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TIME DOMAIN SCATTERING AND RADAR CROSS SECTION CALCULATIONS FOR A THIN, COATED PERFECTLY CONDUCTING PLATE

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Abstract

Radar Cross Section (RCS) calculations for flat, perfectly conducting plates are readily available through the use of conventional frequency domain techniques such as the Method of Moments (MOM). However, if the plate is covered with a dielectric material that is relatively thick in comparison with the wavelength in the material, these frequency domain techniques become increasingly difficult to apply. In this paper, we present the application of the Finite Difference Time Domain (FDTD) technique to the problem of electromagnetic scattering and RCS calculations from a thin, perfectly conducting plate that is coated with a thick layer of lossless dielectric material. Both time domain and RCS calculations will be presented and discussed.

I. Introduction

The Finite Difference Time Domain (FDTD) technique has become increasingly popular in recent years for modeling electromagnetic scattering problems. It is based upon the time domain form of Maxwell's equations, in which temporal and spatial derivatives are approximated by finite differences, and the electric and magnetic fields are interleaved spatially and temporally. Transient scattering behavior is easily examined and through the use of non-sinusoidal plane wave excitation, wideband frequency results can be obtained. The technique was first proposed by Yee [1] in 1966 and is inherently volumetric, which makes it ideal for modeling volumetric scatterers. Thin scatterers can easily be accommodated, and recently the technique has been expanded to include dispersive materials [2], plasmas [3], and chiral materials [4]. Through the use of a near to far zone transformation [5], far zone scattered fields (and thus RCS data) are readily available. This paper presents time domain scattering and RCS calculations over 0-3 GHz for several incidence angles from a thin, perfectly conducting (PEC) plate that is coated with a uniform lossless dielectric layer.

II. Problem Description

The scattering problem was a 3λ by 6λ (at 3 GHz) perfectly conducting plate that was coated with a 5 cm thick lossless dielectric layer with relative dielectric constant of $\epsilon_r = 4.0$. Figure 1 shows the problem geometry with the dielectric layer on top of the plate. The wavelength (at 3 GHz) inside the dielectric layer is $\lambda_0/\sqrt{\epsilon_r} = 5.0$ cm, where λ_0 is the free space wavelength at 3 GHz. Thus, the dielectric coating is relatively thick at 1λ. The spatial increment (cell size) was chosen to be 1 cm, which provides a spatial resolution of 5 cells/λ inside the dielectric coating and 10 cells/λ_0 in free space.

The problem space size was chosen to be 61 by 121 by 49 cells in the x, y and z directions respectively. The plate was centered within the problem space in the x and y directions. The plate was positioned low in the problem space in the z direction to allow any specular reflections multiple encounters with the outer radiation boundary condition (ORBC).

The plate was constructed with 30 by 60 by 5 cells in the x, y and z directions for the dielectric coating, and with 30 by 60 by 0 cells for the PEC plate. The dielectric coating was constructed first, and the PEC plate was constructed on the bottom of the dielectric layer to avoid any air gaps within the scatterer. A 15 cell and 30 cell border on each side of the scatterer in the x and y directions provided adequate margin for the near to far zone transformation integration surface and for the ORBC.

A θ-polarized, Gaussian pulse incident plane wave with a maximum amplitude of 1000 V/m and a total temporal width of 128 time steps was chosen. The time step was 0.0192 ns and the total number of time steps was 2048.

III. Computations and Discussion

Calculations were made at incidence angles $\theta = 0.0$, $\theta = 60.0$, $\theta = 85.0$ and $\theta = 90.0$ degrees for both an uncoated and coated plate. The incidence angle was taken from the +z axis, the ϕ incidence angle was $\phi = 0.0$ degrees for all computations, and the far field computations were for backscatter only. The θ-polarized scattered and incident fields were then transformed to the frequency domain via an FFT and RCS was determined. Each computational problem required slightly more than one hour of CPU time on a Cray Y-MP supercomputer.

Figure 2 shows the θ-polarized time domain far zone scattered electric field for incidence angle $\theta = 0.0$ degrees. Note for the coated plate the early reflection from the top edge of the dielectric layer. Also note the time domain response for the coated plate is not markedly different from the uncoated plate except for some additional "ringing" due to energy being confined within the dielectric coating. Figure 3 shows the RCS computations versus frequency again for both the uncoated and coated plate, and the RCS for both cases does not differ substantially.

Figure 4 shows the θ-polarized time domain far zone scattered field for incidence angle $\theta = 60.0$ degrees. Note the time responses differ more substantially for this case as more energy is being confined within surface wave modes of the dielectric layer. Figure 5 shows the corresponding RCS. Note the small peaks that have appeared in the RCS for the coated plate. We postulate these peaks correspond to surface wave modes that have been excited and radiate energy to the far field. As an approximation, we computed cutoff frequencies for waveguide modes for an infinite, dielectric covered ground plane according to Balanis [6]. These waveguide modes and corresponding cutoff frequencies are tabulated in Table 1. Examining the RCS of the coated plate, it is easily seen that a peak in the RCS is in close proximity to each cutoff frequency from Table 1. The peaks in the RCS are not located exactly at the cutoff frequencies of Table 1, probably due to the finite size of the plate.

Mode	Cutoff Frequency (GHz)
TM_0	0.00000
TE_1	0.86589
TM_2	1.73718
TE_3	2.59767

Table 1. Modes and cutoff frequencies for an infinite ground plane covered with a 5 cm thick dielectric layer of $\epsilon_r = 4.0$.

Figure 6 shows the θ-polarized time domain far zone scattered field for incidence angle $\theta = 85.0$ degrees. Also shown in Figure 6 is the far zone scattered field for a 5 cm thick 3λ by 6λ dielectric layer. Since this incidence angle is near grazing, we expect to see little scattered field for the uncoated plate. Examining the time responses in Figure 6, the uncoated plate response is indeed quite small in comparison to the dominant coated plate response. The dielectric layer response has the same general form as the coated plate response but is smaller in magnitude. Figure 7 shows the corresponding RCS. Note the large peaks and lobing structure for the coated plate and dielectric layer RCS. These can be attributed to radiation from surface wave modes of the dielectric cavity.

Figure 8 shows the θ-polarized time domain far zone scattered field for incidence angle $\theta = 90.0$ degrees. The response for the zero-thickness uncoated plate is zero, while the coated plate time response does not differ substantially from that for incidence angle $\theta = 85.0$ degrees. Figure 9 shows the RCS for the coated plate only, and it is also similar to the coated plate RCS for incidence angle $\theta = 85.0$ degrees.

IV. Conclusions

In this paper, the FDTD technique has been applied to model electromagnetic scattering from a perfectly conducting plate coated with a uniform, lossless dielectric layer. Time domain scattering results and frequency domain Radar Cross Section computations were presented and discussed. Large peaks in the RCS were found for the coated plate at large incidence angles (near grazing) due to energy being radiated from surface wave modes of the dielectric layer.

The next step would be to provide a rigorous analytical treatment of the problem of a dielectric layer on a finite sized plate (ground plane) and to derive the surface wave structure of the layer and the far field scattering pattern. To the best of the authors' knowledge, no such treatment has yet been presented. Results obtained from a rigorous theoretical treatment would then be used for comparison with the FDTD scattering computations and measured data.

V. Acknowledgement

The authors would like to thank the NASA Ames Research Center for providing the necessary supercomputer resources, and Dr. Randy Jost for suggesting the problem.

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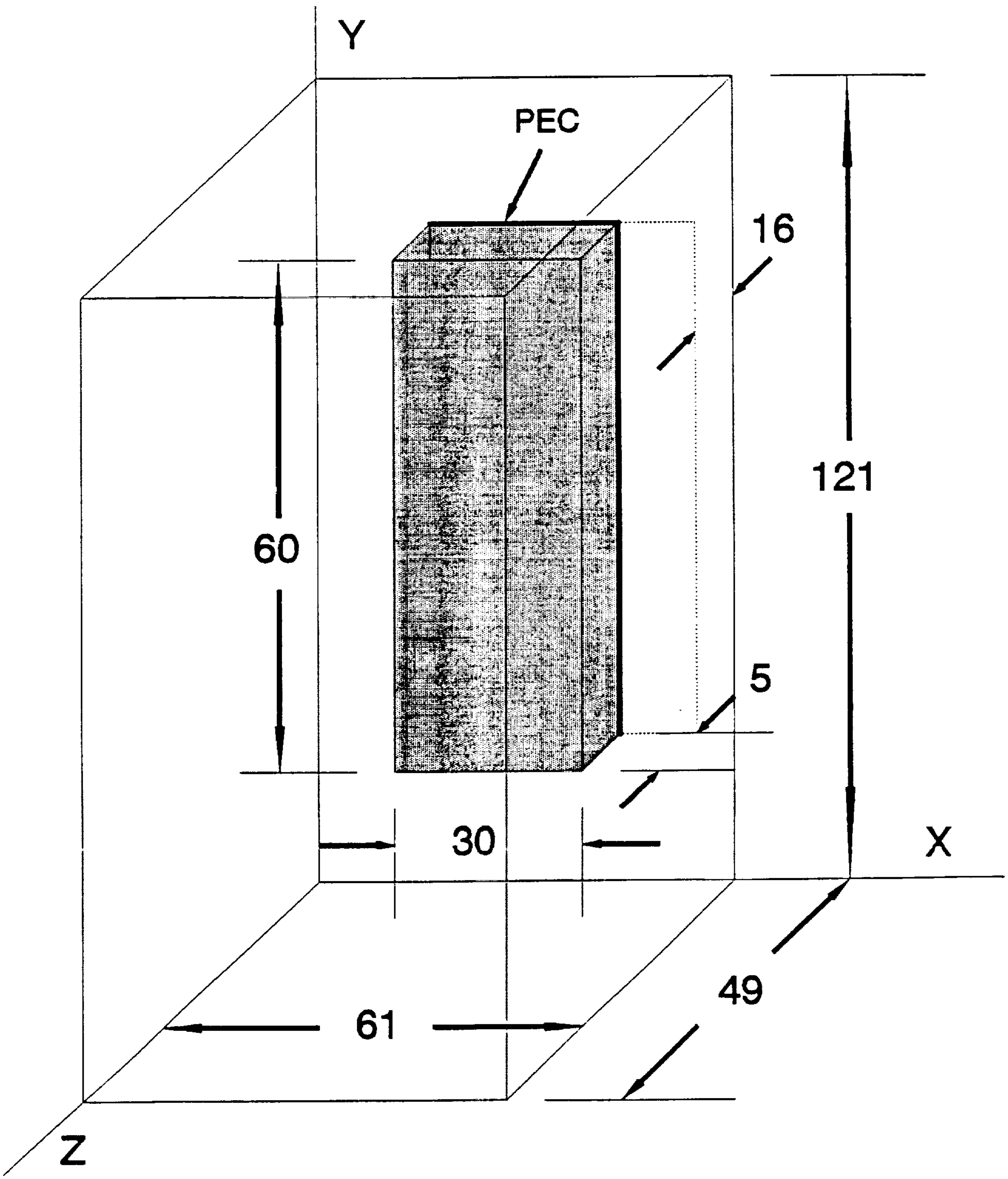

Figure 1. Problem geometry showing problem space size, plate size and plate pcsition.

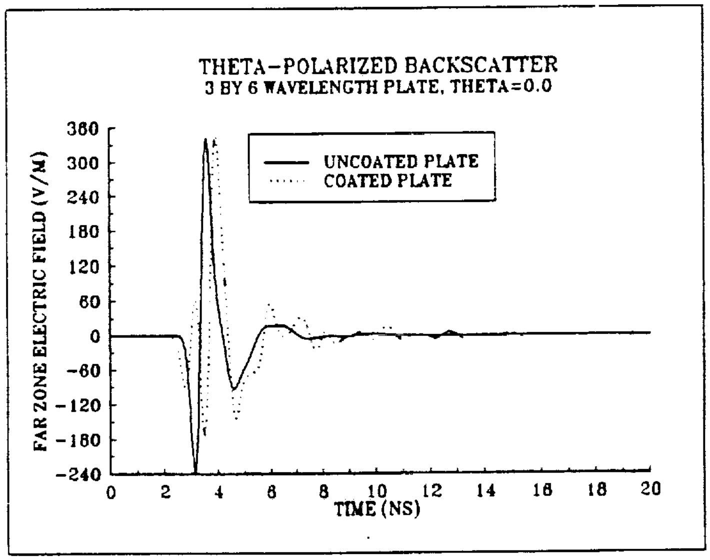

Figure 2. Monostatic, far zone, θ-polarized scattered field for uncoated and coated 3λ by 6λ plate at scattering angle θ =0.0 degrees.

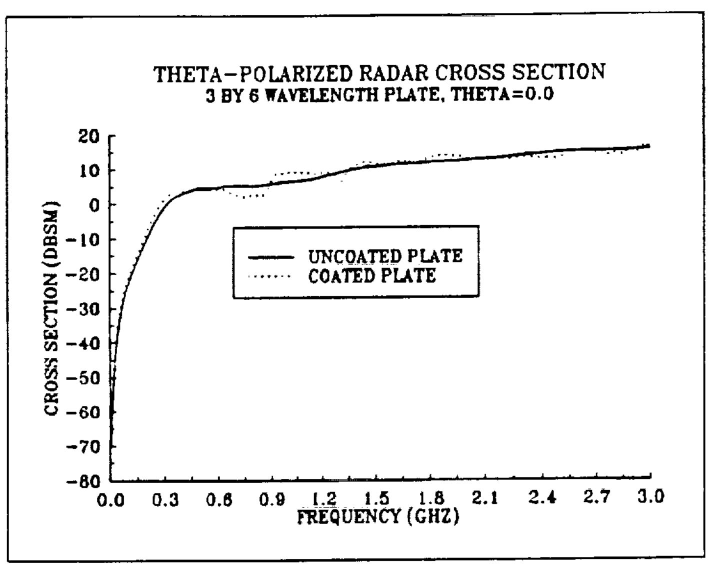

Figure 3. Monstatic Radar Cross Section versus frequency for an uncoated and coated 3λ by 6λ plate at scattering angle θ =0.0 degrees.

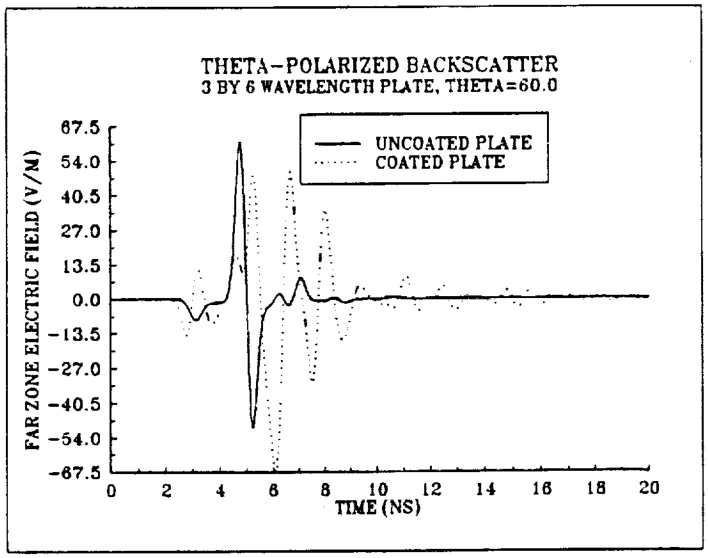

Figure 4. Monostatic, far zone, θ-polarized scattered field for uncoated and coated 3λ by 6λ plate at scattering angle θ =60.0 degrees.

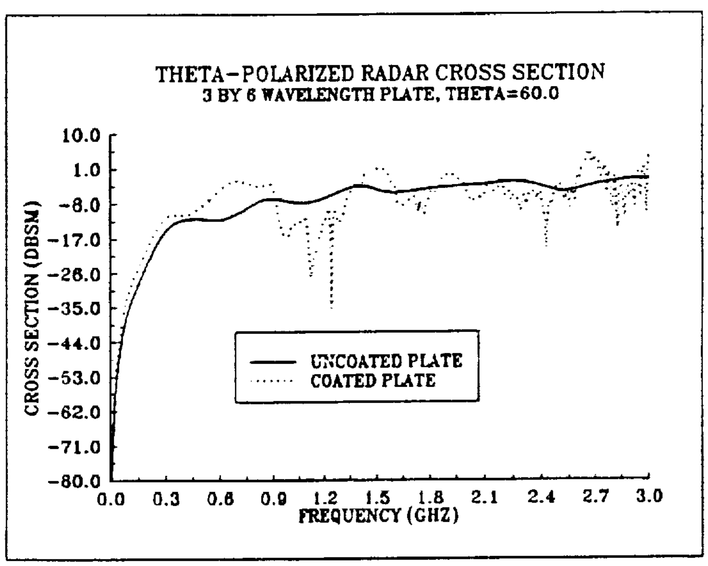

Figure 5. Monostatic Radar Cross Section versus frequency for an uncoated and coated 3λ by 6λ plate at scattering angle θ =60.0 degrees.

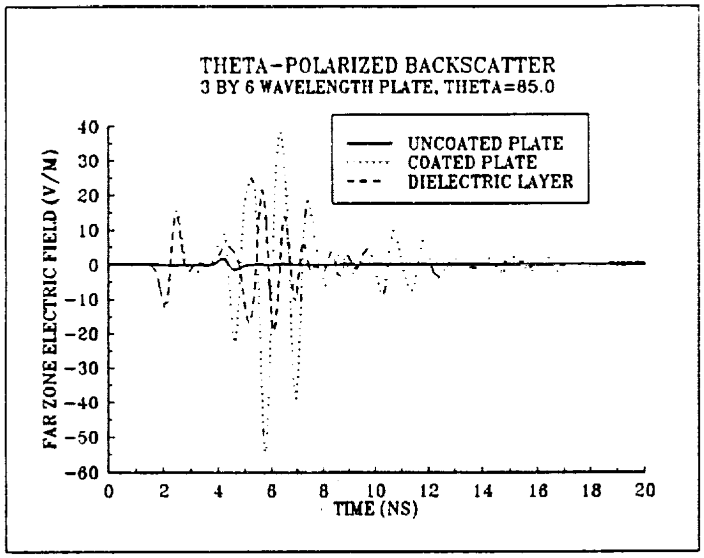

Figure 6. Monostatic, far zone, θ-polarized scattered field for uncoated and coated 3λ by 6λ plate and for 5 cm thick 3λ by 6λ dielectric layer at scattering angle θ =85.0 degrees.

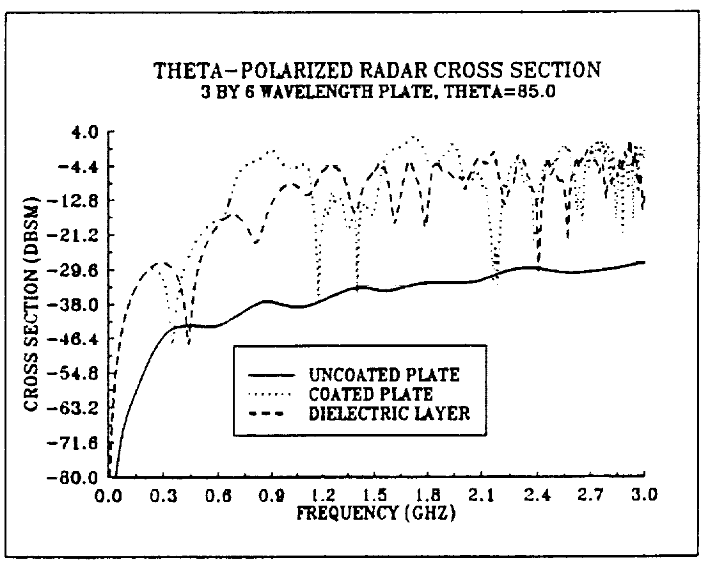

Figure 7. Monostatic Radar Cross Section versus frequency for an uncoated and coated 3λ by 6λ plate and for a 5 cm thick 3λ by 6λ dielectric layer at scattering angle θ =85.0 degrees.

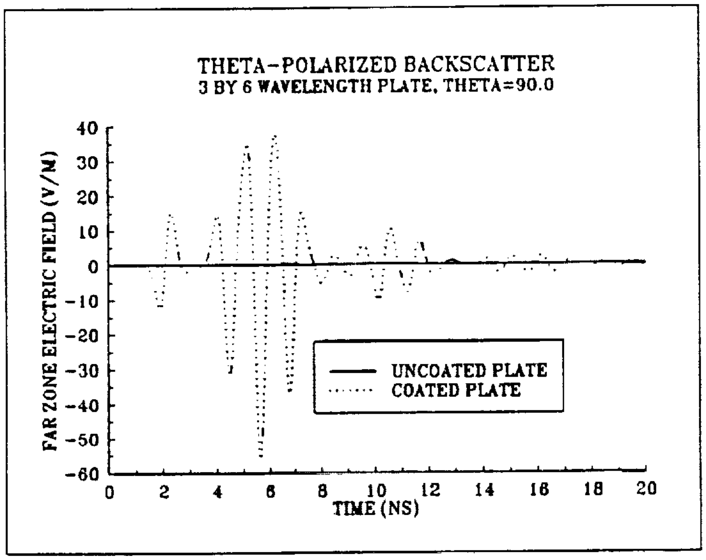

Figure 8. Monostatic, far zone, θ-polarized scattered field for uncoated and coated 3λ by 6λ plate at scattering angle θ =90.0 degrees.

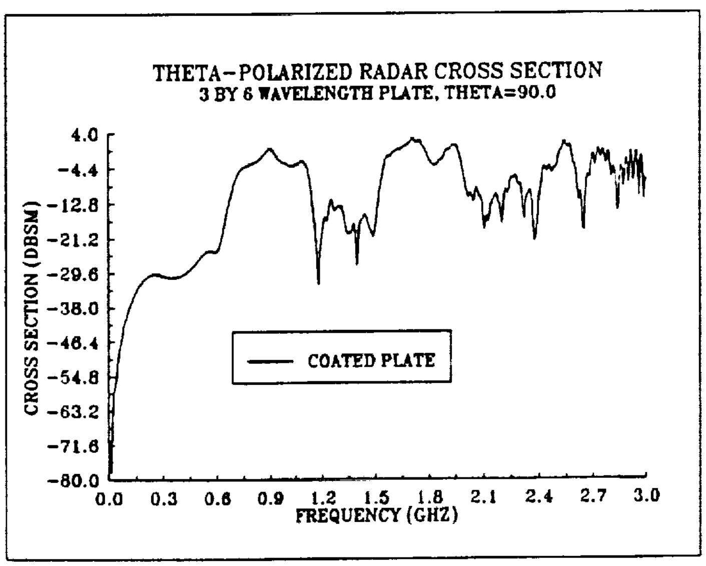

Figure 9. Monostatic Radar Cross Section versus frequency for a coated 3λ by 6λ plate at scattering angle θ =90.0 degrees.