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# Influence of Electrical Properties of the Ground on the Backscatter Coefficient at High Frequency

by

J. G. Steele

December 1965

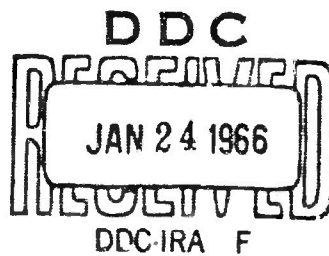
Technical Report No. 121

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RADIO SCIENCE LABORATORY

**STANFORD ELECTRONICS LABORATORIES**

STANFORD UNIVERSITY • STANFORD, CALIFORNIA



SEL-65-110

INFLUENCE OF ELECTRICAL PROPERTIES OF THE GROUND  
ON THE BACKSCATTER COEFFICIENT AT HIGH FREQUENCY

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Radioscience Laboratory  
Stanford Electronics Laboratories  
Stanford University                  Stanford, California

### ABSTRACT

A theoretical expression for the relative backscatter coefficient was evaluated for different values of the dielectric constant and conductivity of the ground, the wavelength, polarization and incidence angle of the radiation, and the heights of the scatterers above the ground. The resulting curves of backscatter coefficient vs angle of incidence are not unlike some experimentally derived curves for hf backscatter, especially with regard to the differences between horizontal and vertical polarization and between land and sea.

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SYMBOLS

dS	element of area of the ground
n	height distribution of scatterers
G	vertical radiation pattern of a scatterer
I	interference pattern due to the ground
P	vertical radiation pattern of a scatterer, modified by the ground
R	reflection coefficient of the ground, $ R  e^{-i\phi}$
$\gamma$	angle of elevation of the incident radiation
$\delta$	path difference between direct and reflected rays
$\epsilon$	dielectric constant of the ground
$\epsilon_0$	dielectric constant of free space
$\epsilon_{rc}$	relative complex dielectric constant, $\frac{\epsilon}{\epsilon_0} - 60i\lambda\sigma$
$\zeta$	height of a scatterer above the ground
$\phi$	phase shift between direct and reflected rays, $\frac{2\pi\delta}{\lambda} + \phi$
$\lambda$	wavelength in meters
$\rho$	$\frac{\sigma_0}{2 \sin \gamma}$
$\sigma$	conductivity in mhos/m
$\sigma_0$	radar cross section per unit area of the ground
$\sigma_1$	standard deviation of $\zeta$
$\Phi$	phase of the reflection coefficient

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Thanks are due Dr. O. G. Villard, Jr., Director of the Radioscience Laboratory, who made the work possible. Mr. D. E. Westover wrote the computer program. The author is the recipient of an overseas Postgraduate Studentship awarded by the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia.

## I. INTRODUCTION

The backscatter coefficient, usually defined as the radar cross section per unit area of the ground, is an important parameter in oblique hf sounding of the ionosphere by use of ground backscatter. The variation of the backscatter coefficient with angle of incidence has been the subject of experimental investigations [Refs. 1 and 2], the interpretation of which suggests that an interference mechanism is significant. For scatterers such as trees, the energy is received and reradiated by means of both direct rays and rays reflected from the ground. The interference between these rays may explain the variation of the backscatter coefficient with angle of incidence and with the polarization of the incident energy. To test this hypothesis, a theoretical expression for the backscatter coefficient was set up in terms of the heights of the scatterers and the reflection coefficient of the ground. The reflection coefficient in turn depends on the electrical properties of the ground and the wavelength and polarization of the radiation. Calculations were performed for different combinations of these parameters, and this paper presents and discusses the results.

## II. THEORY

The theory for ground backscatter is similar to Goldstein's droplet theory for backscatter from the sea at centimetric wavelengths [Ref. 3]. The notation closely follows that of Beckmann and Spizzichino [Ref. 4].

Consider a single scatterer as an elementary dipole at a height  $\zeta$  above a reflecting plane, illuminated by radiation of wavelength  $\lambda$  incident on the plane at an angle of elevation  $\gamma$ .

The vertical radiation pattern of the scatterer and ground may be described by

$$F(\zeta, \gamma) = I(\zeta, \gamma) G(\gamma) ,$$

where  $I(\zeta, \gamma)$  is the dipole radiation pattern. Let  $G(\gamma) = \cos^2 \gamma$  for vertical polarization and  $G(\gamma) = 1$  for horizontal polarization.  $I(\zeta, \gamma)$  is proportional to  $(1 - |R|)^2 + 4|R| \cos^2 (\phi/2)$ , where

$$\phi = \frac{2\pi\delta}{\gamma} + \Phi$$

$$\delta = 2\zeta \sin \gamma$$

$$|R| e^{-i\Phi} = \begin{cases} \frac{\epsilon_{rc} \sin \gamma - (\epsilon_{rc} \cos^2 \gamma)^{1/2}}{\epsilon_{rc} \sin \gamma + (\epsilon_{rc} \cos^2 \gamma)^{1/2}} & \text{(vertical polarization)} \\ -1 & \text{(horizontal polarization)} \end{cases}$$

$$\epsilon_{rc} = \frac{\epsilon}{\epsilon_0} - 60i\lambda\sigma .$$

The power returned from a single scatterer is proportional to  $P^2(\zeta, \gamma)$ , and from  $n$  scatterers,  $nP^2(\zeta, \gamma)$ , if all the scatterers are at the same height  $\zeta$ .

Let the height distribution of scatterers be

$$n(\zeta) = \frac{1}{\sigma_1 (2\pi)^{1/2}} \exp\left(-\frac{\zeta^2}{2\sigma_1^2}\right) \quad \text{for } \zeta \geq 0$$

where  $\sigma_1$  is the standard deviation from zero height.

Let the horizontal distribution of scatterers be uniform, and consider an area  $dS$  from which power is being returned. The number of scatterers at height  $\zeta$  above  $dS$  is proportional to  $n(\zeta) dS$ , and the power returned is proportional to  $P^2(\zeta, \gamma) n(\zeta) dS$ .

The power returned from scatterers of all heights is proportional to

$$\int_{\zeta=0}^{\infty} P^2(\zeta, \gamma) n(\zeta) dS d\zeta ;$$

that is, proportional to

$$G^2(\gamma) dS \int_0^{\infty} I^2(\zeta, \gamma) n(\zeta) d\zeta .$$

The radar cross section per unit area, or backscatter coefficient, is therefore

$$\sigma_o(\gamma) \propto G^2(\gamma) \int_0^{\infty} I^2(\zeta, \gamma) n(\zeta) d\zeta .$$

This expression was evaluated for different values of  $\epsilon/\epsilon_o$ ,  $\lambda$ ,  $\sigma$ , and  $\sigma_1$ , and for both horizontal and vertical polarizations. For vertical polarization, the Brewster angle was also derived.

In order to obtain results applicable to a wide range of data, it was found convenient to work in terms of  $\epsilon/\epsilon_o$ ,  $\sigma\lambda$ , and  $\sigma_1/\lambda$ , setting  $\sigma_1/\lambda$  equal to 0.01, 0.1, and 1.0 in turn. For vertical polarization, all combinations of  $\epsilon/\epsilon_o = 3, 10, \text{ and } 30$  were used with  $\sigma\lambda = 0.0001, 0.001,$

0.01, and 0.1; also, the combination  $\epsilon/\epsilon_0 = 80$  was used with  $\sigma\lambda = 0.4$ , 4, 40, and 400. These combinations included such cases as very dry soil ( $\epsilon/\epsilon_0 = 3$ ,  $\sigma = 0.0001$ ), ice ( $\epsilon/\epsilon_0 = 3$ ,  $\sigma = 0.1$ ), moist soil ( $\epsilon/\epsilon_0 = 30$ ,  $\sigma = 0.01$ ), and sea ( $\epsilon/\epsilon_0 = 80$ ,  $\sigma = 4$ ).

### III. DEPENDENCE OF $\sigma_o(\gamma)$ ON THE INPUT PARAMETERS

#### A. HORIZONTAL POLARIZATION

With horizontal polarization,  $\sigma_o(\gamma)$  is very sensitive to variations in  $\sigma_1$ . Figure 1 shows that  $\sigma_o(\gamma)$  may decrease by 40 db when  $\sigma_1/\lambda$  is decreased by a factor of 10.

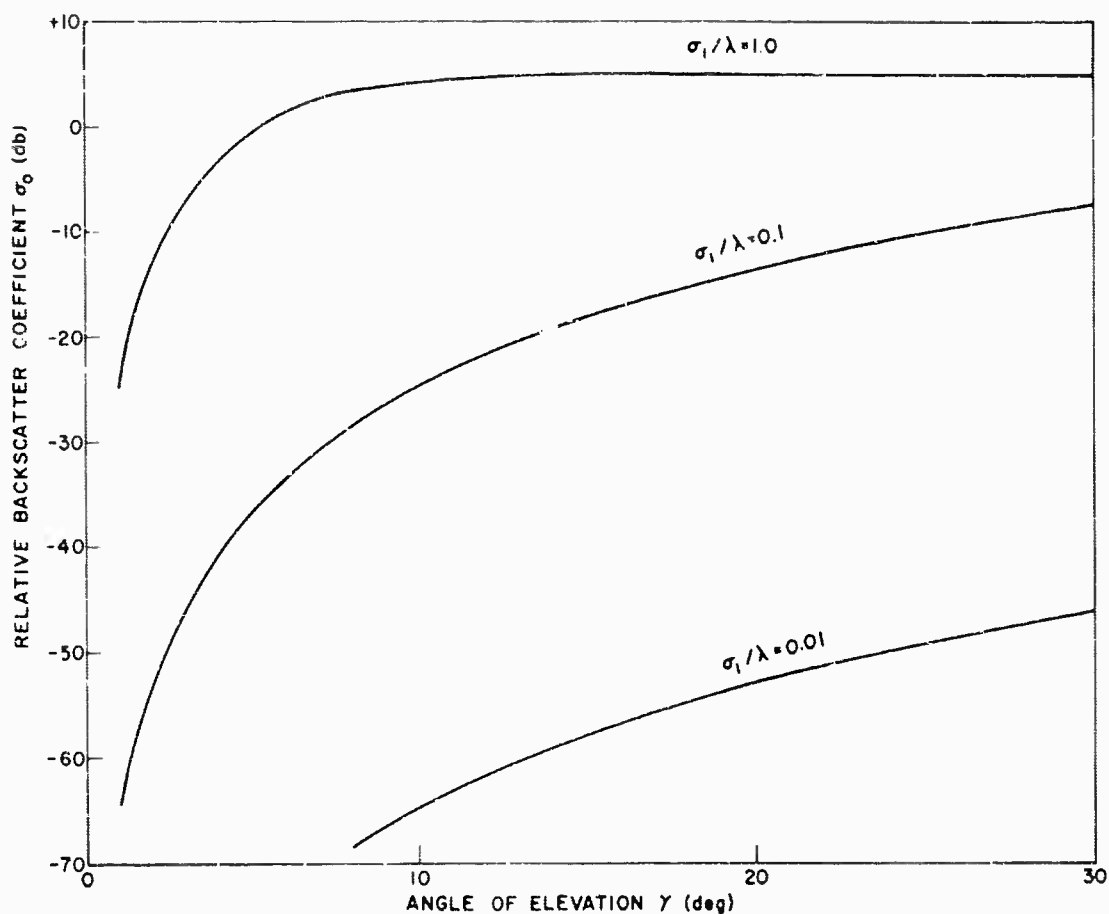


FIG 1. RELATIVE BACKSCATTER COEFFICIENT VS ANGLE OF ELEVATION FOR HORIZONTAL POLARIZATION, SHOWING THE EFFECT OF VARYING THE HEIGHTS OF SCATTERERS.

#### B. VERTICAL POLARIZATION

##### 1. Changes in $\sigma_1/\lambda$

Figure 2 is for average ground ( $\epsilon/\epsilon_o = 10$ ,  $\sigma = 0.001$ ) and a wavelength of 10 m. Provided  $\sigma_1/\lambda$  is less than 0.1,  $\sigma_o(\gamma)$  is almost

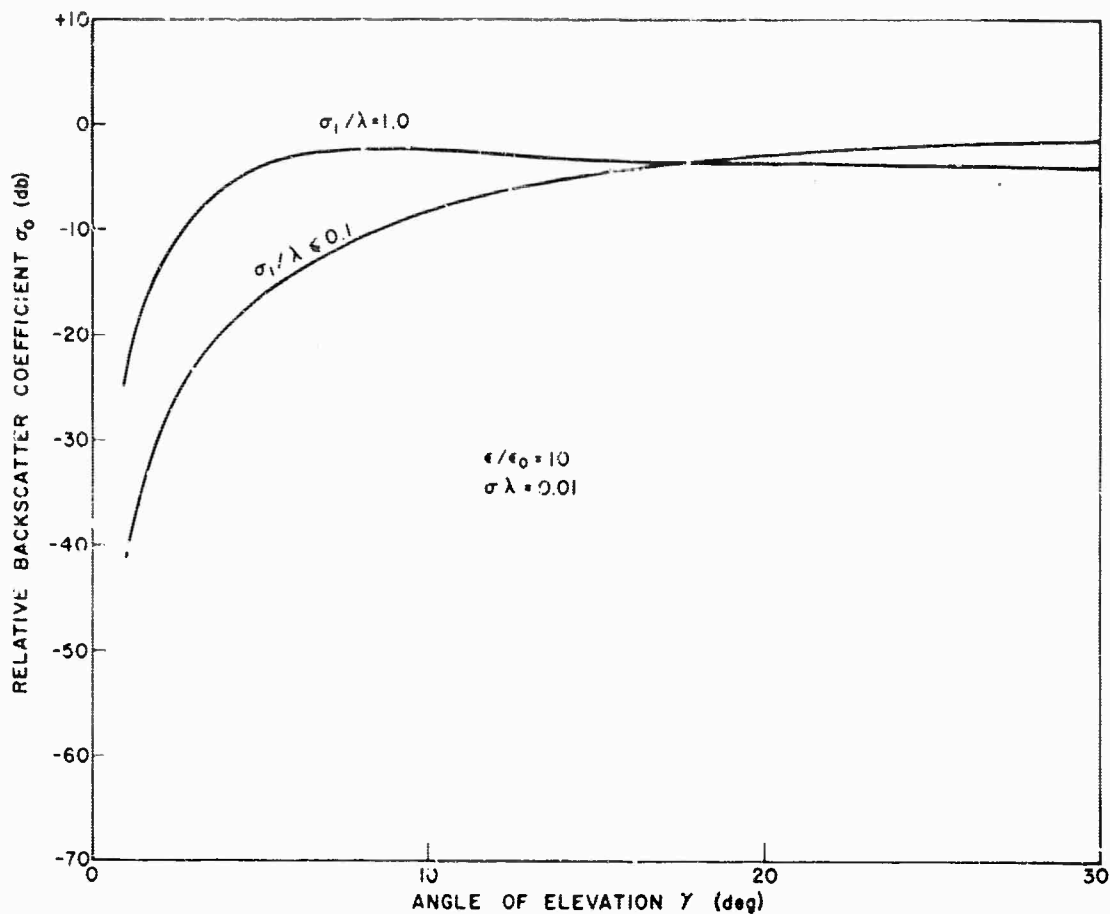


FIG. 2. RELATIVE BACKSCATTER COEFFICIENT VS ANGLE OF ELEVATION FOR VERTICAL POLARIZATION, SHOWING THE EFFECT OF VARYING THE HEIGHTS OF SCATTERERS.

unaffected by changes in  $\sigma_1$ . (This conclusion is qualified in Section VI.) Presumably, it is also unaffected by the actual form of the height distribution. In view of this, the case for  $\sigma_1/\lambda \leq 0.1$  will be the usual standard when considering the effects of other parameters in this paper.

## 2. Changes in $\sigma\lambda$

Variations in  $\sigma\lambda$  have very little effect on  $\sigma_0(\gamma)$ , provided  $\sigma\lambda$  is less than 0.1 and  $\epsilon/\epsilon_0$  is less than 30. In other words, for most land surfaces, variations in  $\sigma$  are unimportant at high frequency. For sea ( $\epsilon/\epsilon_0 = 80$ ,  $\sigma = 4$ ), variations in  $\sigma\lambda$  do have a significant effect. Figure 3 shows that if  $\sigma_1/\lambda = 0.1$ , an increase from 0.1 m to

100 m in  $\lambda$  may give rise to a 10-db increase in  $\sigma_0$  at 5 deg, and a 30-db increase at 1 deg. The dots on the curves indicate the Brewster angle, showing that increase of  $\sigma\lambda$  decreases the Brewster angle, which inhibits the low-angle decrease in  $\sigma_0$  until very low angles.

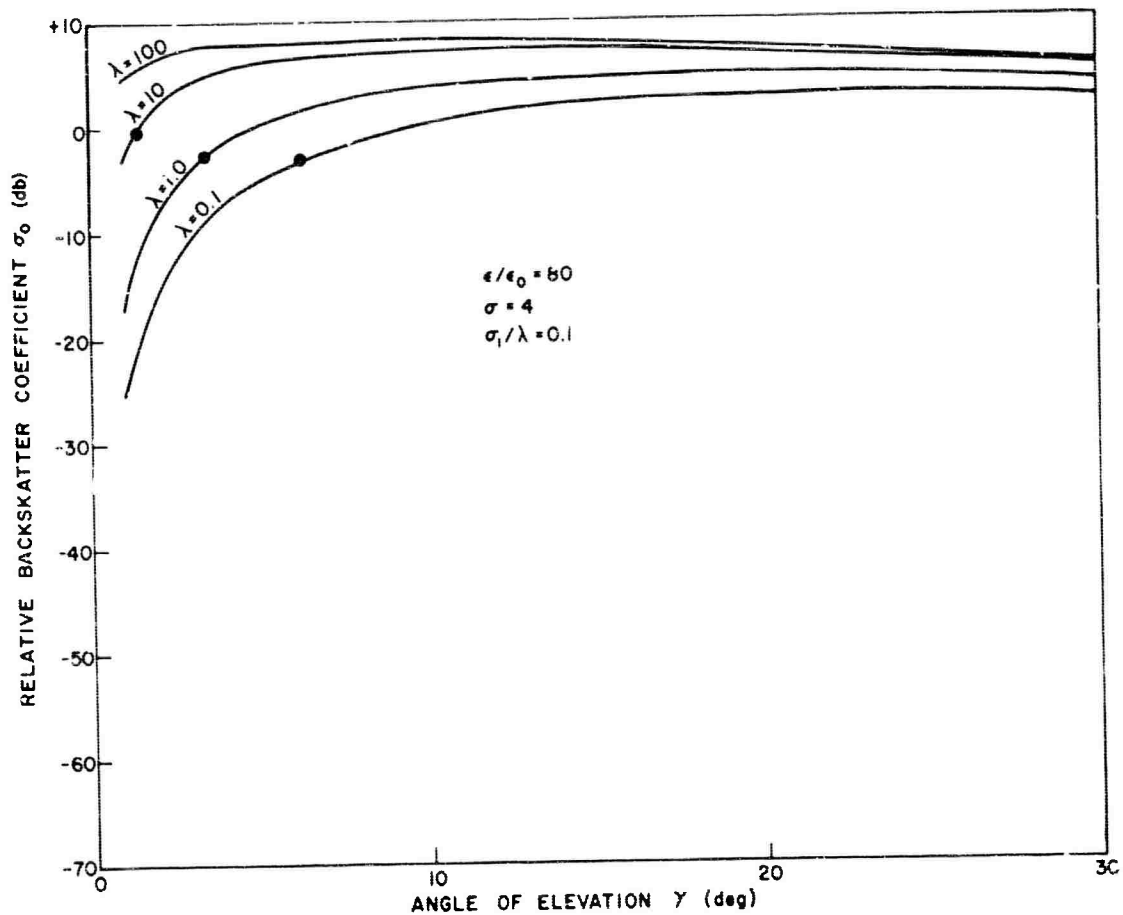


FIG. 3. RELATIVE BACKSCATTER COEFFICIENT VS ANGLE OF ELEVATION FOR THE SEA, WITH VERTICAL POLARIZATION, SHOWING THE EFFECT OF VARYING THE WAVELENGTH. The dots represent Brewster angles.

### 3. Changes in $\epsilon/\epsilon_0$

The parameter  $\epsilon/\epsilon_0$  has a large influence on  $\sigma_0(\gamma)$  and on the Brewster angle. The curves in Fig. 4 for moist land ( $\epsilon/\epsilon_0 = 30$ ) and dry land ( $\epsilon/\epsilon_0 = 3$ ) indicate that for a given area concentration of scatterers,  $\sigma_0(\gamma)$  is about 10 db larger for moist land than for dry land,

in spite of the fact that the difference in  $\sigma$ , as mentioned in the last paragraph, is not significant. Increase of  $\epsilon/\epsilon_0$  affects the Brewster angle in the same way as increase of  $\sigma\lambda$ , moving it to lower angles of elevation.

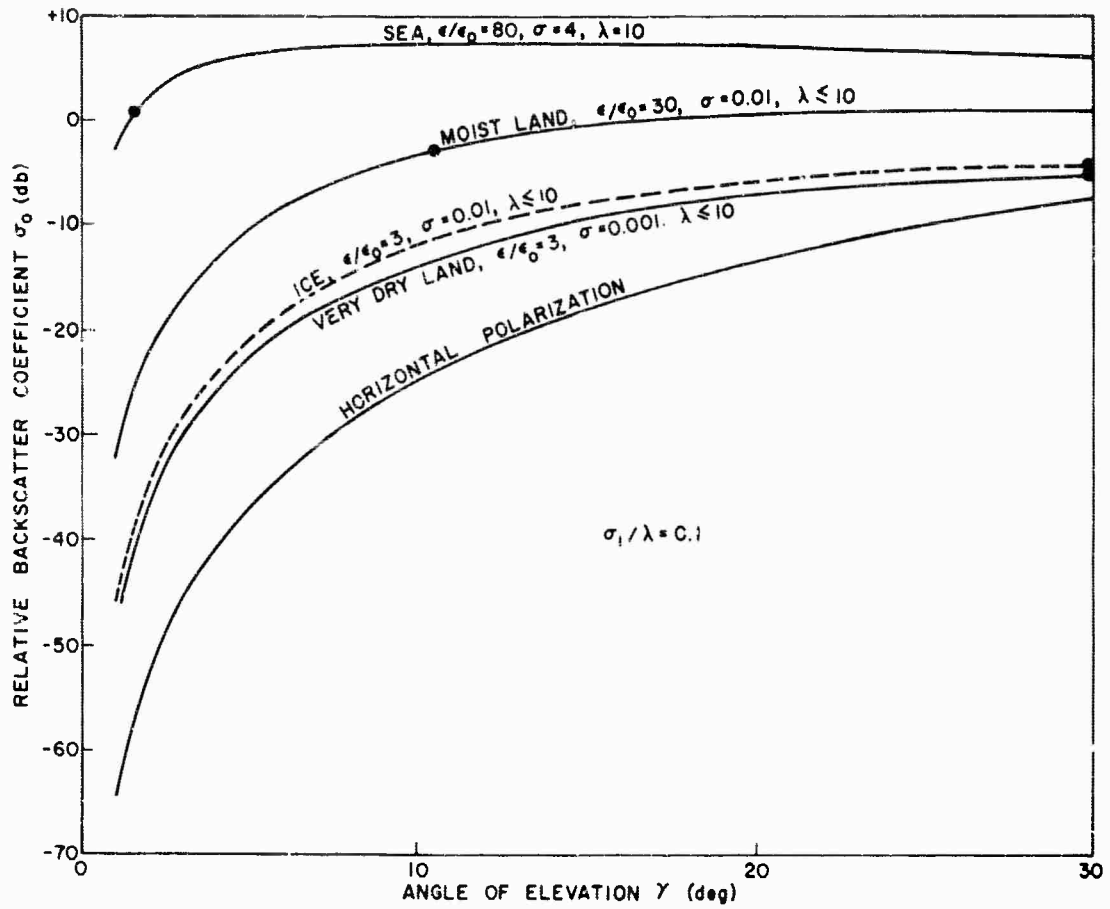


FIG. 4. RELATIVE BACKSCATTER COEFFICIENT VS ANGLE OF ELEVATION WITH HORIZONTAL POLARIZATION; AND WITH VERTICAL POLARIZATION AND DIFFERENT GROUND CONSTANTS, AND A WAVELENGTH OF 10 M. The dots represent Brewster angles.

#### IV. RESULTS FOR TYPICAL TYPES OF GROUND

Figure 4 compares the curves calculated for various types of ground, when  $\sigma_1/\lambda = 0.1$  and  $\lambda = 10$  m. For a given area density of scatterers, the sea is the best scattering surface with vertical polarization. Horizontal polarization gives a poorer return than vertical for any of the surfaces considered.

When the same curves were plotted for  $\sigma_1/\lambda = 1$ , the effects due to ground constants and polarization were largely suppressed, and at low angles all the curves agreed to within a few decibels. In making comparisons between these curves, one should remember that they correspond to a constant area density of scatterers on the surface, which may in practice vary considerably. Also, it should be remembered that the number of horizontal scatterers is probably considerably less than the number of vertical scatterers, especially at heights comparable to a wavelength at high frequency. Probably  $\sigma_0(\gamma)$  for horizontal polarization is always less than that for vertical polarization, even when  $\sigma_1/\lambda = 1$ .

## V. COMPARISON WITH EXPERIMENTAL RESULTS

It is of interest to compare the general trends of the  $\sigma_0(\gamma)$  curves with experimentally derived curves. Figure 5 presents the experimental curves of Hagn [Ref. 1] for horizontal polarization, with the curve calculated for  $\sigma_1/\lambda = 0.1$  revised to conform to the coefficient  $\rho = \sigma_0/(2 \sin \gamma)$  and reproduced in various positions on the graph for comparison with the experimental curves. Figure 6 follows the same procedure for vertical polarization, except that in this case there is a different calculated curve for each type of ground, and each calculated curve appears only once, after being scaled to match the corresponding experimental curves as closely as possible.

The polarization dependence is rather well described by the theory, and for vertical polarization the slope difference between the curves for sea and land seems to be reproduced. The theory provides an explanation for the relatively high values of  $\sigma_0$  at angles near the Brewster angle, and for the rapid decrease in  $\sigma_0$  at lower angles [Ref. 2]. The theory does not, however, adequately explain the "knee effect" that is sometimes observed [Refs. 1 and 2].

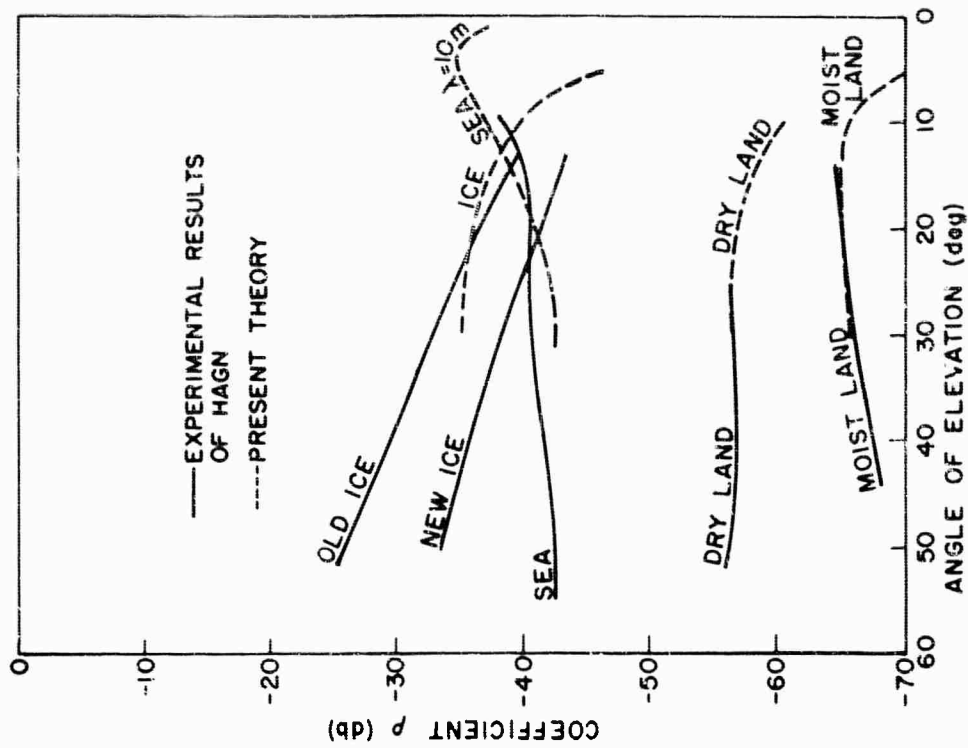


FIG. 6. COMPARISON OF THE PRESENT THEORY WITH THE EXPERIMENTAL RESULTS OF HAGN: VERTICAL POLARIZATION.

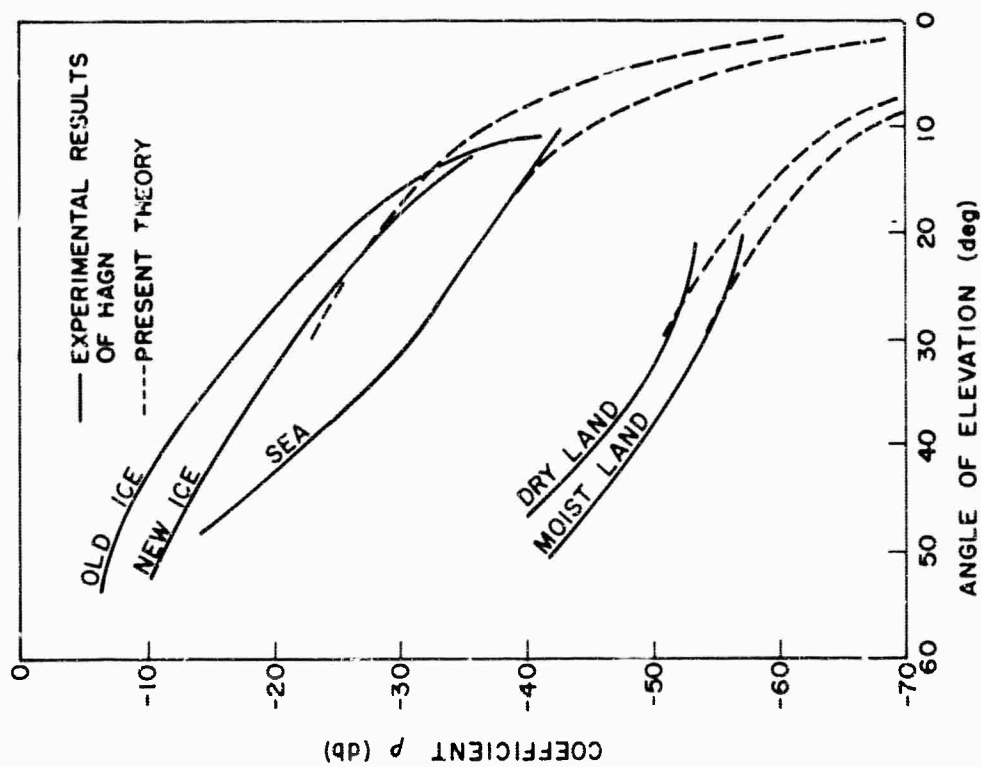


FIG. 5. COMPARISON OF THE PRESENT THEORY WITH THE EXPERIMENTAL RESULTS OF HAGN: HORIZONTAL POLARIZATION.

## VI. CONCLUSION

The partial success of this theory to account for the  $\sigma_0(\gamma)$  dependence for different values of  $\epsilon/\epsilon_0$ ,  $\sigma$ ,  $\sigma_1$  at high frequency suggests that a model consisting of scattering objects rising out of a reflecting plane is likely to be of some value. Wetzel [Ref. 5], using a similar model and a more rigorous theory, has estimated the radar cross section of a tree of height  $\lambda/2$  for angles below 30 deg and has predicted strong polarization dependence, and a sharp fall-off in cross section below about 14 deg when the Brewster angle was 22 deg.

In criticism of the present theory, it is pointed out that a tree or other scatterer is not a collection of "elementary" dipoles radiating independently. A tree of height  $\lambda/2$ , for example, would exhibit resonance and scatter more strongly. The theory is most realistic when  $\sigma_1/\lambda \cong 0.1$ .

Further, the conclusion of Section III.B.1--that provided the area density of elementary dipoles is constant,  $\sigma_0$  becomes independent of  $\sigma_1$  if  $\sigma_1/\lambda \cong 0.1$ --is not strictly correct. A model of short cylinders would be more realistic. As  $\sigma_1/\lambda$  approaches zero, there should be a decrease in cylinder lengths, and  $\sigma_0$  should decrease rapidly according to the Rayleigh scattering law.

#### REFERENCES

1. G. Magn, "An Investigation of the Direct Backscatter of High-Frequency Radio Waves from Land, Sea Water, and Ice Surfaces," Final Report II, SRI Project No. 2909, Stanford Research Institute, Menlo Park, Calif., May 1962.
2. J. G. Steele, "Backscatter of 16 Mc/s Radio Waves from Land and Sea," Austral. J. Phys., 18, Aug 1965, pp. 317-327.
3. H. Goldstein, "Frequency Dependence of the Properties of Sea Echo," Phys. Rev., 70, 2, Dec 1946, pp. 938-946.
4. P. Beckmann and A. Spizzichino, "The Scattering of Electromagnetic Waves from Rough Surfaces," The Macmillan Company, New York, 1963.
5. L. Wetzel, "On HF Ground Backscatter," unpublished paper, Institute for Defense Analyses, Arlington, Va., 1965.

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## KEY WORDS

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 HF BACKSCATTER COEFFICIENT  
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 Dependence on Surface Properties  
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