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ANTENNA FEEDS FOR SEQUENTIALLY LOBED RADARS

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ANTENNA FEEDS
FOR SEQUENTIALLY LOBED RADARS

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April 15, 1949

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ABSTRACT

A study of the dependence of angle and range sensitivities of a tracking radar on the design of antenna feed has previously been made. The results of this study are applied to the design of several types of feeds, including conical scan, for a sequentially lobed radar. Range and angle sensitivities are calculated and compared for each type of feed.

PROBLEM STATUS

This is an interim report on one phase of this problem.

AUTHORIZATION

NRL Problem R12-01D

ANTENNA FEEDS FOR SEQUENTIALLY LOBED RADARS

INTRODUCTION

A previous report[1] has presented the relationship of angle and range sensitivities of a tracking radar to the design of antenna feed. Expressions were derived which specify the size and position of the elements in the feed. Applications were made to several types of feed for a simultaneous radar and to one type of feed for a sequential radar. Because of increased interest in feeds for sequentially lobed radars, the work is extended in this report to include several types of feed.

It has been pointed out that all previous work has neglected the effect of automatic gain control (AGC) in the radar receiver. This neglect has been deliberate, but its justification has not been given. The careful feed design under discussion is of importance only when the signal-to-noise ratio is small. If the ratio is high, any rough design is satisfactory. Since AGC is inoperative at small signal-to-noise ratios, its effect has not been considered.

If a square secondary aperture of side c is fed by n equal primary apertures of dimensions a and b and with the kth aperture at distances g_k and h_k off the antenna axes, the transmitting or receiving pattern has been shown[2] to be

$$E(\theta', \phi') = \sum_{k=1}^{n} \alpha_k \left[\mathrm{Si}(\theta' + g_k' + a') - \mathrm{Si}(\theta' + g_k' - a')\right] \times \left[\mathrm{Si}(\phi' + h_k' + b') - \mathrm{Si}(\phi' + h_k' - b')\right] / \sqrt{a'b'n}. \tag{1}$$

Here θ and ϕ are angles off axis measured in two perpendicular planes, $\mathrm{Si}(x) = \int_0^x \sin y/y \, dy$, and $\alpha_k = \pm 1$, depending on the phase of the illumination of the primary aperture in transmitting, or on the manner of summing the aperture signals in receiving. Also,

$$\theta' = \pi c\theta/\lambda, \qquad g_k' = \pi c g_k/R_o\lambda, \qquad a' = \pi ca/R_o\lambda,$$
$$\phi' = \pi c\phi/\lambda, \qquad h_k' = \pi c h_k/R_o\lambda, \qquad b' = \pi cb/R_o\lambda.$$

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[1] Hastings, A. E., "Antenna Feeds for Tracking Radars - II," NRL Report R-3334, 13 August 1948 (Confidential)

[2] In equation 1 above, certain parameters are omitted because they are held constant.

The wavelength is λ, and R_o is the focal length of a lens or paraboloidal reflector used in the secondary aperture. The application of equation (1) to several types of sequential feed follows.

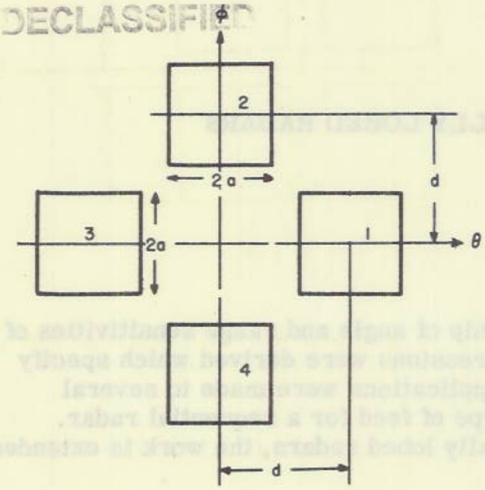

Fig. 1 - 4-aperture diamond feed

4-APERTURE DIAMOND FEED

The arrangement of apertures is shown in Figure 1. For transmitting, $n = 4$, $a' = b'$, $\phi = 0$, and the other parameters are given by

Aperture	1	2	3	4
α_k	1	1	1	1
g_k'	d	0	-d	0
h_k'	0	d	0	-d

If these substitutions are made in (1), and if the approximation for $\theta << p$, $Si(p + \theta) = Si(p) + \theta \sin p/p$, is made, the transmitting pattern is given by

$$E_t = 4\, Si(a') \; [Si(d' + a') - Si(d' - a')] \; /a'.$$

The range signal E_r involves a two-way pattern, so that

$$E_r = E_t^2 = 16\, Si^2(a') \; [Si(d' + a') - Si(d' - a')]^2 \; /a'^2 .$$

For angle reception in the θ coordinate, apertures 1 and 3 are used. Then $n = 2$, $a' = b'$, $\phi' = 0$, and the parameters are given by

Aperture	1	3
α_k	1	1
g_k'	d′	-d′
h_k'	0	0

Substitution of these values in (1) gives an equivalent transmitted pattern for E_{1-3}. The angle signal is proportional to $E_t E_{1-3}$ or

$$E_a = 4\sqrt{2}\, Si^2(a') \; [Si(d' + a') - Si(d' - a')] \; [Si(\theta' + d' + a') - Si(\theta' + d' - a') - Si(\theta' - d' + a') + Si(\theta' - d' - a')] \; /a'^2 .$$

4-APERTURE SQUARE FEED

Figure 2 shows the arrangement of apertures. For transmitting, $n = 4$, $a' = b'$, $\phi' = 0$, and the other parameters are given by

Aperture	1	2	3	4
α_k	1	1	1	1
g_k'	d′	-d′	-d′	d′
h_k'	d′	d′	-d′	-d′

If these substitutions are made in (1) and approximations made, the transmitting pattern is given by

$$E_t = 2\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^2/a'.$$

The range signal is

$$E_r = E_t^2 = 4\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^4/a'^2.$$

For angle reception in the θ coordinate, all apertures are used according to

Aperture	1	2	3	4
α_k	1	-1	-1	1
g_k'	d′	-d′	-d′	d′
h_k'	d′	d′	-d′	-d′

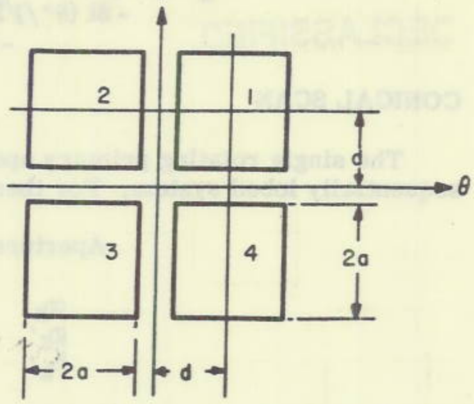

Fig. 2 - 4-aperture square feed

Then $E_a = E_t E_{1-2-3+4}$, and from (1),

$$E_a = 2\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^3\,[\mathrm{Si}\,(\theta' + d' + a') - \mathrm{Si}\,(\theta' + d' - a') - \mathrm{Si}\,(\theta' - d' + a') + \mathrm{Si}\,(\theta' - d'' - a')]\,/a'^2.$$

4-APERTURE SKEW-DIAMOND FEED

In this feed (Figure 3) the new angular coordinates are θ'' and ϕ'', where $\theta' = \theta''/\sqrt{2}$ and $\phi' = \phi''/\sqrt{2}$. For transmitting, n = 4, a′ = b′, and the other parameters are given by

Aperture	1	2	3	4
α_k	1	1	1	1
g_k'	d′	-d′	-d′	d′
h_k'	d′	d′	-d′	-d′

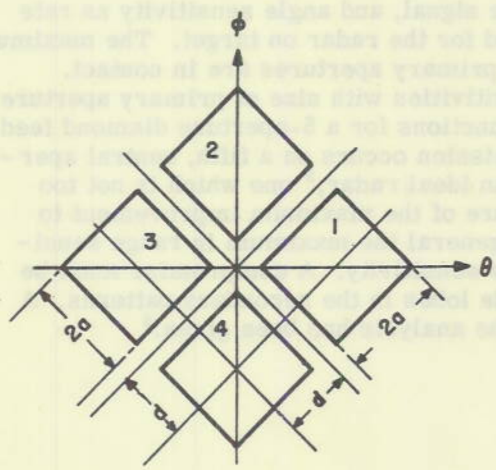

Fig. 3 - 4-aperture skew-diamond feed

From (1) the transmitting pattern is given by

$$E_t = 2\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^2/a'.$$

The range signal is

$$E_r = E_t^2 = 4\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^4/a'^2.$$

For angle reception in the θ'' coordinate, apertures 1 and 3 are used according to

Aperture	1	3
α_k	1	-1
g_k'	d′	-d′
h_k'	d′	-d′

Then $E_a = E_t E_{1-3}$, and from (1),

$$E_a = \sqrt{2}\,[\mathrm{Si}\,(d'+a') - \mathrm{Si}\,(d'-a')]^2 \Big\{[\mathrm{Si}\,(\theta''/\sqrt{2} + d' + a') - \mathrm{Si}\,(\theta''/\sqrt{2} + d' - a')]^2 - [\mathrm{Si}\,(\theta''/\sqrt{2} - d' + a') - \mathrm{Si}\,(\theta''/\sqrt{2} - d' - a')]^2\Big\} .$$

CONICAL SCAN

The single rotating primary aperture can be treated as a pair of apertures in a sequentially lobed system. For these apertures, both in transmission and reception,

Aperture	1	2
α_k	1	1
g_k'	d'	-d'
h_k'	0	0

Then for $\phi' = 0$ and n = 1, the secondary patterns for the apertures are

$$E_1 = 2\,\mathrm{Si}\,(b')\,[\mathrm{Si}\,(\theta' + d' + a') - \mathrm{Si}\,(\theta' + d' - a')]/\sqrt{a'b'},$$

and

$$E_2 = 2\,\mathrm{Si}\,(b')\,[\mathrm{Si}\,(\theta' - d' + a') - \mathrm{Si}\,(\theta' - d' - a')]/\sqrt{a'b'}.$$

The angle signal is proportional to $E_1^2 - E_2^2$ or

$$E_a = 2\,\mathrm{Si}^2\,(b')\,\Big\{[\mathrm{Si}\,(\theta' + d' + a') - \mathrm{Si}\,(\theta' + d' - a')]^2 - [\mathrm{Si}\,(\theta' - d' + a') - \mathrm{Si}\,(\theta' - d' - a')]^2\Big\}/a'b'.$$

It is advantageous to have the single aperture rotating about its axis as it simultaneously revolves about the antenna axis. This allows complete freedom in choosing the parameter b' to maximize the angle sensitivity. Range signal on target is E_1^2, or

$$E_r = 4\,\mathrm{Si}^2\,(b')\,[\mathrm{Si}\,(d' + a') - \mathrm{Si}\,(d' - a')]^2/a'b'.$$

RESULTS OF APPLICATIONS

From the equations derived, range and angle sensitivities can be calculated for each type of feed. Range sensitivity is defined as range signal, and angle sensitivity as rate of change of angle signal with angle, both evaluated for the radar on target. The maximum sensitivities for each type of feed occur when the primary apertures are in contact. Figures 4 through 7 show the variation of the sensitivities with size of primary aperture for apertures in contact. Included are the same functions for a 5-aperture diamond feed (Figure 8) previously described,[3] in which transmission occurs on a fifth, central aperture. All sensitivities are expressed relative to an ideal radar,[3] one which is not too restricted by practice and which can give a measure of the maximum improvement to be expected in existing radars. It is seen that in general the maximum in range sensitivity does not coincide with the maximum in angle sensitivity. A compromise must be made, which may also involve the amplitude of side lobes in the secondary patterns. A discussion of the assumptions and limitations of the analysis has been given.[3]

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[3] NRL Report R-3334

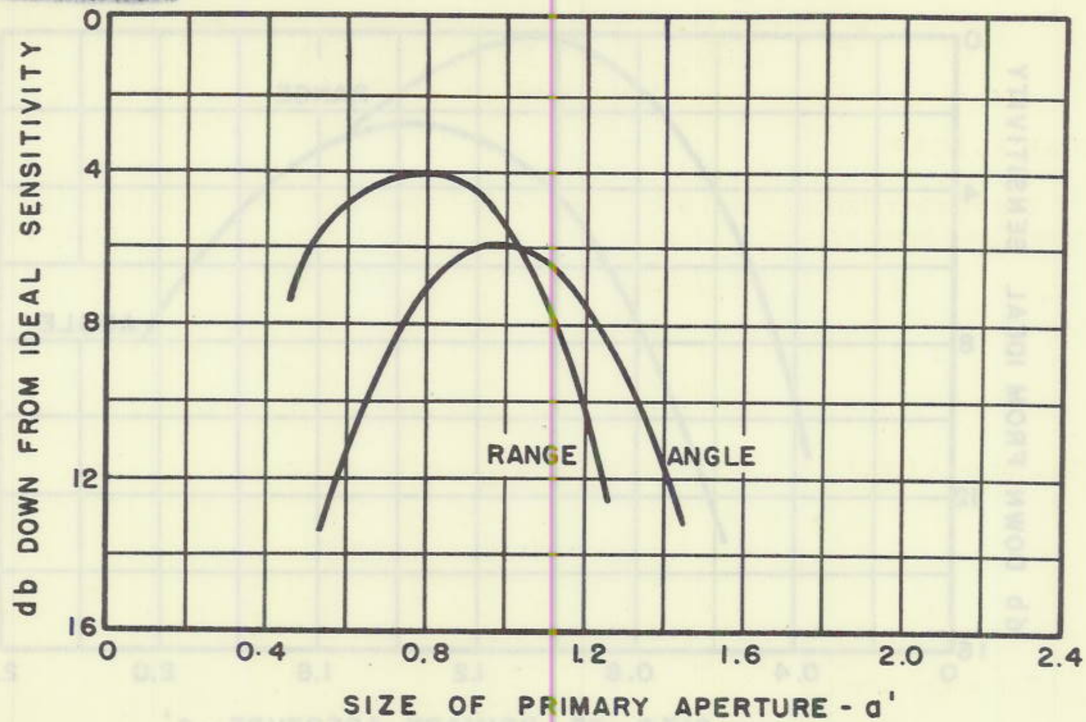

Fig. 4 - Sensitivities for 4-aperture diamond feed

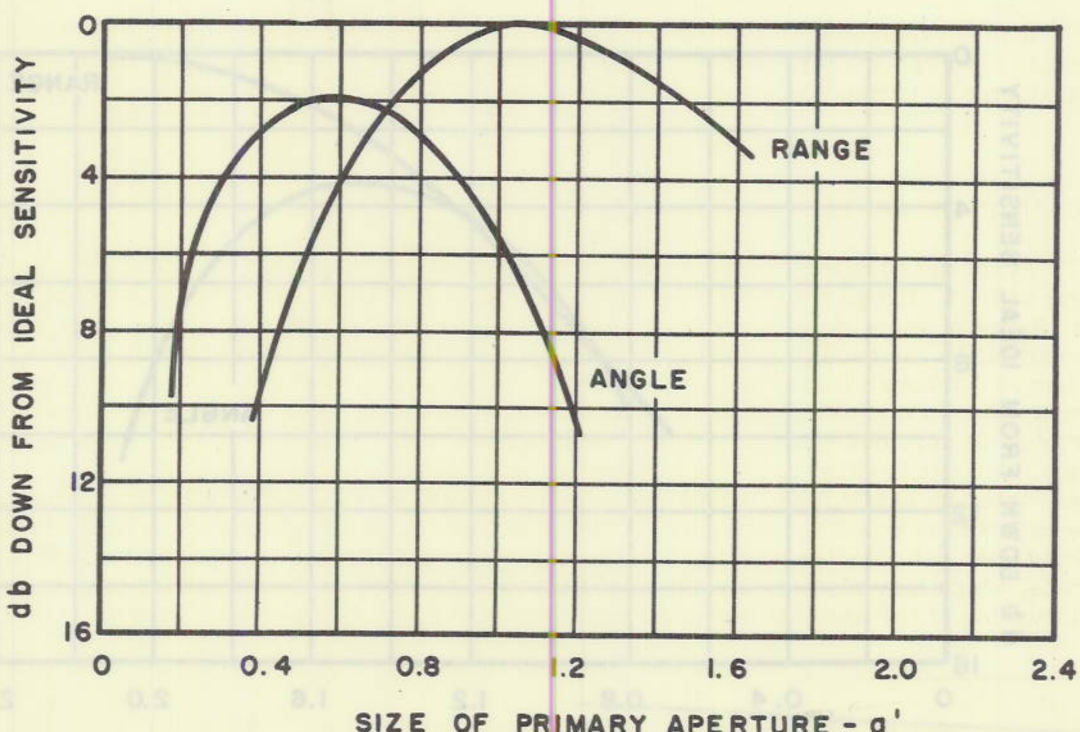

Fig. 5 - Sensitivities for 4-aperture square feed

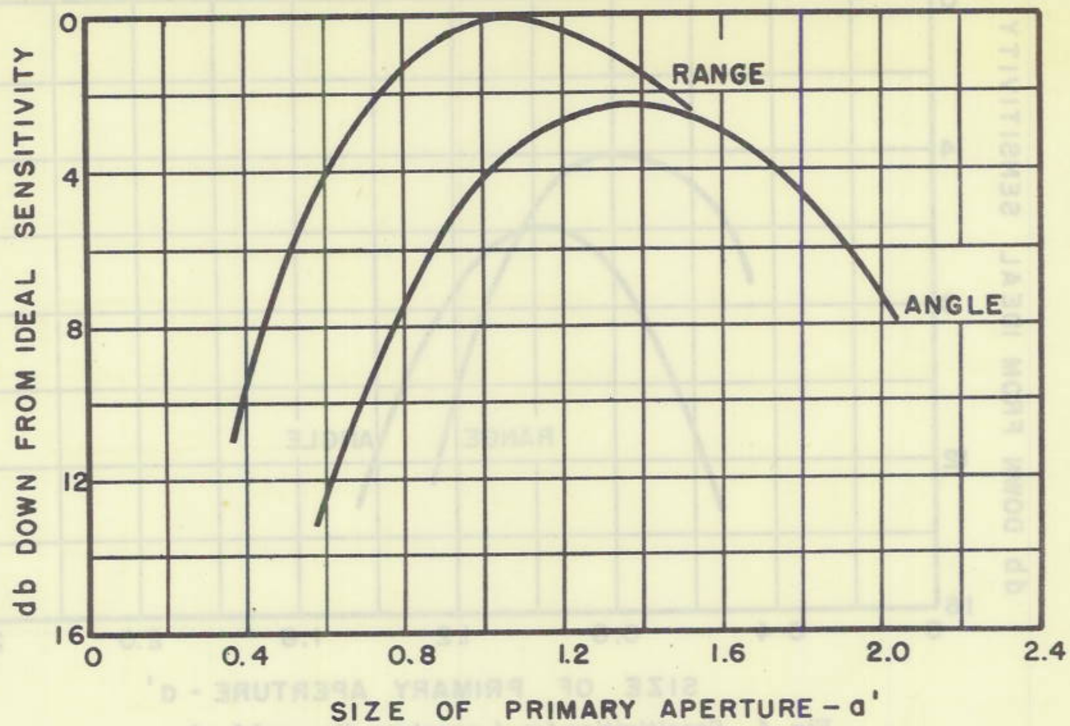

Fig. 6 - Sensitivities for 4-aperture skew-diamond feed

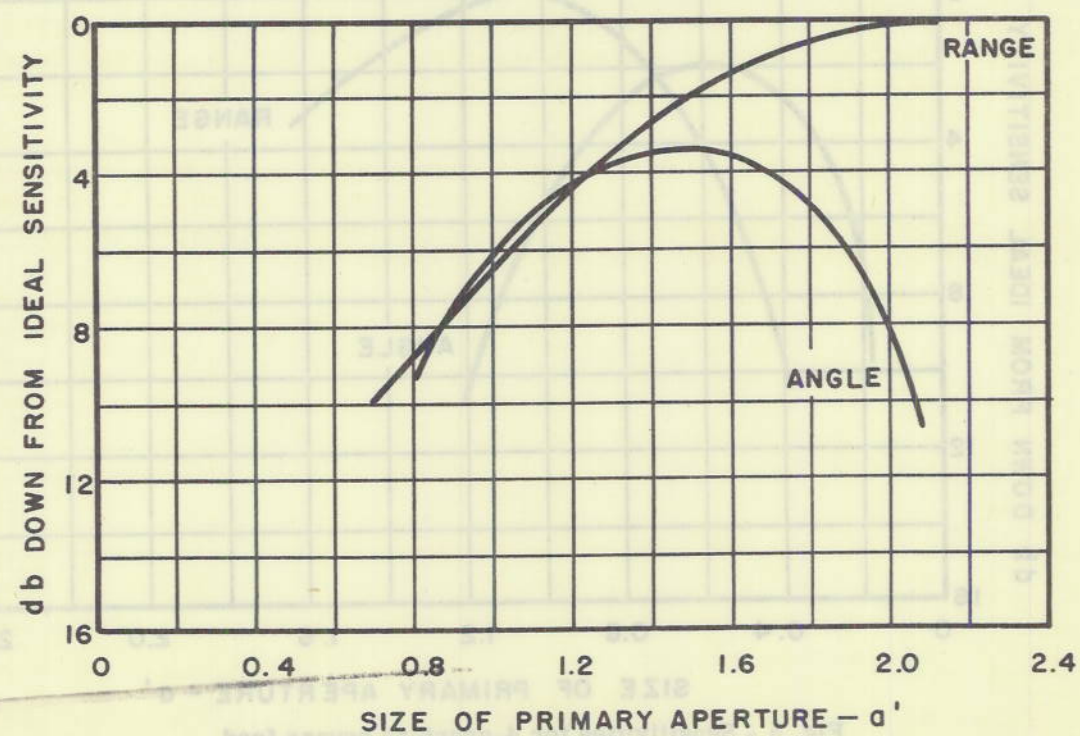

Fig. 7 - Sensitivities for 5-aperture diamond feed

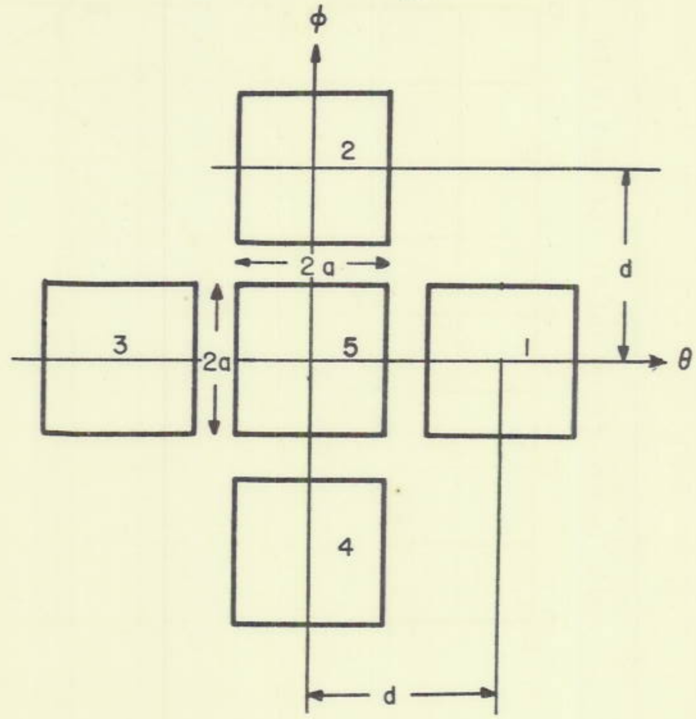

Fig. 8 - 5-aperture diamond feed

All feeds except the 4-aperture diamond have approximately the same sensitivities and loss in range sensitivity at maximum angle sensitivity. A choice can then be based mainly on the mechanical complexity of the associated system of the lobe-switching and signal combining.

The maximum angle sensitivity, 1.9 db down from ideal, occurs for conical scan when $a' = 1.9$, $b' = 2.2$, and $d' = 1.4$. With these values the range sensitivity is 8.8 db down from ideal. Since with three parameters a plot of both sensitivities against the parameters would be very complex, no sensitivity curves are shown.

* * *

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