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**TITLE**

CALCULATION AND MEASUREMENT OF HPM FIELDS SCATTERED BY A TARGET WITH OPENINGS

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# CALCULATION AND MEASUREMENT OF HPM FIELDS SCATTERED BY A TARGET WITH OPENINGS

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## ABSTRACT
This paper concerns the computation and measurement of HPM fields inside and outside a structure with openings. RCS computations and measurements are made for a number of targets. The computations use both frequency-domain and time-domain methods, and the results are then compared with those measured in an anechoic chamber. An attempt is made to correlate various quantities such as the RCS, the scattered fields inside a structure, and the time-domain scattered far-fields. It is shown that some of the scattered far-field quantities may be used to identify the target scattering centres, the frequencies at which maximum coupling occurs, and the cut-off frequencies of a target.

## INTRODUCTION
Structures such as airplanes, helicopters, and missiles represent an important class of targets for HPM coupling analysis and measurements, since they have apertures and slots through which the HPM fields may enter the structure. Scattered fields near such objects (inside and outside) are affected by the size and location of the openings. Scattered far-fields (e.g. RCS) are also affected by the nature of the openings. Thus the measurement and calculation of the fields near a target and the RCS in the frequency and time domains may provide information on the scattering and coupling properties of a target.

Ling, Lee and Chou have used a shooting and bouncing ray approach to look at the RCS of open waveguides [1] and other complicated objects [2]. Pathak and Burkholder [3] have analyzed the electromagnetic scattering of open-ended waveguides using a combination of asymptotic and modal techniques. These approaches are generally valid when the structure dimensions are large compared to the wavelegth.

In this paper, the fields inside a structure and the RCS are calculated using a moment method solution of the electric field integral equation (EFIE) in the frequency domain. The correlation between the internal fields and the RCS is studied. Time-domain RCS is then obtained by multiplying the frequency-domain RCS with the spectrum of an appropriate pulse and taking an inverse Fourier transform. This time-domain response reveals information on the location of the scattering centres of the target. The time-domain response and the frequency-domain response are then used to obtain time-frequency distributions (TFDs), which in turn reveal new information on the target, such as the identification of the target cut-off frequencies.

## FREQUENCY-DOMAIN RESPONSE
Figure 1 shows some of the objects used in the study. A plane electromagnetic wave illuminates the structures. Reference [4] describes a simple and efficient numerical procedure for scattering in frequency domain by arbitrarily shaped bodies, using the moment method to solve the electric field integral equation (EFIE). The object surface is modelled using planar triangular patches (for example, Figure 2). Because of the EFIE formulation the procedure is applicable to both open and closed surfaces. This procedure has been applied to a wide variety of electromagnetic interaction problems and has yielded excellent agreement between this, other numerical methods, and exact analytic formulations. In JUNCTION [5], the EFIE approach is extended to analyze an arbitrary configuration of conducting wires and bodies. The algorithm developed can handle wire-to-wire, surface-to-surface, and wire-to-surface junctions. Both near-field and far-field quantities such as the RCS can be computed. A modified version of JUNCTION is used here as the "EFIE method".

Figure 3 shows the computed electric field in and around a cylinder with openings for plane wave incidence at 9.0 GHz. It shows the reflected and the transmitted fields along the axis of the cylinder. Figure 4 shows both the computed and measured RCS of the cylinder from 2 to 18 GHz. Figure 5 shows a plot of the peak field magnitude inside the cylinder at different frequencies, compared with the RCS. It shows a correspondence between the peak field magnitude and the RCS:

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whenever the RCS is high, the field inside the structure is low. In simple objects like the one used in this example, and for this angle of incidence, this correspondence may be explained by using simple laws of reflection and transmission of EM waves. The correspondence may be used for predicting coupling to an object from far field quantities.

## TIME-DOMAIN RESPONSE

Time-domain behaviour of the fields or the time-domain RCS can be obtained by multiplying the frequency-domain response with the spectrum of an appropriate incident pulse and taking an inverse Fourier transform. Figure 6 shows the time-domain impulse response RCS for a cylinder open at one end. It shows the location of the scattering centres of the target. The first peak corresponds to the leading edge (or the open end) of the target and the second peak corresponds to the trailing edge (or the closed end) of the target. The magnitude of the peaks is related to the magnitude of the reflection from the leading and the trailing ends.

## TIME-FREQUENCY DISTRIBUTIONS

The time-domain and the frequency-domain responses give important information on the electromagnetic scattering properties of a target. Use of time-frequency distributions (TFDs) [6] gives further information on a target which neither the time- nor the frequency-domain response is able to provide alone. TFDs are obtained by computing a short-time Fourier transform of the time-domain response $f(t)$ or the frequency-domain response $F(\Omega)$ as follows:

$$S(\tau,\Omega) = \int f(t)g(t-\tau)e^{-j\Omega t}dt$$

$$S(\tau,\Omega) = \frac{e^{-j\Omega\tau}}{2\pi}\int F(\omega)G(\Omega-\omega)e^{j\tau\omega}d\omega$$

where $g(t)$ and $G(\Omega)$ are the window function in time and frequency domain, respectively.

Figure 7 shows a TFD obtained by computing a short-time Fourier transform from the time-domain impulse response. Frequency-domain and time-domain responses are also shown along the two axes. From the TFD, one can easily identify the leading and the trailing edges of the structure. In addition one can also identify the cut-off frequencies of the cylindrical cavity at 3.5 and 10.2 GHz. This information is not available from the time- or frequency-domain response alone and can be used to further characterize a structure using far-field quantities.

## CONCLUSIONS

In this paper frequency- and time-domain responses of a structure have been computed using the moment method and inverse Fourier transformation. Both near field and far field quantities were computed. In the cases considered, there is a correspondence between the fields inside a structure and the RCS. Time-domain RCS was computed and has been shown to provide information on the location of the scattering centres of the target. Time-frequency distributions were also computed and it has been shown that the TFDs provide more information (such as the cut-off frequencies) on a target than that provided by the frequency- and the time-domain responses alone. Thus study of far field quantities (for example, RCS) in the frequency domain, in the time domain, and as TFDs can all reveal important target information, such as the frequencies at which the maximum coupling occurs and the cut-off frequencies.

## REFERENCES


1. Ling, H., Lee, S. W., and Chou, R. C., "High Frequency RCS of Open Cavities with Rectangular and Circular Cross-sections", *IEEE Trans. Antennas Propagat.*, AP-37, 1989, pp. 648-654.

2. Lee, S. W. et al, "XPATCH: A High Frequency Electromagnetic Prediction Code and Environment for Complex Three-Dimensional Objects", *IEEE Antennas and Propagation Magazine*, Vol. 36, No. 1, Feb. 1994, pp. 65-69.

3. Pathak, P. H. and Burkholder, R. J. "Modal, Ray and Beam Techniques for Analyzing the EM Scattering by Open-Ended Waveguide Cavities", *IEEE Trans. Antennas Propagat.*, AP-37, 1989, pp. 637-647.

4. S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic Scattering by Surfaces of Arbitrary Shape", *IEEE Trans. Antennas Propagat.*, AP-30, 1982, pp. 409-418.

5. S.-U. Hwu and D. R. Wilton, "Electromagnetic Scattering and Radiation by Arbitrary Configurations of Conducting Bodies and Wires", *University of Houston, Technical Report* 87-17, 1988.

6. Moghadder, A. and Walton, E. K., "Time-Frequency Distribution Analysis of Scattering from Waveguide Cavities", *IEEE Trans. Antennas Propagat.*, AP-41, 1993, pp. 677-680.

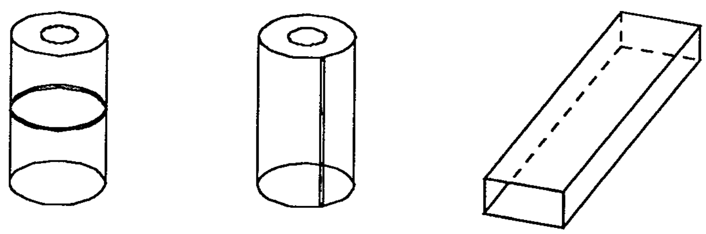

Figure 1. Some of the objects used in this study.

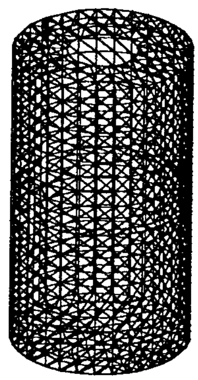

Figure 2. Example of a triangular surface-patch model for EFIE.

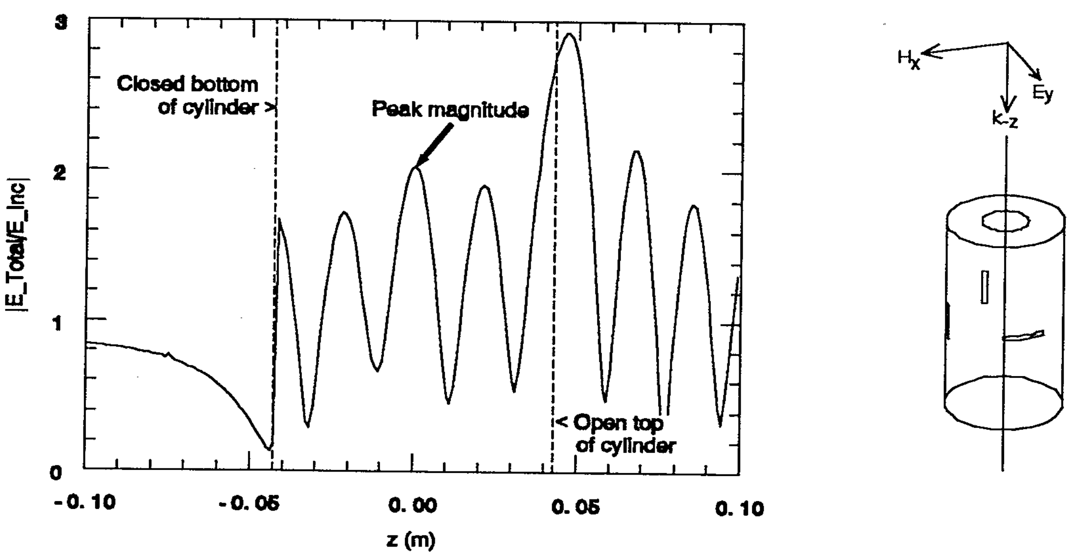


Figure 3. Total electric field along an axis of a cylinder with openings, for plane wave incidence.

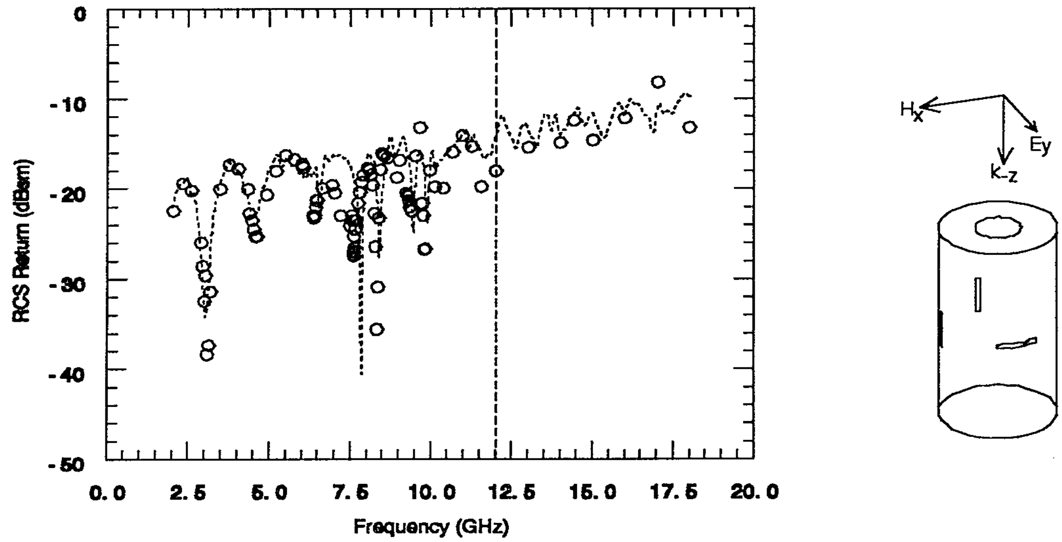


Figure 4. RCS of the cylinder with a hole and three slots.
Dashed curve = Measurement. Circles = EFIE.
Vertical dashed line = λ/5 simulation limit.

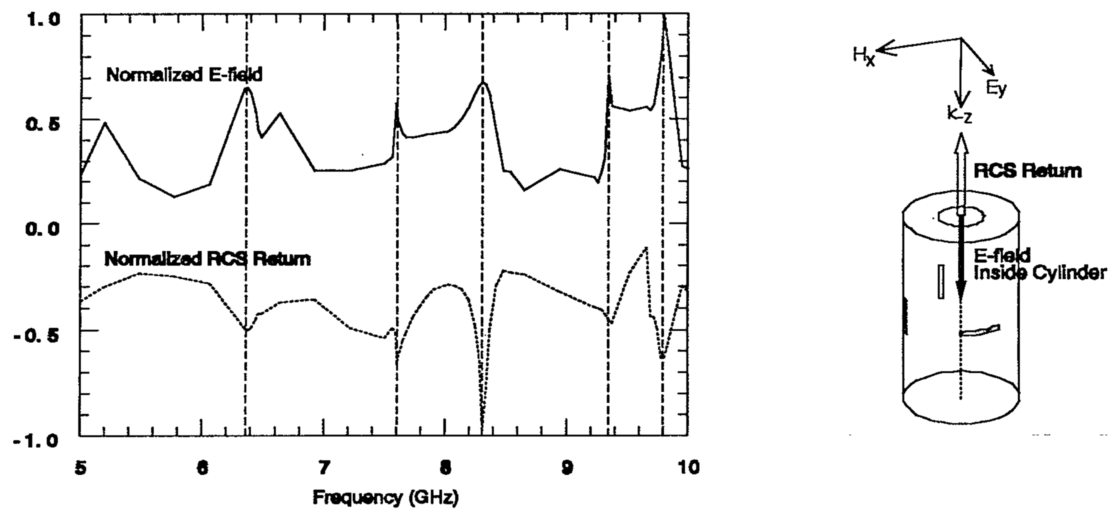


Figure 5. RCS return versus peak magnitude of the E-field inside the cylinder.

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|---|---|
| Dotted curve = | RCS return normalized to peak value -1.0. |
| Solid curve = | Peak magnitude of the total electric field inside the cylinder, normalized to maximum value +1.0. |
| Vertical dashed lines = | Minimum RCS return and maximum E-field frequencies. |

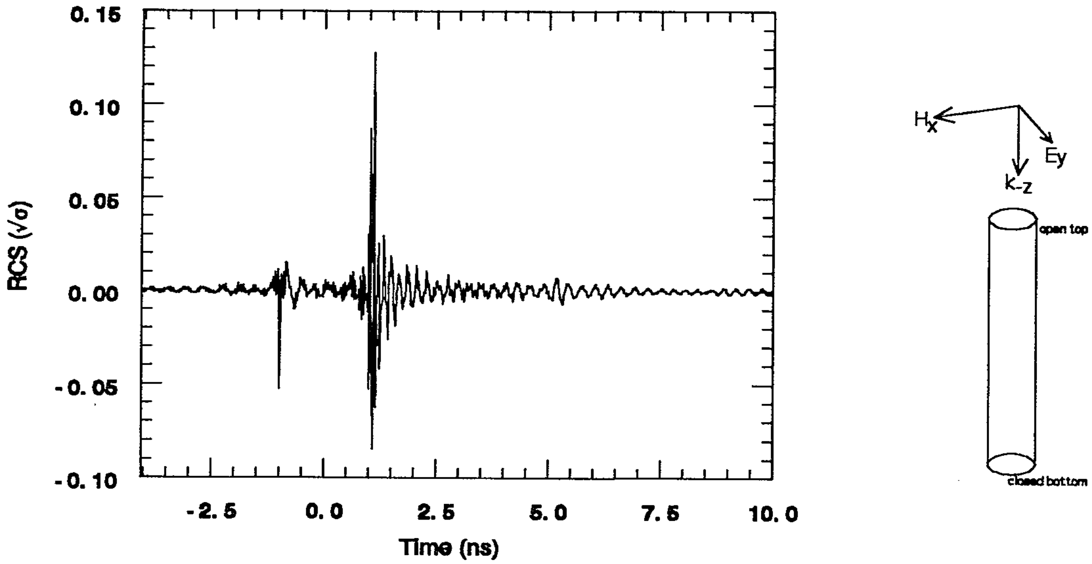


Figure 6. Time-domain RCS (i.e. back-scattered far-field) of a cylinder with one open end.

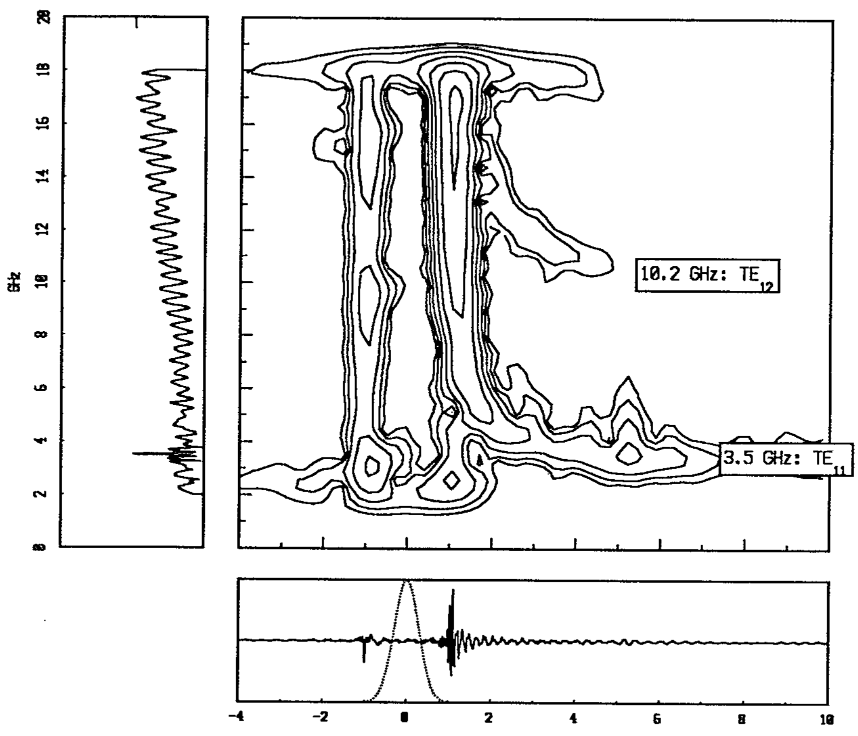


Figure 7. TFD of the cylinder with one open end. Frequency domain and time domain responses are shown along the vertical and horizontal axis, respectively. The dotted curve represents the window function in the time domain.

## DISCUSSION

P.D. SMITH
How does noise affect the determination of cutoff frequencies (of the hollow tube or box) in the time frequency calculation ? How much noise can be added before these disappear ? Does it work for real data as well as numerically calculated data ?

AUTHOR'S REPLY
The method works for calculated and measured results. The data for TFD's was obtained from measured results. Noise affects (measurement noise) if it can not be gated out and is in the same time location as that required for the determination of the cut-off frequencies.

P.D. SMITH
How well were the aperture slots represented in your calculations ? Where they one cell thick ? Does this accurately model true aperture size ?

AUTHOR'S REPLY
Along the narrow direction, we use 1 or 2 edges. We use an implementation of END where the tangential boundary condition can be applied on each cell and the object can be infinitesimally thin.

U. LAMMERS
The methodologies you described apply to radar cross-section modeling independent of power. Are you investigating phenomena that apply to high microwave power in particular, such as non-linear effects of imperfect metallic junctions ?

AUTHOR'S REPLY
We have not looked at the non-linear effects of imperfect metallic junctions. Some work at the university of Toronto does look at some non-linear effects.

P. ZWAMBORN
1/ Is the relation power density inside the cylinder versus R.C.S. perhaps a better way to distinguish the relation inside E-field and R.C.S.
2/ How have you solved the causality problems caused by the windowing process before taking the inverse FFT ?
3/ Can you indicate the resolution in determining the cut-off frequency ?

AUTHOR'S REPLY
1/ Thank you for your suggestion. We will also look at the power density VS RCS
2/ There are a number of techniques for taking IFFT of a band-limited signal. We use some of these techniques.
3/ Resolution depends upon a number of factors including window width, length of the structure, noise, type of the window. We are investigating the effect of these factors.