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COMPACT SIMULTANEOUS-LOBING CIRCUITS

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COMPACT SIMULTANEOUS-LOBING CIRCUITS

E. Quigley, H. J. Riblet, T. S. Saad
Submarine Signal Company

November 10, 1948

Approved by:

Dr. L. C. Van Atta, Head, Antenna Research Section
Dr. J. M. Miller, Superintendent, Radio Division I

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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FOREWORD

The simultaneous-lobing principle proposed by Dr. R. M. Page and developed by Radio Division III of NRL should find wide application to precision-location radar systems. Whereas first attention has been given, both to NRL and elsewhere, to ground-based systems, airborne applications can also be visualized. But the r-f circuits used hitherto for simultaneous lobing have been somewhat complex and bulky even for ground equipment and would be out of the question for most airborne installations.

It was primarily with a view to airborne applications and their severe antenna-design problems that the Antenna Research Section initiated the simultaneous-lobing-circuit project at the Submarine Signal Company, Boston, Mass. The very successful research of Dr. H. J. Riblet and co-workers has resulted in an r-f circuit not only compact enough for airborne installations but also of sufficiently high performance to be considered for use in ground equipment.

To obtain proper dissemination of information regarding the nature and performance of this simultaneous-lobing r-f circuit, the report of the Submarine Signal Company, with minor modifications, is being distributed as an NRL Report.

L. C. Van Atta

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ABSTRACT

A simultaneous-lobing (or monopulsing) system eliminates a major source of noise in automatic-tracking radar. Parallel-guide hybrids, of which the performance is readily explained by simple theory, provide the basis for compact and broad-band r-f circuits for simultaneous lobing. With a view toward compact antenna-feed design, three types of guide coupling sections were studied: short slots in narrow wall of guide, staggered slots in narrow wall of guide, and perpendicular slots in broad wall of guide.

It was recognized that, if a four-horn cluster is used as the simultaneous-lobing feed for an antenna, and if narrow-wall and broad-wall coupling sections are used to interconnect the four waveguides, two 90-degree phase shifters suffice to establish the proper phase relations for simultaneous lobing. Three of the waveguides are then suitable for range, azimuth, and elevation inputs respectively, while a matched load terminates the fourth.

Two such simultaneous-lobing circuits have been designed, one more compact and somewhat less broad band than the other. Both were studied for primary and secondary radiation patterns, constancy of coupling, isolation between inputs, output phase, and input SWR. Performance seems adequate in all these respects for many simultaneous-lobing applications. In particular, the nulls in the secondary patterns are fixed in direction and can be reduced below 30 db in the E-plane and 35 db in the H-plane over at least a 2 percent bandwidth.

PROBLEM STATUS

This is an interim report on one phase of NRL Problem No. R09-30R which is supporting research under Problem No. R12-01D. The work was done under Contracts N173s-11563 and N173s-12412 by the Submarine Signal Company of Boston, Mass., and this is the final report under the contracts.

AUTHORIZATION

NRL Problem No. R09-30R.

COMPACT SIMULTANEOUS-LOBING CIRCUITS

INTRODUCTION

A major part of the noise in an automatic-tracking radar employing conical scanning arises from the fact that it is impossible to separate completely from the normal scanning modulation the modulation due to pulse-to-pulse changes in the reflecting power of the target. Accordingly, a number of suggestions have been made for obtaining the basic tracking information from each pulse. Although each of these schemes might be included under the general name, "simultaneous lobing," or "monopulsing," it will be convenient in this report to restrict the use of the term "simultaneous lobing" to the system being developed at NRL under the direction of Dr. R. M. Page. A general description of this system is given in various NRL reports.[1]

It is the object of this report to discuss compact antenna feeds for this system, which are made possible by the use of parallel-guide hybrids.[2] When this work started at the Submarine Signal Company under the sponsorship of NRL, a number of the ideas were untested. As a result, the main effort to date has been to demonstrate the soundness of the scheme rather than to obtain the ultimate in performance. Nevertheless, past experience indicates that any significant improvement in performance of the feeds will first require a re-examination of the accuracy of earlier measurements. For example, one would like to keep the SWR of all components less than 0.25 db, and this will certainly require the abandonment of chokes as coupling devices.

FEED REQUIREMENTS FOR SIMULTANEOUS LOBING

As the system is now proposed, the ideal feed consists of a four-horn cluster, shown in Figure 1, which is fed by three wave guides designated as range, azimuth, and elevation inputs. The inputs are perfectly isolated so that none of the power incident on the range input, say, arrives at the other inputs. Moreover, power incident on the range

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[1] R. M. Page, "Accurate Angle Tracking," NRL Report RA3A22A, December 28, 1944, Secret; J. B. Trevor and A. E. Hastings, "Analysis and Specifications of Simultaneous-Lobing System TAB," NRL Report R-2554, July 1, 1945, Secret; H. L. Gerwin, "Design and Development of Antennas and R-F Components for Simultaneous-Lobing Radar," NRL Report R-3042, Jan. 3, 1947, Secret.

[2] E. Quigley, H. J. Riblet, and T. S. Saad, "Parallel Guide (Quadrature) Hybrids," Submarine Signal Co. Report CF-1080, August 6, 1948, Confidential.

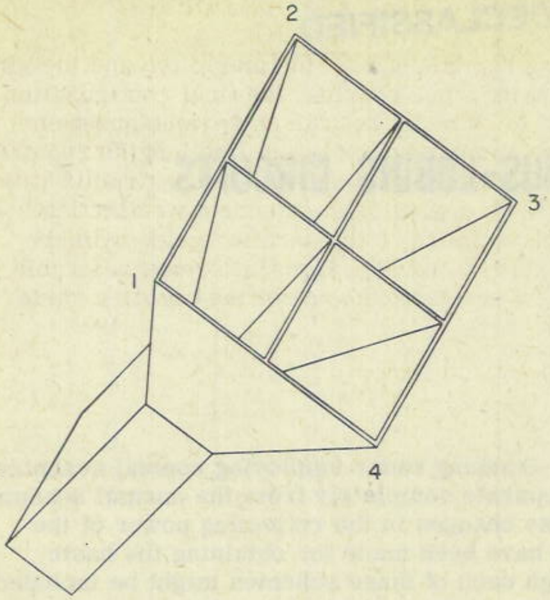

Fig. 1 - Four-horn feed for simultaneous-lobing antenna

input divides equally between the four output horns and arrives in phase at their apertures. On the other hand, although power incident on the azimuth channel divides equally between the output horns, the phase of the energy is such that the voltages at horns 1 and 4 are in phase with each other but just 180 degrees out of phase with the voltages at horns 2 and 3. Similar behavior is required of power incident on the elevation input except, of course, that the voltages at horns 1 and 2 should be out of phase with those at 3 and 4. Needless to say, each of the inputs must be perfectly matched.

The inherent complexity of this circuit makes the realization of these requirements to any useful degree of approximation, even at a single frequency, a major design problem. Certain of these requirements appear to be more important than others, and it would seem desirable to relax some of them wherever possible without loss of system performance.

The ultimate accuracy of the system is closely associated with the depth of the nulls in the patterns obtained from the azimuth and elevation inputs. This depends on the fact that in the vicinity of these nulls there is a phase reversal which becomes more abrupt as the depth of the null increases. Accordingly, the principal design problem is that of obtaining deep nulls whose angular location is independent of frequency. It is clear, then, that when the range input is used, much less severe requirements may be placed on the phase and amplitude of the voltages at the output horns than when either of the other inputs is used. Also, the isolation between the elevation and azimuth inputs is less important than the isolation between each of them and the range input. This follows from the fact that energy entering the elevation input, which is coupled into the range input and is reflected there, will have a very marked effect on the depth of the elevation null as compared to the effect of energy which finds its way into the azimuth input.

The only input SWR which appears to be significant is that encountered at the range input. Furthermore, it appears to be quite possible to relax the requirements[3] on the phase of the voltages at the output horns for the azimuth and elevation inputs. Suppose that, for the azimuth input, horns 1 and 4 are no longer exactly in phase with each other. This would have a very small effect on the performance of the system as long as horns 2 and 3 are exactly out of phase with horns 1 and 4, respectively. Similar arguments can be found to show that the power balance need not be exact either.

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[3] These phase requirements assume perfect symmetry in the location of the feed about the axis of the antenna system. Little is known about the phases needed for asymmetrical systems.

APPLICATION OF PARALLEL-GUIDE HYBRIDS TO SIMULTANEOUS LOBING

Circuits for SL have been constructed using hybrids of both the magic tee and the ring variety.[4] Because of the rather awkward shapes of these hybrids, the final configuration of the SL circuit employing them not only tends to be bulky but raises serious questions about bandwidth and performance because of the number of bends and line lengths required. Because of the shape of the parallel hybrid, it has been found possible to construct a rather compact SL circuit which accordingly minimizes line length and extraneous reflection problems. Since the phase and amplitude characteristics of the parallel-guide hybrids are different from those of the more conventional tee and ring types, it seems desirable to include in this discussion some explanation[5] of the performance of the parallel-guide hybrids which have been used.

SIMPLE THEORY[6]

To date all parallel-guide hybrids have had a plane of symmetry running their full length. Such an arrangement is shown schematically in Figure 2. It is convenient to

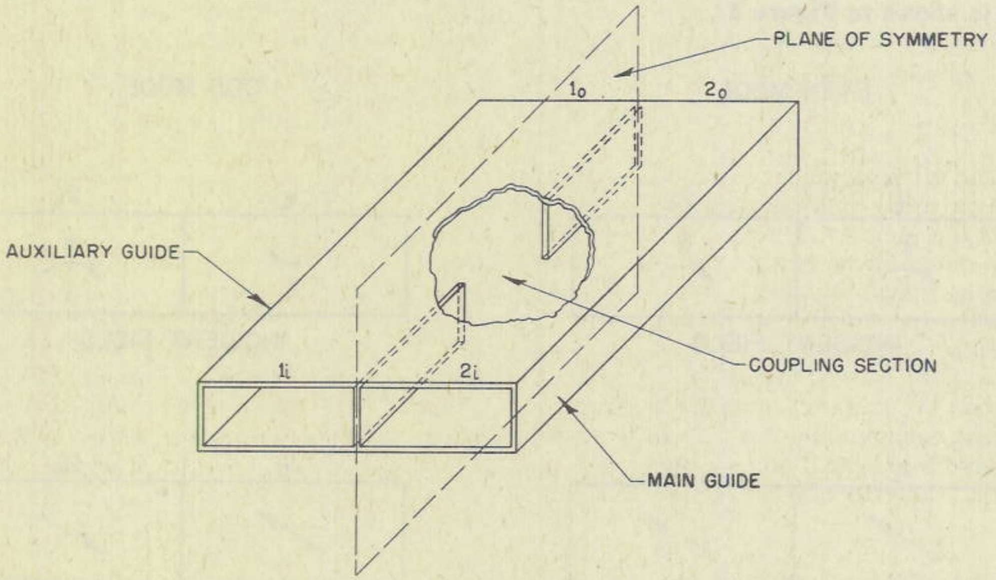

Fig. 2 - Parallel-guide hybrid, schematic

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[4] W. A. Tyrrell, "Hybrid Circuits for Microwaves," Proc. I.R.E., vol. 35; pp. 1294-1306, November 1947.

[5] This discussion is taken bodily from the report of reference 2.

[6] This theory constitutes a very slight extension of that given by B. A. Lippman, "Theory of Directional Couplers," M.I.T. Radiation Laboratory Report 860, Dec. 28, 1945, pp. 33-35.

picture the coupling mechanism as the slot resulting from the removal of a length of the wall common to two wave guides attached as shown.

Of course, any other arrangement having the same symmetry would serve as well. When power is incident on the main guide 2 at terminal 2_i, it proceeds along that wave guide until it encounters the coupling section. Here it begins to cross over into the auxiliary guide. Under suitable design conditions, by the time the energy reaches the end of the coupling section it will have divided so that the power leaving at terminal 1_o just equals that leaving at 2_o. If, in addition, no power leaves at terminal 1_i and none is reflected at terminal 2_i, assuming perfectly matched terminations at 1_o and 2_o, the structure is an ideal wave-guide hybrid having unity standing-wave ratio. Under the condition of symmetry assumed, it is rather easy to determine, in a general way, the principal characteristics to be expected of different type coupling sections.

Under normal test conditions, energy is incident on but a single terminal of the hybrid, say terminal 2_i. This case may be synthesized by assuming symmetrical and antisymmetrical fields incident on terminals 1_i and 2_i as shown in Figure 2. It is important to observe that the symmetry or antisymmetry of the two modes of excitation is maintained in the coupling section, assuming it to be perfectly symmetrical, so that we may properly use the idea of even or odd modes in the hybrid. Accordingly, the reflected and transmitted voltages in each mode will preserve the evenness or oddness of the incident voltages. This is shown in Figure 3.

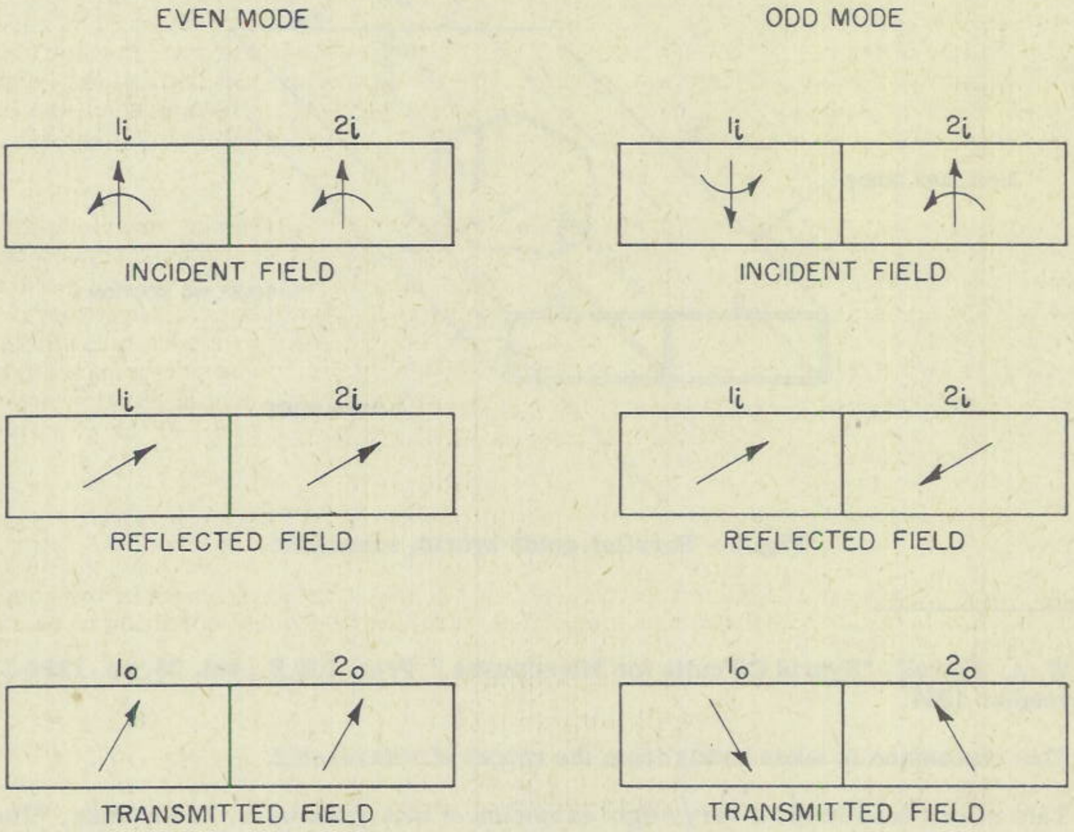

Fig. 3 - Field relations in the parallel-guide hybrid

Of course, the relative phases and amplitudes of the reflected and transmitted voltages, assuming incident voltages which are in phase, will be determined by the specific geometry of the hybrid under consideration. We see immediately that the condition for perfect isolation between the input terminals is that the reflected voltages shall add up to zero at terminal 1_i. If we require, as is usually the case, that the input standing-wave ratio at terminal 2_i shall be unity, we have the additional requirement that the reflected voltages for the two modes of excitation must cancel at this terminal. A moment's consideration of Figure 3 will indicate that this can happen only if the reflected voltages in the even and the odd modes are both zero. We thus have our first requirement for an ideal parallel-guide hybrid.

Fortunately, for all the parallel-guide hybrids to be described, this condition is satisfied automatically for one of the modes. In the case of hybrids coupled in the narrow wall by the odd mode, this follows from the fact that, for this mode, the electric field is zero at the separating wall. And so the presence of this wall or any portion of it has no effect on the propagation of this mode. Thus, for the parallel-guide hybrids under discussion, the problem of maintaining high isolation and low standing-wave ratio is simply the problem of obtaining a low standing-wave ratio for the mode in which the coupling arrangement actually appears.

Under the assumption that this requirement has been perfectly fulfilled, we see that the voltages of the transmitted field in both modes are of exactly the same magnitude. Thus, the manner in which the power is shared between the outputs is determined entirely by the phase relationships between these voltages at the output terminals 1_o and 2_o. Of course, until the coupling section is reached, there will be no relative phase shift and no power coupled into guide 1. The guide wave length for the even mode will, in general, differ from the guide wave length in the odd mode in the coupling section, and the relative phases will differ as a consequence. Once the coupling section has been passed, the relative phases of the two modes are fixed, and there is no possibility for further power transfer.

This picture leads to two interesting conclusions. In the first place, simple addition of the voltages of the transmitted fields for Figure 2 for arbitrary phases will show that the output voltages of the directional coupler (on the assumption of unity standing-wave ratio and infinite isolation) must always be ninety degrees out of phase. Moreover, if the device is to behave as a hybrid, the transmitted fields in the two modes must themselves differ by ninety degrees. Thus the second condition for hybrid performance from a directional coupler is that the effective electrical length of the coupling section must differ by an odd multiple of ninety degrees for the even and odd modes. If the effective length of the coupling section is L, this condition may be written

$$\frac{L}{\lambda_g} - \frac{L}{\lambda^{(c)}_g} = \frac{2k+1}{4}, \qquad (1)$$

where k is a positive or negative integer and $\lambda^{(c)}_g$ is the guide wave length in the coupling section. For broad-band hybrid characteristics, then, the additional condition to be satisfied is

$$\frac{d}{d\lambda}\left(\frac{1}{\lambda_g} - \frac{1}{\lambda^{(c)}_g}\right) = 0 \qquad (2)$$

or some equivalent.

From this discussion, we immediately conclude that, when the effective length of the coupling section differs by 180 degrees for the two modes, all of the power will have transferred to the auxiliary guide. It will be convenient to refer to this condition as complete crossover. For coupling sections of even greater length, the power oscillates back and forth between the main and auxiliary guides.

SPECIFIC HYBRIDS

Short-Slot, Narrow-Wall Hybrid

A particularly simple case results when the slot extends the full height of the guide as shown in Figure 2. In this case the even mode in the coupling section is the $TE_{(1,0)}$ mode for a wave guide twice the width of the individual guides making up the hybrid. The guide wave length in the coupling section is then readily determined for both the even and odd modes. Except for small errors introduced by the reflections encountered when entering and leaving the coupling section, the amount of power transferred from the main guide to the auxiliary guide, for a known length of slot, may be readily estimated. Unfortunately, the slot lengths required for hybrid performance are not those for which reflections cancel each other so that the first condition for an ideal hybrid is realized. Accordingly, the device[7] as described thus far appears to have no usefulness as a hybrid.

Since the guide wave length for the even mode is less than that for the odd mode in the coupling section, the phase of the voltage in the auxiliary guide must lead the voltage in the main guide by 90 degrees. This follows readily from the argument of the previous section for the case of complete cancellation of reflections so long as the length of the coupling section is less than that required for the first complete crossover.

This case is of some theoretical interest, however, since we have been able to predict at one frequency, with an over-all accuracy of the order of one or two tenths of a decibel, all of the characteristics of certain directional couplers of this type. The principal problem is the explicit determination of the scattering characteristics associated with the transition from the even mode in the separate guides 1 and 2 to the $TE_{(1,0)}$ mode in the combined guides. The complete determination of the required scattering matrix is made possible by the work of Carlson and Heins.[8]

Although there is no short slot of this type having a length for which both the conditions of an ideal hybrid are satisfied, at least in a 1″ x 1/2″ wave guide, we have found that a slot 1/4″ high and about 1-1/4″ long cut in the common side wall has excellent hybrid characteristics over a small but usable portion of the x-band. The performance of a hybrid having approximately these dimensions is shown in Figure 4.

One would expect that decreasing the height of the slot would decrease the guide wave length in the even mode and thus reduce the length required to obtain the ninety-degree relative phase shift for hybrid performance. This effect is readily observed and leads to the apparently surprising result that decreasing the size of the coupling hole increases the power transfer for a given length. For this particular hybrid, the over-all reflection is reduced by spacing the entrance and exit points of the coupling section so that their individual reflections cancel. However, an alternative would be some sort of tapering or matching arrangement.

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[7] M. J. Surdin, JIEE, Pt. IIIA, 93, No. 4, pp. 735-6, (1946). Surdin does not appear to have arrived at hybrid performance.

[8] J. F. Carlson and A. E. Heins, "The Reflection of an Electromagnetic Plane Wave by an Infinite Set of Plates, I," Quar. of App. Math. 4:313-329, Jan. 1947.

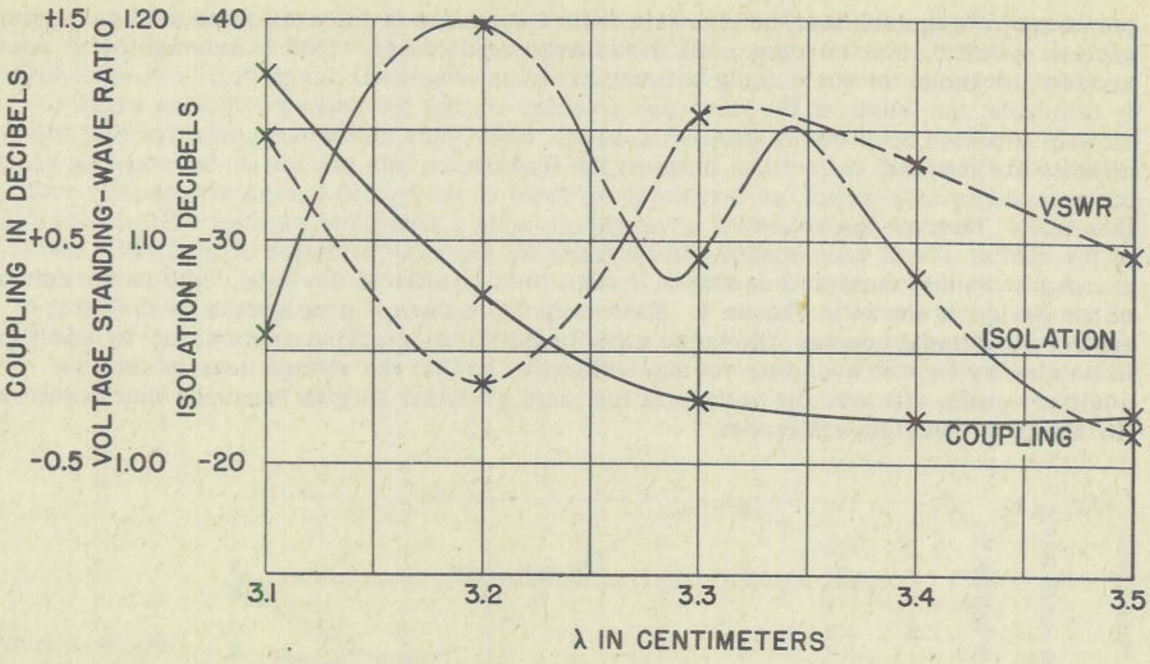

Fig. 4 - Performance of a short-slot, narrow-wall hybrid in 1″ x 1/2″ guide with a slot 1/4″ high x 1-1/4″ long

Staggered-Slot, Narrow-Wall Hybrid

This device is illustrated in Figure 5. The performance of a coupling section (comprising a cascade of coupling apertures of the type being used here) may be characterized by its equivalent propagation constant and characteristic impedance.[9] Broad-band

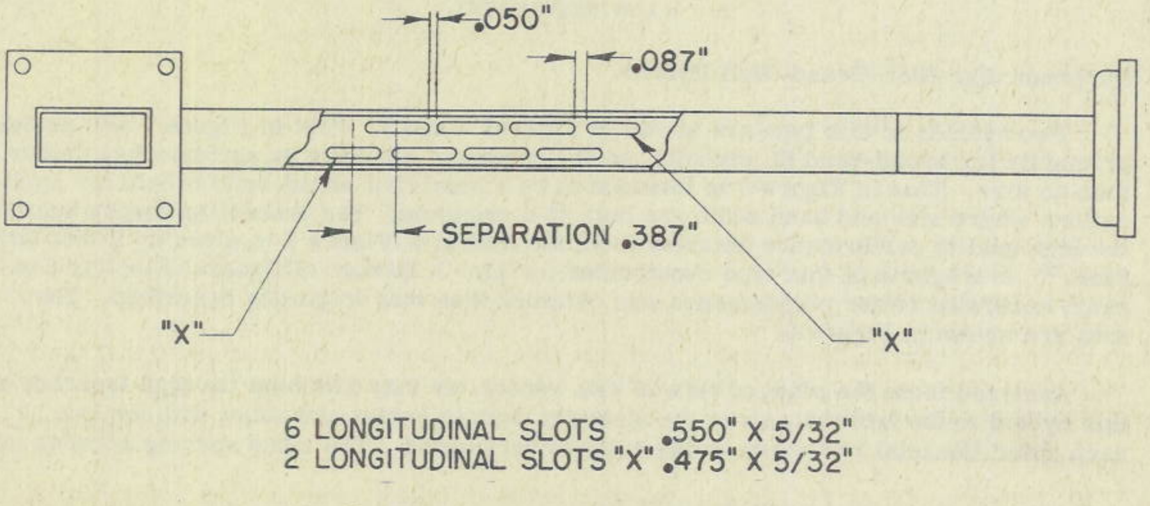

Fig. 5 - Staggered-slot, narrow-wall hybrid

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[9] H. J. Riblet, Proc. I.R.E., Vol. 35, Nov. 1947, pp. 1310-1311.

performance requires that the characteristic impedance of the even mode in the coupling section match that of the even mode in the separated guides. This is accomplished, approximately, by choice of the spacing between the slots once their length has been established. In this case, the length of the slots was selected so that the second condition would be closely satisfied over the 12-percent x-band. Even after an optimum slot spacing was chosen, the residual reflections between the transitions into and out of the coupling section had a tendency to interact, so that the directivity of the hybrid varied excessively over this band. Through the expedient of tapering, using a somewhat smaller slot at each end of the hybrid, it has been possible to increase the over-all isolation of the hybrid and to arrange it so that maximum isolation occurs in the center of the band. The performance of the device is shown in Figure 6. Since only two modes of propagation exist in this type of directional coupler, the guide wave length in the coupling section may be inferred to be shorter for the even than for the odd mode, so that the voltage coupled into the auxiliary guide will lead the voltage in the main guide for lengths less than that required for the first complete crossover.

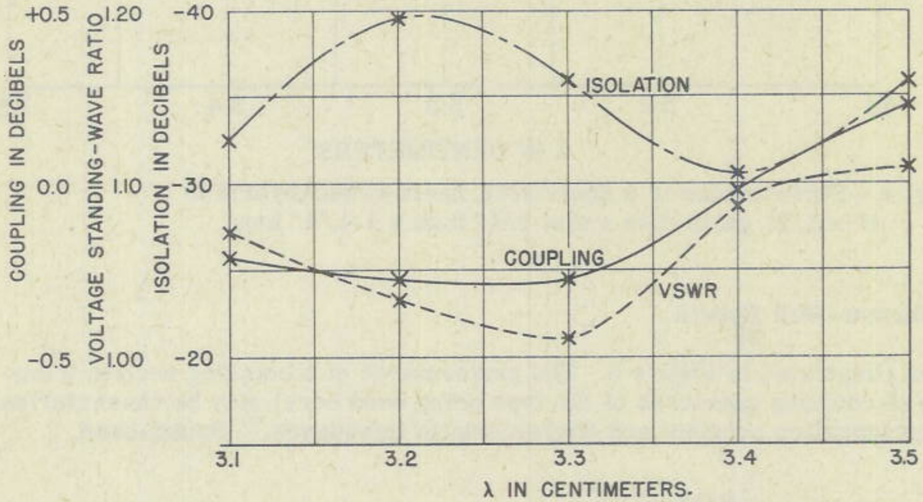

Fig. 6 - Performance of the staggered-slot, narrow-wall hybrid shown in Figure 5

Perpendicular-Slot, Broad-Wall Hybrid

Two hybrids of this type are shown in Figures 7 and 8. That in Figure 7 was designed primarily for broad-band SL circuits, so the emphasis has been on performance rather than on size. That in Figure 8 is intended to be a small but broad-band hybrid for applications where size and band width are both at a premium. The underlying theory behind the high quality performance obtained from the hybrid of Figure 7 is given by Riblet and Saad.[10] In a hybrid of this type constructed for Mr. J. Barker of General Electric Company, somewhat better performance was obtained than that originally described. The data are shown in Figure 9.

Analyzed from the point of view of this report, we may attribute the high isolation of this hybrid to the fact that, since the slots are both in series and shunt with the line at each point, the total reflection at any point is very small. The close spacing between pairs

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[10] H. J. Riblet and T. S. Saad, "A New Type of Wave Guide Directional Coupler," Proc. I.R.E., Vol. 36, p. 64, Jan. 1948.

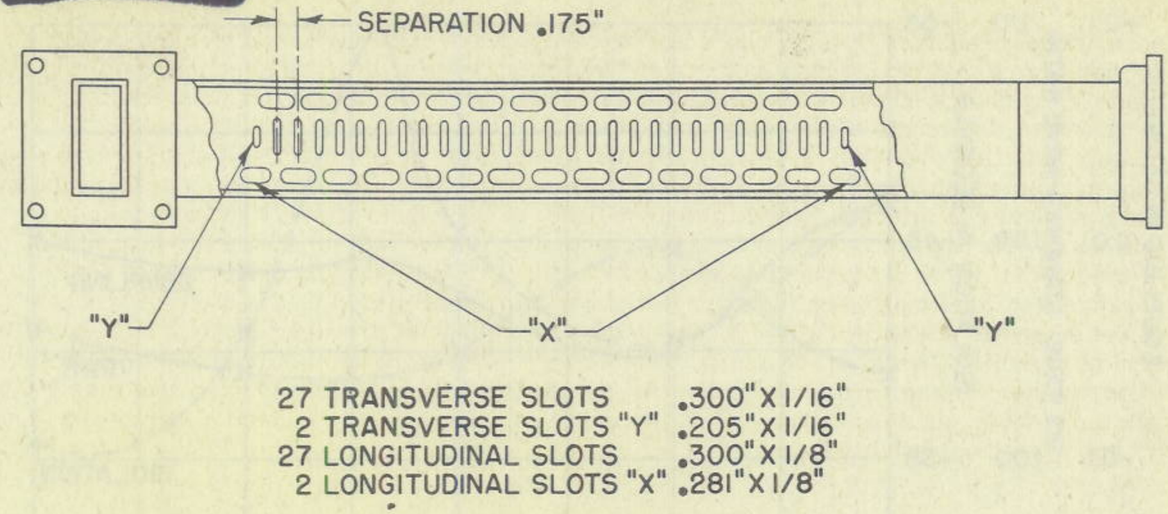

Fig. 7 - Perpendicular-slot, broad-wall hybrid designed for broad-band performance

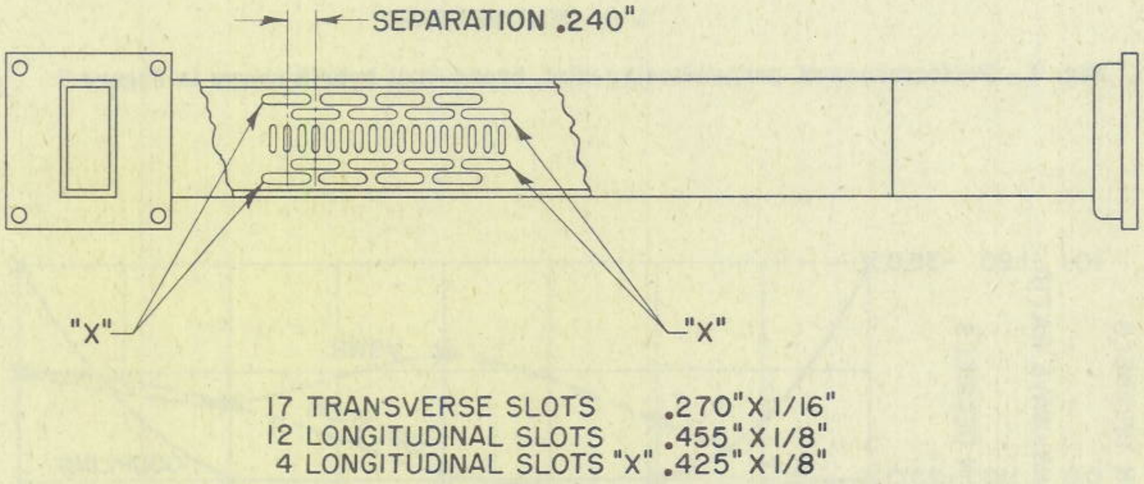

Fig. 8 - Perpendicular-slot, broad-wall hybrid designed for minimum size consistent with reasonable band width

of slots results in further cancellation of reflections. A simple explanation of the broad-band power division is not easy to give, but it depends roughly on the fact that, for small slots, the frequency characteristics of the side and center slots tend to cancel each other. By proper balance of these effects, it has been possible to construct a hybrid which splits the input power to within ± 0.05 db over the 12 percent x-band.

Figure 8 gives an idea of what may happen when one attempts to compress as much as possible the length of this type of directional coupler and still maintain broad-band power division. In general the area of the coupling wall is used more efficiently by large slots. Larger slots, however, have a frequency sensitivity of their own which tends to compensate the side-slot frequency sensitivity already mentioned. This requires longer slots on the side than those in the center. As a consequence, it is more difficult to

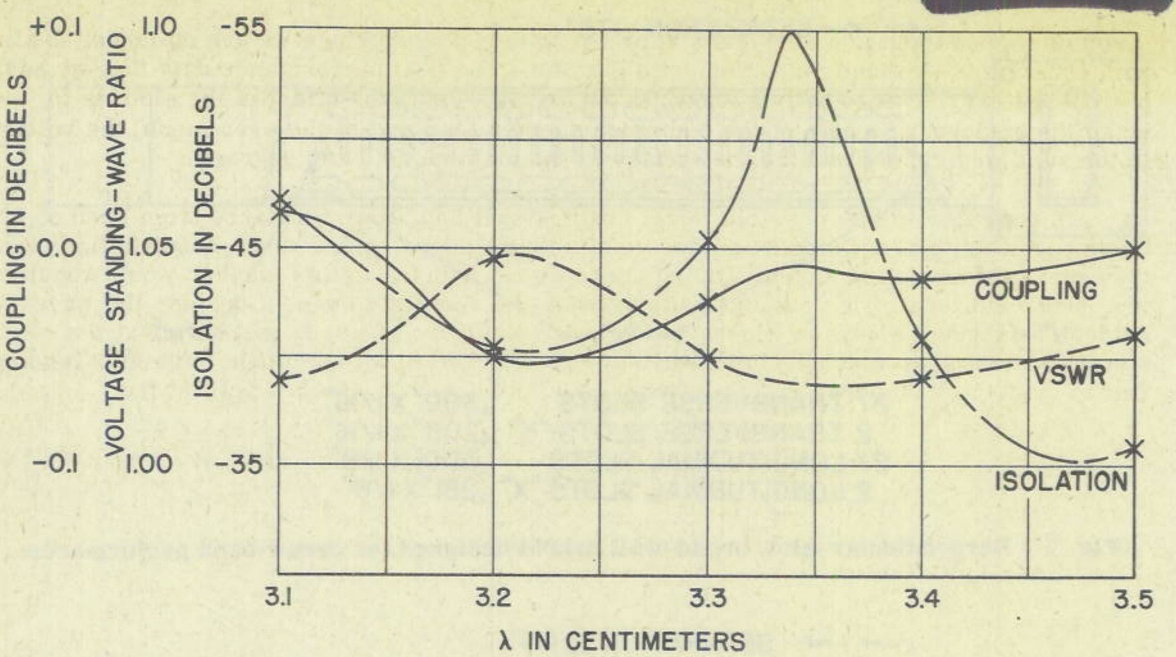

Fig. 9 - Performance of perpendicular-slot, broad-wall hybrid shown in Figure 7

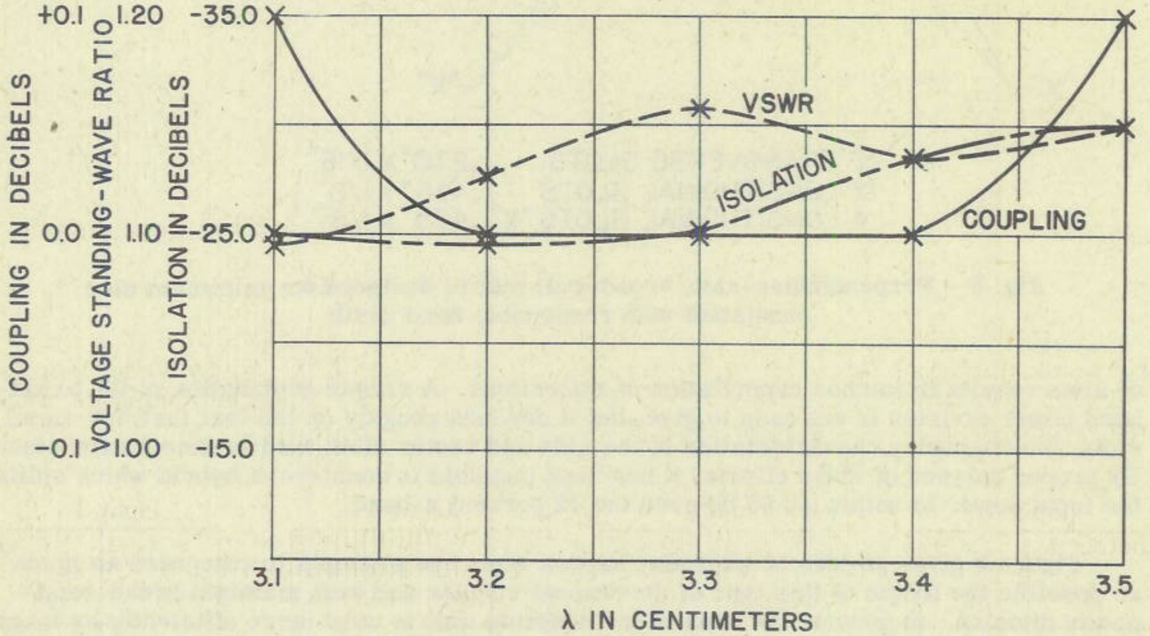

Fig. 10 - Performance of perpendicular-slot, broad-wall hybrid shown in Figure 8

maintain a good input standing-wave ratio for the even mode since we are no longer dealing with equal slots in shunt and series with the line. The best performance data that we have been able to arrive at to date is shown in Figure 10. Since the effect of the slots is to make the guide wave length of the odd mode shorter than that of the even mode, the voltage in the auxiliary guide must lag the voltage in the main guide by 90 degrees.

Although it would be possible to get conventional hybrid performance from each of these parallel-guide hybrids by adding a suitable 90-degree phase shift, construction of the exact analogue of SL circuits using conventional hybrids in this manner would require four phase shifters. This number can, however, be reduced to two. Consider the wave guide arrangement shown in Figure 11. Energy incident at input 1_i will divide at the staggered-slot side-wall hybrid between guides 1 and 2, with the voltage in guide 2 leading that in guide 1 by 90 degrees. The energy in guides 1 and 2 will then split at the perpendicular-slot hybrids where the voltages in guides 3 and 4 will lag by 90 degrees the voltages in guides 2 and 1, respectively. By symmetry, we may represent the phase of the outputs for the various inputs by the accompanying charts.

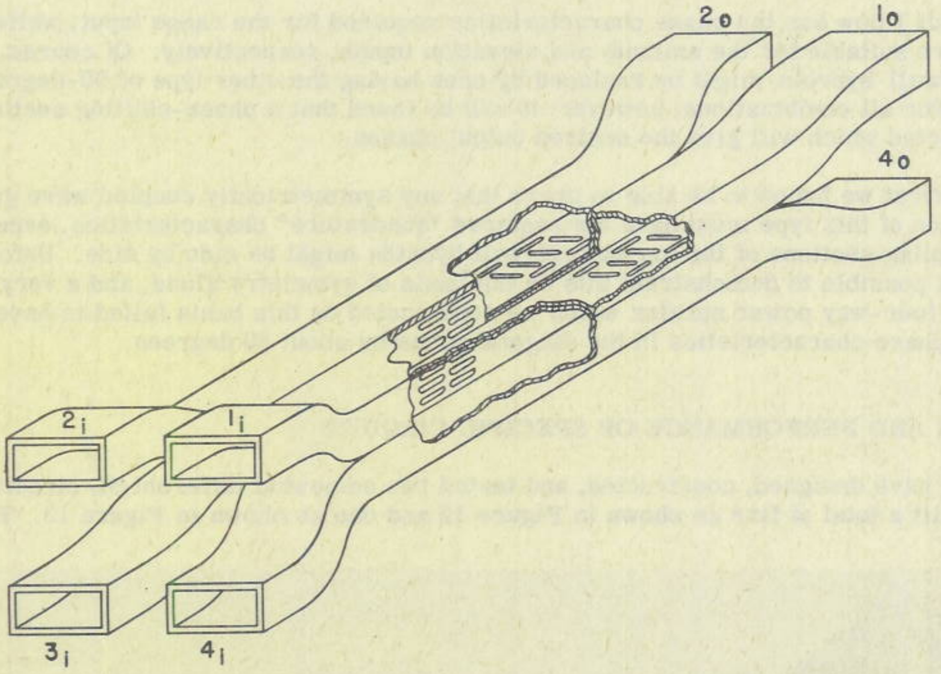

Fig. 11 - Four-guide hybrid arrangement

input 1

output 1 0°	2 +90°
4 -90°	3 0°

input 2

1 +90°	2 0°
4 0°	3 -90°

input 4

1 -90°	2 0°
4 0°	3 +90°

input 3

1 0°	2 -90°
4 +90°	3 0°

It is now possible to obtain the phase configuration required for SL by the use of two fixed phase shifters. It will be found, for example, that if we place a -90-degree phase shifter in output 2 and a +90-degree phase shifter in output 4, the following phase arrangements result.

input 1

0°	0°
0°	0°

input 2

+90°	-90°
+90°	-90°

input 4

-90°	-90°
+90°	+90°

input 3

0°	-180°
+180°	0°

Input 1 now has the phase characteristics required for the range input, while inputs 2 and 4 are suitable for the azimuth and elevation inputs, respectively. Of course, the top or sidewall hybrids might be replaced by ones having the other type of 90-degree phase shift. For all combinations, however, it will be found that a phase-shifting section can be constructed which will give the desired output phases.

At first we hoped to be able to prove that any symmetrically coupled wave guide configuration of this type must have the required "quadrature" characteristics, even though the coupling sections of the top and sidewall hybrids might be side by side. Unfortunately it is not possible to demonstrate this on the basis of symmetry alone, and a very satisfactory four-way power splitter which we constructed on this basis failed to have the required phase characteristics in the diagonal arms by about 30 degrees.

DESIGN AND PERFORMANCE OF SPECIFIC CIRCUITS

We have designed, constructed, and tested two somewhat different SL circuits. We have built a total of five as shown in Figure 12 and one as shown in Figure 13. They differ

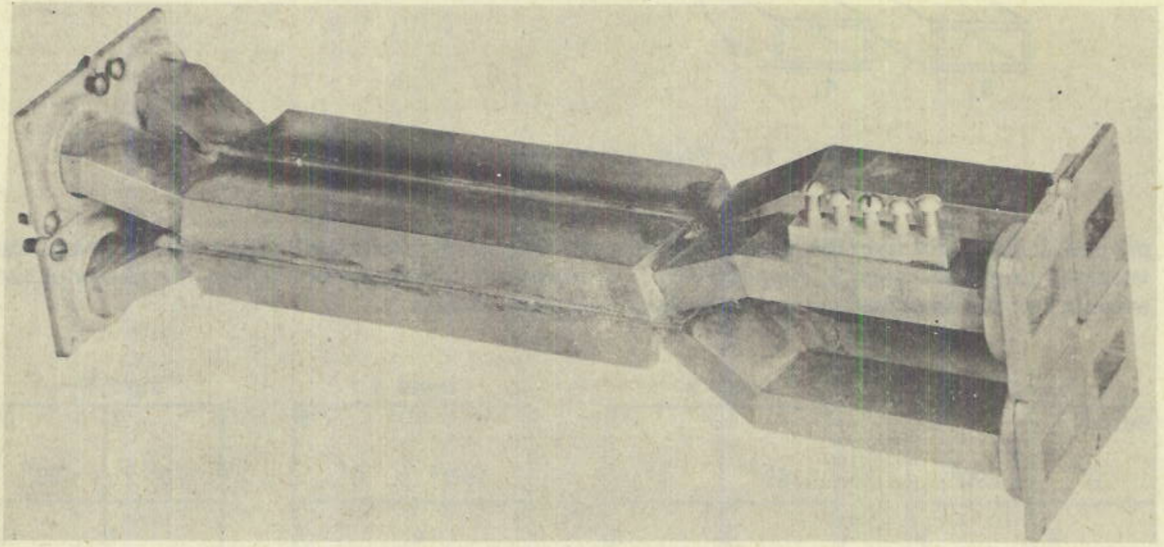

Fig. 12 - Model 1, simultaneous-lobing circuit

in two respects. In model 1, shown in Figure 12, the phase-shifting sections are placed in the wave guide, and the side-wall hybrids are of the staggered-slot type. The considerable reduction in over-all size accomplished in model 2, Figure 13, is made possible by including the phase shifters in the output horns and by replacing the staggered-slot hybrids by single-slot side-wall hybrids. In both, the phase shifters consist of five inductive rods or capacitive screws binomially proportioned, while the top-wall hybrids are of the compressed perpendicular-slot variety. Although the model of Figure 13 is the more compact, that of Figure 12 is of broader band and appears to be admirably suited for studying some of the questions involved in determining optimum horn dimensions.

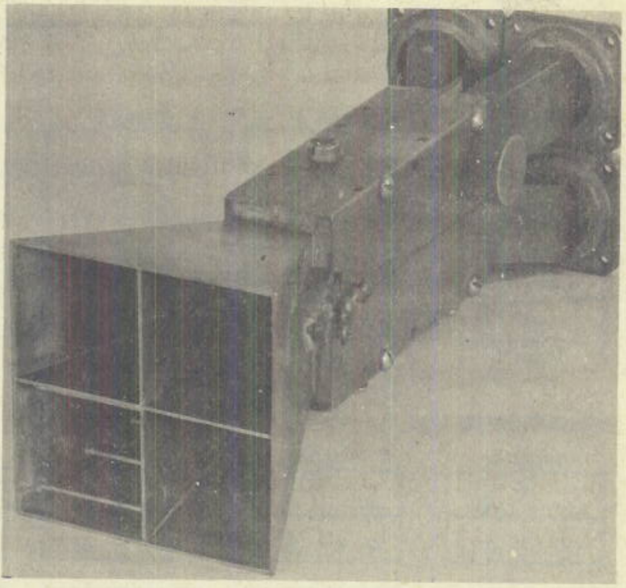

Fig. 13 - Model 2, simultaneous-lobing circuit

The first step in the construction of each of these circuits has been the design and construction of four-way power dividers, as shown in Figure 11, with chokes and flanges on the wave-guide terminals to provide for convenient measurement. Figure 14 gives a good idea of the method of construction used to date, although, in the final models, the side- and top-wall couplers do not overlap.

Since the phase and amplitude characteristics of these hybrids are critical functions of the guide dimensions, special care should be used in the soldering of the parts to assure symmetry. In the construction of model 2, this was done by pinning the parts together with drill rod before soldering. Even so we have been unable to construct the parts so as to obtain power balance better than a tolerance of about ± 0.3 db. Accordingly, some sort of tuning adjustment has been required. In the model 1 circuit, this was done by inserting pins into the longitudinal slots and thereby changing their effective size. In the model 2 circuit, portholes in the heavy brass walls were provided so that the slot lengths could be altered by filing.

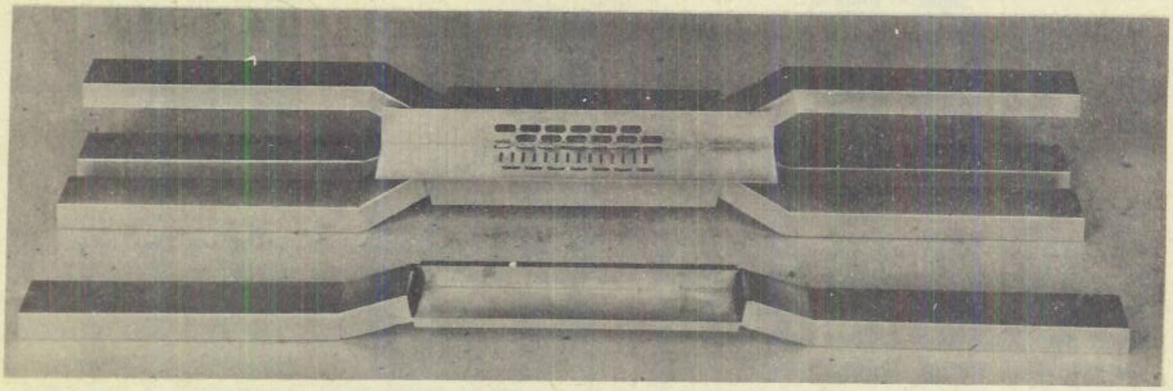

Fig. 14 - Method of construction of experimental simultaneous-lobing circuits

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COUPLING IN Db.

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
0	+.1	+.15	0	0	+.05	+.1	0	0	+.05	+.05	0
+.05	0	-.05	0	+.05	-.05	-.1	0	+.05	-.1	-.2	-.05
+.05	-.05	-.05	0	+.05	-.05	-.05	0	+.05	-.05	-.1	-.05
0	0	+.05	0	0	0	+.05	0	0	0	-.05	0
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

ISOLATION IN Db.

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
---	-37	-37	---	---	-37	-37	---	---	-37	-37	---
-30.6	-20.8	-20.8	-27.6	-26.1	-20.2	-20.2	-25.1	-24.3	-19.6	-19.7	-23.9
-27.5	-20.8	-20.8	-26.5	-27.0	-20.2	-20.3	-24.8	-24.7	-19.6	-19.7	-23.8
---	-37	-37	---	---	-37	-37	---	---	-37	-37	---
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

PHASE IN DEGREES

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
0	92.2	89.6	0	0	93.2	88.5	0	0	92	88.7	0
-86.6	+.7	3.7	-88.6	-85	3.5	2.9	-88.3	-86.5		5.0	-88.5
-93.7	-1.5	-4.3	-91.0	-93.3	-.8	-4.2	-92	-95.6	-1.5	-4.2	-92.9
0	89.5	93.7	0	0	90.5	94	0	0	89.3	93.5	0
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

VSWR

Input 4	Input 3	Input 4	Input 3	Input 4	Input 3
1.14	1.12	1.11	1.10	1.11	1.10
1.15	1.15	1.12	1.16	1.15	1.18
Input 1	Input 2	Input 1	Input 2	Input 1	Input 2

Fig. 15 - Performance of model 2 circuit without horns and phase shifters

Figure 15 gives, in condensed form, the significant characteristics of the model 2 circuit before the addition of the phase shifters. After balancing by tuning, the model 1 circuit was completed by replacing two of the sections of guide at the output end by phase-shift sections whose characteristics had been determined previously. The final characteristics of one of these model 1 circuits is shown in Figure 16. Although no patterns were taken with this particular circuit, patterns were taken with the circuit of this type delivered to NRL. For this purpose, horns 1-5/8 x 1-5/8" were added to the output

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COUPLING IN Db.

9425 Mc				9375 Mc				9325 Mc			
Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
-.1	+.15	0	-.1	-.1	+.1	-.05	-.05	-.1	+.05	-.05	0
+.1	+.1	+.1	0	+.15	0	+.05	-.05	+.15	0	+.1	-.05
+.05	0	+.15	0	+.1	-.1	+.1	-.05	+.05	-.1	0	-.15
0	0	-.1	+.1	0	0	-.15	+.1	0	+.05	-.1	+.1
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

ISOLATION IN Db.

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
---	-23.3	-22.8	---	---	-22.1	-22.2	---	---	-20.8	-20.8	---
-34.3	-27.3	-27	-35	-33.5	-26.5	-26.5	-34	-31.7	-24.7	-24.9	-32.5
-35.2	-27.7	-27.6	-35	-34.3	-27	-27.3	-34.8	-33	-25.3	-25.5	-33
---	-26.1	-25.8	---	---	-24.6	-24.5	---	---	-25.7	-25.3	---
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

PHASE IN DEGREES

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
-3	+183	-3.2	+3.2	+179.6	+3.6	-2.8	+2.8	+178.4	+3.2	+180.8	+183.2
+177.4	+1.0	+177.2	+181.2	-3.6	+183.6	+177.2	+182.8	-4.8	+184.7	-2.4	+3.2
+181	+2.2	-.4	+2.0	+182.4	+2.4	+1.6	+2.4	+2.4	+184	+2.8	+2.0
+177.8	-1.0	-2.0	-1.2	+177.6	+.8	-2.4	-.8	-4.0	+181.6	-2.8	+.4
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

VSWR

Input 4	Input 3	Input 4	Input 3	Input 4	Input 3
1.06	1.04	1.06	1.04	1.08	1.07
1.03	1.05	1.04	1.05	1.05	1.06
Input 1	Input 2	Input 1	Input 2	Input 1	Input 2

Fig. 16 - Performance of model 1 circuit

terminals and the whole used to illuminate a four-foot metal-plate lens having a focal length of four feet. Figures 17 and 18 show the sum and difference patterns respectively for both planes at the design frequency. Figure 19 shows how the null depths varied as a function of frequency over the 12-percent x-band.

The completion of the model 2 circuit was more difficult because of the additional complication introduced by placing the phase-shift elements in the horns. The significant

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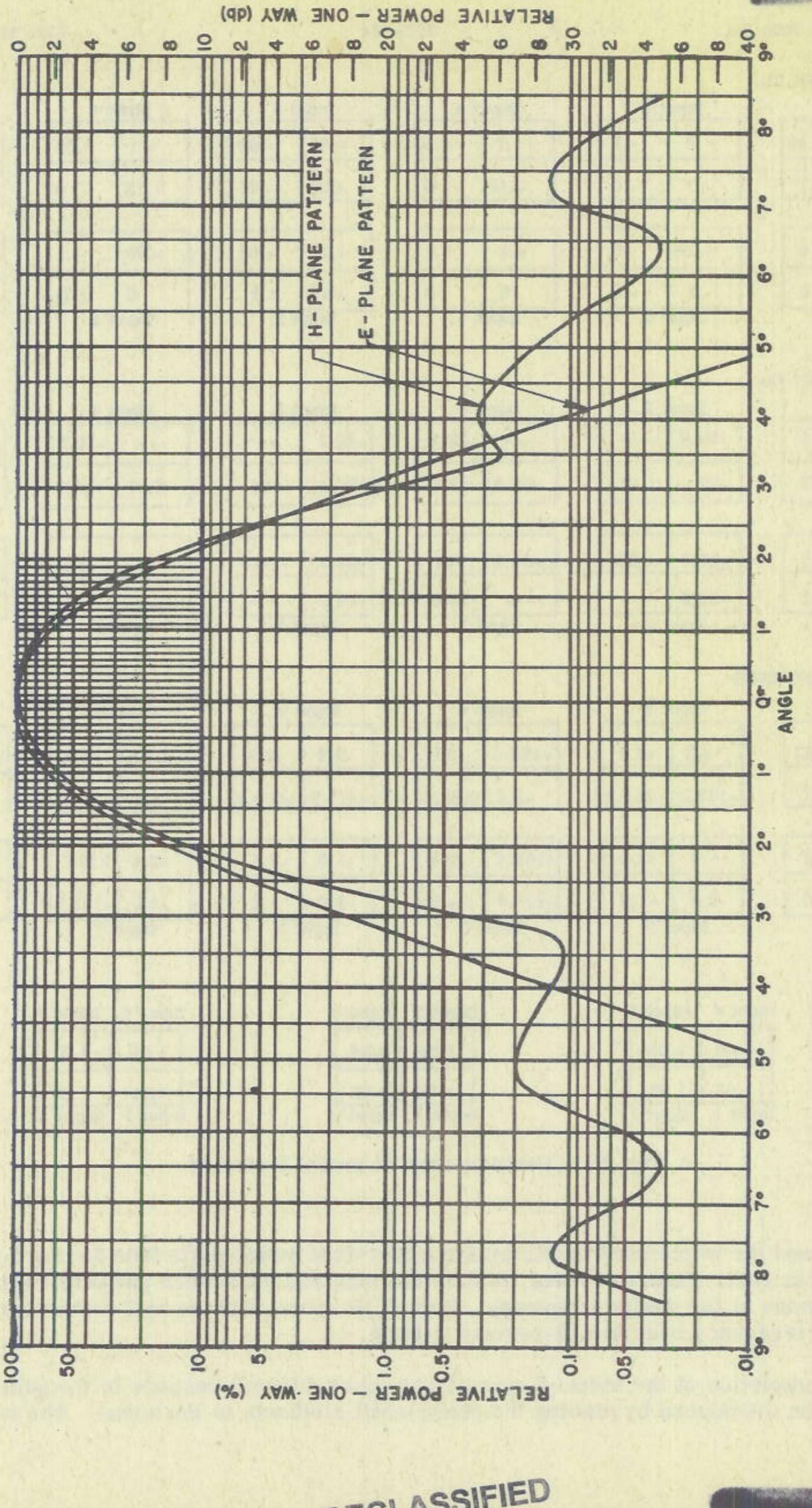

Fig. 17 - Sum patterns of lens fed by model 1 circuit

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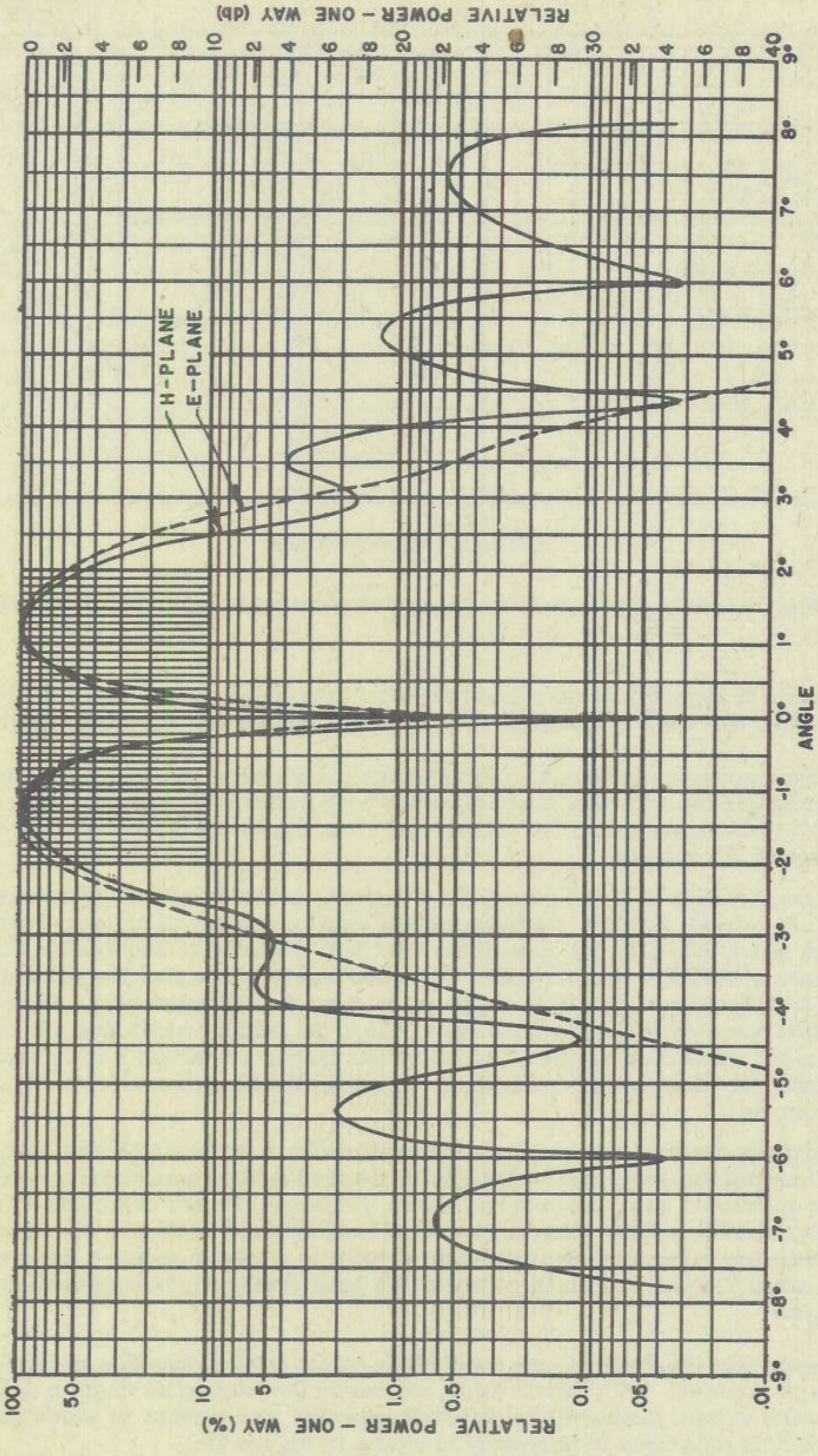

Fig. 18 - Difference patterns of lens fed by model 1 circuit

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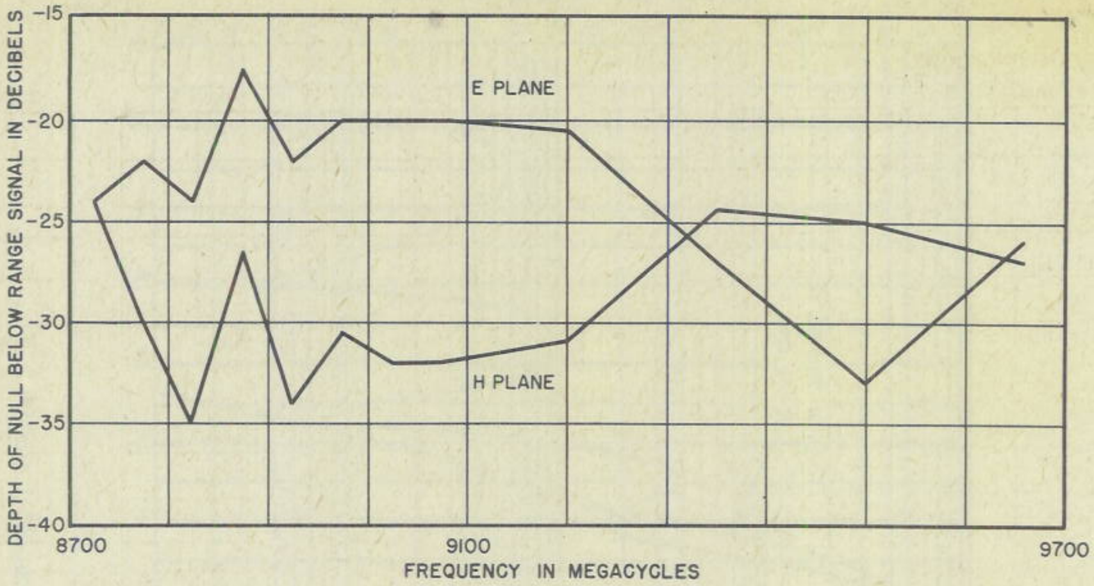

Fig. 19 - Null depths in horn difference patterns using model 1 circuit

data that could be determined by measurements at the inputs to the model 2 circuit are given in Figure 20. Here it should be observed that input 2 was the range input.

In designing the phase-shift horns, the principal question was whether or not the phase-shifting screws and rods would alter the horn patterns by exciting higher modes. Figures 21 and 22 indicate that the screws and rods may be so placed as to have a negligible effect on the patterns.

Since measurements of the power division at the horns and the relative phases are very difficult to make directly, we have instead made a number of primary pattern measurements from which this data will have to be inferred. Figures 23 and 24 give the sum patterns in both planes at 3.3, 3.4, and 3.5 cms. The wider range of frequencies is chosen because there was no appreciable change in the patterns over the narrower band. Figures 25 and 26 show the difference patterns over this band. Since the angular scale was not shifted during the experiment, these data suggest that the output phases are within a few degrees of that desired since, for this arrangement, phase errors at the horns result directly in angular motion of the null.

Secondary pattern measurements were made using a metal-plate lens having an aperture of 46" and a four-foot focal length. With the feed located approximately on axis and focused for maximum gain, the patterns shown in Figure 27 were obtained. Variation in depth of the azimuth and elevation nulls over a band is given in Figure 28. It should be observed that this particular feed appears to result in a loss in gain for the over-all antenna of about 2 db as compared with what we have previously been able to obtain with the same lens.

It is clear that the depth of null should be a fairly critical function of the location and orientation of the feed. With this in mind, we moved the feed so as to get a deeper null simultaneously in both planes at the center frequency. The manner in which this depth of null varied as a function of frequency is shown in Figure 29.

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COUPLING IN Db.

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

ISOLATION IN Db.

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
			---				---				---
		-21.8				-22				-21.8	
			-29.3				-34				-25
		-33.6	---			-27.5	---			-34.8	---
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

PHASE IN DEGREES

Input 4		Input 3		Input 4		Input 3		Input 4		Input 3	
Input 1		Input 2		Input 1		Input 2		Input 1		Input 2	

VSWR

Input 4	Input 3	Input 4	Input 3	Input 4	Input 3
1.03	1.15	1.04	1.14	1.09	1.15
1.06	1.26	1.10	1.29	1.16	1.29
Input 1	Input 2	Input 1	Input 2	Input 1	Input 2

Fig. 20 - Performance of model 2 circuit with horns and phase shifters

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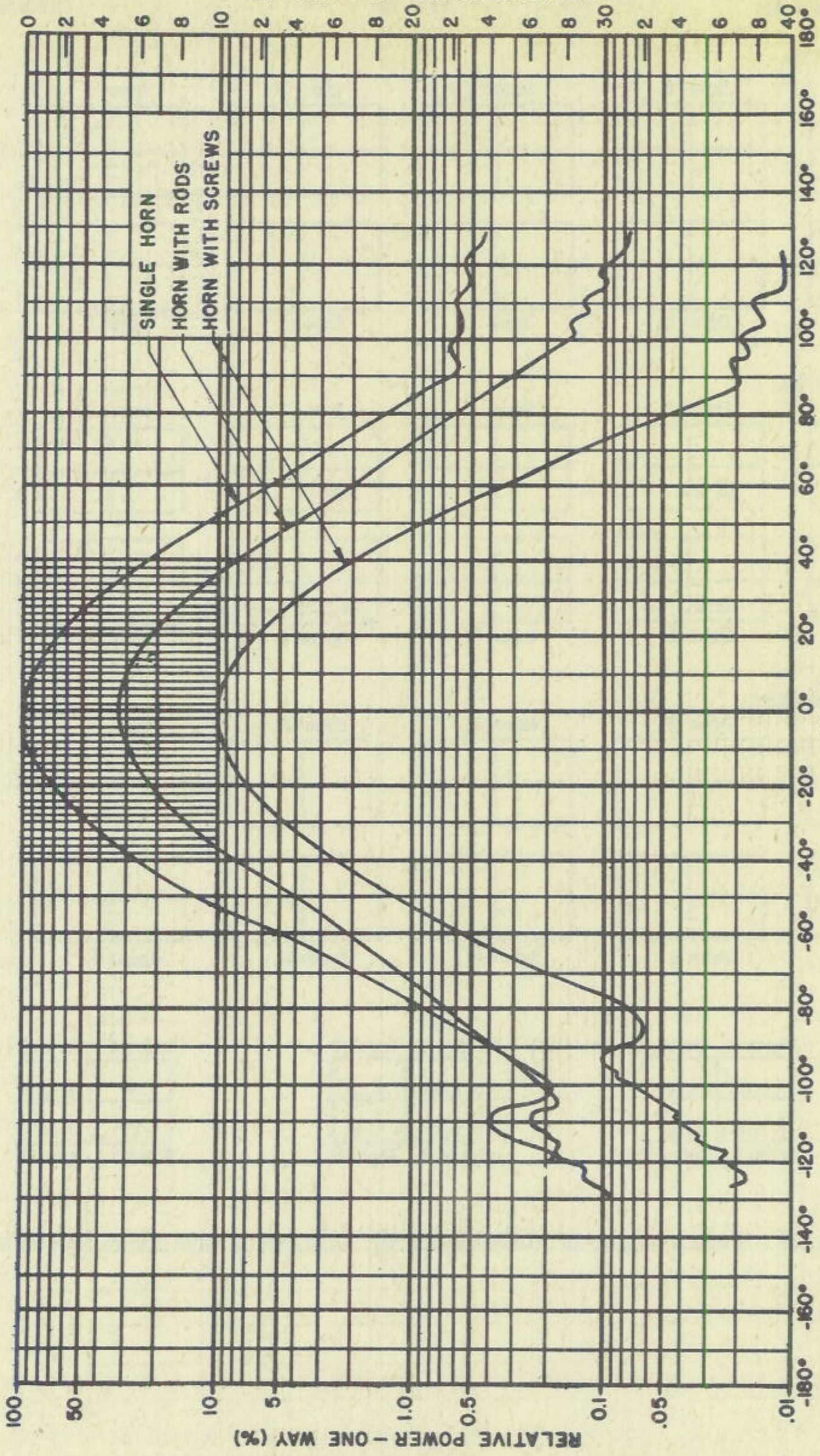

Fig. 21 - Effect of rods and screws on H-plane pattern of single horn (λ = 3.4 cm)

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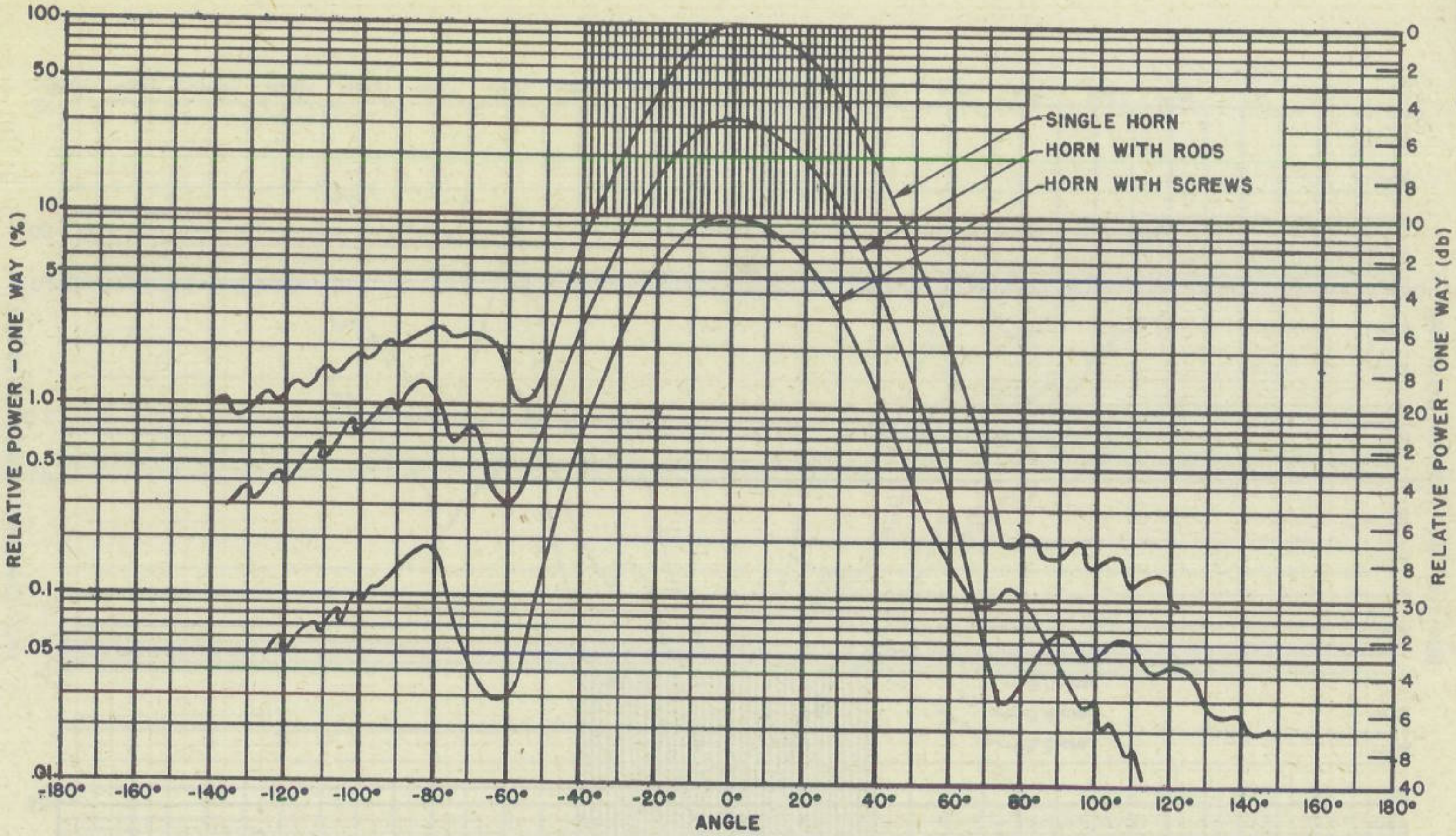

Fig. 22 - Effect of rods and screws on E-plane pattern of single horn ($\lambda = 3.4$ cm)

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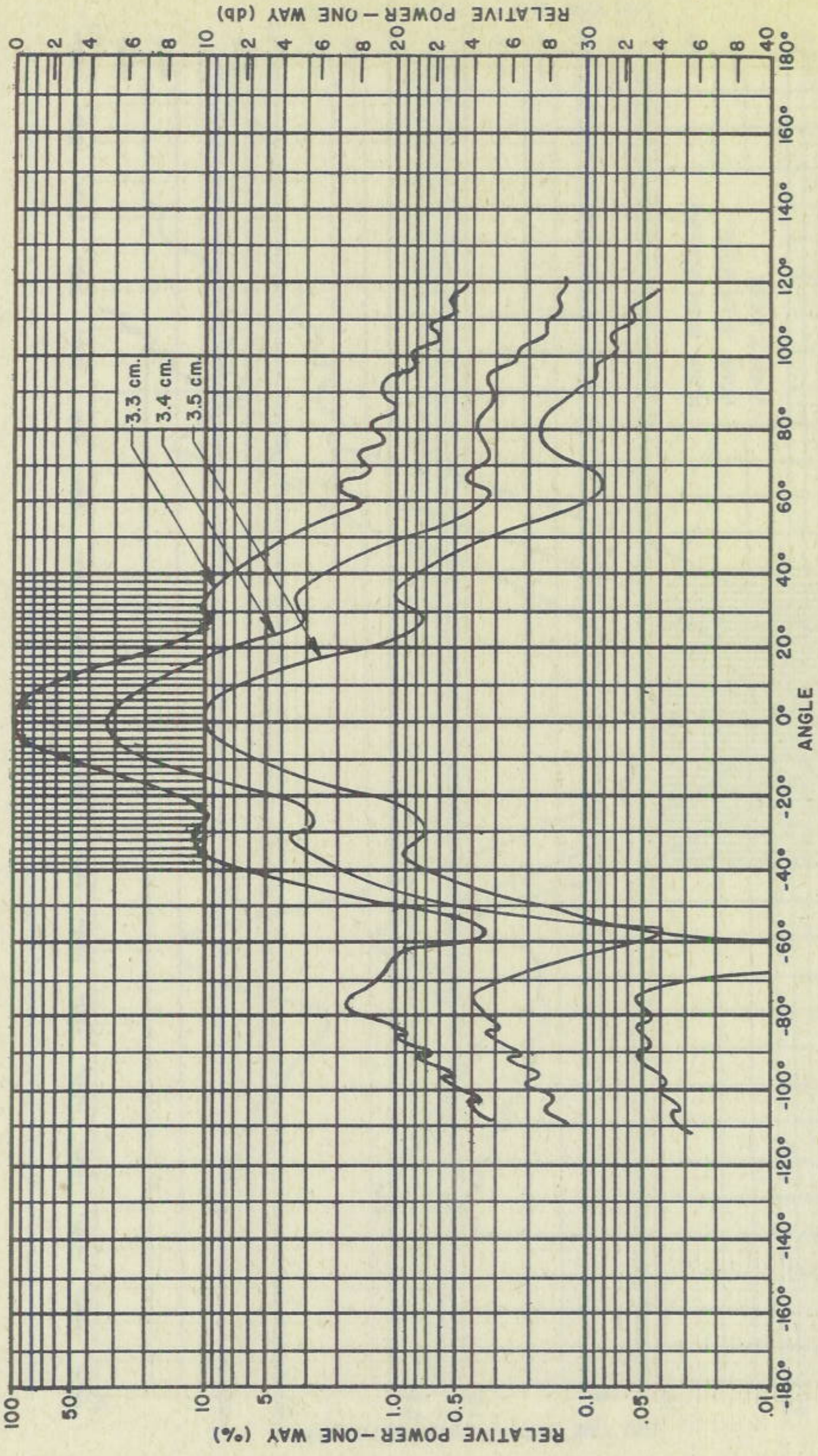

Fig. 23 - Sum patterns of four-horn feed (E-plane)

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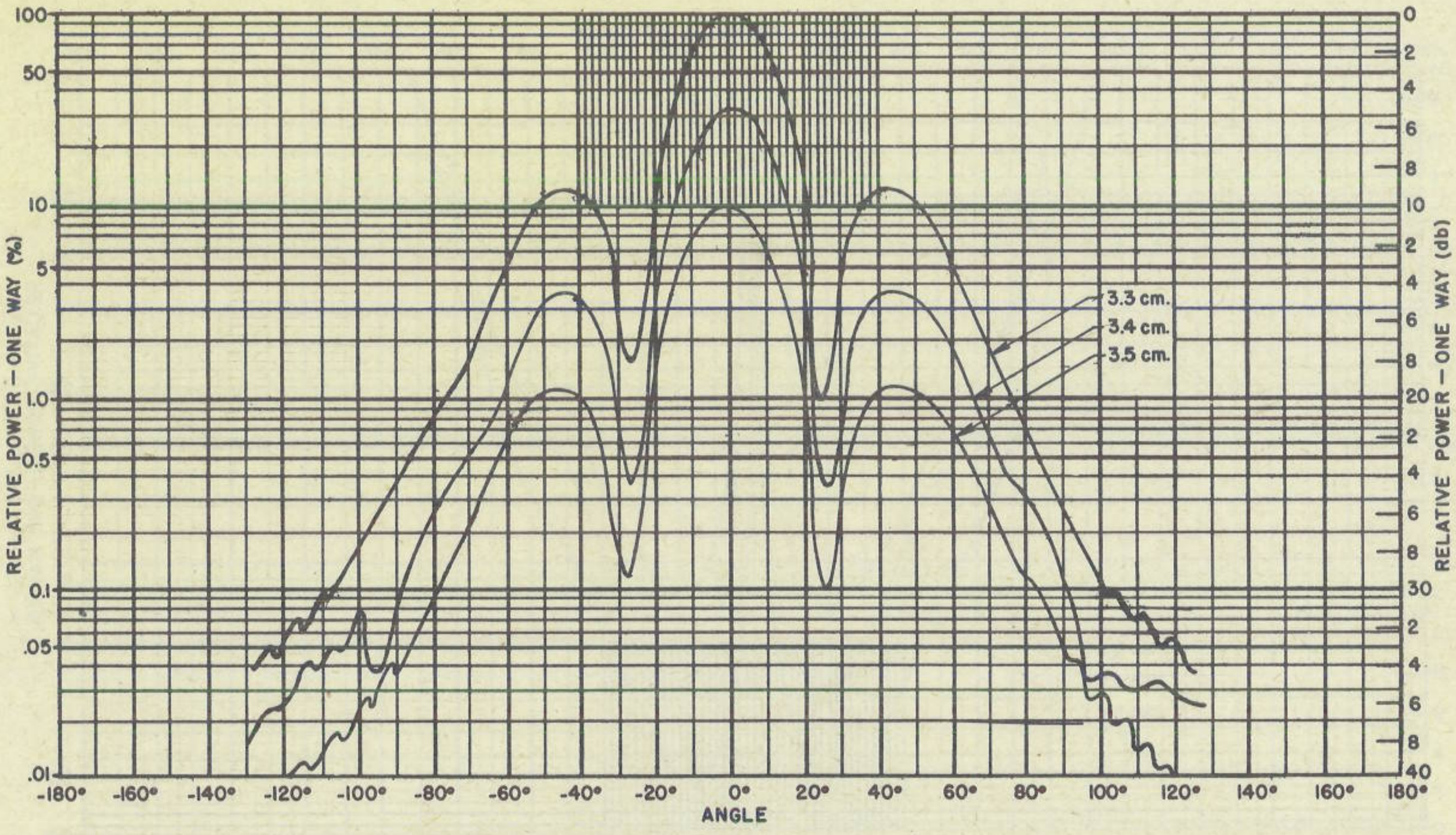

Fig. 24 - Sum patterns of four-horn feed (H-plane)

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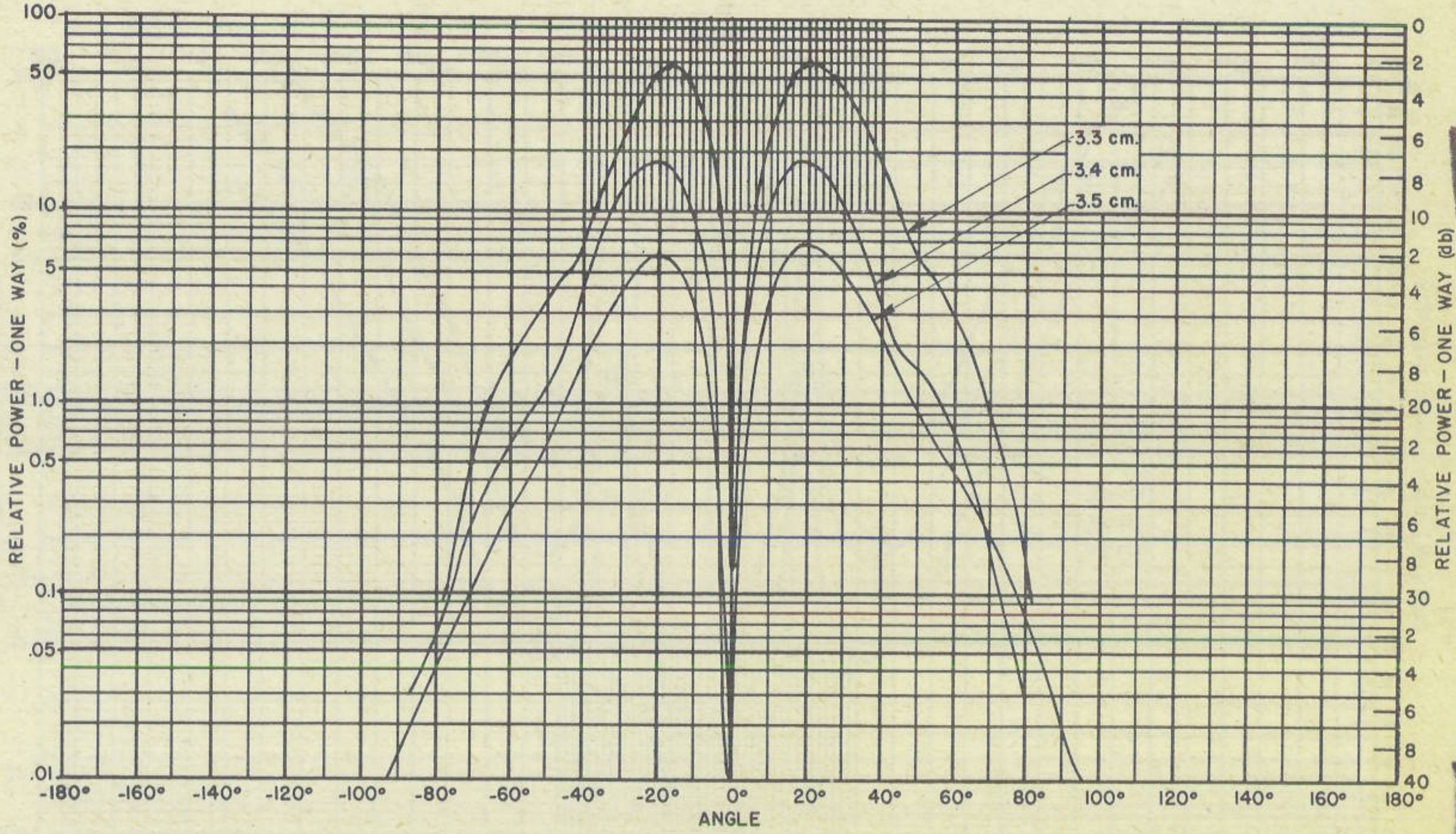

Fig. 25 - Difference patterns of four-horn feed (E-plane)

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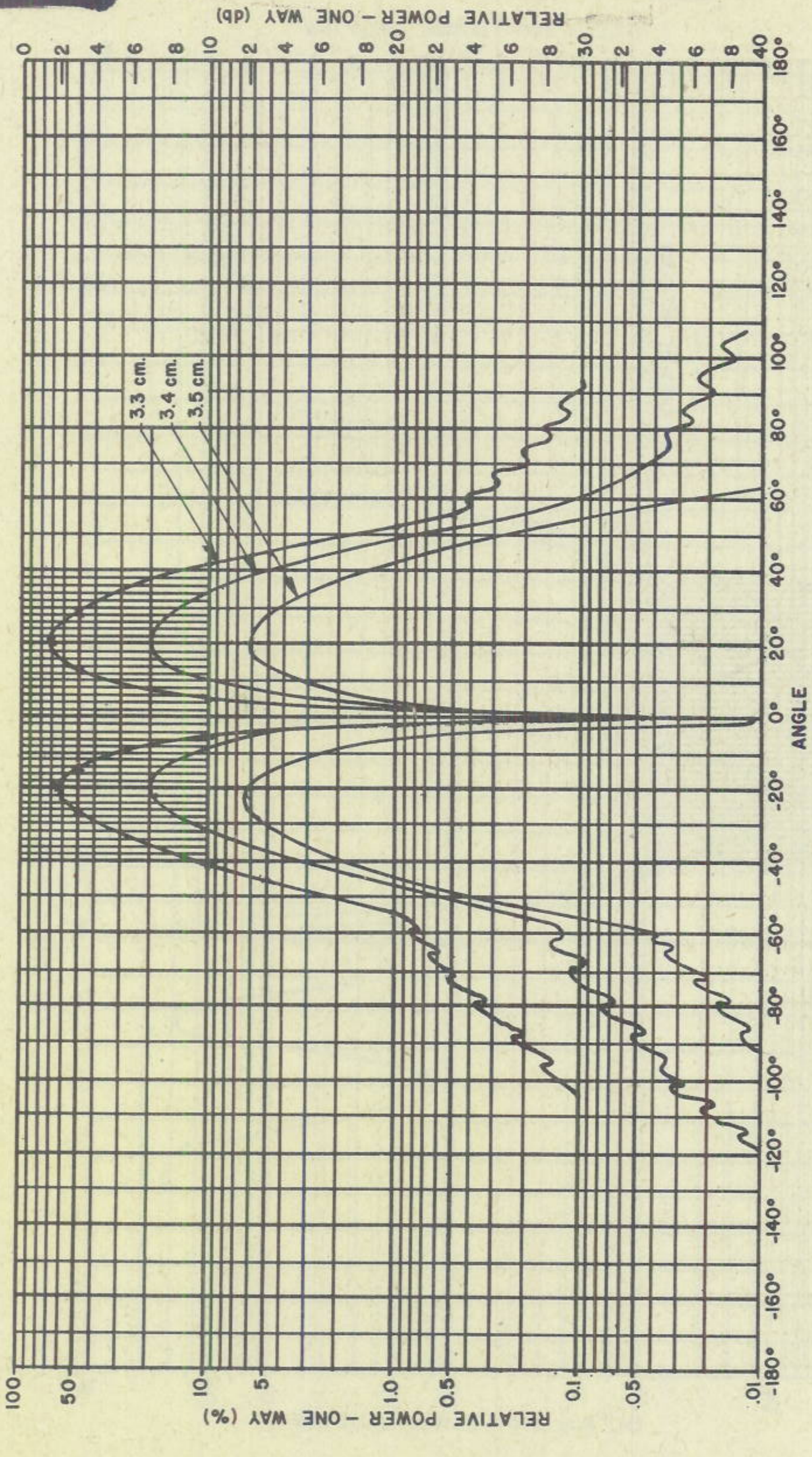

Fig. 26 - Difference patterns of four-horn feed (H-plane)

[redacted]

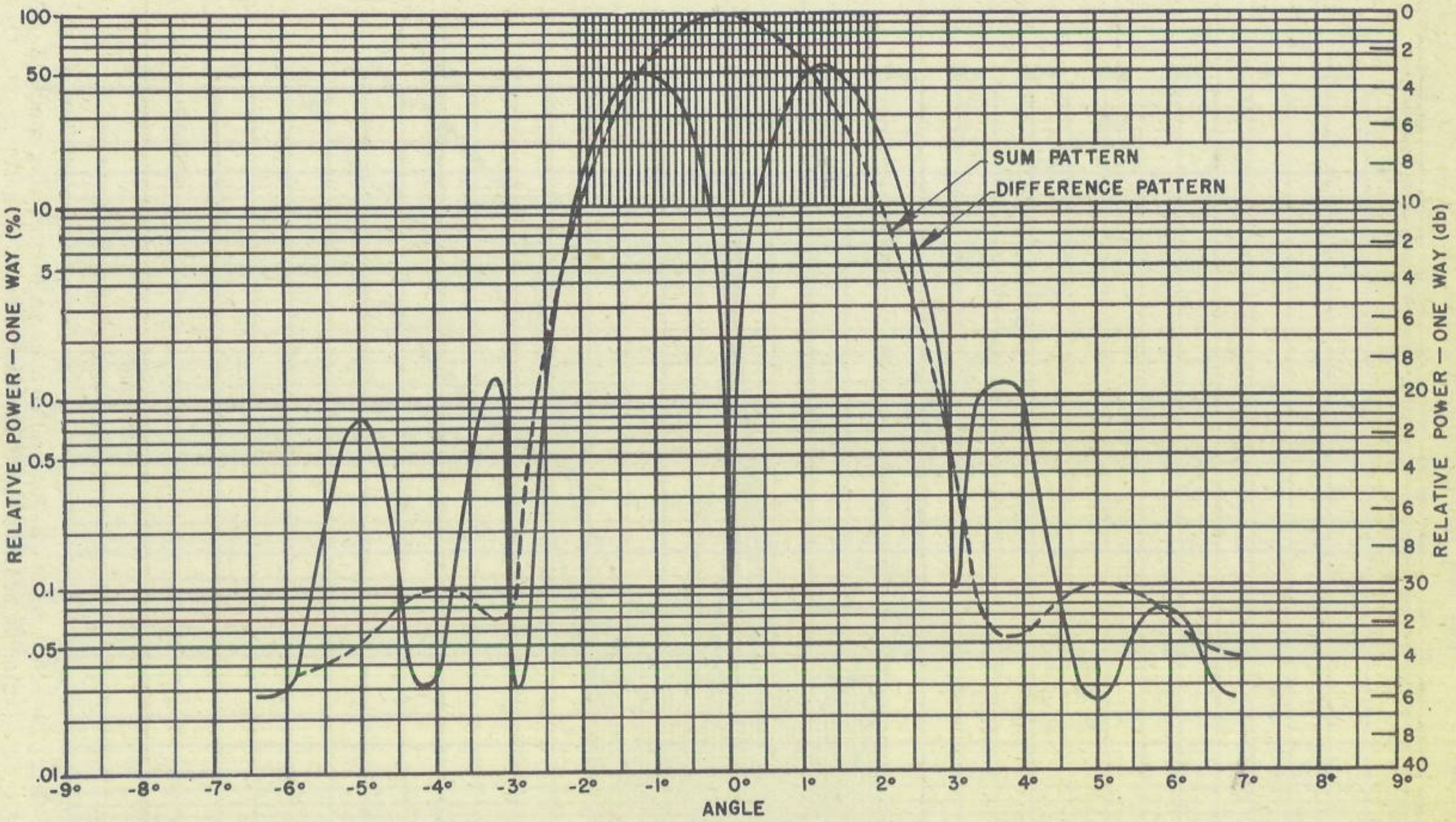

Fig. 27 - H-plane patterns of lens with four-horn feed adjusted for maximum gain (gain = 34 db at λ = 3.4 cm)

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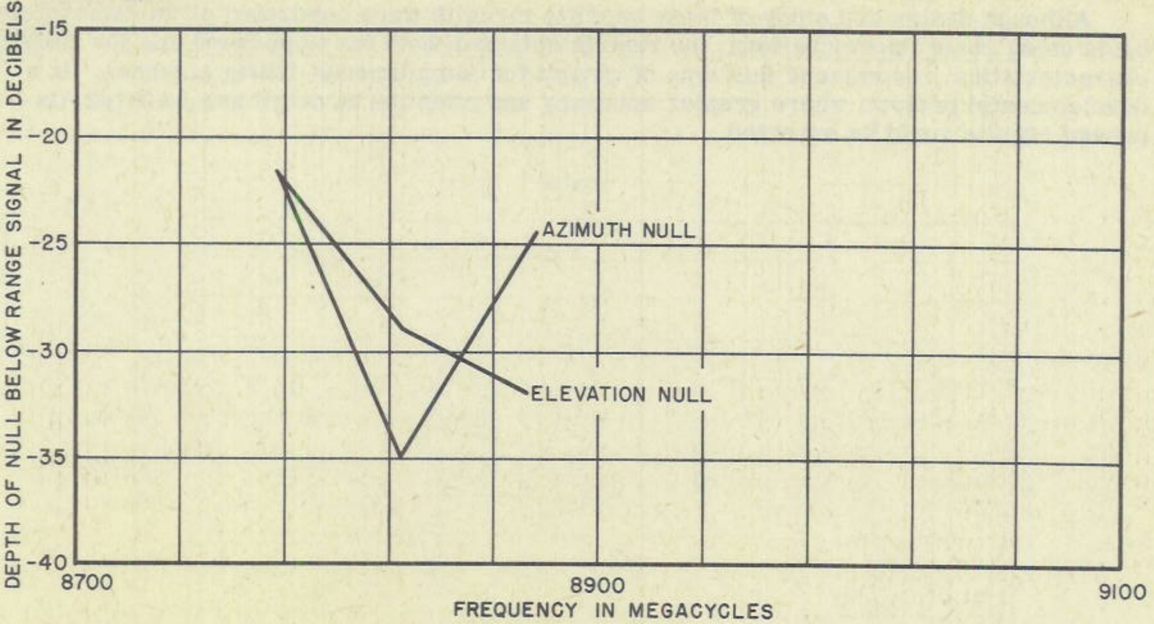

Fig. 28 - Null depths in lens difference patterns using model 2 circuit positioned for maximum gain

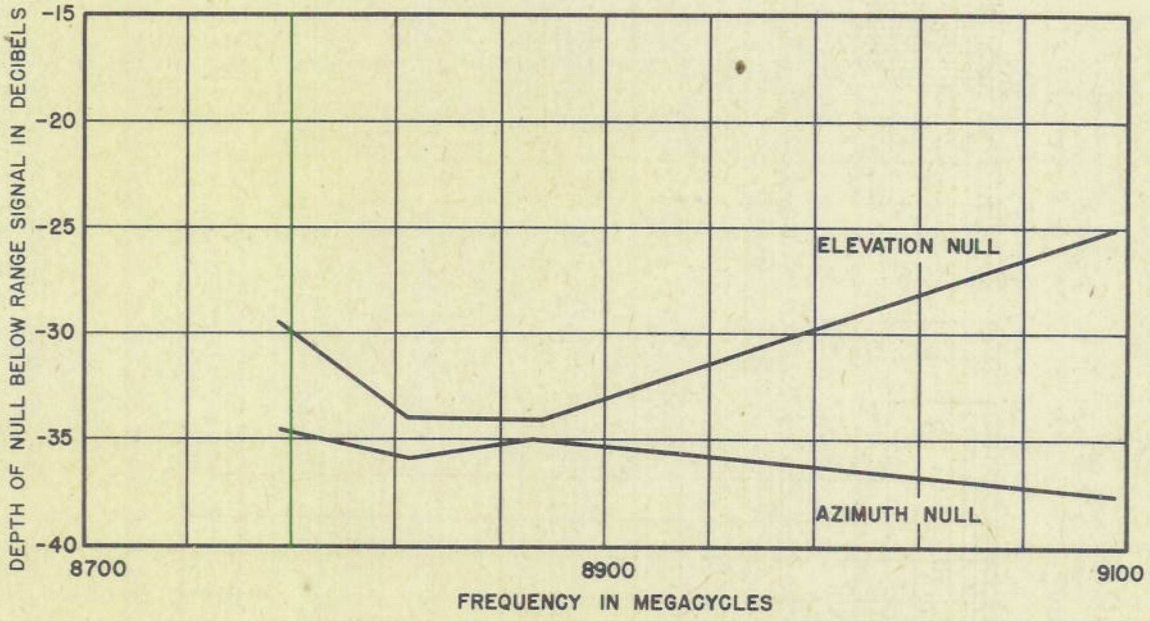

Fig. 29 - Null depths in lens difference patterns using model 2 circuit positioned for maximum depth of nulls

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Although design and study of these specific circuits were conducted on an exploratory basis using some improvisations, the results obtained, both for impedance and for pattern characteristics, recommend this type of circuit for simultaneous-lobing antennas. In a developmental project, where greater accuracy and attention to detail are justified, improved results could be expected.

* * *