AD-A083 922 ARMY ENGINEER TOPOGRAPHIC LABS FORT BELVOIR VA F/G 17/9
BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM A LAYER OF VEGETAT--ETC(U)
FEB 80 R A HEVENOR
UNCLASSIFIED ETL-R008 NL

1 OF 1
AD
A083922

END
DATE
FILMED
-80
DTIC

U.S. ARMY

LEVEL II

ENGINEER TOPOGRAPHIC LABORATORIES

FORT BELVOIR, VIRGINIA

ADA083922

ETL-R008

BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM A LAYER OF VEGETATION

by

Richard A. Hevenor

Approved for public release; distribution unlimited

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES

80 4 28 027

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (14) ETL-R-008	2. GOVT ACCESSION NO.: AD-A083 922
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Backscattering of Electromagnetic Waves from a Layer of Vegetation	5. TYPE OF REPORT & PERIOD COVERED: Paper
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Mr. Richard A. Hevenor	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: USA Engineer Topographic Laboratories, Fort Belvoir, VA 22060	12. REPORT DATE: (11) 15 February 1980
	13. NUMBER OF PAGES: 26 total incl drawings
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 27	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Radar Backscattering,
Vegetation
Volume Scattering,
Random Media
Renormalization

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A theoretical model for the backscattering of electromagnetic waves from a layer of vegetation is computed using a first order renormalization technique to determine volume scattering. The vegetation soil interface is assumed rough according to the tangent plane approximation and the scattering from this boundary is added incoherently to the volume scattering result. The mean wave in the vegetation is obtained using a bilocal approximation of the Dyson's equation. A free space dyadic Green's function is used along with a correlation function of the dielectric fluctuations which is exponential in form and which also possess different correlation lengths 1, 1

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 403192

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) and l_z in the x, y, and z, directions. Effective propagation constants are obtained bor both horizontal and vertical polarizations. The scattered wave is solved for using a two-dimensional Fourier transform technique and the boundary condtions at either end of the vegetation layer are matched. The far field back scatter coefficients are computed for both horizontal and vertical polarizations. The mean and variance of the dielectric fluctuations are calculated with the aid of Peake's model for the dielectric constant of vegetation. The theory is matched to experimental data taken from a corn field. The resulting values for the correlation parameters are then used to monitor the growth pattern of the corn field over a period of time. Comparison between the theoretical and experimental results over this time period are shown. The theory is also matched to experimental data from spring and fall deciduous trees. An elementary sensitivity analysis is also shown in which the change in the backscatter coefficient is plotted as a funtion of incidence angle for a given change in one input parameter

BACKSCATTERING OF ELECTROMAGNETIC WAVES FROM A LAYER OF VEGETATION

by

Richard A. Hevenor

Electronics Engineer

United States Army Engineer Topographic Laboratories

Research Institute

Center for Theoretical and Applied Physical Sciences

Fort Belvoir, Virginia 22060

Abstract

A theoretical model for the backscattering of electromagnetic waves from a layer of vegetation is computed using a first order renormalization technique to determine volume scattering. The vegetation soil interface is assumed rough according to the tangent plane approximation and the scattering from this boundary is added incoherently to the volume scattering result. The mean wave in the vegetation is obtained using a bilocal approximation of the Dyson's equation. A free space dyadic Green's function is used along with a correlation function of the dielectric fluctuations which is exponential in form and which also possess different correlation lengths ℓ_x, ℓ_y, and ℓ_z in the x, y, and z, directions. Effective propagation constants are obtained for both horizontal and vertical polarizations. The scattered wave is solved for using a two-dimensional Fourier transform technique and the boundary conditions at either end of the vegetation layer are matched. The far field backscatter coefficients are computed for both horizontal and vertical polarizations. The mean and variance of the dielectric fluctuations

are calculated with the aid of Peake's model fcr the dielectric constant of vegetation. The theory is matched to experimental data taken from a corn field. The resulting values for the correlation parameters are then used to monitor the growth pattern of the corn field over a period of time. Comparison between the theoretical and experimental results over this time period are shown. The theory is also matched to experimental data from spring and fall deciduous trees. An elementary sensitivity analysis is also shown in which the change in the backscatter coefficient is plotted as a function of incidence angle for a given change in one input parameter.

I. Introduction

This paper will present some results of a theory which was developed for the purpose of analyzing the nature of radar backscattering from certain types of vegetation. The vegetation is simulated by a continuous random medium and use is made of a first order renormalization technique to calculate the radar backscatter coefficient. The influence of an irregular vegetation soil interface is also considered using a noncoherent approach. Recently, Fung[1] solved the problem of scattering from a vegetation layer using a scalar first order renormalization approach. His solution, however, did not consider the existence of a rough vegetation soil boundary. Fung did consider an anisotropic correlation function in which the horizontal variation is different from the vertical. Tsang and Kong[2] solved the problem of volume scattering from a half space random medium which contains lateral and vertical fluctuations. A radiative transfer approach was used to calculate the backscattering cross sections up to second order in approximation. This enabled the cross polarized terms to be obtained.

There are two important and somewhat related practical applications for developing and analyzing various radar scattering theories. The first application is radar image simulation of terrain features. In this problem the radar system parameters and terrain parameters are assumed known and used to calculate a radar response in the form of a grey tone or density. The scattering theories can be used to compute the radar backscatter coefficient which in turn is used to calculate grey tone. The use of scattering theories in this type of application is straight-forward even though a solution for any one particular scattering problem may be extremely complicated. The second application is in the field of remote sensing of terrain in which the sensor response must be utilized to determine various terrain parameters. The use of the scattering theories for this application is not straightforward. There are, however, two important uses of scattering theories which bear directly on remote sensing. The first of these is a parameter sensitivity study. The theory can be used to analyze the influence of various vegetation, terrain and radar parameters upon the sensor response. Such parameters as surface roughness, soil moisture, vegetation height and density could be varied one at a time in order to determine the influence on the sensor response. This type of analysis should lead to a determination of what radar parameters are most sensitive to certain terrain parameter changes. This type of analysis assumes the existence of verified scattering theories which have been developed and compared with existing experimental data. The second use of scattering theories would be to analyze the radar response for two different types of terrain features in an effort to see if the two features could be distinguished from each other on an image. Once again this would assume the existence of verified scattering theories which have been developed and tested against experimental data. These applications provide the incentive for developing, analyzing, and testing various scattering theories.

In what follows we will consider the geometry of the scattering problem to be solved and discuss the technique used for the solution. The form of the final answer for the backscatter coefficient will be shown, and section II will compare the resulting theory with existing experimental data. Also, some results from a sensitivity of input parameters study will be shown.

Figure 1 shows the scattering geometry of the vegetation problem. A plane wave with a time harmonic dependence of exp $(j\omega t)$ is incident from free space at an angle θ_i onto a layer of vegetation. The mean thickness of the vegetation is L. The vegetation soil boundary is considered to be randomly rough according to the tangent plane approximation. The vegetation is simulated by a continuous random medium in which $\varepsilon(\underline{r})$ and $\sigma(\underline{r})$ represent the three dimensional random dielectric and conductivity fluctuations, respectively. These fluctuations consist of the sum of an average and a fluctuating component. The standard deviations of the fluctuations are represented by η_1 and η_2. The true angle of refraction of the mean wave in the random medium is θ_e. The soil below the vegetation is assumed homogeneous with a complex propagation constant k_3. The magnetic permeability for all three media is assumed to be that of free space. The polarization of the incident wave was taken to be either horizontal or vertical. A first order renormalization method was used to calculate the mean and scattered waves in the random medium. A solution was developed first for the case where the vegetation soil boundary is a plane interface. The effects of an irregular boundary were considered in a noncoherent manner. The dielectric and conductivity fluctuation terms ($\varepsilon'(\underline{r})$ and $\sigma'(\underline{r})$) are generated by statistically homogeneous random processes. The mean of each process is zero and the correlation functions are identical and exponential in form with ℓ_x, ℓ_y and ℓ_z representing the correlation distances in x, y, and z. The correlation functions have been chosen to be anisotropic. It is believed that this representation with unequal correlation distances, is closer to reality than an isotropic correlation function. This is because the size of the vegetation scatterers in a horizontal plane is generally not the same as the size of the scatterers in a vertical plane. The mean wave in the random medium is determined from the bilocal approximation of the Dyson's equation. Plane wave solutions to the Dyson's equation were obtained using the form of a free space dyadic Green's function. The free space propagation constant was replaced with the average background propagation constant of the random medium. A three dimensional Fourier transform of the Green's function was used. A solution for the z component of the effective propagation constant of the mean wave was obtained for both horizontal and vertical polarizations. Once the mean wave had been calculated and the appropriate boundary conditions matched for the mean waves in all three media, then the scattered wave in the random medium was computed using the first order renormalized equation for the scattered wave. This scattered wave was computed using a two dimensional Fourier transform technique. This also allowed the calculation of the scattered waves in air. The necessary boundary conditions were matched and the backscatter coefficient was computed for horizontal and vertical polarizations. The influence of the rough boundary between the vegetation and the soil was considered apart from the volume scattering solution, using the tangent plane method. The backscatter coefficient for the rough surface scattering had to be modified by the attenuation through the vegetation. This result was then added to the volume scattering solution to obtain a final answer for the backscatter coefficient. The form of this result is given below:

$$\sigma^o_{HH} = \sigma^o_{HHS} \exp(-4\alpha_{e1} L \sec\theta_{e1}) + \sigma^o_{HHV} \tag{1}$$

$$\sigma^o_{VV} = \sigma^o_{VVS} \exp(-4\alpha_{e2} L \sec\theta_{e2}) + \sigma^o_{VVv} \tag{2}$$

where:

σ^o_{HHS} and σ^o_{VVS} are the rough surface scattering coefficients for horizontal and vertical polarizations.

α_{e1} and α_{e2} are the attenuation portions of the effective propagation constant for horizontal and vertical polarizations, respectively.

θ_{e1} and θ_{e2} are the true angles of refraction of the mean wave in the random medium for horizontal and vertical polarizations, respectively.

σ^o_{HHv} and σ^o_{VVv} are the volume scattering coefficients for horizontal and vertical polarizations.

An elementary permittivity model was developed to relate certain parameters of the random medium to the parameters of actual vegetation. Use was made of a model provided by Peake and Oliver[3] for the complex dielectric constant of vegetation. This in turn was used to help compute values for the means and variances of the dielectric and conductivity fluctuations.

II. Numerical Results

This section will show the results of sample calculations for equations (1) and (2) and will also show the results of some sensitivity calculations where the change in backscatter coefficient is analyzed for a given change in one input parameter. The input parameters for the model are:

1. Angle of incidence (θ_i)
2. Fraction of water by weight in the vegetation (F)
3. Volume of vegetation divided by the total volume of vegetation plus air (R_v)
4. Correlation distance in the x direction (ℓ_x)
5. Correlation distance in the y direction (ℓ_y)
6. Correlation distance in the z direction (ℓ_z)
7. Mean thickness of the vegetation layer (L)
8. Relative dielectric constant of the soil below the vegetation (ε_g)
9. Conductivity of the soil below the vegetation (σ_3)
10. Frequency (f)
11. Ratio of the standard deviation of the rough surface fluctuations to the correlation distance of the fluctuations (m_s)

The output of the computer calculations is the backscatter coefficient in decibels. Figures 2 through 7 match the theory with experimental data taken from corn at three different times during the growing season. The peak which occurs at normal incidence is due to rough surface scattering and changes according to the thickness of the layer and the vegetation moisture content. Figures 8 and 9 match the theory to experimental data taken from spring and fall deciduous trees. These results are also compared to some results derived for corn. Figure 10 presents a study of σ^o variations with the fraction of water by weight in the vegetation. For small angles of incidence (less than 10°) increasing F results in a slightly lower value of σ^o. This is due to the fact that surface scattering is dominant at these angles and increases in F yield more attenuation for the mean wave. At larger angles of incidence (greater than 20°) volume scattering is dominant and increases in F increase the level of σ^o. Figure 11 presents a study of σ^o variations with L. Figure 12 shows a study of σ^o variations with ℓ_x. For angles of incidence less than approximate 50°, an increase in ℓ_x results in larger values of σ^o. For angles of incidence greater than 50° an increase in ℓ_x results in σ^o falling off faster with incidence angle. For angles of incidence less that 10° changes in ℓ_x have no influence on σ^o since the surface scattering is dominant. Figure 13 presents a study of σ^o variations with ℓ_z. Increasing ℓ_z results in increasing the level of σ^o except for angles of incidence less that 10°. Figure 14 shows a study of σ^o variations with ε_g. In this figure the change in $\sigma^o(\Delta\sigma^o)$ is plotted as a function of incidence angle for a change in ε_g of 40. It can be seen that for small angles of incidence this results in large changes in σ^o. As the incidence angle increases, however, $\Delta\sigma^o$ rapidly decays toward zero as the lower surface has less influence on the result. Figure 15 shows a study of σ^o variations with ℓ_x. The change in σ^o is plotted as a function of incidence angle for a change in ℓ_x equal to one centimeter. For angles of incidence less than 20^o, $\Delta\sigma^o$ is practically zero. At these angles the rough surface scattering is most inportant and changes in ℓ_x have little or no affect on σ^o. As the angle of incidence increases; $\Delta\sigma^o$ swings downward to a value of approximately -4db at 80^o.

We will conclude this section with a brief discussion of the limitations and difficulties with the developed theory. It appears valid to simulate a region of vegetation with a continuous random medium although it is not certain as to how well the first order renormalization technique does in solving the problem. It is not clear how much multiple scattering is being considered and it is not even clear as to how much multiple scattering must be considered. A free space dyadic Green's function was used in solving the Dyson's equation and what should have been used was a Green's function applicable to a layered problem. An anisotropic correlation function was used, however, this did not result in a depolarization term. The existence of depolarization is clearly evident from the experimental data. The reason for this depolarization is as yet unknown. A depolarization term could be obtained by computing the scattered field to a second order approximation. It could also be obtained by initially allowing for an anisotropic random medium. Which approach is correct is unclear at this time.

III. Conclusions

The following conclusions have been made as a result of this work:

1. A theory has been developed to explain electromagnetic wave scattering from a vegetation layer possessing an irregular vegetation soil boundary.

2. The theory developed was for like polarized (HH or VV) components only and no result was obtained for the depolarized components.

3. For certain types of vegetation such as corn it was found that the irregular vegetation soil boundary dominates the backscattering result for angles of incidence between 0° and 20°.

4. In general the affect of the rough surface boundary between the vegetation and soil increases with decreases in frequency, vegetation moisture content, vegetation volume, and layer thickness.

5. The σ° versus incidence angle curve was shown to be sensitive to very slight changes in the correlation distance in z.

6. The predictability of the σ° versus incidence angle curve depends upon a very detailed knowledge of the statistical properties of the dielectric fluctuations of the vegetation and surface roughness properties of the soil below. Such knowledge as this for particular vegetation features does not exist at the present time. Future work should include attempts to obtain this detailed understanding if theoretical models are to have ultimate usefulness in predicting scattering from vegetation features.

References

1. A. K. Fung, "Scattering From A Vegetation Layer", IEEE Transactions on Geoscience Electronics, Vol. GS-17, No. 1. January 1979.

2. L. Tsang and J. A. Kong, "Radiative Transfer Theory for Active Remote Sensing of Half Space Random Media", Radio Science, Vol. 13, No. 5, September-October 1978.

3. W. H. Peake and T. L. Oliver, "The Response Of Terrestial Surfaces At Microwave Frequencies", Technical Report AFAL-TR-70-301, The Ohio State University Electroscience Laboratory AD884106.

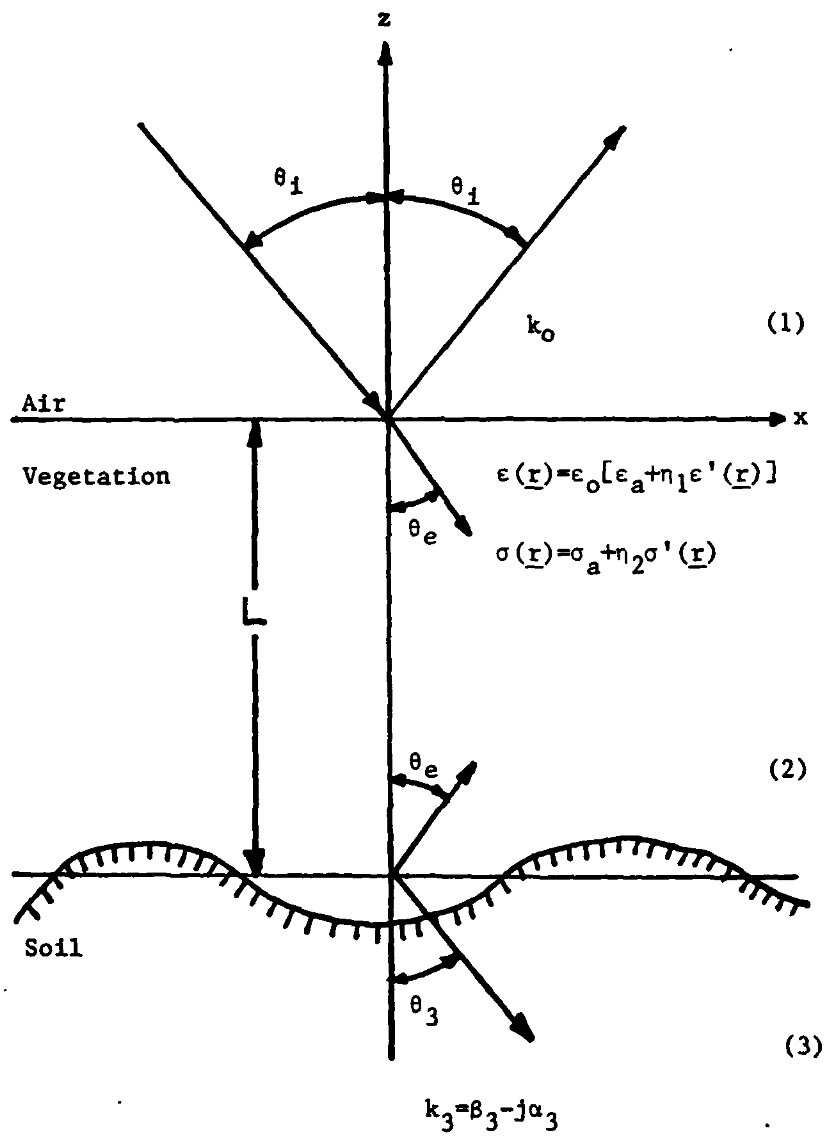

Figure 1 - Scattering Geometry

$$\sigma^o_{HH}=\sigma^o_{HHS}\exp(-4\alpha_{e1}L\sec\theta_{e1})+\sigma^o_{HHv}$$

$$\sigma^o_{VV}=\sigma^o_{VVS}\exp(-4\alpha_{e2}L\sec\theta_{e2})+\sigma^o_{VVv}$$

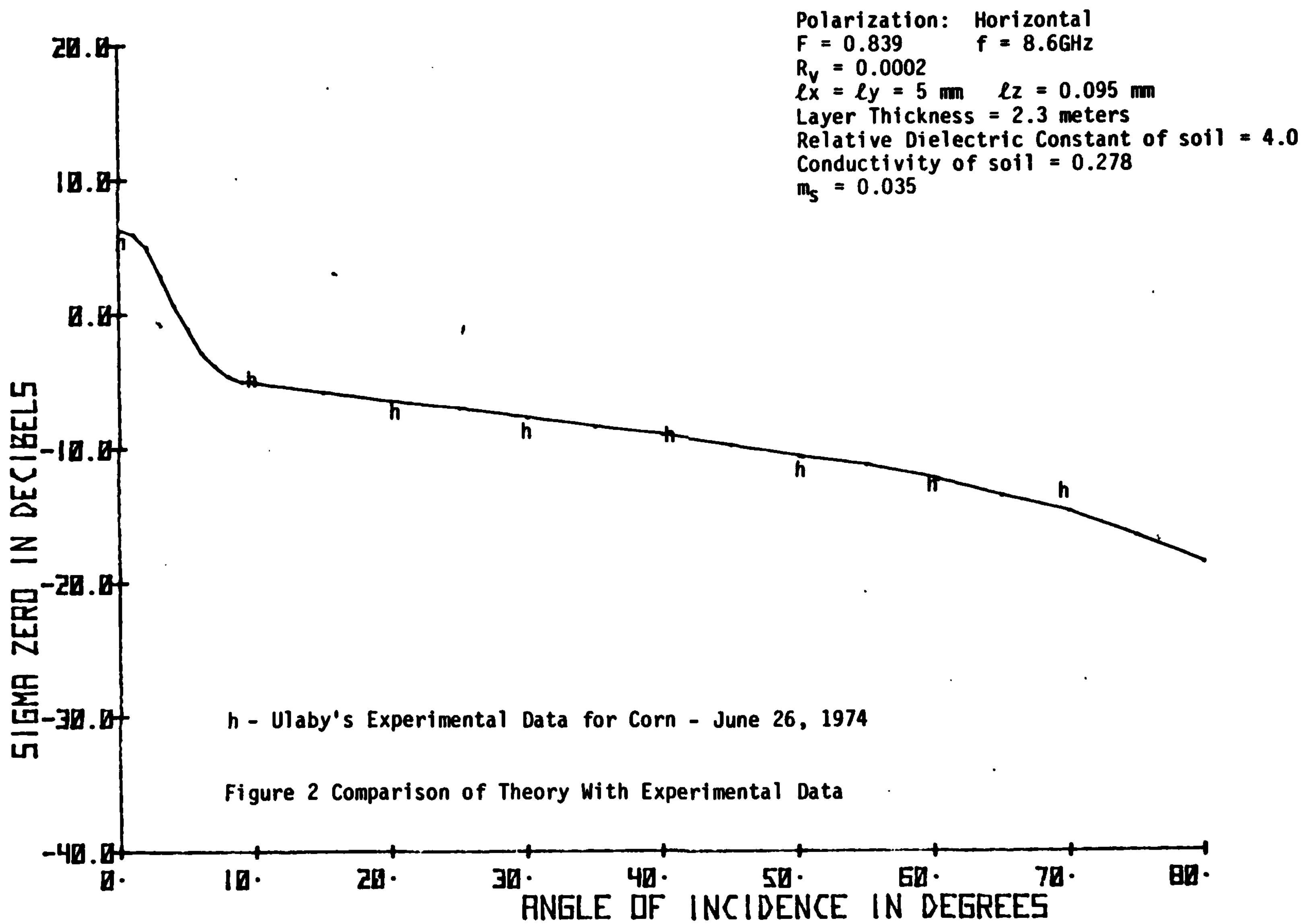

Figure 2 Comparison of Theory With Experimental Data

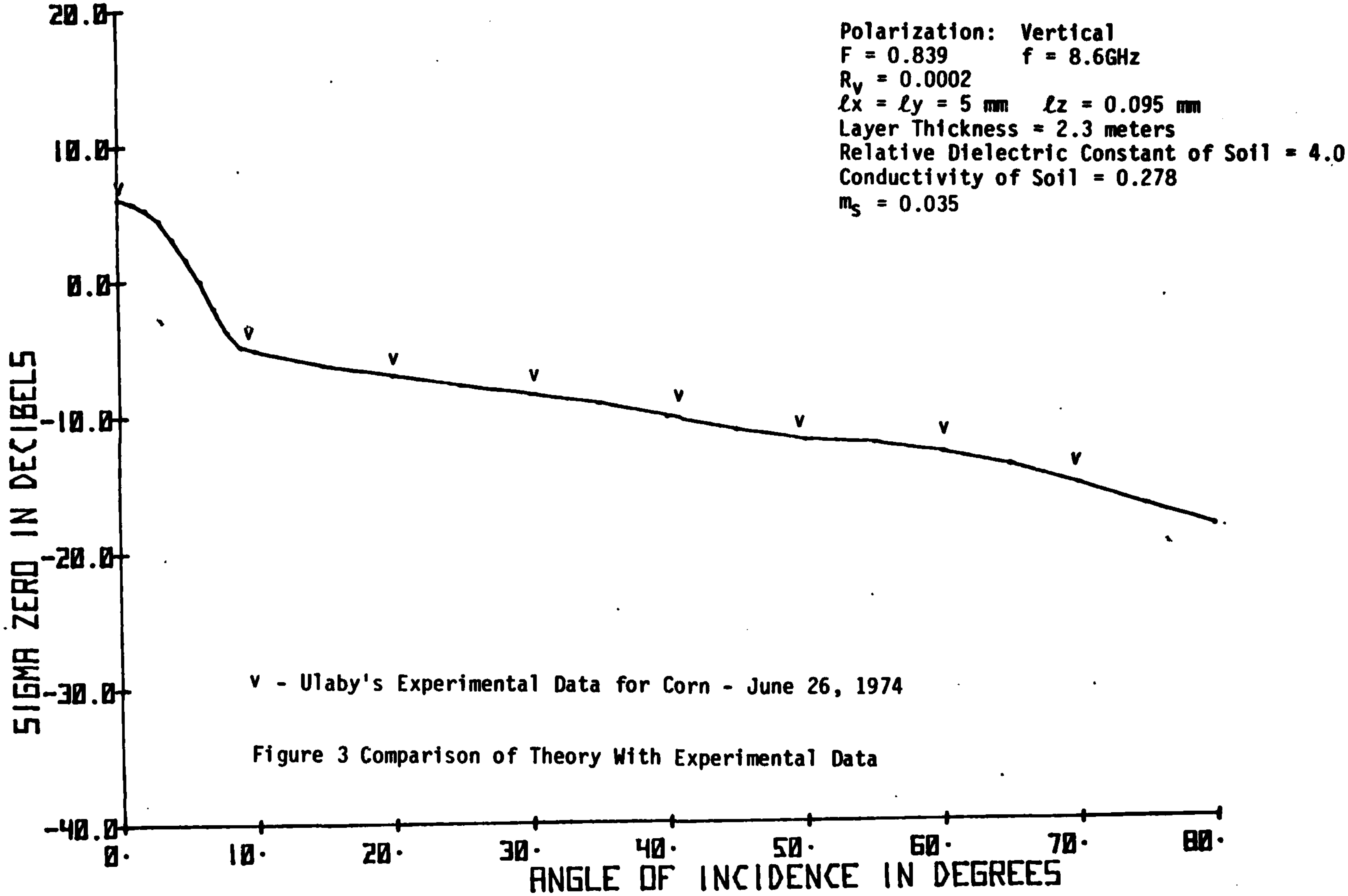

Figure 3 Comparison of Theory With Experimental Data

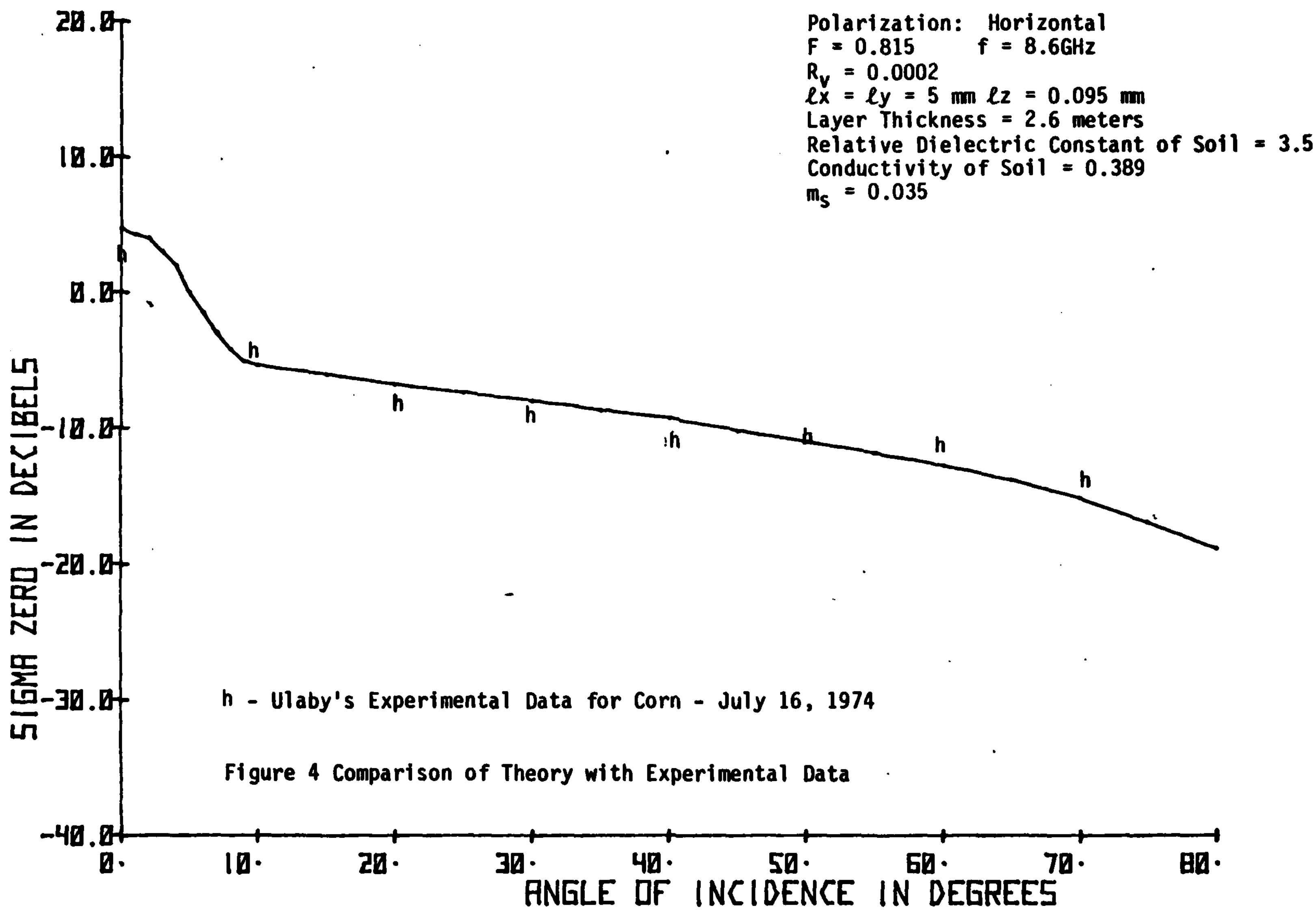

Figure 4 Comparison of Theory with Experimental Data

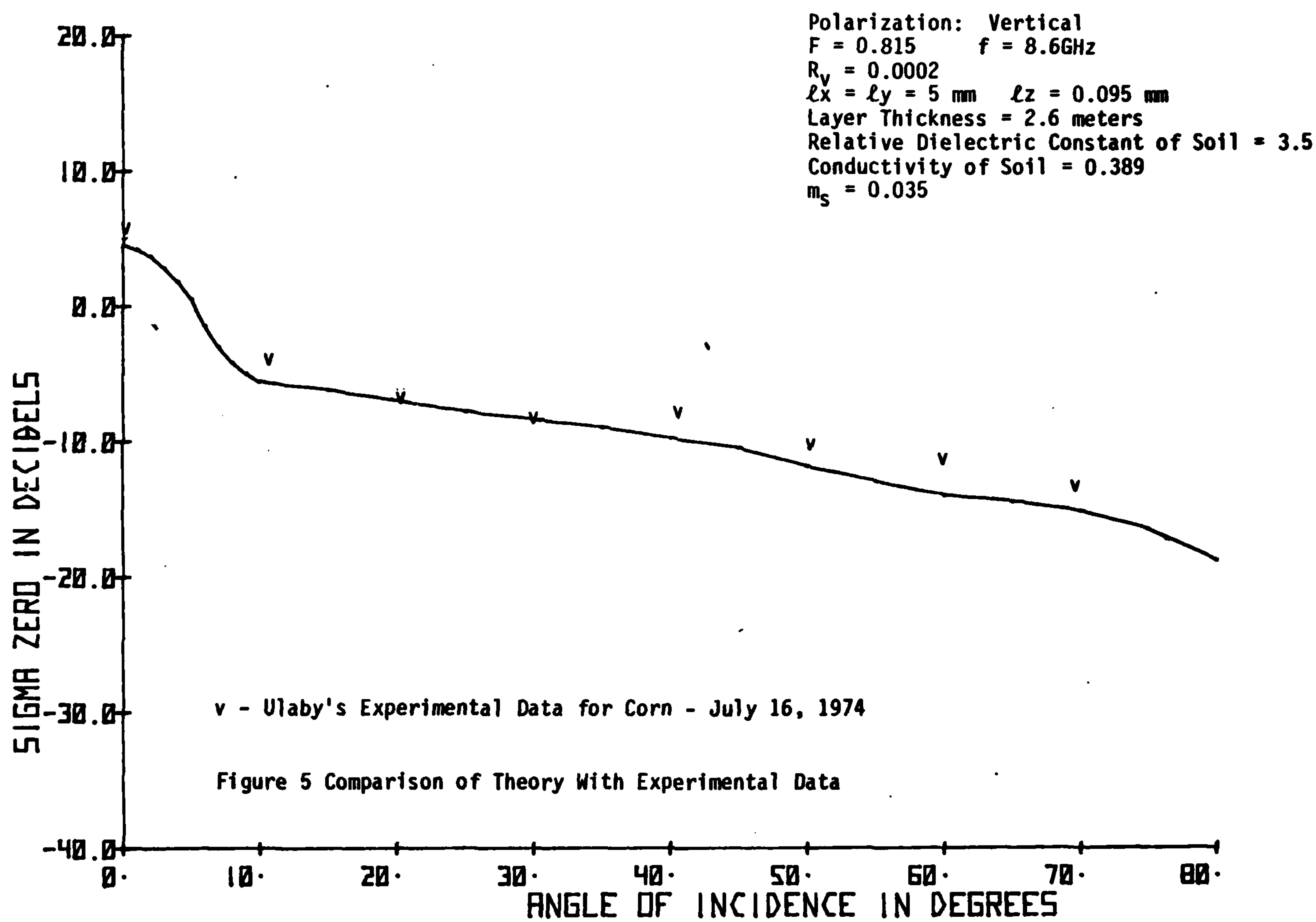

Figure 5 Comparison of Theory With Experimental Data

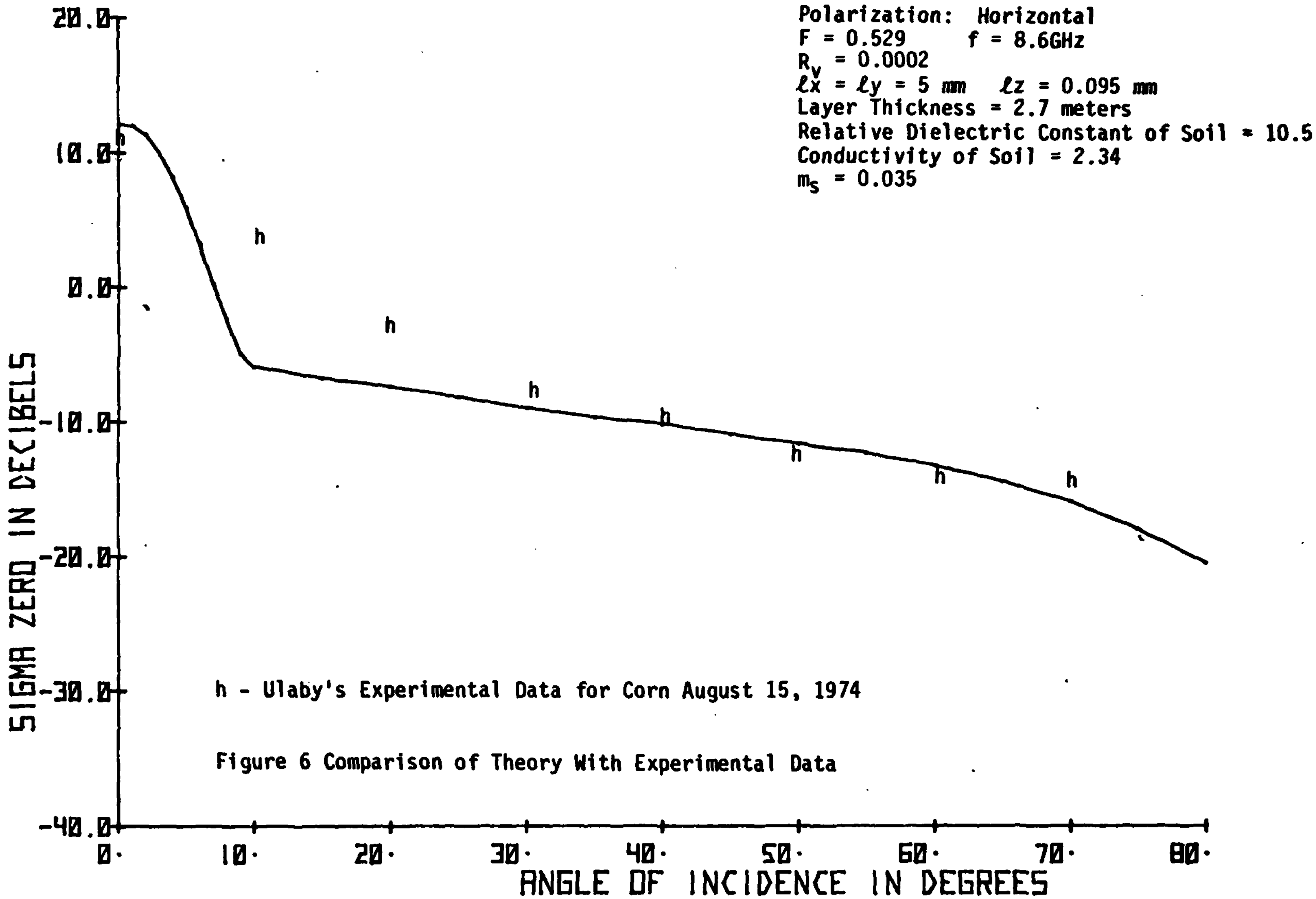

Figure 6 Comparison of Theory With Experimental Data

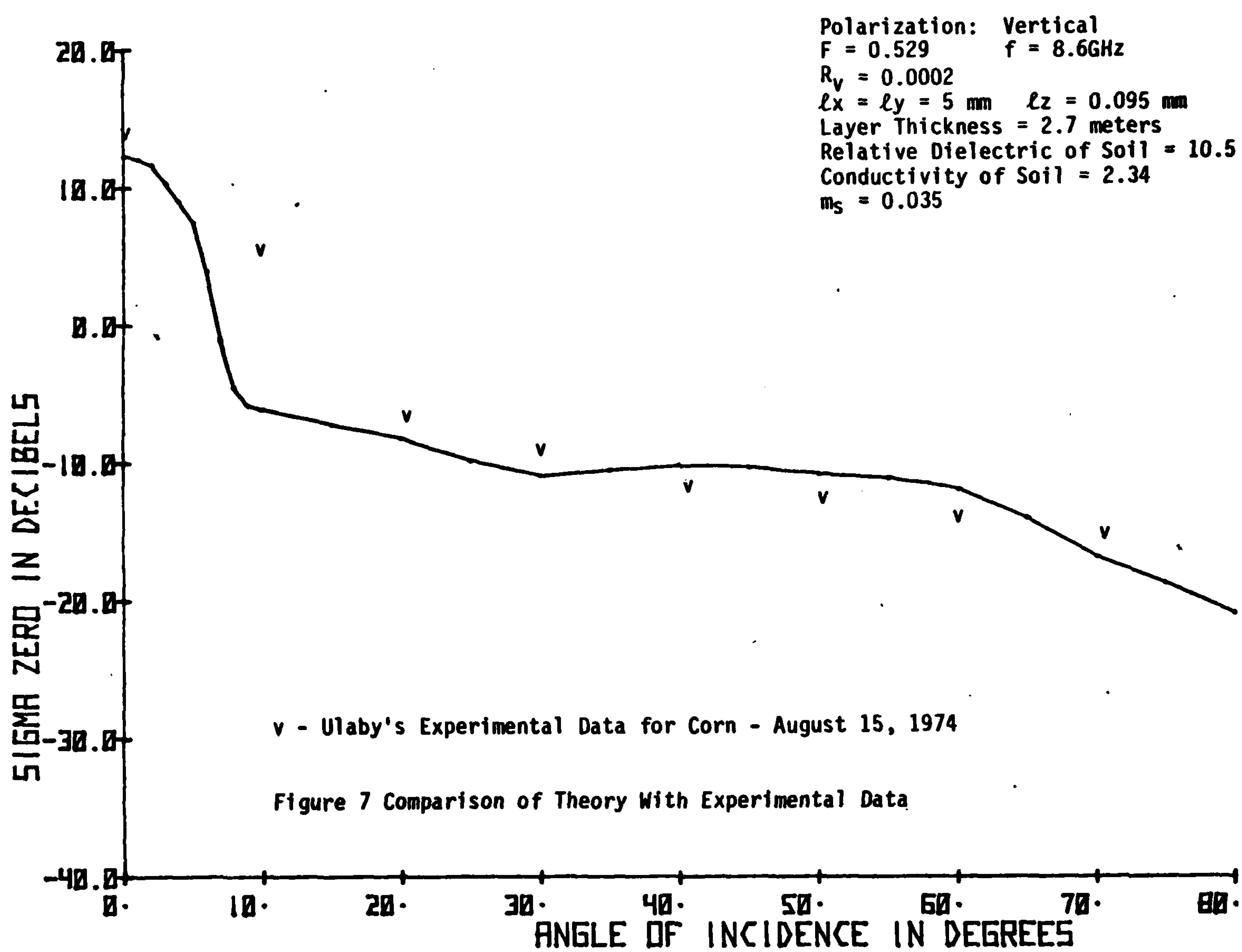

Figure 7 Comparison of Theory With Experimental Data

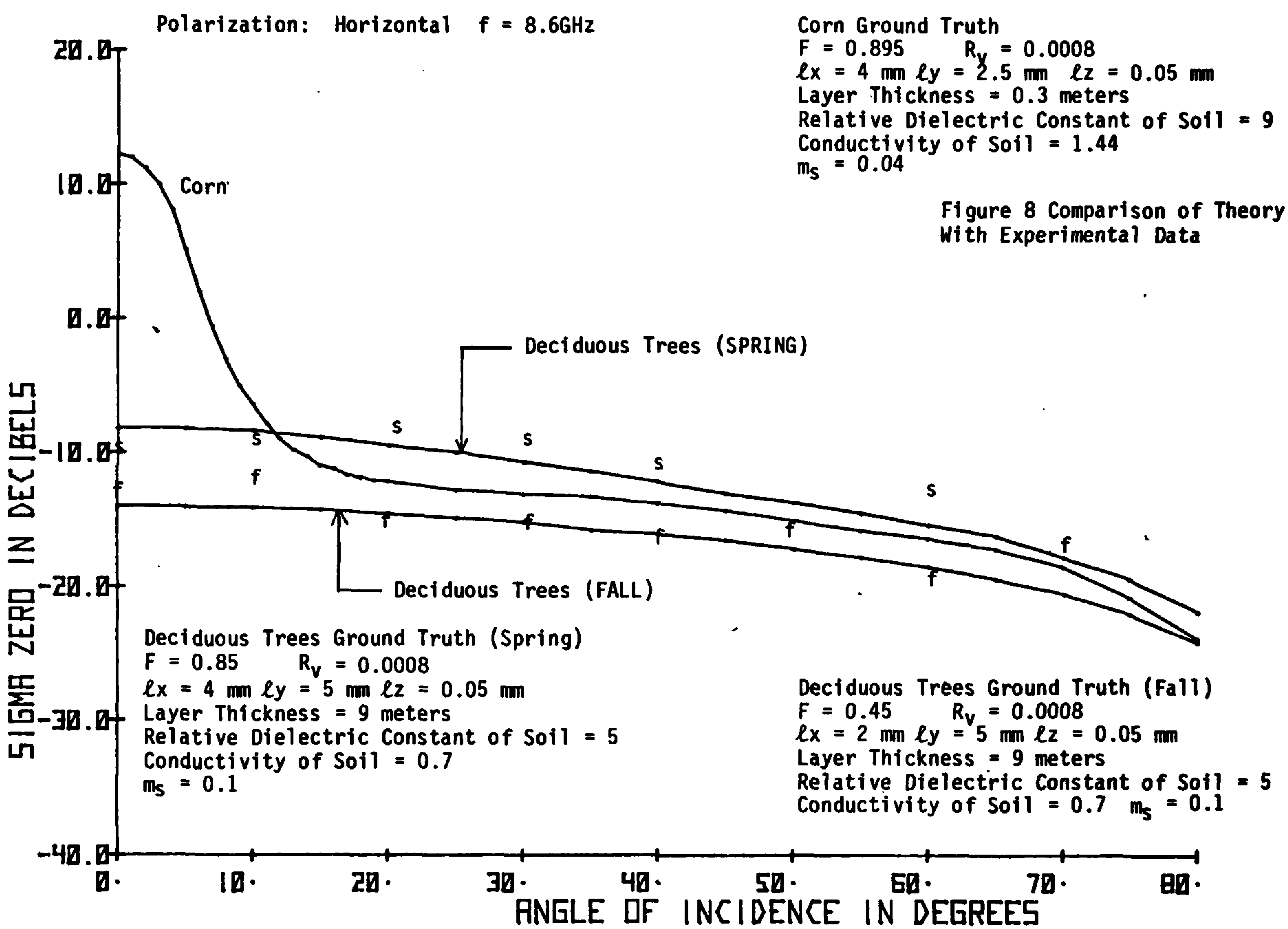

Figure 8 Comparison of Theory
With Experimental Data

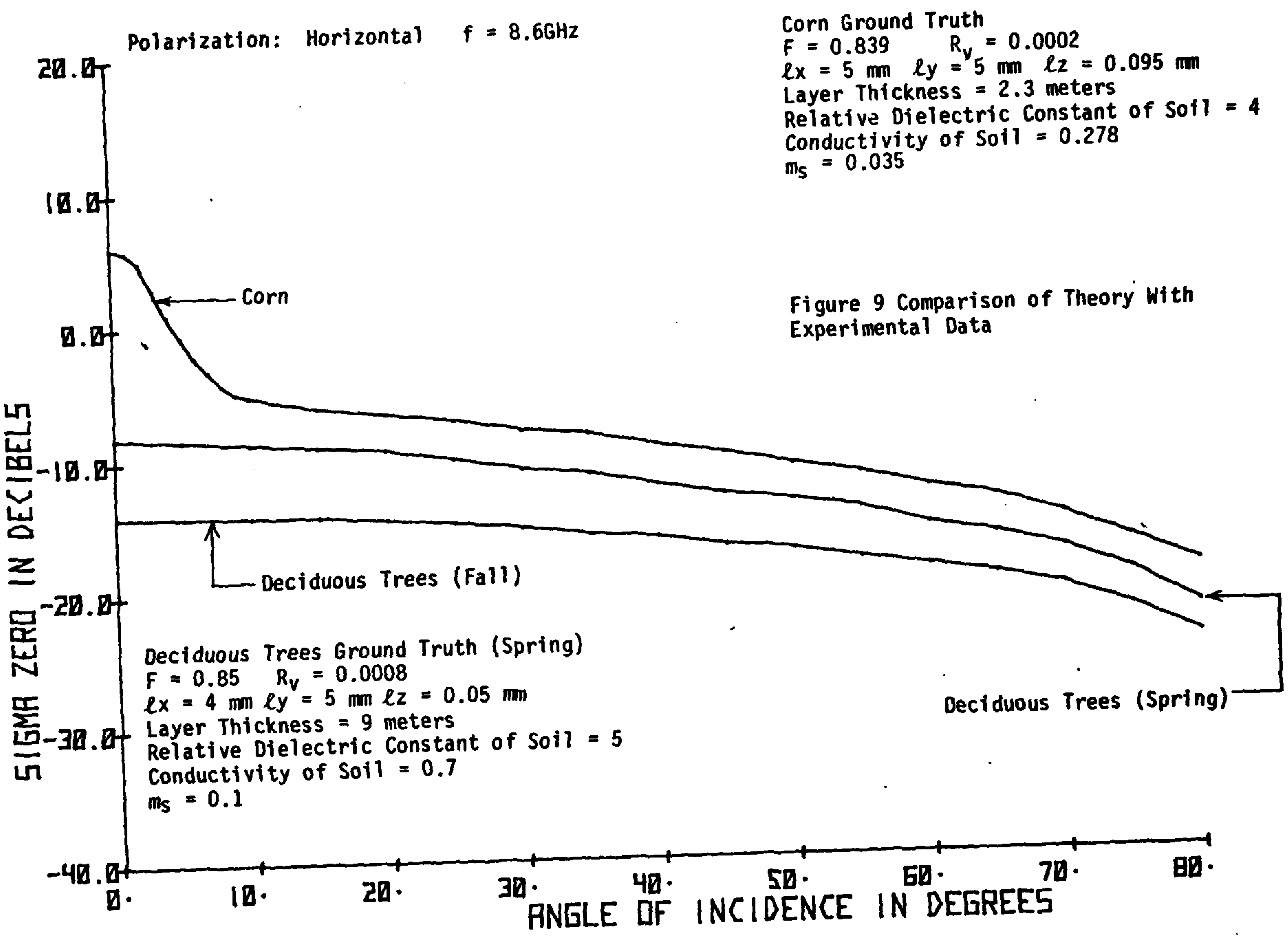

Figure 9 Comparison of Theory With Experimental Data

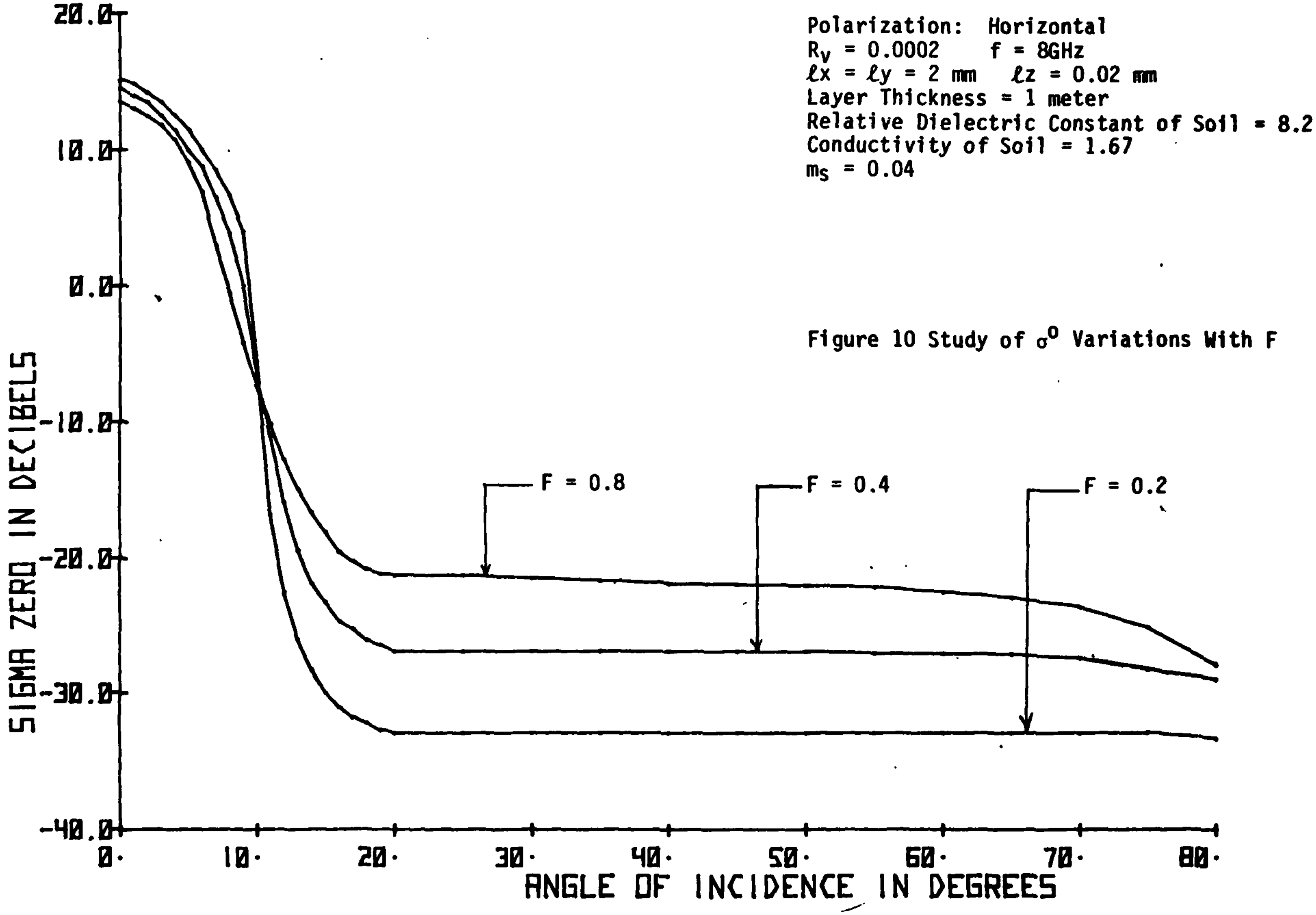

Figure 10 Study of σ^0 Variations With F

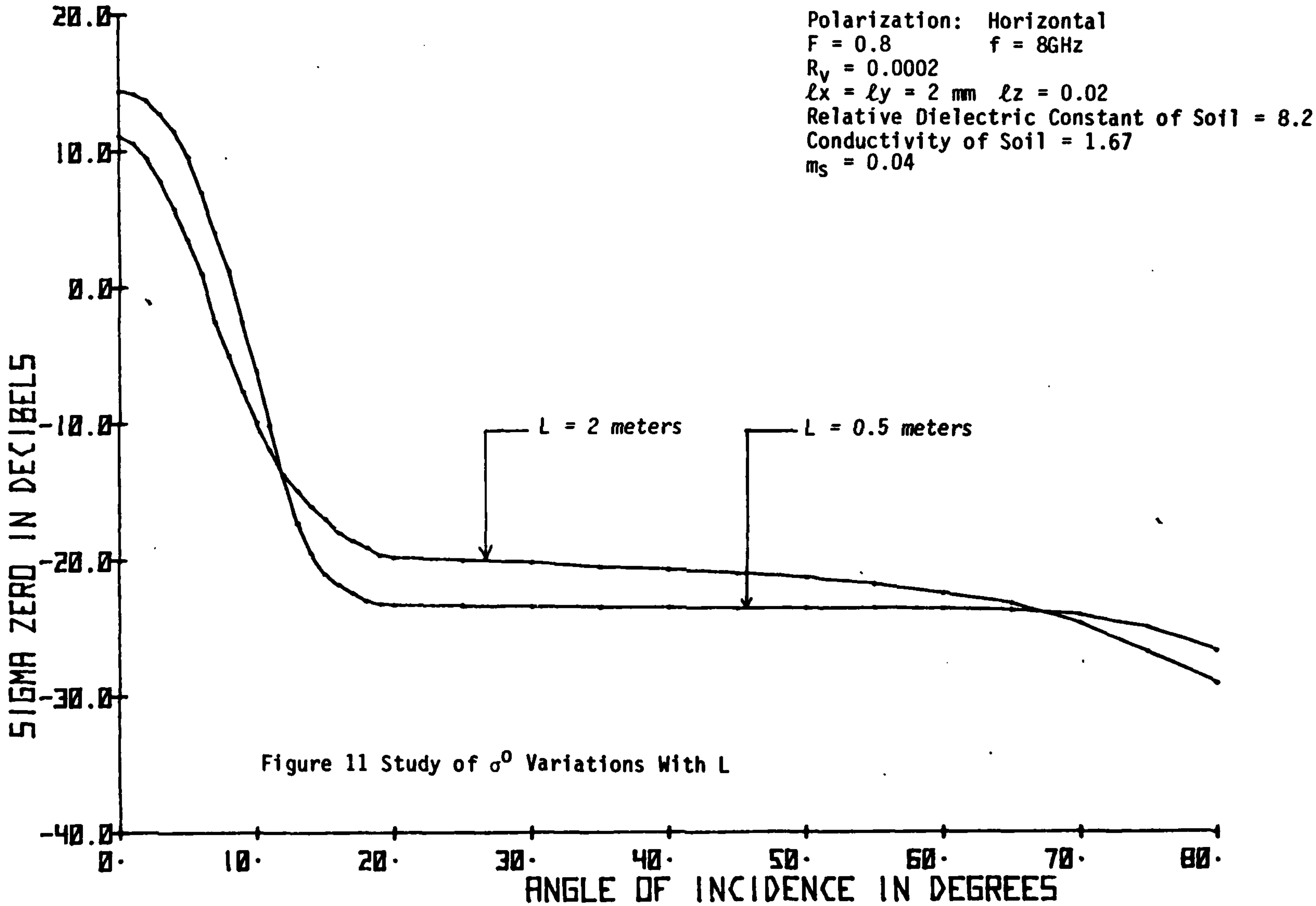

Figure 11 Study of σ^0 Variations With L

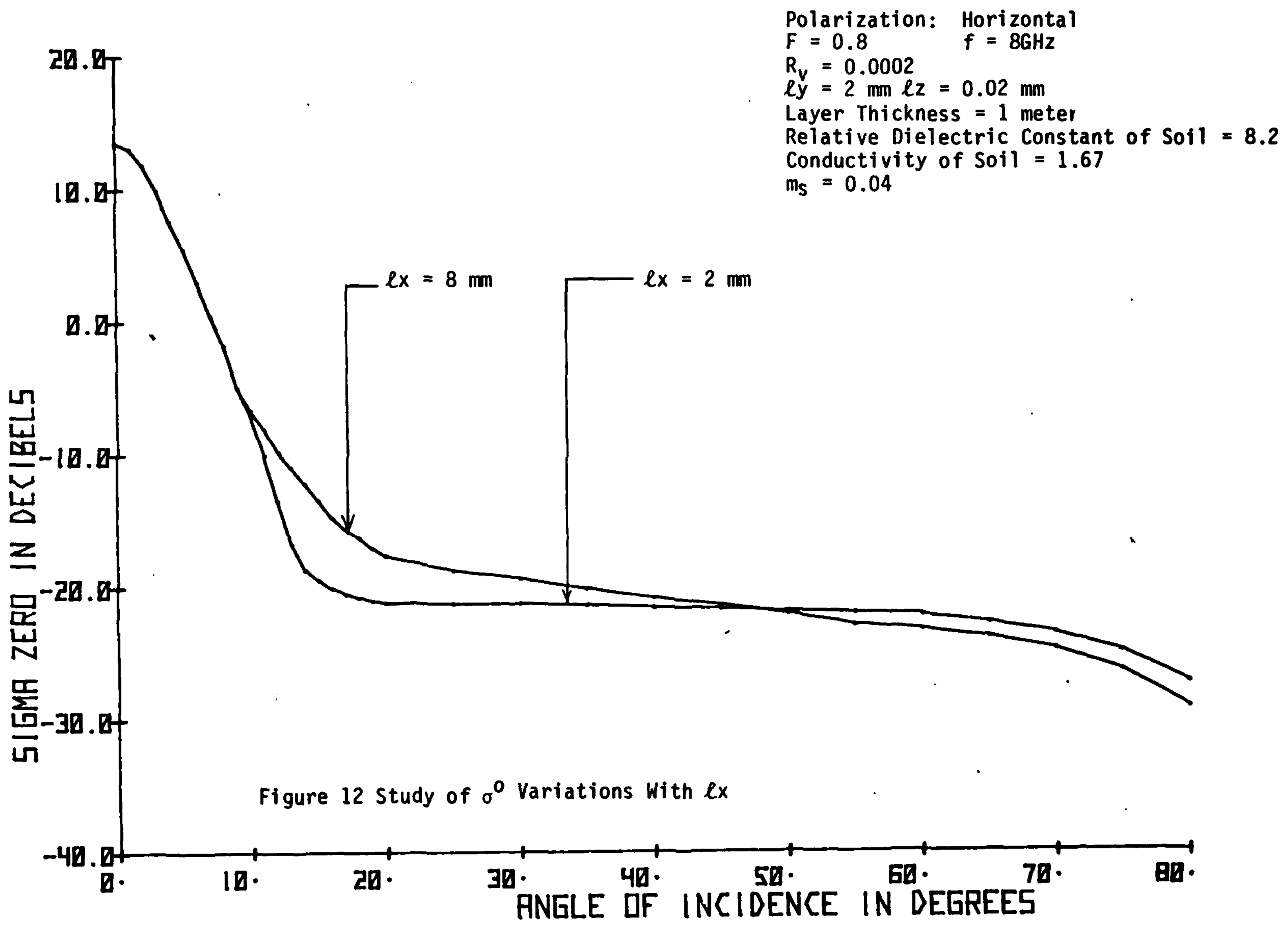

Figure 12 Study of σ^0 Variations With ℓx

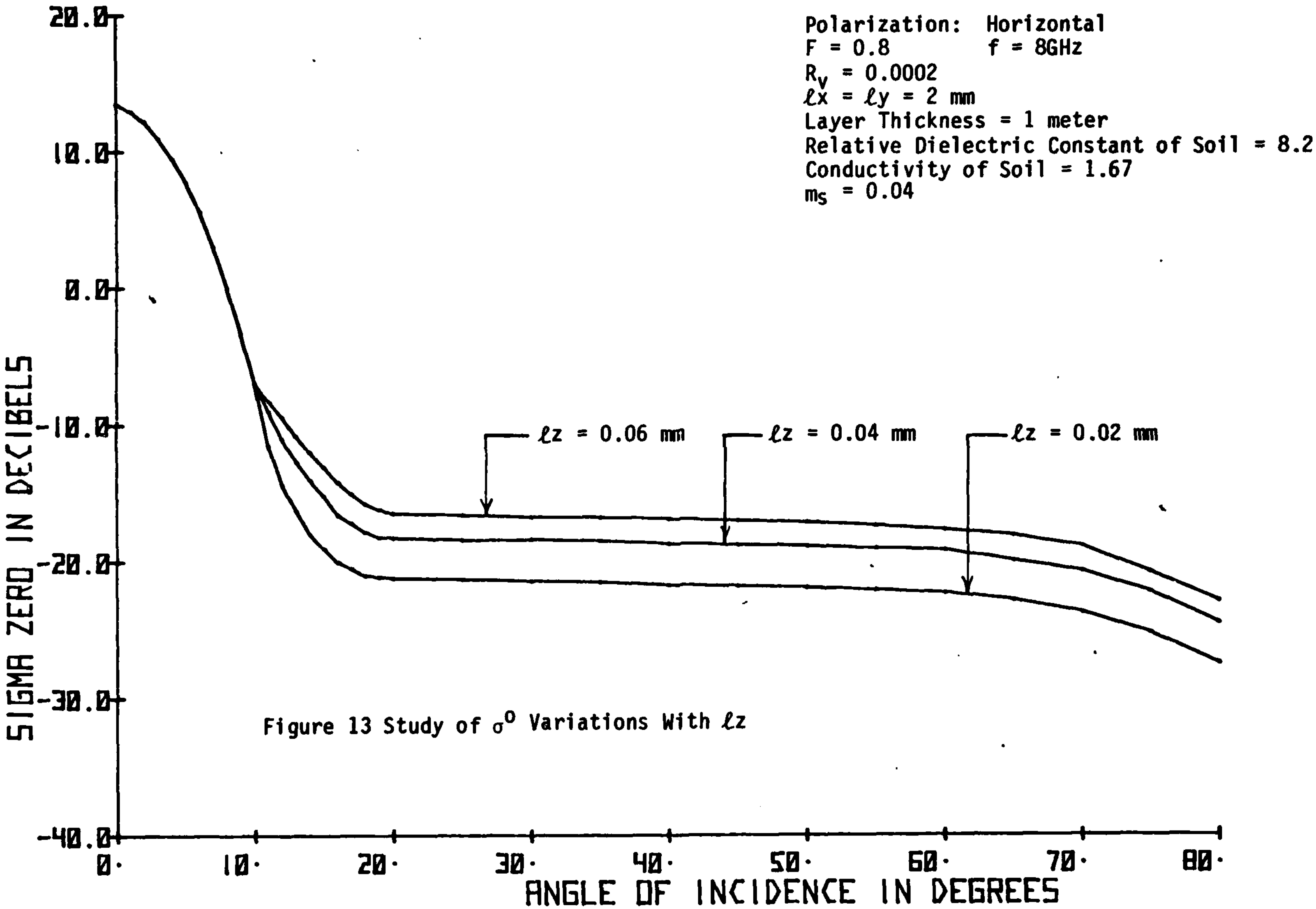

Figure 13 Study of σ^0 Variations With ℓz

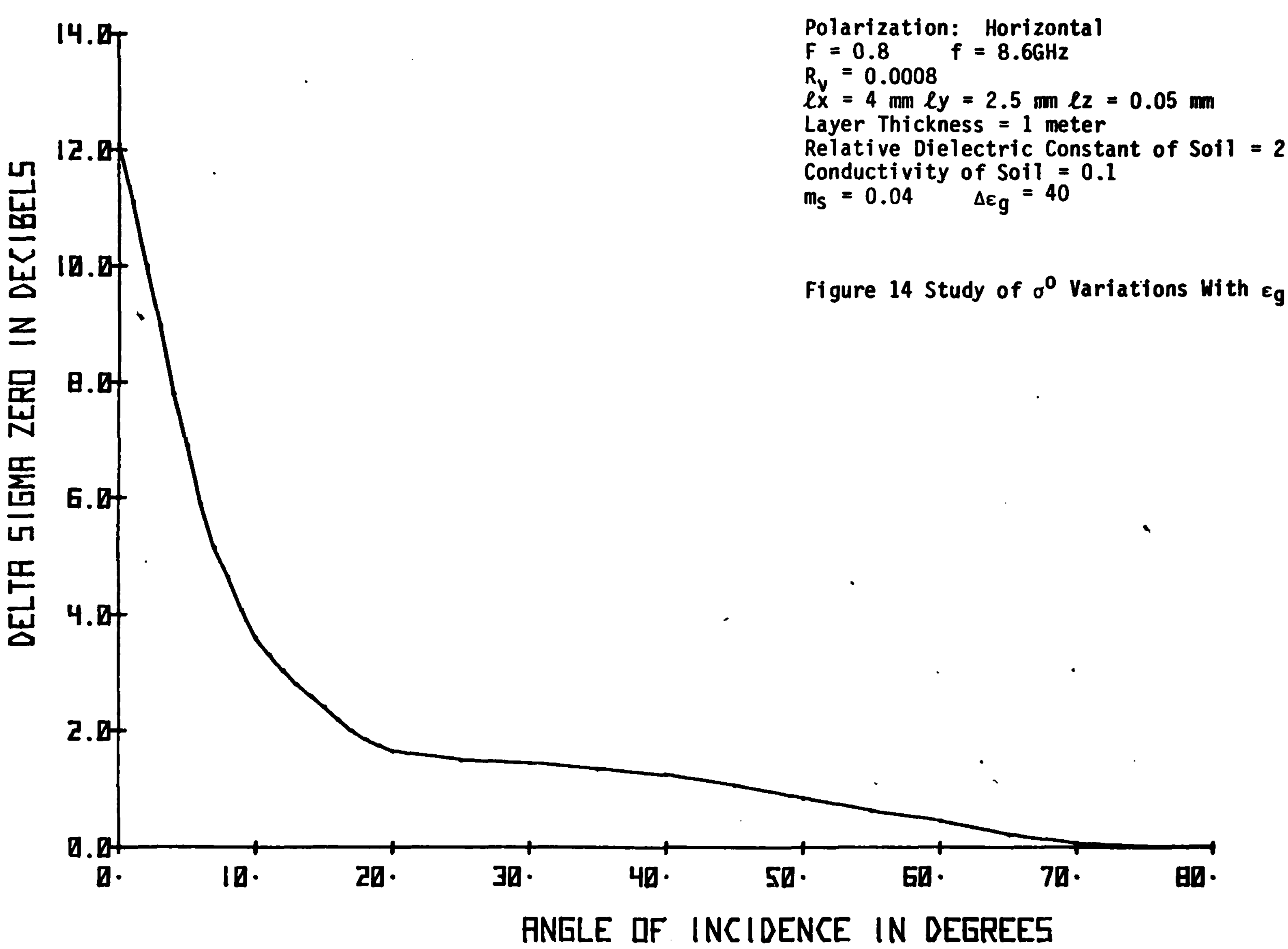

Figure 14 Study of σ^0 Variations With ε_g

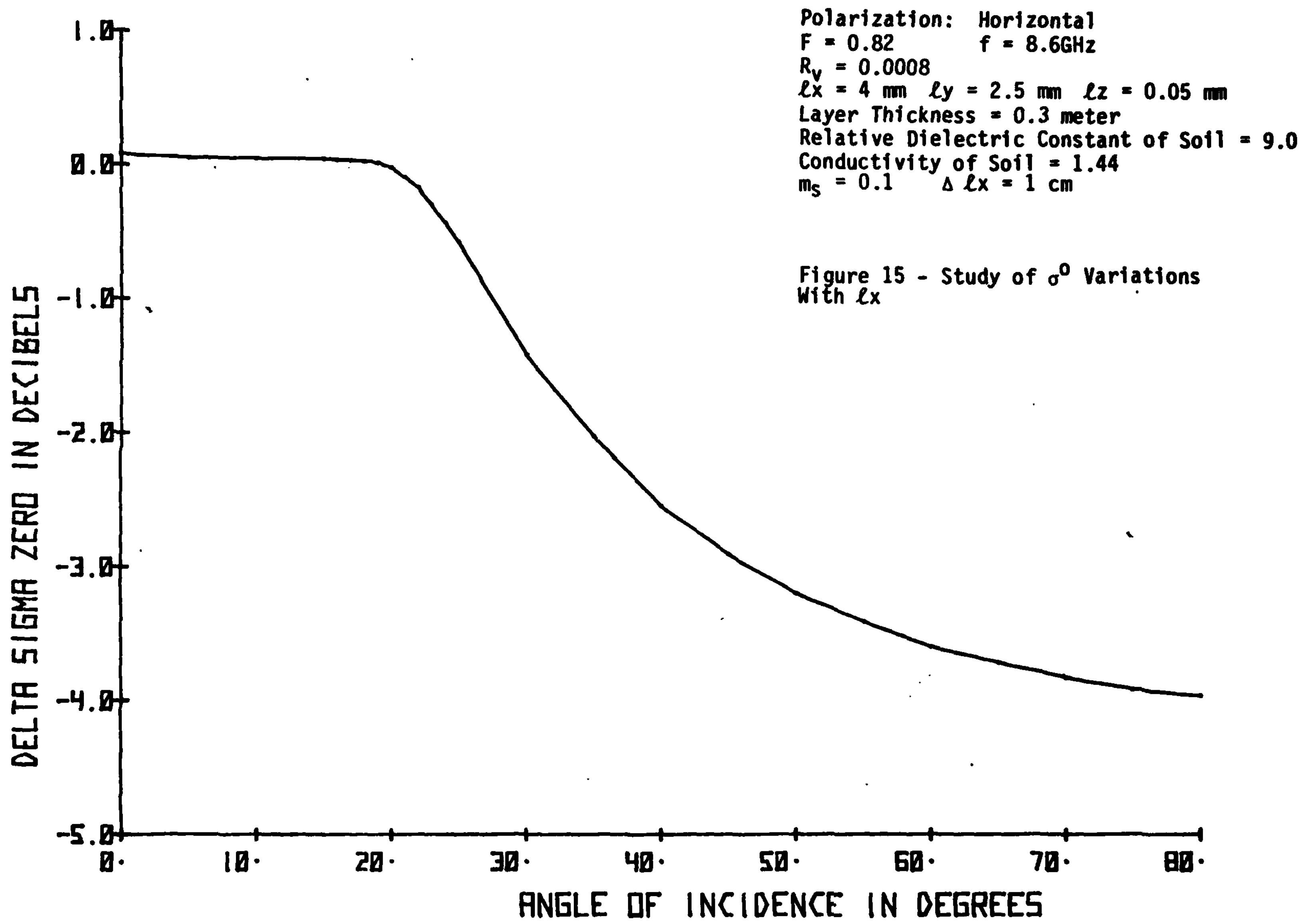

Figure 15 - Study of σ^0 Variations With ℓx