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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Comparison of Reflective Properties of Corner Reflector Clusters and Luneburg Lens Reflectors

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OFFICE OF AEROSPACE RESEARCH
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MICROWAVE PHYSICS LABORATORY PROJECT 4600

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Abstract

The reflective properties of rectangular corner reflector clusters and Luneburg lens reflectors are analyzed, and the relative effectiveness and efficiency of these reflectors in producing large radar cross sections over a wide range of aspect angles is compared. The Luneburg lens reflector is found to be very effective and efficient, but is expensive, heavy, and difficult to repair. In contrast, the rectangular corner reflector cluster is inexpensive, repairable, and can be made lightweight, but is not an efficient reflector when used over wide ranges of aspect angles.

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1. INTRODUCTION

Corner reflectors, singly and in clusters, and Luneburg lens reflectors are passive electromagnetic targets that have large scattering cross sections for certain ranges of angles. The purpose of this investigation is to analyze the reflective properties of these two types of targets in order to compare their effectiveness and efficiency as radar reflectors when used over wide ranges of aspect angles. Relative advantages and disadvantages for various applications will be discussed and conclusions drawn.

2. CORNER REFLECTORS

The corner reflectors to be considered are all of the rectangular type, that is, each face is a square (see Figure 1a). From the standpoint of geometric optics, rays that are reflected by all three faces of a corner reflector will after the third reflection be directed parallel to the incident ray but opposite in direction. Rays that are reflected by only one or two of the faces of a corner reflector will in general not be redirected parallel and opposite to the incident ray except when the incident ray is normal to a face or lies in a plane normal to an edge.

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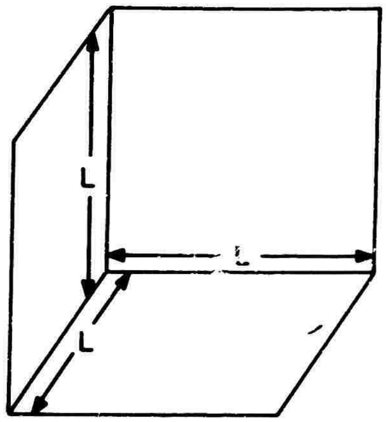

Figure 1a. Single Rectangular Corner Reflector of Edge L

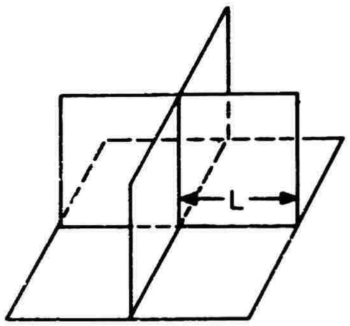

Figure 1b. Four-element Rectangular Corner Reflector Cluster of Edge L

For each direction from which a plane wave can be incident on a reflector there is an associated radar cross section σ (Silver, 1949). The solid angle in space over which σ exceeds a given value is the solid angular coverage for that reflector for that given value of σ. We shall denote this solid angular coverage by just the term coverage.

Although for a corner reflector the peak values of σ due to single or double reflections are larger than the peak values of σ due to triple reflections, the coverage over which single and double reflections constitute the predominant contribution to σ is relatively small. At X band, for instance, for a four-element corner reflector cluster (see Figure 1b) of edge length L = 30 in., the coverage due to single and double reflections is less than 1 1/2 percent of a hemisphere. Since the triple reflections constitute the predominant contribution to σ for all incident wave directions other than those normal to an edge or normal to a face, it is clear that coverage for a corner reflector cluster is determined principally by triple reflections.

Theoretical and experimental curves of the relative radar cross section of a rectangular corner reflector are shown in Figure 2 (O'Neal, 1943). A diagram of the (μ, η) angular coordinate system is also shown in Figure 2. The theoretical curves were calculated for triple reflection only and all curves were normalized to the theoretical peak triple reflection radar cross section $\sigma_o = 12\pi L^4/\lambda^2$. This peak value occurs for an incident wave from a direction making equal angles of $\cos^{-1}(1/\sqrt{3})$ with each of the three interior edges of the corner reflector. We shall refer to a line through the vertex of a corner reflector along the direction of peak σ as the axis of the corner reflector. Note that although the pairs of curves compared in Figure 2 differ by 2^o to 3^o in value of η, they still indicate good agreement between theory and experiment and bear out the predominance of triple reflection.

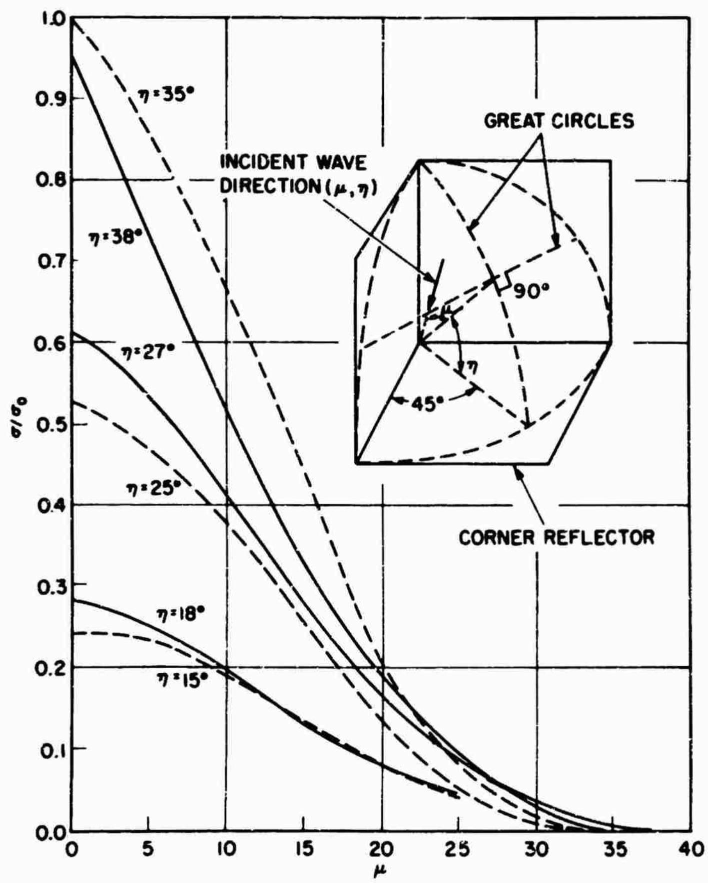

Figure 2. Curves of σ/σ_0 for a Rectangular Corner Reflector for Various Directions of the Incident Wave (theoretical———; experimental— — —)

Direction angle pairs (μ, η) corresponding to constant radar cross section contours 3 db, 6 db, 10 db, 13 db, and 20 db below σ_0 were determined from curves of the type shown in Figure 2. These coordinates were then converted to a spherical coordinate system with polar axis OZ' along the axis of the corner reflector (see Figure 3). The polar angle ϕ and the azimuth angle θ comprise the new direction angle pair (ϕ, θ). A plot of constant σ / σ_0 contours in these angular coordinates is given in Figure 4. From these curves, σ/σ_0 vs the percentage of hemispheric coverage was determined for a four-element rectangular corner reflector cluster (see Figure 5).

Corner reflectors require a certain degree of accuracy and rigidity in construction to attain and maintain their performance. According to Spencer (1944), σ is reduced by 3 db if two of the reflector faces are perfectly aligned and the third face is rotated out of alignment by an angle $\tan^{-1}(0.4\lambda/L)$ about one of the inner edges of the corner reflector. Again, the reduction in σ will be 3 db if all three faces are rotated out of alignment about their inner edges by an angle $\tan^{-1}(0.24\lambda/L)$.

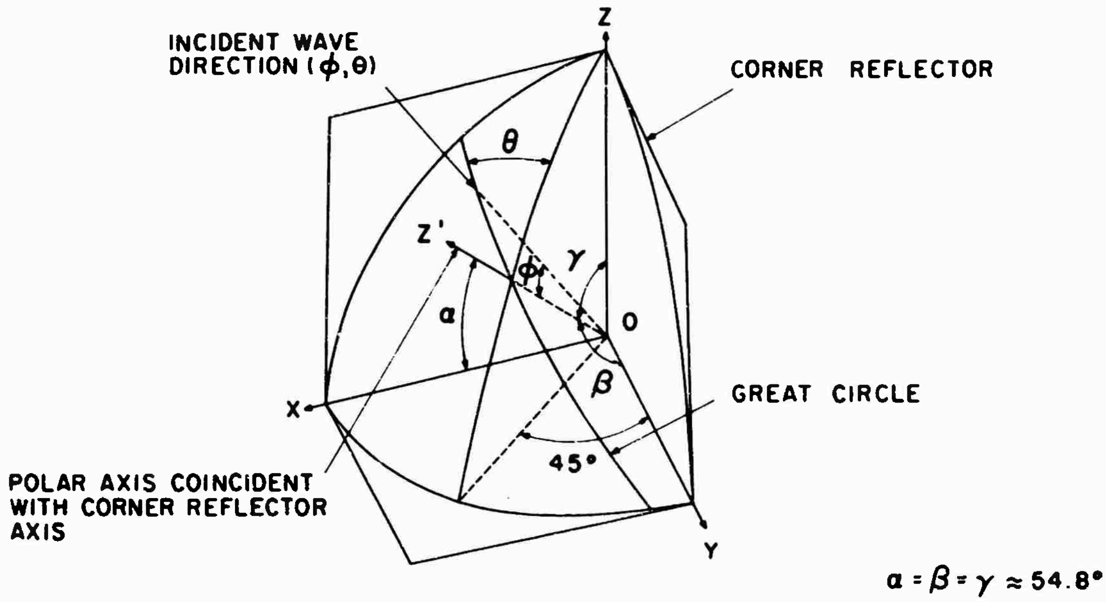

Figure 3. The (ϕ,θ) Coordinate System in a Corner Reflector

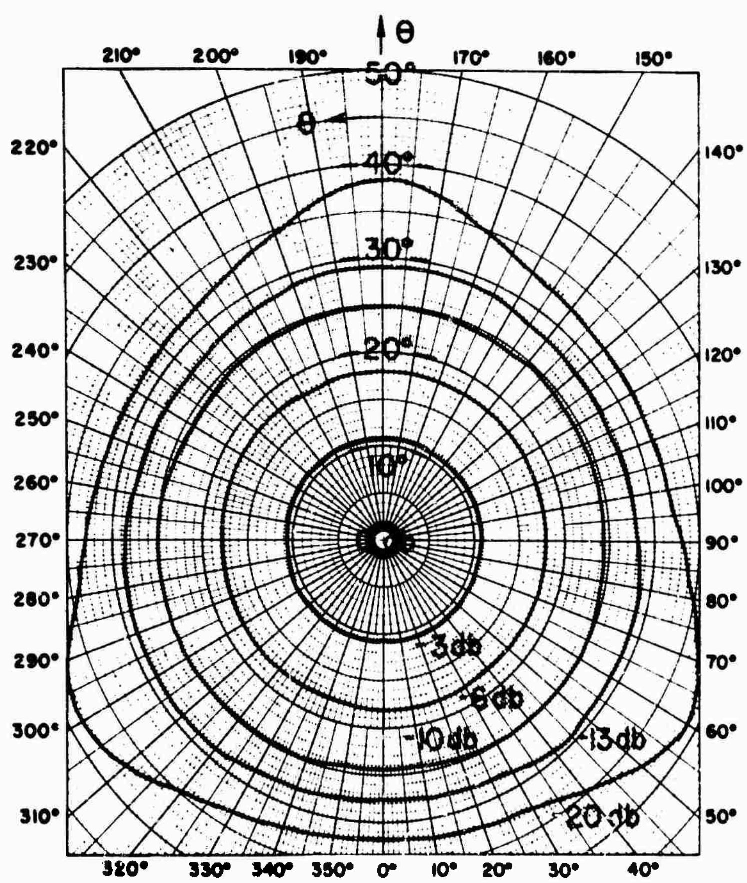

Figure 4. Constant σ/σ_0 Contours for a Rectangular Corner Reflector in (ϕ, θ) Coordinates

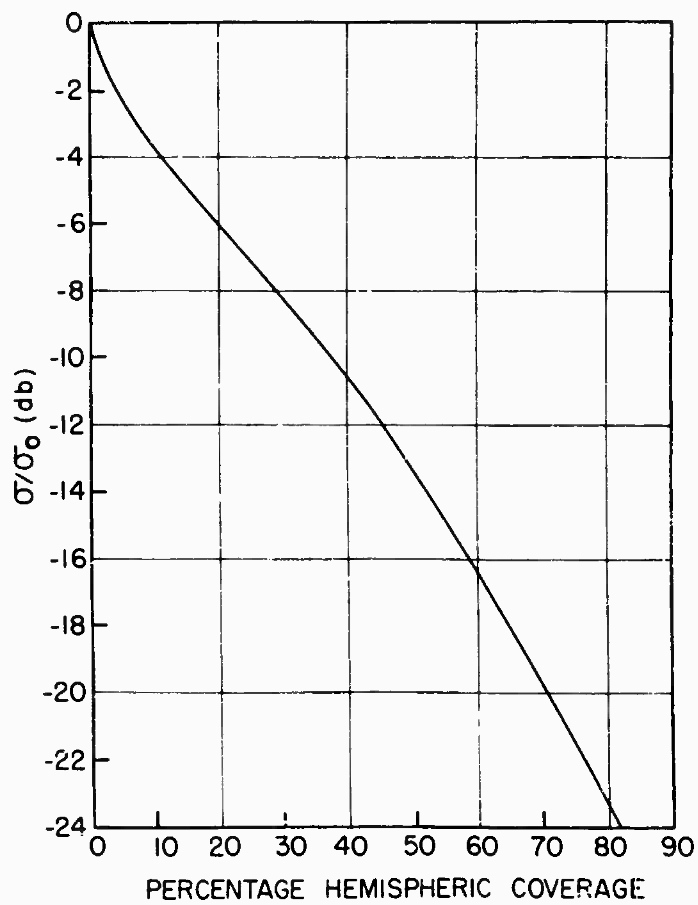

Figure 5. Plot of σ/σ_0 vs Percentage of Hemispheric Coverage for a Four-element Rectangular Corner Reflector

As L/λ increases, these tolerances become tighter and the corner reflector becomes more difficult to build. The design is generally a compromise between minimizing weight and achieving sufficient strength to maintain alignment. In this discussion of construction tolerances it has been assumed that the faces are flat. If they are not flat then additional losses may be present.

3. LUNEBURG REFLECTOR

The Luneburg lens is spherical in shape and focuses an incoming plane wave to a point on its surface diametrically opposite the direction from which the incoming plane wave is incident (see Figure 6a). A Luneburg lens reflector consists of a Luneburg lens with a conducting cap over a portion of its surface (see Figure 6b). An incoming plane wave focused by the lens is reflected by the conducting cap, recollimated by the lens, and transmitted directly back along the path of the incoming wave. Theoretically, if the reflector cap subtends a cone whose full angle

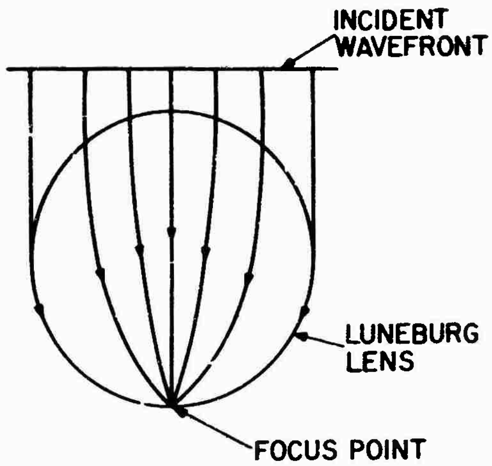

Figure 6a. Luneburg Lens (receiving)

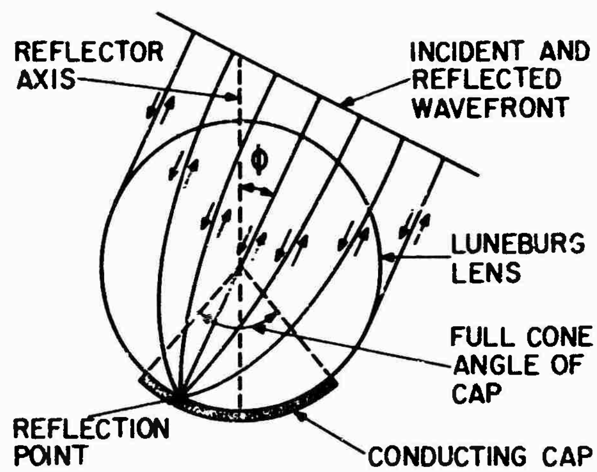

Figure 6b. Luneburg Lens Reflector

is less than or equal to 90° the Luneburg reflector acts like a conducting circular flat plane whose radius a equals that of the lens, the plate being oriented normal to the incoming wave for all waves incident from directions diametrically opposite the cone of directions subtended by the cap; if the cap subtends a cone whose full angle is greater than 90° then for certain directions of the incoming wave the receiving and transmitting apertures will be partially blocked. Experimentally, however, it has been found (Emerson and Cumming, Inc., 1961) that although there will be aperture-blockage for some directions, a Luneburg lens that has a cap subtending a cone of full angle 140° gives very efficient coverage over a cone of full angle of about 130°.

Figure 7a is an experimental plot (Emerson and Cumming, Inc., 1961) showing the X-band coverage of a Luneburg reflector that has a 6-in. radius and a 140° cap. The plot is normalized to σ_1, the theoretical peak radar cross section for a Luneburg reflector of 6-in. radius, that is, the peak σ for a conducting circular flat plate whose radius is 6 in. In the sense that σ remains fairly constant over the designed region of coverage and then drops off rapidly, the Luneburg reflector is very efficient in its coverage particularly as compared with the corner reflector (see Figure 2). For cones of directions of full angle less than 130°, even more efficient coverage can be obtained by using a smaller reflecting cap. Figure 7b is an experimental plot (Emerson and Cummings, 1961) showing the X-band coverage of a 6-in.-radius Luneburg reflector with a 90° cap. In this case, since there is no aperture blockage by the cap, extremely efficient coverage is obtained over a cone of full angle of about 83°.

The approximate 1.5-db discrepancy between the theoretical peak σ (0 db) and the experimental peak σ (-1.5 db) in the curves of Figures 7a and 7b can be attributed

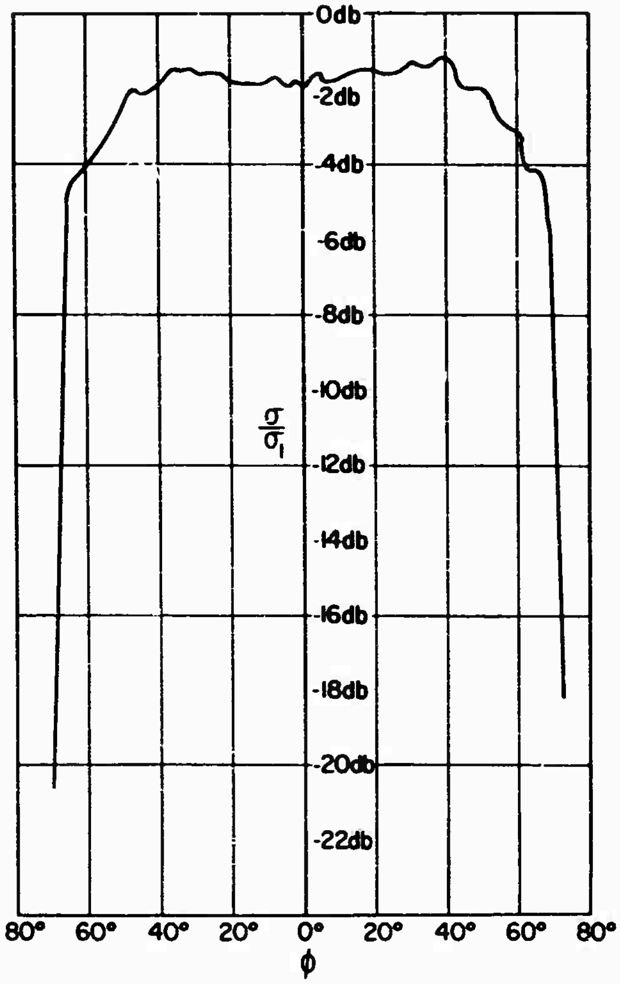

Figure 7a. X-band Coverage of Luneburg Reflector With 140° Cap

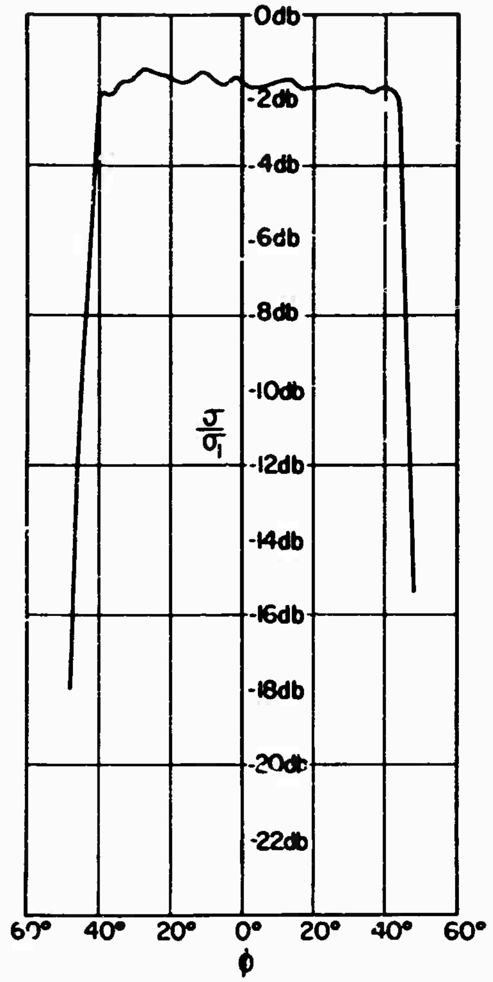

Figure 7b. X-band Coverage of Luneburg Reflector With 90° Cap

to dielectric losses and imperfect focusing in the lenses. Emerson and Cumming lenses, having stepwise changes in dielectric constant, are of course only approximations to ideal Luneburg lenses, whose dielectric constant varies continuously with radius. The local oscillations in Figures 7a and 7b are probably due to imperfections in the lenses, but the falloff at the shoulders for the 140° cap (Figure 7a) is due to aperture-blockage by the cap.

According to Emerson and Cumming, Inc., the following losses relative to theoretical values are characteristic of their Luneburg reflectors.

Table 1.

Luneburg Reflector Radius (in.)	Loss (db)
6	1
12	2-3
18	3-5
24	6

4. COMPARISON OF SOLID ANGULAR COVERAGE

In order to compare the coverage of a four-element corner reflector cluster with that of a Luneburg reflector having a 140° cap, dielectric and defocusing losses in the Luneburg reflector were neglected, leaving aperture-blockage as the predominant effect. Thus, the general shape of the curve in Figure 7a was used, but the 1.5-db loss and local oscillations were excluded. For the corner reflector cluster, the curve in Figure 5 was used, it being thereby assumed that the coverage is determined entirely by triple reflection and that there are no misalignment losses in the cluster.

Plots of σ/σ_0 vs percentage of hemispheric coverage, comparing the corner reflector cluster and single Luneburg reflector for various ratios of L to a (see Figure 8), clearly show the superiority of the Luneburg reflector over the corner reflector cluster. If for a given value of σ a Luneburg reflector of radius a will produce about 60 percent hemispheric coverage, then to produce the same coverage, a corner reflector cluster must have an edge $L \approx 2.5\ a$ (see Figure 1b).

The locations of the regions of coverage for the two types of reflectors are different. The coverage for a corner reflector cluster is primarily centered about each of the axes of the four corner reflectors (see Figure 4). The coverage for a single Luneburg reflector with a 140° cap lies in a cone diametrically opposite the cap, the axis passing through the center of the cap, but a coverage region of any desired shape that falls within that obtained with the 140° cap can be attained by properly shaping the cap. Total hemispheric coverage is impracticable with corner reflector clusters but can be attained very efficiently by means of a cluster of three Luneburg reflectors with properly shaped caps.

5. CONCLUSIONS

For coverage of about 60 percent of a hemisphere, a single Luneburg reflector whose radius is only about 1/2.5th the edge length of a four-element corner reflector cluster is as effective as the cluster. Clearly, the Luneburg reflector is much more efficient than the corner reflector, but the Luneburg reflector is heavy, expensive (see Table 2), and practically impossible to repair in the field if the lens is damaged. The corner reflector, however, can be made fairly lightweight, is not particularly expensive, and can be repaired in the field. For shipping purposes it can be made collapsible or dismantlable and packed in a very thin package, whereas the Luneburg reflector cannot be collapsed but must be shipped at its full bulk.

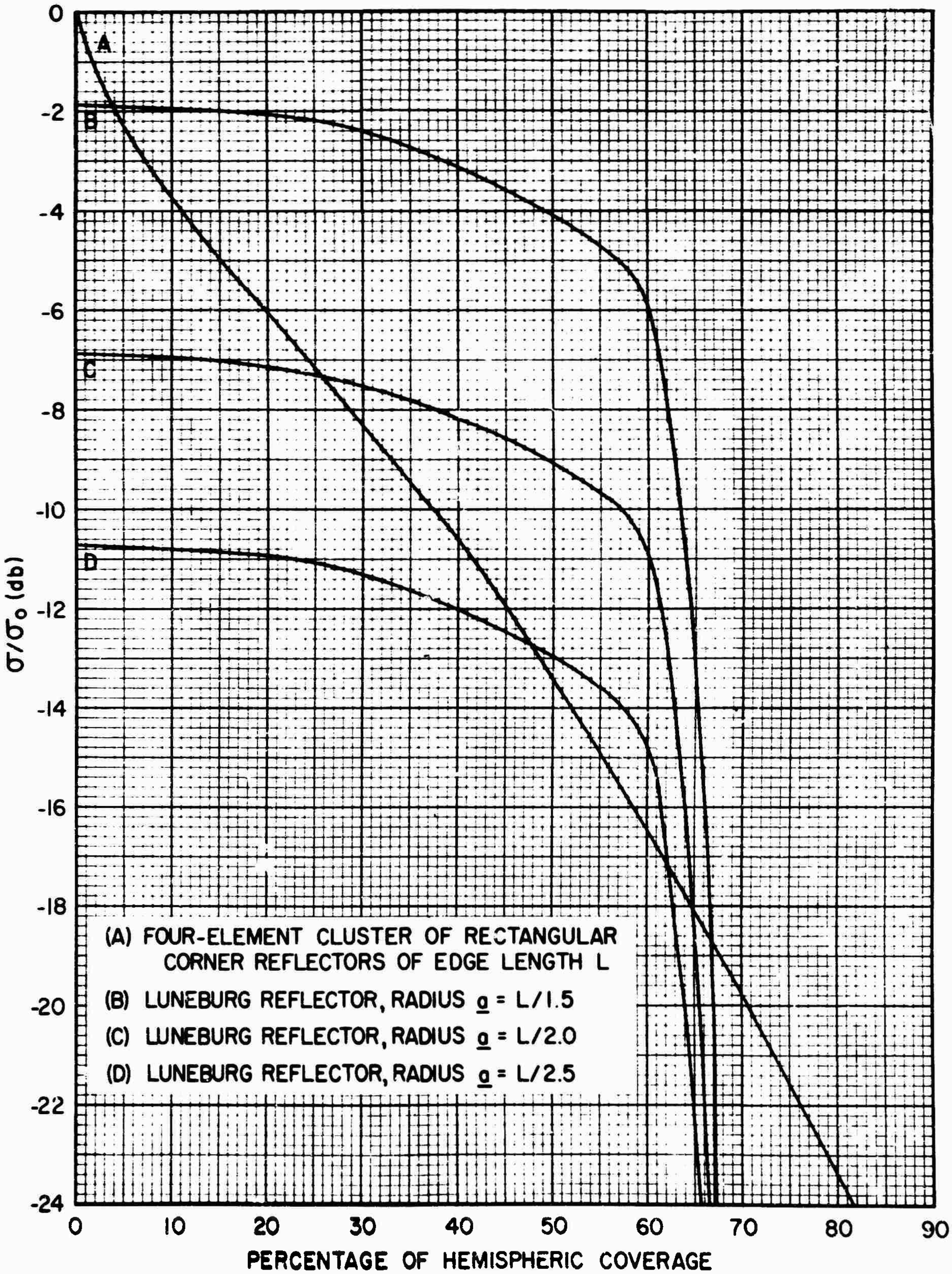

Figure 8. Coverage Comparison of Four-element Cluster of Rectangular Corner Reflectors and Single Luneburg Reflectors (140° cap) of Various Radii. Dielectric and defocusing losses in the Luneburg reflector, and misalignment losses in the corner reflector cluster, are neglected

Table 2. Sizes, Weights, and Prices of Luneburg Reflectors of the Emerson and Cumming, Inc., Type

Radius (in.)	Weight (lb)	Unit Price		
		1	10	100
6	10.9	$ 495	$ 475	$ 350
12	86.0	1400	1250	880
18	292.0	3100	2065	-
24	685.0	8800	7650	-

Generally speaking, if physical size and wide angle coverage (greater than or equal to 60 percent of a hemisphere) are more important than repair, weight, and cost, then the Luneburg reflector singly or in a cluster is the best solution. If maintenance, weight, cost, and collapsibility are more important than uniform wide angle coverage and physical space requirements, then the corner reflector is the best solution.

References

Emerson and Cumming, Inc. (1961), Ecco Reflector, Experimental Data, Technical Bulletin 12-2-1B, Canton, Mass., 30 October 1961.

O'Neal, R. D. (1943), curves taken from The Application of Corner Reflectors to Radar (experimental), M.I.T. Radiation Laboratory Report 55-4, 1 July 1943.

Silver, S. (1949), Microwave Antenna Theory and Design, M.I.T. Rad. Lab. Ser. Vol. 12, McGraw-Hill, p. 5, on scattering cross section.

Spencer, R.C. (1944), Optical Theory of the Corner Reflector, M.I.T. Radiation Laboratory Report AT 1-5763.

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