radiation from the higher-order modes should be insignificant beyond several beamwidths (e.g., see Ref. 10), suggesting that the absorber fundamentally causes increased sidelobe levels in the approximate 15- to 40-degree region. This point is discussed further in Section III.

2.1.2 Absorber-lined antenna interior: effect on wide-angle sidelobes

Figures 4 and 5 show that absorber can significantly affect wide-angle sidelobe levels, especially for transverse polarization. This point is further illustrated in Figs. 8 through 11, which present smoothed* directivity patterns for 3.95-GHz principal and cross-polarized operation. Note that when the antenna receives a transversely polarized

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* Smoothed radiation patterns are prepared by the widely accepted technique of drawing an envelope across *peaks* in the antenna radiation pattern. We show a 180-degree envelope that represents the worst sidelobe performance over the full 360-degree transverse measurement plane.

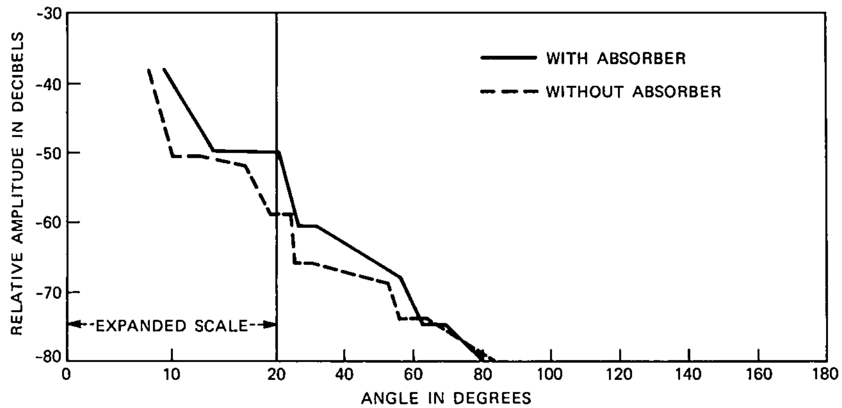

Fig. 9—Smoothed radiation pattern. Antenna equipped with blinders. Longitudinal polarization, transverse measurement plane; 3.95 GHz.

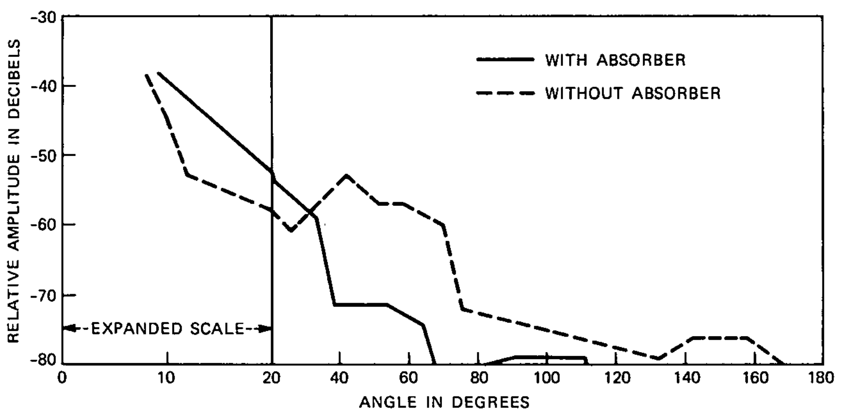

Fig. 10—Smoothed radiation pattern. Antenna equipped with blinders. Transverse polarization response of longitudinal polarization illumination, transverse measurement plane; 3.95 GHz.

signal (co- or cross-polarized), sidelobes beyond approximately 40 degrees are generally reduced, sometimes by 10 dB or more. Even for longitudinally polarized reception, some improvement can be attained, though the differences are not as significant. Radiation patterns were also measured for 6- and 11-GHz operation. These measurements show the same qualitative effects as discussed above and are therefore omitted for brevity.

Wide-angle sidelobe suppression, like that noted above, is commonly attributed to reduced edge diffraction. If that were the case, a narrow strip of absorber adjacent to the side diffracting edges would accomplish the same function. This issue was explored in the second phase of the investigation.

2.2 Absorber-lined diffracting edges

In the second phase of our study, the multiple-edge blinders were removed, and a 3.5-inch strip of 2-inch-thick absorber was recessed and placed adjacent to each of the side diffracting edges, as illustrated by Fig. 3. Transverse polarization patterns were measured, with a typical result shown in Fig. 12 (near-in sidelobes were unaffected). We have noted that beyond approximately 40 degrees, the narrow absorber strip reduces sidelobes by 4 dB or more. This performance, while less

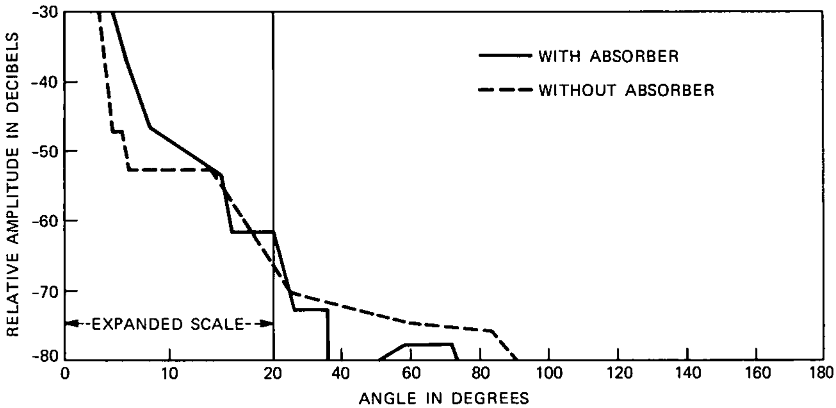

Fig. 11—Smoothed radiation pattern. Antenna equipped with blinders. Longitudinal polarization response to transverse polarization illumination, transverse measurement plane; 3.95 GHz.

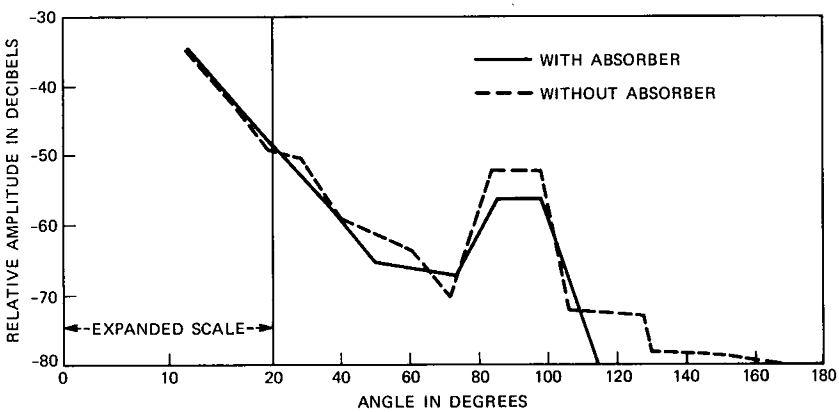

Fig. 12—Smoothed radiation pattern. Antenna not equipped with blinders. Transverse polarization, transverse measurement plane; 3.74 GHz.

impressive than the more consistent suppression exemplified by Fig. 8, shows the benefit of using absorber, and more clearly defines the diffraction-limited region of this antenna as lying beyond 40 degrees in the azimuthal plane.

After comparing the two absorber placement tests described above, we conclude: (1) within approximately 15 degrees of the main beam, lining the antenna sidewalls increases sidelobe levels, an effect probably due to the excitation of higher-order modes; (2) beyond approximately 40 degrees, the radiation pattern is dominantly affected by exterior aperture edge diffraction, and absorbent materials can significantly reduce that contribution to the far-field pattern; and (3) in the intermediate angular region of 15 to 40 degrees, absorber on the sidewalls affects the radiation pattern in unexpected ways. This last point is further developed in the next section.

III. ANALYTIC METHODS FOR DESCRIBING RADIATION FROM PYRAMIDAL HORN-REFLECTOR ANTENNAS

The Aperture Field Method (AFM) and Geometrical Theory of Diffraction (GTD) are the principal analytic methods used to describe radiation from large-aperture, reflector antennas. A number of different studies have shown the AFM to be quite accurate in predicting

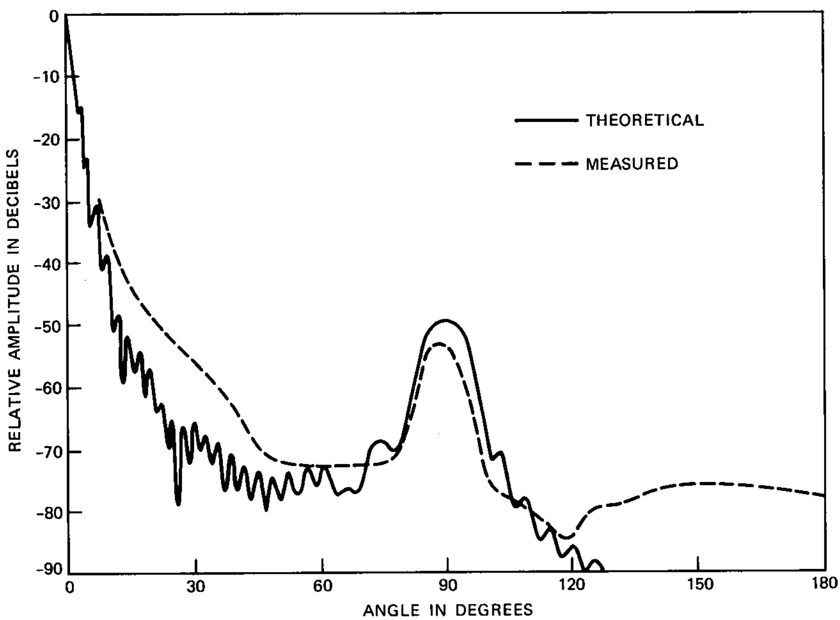

Fig. 13—Measured and theoretical patterns of a pyramidal horn-reflector antenna without multiple-edge blinders. Transverse polarization, transverse measurement plane; 4 GHz (adapted from Ref. 13).

sidelobe behavior down to -40 dB and within approximately 10 degrees of the main beam of a pyramidal horn-reflector antenna,[2,11,12] Theoretical limitations associated with this method for wide-angle radiation are well established.

Wide-angle radiation patterns are predicted using GTD. Transverse-plane analyses of the pyramidal horn-reflector by Thomas[4,5] and Siller[8] considered single diffraction from the exterior aperture edges with equivalent magnetic line sources. Their theoretical patterns showed good qualitative agreement with measured characteristics. Mentzer has used both the AFM and a more complete GTD model to analyze radiation from this antenna.[13] This latter analysis includes radiation from both the top and bottom aperture edges, using slope wave diffraction, as well as reradiative multiple diffraction. A result from Mentzer's study is presented in Fig. 13 for transverse polarization of the aforementioned standard horn-reflector antenna. Envelope discrepancies beyond 120 degrees, where the pattern is nearly 80 dB down, are not important and are probably due to radiation leakage during the measurements and/or small inadequacies in the analytic model. The pattern disparity between approximately 10 and 45 degrees is more prominent, however, and suggests radiating sources heretofore unconsidered.

Mentzer's analytic study did not include two sources of radiation that are intimately affected by absorber on the sidewalls of the visible antenna aperture. The first of these sources corresponds to wedge diffraction at the interface of the paraboloid and horn sidewalls. Radiation from these two wedges would be influenced by Semplak's absorber placement, as well as our own (see Fig. 2, appropriate to the first phase of this study). The second of the unconsidered sources corresponds to an infinite set of surface currents imaged into the walls of the visible aperture from the offset paraboloidal reflector. These imaged sources would also be influenced by our first absorber treatment. Simple ray optics and diffraction theory indicate that both of the aforementioned sources would radiate predominantly into the 0- to 45-degree region, though their relative contribution to the composite radiation pattern is presently unknown.

IV. CONCLUSIONS

An experimental investigation into the suppression of wide-angle radiation from pyramidal horn-reflector antennas is reported in this study. We first show that lining the sidewalls of the antenna dramatically affects sidelobe structure and energy, with sidelobe reduction occurring over a wide angular region for transverse polarization operation. Elevated near-in sidelobes are probably due to some aperture blockage, as well as the modification of radiation sources that have not previously been considered in theoretical analyses of this antenna. Subsequent absorber placement on the antenna's side diffracting edges also leads to wide-angle sidelobe suppression and helps to identify the pattern region beyond approximately 40 degrees as predominantly diffraction limited.

These experimental results are related to a recent study by R. A. Semplak on selective near-in sidelobe reduction for a pyramidal horn-reflector antenna. Taken together, the investigations suggest that judicious microwave absorber placement could suppress sidelobe energy throughout major (i.e., near-in and far-out) regions of the azimuthal radiation plane.

V. ACKNOWLEDGMENT

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