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DESIGN OF NULLS IN ANTENNA FRESNEL ZONES FOR POSSIBLE RFI REDUCTION APPLICATIONS

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-63-132

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Electronic Warfare Laboratory
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Project No. 4540, Task No. 454001

(Prepared under Contract No. AF30(602)-2711 by the Antenna Laboratory, Department of Electrical Engineering, Ohio State University Research Foundation, Columbus, Ohio)

FOREWORD

The research reported herein was performed in the Antenna Laboratory, Department of Electrical Engineering, The Ohio State University, under Contract No. AF30(602)-2711 between The Ohio State University Research Foundation and Rome Air Development Center, Air Force Systems Command, USAF, Griffiss AFB, N. Y. Mr. Karl Kirk of Rome Air Development Center was the contract initiator.

This report (Contractor's No. 1423-3) was written by Li-Jen Du and Leon Peters, Jr. of The Ohio State University Antenna Laboratory.

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ABSTRACT

The rather unconventional concept of designing a null into the Fresnel zone of an antenna is considered. A method is given that makes it possible to produce a null at some specific position. A possible application is the reduction of radio frequency interference.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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DESIGN OF NULLS IN ANTENNA FRESNEL ZONES
FOR POSSIBLE RFI REDUCTION APPLICATIONS

INTRODUCTION

In the Fresnel region of an antenna the usual characteristic side lobes have not yet been formed. However, deep minima can appear in this region due to the phenomena of aperture blocking. For example, they could be introduced in the Fresnel zone pattern of a parabolic antenna by the aperture blocking caused by the antenna feed or by the application of radar absorber material.

It has been suggested that this type of minima ld be used for the purpose of radio frequency interference reduction. rticular if a large stationary antenna is being used, say, as a repea t might be desirable to operate some other installation in its vicinity. Thus, if a null could be created in the radiation from that antenna at the position of the other installation then a significant reduction in interference is obtained. As an example an omni-directional television antenna could be operated in the vicinity of a repeater station with greatly reduced interference. In this report the existence of these deep minima are demonstrated and methods for positioning the blocked portion of the aperture to get a deep minima at the desired place are given. An undesirable feature is that the side lobe distribution in the far field pattern will be increased under certain conditions.

COMPUTER PROGRAM

A computer program for the pattern of an antenna at any range is available at this laboratory. This program is based on the Schelkunoff Equivalence Principle. The sources and the conducting plane can be replaced by magnetic $\vec{K}$ and electric $\vec{J}$ surface currents over the surface which was occupied by the conducting plane including the aperture. These surface currents are defined by the relations

$$\vec{J} = \hat{n} \times \vec{H} \qquad \vec{K} = \vec{E} \times \hat{n}$$

where $\vec{E}$ and $\vec{H}$ are the fields which were set up over the aperture by the sources and n is the unit normal on the plane of aperture directed into the source-free region. In view of the symmetry of the fields produced by $\vec{J}$ and $\vec{K}$, together with the fact that these equivalent surface currents generate zero field in the source region, it can be shown that an electric current $2\vec{J}$ or a magnetic current $2\vec{K}$ will generate the original field in the source-free region, if either current is considered to be radiating into space homogeneous in μ and ϵ.

The magnetic surface current $2\vec{K}$ has associated with it a magnetic vector potential $\vec{F}$ given by the relation

$$\vec{F}(r) = \frac{\epsilon}{4\pi} \iint_S 2\vec{K}(r')\,\psi(r', r)\,ds'$$

where $\psi = e^{ikr}/r$

$k = 2\pi/\lambda \qquad r = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$

Time factor $e^{-i\omega t}$ is suppressed. The electric field is given by

$$\vec{E} = -\frac{1}{\epsilon}\ \nabla \times \vec{F}$$

after substitution by

$$\vec{E} = \frac{1}{2\pi} \iint_{ap.} (\vec{E}' \times n)\ \nabla\psi\, ds'$$

where $\vec{E}'$ is the electric field on the aperture.

The orientation of the corrdinate system is shown in Fig. 1. The electric field is assumed to be linearly polarized in the y-direction and the aperture is located in the x = 0 plane. Then the expression for $\vec{E}$ at the observation point can be written as

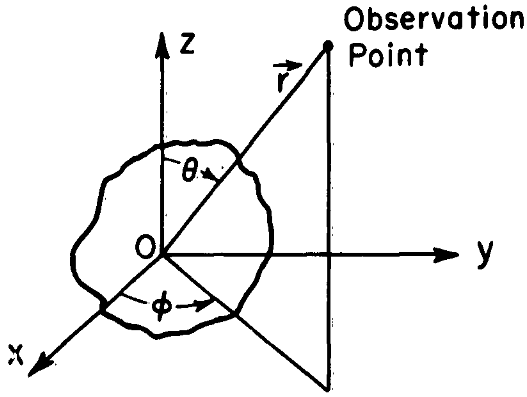

Fig. 1. Corrdinate System.

$$\vec{E} = \frac{1}{2\pi} \iint_{ap.} (E_y' \hat{y} \times \hat{x}) \times \hat{r} \frac{d\psi}{dr} dy' dz'$$

Radial components of the fields in the Fresnel region are negligible. The y-component of the near field at the plane $x = x_o$ is

$$E_y'' (x_o, y, z) = \frac{-x_o}{2\pi} \iint_{ap.} E_y' \frac{(ikr - 1)}{r^3} e^{ikr} dy' dz'$$

and the far field approximation is

$$E_\phi(r, \theta, \phi) = \frac{-ik}{2\pi r} e^{ikr} \sin\theta \iint_{ap.} E_y'(y', z') e^{-ik\eta(o, y', z')} dy' dz'$$

where $\eta = x' \sin\theta\cos\phi + y' \sin\theta\sin\phi + z' \cos\theta$. For the purpose of analysis all distance quantities are measured in terms of wavelength. The aperture of the antenna is sub-divided into square meshes whose sides are δ wavelengths. The assumed field is constant in each mesh and is set equal to the actual field distribution of the aperture at the center of the mesh. The fields in a parallel plane x_o wavelengths from the aperture are calculated in terms of a constant field in a similar mesh in order to simplify the computer program and the field in that mesh is assumed to be the actual field at its center. Certainly, if δ is sufficiently small, the results may be made as accurate as desired. Trapezoidal rule was used to evaluate these integrals for numerical computation. These field components are then calculated by the following formulas

$$E_{\phi_{real}} = K(r) \sin\theta \sum_{ap.}\sum \left[E'_{y(real)} \cos u + E'_{y(imag.)} \sin u \right]$$

$$E_{\phi_{imag.}} = K(r) \sin\theta \sum_{ap.}\sum \left[E'_{y(imag.)} \cos u - E'_{y(real)} \sin u \right]$$

where $K(r) = -i\,\delta^2 \dfrac{e^{i2\pi r}}{r}$, $E_\phi = E_{\phi_{real}} + i\,E_{\phi_{imag.}}$

$$u = 2\pi\delta\,(m \sin\theta \sin\phi + n \cos\theta)$$

$$E''_{y_{real}} = x_o\,\delta^2 \sum_{ap.}\sum \left[E'_{y(real)}\,A + E'_{y(imag.)}\,B \right]$$

$$E''_{y_{imag.}} = x_o\,\delta^2 \sum_{ap.}\sum \left[E'_{y(imag.)}\,A - E'_{y(real)}\,B \right]$$

where $A = \dfrac{\sin 2\pi r}{r^2} + \dfrac{\cos 2\pi r}{2\pi r^3}$ $\qquad B = \dfrac{\cos 2\pi r}{r^2} - \dfrac{\sin 2\pi r}{2\pi r^3}$

$$E''_y = E''_{y_{real}} + i\,E''_{y_{imag.}}$$ [1]

The selected circular aperture distribution has the form $(1 - r^2)$ and the phase is uniform. The blocked part of the aperture is approximated by assuming the field on that part of the aperture to be zero.

The accuracy of the method of analysis is indicated in Fig. 3a for this aperture distribution. The fields obtained from this aperture distribution are well known and the envelope of the more precise pattern shown in the same figure agrees well with the computed pattern. The program however fails to predict the proper null depth. The result could be improved by choosing smaller meshes but at considerably more expense and it is of sufficient accuracy for the present purposes.

DESIGN METHOD

As a first step it is necessary to determine the magnitude and relative phase of the field strength from the unblocked aperture at the location where we wish to minimize the signal level. By some aperture blocking method we want to create additional fields which exactly cancels this field. The aperture blocking could be accomplished by the application of radar absorber material to some small section of the antenna. In this case the total fields are given by

$$E^t = E^{RAM} + E^{ANT}$$

where E^{ANT} is the unperturbed antenna fields and E^{RAM} is the field due to the radar absorber material. Since E^t is zero in the vicinity of the absorber E^{RAM} must be negative of the aperture distribution of the antenna proper.

Next the field components at this location from each mesh on the antenna aperture are calculated. The positions and the combination of the meshes to be blocked can then be selected so that the field E^{RAM} generated will nearly equal to the negative of the field E^{ANT}. This process may be simplified considerably since far field conditions may be assumed in computing the fields due to E^{RAM} at the desired location.

A first order approximation of the desired position and area to be blocked is helpful in obtaining final results. This approximation is illustrated in Fig. 2. The required phase of the fields due to the blocking radar absorber material to produce the desired null is $(\Delta\phi + 180^o)$. The 180^o is naturally introduced since $E^{RAM} = - E^{ANT}$. Thus

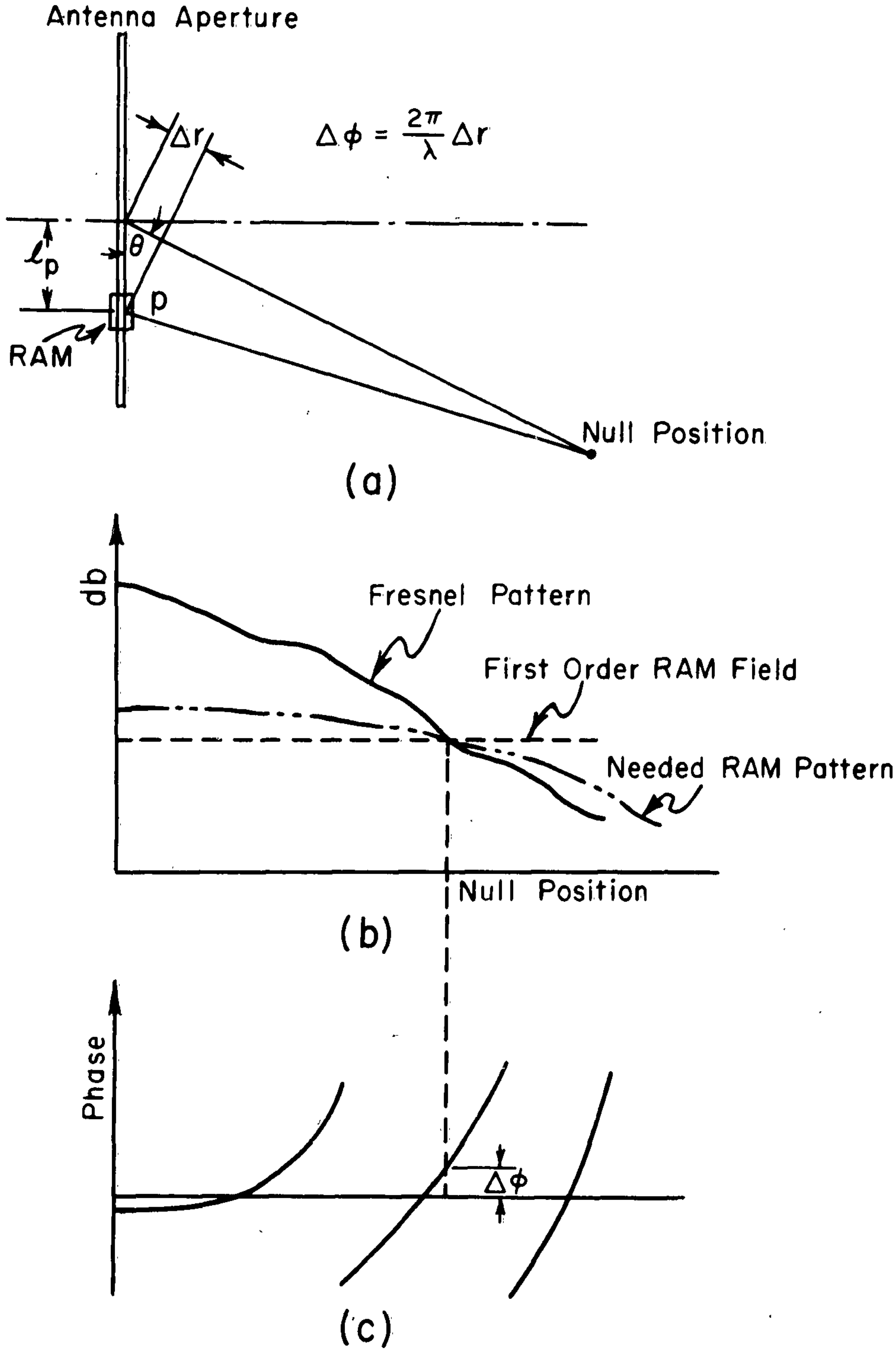

Fig. 2. Method for approximating absorber size and position.

$$\frac{\ell p}{\lambda} = \frac{\Delta\phi(\text{degrees})}{360 \cos \theta}$$

where the pertinent parameters are illustrated in the same figure. A first order approximation for the required amount of absorber is readily obtained by assuming a uniform distribution of magnitude E^{ANT} around the position P. Furthermore, the fields radiated by this blocking aperture are assumed to be independent of aspect as is indicated in Fig. 2b. Note that the range must also be considered as shown in the equations evaluating the far field components.

Now that the approximate area is obtained it may be modified by introducing the angular dependence of this radiated field. At this point only small changes of position and area are required to produce the desired null.

RESULTS OF SAMPLE PROBLEMS

The far field pattern calculated from the computer program in the xy plane (E-plane) of the selected antenna aperture of diameter 16.5λ and distribution $(1 - r^2)$ is shown in Fig. 3a. The Fresnel zone field in the xy plane with $x = 50\lambda$ and y ranging from 0 to 28.296λ is illustrated in Fig. 3b. A first attempt is made to locate a null at the position where the phase of the field equal 180° by estimating the size and position of the aperture to be blocked as indicated in Fig. 4. The minimum is found just one mesh ($\delta = 0.786\lambda$) from the chosen point. However, it is not deep. Using the same blocked aperture the field variation along the line perpendicular to the former one but in the xz plane (see Fig. 5) has a wider null and the minimum lies at the mesh point $x = 50\lambda$, $z = 14.148\lambda$. The far field patterns are also similar for both cases. It is shown that the main beam has not been affected appreciably but the side lobe level becomes a little higher and the pattern becomes smoother than the unblocked one. The far field due solely to the blocked part of the aperture are shown in Fig. 6. It is shown by comparison of this pattern with the pattern of the blocked aperture that the two patterns are nearly identical exclusive of the region near the main beam. Thus the far field side lobes in this case are now due to the blocked portion of the aperture.

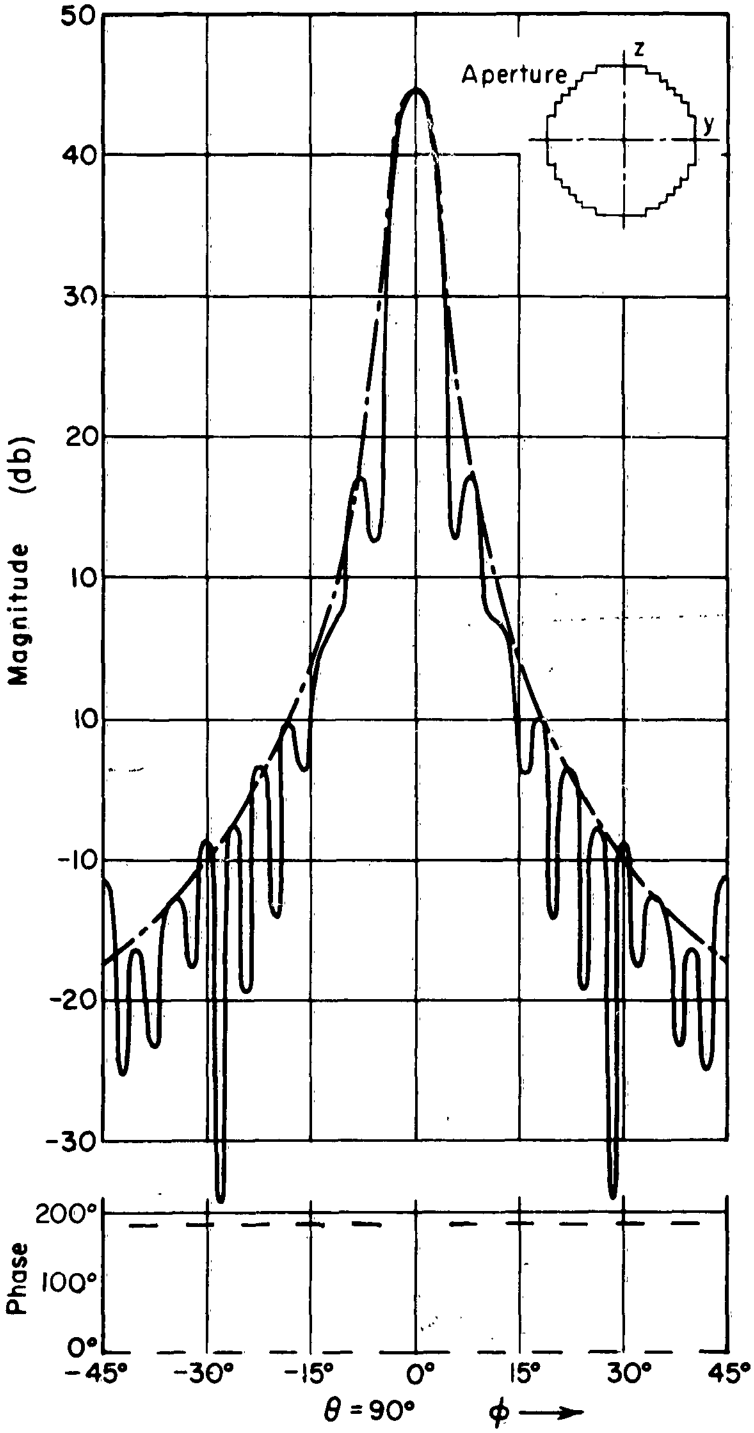

Fig. 3a. Antenna Patterns
(a) Farfield
for mesh size δ=0.786λ
Envelope from continuous distribution

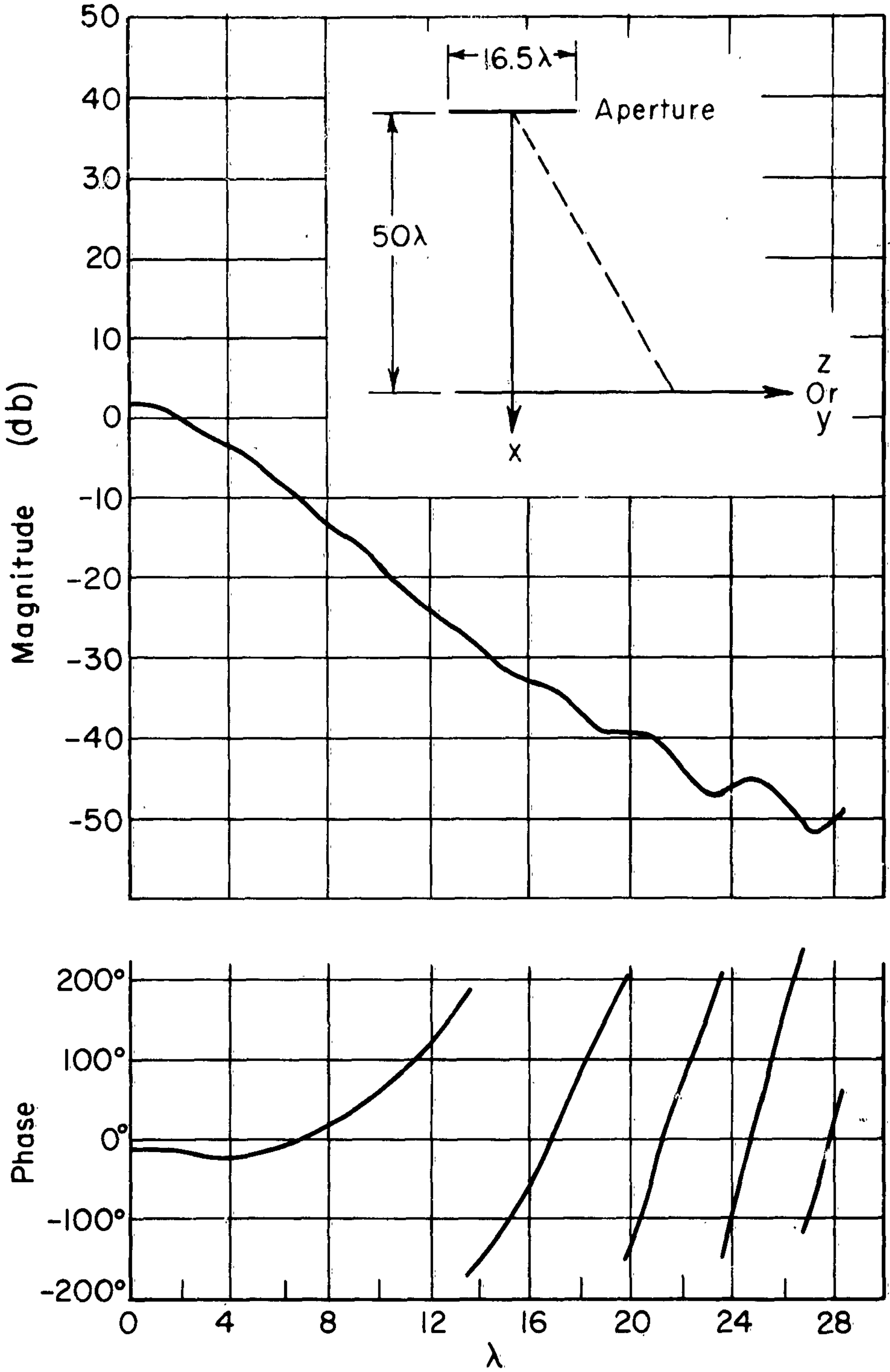

Fig. 3b. Fresnel Zone Pattern.

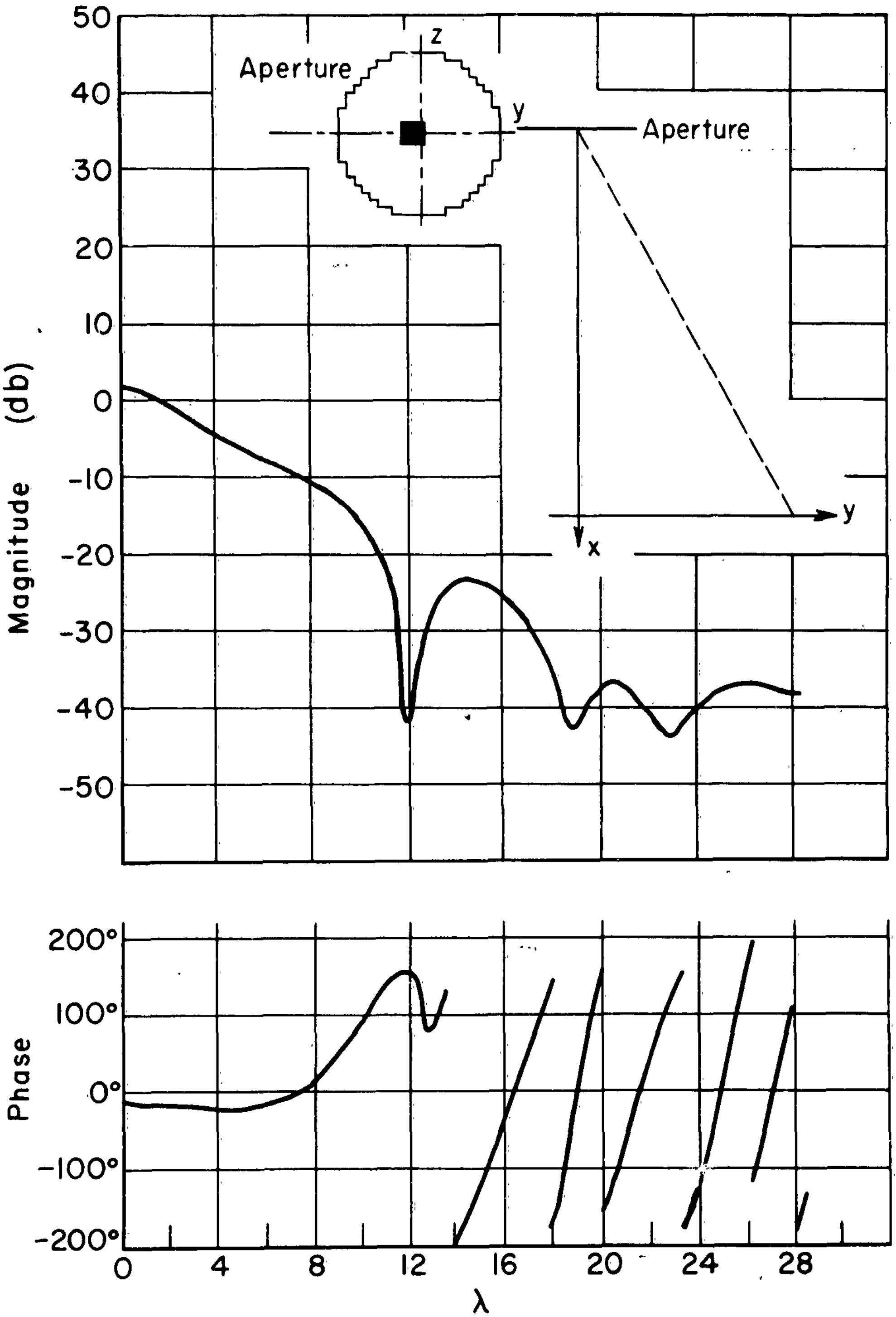

Fig. 4a. Fresnel zone pattern with absorber applied (first attempt).

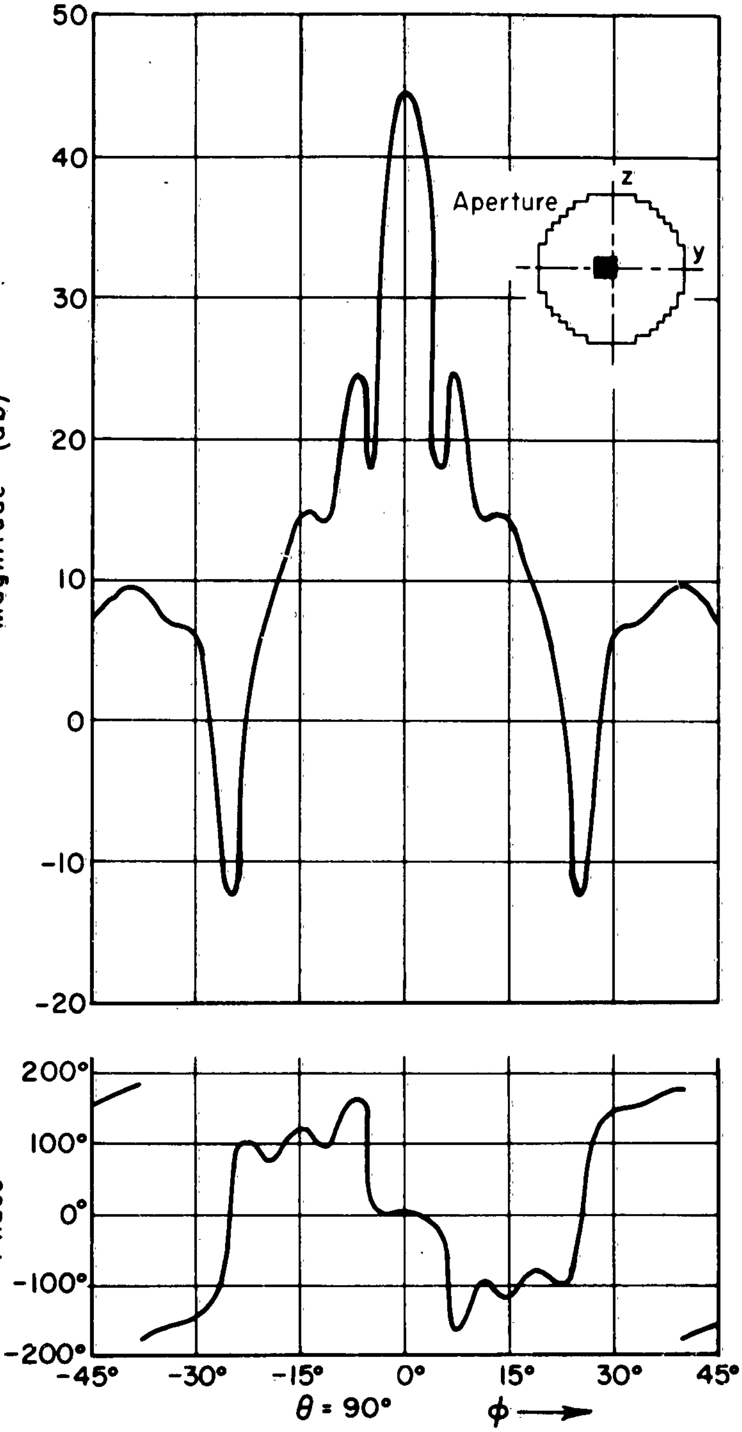

Fig. 4b. Far Field Pattern in x y plane with Absorber Applied.

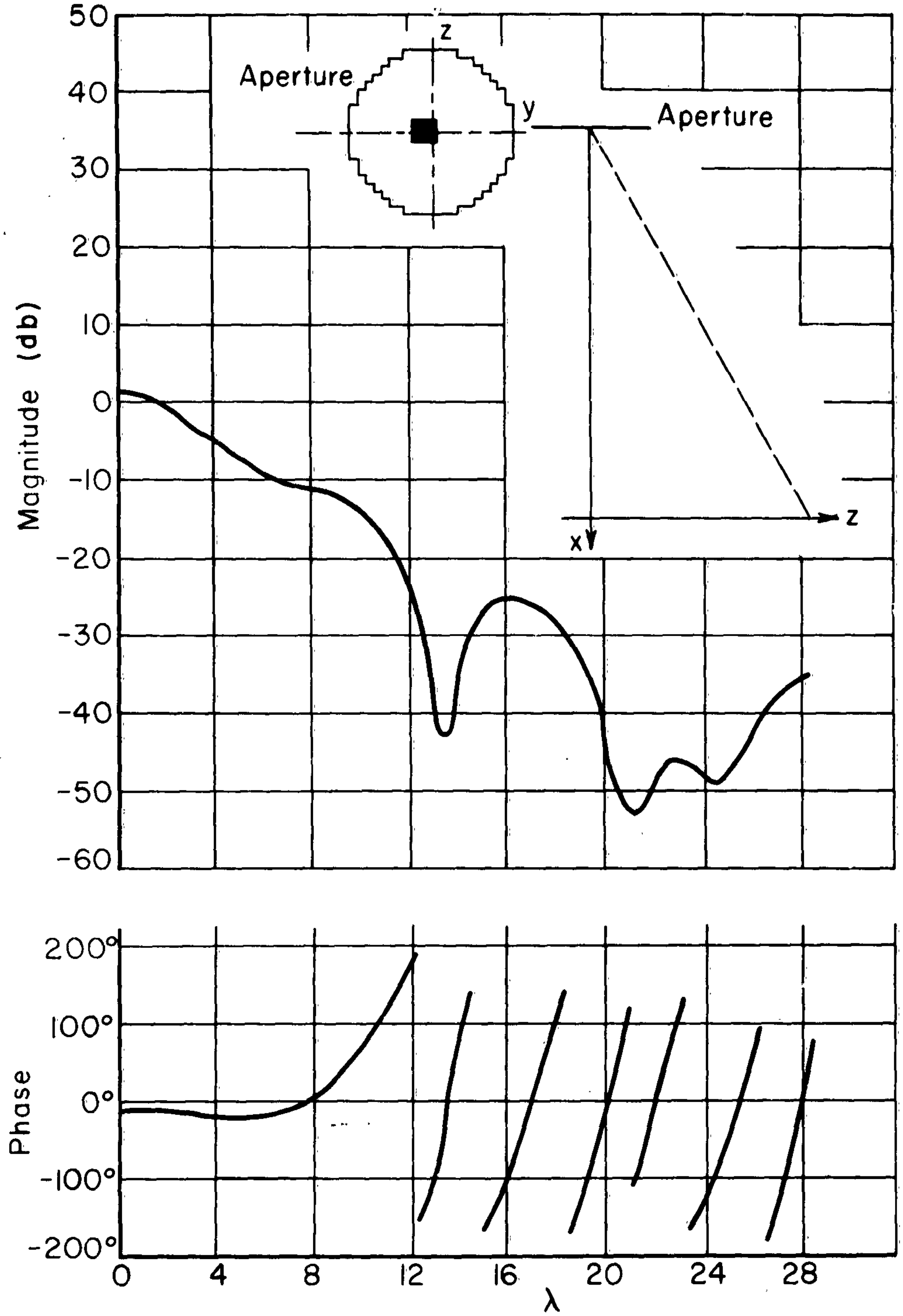

Fig. 5a. Fresnel Pattern in x z plane
with Absorber Applied

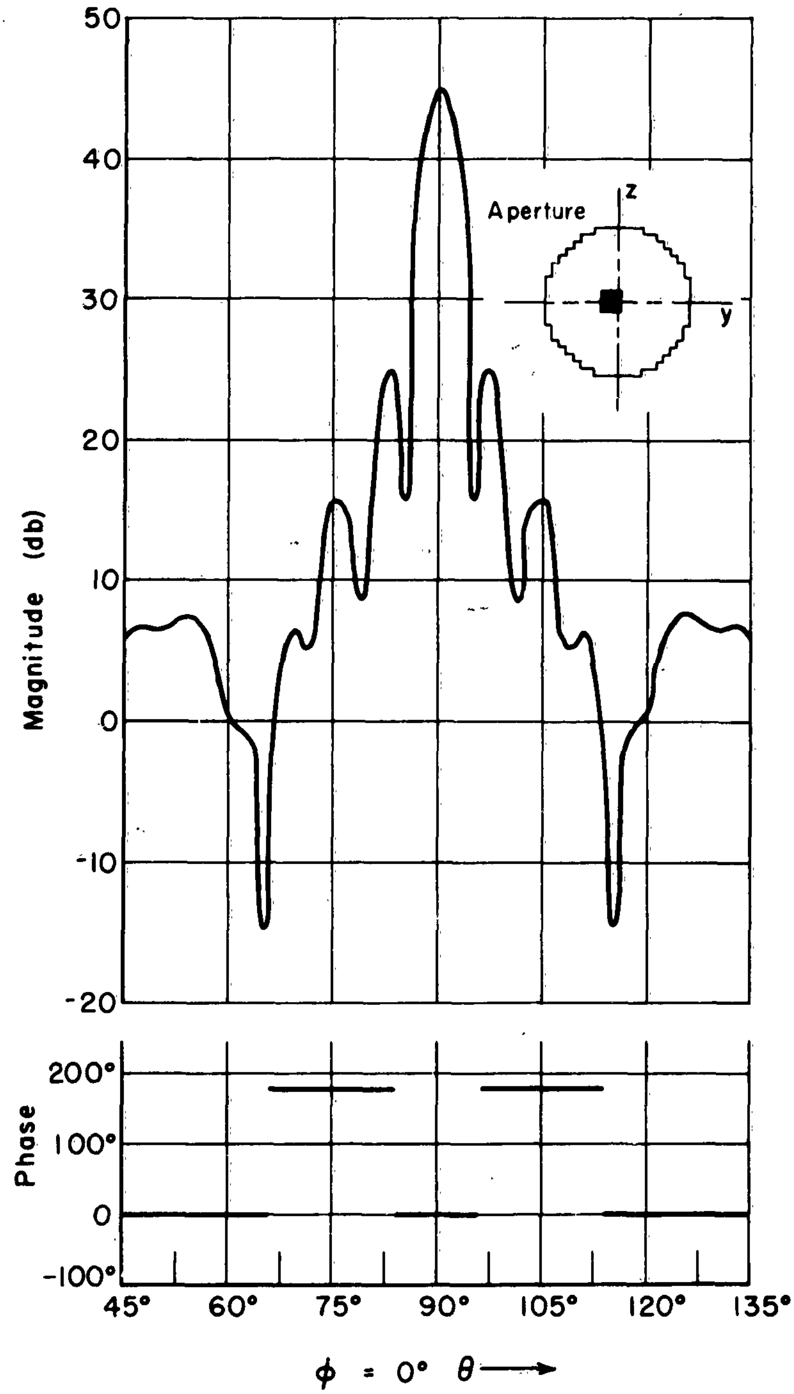

Fig. 5b. Far Field Pattern in x z plane with Absorber Applied

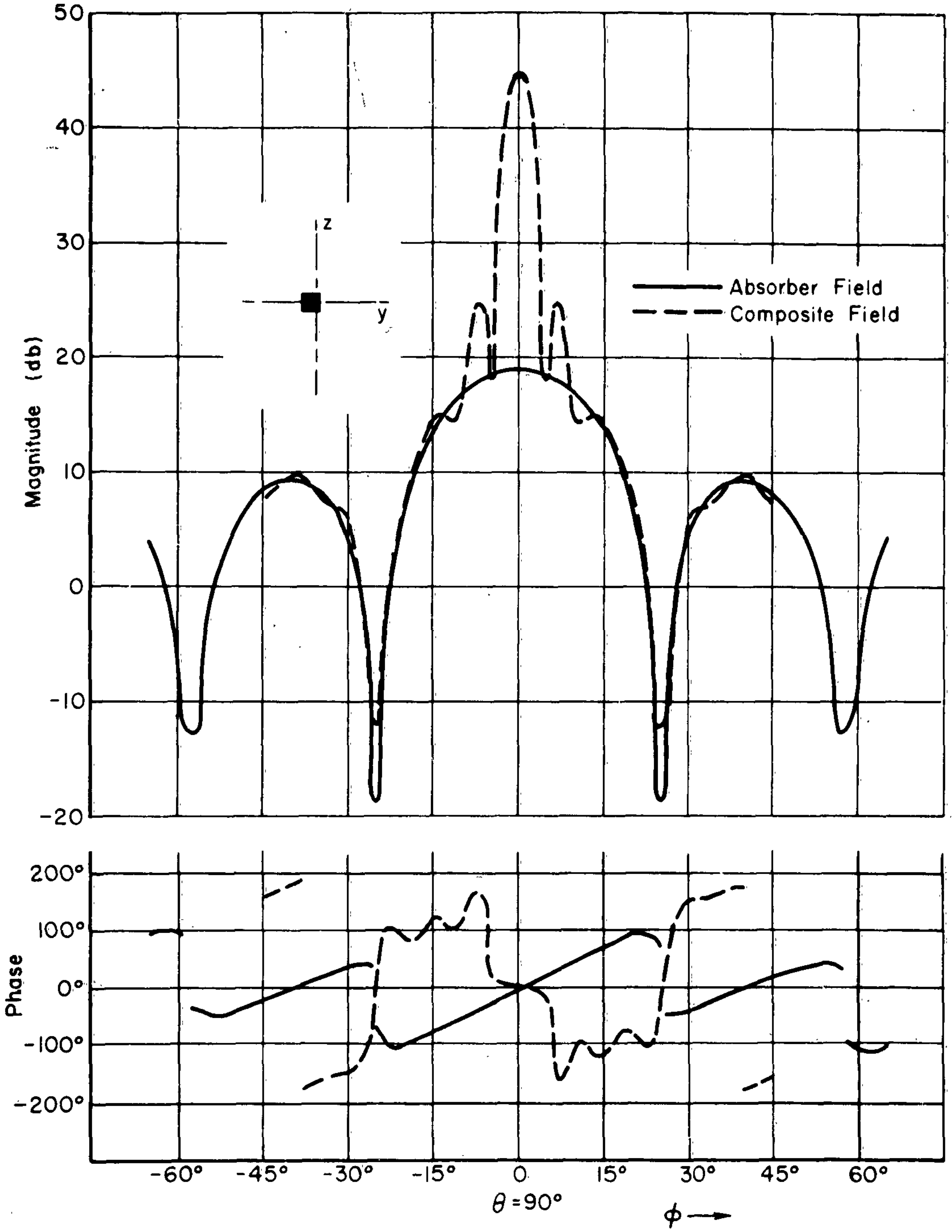

Fig. 6a. Comparison of Fields for Composite Aperture with Fields due to Absorber Alone in x y plane.

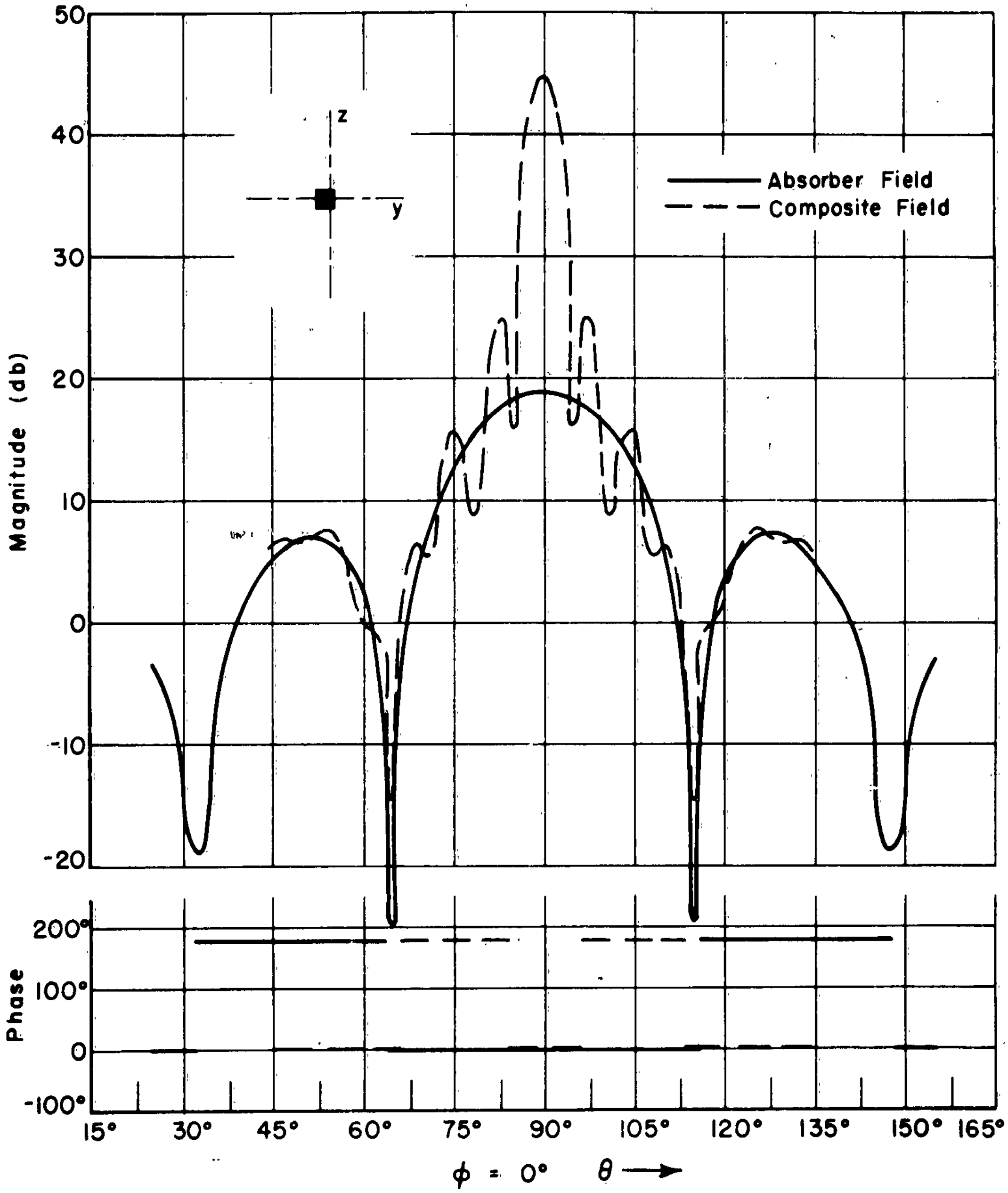

Fig. 6b. Comparison of Fields for Composite Aperture with Fields due to Absorber Alone in x z plane.

After the fields at the minimum point due to each mesh on the aperture were calculated adjustments of the signal level at the minimum point were made by changing the part of the aperture to be blocked. Improved results for the cases shown in Figs. 4 and 5 are illustrated in Figs. 7 and 8 respectively. The last case considered is shown in Fig. 9. A deeper and wider minimum appers in the Fresnel region around the mesh point $x = 50\lambda$, $y = 20.4\lambda$. The far field patterns are influenced in the same manner as the former two cases. Owing to the fact that less of the aperture was blocked the main beam and the first side lobe are nearly unaffected. These other side lobe levels are lower than that of the previous cases but are still due chiefly to the blocked portion of the appears.

POSSIBLE EXPERIMENTAL APPLICATION

It has been demonstrated that the concept of introducing a null in Fresnel zone is possible theoretically. A question naturally arises as to whether this would be possible for a practical antenna. The most obvious problems that may happen in this event are to be considered in this section.

First of these is that an ideal absorber does not exist. This would merely require that an additional amount of the area be coated with absorber to compensate for this imperfection. Commercially available absorbers provide adequate reduction that the area to be coated would be modified only slightly in terms of the required size. Any perturbations of phase could be controlled by slight displacement of the absorber.

In this report, use has been made of the aperture distribution and a computer program to evaluate the results. Thus it would appear necessary to measure the aperture distribution to apply such a technique and then locate the desired position and size of the absorber using the method outlined above. Such a computation is not always feasible and is comparatively expensive. A more appropriate method would consist of measuring the aperture amplitude and phase distribution and the magnitude and phase of the radiated signal at the point where a deep null is desired. The methods outlined could now be applied and would require only the far field computations for the blocked portions of the aperture which are relatively simple.

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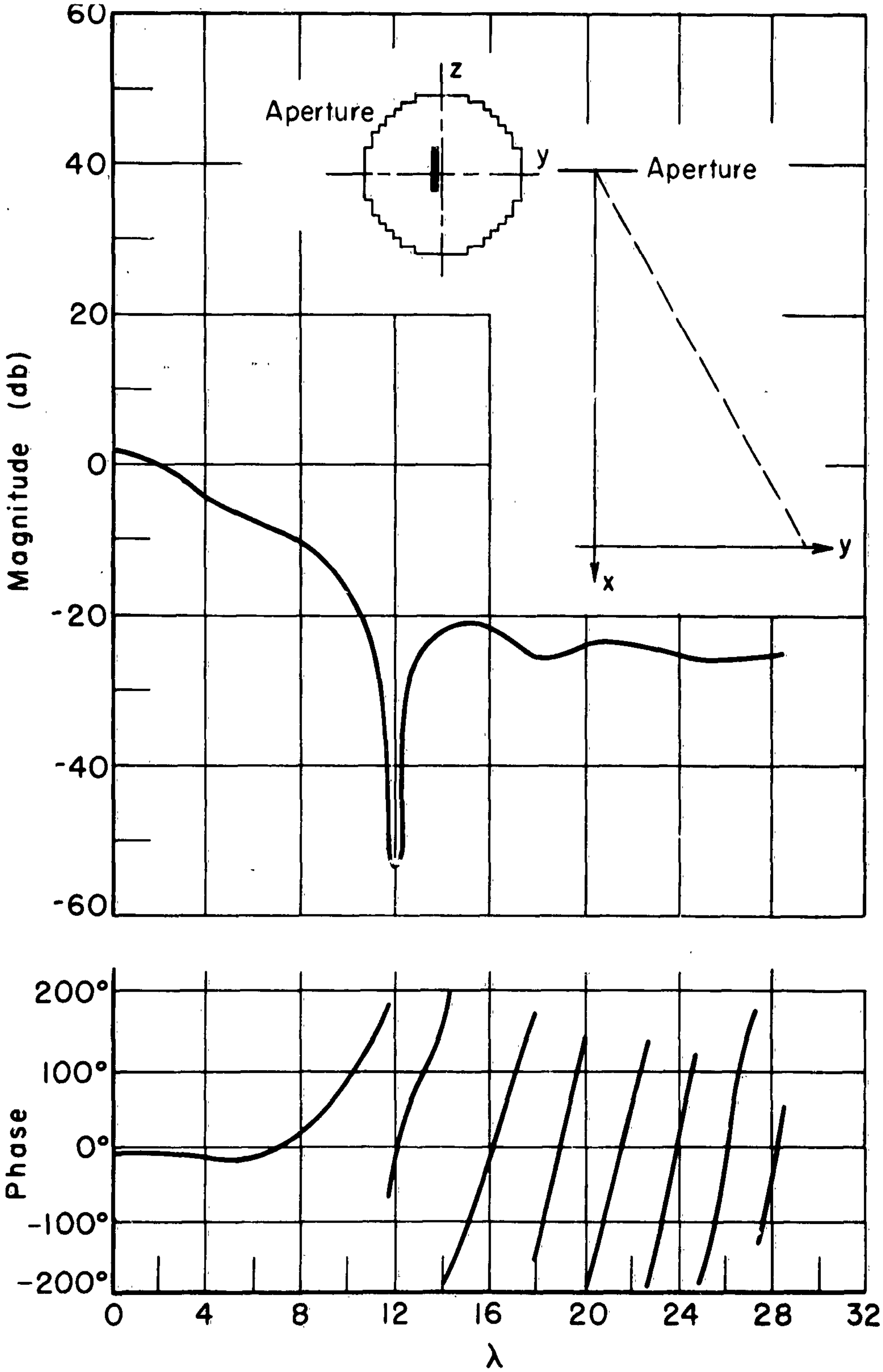

Fig. 7. Fresnel pattern with absorber applied (second attempt).

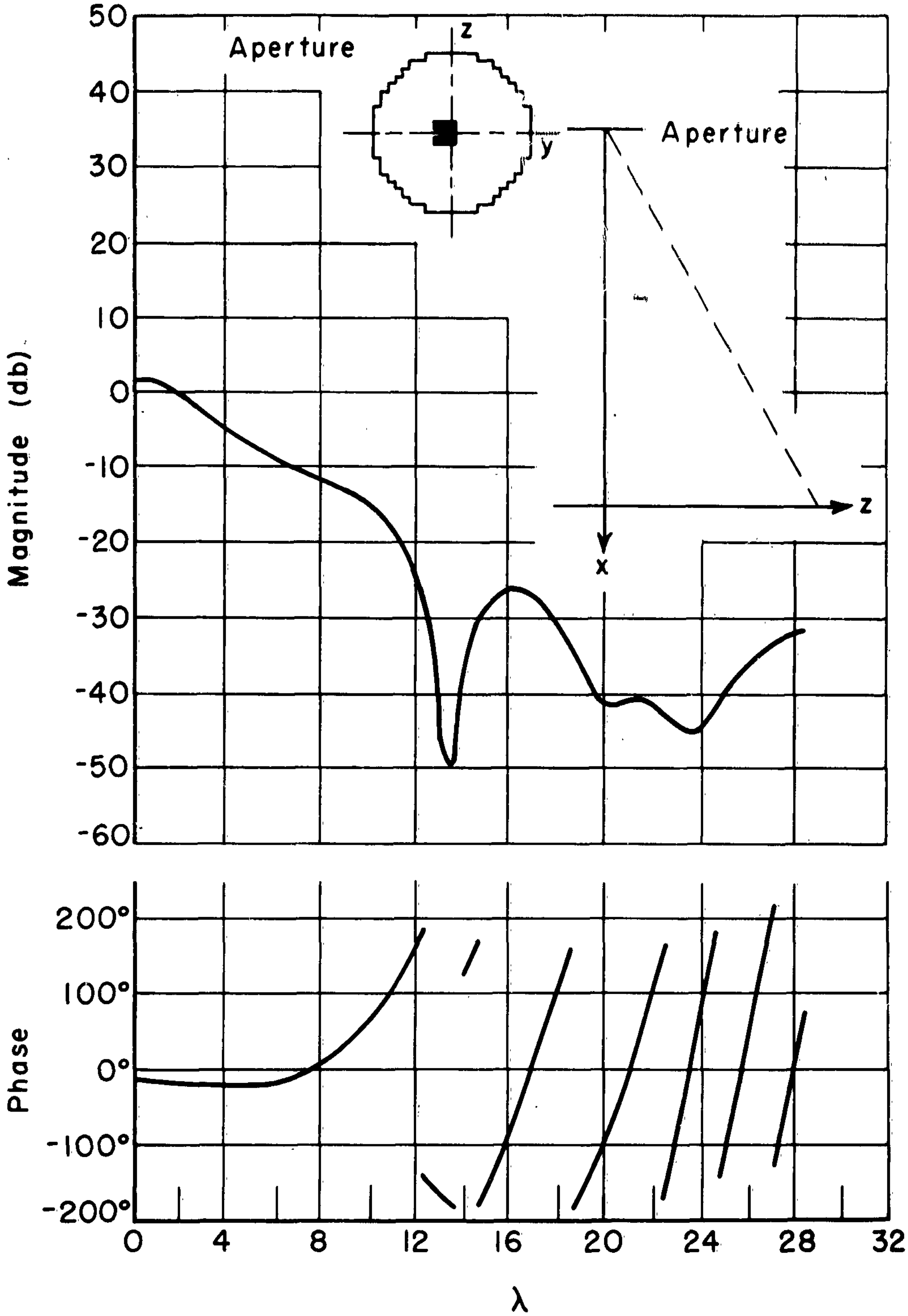

Fig. 8. Fresnel Pattern in the x z plane with Absorber Applied as Shown.

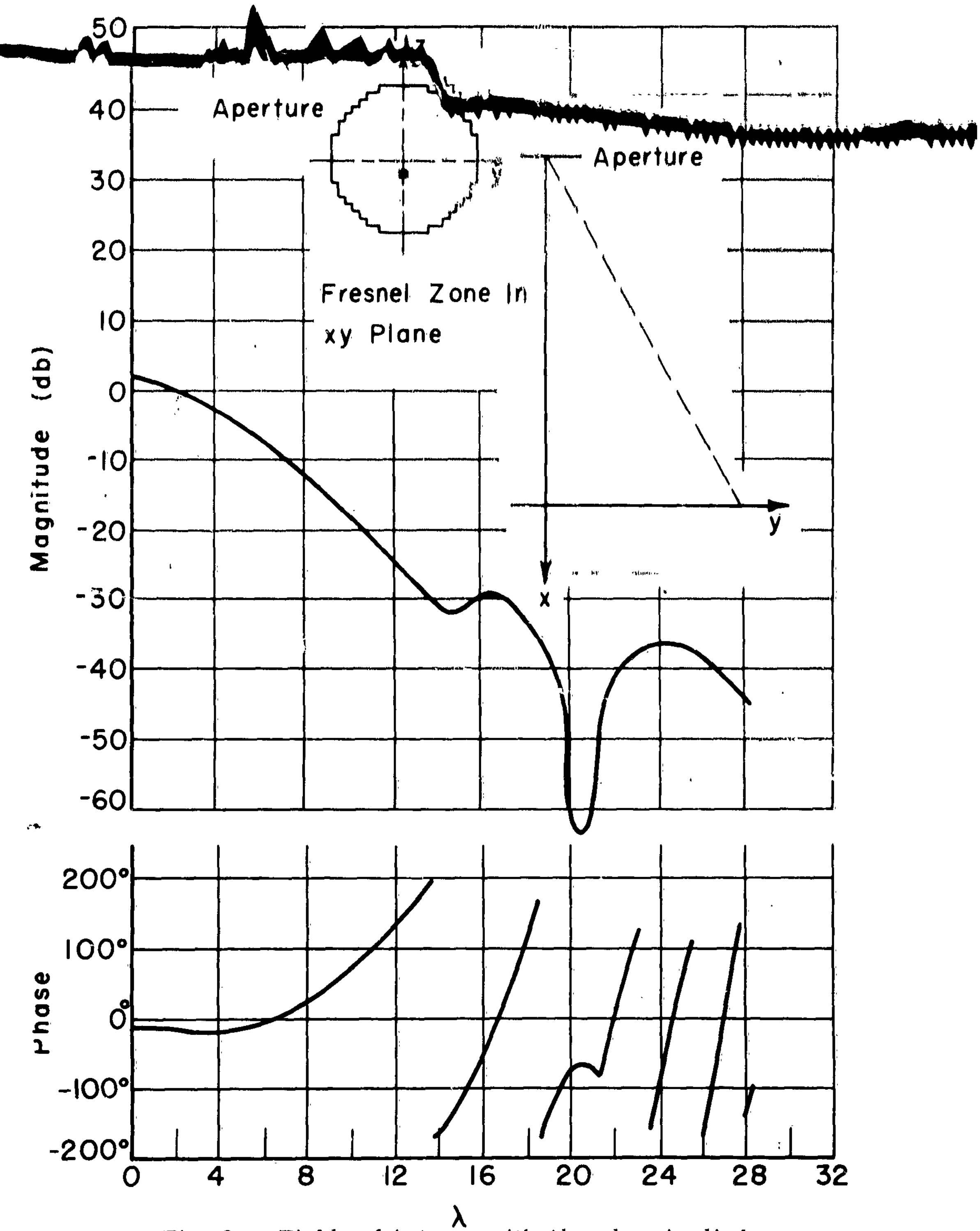

Fig. 9a. Fields of Antenna with Absorber Applied to Fresnel Zone in x y Plane, Produce Null at y = 20.4λ.

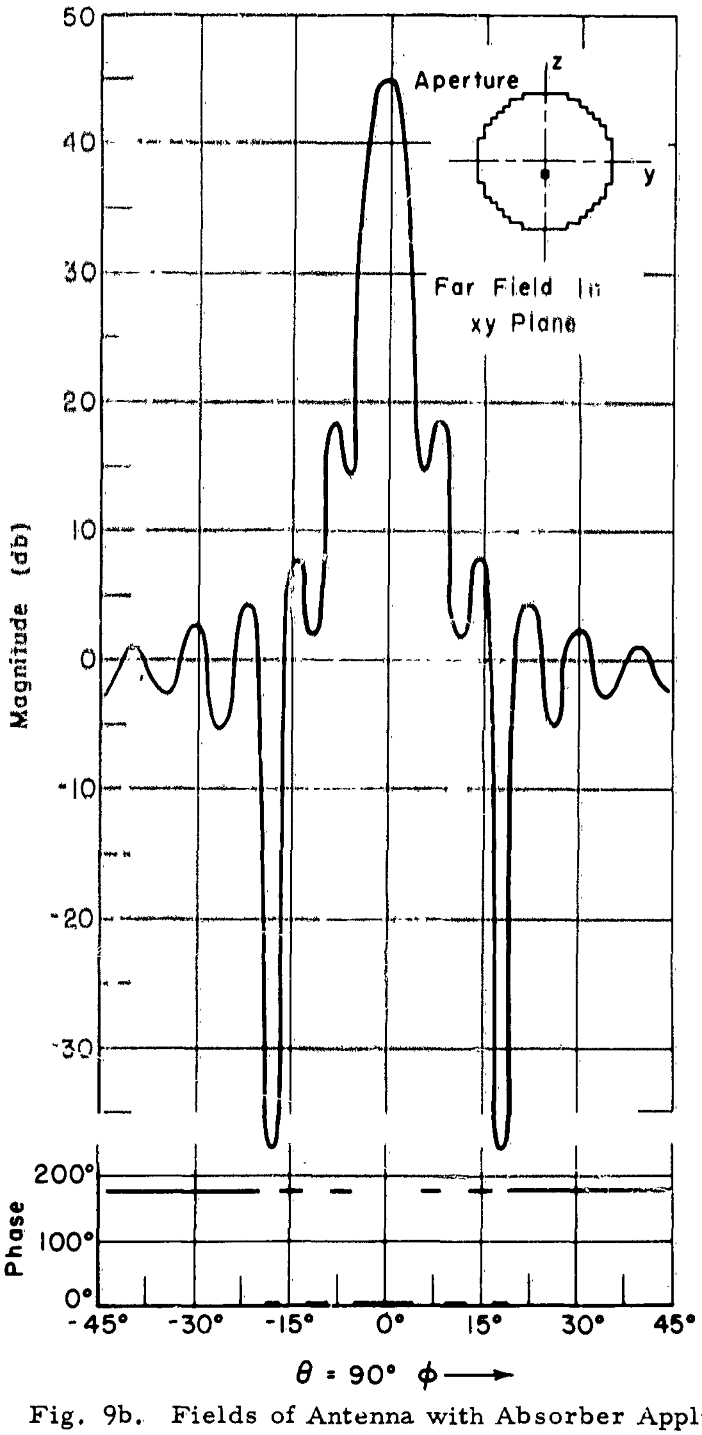

Fig. 9b. Fields of Antenna with Absorber Applied to Far Field in x y Plane, Produce Null y = 20.4λ.

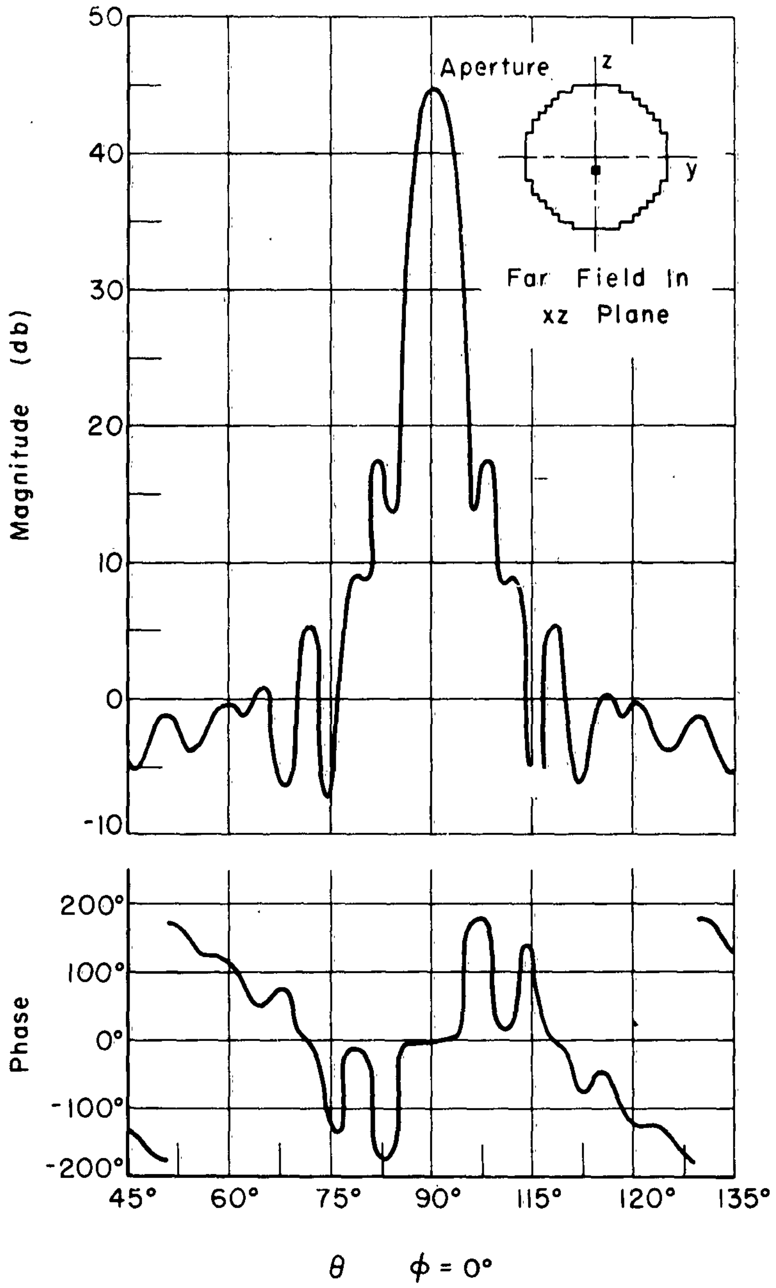

Fig. 9c. Fields of Antenna with Absorber Applied to Far Field in x z Plane, Produce Null y = 20.4λ.

CONCLUSIONS

It has been shown that by proper antenna aperture blocking a deep minimum can be located at the specific position in the Fresnel zone. If the size of the blocked part of the antenna is much smaller than the aperture itself there is no significant influence on the main beam. However, side lobe levels become higher as more of the aperture is blocked. A wider and deeper minimum is obtained at the position more distant from the main beam axis. The area on the plane $x = 50\lambda$ which has signal level below -40 db is about $0.786 \times 2.358\lambda^2$ for the blocked apertures shown in Figs. 7 and 8 and about $3.144 \times 6.28\lambda^2$ for that shown in Fig. 9.

The results from this study indicate that the position rather than the size of the blocked area on the aperture is the more important factor in determining a deep minimum at the desired position. As the side lobe levels becomes higher the purpose of acquiring a minimum in the Fresnel region will be compensated by more power radiated in the directions other than that of the main beam. The area covered by the deep minimum is small as compared with the dimensions of the antenna aperture. So results reported here can be applied to the cases where a relatively small area of deep minimum is desired around a larger antenna. If another antenna is set in the minimum position further reduction of interference would be obtained if this other antenna is orthogonally polarized to the main aperture. The phase of the near field varies more quickly as the distance from the main beam axis increases and this phenomenon is more apparent in the blocked cases.

Fine adjustment about the depth, width and position of Fresnel region minimum spot could be made by choosing a smaller mesh size. Apertures of different size, shape and field distribution can be attempted as a further investigation of this kind of problems.

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1. Collier, J. Robert, "Digital Calculation of Electromagnetic Diffraction from Aperture Blocking," Report 1180-5, 15 September 1961, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract AF 33(616)-7614, Aeronautical Systems Division, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio.

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2. Radio interference
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