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**MICROWAVE HYBRID COUPLER
STUDY PROGRAM**

REPORT NO. 61361-2
CONTRACT DA 36-239 SC-87435
TASK NO. 40645-PM-61-93-93

**THIRD QUARTERLY PROGRESS REPORT
1 NOVEMBER 1961 TO 31 JANUARY 1962**

**U.S. ARMY SIGNAL SUPPLY AGENCY
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MICROWAVE HYBRID COUPLER
STUDY PROGRAM

REPORT NO. 61361-2
CONTRACT DA 36-239 SC-87435

SPECIFICATION SCL-7598, 16 DECEMBER 1960
TASK NO. 40645-PM-61-93-93

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Prepared by:


Seymour B. Cohn

and


Rollin H. Koontz

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SECTION I

PURPOSE

1. Purpose of Program

The objective of this program is to advance the state of the art in the field of microwave 3-db directional couplers through applied research and development. This work is directed toward the development and exploitation of new techniques and approaches which will provide a basis for achieving broad bandwidth 3-db couplers. The constructions to be considered are waveguide and TEM-mode transmission line. In the waveguide construction, the objective is for a 40-percent bandwidth, whereas in the TEM-mode transmission line a five-to-one frequency range is to be achieved.

SECTION II

ABSTRACT

A general method of computing the response of an n-section TEM-mode directional coupler is given and applied to the synthesis of a five-section design. The final results were the design parameters of a five-section coupler having an equal-ripple coupling function bounded by -3.010 ± 0.163 db over a 5.81 to 1 bandwidth. This performance should be compared to -3.0 ± 0.5 db obtainable from a three-section coupler over the same bandwidth.

Coupling and directivity curves are given for the one-section 1-to-2-Gc coupler described previously. The mid-band coupling is -2.6 db, which is 0.1 db greater than the design value. The minimum directivity is 29 db.

A new set of curves is given for the 400 to 2000 Mc three-section coupler described in the Second Quarterly Report. These curves show the results of several minor changes made in the strip-line end sections of the coupler. The maximum coupling variation is now ± 0.5 db between 400 and 2100 Mc, while the minimum directivity in that band has increased to 29 db.

The results of a continuing study of waveguide broad-wall couplers are described. A configuration meeting this program's coupling goal of -3.0 ± 0.5 db over the 8.2 to 12.4 Gc band was achieved. This configuration consists of two rows each containing nine uniform holes. In order to

improve the directivity response, this basic design was then modified into one with tapered eleven-hole rows, as suggested in the First Quarterly Report. A considerable increase in directivity was obtained. During the various tests, however, the existence of minor resonances near the high-frequency end of the band was noted. These resonances are now being studied to determine whether they are important and, if so, to devise techniques for moving them out of the band.

SECTION III
CONFERENCES

1. Conferences

On January 18, 1962, a meeting was held at Rantec Corporation attended by Messrs. J. Agrios of USASRDL, and S. B. Cohn, R. H. Koontz and S. L. Wehn of Rantec. Progress on various aspects of the program was discussed. It was agreed that work would continue on two-row top-wall couplers having eleven holes per row, and on the unsymmetrical side-wall coupler. It was also agreed that a three-section TEM-mode coupler for 0.4 - 2.0 Gc would be constructed with a parallel-strip center section, and that a similar coupler with a re-entrant center section would be constructed for 1 - 5 Gc. Development of a five-section coupler will be deferred at this time.

SECTION IV
FACTUAL DATA

1. Introduction

This is the third quarterly report on a program to develop 3-db directional couplers having increased bandwidth and improved performance. Directional couplers with 3-db coupling (also called hybrid couplers) have many uses; for example, they are basic components of balanced mixers, duplexers, power dividers, ferrite circulators, multiplexing filters, monopulse circuitry, etc. Although considerable progress has been made in the design of broadband 3-db couplers, future microwave systems will require substantial advances. This program of investigation and development is intended to meet that requirement.

A new topic, five-section TEM-mode directional couplers, is treated in this report. In addition, experimental data on broad-wall waveguide couplers and on TEM-mode couplers are presented and discussed.

2. Five-Section TEM-Mode Directional Couplers

Three-section TEM-Mode couplers can provide a coupling deviation of ± 0.4 db over a 5.13 to 1 frequency band. This performance meets the goal of this program (± 0.5 db over 5:1) but by a small margin. For this reason, the potentialities of a five-section design were studied, and are discussed in this report. Only an odd number of sections were considered, since an even number would lead to physical dissymmetry, yielding a non-quadrature phase relationship of the outputs.

Figure 2-1a shows the schematic diagram of the five-section parallel-coupled-line directional coupler. (The following remarks

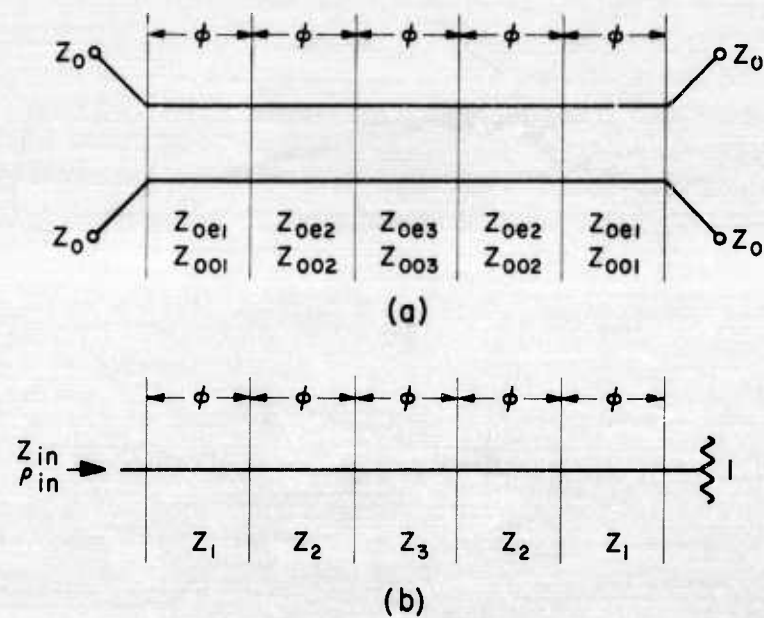


Figure 2-1. Schematic Diagram of $5\lambda/4$ TEM-Mode Coupler (a), and Reduced Equivalent Circuit (b).

hold in general for any number of sections). In order for the ports to be matched and the directivity to be infinite at all frequencies, it is necessary for the following relationship to hold between the even- and odd-mode characteristic impedances of each section.^{1,2}

$$Z_{oei} Z_{ooi} = Z_o^2 \quad (2-1)$$

or

$$\frac{Z_{oei}}{Z_o} = \frac{Z_o}{Z_{ooi}} \quad (2-2)$$

where $i = 1, 2$ or 3 . From equation 2-2 it is clear that the equivalent circuits for the two modes are duals of each other; that is $(Z_{in})_e / Z_o = Z_o / (Z_{in})_o$ and $(\rho_{in})_e = -(\rho_{in})_o$ where Z_{in} is input impedance and ρ_{in} is input reflection coefficient with Z_o loads on the other three ports.

Furthermore, the coupling ratio is given simply by

$$k = |\rho_{in}|$$

where $|\rho_{in}|$ is the magnitude of $(\rho_{in})_e$ or $(\rho_{in})_o$. Thus, it is only necessary that the equivalent circuit for one mode be considered, as in Figure 2-1b. If we let this circuit represent the even-mode condition, then

$$Z_1 = \frac{Z_{oe1}}{Z_o}, \quad Z_2 = \frac{Z_{oe2}}{Z_o}, \quad Z_3 = \frac{Z_{oe3}}{Z_o} \quad (2-3)$$

where $Z_1, Z_2,$ and Z_3 are all greater than unity.

The desired coupling response achievable with five sections is sketched in Figure 2-2. The curve has five equal maxima and two equal minima deviating by an amount δ from the -3 db nominal value (-3.01 db to be more exact). A specific set of values of Z_1 , Z_2 , and Z_3 is needed to obtain this equal-deviation response.

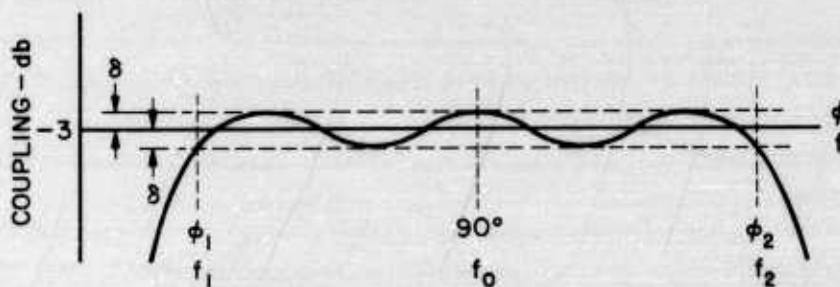


Figure 2-2. Equal-Ripple Response of a Five-Section TEM-Mode Directional Coupler

The circuit in Figure 2-1b is of a type that can be synthesized exactly to yield the desired response function. However, inasmuch as only one numerical solution to the problem was desired, it was considered more economical to obtain the correct values of Z_1 , Z_2 , and Z_3 by judicious mathematical trial and error.

Because the circuit in Figure 2-1b is symmetrical and lossless, its properties can be determined from half the structure, as shown in Figure 2-3. In terms of the A, B, C, D matrix parameters of this half

structure, the power transmission coefficient is³

$$|t|^2 = \frac{1}{1 - (AB-CD)^2} \quad (2-4)$$

A basic property of the ABCD parameters of a lossless two-port network is that A and D are real while B and C are imaginary.

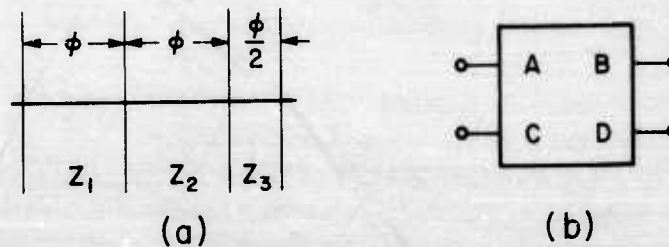


Figure 2-3. Half Structure of the Five-Section Coupler (a) and its ABCD Matrix Representation (b)

Let

$$A = a, \quad B = jb, \quad C = jc, \quad D = d \quad (2-5)$$

where a, b, c, and d are real. Then

$$|t|^2 = \frac{1}{1 + (ab-cd)^2} \quad (2-6)$$

and

$$k^2 = |\rho_{in}|^2 = 1 - |t|^2 = \frac{(ab-cd)^2}{1 + (ab-cd)^2} \quad (2-7)$$

The matrix multiplication for the circuit of Figure 2-3 is expressed as follows in terms of the matrices for the individual line lengths.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \phi & jZ_1 \sin \phi \\ \frac{j}{Z_1} \sin \phi & \cos \phi \end{bmatrix} \cdot \begin{bmatrix} \cos \phi & jZ_2 \sin \phi \\ \frac{j}{Z_2} \sin \phi & \cos \phi \end{bmatrix} \cdot \begin{bmatrix} \cos \frac{\phi}{2} & jZ_3 \sin \frac{\phi}{2} \\ \frac{j}{Z_3} \sin \frac{\phi}{2} & \cos \frac{\phi}{2} \end{bmatrix} \quad (2-8)$$

The process used in calculating A, B, C and D was to select likely values of Z_1 , Z_2 , and Z_3 , compute the various elements in the matrices for given values of ϕ , and then to perform the numerical matrix multiplication.

Choosing the correct set of values of Z_1 , Z_2 , and Z_3 is a complex problem. However, one simple relationship between their values can be established at $\phi = 90^\circ$, where

$$Z_{in} = \frac{Z_1^4 Z_3^2}{Z_2^4} = \frac{1 + k_o}{1 - k_o}, \quad (2-9)$$

k_o being the coupling ratio at band center.

A consideration of the principal of operation of the five-section coupler led to the conclusion that, respectively, Z_3/Z_2 and Z_2/Z_1 should be approximately equal to Z_2/Z_1 and Z_1 for the three-section coupler (assuming an analogous notation for the latter). As a first trial, the three-section coupler having -3 ± 0.5 db coupling over a 5.8:1 band was

used as a prototype, so that $Z_3/Z_2 = 3.76/1.296$. Then a value of $C_0 = -3.01 + 0.14 = -2.87$ db, or $k_0 = 0.717$, was assumed. Equation (2-9) then yielded $Z_1 = 1.098$, $Z_2 = 1.421$, $Z_3 = 4.13$. A detailed calculation, using Equations (2-5), (2-7) and (2-8) led to a coupling-curve shape that was quite good, but deviating from an equal-ripple response by a few hundredths of a decibel. It was judged that Z_2 was the quantity at fault. Next $Z_2 = 1.4182$ was used with the previous values of Z_1 and Z_3 , which led to considerable improvement. Finally $Z_2 = 1.4170$ was used, resulting in the equal-ripple coupling function plotted in Figure 2-4. In a 5.81 to 1 band, the coupling is within -3.01 ± 0.163 db.

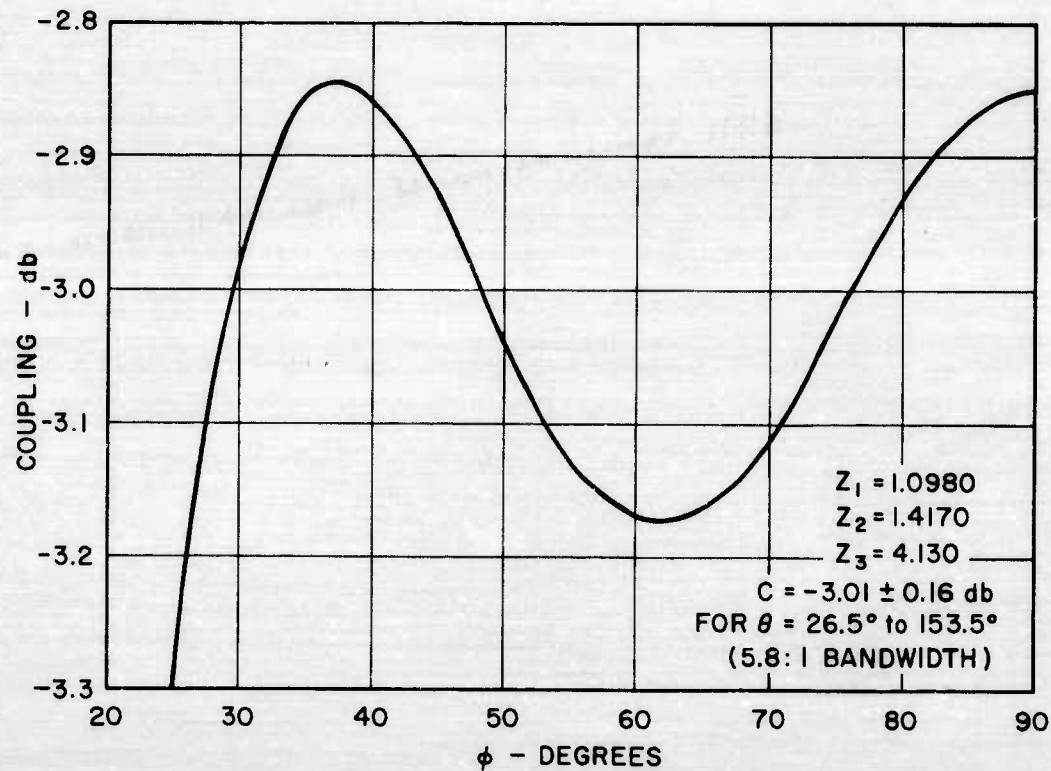


Figure 2-4. Theoretical Response of Five-Section TEM-Mode Coupler

The increase from three to five sections reduces the deviation from 0.5 db to 0.163 db for the same bandwidth. Whether this improvement justifies the additional complexity of the design should be carefully considered. It should be noted further that the center section will be more extreme in its dimensions for five sections than for three since its value of Z_{oe} is about 10 percent higher.

3. TEM-Mode Directional Couplers

a. 1000 - 2000 Mc Coupler

In the Second Quarterly Report a 1000 - 2000 Mc one-section re-entrant coupler was described briefly, but its response curve was not measured early enough to include in that report. Therefore, its measured coupling and directivity curves are shown in Figure 3-1. At mid-

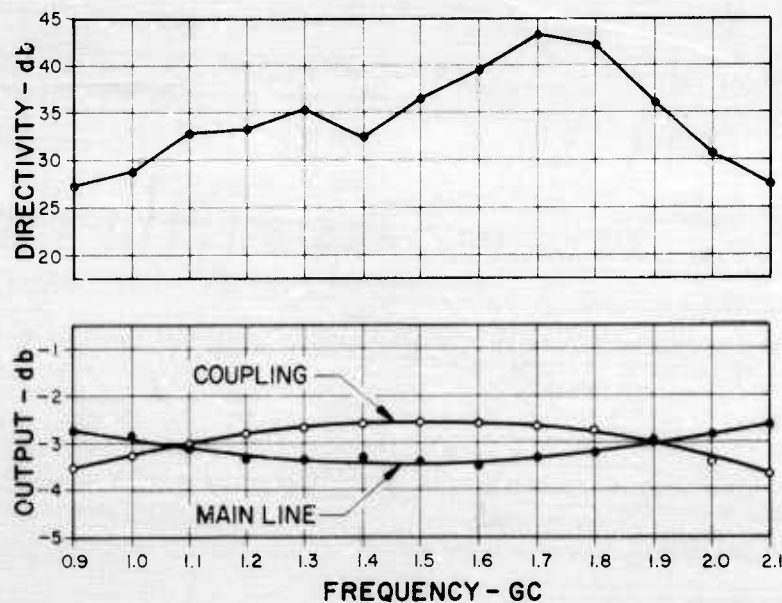


Figure 3-1. Response of a 1 to 2-Gc Single Section Re-entrant Directional Coupler

band the coupling is -2.6 db, which is 0.1 db greater than the design value. The minimum directivity in the 1000 to 2000 Mc band is 29 db. This good performance was obtained without any effort to improve the results by experimental modification.

b. 400 - 2000 Mc Coupler

A three-section coupler with a re-entrant center section and strip-line end sections was described in the Second Quarterly Report. Its performance in its design band of 400 - 2000 Mc conformed approximately to the ideal, but exhibited certain imperfections. At band center the unbalance between the coupled- and main-arm outputs was 1.0 db, which is close to the design value of 0.86 db.* However, the maximum unbalances at the outer loops between the coupling- and main-line curves were unequal, being 0.5 db at the lower-frequency loop and 1.3 db at the higher-frequency loop. In addition, the directivity was poor, dropping to 20 db at 1500 Mc.

A decision was made endeavoring to improve the coupling and directivity responses. The inequality of the unbalance loops was judged to be due to excessive length of the end sections. The end sections were shortened by small amounts with a reduction of the inequality being noted each time, while the center-frequency unbalance remained constant at 1.0 db. Therefore when an upper-loop unbalance of 1.0 db was obtained,

* This coupler was designed for a coupling response oscillating in the range -3.0 ± 0.4 db. Assuming no losses, when the coupling is -2.6 db, the main-arm-output will be -3.46 db, so that the unbalance of outputs is 0.86 db. Similarly, if the coupling were -2.5 db, the unbalance would be 1.08 db.

no further change in length was made; although, the lower-loop unbalance had increased to only 0.7 db.

Next a brief series of experiments with foil tabs placed at various points on the end-section strips resulted in a substantial improvement in directivity. The final results of directivity and coupling response are shown in Figure 3-2.

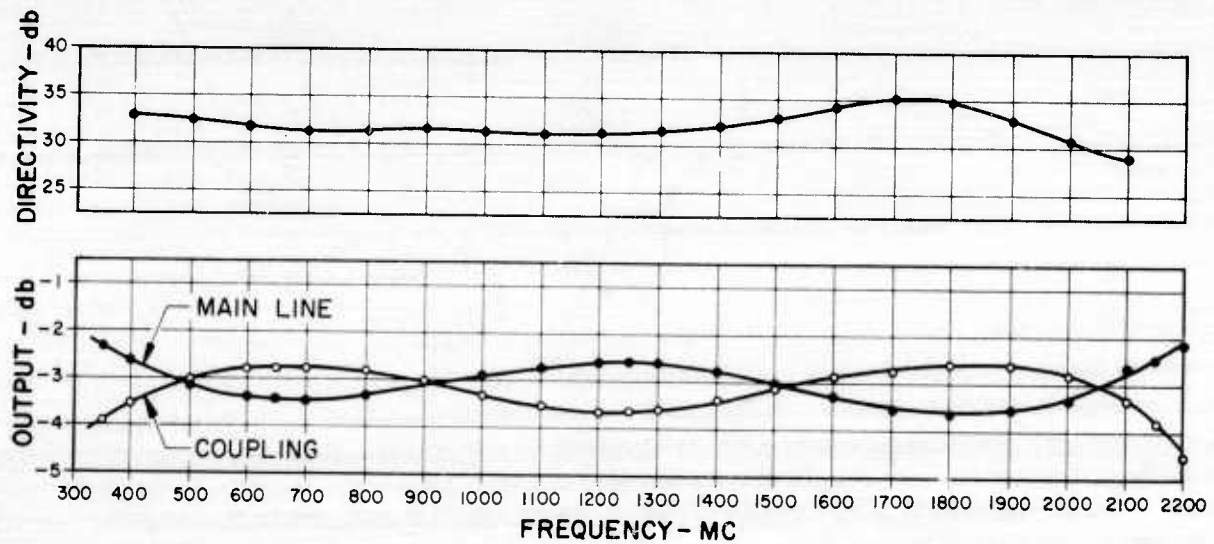


Figure 3-2. Response Curves for 400 - 2000 Mc Three-Section Directional Coupler with Re-entrant Center Section, After Modifying End Sections

c. Anticipated Problems of a 1 - 5 Gc Model

The 0.4 to 2.0 Gc coupler has very good performance in its band, meeting the objectives of this program. However, the task remains to construct a model in the 1 to 5 Gc range.

If all dimensions are scaled accurately from the 0.4 to 2.0 Gc model, a successful 1 to 5 Gc model will be assured. However, the

very small dimensions and tolerances that would result leads one to strive for a design having larger-than-scaled cross sections. In order to explore the feasibility of this approach, the 0.4 to 2.0 Gc model was tested in its second response band, which centers at about 3750 Mc. The results are plotted in Figure 3-3.

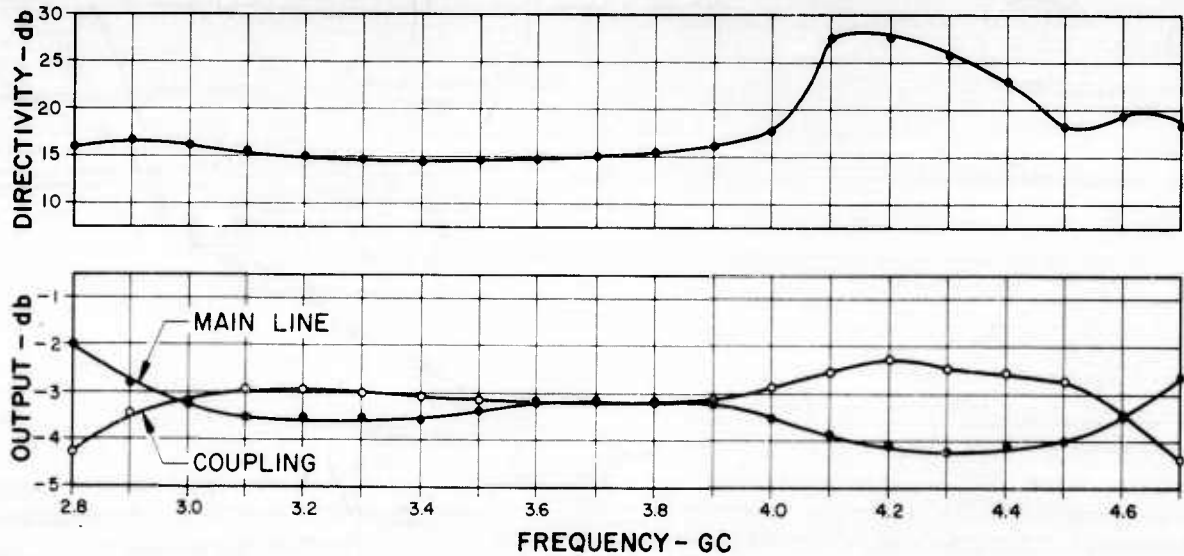


Figure 3-3. Second Order Response of 400 - 2000 Mc Directional Coupler

The coupling curve in Figure 3-3 exhibits the proper shape although it deviates considerably from the desired results. The coupling value at mid-band is too great by about 0.5 db, and in addition, the unequal side loops indicate again that the end sections are too long. The directivity is also poor, having a minimum value of 14.5 db.

Despite the imperfections of the 0.4 to 2.0 Gc model in its second-response band, it was decided to construct a model for 1 to 5 Gc

having the same cross sections, but with lengths reduced in a 2.5-to-1 ratio. An attempt will be made to achieve good performance by experimentally varying the parameters of this design. The advantage to be gained by the large cross-sectional dimensions justifies the risk in this approach. If good performance cannot be achieved, a second model with reduced cross sections will be constructed.

d. Discussion of Re-entrant and Parallel-Strip Cross Sections

Thus far, all experimental models built under this program have used the re-entrant cross section. This novel cross section is easily constructed to close tolerances, and will probably support higher power than equivalent parallel-strip cross sections. The directivity achieved with these designs is better than has previously been published. However, there is no reason to believe at this time that conventional parallel-strip designs are not capable of equal performance. In order to explore this point, a 0.4-to-2.0 Gc three-section model is being constructed with the same end sections as previously used, but with a broad-side-coupled strip-line center section in which the strips are oriented perpendicular to the ground planes. The ground-plane spacing is 0.750 inch, the strips are 0.264 inch wide by 0.032 inch thick, and the spacing is about 0.023 inch. If the results are favorable, a model will also be constructed for the 1-to-5 Gc band.

4. Experimental Data on Waveguide Broad-wall Directional Couplers

In the First Quarterly Report, data was shown on three broad-wall coupling structures. Of these, only Structure 3 had a coupling

level sufficient to show promise. By referring to the response curve of this structure in the First Quarterly Report, it will be noted that the coupling at the high end of the band is excessive, (approximately -1.8 db). It was evident from this curve that the coupling would have to be reduced at the high end of the band to flatten the response. Since coupling of the center holes increases with increasing frequency, a reduction of the center hole aperture is indicated if the response is to be improved.

Because of the difficulty involved in predicting the proximity effects of the apertures, it was decided that a structure identical to Structure 3 be constructed, but with the center row composed of 9 circular holes. Data was taken on Structures 7, 10 and 14 having hole diameters of 0.201-, 0.242-, and 0.261-inch respectively. The response of the coupling structure improved with each increase in diameter, the 0.261-inch diameter unit giving the best response. In Figure 4-1 is shown a reproduction of the data on Structure 14. Note that the response is reasonably flat but slightly over-coupled at the low end.

No additional changes were made to improve this three-row structure because, before acquiring the above data, a two-row design program was initiated which resulted in a promising structure which was mechanically simplified.

The first two-row coupling structure, 6 consisted of rectangular holes, 0.360 inch long by 0.290 inch wide with the center line of each

Model No. 14 Serial No. ---- Tested By Uyetani
 Customer Sig Corps Project No. 61361 Date 2/14/62

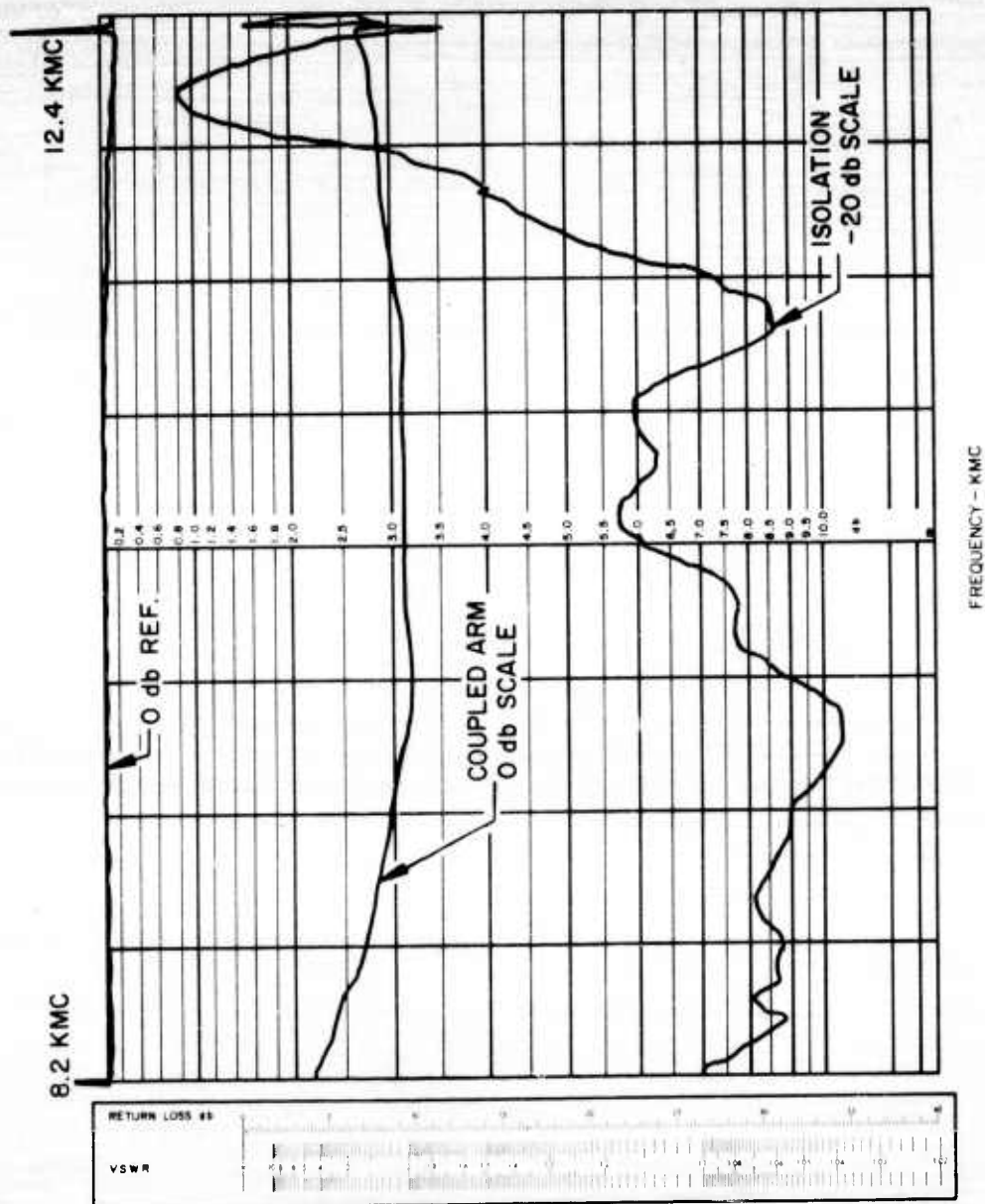


Figure 4-1. Calibrated Data Recording Graph for Structure 14

row of 9 holes spaced 0.300 inch from the center line of the insert. The coupling varied from -2.9 db at the low end to -5.0 db at the high end. The response was flattened in Structures 8 and 9 by reducing the row-to-center-line spacing from 0.300 inch to 0.280- and 0.240 inch respectively. As expected, the high frequency coupling increased as the rows were brought closer together.

In changing the spacing from 0.280 inch to 0.240 inch, however, the low frequency coupling dropped appreciably. It was evident at this stage that the entire level of coupling would have to be raised, which was accomplished by widening the individual holes of Structures 8 and 9 by 0.040 inch toward the center line of the insert. This resulted in Structures 11 and 12 having row-to-center-line spacing of 0.260- and 0.220 inch respectively and apertures of 0.360 inch x 0.320 inch.

Structure 11 had a nearly perfect coupling function, which is shown in Figure 4-2. Note also that the isolation was reasonably high having a minimum at the high end of the band of about -21.5 db. Structure 12, whose response is not shown had a very poor response with approximately 7 db isolation at the high end of the band.

At first, the response of Structure 12 was not explicable since all other coupling structures had reasonably good isolation. However, if the directivity function given in the First Quarterly Report for an array containing 9 holes is solved for $\phi = 130^\circ$, it is found that:

$$D = 20 \log_{10} \left| \frac{9 \sin 130^\circ}{\sin 1170^\circ} \right| = 20 \log_{10} \left| \frac{9 \sin 50^\circ}{\sin 90^\circ} \right| = 16.75 \text{ db}$$

Model No. 11 Serial No. ---- Tested By R. Koontz
 Customer Sig Corps Project No. 61361 Date 1/8/62

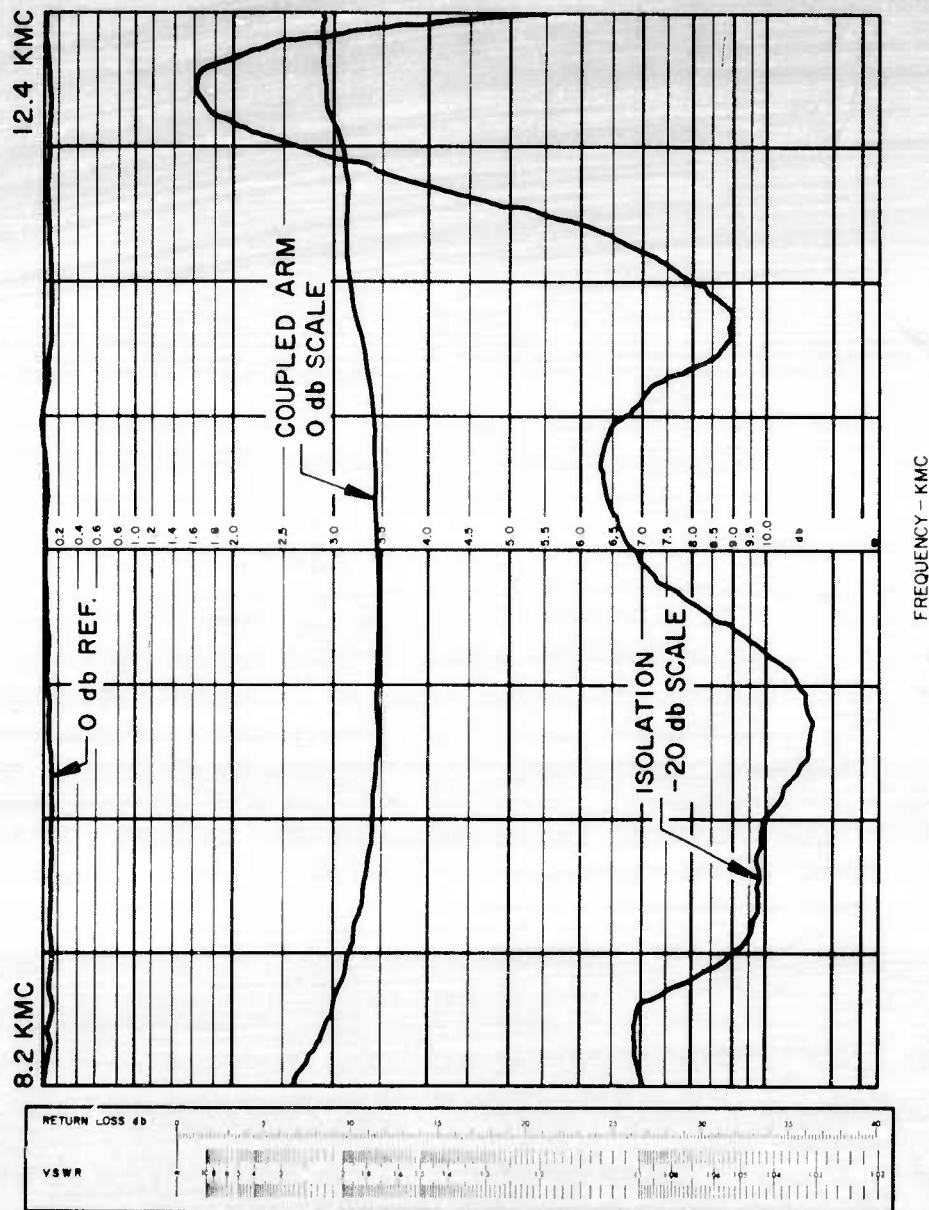


Figure 4-2. Calibrated Data Recording Graph for Structure 11

One must add to this the intrinsic hole directivity of approximately -5.0 db. Therefore, the expected directivity is $16.75 - 5.0 = 11.75$ db. Thus, coupling Structure 12 comes closer to obeying theory than any of the others whether they be two- or three-row arrays. Although the higher isolation properties of the other units cannot be explained, it may be related to the side-wall proximity since Insert 12 has holes spaced farther from the side wall than in any other insert, be it a two- or three-row. In this regard we were quite fortunate, since the high isolation allowed us to measure coupling changes for various inserts without concern for reflected power. This procedure was possible since a one-to-one correspondence exists between the reflection coefficient at the input and the isolation, as pointed out in the First Quarterly Report.

Having found a uniform hole structure with good coupling characteristics, the next problem was to improve the directivity. As discussed in the First Quarterly Report, the proposed manner for obtaining directivity was to convert the row of nine uniform holes into a row consisting of three superimposed Tchebyscheff arrays. Prior to testing various Tchebyscheff designs, however, a uniform array identical to Structure 11 but having its two rows displaced longitudinally by one space, or $\lambda_{g0}/4$, was tried. It was theorized that since the intrinsic isolation of Structure 11 was quite high, perhaps the additional cancellation afforded by this simple change would yield a unit with directivity exceeding the 25-db goal. Figure 4-3 depicts the data taken on Unit 16. A comparison of the directivity with that of Insert 11 shows that there was an improvement in directivity

Model No. 16 Serial No. ---- Tested By R. Koontz
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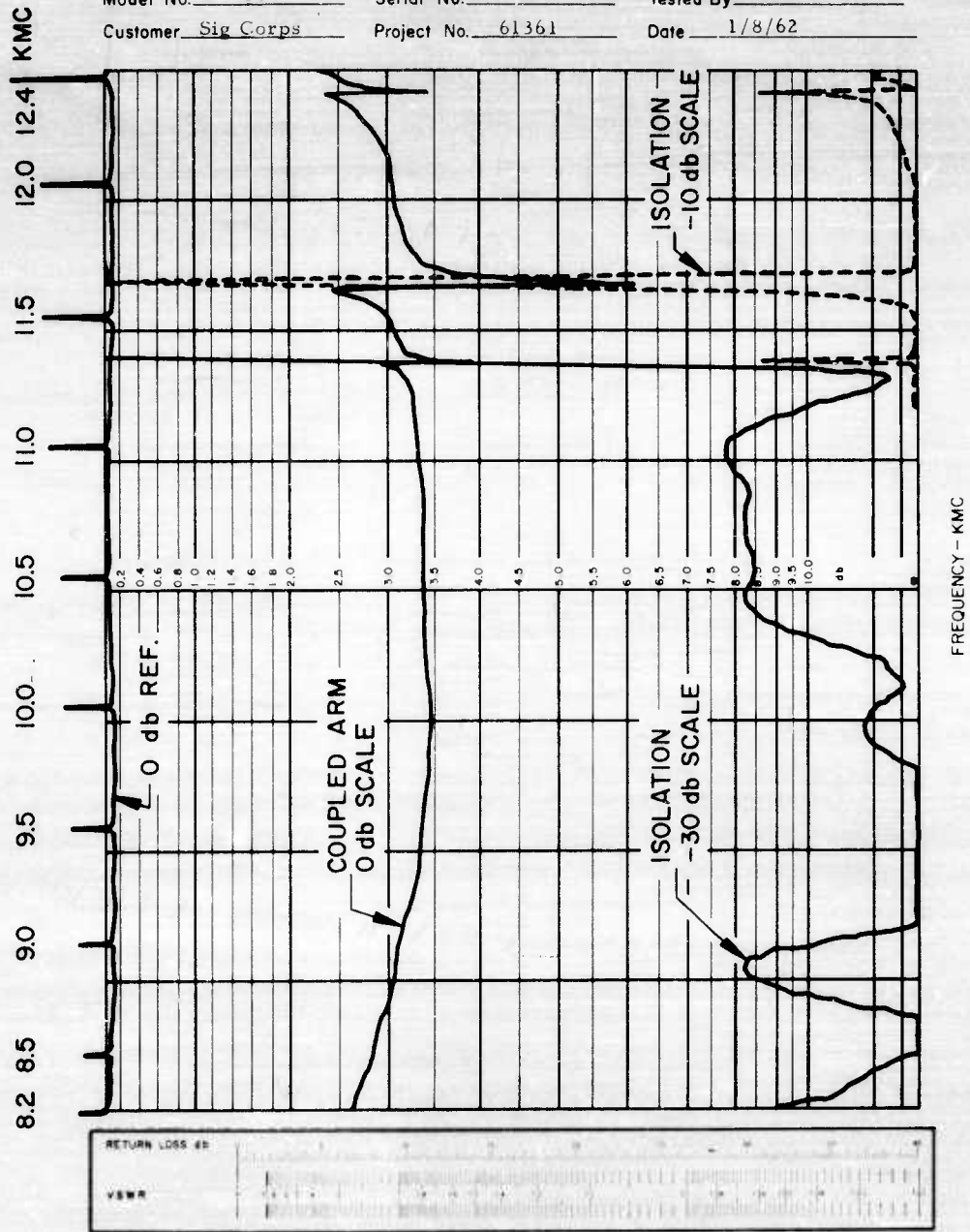


Figure 4-3. Calibrated Data Recording Graph for Structure 16

averaging about 10 db over most of the band except where the resonance spikes occurred. The generation of these resonance spikes was particularly interesting since measurement on earlier units had revealed a single minor resonance at the top end of the band. Later in the program it was found, through measurements on Tchebyscheff arrays, that all displaced-row inserts generated distinct resonance spikes comparable to those of Insert 16.

In order to improve the directivity of Insert 11 several inserts were built based on the superposition of three Tchebyscheff arrays of five holes each, resulting in an eleven-hole row. (see First Quarterly Report for a discussion of the superposition of Tchebyscheff arrays.) The relative amplitudes of the coupling from each hole were as follows:

1	2.828	3.828	3.828	3.828	3.828	3.828
	3.828	3.828	2.828	1		

The tapering of the end holes was based on the coupling being proportional to the diameter cubed for round holes, and proportional to area to the three-halves power for rectangular.

An entire family of inserts with various apertures based on the above coupling criteria has been built and tested. One of the better inserts is 30. Two tapered coupling holes at the ends of each array are square in this insert. The end hole is 0.250 inch on a side and the hole next to the end is 0.315 inch. The inside edge of each hole lies on a line formed by the inside edge of the center holes of the array. Data taken for this structure is shown in Figure 4-4. It should be noted that the 25-db directivity goal is met and that with minor improvement the 3.0 ± 0.5 db goal would be met.

Model No. 30 Serial No. --- Tested By R. Koontz
 Customer Sig Corps Project No. 61361 Date 1/16/62

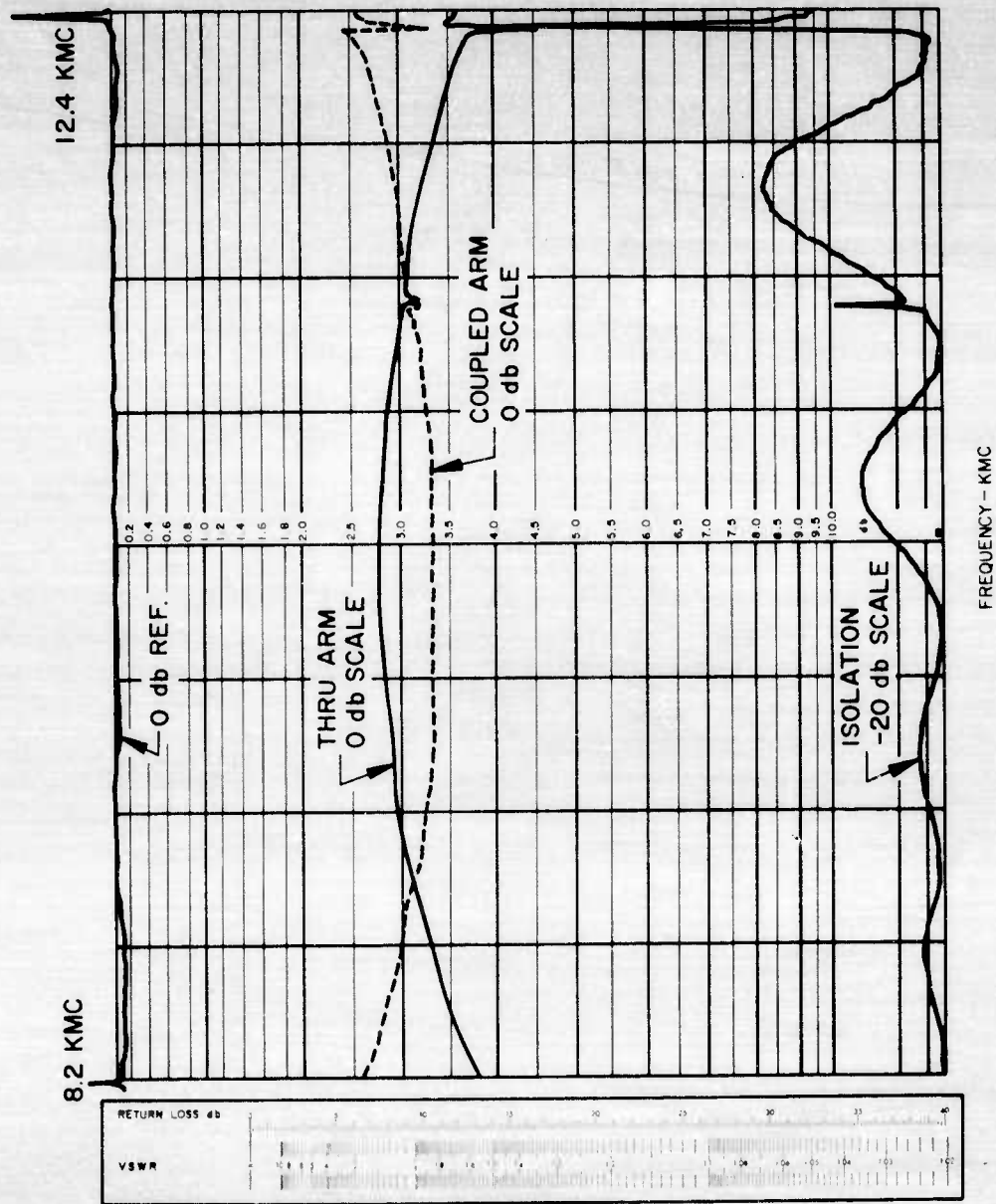


Figure 4-4. Calibrated Data Recording Graph for Structure 30

The existence of minor resonances was disappointing, but not unexpected, in view of measurements on displaced-row designs. The displaced-row design, which lacks symmetry in a gross manner, indicates that minor asymmetry in the symmetrical design may cause minor resonances.

In the next period more work will be done toward improving the coupling and directivity of the various inserts that show promise as well as toward elimination of the resonance spikes. A few experiments aimed at testing a theory of the generating mechanism have already been conducted with inconclusive results. Additionally, an experiment was performed with the displaced-row design Number 24, wherein it was possible to move the resonances up in frequency by placing a series of wires between the narrow walls of each of the top and bottom guides along the coupling region.

It was evident from the results of this experiment that additional wires could move the resonance out of the band. Of more importance, is the conclusion that can be drawn from the experiment regarding the electric field orientation of the undesired resonant modes; namely that these resonances have electric-field components parallel to the broad wall of the guide. In the next report the subject of the resonance generating mechanism will be treated in more detail.

SECTION V

CONCLUSIONS

Design parameters have been computed for a five-section TEM-mode 3-db directional coupler. It was found that its coupling deviation is about one-third that of a three-section coupler having the same bandwidth. However, since the three-section coupler meets the goals of this program, the construction of a five-section model has been deferred.

A number of minor changes in the end sections of the 400 to 2000 Mc coupler has improved the performance such that the coupler now meets the goals of the program. It is not certain whether the same cross-section dimensions are capable of yielding good performance in a 1 to 5 Gc design, but in view of the structural advantages of large cross sections, such a model is now being constructed. Also, it is not yet known whether the re-entrant cross section offers electrical advantages over conventional broad-side-coupled-strip cross sections. In order to answer this question, a 400 - 2000 Mc coupler with a coupled-strip center section and the end sections used previously has been designed and is being constructed.

Comparable results have been achieved with two-row and three-row broad-wall couplers. Because of its simpler construction, all recent work has been done using two-row designs. After developing a successful nine-uniform-hole-per-row model, a series of tapered eleven-hole-row models were tested. As expected, the same coupling

response was achieved, while a large increase in directivity was obtained. Weak resonances near the high-frequency end of the band have been observed that are as yet only partially understood. If these resonances prove important, steps will be taken to move them out of the band of interest.

SECTION VI
PROGRAM FOR NEXT INTERVAL

A three-section 400 to 2000 Mc TEM-mode coupler containing a coupled-strip center section will be tested. One or more 1 to 5 Gc models containing various types of center sections will also be constructed and tested.

Work on waveguide broad-wall couplers will continue, with emphasis on the minor resonances observed near the upper end of the frequency band. A final model best meeting the contract goals will be fabricated.

A study of the unsymmetrical side-wall coupler will be carried to a conclusion, and a final model constructed.

The final report on this program will be prepared.

SECTION VII

LIST OF REFERENCES

1. S. B. Cohn, et al, "Final Report, Strip Transmission Lines and Components," Stanford Research Institute, Project 1114, Contract DA 36-039-SC-63232; February 1957
2. E. M. T. Jones and J. T. Bolljahn, "Coupled Strip-Transmission Line Filters and Directional Couplers," IRE Trans., MTT-4, pp. 75-81 (April 1956).
3. E. M. T. Jones and S. B. Cohn, "Two Theorems for Dissipationless Symmetrical Networks," Proc. IRE, vol. 45, p. 1016; July, 1957

SECTION VIII

IDENTIFICATION OF KEY TECHNICAL PERSONNEL

	Hours
Dr. Seymour B. Cohn Specialist	92
Mr. Alvin Clavin Senior Engineer	4
Mr. Rollin H. Koontz Senior Engineer	169
Mr. Stanley L. Wehn Engineer	129.5
Mr. Robert W. Jansen Engineer	3
Mr. Robert Uyetani Engineer	40

<p>AD DIV Rantec Corporation, Calabasas, California MICROWAVE HYBRID COUPLER STUDY PROGRAM by S. B. Cohn and R. H. Koontz. Third Quarterly Progress Report, 1 November 1961, 31 January 1962, 31 Pages, including illustration Report No. 61361-2 Contract DA 36-239 SC-87435 Unclassified Report</p> <p>A general method of computing the response of an n-section TEM-Mode directional coupler is given and applied to the synthesis of a five-section design. The final results were the design parameters of a five-section (over)</p>	<p>UNCLASSIFIED</p> <p>I Microwave Hybrid Coupler Study Title: Coupler Study Program S. B. Cohn and R. H. Koontz Army Signal Supply Agency Fort Monmouth, N. J. Contract DA 36-239 SC-87435</p> <p>ASTIA</p> <p>UNCLASSIFIED</p>	<p>AD DIV Rantec Corporation, Calabasas, California MICROWAVE HYBRID COUPLER STUDY PROGRAM by S. B. Cohn and R. H. Koontz. Third Quarterly Progress Report, 1 November 1961, 31 January 1962, 31 Pages, including illustration Report No. 61361-2 Contract DA 36-239 SC-87435 Unclassified Report</p> <p>A general method of computing the response of an n-section TEM-Mode directional coupler is given and applied to the synthesis of a five-section design. The final results were the design parameters of a five-section (over)</p>	<p>UNCLASSIFIED</p> <p>I Microwave Hybrid Coupler Study Title: Coupler Study Program S. B. Cohn and R. H. Koontz Army Signal Supply Agency Fort Monmouth, N. J. Contract DA 36-239 SC-87435</p> <p>ASTIA</p> <p>UNCLASSIFIED</p>
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<p>AD</p> <p>coupler having an equal-ripple coupling function bounded by -3.010 ± 0.163 db over a 5.81 to 1 bandwidth which may be compared to -3.0 ± -0.5 db obtainable from a three-section coupler over the same bandwidth. Coupling and directivity curves are given for the one-section, 1- to -2 Gc coupler in addition to a new set of curves for the 400 to 2000 Mc three-section coupler. The results of a continuing study of waveguide broad-wall couplers are presented. A configuration consisting of two rows each containing nine uniform holes meeting the program coupling goal of -3.0 ± 0.5 db over 8.2 to 12.4 Gc was achieved. This basic design was then modified into one with tapered eleven-hole rows which improved the directivity response.</p>	<p>DIV</p>	<p>AD</p> <p>coupler having an equal-ripple coupling function bounded by -3.010 ± 0.163 db over a 5.81 to 1 bandwidth which may be compared to -3.0 ± -0.5 db obtainable from a three-section coupler over the same bandwidth. Coupling and directivity curves are given for the one-section, 1- to -2 Gc coupler in addition to a new set of curves for the 400 to 2000 Mc three-section coupler. The results of a continuing study of waveguide broad-wall couplers are presented. A configuration consisting of two rows each containing nine uniform holes meeting the program coupling goal of -3.0 ± 0.5 db over 8.2 to 12.4 Gc was achieved. This basic design was then modified into one with tapered eleven-hole rows which improved the directivity response.</p>	<p>DIV</p>	<p>UNCLASSIFIED</p> <p>UNITERMS</p> <p>Broad Bandwidth</p> <p>Directional Coupler</p> <p>Directivity</p> <p>Five-Section</p> <p>400 - 2000 Mc</p> <p>1000 - 2000 Mc</p> <p>Parallel-Strip</p> <p>Re-entrant</p> <p>Single-Section</p> <p>Tchebyscheff</p> <p>TEM-Mode</p> <p>3-db Coupler</p> <p>UNCLASSIFIED</p>
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