CROSS POLARIZATION DIAGNOSTICS

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Abstract

The cross polarized radar cross section of simple axially symmetric objects is shown to be related to transverse body dimensions and the severity of any edges.

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When a body is illuminated by an electromagnetic wave, the far zone backscattered field usually includes both direct and cross polarized components. Historically, the former has been more widely studied because it is the component typically sensed by monostatic radars and since it contains all specular contributions, it tends to be the larger of the two. In contrast, the cross polarized return is produced by more subtle contributions which elementary theories, such as geometrical and physical optics, cannot predict [1]. Because of this dependence on the finer details of the object, the cross polarized return contains information about the scatterer that is not readily obtainable from the direct return.

By way of illustration, consider a metallic body of revolution. The cross polarized return is zero at all aspect angles if the incident electric vector is in or perpendicular to the plane containing the axis and the line of sight and, in particular, is zero on axis for all polarizations. But if the electric vector is inclined, the cross polarized return rises to a peak at some aspect angle and then decreases in an oscillatory manner. The location of this peak can be used to estimate a transverse dimension of the body, whereas the amplitude of the peak is a measure of its 'edginess'. The latter feature of cross polarized returns is evident in Figure 1.

The data in Figure 1 were obtained from S- and X-band measurements of the backscattering for a variety of axially symmetric targets. The transmitted and received polarizations were inclined ± 45 degrees to the horizontal and the resulting patterns were recorded over an angular range $-30^{\circ} \leq \phi \leq 30^{\circ}$ about the axis. A thin horizontal wire $1.75\ \lambda$ long was used for calibration, this length being chosen because the broadside return is relatively insensitive to the precise dimensions. The peak returns of each pattern closest to, and on either side of, axial incidence were read and averaged to produce a datum point in Figure 1.

Four types of bodies were measured: thin disks, right circular cones, cones with rounded edges, and cone-spheres, where these have been listed in the order of decreasing severity of edge. The peak values of their cross polarized cross sections, σ_{cr}, are normalized with respect to λ^2 and plotted in Figure 1 as a function of $ka = 2\pi a/\lambda$, where a is the maximum radius of the object. For a given ka, the returns decrease with decreasing edginess, with the effect becoming more pronounced as ka increases. Thus disks and sharply edged cones have the strongest returns, cone-spheres the weakest, and cones with rounded edges have intermediate values. The difference between cones and cone-spheres is as much as 30dB for $ka = 20$.

One can predict this behaviour with reasonable accuracy using the geometrical theory of diffraction. Consider, for example, a right circular cone of half angle γ. The formulae given by Senior and Uslenghi [2] are relevant, provided ka is large enough to fix the peak of the cross polarized lobe within the backward cone (i.e., $\phi \leq \gamma$). Inserting these into the expression for σ_{cr} given by Knott, et al [3], and retaining only those terms corresponding to first order scattering from the edge, we have

$$\frac{\sigma_{cr}}{\lambda^2} = \frac{1}{\pi}\left\{ Aka\ J_2\,(\xi)\right\}^2 , \tag{1}$$

where $A = \frac{1}{n}\cot\frac{\pi}{2n}$, $n = \frac{3}{2} + \frac{\gamma}{\pi}$, $\xi = 2ka \sin\phi$, and $J_2(\xi)$ is the Bessel function of second order. Equation (1) reduces to the known expression for the disk when $n = 2$, $(\gamma = \frac{\pi}{2})$, but is relatively insensitive to cone angle, varying less than 2.3dB over the full range from a cone of vanishing angle to a disk. The Bessel function attains a maximum value of 0.486 (for $\xi = 3.05$) and the peak cross section is obtained when this value is used in Eq. (1). The results for disks and narrow cones are plotted as solid lines in Figure 1 and the agreement with experiment is of the order of 1dB.

A similar calculation can be carried out for a cone-sphere using the rigorous expressions for the diffraction coefficients associated with the join [4]. On the assumption that the join is the only source of depolarization, and if $ka >> 1$,

$$\frac{\sigma_{cr}}{\lambda^2} = \frac{1}{4\pi}\left\{\frac{\cos^2\gamma\cos\phi}{\cos 2\gamma + \cos 2\phi}\right\}^2\left\{J_2^2\,(\xi) + \tan^2\gamma\tan^2\phi\,J_1^2\,(\xi)\right\} , \tag{2}$$

where now $\xi = 2ka\cos\gamma\sin\phi$. The second term in (2) can be neglected for narrow cones and the peak value of the resulting formula is plotted as a dashed line in Figure 1. The agreement with experiment is reasonable in view of the extremely low levels measured, but the systematic discrepancy for small ka suggests that there may be another source of depolarization, such as creeping waves.

Equations (1) and (2) reveal an aspect variation dominated by the Bessel function J_2 and this has been found true of other shapes that have been studied. For example, the cross polarized return of a wire loop is given by Eq. (1) with A set equal to 1/2, and we conjecture that the aspect dependence of any ring discontinuity is given by $J_2(\xi)$. The explicit dependence on ξ suggests that the location of the peak return is a measure of transverse body dimension and that the amplitude gives some information about shape. The successful use of these facts to gauge unknown objects hinges, of course, on the availability of sufficient aspect angle coverage to embrace the first peak of the cross polarized cross section.

References

[1] Knott, E.F. and T.B.A.Senior, "Polarisation Characteristics of Scattered Fields", Electronic Letters, 7, No. 8, 22 April 1971, pp. 183-184.

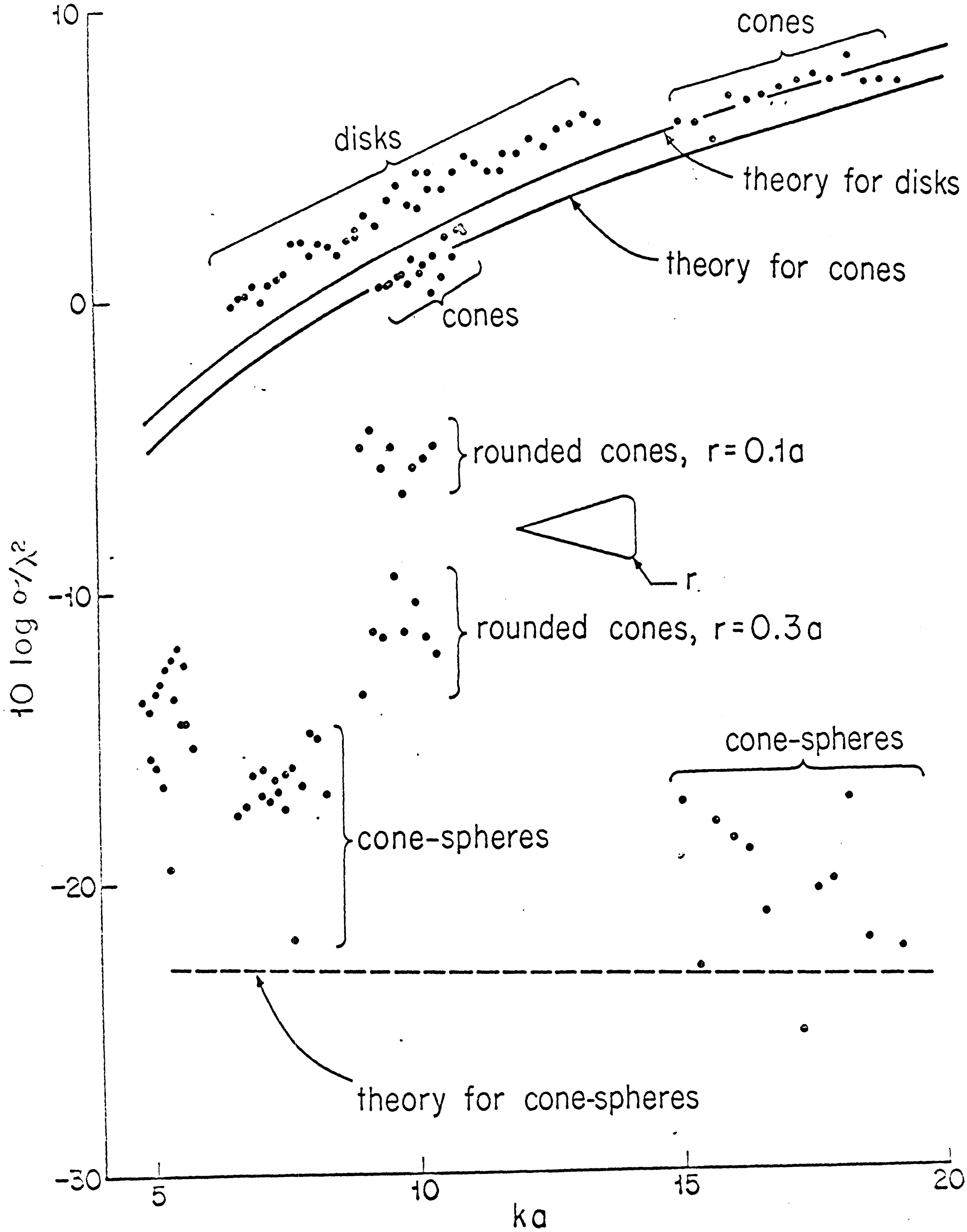
[2] Senior, T.B.A. and P.L.E.Uslenghi, "High-frequency Backscattering from a Finite Cone", Radio Science, 6, No. 3, March 1971, pp. 393-406.

[3] Knott, E.F., T.B.A.Senior and P.L.E.Uslenghi, "High-frequency Back-scattering from a Metallic Disk", IEE (London), to be published 1971.

[4] Senior, T.B.A., "Diffraction Coefficients for a Discontinuity in Curvature," Electronic Letters, 7, No. 10, 20 May 1971, pp. 249-250.

Figure Captions

Figure 1: Cross polarized radar cross sections.



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