AD 413990

UNCLASSIFIED

Technical Report...

MICROWAVE FERRITE DEVICES

(OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS)

FOURTH QUARTERLY REPORT

15 January 1963 to 15 April 1963

Report No. 4 Contract No. DA-36-039-SC-89214

SIGNAL CORPS TECHNICAL REQUIREMENT SCL-7644
DEPARTMENT OF THE ARMY PROJECT NO 3A-99-15-002

U. S. ARMY ELECTRONICS RESEARCH AND
DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

SPERRY
MICROWAVE ELECTRONICS COMPANY
DIVISION OF SPERRY RAND CORPORATION
CLEARWATER, FLORIDA

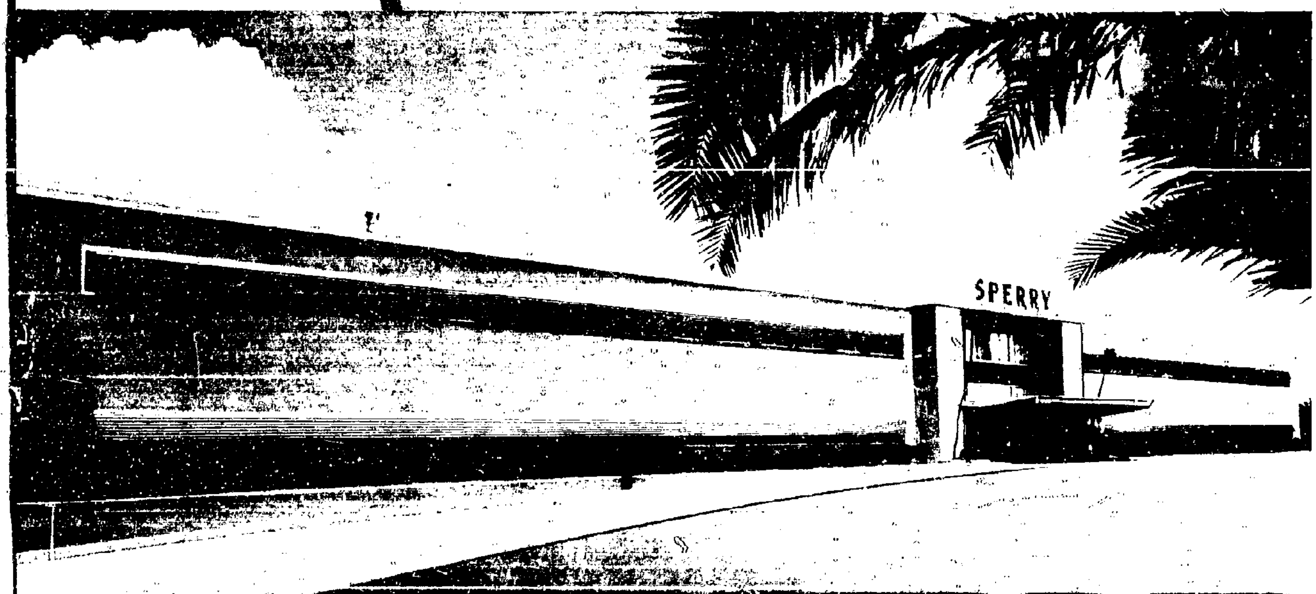
ASTIA AVAILABILITY NOTICE

"Qualified requestors may obtain copies of this report from ASTIA. ASTIA Release to OTS Not Authorized."

SPERRY

MICROWAVE ELECTRONICS COMPANY

DIVISION OF SPERRY RAND CORPORATION



- RESEARCH
- DE ELOPMENT
- PRODUCTION

Weapons Systems Support Equipment

- Rapid Automatic Checkout Equipment
- System Evaluators
- System Performance Monitors
- Simulators for Training Personnel

Test Equipment

- for Radar and other Systems
- for Production Line and Laboratory Testing Microwave Components

Microwave Components

Antennas

Microwave Solid State Devices and Materials

Microline and RACE are trademarks applied to quality products of the Sperry Microwave Electronics Company.

FOURTH QUARTERLY REPORT

MICROWAVE FERRITE DEVICES

(OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS)

15 January 1963 to 15 April 1963

Contract No. DA-36-039-SC-89214

Signal Corps Technical Requirement SCL-7644
dated 18 October 1961

May 1963

Development of Octave Bandwidth Y-Junction Circulators

Prepared by:

J. W. Simon

G. A. Burdick

W. C. Heithaus

Approved by:

B. J. Duncan

SPERRY MICROWAVE ELECTRONICS COMPANY
DIVISION OF SPERRY RAND CORPORATION
CLEARWATER, FLORIDA

SJ-224-0041-4

Copy No. 55

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Preceding Page Blank

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

1. PURPOSE OF PROGRAM

1.1 PURPOSE OF PROGRAM

The purpose of this program is to advance the state-of-the-art in the field of microwave ferrite three port circulators through applied research and development. Advanced ferrite techniques and approaches will be applied to the development of symmetrical three port circulators having one octave bandwidth. The circulators which are developed will jointly cover the frequency range of 400 to 8000 mc.

This series of fixed tuned three port circulators will operate in TEM mode strip transmission line and have the performance characteristics indicated below.

Frequency mc/sec	400-800	600-1200	1000-2000	1500-3000	2000-4000	4000-8000
Reverse loss, db (Ports 2-1, 1-3, & 3-2)	20 min.	20 min.	20 min.	20 min.	20 min.	20 min.
Forward loss, db (Ports 1-2, 2-3, & 3-1)	0.5 max.	0.5 max.	0.3 max.	0.3 max.	0.3 max.	0.3 max
VSWR, at all ports, max.	1.20:1	1.20:1	1.20:1	1.20:1	1.20:1	1.20:1
Terminations	Coaxial Type N	Coaxial Type N	Coaxial Type N	Coaxial Type N	Coaxial Type N	Coaxial Type N
Min. CW Power	5 watts	5 watts	5 watts	5 watts	5 watts	5 watts

It is also the purpose of this program to provide a theoretical analysis explaining the basic mechanism that governs the microwave propagation at the junction of the circulator and to present an analytical method for determining optimum circulator performance over a frequency band of interest.

In addition to the original scope of the existing program, the following series of fixed tuned three port circulators have been made a part of this program.

Frequency Mc/sec	200-400	7000-10000	8200-12400
Reverse Loss db (Ports 2-1, 1-3, & 3-2)	15 min.	20 min.	20 min.
Forward Loss, db (Ports 1-2, 2-3, & 3-1)	1.0 max.	0.5 max.	0.5 max.
VSWR, at all ports, max.	1.30:1	1.20:1	1.20:1
Transmission Structure	Stripline	RG-51/U	RG-52/U
Terminations	Coaxial Type N	UG-51/U	UG-39/U
Min. CW Power	5 watts	50 watts	50 watts

2. ABSTRACT

As part of the theoretical study, the effects of introducing a nonzero linewidth in the equations for μ_{eff} are considered for the first time. Some interesting results are reported which are in agreement with earlier empirical data.

A substantial increase in bandwidth has been achieved in the 400 - 800 Mc band through the use of reduced strip width and puck heights.

Octave bandwidths have been achieved in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc circulators through the use of improved microwave parameters and matching techniques. The circulators for the remaining two bands, 1.5 - 3.0 Gc and 4.0 - 8.0 Gc, are currently being modified to reflect similar changes.

3. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

3.1 PUBLICATIONS

None in this reporting period.

3.2 LECTURES

None in this reporting period.

3.3 REPORTS

None in this reporting period.

3.4 CONFERENCES

A conference was held on March 28, 1963 at the U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey. Present were Messrs. N. Lipetz, J. Agrios, I. Bady, E. Freibergs, and R. Stern of the Signal Corps and Messrs. B. J. Duncan, F. Tyrdall and J. W. Simon of the Sperry Microwave Electronics Company, Clearwater, Florida.

The purpose of this meeting was to discuss the technical progress of the program.

4. FACTUAL DATA

4.1 GENERAL

Technical activity during the fourth quarter on the theoretical phase of this program consisted of studying desirable regions of operation for optimum bandwidth, assuming a necessary condition to be kR equal to a constant over the band. From this study, facts pointing to a possible dependence of bandwidth on linewidth were brought to light.

In the development area, significant progress was made in all six bands. Several new techniques were developed which have been utilized to achieve full octave bandwidths.

4.2 THEORETICAL INVESTIGATION

If one starts with the assumption that it is desirable to make kR a constant for increasing bandwidth and if linewidth is included in the equation for μ and k some interesting consequences arise.

Thus

$$K = \omega\sqrt{\mu_{eff}\ \varepsilon} \qquad (1)$$

where

$$\mu_{eff} = \frac{\mu^2 - k^2}{\mu} \qquad (2)$$

and, neglecting the imaginary parts

$$\mu = 1 + \frac{hm(h^2 - 1)}{(h^2 - 1)^2 + s^2} \tag{3}$$

$$k = \frac{m(h^2 - 1)}{(h^2 - 1)^2 + s^2} \tag{4}$$

where, as usual, Bosma's notation has been used. The symbol "s" is the "normalized" linewidth and is given by

$$s = \frac{\gamma \Delta H}{\omega} \tag{5}$$

If "s" is set equal to zero considerable simplification of Equations (3) and (4) results and μ_{eff} is given by

$$\mu_{eff} = 1 + \frac{m(m + h)}{h^2 + hm - 1} \tag{6}$$

To bring out the frequency dependence in Equation (6) specifically, let

$$B = H + 4\pi M_s \tag{7}$$

Then

$$\mu_{eff} = 1 + \frac{\gamma^2 4\pi M_s B}{\gamma^2 HB - \omega^2} \tag{8}$$

A typical plot of Equation (8) is given in Figure 1.

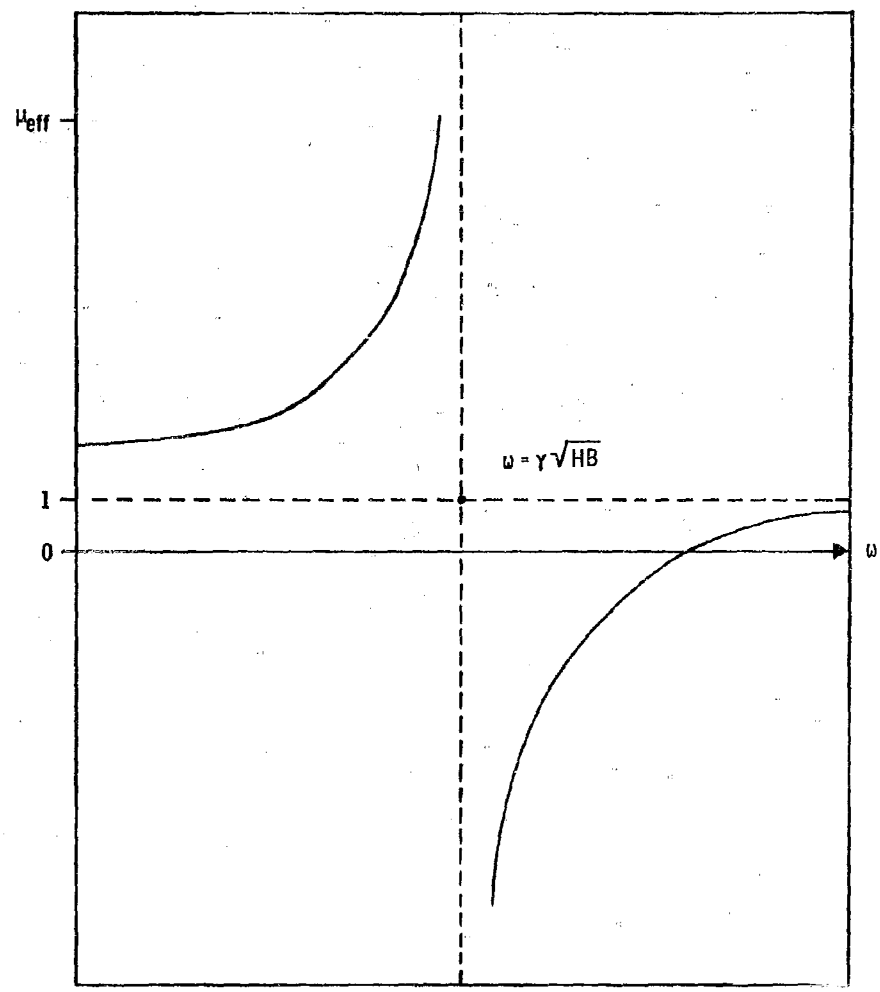


Figure 1. μ_{eff} vs ω for Zero Linewidth

To keep k constant (and hence also kR for a fixed R), it is necessary to work in a region where the magnitude of μ_{eff} is proportional to ω^{-2}. The only possible region satisfying this condition in Figure 1 is the region just to the right of the singularity at $\omega = \gamma\sqrt{HB}$. Assuming an infinite media, Kittel's equation can be used and this region is below magnetic resonance (on the high frequency side), i.e., ω is greater than ω_r where $\omega_r = \gamma H$ and H is the internal magnetic biasing field. Thus, for zero linewidth there exists just one region where the magnitude of μ_{eff} decreases with increasing frequency. However, if a nonzero linewidth is included, a rather dramatic and abrupt change occurs in the appearance of Figure 1. This is to say, any linewidth greater than zero - independent of how small the linewidth is - introduces a new point at which μ_{eff} becomes infinite. This can be seen most easily by examining Equation (2). In general, μ_{eff} becomes infinite whenever μ becomes zero. When s is not zero, setting μ equal to zero results in a quartic equation for ω if we treat H and $4\pi M_s$ as parameters.

Two of the roots correspond to negative frequencies and are therefore of no practical importance. The two physically meaningful roots are

$$\omega_1 = \frac{\gamma}{\sqrt{2}}\left\{H^2 + HB - (\Delta H)^2 + \sqrt{\left[H^2 + HB - (\Delta H)^2\right]^2 - 4H^3B}\right\}^{1/2} \quad (9)$$

and

$$\omega_2 = \frac{\gamma}{\sqrt{2}}\left\{ H^2 + HB - (\Delta H)^2 - \sqrt{\left[H^2 + HB - (\Delta H)^2\right]^2 - 4H^3 B}\right\}^{1/2} \quad (10)$$

The first root, ω_1, corresponds to the root $\omega = \gamma\sqrt{HB}$ which has been slightly displaced due to the nonzero linewidth. The second root corresponds to an entirely new singular point for μ_{eff}. From Equation (10) it is seen that

$$\omega_2 \xrightarrow[\Delta H \to 0]{} \gamma H$$

A typical curve for nonzero linewidth is given in Figure 2.

The broken line curve near the first singularity shows the effect of increasing the linewidth; it increases the region within which μ_{eff} decreases with increasing frequency. This is the qualitative behavior required to reduce the variance of kR. For infinite media, this second singularity occurs very near magnetic resonance ($\omega_r = \gamma H$) and introduces a region just below and just above magnetic resonance where the magnitude μ_{eff} decreases with increasing frequency. Thus, if minimizing the variance of kR is desirable for increasing bandwidth, this would suggest that it is desirable to operate close to magnetic resonance both above and below resonance. Below magnetic resonance, the region to the right of the second singularity may also prove desirable.

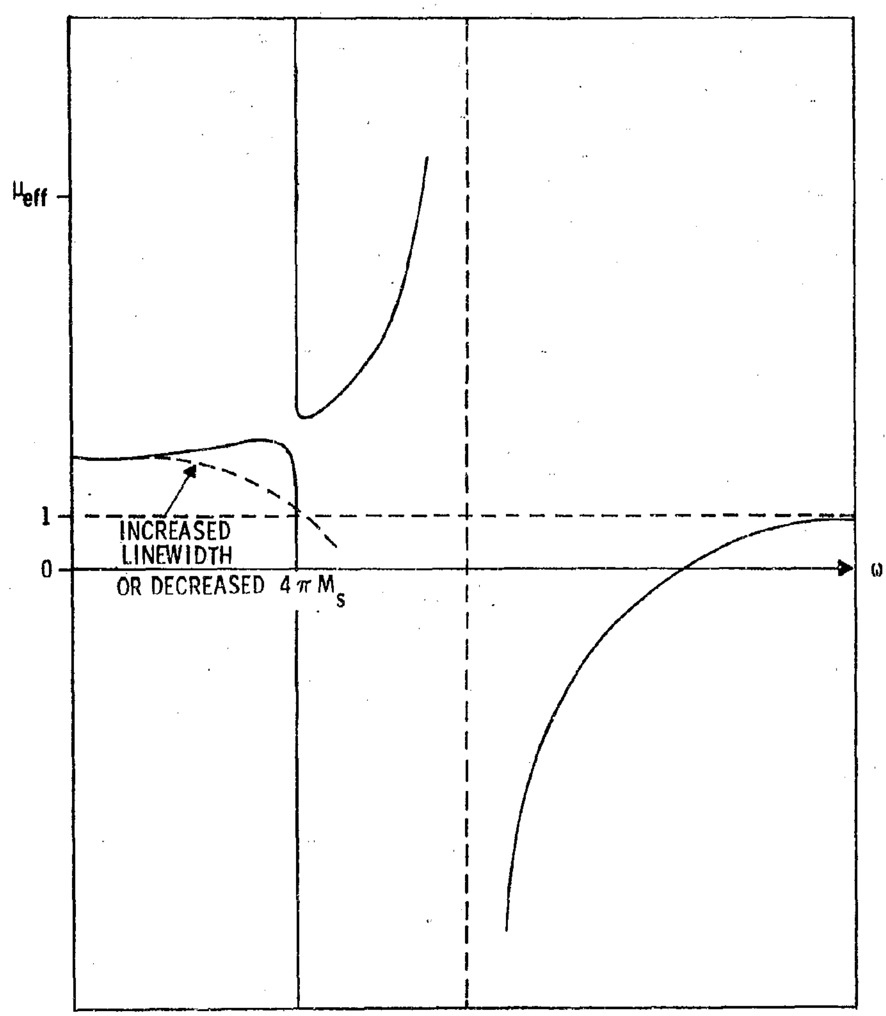


Figure 2. μ_{eff} vs ω for Non Zero Linewidth

Another point of interest worth speculating on is the possible effect $4\pi M_s$ has on bandwidth, according to this model. When operating in the region between the two singularities an upper limit on the expected bandwidth (without added matching structures) can be taken as the separation of the singularities. This suggests that for operation in this region $4\pi M_s$ should be as large as other factors will allow since

$$\omega - \omega_2 = \gamma \quad (\sqrt{HB} - H)$$

and

$$B = H + 4\pi M_s.$$

The region above resonance (to left of ω_2) is increased with decreasing $4\pi M_s$. Thus, a $4\pi M_s$ as low as possible may be desired for above resonance operation. Some evidence of this has been observed experimentally and was reported in the third quarterly report.

The effect on bandwidth in other regions is not obvious and will not be pursued unless this model proves fruitful elsewhere.

A summary of theoretical work is currently being prepared and will be included in the next quarterly report.

4.3 DEVICE DEVELOPMENT

4.3.1 Introduction

The basic development on all of the circulators due for delivery 15 May, 1963 is essentially complete. Minor problems are still being worked on in the 1.5 - 3.0 Gc and the 4.0 - 8.0 Gc regions, however, it is felt that these can be worked out satisfactorily.

Essentially, all of the design goals have been met in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc regions. The development procedures used for the development of the first three units are being carried out in a similar fashion for the two remaining units, and the results are expected to be comparable.

The basic technique which has been successfully used to extend the bandwidth to the desired octave was carried out in two ways. First, it was observed that the impedance plots of the circulators in the 600 - 1200 and 1000 - 2000 Mc regions were such that the addition of a series resonant circuit could further improve the matched performance considerably. With these resonant elements placed in each circulator port, it was essentially possible to match the end frequencies without affecting the impedance characteristics of the center frequencies. Using this technique it was possible to match the 0.6 - 1.2 and the 1.0 - 2.0 Gc units.

A second method which was found to produce improved results was an alteration of the center conductor geometry. Specifically, it was found that in the 2.0 - 4.0 Gc circulator small changes in the center conductor geometry simplified the matching sufficiently that the conventional dielectric transformers could be used to achieve the octave bandwidth. It was also found that the characteristics of the 1.0 - 2.0 Gc unit could be further improved using this method.

4.4 DEVICE PERFORMANCE IN SPECIFIC BANDS

4.4.1 UHF (400 to 800 Mc)

During this quarter, the evaluation of ferrite materials No. 6A and 13, Table I, was continued. Material No. 6A is an iron deficient version of material No. 6 which was discussed in the last report. This iron deficient material was tested under conditions similar to those used for material No. 6. The results indicated that the impedance versus frequency characteristics are not as good as those reported in the third quarterly report for material No. 6. This is possibly due to the large drop in the magnetization of this material. Further testing of material No. 6A will be discontinued in the above resonance experiments as materials No. 6 and 13 have displayed superior characteristics.

In the testing of material No. 13, a significant improvement in results has been accomplished by using a totally new stripline structure of a narrower stripwidth. The new stripline configuration is illustrated in

TABLE I (Sheet 1 of 2)

	MATERIAL COMPOSITION	ΔH	ε	$4\pi M_s$	°C Curie Temp.	g-factor	tan δ *(less than)
1.	$3Y_2O_3 \cdot 5(60\% Gd_2O_3 \cdot 40\% Fe_2O_3)$	200	17.50	743	280°	2.06	0.0005
2.	$3Y_2O_3 \cdot 5(15\% Al_2O_3 \cdot 85\% Fe_2O_3)$	40	15.80	700	170°	2.02	0.0005
2A.	$3Y_2O_3 \cdot 5(15\% Al_2O_3 \cdot 85\% Fe_{1.925}O_3)$	39	14.20	653	170°	2.02	0.0001
3.	$3Y_2O_3 \cdot 5(15\% Ga_2O_3 \cdot 85\% Fe_2O_3)$	55	15.73	619	180°	2.01	0.003
4.	$13\% Al_2O_3 \cdot 56.48\% MgO \cdot 6.26\% MnO \cdot 24.26\% Fe_2O_3$	80	11.20	500	120°	2.00	0.0005
5.	$11.18\% Al_2O_3 \cdot 56.48\% MgO \cdot 6.26\% MnO \cdot 26.08\% Fe_2O_3$	90	11.50	600	100°	1.96	0.0005
6.	$3Y_2O_3 \cdot 5(25\% Al_2O_3 \cdot 75\% Fe_2O_3)$	40	14.38	315	140°	2.03	0.0002
7.	$3Y_2O_3 \cdot 5(27\% Al_2O_3 \cdot 73\% Fe_2O_3)$	40	14.25	300	136°	2.10	0.0002
8.	$3Y_2O_3 \cdot 5(20\% Al_2O_3 \cdot 80\% Fe_2O_3)$	40	16.0	500	150°	2.024	0.002
8A.	$3Y_2O_3 \cdot 5(20\% Al_{1.925} \cdot 80\% Fe_{1.925}O_3)$	52	15.1	379	150°	2.03	0.0001
8B.	$3Y_2O_3 \cdot 5(20\% Al_{1.950} \cdot 80\% Fe_{1.950}O_3)$	48	15.3	435	150°	2.03	0.0183
8C.	$3Y_2O_3 \cdot 5(20\% Al_{1.975} \cdot 80\% Fe_{1.975}O_3)$	32	16.0	500	150°	2.03	0.0374
9.	$3Y_2O_3 \cdot 5(12\% Al_2O_3 \cdot 88\% Fe_2O_3)$	40	16.0	940	180°	2.016	0.002
9A.	$3Y_2O_3 \cdot 5(12\% Al_2O_3 \cdot 88\% Fe_{1.925}O_3)$	60	15.4	836	180°	2.02	0.0001
10.	$3Y_2O_3 \cdot 5(10\% Al_2O_3 \cdot 90\% Fe_2O_3)$	40	16.0	1040	200°	2.017	0.002
10A.	$3Y_2O_3 \cdot 5(10\% Al_2O_3 \cdot 90\% Fe_{1.925}O_3)$	44	15.5	1005	200°	2.02	0.0001
11.	$3Y_2O_3 \cdot 5(8\% Al_2O_3 \cdot 92\% Fe_2O_3)$	40	16.0	1120	210°	2.016	0.002
11A.	$3Y_2O_3 \cdot 5(8\% Al_2O_3 \cdot 92\% Fe_{1.925}O_3)$	40	15.8	1112	210°	2.020	0.0001
12.	$3Y_2O_3 \cdot 5(8\% Ga_2O_3 \cdot 92\% Fe_2O_3)$	51	16.0	1112	240°	2.002	0.002
13.	$3Y_2O_3 \cdot 5 Fe_2O_3$	40	16.0	1780	280°	2.037	0.0001
14.	$9.1\% Al_2O_3 \cdot 51.62\% MgO \cdot 5.68\% MnO \cdot 33.6\% Fe_2O_3$	200	12.8	1142	150°	2.019	0.0005

TABLE I (Sheet 2 of 2)

	MATERIAL COMPOSITION	ΔH	ε	4πMs	°C Curie Temp.	g-factor	tan δ *(less than)
15.	30% NiO · 3.4% CuO · 0.9% CoO · 0.7% MnO · 52.4% Fe_2O_3 12.6% Al_2O_3	326	12.7	1240	426°	2.570	0.001
16.	5.0% Al_2O_3 · 51.62% MgO · 5.68% MnO · 37.7% Fe_2O_3	258	12.5	1800	216°	2.055	0.0005
17.	2.5% Al_2O_3 · 50% MgO · 1.5% MnO · 46% Fe_2O_3	245	12.5	1530	295°	2.035	0.0005
18.	$3Y_2O_3$ · 5(17% $Al_{1.925}$ · 83% $Fe_{1.925}O_3$)	38	15.1	527	160°	2.02	0.0001
19.	3(20% Gd_2O_3 · 80% Y_2O_3) · 5 $Fe_{1.925}O_3$	118	15.9	1391	280°	2.04	0.0001
20.	3(40% Gd_2O_3 · 60% Y_2O_3) · 5 $Fe_{1.925}O_3$	168	16.2	1020	280°	2.04	0.0001
21.	3(50% Gd_2O_3 · 50% Y_2O_3) · 5(2% Al_2O_3 · 98% Fe_2O_3)	160	16.2	760	265°	2.03	0.001
22.	3(30% Gd_2 · 70% Y_2O_3) · 5(8% $Al_{1.925}O_3$ · 92% $Fe_{1.925}O_3$)	144	15.9	567	210°	2.04	0.0001
23.	50.75% NiO · 1.02% MnO · 48.22% Fe_2O_3	1000	12.8	2400	580°	2.41	0.001
24.	13.95% NiO · 36.80% ZnO · 1.02% MnO · 48.22% Fe_2O_3	130	15.1	2200	91°	2.06	0.0005
25.	16.50% NiO · 34.26% ZnO · 1.02% MnO · 48.22% Fe_2O_3	110	14.9	3080	126°	2.08	0.0006
26.	20.30% NiO · 30.46% ZnO · 1.02% MnO · 48.22% Fe_2O_3	100	14.4	4040	177°	2.10	0.0063
27.	30.46% NiO · 20.30% ZnO · 1.02% MnO · 48.22% Fe_2O_3	125	13.9	4800	313°	2.17	0.0141
28.	3(92.5% Y_2O_3 · 7.5% Sm_2O_3) · 5 Fe_2O_3	145	**	1750	280°	2.00	**
29.	3(60% Y_2O_3 · 30% Gd_2O_3 · 10% Dy_2O_3) · 5 Fe_2O_3	465	**	1130	280°	1.82	**

*Where tan δ is the ratio of the imaginary part of the dielectric constant to the real part (tan δ = ε''/ε'). These are typical values for these materials.

**Values were not measured.

Figure 3. This structure has produced a close grouping of impedance characteristics and can be matched utilizing a shield disk beneath the ferrite. This type of matching seems inherently better for above resonance circulators, in contrast to the quarter wave matching transformer technique used for below resonance type circulators. This is particularly advantageous at the lower frequencies where quarter wavelength transformers become excessively long.

Several shield diameters were tried and their impedance characteristics are shown in Figure 4. The VSWR, isolation, and forward loss characteristics of the 1.250 inch shield are shown in Figure 5. Although these characteristics do not meet the design performance goals, this represents a substantial improvement for this band.

During the next quarter, other shield diameters will be investigated and a further reduction in stripwidth and ground plane spacing will be explored.

4.4.2 <u>Lower L-Band (600 to 1200 Mc)</u>

Previous work in this band indicated that the use of material No. 6 in conjunction with either the 1.750 or 2.000 inch shield diameter would provide broadband operation and final optimization would be accomplished using the deliverable hardware.

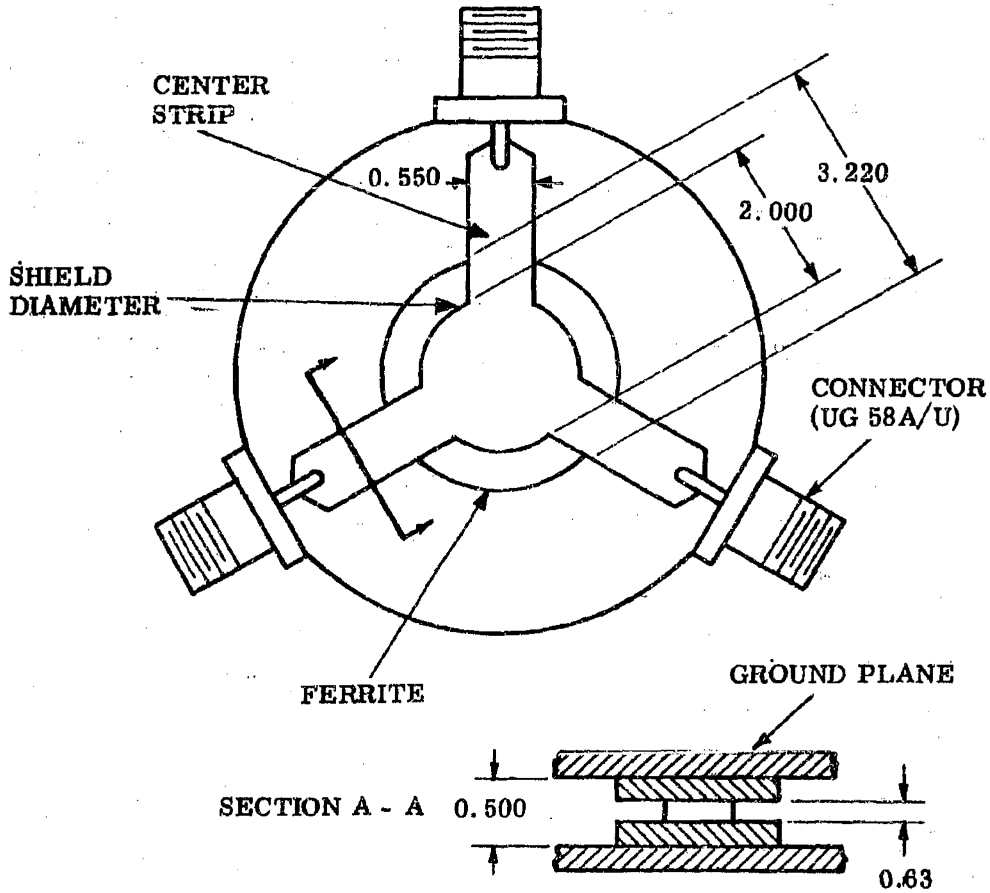


Figure 3. Strip Transmission Line Circulator Housing and Ferrite Configuration

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(Fe_{1.925}O_3)$
PUCK SIZE	-	3.220 IN. DIAMETER x 0.115 IN. HIGH
GROUND PLANE SPACING	-	0.255 IN.
STRIP WIDTH	-	0.300 IN.
STRIP THICKNESS	-	0.025 IN.
SHIELD DIAMETER	-	* IN.
MAGNETIC FIELD	-	Δ GAUSS
REFERENCE PLANE	-	FERRITE FACE

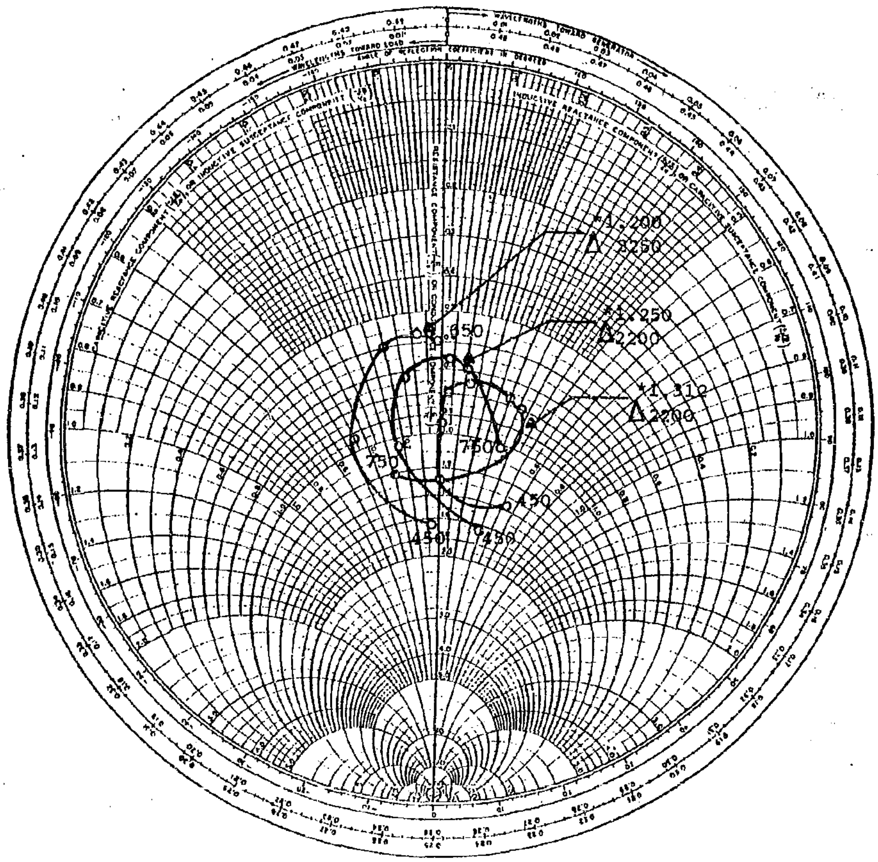


Figure 4. Impedance Grouping, and Effect of Shield Disk for Material No. 13. Table I ($4\pi M_s = 1780$)

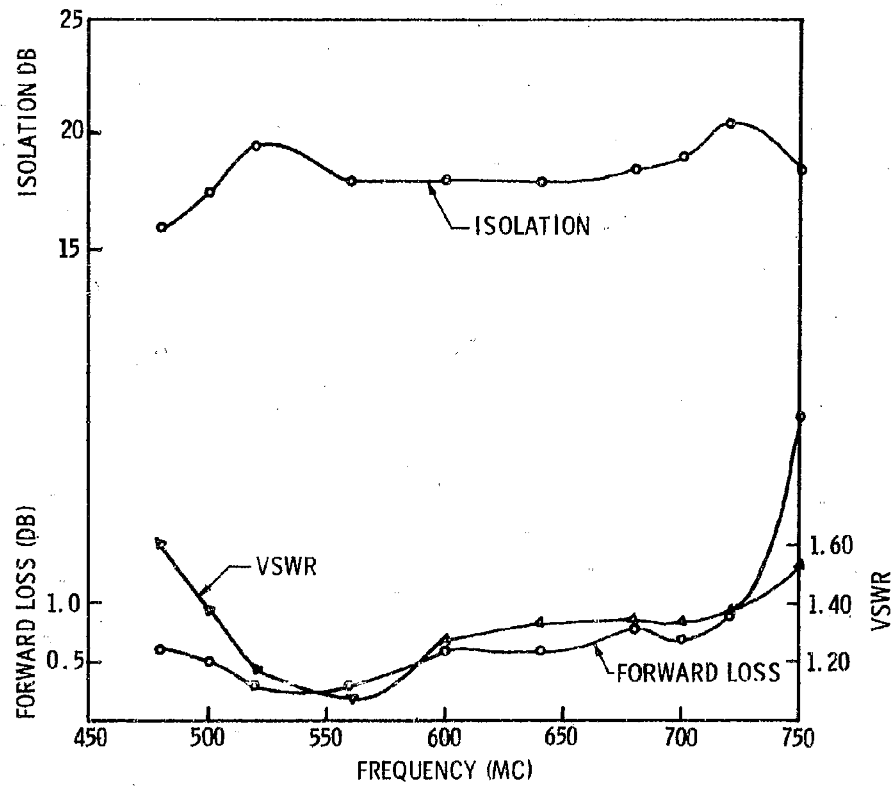


Figure 5. Room Temperature Characteristics of a Matched UHF Circulator Above Resonance

Both shields were tested and the results matched using the conventional dielectric transformers. These results are shown in Figures 6 and 7, respectively.

The impedance plot shown in Figure 7 is one which can be further improved by the addition of a resonant element having an impedance with an equal magnitude and an opposite phase slope. This type of circuit can be attained by the use of an open circuited, quarter-wavelength stub in series with the stripline center conductor. A stub of this type is equivalent to a series resonant circuit whose resonance frequency is controlled by the length of the stub. This circuit was built and tested in a separate housing, the results of which are shown in Figure 8. A sketch of this device is shown in Figure 9, and a photograph of this circuit built into the circulator is shown in Figure 10. The addition of this second matching structure produced the desired result when used in conjunction with the 2.000 inch shield with the exception that the center frequency of the octave bandwidth was shifted up by approximately 50 Mc.

Both units were built in this manner and produced results characteristic of those shown in Figure 11. The final characteristics are presently being measured and will be reported in the next report.

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(25\%\,Al_2O_3 \cdot 75\%\,Fe_{1.925}O_3)$
PUCK SIZE	-	3.200 IN. DIAMETER x 0.219 IN. HIGH
GROUND PLANE SPACING	-	0.219 IN.
STRIP WIDTH	-	0.550 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	1.750 IN.
MAGNETIC FIELD	-	190 GAUSS
REFERENCE PLANE	-	FFRRITE FACE

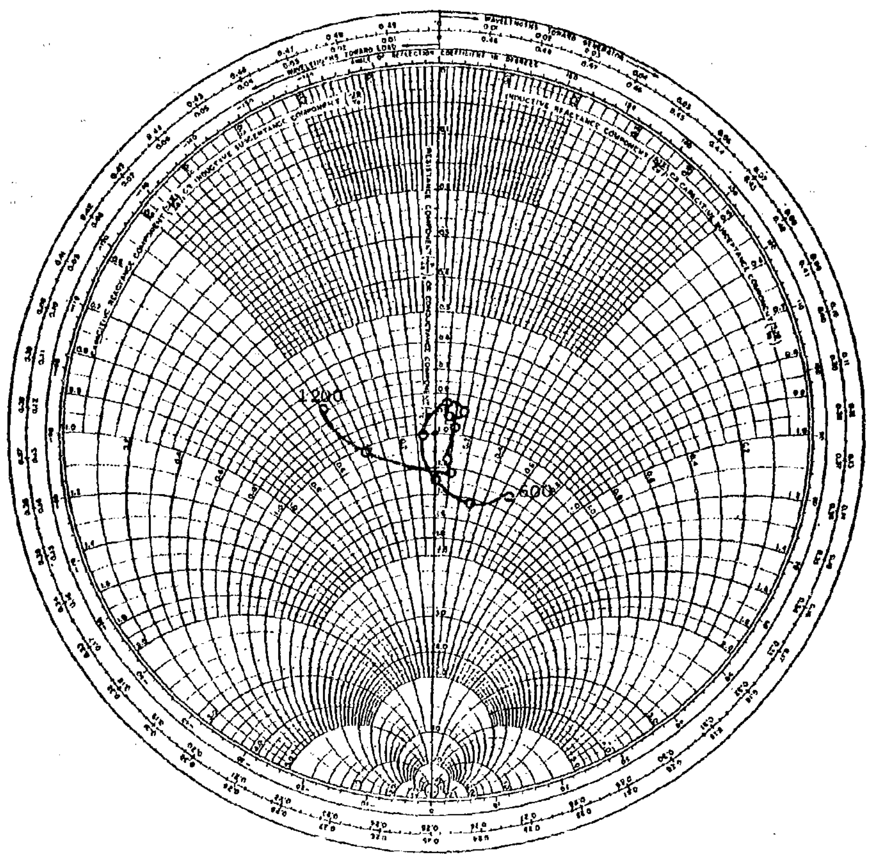


Figure 6. Impedance Grouping for 1.750 inch Diameter Shield and Material No. 6. Table I ($4\pi M_s$ = 315)

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(25\%\,Al_2O_3 \cdot 75\%\,Fe_{1.925}O_3)$
PUCK SIZE	-	3.200 IN. DIAMETER x 0.219 IN. HIGH
GROUND PLANE SPACING	-	0.500 IN.
STRIP WIDTH	-	0.550 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	2.000 IN.
MAGNETIC FIELD	-	190 GAUSS
REFERENCE PLANE	-	1.700 IN. FROM FERRITE FACE

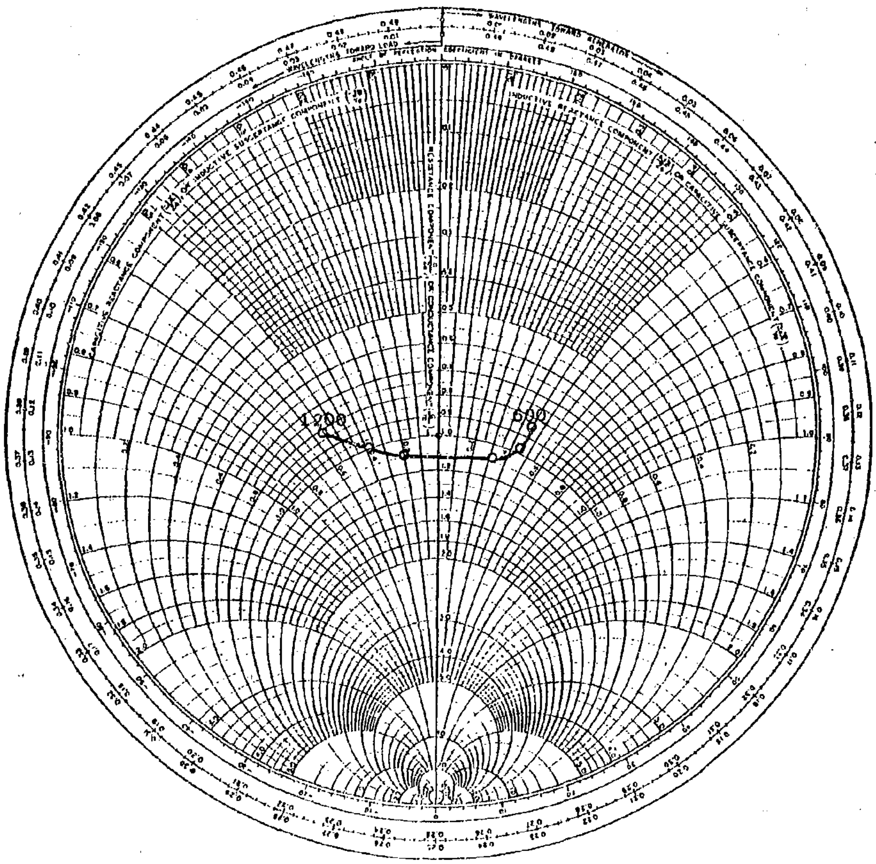


Figure 7. Impedance Grouping for 2.000 inch Diameter Shield and Material No. 6. Table I ($4\pi M_s$ = 315)

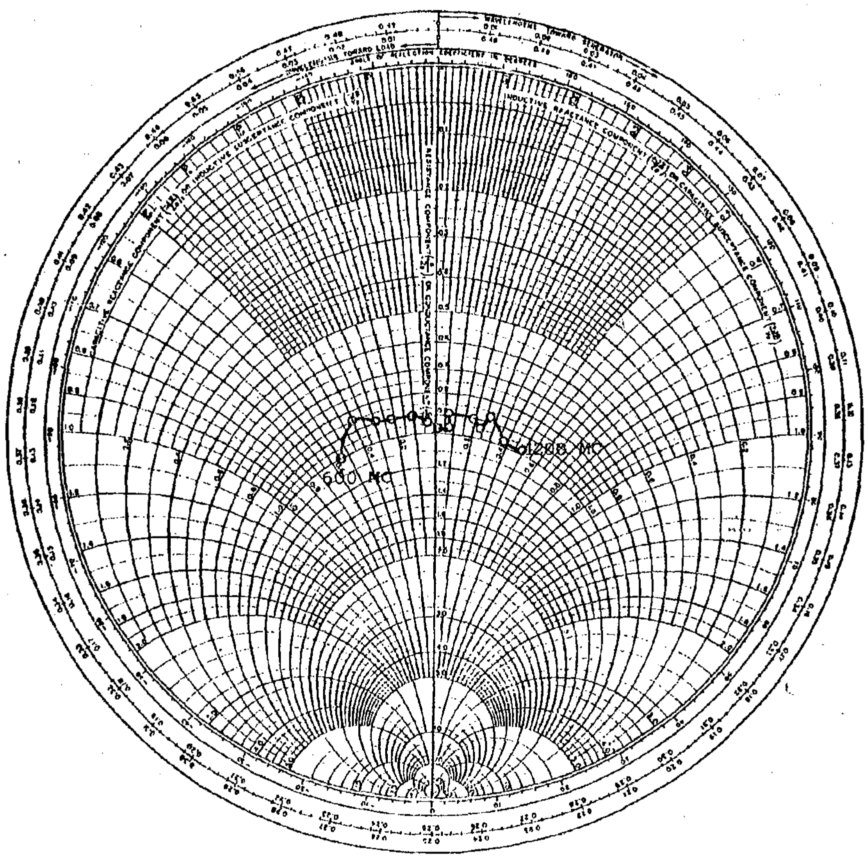


Figure 8. Impedance Characteristics of a Quarter Wavelength Open Circuited Resonant Stub (600 - 1200 Mc)

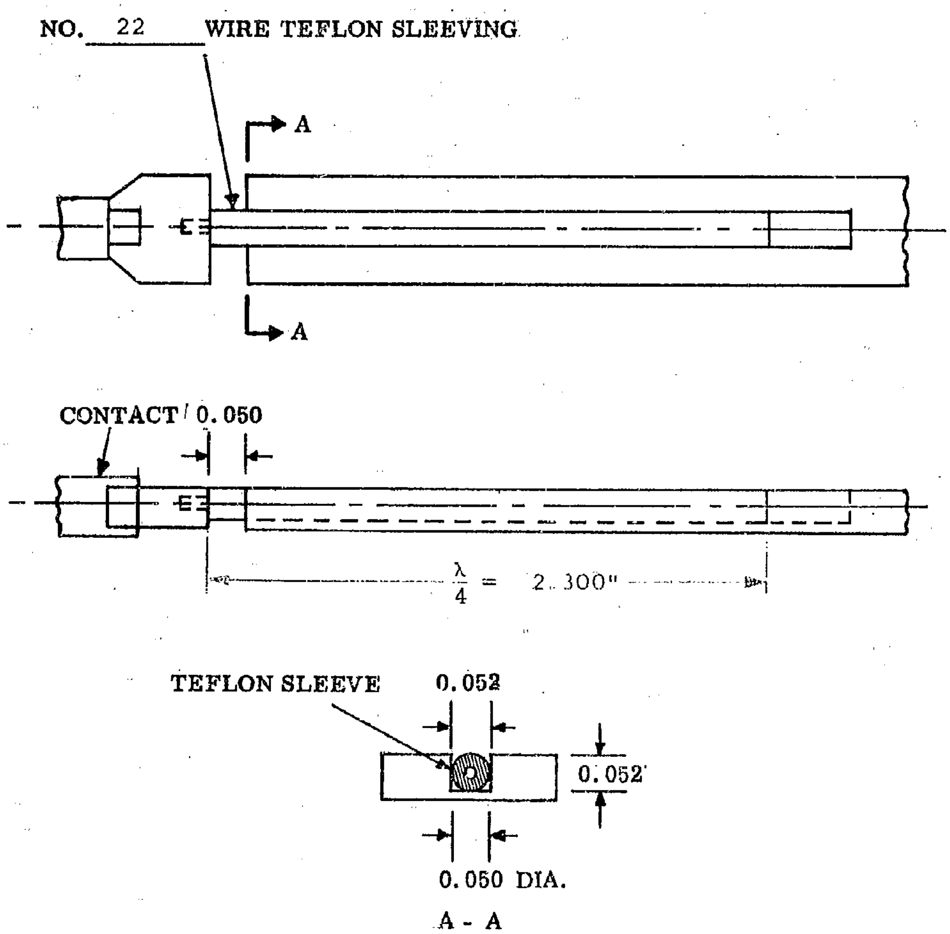


Figure 9. Open Circuited Quarter-Wavelength Stub Mounted in Series with Stripline Center Conductor

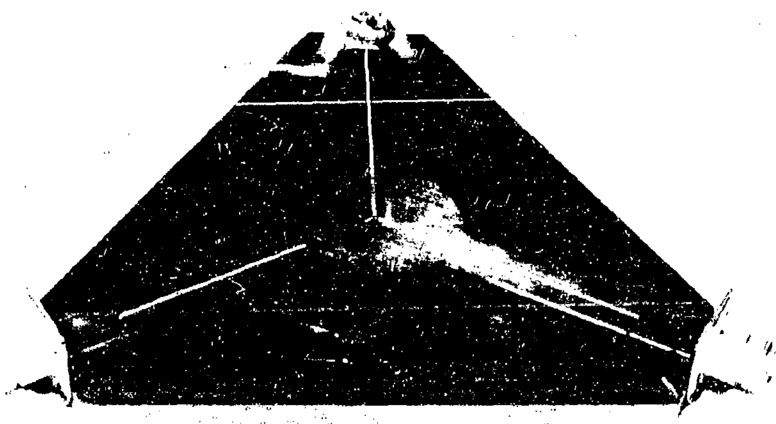


Figure 10. Assembly of 600 - 1200 Mc Circulator Utilizing Resonant Stubs

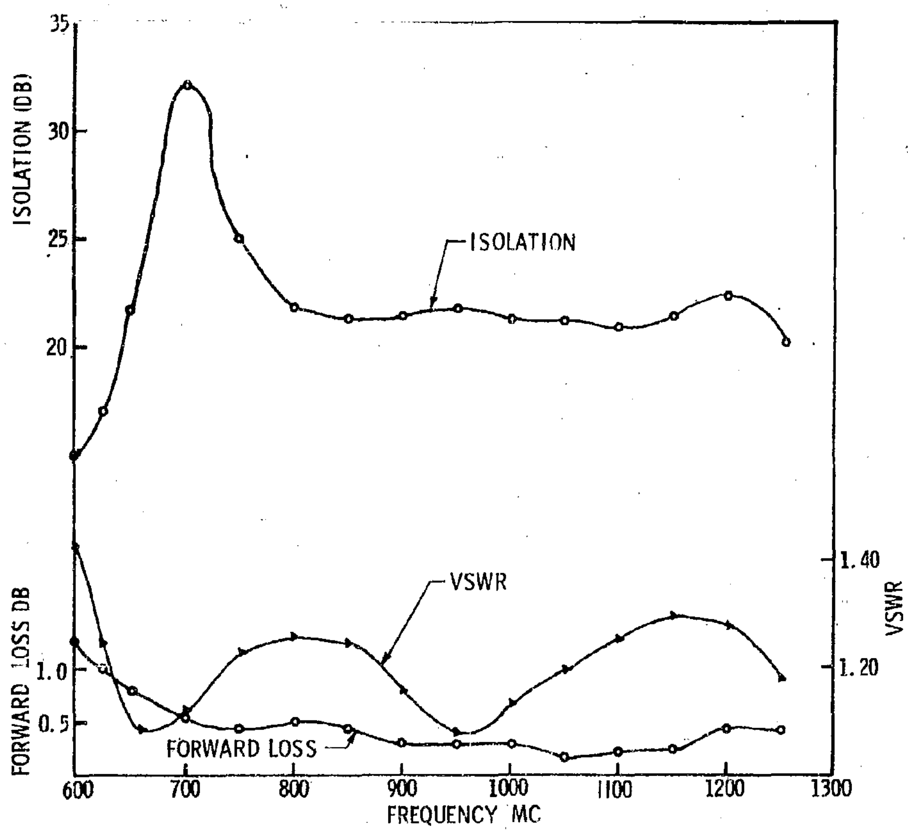


Figure 11. Octave Bandwidth Operating Characteristics of the 600 - 1200 Mc Circulators

The approximate low frequency limit of 742 Mc established for the lowest frequency at which a below resonance low loss circulator could be built using material No. 6 has been very closely approached in these two devices. It is felt that this limit probably will not be reduced appreciably until a ferrite material can be developed which has a considerably narrower linewidth than those presently available.

4.4.3 L-Band (1.0 to 2.0 Gc)

On the basis of the promising results obtained previously, two materials (#8A and #18) were tested in both the puck and triangular configurations. This evaluation was carried out by carefully matching each of the separate materials and geometries in the deliverable circulator housings.

Previously the impedance plots made on each ferrite have guided the selection of optimum materials. However, because of the interaction of a number of complex reflection coefficients (due to the imperfect coax-to-stripline transitions, boundary reflections from the dielectric transformers, etc.), the best choice can be made only after each material has been individually matched.

These tests revealed that the combination which produced the optimum matched results was material #8A in the shape of a 1.400 inch diameter puck. The unmatched and matched results are shown in Figure 12. These results were obtained using the conventional quarter wavelength dielectric transformers.

In the impedance plot of Figure 12, it should be noted that only the end points are high and that the impedance mismatch is due almost entirely to an imaginary component. As was the case in the 600 - 1200 Mc unit, the addition of a series resonant circuit appeared to be possibly beneficial. A suitable series resonant circuit was developed using the dimensions illustrated in Figure 9, with the exception that the wire length is 1.250 inches long. The impedance plot of this circuit was taken and is shown in Figure 13. With the addition of the series resonant stub in each of the circulator arms, the matched data was improved as is illustrated in Figure 14.

Further work was carried out on this device in an effort to reduce the VSWR at the center frequencies. This work revealed that the insertion of small tuning tabs which come in contact with the center conductor, as shown in Figure 15, provided an additional improvement in the VSWR. These tabs were soldered into place and the results of the combined dielectric transformer, series resonant circuit

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(20\%\ Al_2O_3 \cdot 80\%\ Fe_{1.925}O_3)$
PUCK SIZE	-	1.400 IN. DIAMETER x 0.219 IN. HIGH
GROUND PLANE SPACING	-	0.500 IN.
STRIP WIDTH	-	0.550 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	360 GAUSS
REFERENCE PLANE		FERRITE FACE (TOP CURVE) DIELECTRIC FRONT FACE (BOTTOM CURVE)

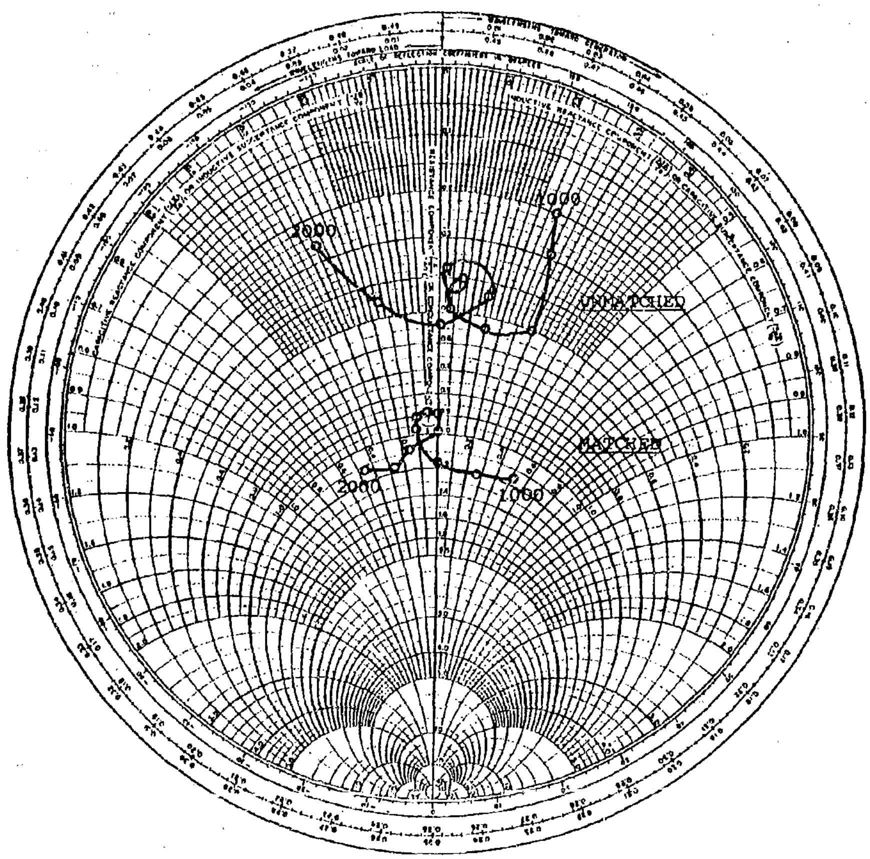


Figure 12. Impedance Grouping Before and After Matching for Material No. 8A, Table I. ($4\pi M_s$ - 379)

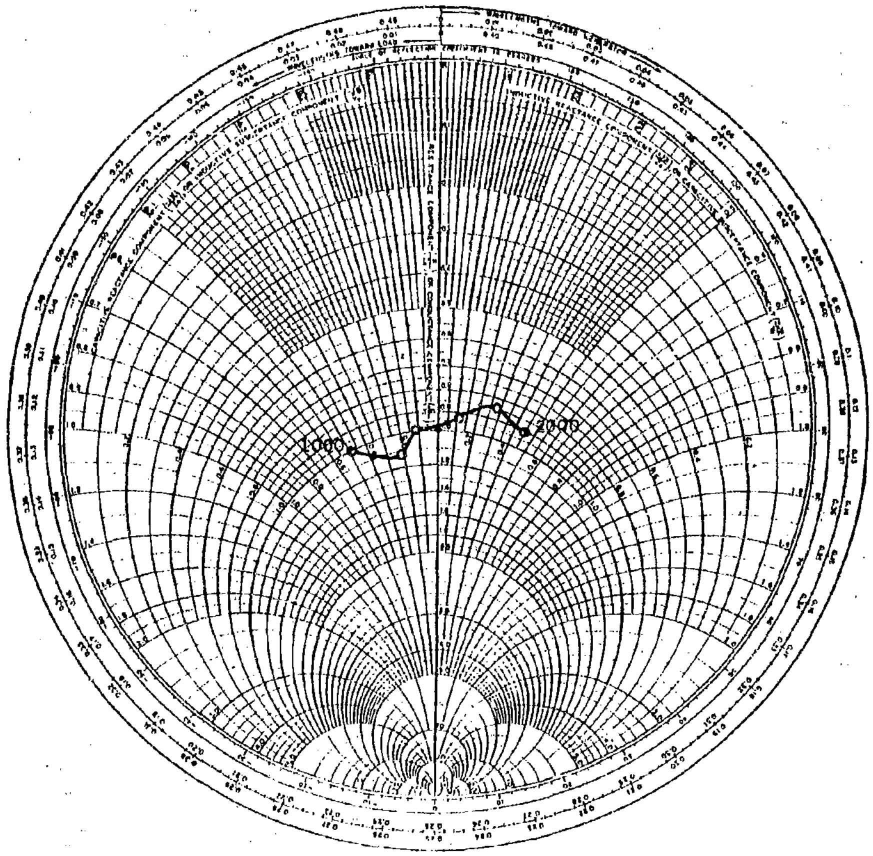


Figure 13. Impedance Characteristics of a Quarter Wavelength Open Circuited Resonant Stub (1.0 - 2.0 Gc)

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5(20\%\ Al_2O_3 \cdot 80\%\ Fe_{1.925}O_3)$
PUCK SIZE	-	1.400 IN. DIAMETER x 0.219 IN. HIGH
GROUND PLANE SPACING	-	0.500 IN.
STRIP WIDTH	-	0.550 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	360 GAUSS
REFERENCE PLANE	-	DIELECTRIC FRONT FACE

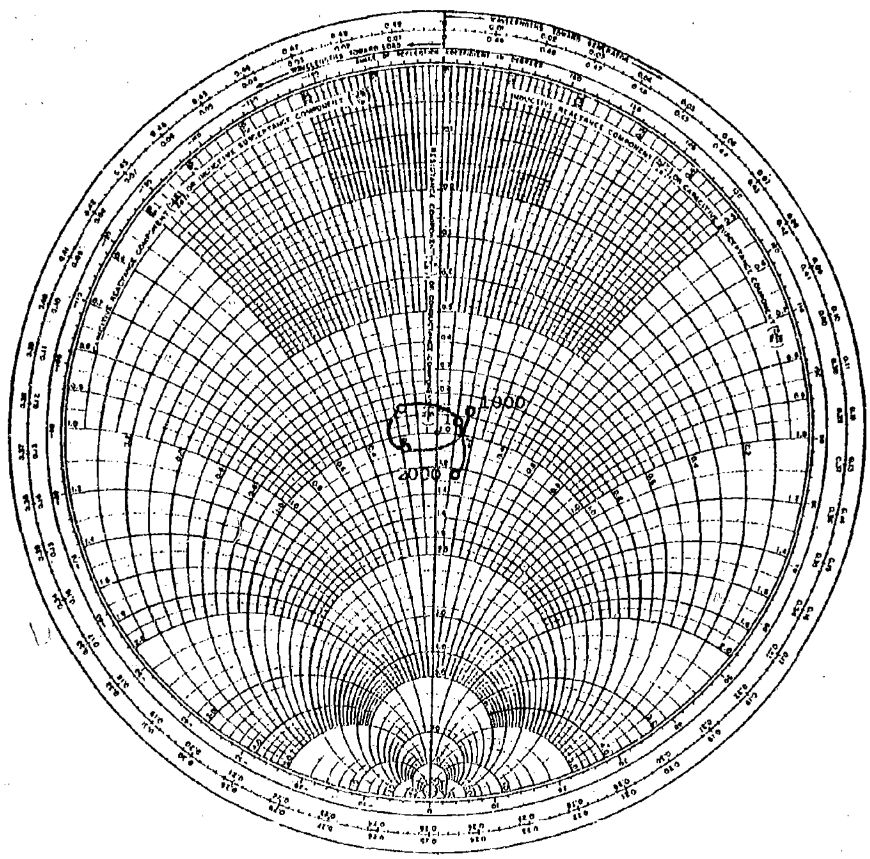


Figure 14. Impedance Grouping After Matching Using Dielectric Transformers and a Resonant Stub

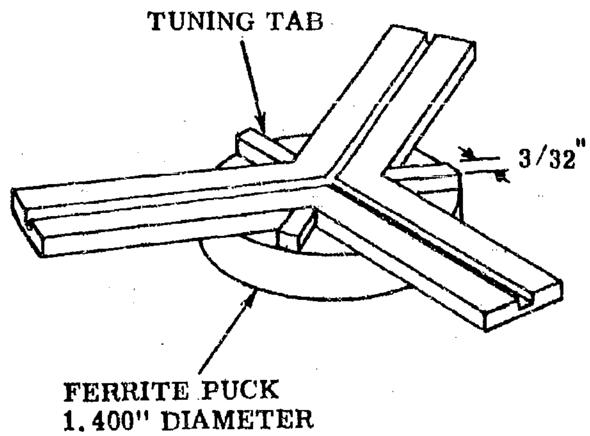


Figure 15. Sketch of 1.0 - 2.0 Gc Circulator with Tuning Tabs

and the tuning tabs are given in Figure 16. The VSWR, isolation and insertion loss of this circulator are shown in Figure 17.

This technique is currently being pursued in the fabrication of the second deliverable unit. The final data of both units will be presented in the next quarterly report.

4.4.4 Low S-Band (1.5 to 3.0 Gc)

On the basis of the work done in the last quarter, two materials (No. 2A and 18) were chosen for testing and

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(20\%\,Al_2O_3 \cdot 80\%\,Fe_{1.925}O_3)$
PUCK SIZE	-	1.400 IN. DIAMETER x 0.219 IN. HIGH
GROUND PLANE SPACING	-	0.500 IN.
STRIP WIDTH	-	0.550 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	360 GAUSS
REFERENCE PLANE	-	FERRITE FACE

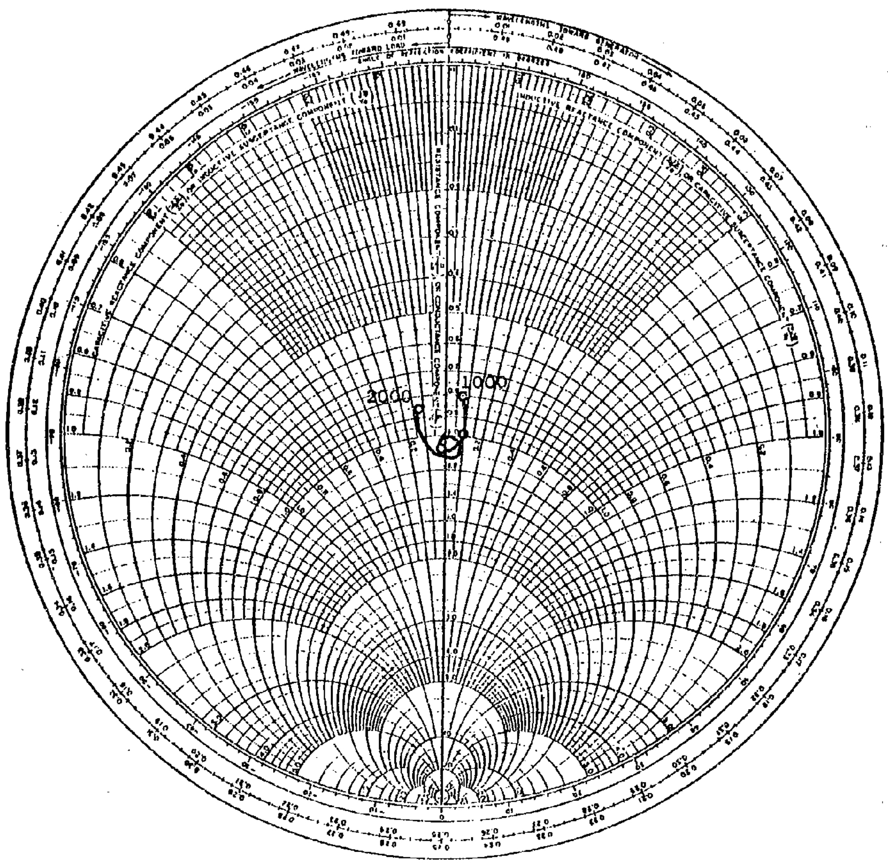


Figure 16. Impedance Grouping After Matching Using Dielectric Transformers, Resonant Stubs, and Tuning Tabs

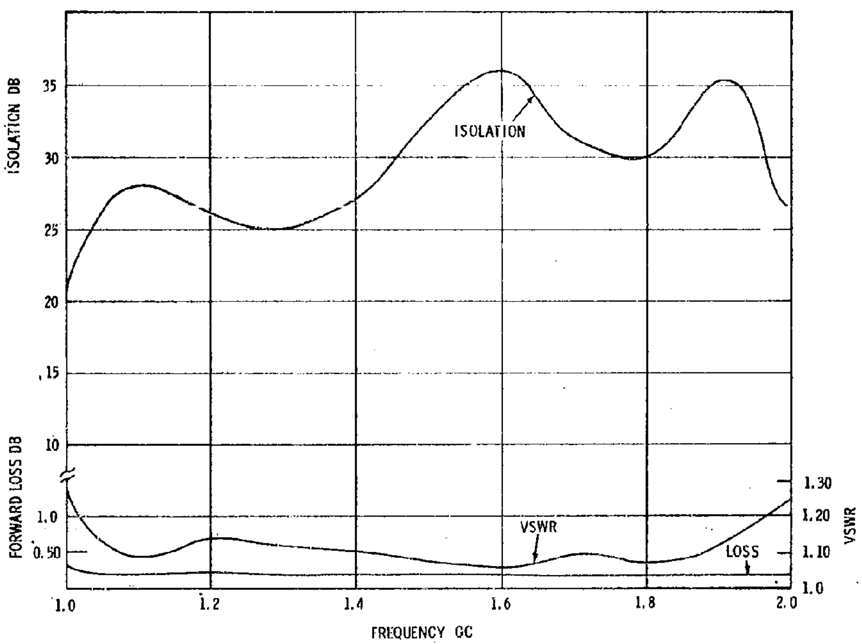


Figure 17. Octave Bandwidth Operating Characteristics of the 1.0 – 2.0 Gc Circulator

optimization in the final unit. Only initial testing has been accomplished at this time, as it was expected that the results obtained in optimizing the 1.0 to 2.0 and 2.0 to 4.0 Gc bands would be useful in this band.

Preliminary testing of material No. 2A in the circulator shows great promise, if the techniques of using a series resonance circuit can be utilized in this frequency range. This material was matched using dielectric transformers, and the results are illustrated in Figure 18. Although this plot is not in exactly the optimum position for the application of the series resonant element, it is felt that with further work it can be shifted into the correct position.

During the next quarter, materials #2A and #18 will be further evaluated and the material yielding the best performance will be chosen for the finalized unit. It is expected that the desired characteristics will be achieved by using techniques similar to those in the 1.0 - 2.0 and 2.0 - 4.0 Gc bands. These results will be reported in the next quarterly report.

4.4.5 S-Band (2.0 to 4.0 Gc)

Effort during the previous quarter revealed that ferromagnetic materials having $4\pi M_s$ values on the order of 1000 gauss produced the broadest practical operating bandwidths. With the use of these optimum materials and conventional matching techniques some difficulty has been encountered in matching these devices over an octave bandwidth. It was felt

FERRIMAGNETIC MATERIAL	-	$3Y_2O_3 \cdot 5\,(15\%\ Al_2O_3 \cdot 85\%\ Fe_{1.925}O_3)$
PUCK SIZE	-	0.980 IN. DIAMETER x 0.115 IN. HIGH
GROUND PLANE SPACING	-	0.255 IN.
STRIP WIDTH	-	0.300 IN.
STRIP THICKNESS	-	0.025 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	720 GAUSS
REFERENCE PLANE	-	FERRITE FACE

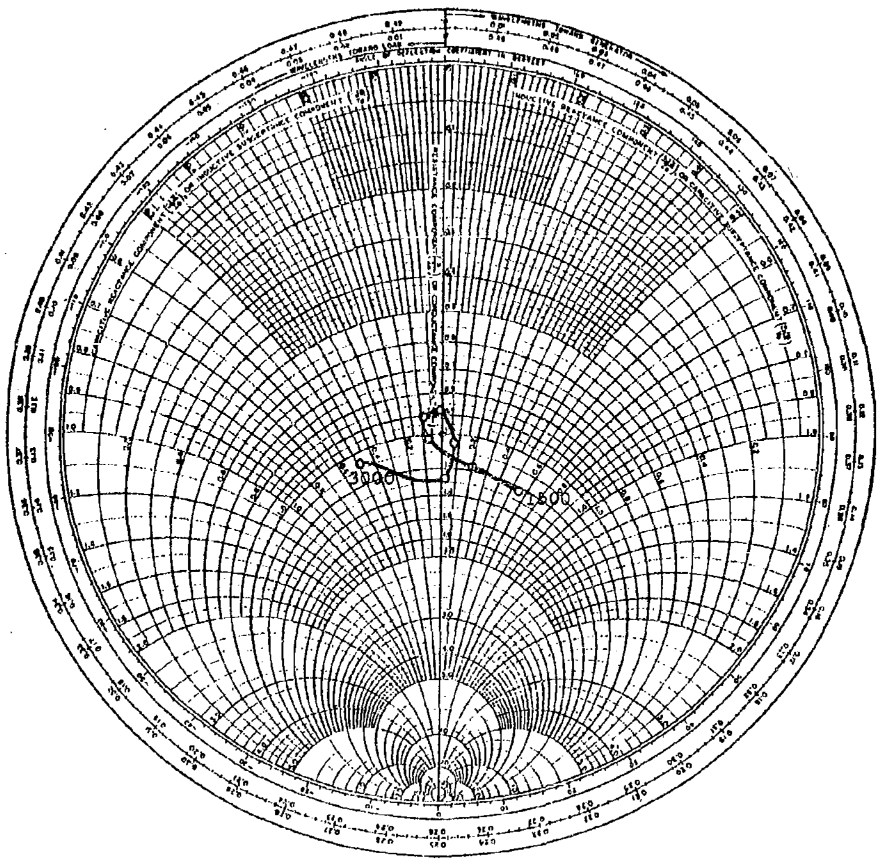


Figure 18. Impedance Grouping After Matching for Material No. 2A, Table I ($4\pi M_s = 653$)

that minor variations in the microwave structure might yield the possible means for simplifying the matching problem. Using this approach, variations in the strip width, strip thickness, center conductor geometry etc. were evaluated for possible improvement in the grouping of the impedance characteristics.

From this empirical approach, a new center conductor geometry, not radically different from the ones previously used, was derived. The new geometry made it possible to achieve the required match across the 2.0 - 4.0 Gc band using the conventional dielectric transformers. Figure 19 is a scaled drawing of this center conductor.

Upon successfully matching one unit, using material No. 10A, the second unit was matched using material No. 9A with equal success. Typical results of these units are shown in Figure 20. The final characteristics of these circulators are currently being measured and will be presented in the next quarterly report.

4.4.6 C-Band (4.0 - 8.0 Gc)

During this quarter a study was made to determine if the present bandwidth could be extended by increasing the mumber of matching transformers from one to two. Two transitions were designed[1] which theoretically match a 50 ohm impedance line into a 12.5 and a 20 ohm impedance line respectively. The 12.5 and 20 ohm values were picked because most unmatched circulators in this frequency band have input impedance values in this general range. The

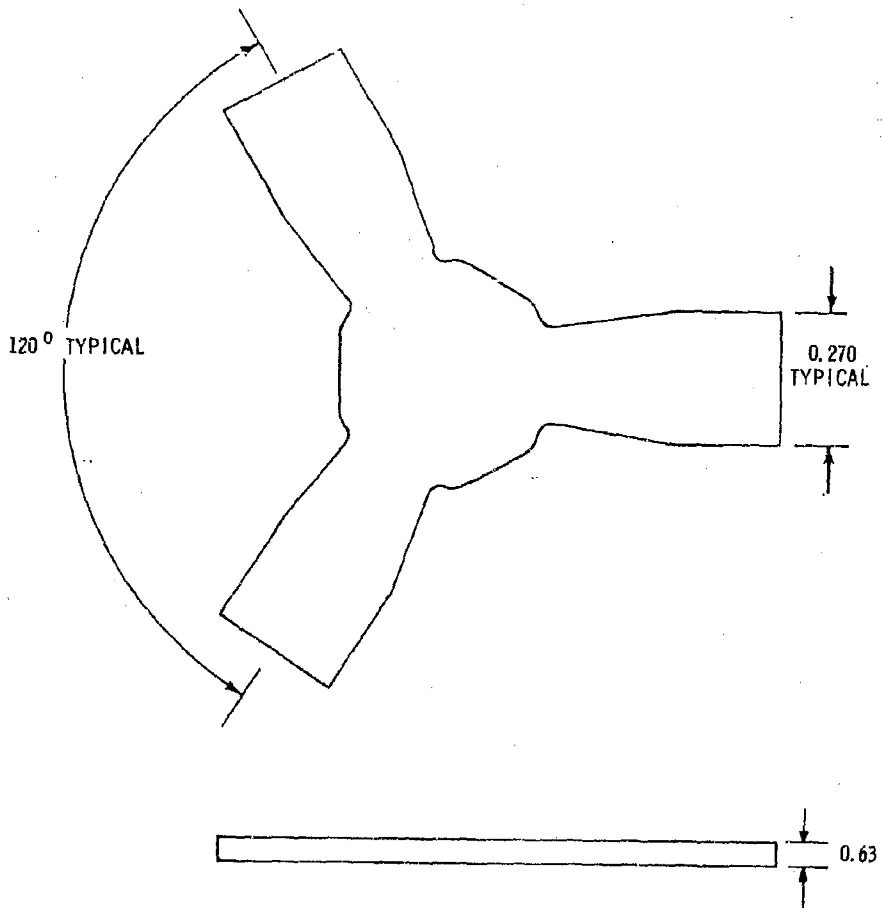


Figure 19. Scaled Drawing of Modified 2.0 - 4.0 Gc Center Conductor

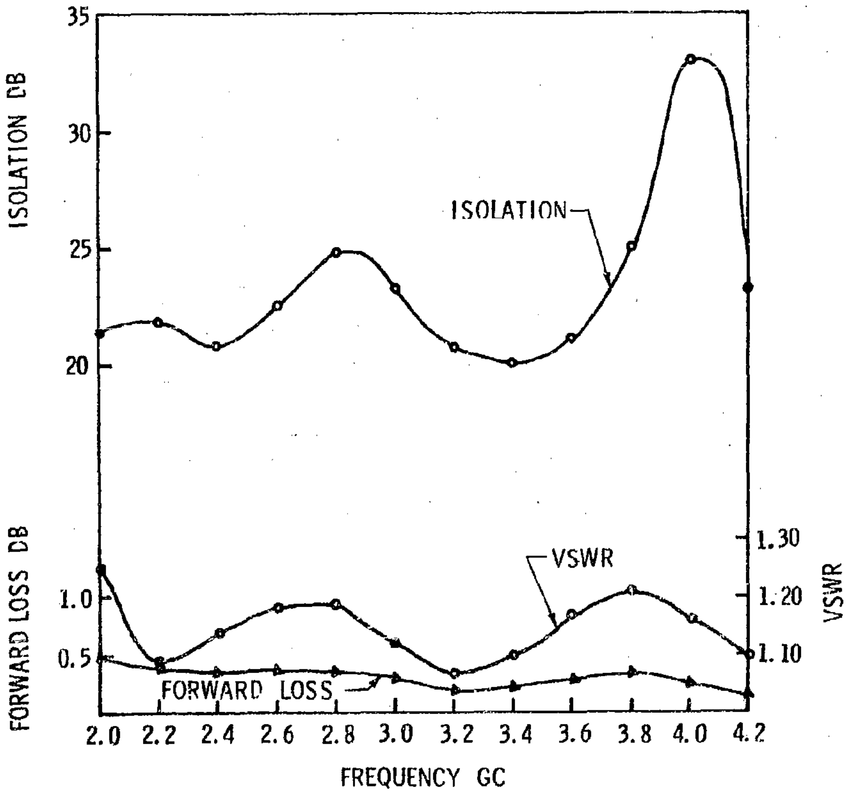


Figure 20. Octave Bandwidth Characteristics of the 2.0 - 4.0 Gc Circulators

impedance of each transformer was adjusted by loading the transmission line with the proper dielectric constant. Although the dielectric constant necessary to obtain the exact impedance required for the Tchebycheff design were not available, the values which were substituted were considered close enought to provide meaningful results for this test. Both the design and the actual numbers which were used are tabulated in Table II. A sketch depicting the geometry and method of assembly is illustrated in Figure 21.

The circulator which has produced the best results thus far, and whose characteristics and pertinent dimensions

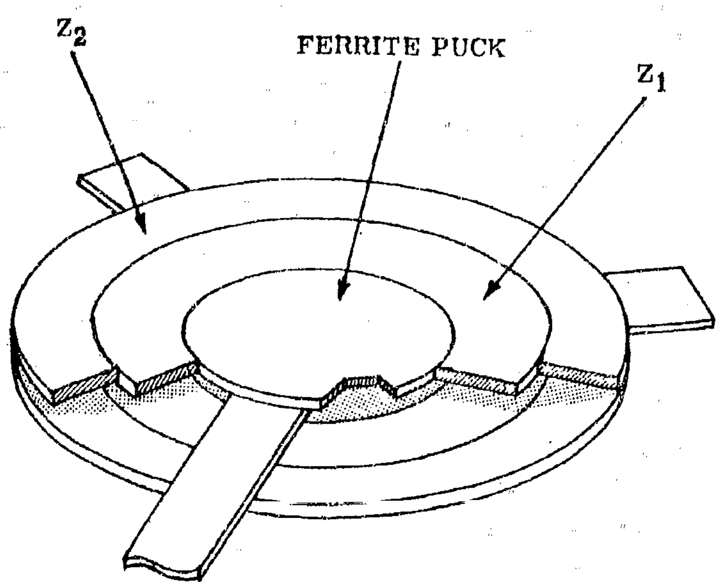


Figure 21. Two Section Quarter Wavelength Transformer Assembly

TABLE II

TWO SECTION QUARTER WAVELENGTH MATCHING TRANSFORMERS

	Calculated Impedance Ohms	Dielectric Constant Required	Dielectric Constant Used	Length Inches
	Transformer Design for Matching 50 Ohms to 20 Ohms			
Z_2	38.5	1.69	1.60	0.377
Z_1	26.0	3.69	4.0	0.225
	Transformer Design for Matching 50 Ohms to 12.5 Ohms			
Z_2	33.6	2.215	2.1	0.350
Z_1	18.58	7.24	7.0	0.192

are given in the third quarterly report, Figure 37, was used for the evaluation of the double transformer matching rings. A Smith Chart plot of this unit unmatched is shown in Figure 22. A typical impedance plot with a single matching transformer element in each of the arms is shown in Figure 23. The results of adding the double step transformers are illustrated in Figures 24 and 25. From these impedance plots it can be seen that some improvement has been derived through the use of the 50 ohm to 20 ohm transition over that of the single transformer. The response of the 50 ohm to 12.5 ohm transition has been over compensated, as was expected, on the basis of the unmatched impedance plot. From these results, it appeared that further investigation in this area might prove to be valuable in effecting greater bandwidths. However, no further work was done on this scheme during this quarter due to a lack of time. Based on all results available it has been decided that the remaining time will be utilized incorporating the new broadbanding techniques which were very successful in the lower frequency bands.

Further work has been carried out on material No. 13, which indicated from the previous Smith Chart data that the impedance grouping of the unmatched plot should yield

FERRIMAGNETIC MATERIAL -

$5.0\%\ Al_2O_3 \cdot 51.62\%\ MgO \cdot 5.68\%\ MnO_2 \cdot 37.7\%\ Fe_2O_3$

PUCK SIZE	- .415 IN. DIAMETER x .100 IN. HIGH
GROUND PLANE SPACING	- .262 IN.
STRIP WIDTH	- .250 IN.
STRIP THICKNESS	- .062 IN.
SHIELD DIAMETER	- NONE
MAGNETIC FIELD	- 660 GAUSS
REFERENCE PLANE	- FERRITE FACE

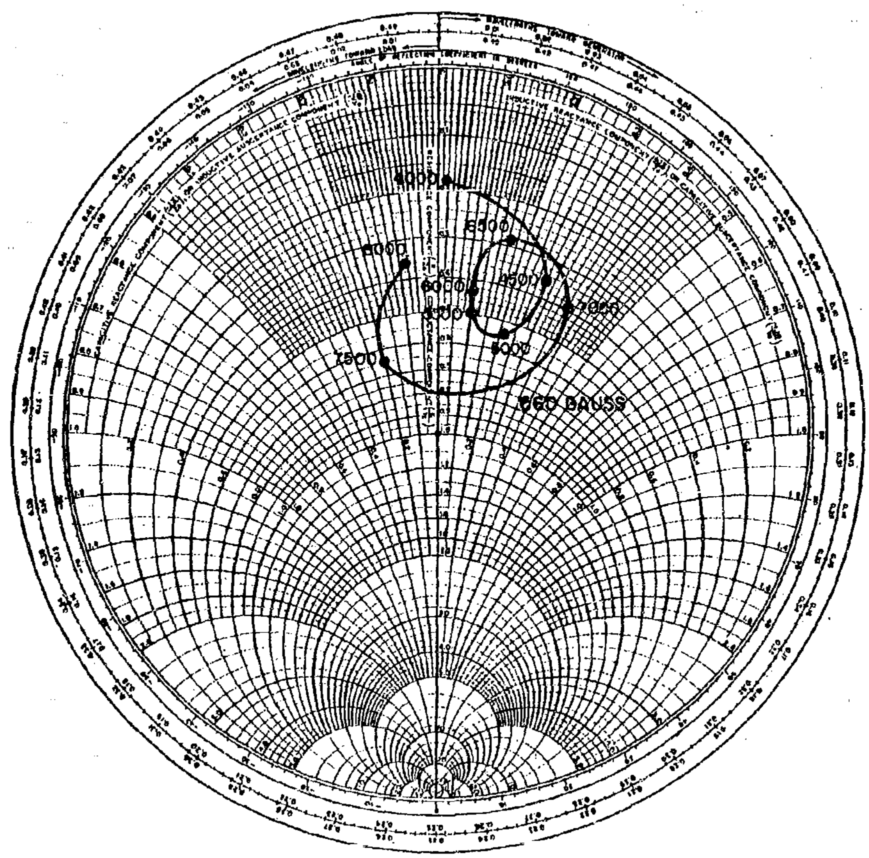


Figure 22. Impedance vs Frequency Characteristics of a C-Band Circulator Using Material No. 16. Table I. ($4\pi M_s$ = 1800 gauss)

FERRIMAGNETIC MATERIAL	-	5.0% Al_2O_3 · 51.62% MgO · 5.68% MnO_2 · 37.7% Fe_2O_3
PUCK SIZE	-	0.415 IN. DIAMETER x 0.100 IN. HIGH
GROUND PLANE SPACING	-	0.262 IN.
STRIP WIDTH	-	0.250 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	600 GAUSS
REFERENCE PLANE	-	FACE OF MATCHING RING

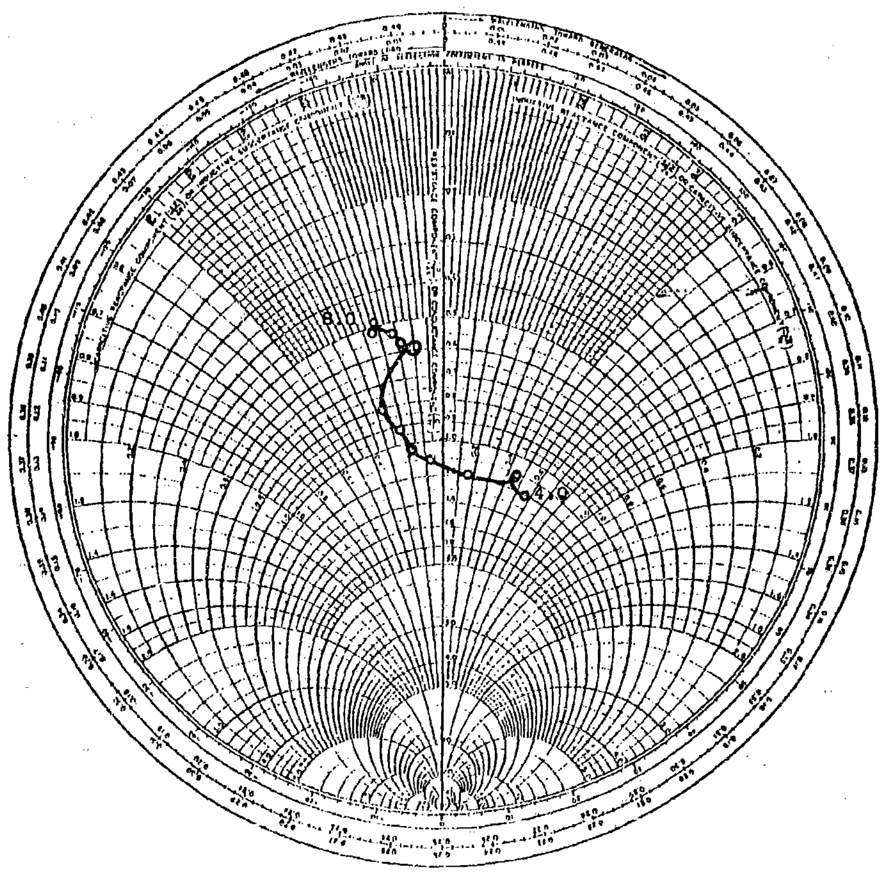


Figure 23. Impedance vs Frequency Characteristics of a C-Band Circulator Using a One Section Quarter Wavelength Matching Transformer. (50 - 20 ohms)

FERRIMAGNETIC MATERIAL	-	5.0% Al_2O_3 · 51.62% MgO · 5.68% MnO_2 · 37.7% Fe_2O_3
PUCK SIZE	-	0.415 IN. DIAMETER x 0.100 IN. HIGH
GROUND PLANE SPACING	-	0.262 IN.
STRIP WIDTH	-	0.250 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	660 GAUSS
REFERENCE PLANE	-	FACE OF MATCHING RING

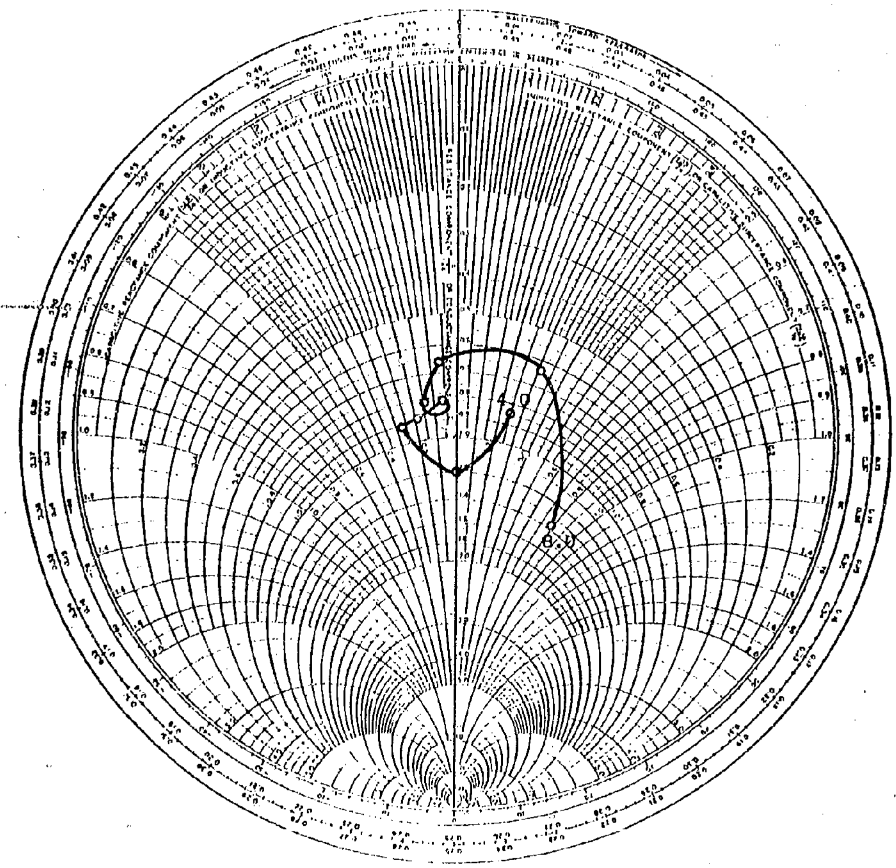


Figure 24. Impedance vs Frequency Characteristics of a C-Band Circular Using a Two Section Quarter Wavelength Matching Transformer (50 - 20 ohms)

FERRIMAGNETIC MATERIAL	-	$5.0\% Al_2O_3 \cdot 51.62\% MgO \cdot 5.68\% MnO_2 \cdot 37.7\% Fe_2O_3$
PUCK SIZE	-	0.415 IN. DIAMETER x 0.100 IN. HIGH
GROUND PLANE SPACING	-	0.262 IN.
STRIP WIDTH	-	0.250 IN.
STRIP THICKNESS	-	0.062 IN.
SHIELD DIAMETER	-	NONE
MAGNETIC FIELD	-	660 GAUSS
REFERENCE PLANE	-	FACE OF MATCHING RING

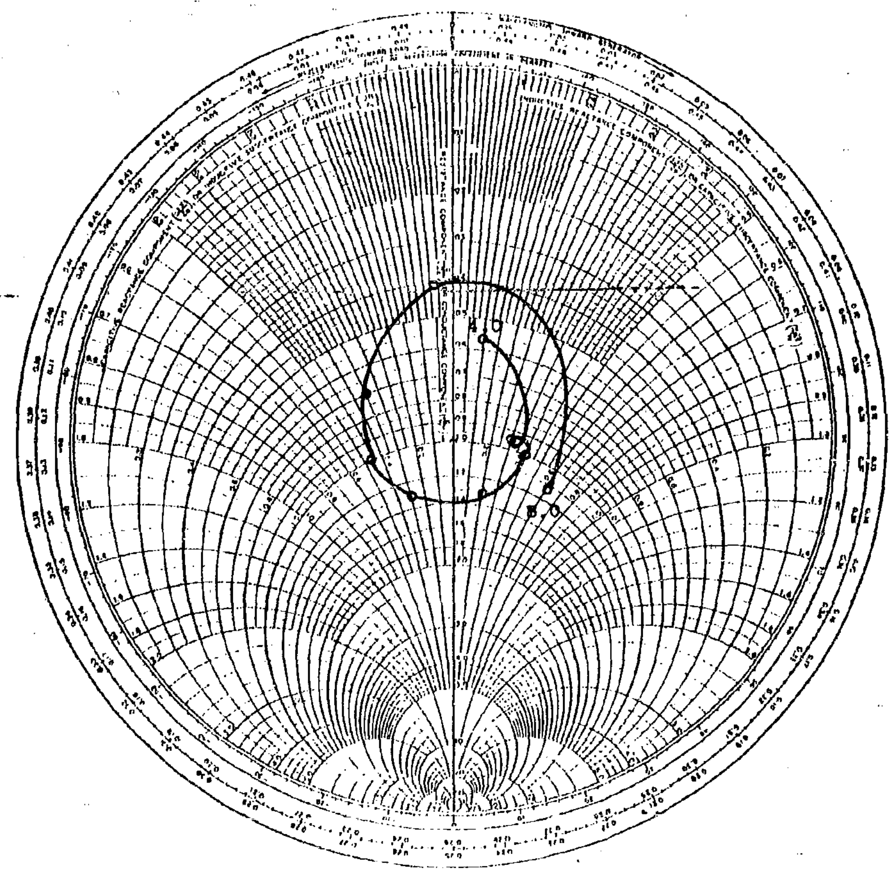


Figure 25. Impedance vs Frequency Characteristics of a C-Band Circulator Using a Two Section Quarter Wavelength Matching Transformer (50 - 12.5 ohms)

broadband operating characteristics. To date this material has produced slightly better results than material No. 16. The final design has not been completed as yet; however, it is anticipated that it will not change radically from the design previously indicated. The best data produced in this interim is not appreciably better than that described in the last report and thus will not be reproduced here. It is expected that the use of the new techniques, developed during this quarter will provide the small assistance needed to improve the characteristics enough to meet the design goals. These techniques are presently being investigated and will be reported in the next quarterly report.

4.5 REFERENCES

1. S. B. Cohn "Optimum Design of Stepped Transmission Line Transformers", IRE Trans. on Microwave Theory and Techniques, Volume MTT-3, No. 3, pp. 16-21, April 1955.

5. CONCLUSIONS

Circulators in the 600 - 1200 Mc, 1.0 - 2.0 Gc and 2.0 - 4.0 Gc bands have been completed which very nearly meet all of the program design goals. The technique used for optimizing these units are presently being employed for completing the 1.5 - 3.0 Gc and 4.0 - 8.0 Gc circulators and it is expected that similar characteristics will result.

Two new techniques have been developed for extending the circulator bandwidth. These have consisted of using a resonant tuned stub for increasing the bandwidth of the VSWR characteristics and using an improved center conductor geometry.

In the 400 - 800 Mc region a considerable improvement in bandwidth has been obtained through the use of narrower strip widths and smaller puck heights when used in conjunction with pure yttrium garnet. Experimental evidence indicates at this time that the optimum shield diameter is approximately 1.250 inches.

6. PROGRAM FOR NEXT INTERVAL

A summary of the theoretical study will be completed and presented in the next quarterly report.

Work will continue on the 400 - 800 Mc circulator with emphasis being placed on utilizing new matching techniques. Testing will be continued to determine the effects of further reducing the stripwidth and ground plane spacing.

The second 1.0 - 2.0 Gc circulator will be completed and tested. It is anticipated that the present work on the 1.5 - 3.0 and 4.0 - 8.0 Gc units will be successfully completed in early June. The development of these units is being modeled after the 600 - 1200, 1.0 - 2.0 Gc and 2.0 - 4.0 Gc units, and it is expected that similar characteristics will be obtained.

During the next interim, efforts to develop the 200 - 400 Mc coaxial circulator will be initiated. Existing test housings will be used for this development effort and a small number of ferrite pucks will be manufactured for initial testing. It is felt that a concentrated effort should be maintained in the 400 - 800 Mc region for the purpose of developing and improving broadbanding techniques which are applicable above resonance. Until these techniques are sufficiently developed a lesser effort should be expended.

The initial experiments in the 200 - 400 Mc band will be made on a sampling basis to compare the effectiveness of techniques developed in the 400 - 800 Mc region. Final development in both bands will be initiated only after better techniques have been devised.

The test structures to be used in the development of the 7.05 - 10.0 Gc and 8.2 - 12.4 Gc waveguide circulators will be designed and fabricated during the next interim. The ferrite materials will be selected largely on the basis of past experience. Approximate starting values can be extrapolated from Figure 38 of the Third Quarterly Report.

7. IDENTIFICATION OF PERSONNEL

The personnel involved in this program are as follows:

Supervisory	Hours
B. J. Duncan	18.0
E. W. Matthews, Jr.	24.0
G. J. Neumann	36.0
Device Development	
J. W. Simon	172.0
W. C. Passaro	148.0
D. H. Landry	72.0
W. C. Heithaus	117.0
Theoretical	
G. A. Burdick	257.5
J. E. Pippin	6.0
J. A. Hart, Jr.	65.0
Materials Development	
L. R. Hodges	40.0

Biographies of most of the above individuals were included in the First and Second Quarterly Report. Biographies of new personnel appear on the following pages.

In addition to the hours reported each quarter in the above section of these reports, an independent research and development effort is being contributed by Sperry in support of this program. During this quarter approximately 226 additional man hours were expended on device development as part of this independent research effort.

J. A. Hart, Jr., Engineer

J. A. Hart was born in 1940 in Thomasville, Georgia. He received a Bachelor of Electrical Engineering degree from Georgia Institute of Technology in 1962.

Mr. Hart joined Sperry Microwave Electronics Company in April of 1962 and was assigned to development work on a monitor for Air Traffic Control Radar Beacon System ground stations. Mr. Hart was later assigned to development efforts associated with Sperry's Radar Performance Analyzer test equipment line. Presently he is assigned to the Advanced Studies Group in the Microwave Equipment Department where he is performing studies on transient radiation effects in microwave duplexing devices and investigating the thermal impedance of microwave diodes.

Professional Experience

- Design and development of ATC Radar Beacon System ground station monitoring equipment
- Circuit development for Radar Performance Analyzer equipment
- Theoretical computations assiciated with broad band circulator study
- Development work on a background scintillation counter at Georgia Tech Engineering Experiment Station
- Development of instrumentation for use in the investigation of thermal impedance of microwave diodes

Professional Societies

IEEE

	Copies
OASD (R&E) Attn: Technical Library Room 3E1065 The Pentagon Washington 25, D. C.	1
Chief of Research and Development OCS, Department of the Army Washington 25, D. C.	1
Commanding General U. S. Army Materiel Command ATTN: R&D Directorate Washington 25, D. C.	1
Commanding General U.S. Army Electronics Command ATTN: AMSEL-AD Fort Monmouth, New Jersey	1
Director, U.S. Naval Research Laboratory Attn: Code 2027 Washington 25, D. C.	1
Commander, Aeronautical Systems Division Attn: ASAPRL Wright-Patterson Air Force Base, Ohio	1
Hq, Electronic Systems Division Attn: ESAL L. G. Hanscom Field Bedford, Massachusetts	1
Commander, Air Force Cambridge Research Laboratories Attn: CRO L. G. Hanscom Field Bedford, Massachusetts	1
Commander, Air Force Command & Control Development Division Attn: CRZC L. G. Hanscom Field Bedford, Massachusetts	1
Commander, Rome Air Development Center Attn: RAALD Griffiss Air Force Base, New York	1
Commander, Armed Services Technical Information Agency Attn: TISIA Arlington Hall Station Arlington 12, Virginia	10

	Copies
Chief, U.S. Army Security Agency Arlington Hall Station Arlington 12, Virginia	2
Deputy President U. S. Army Security Agency Board Arlington Hall Station Arlington 12, Virginia	1
Commanding Officer Harry Diamond Laboratories Attn: Library, Room 211, Building 92 Washington 25, D. C.	1
Corps of Engineers Liaison Office U. S. Army Electronics Research and Development Laboratory Fort Monmouth, New Jersey	1
AFSC Scientific/Technical Liaison Office U. S. Naval Air Development Center Johnsville, Pennsylvania	1
Commanding Officer U. S. Army Electronics Materiel Support Agency Attn: SELMS-ADJ Fort Monmouth, New Jersey	1
Marine Corps Liaison Office U. S. Army Electronics Research and Development Laboratory Attn: SELRA/LNR Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics Research and Development Laboratory Attn: Director of Research Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics Research and Development Laboratory Attn: Technical Documents Center Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics Research and Development Laboratory Attn: SELRA/ADJ (FU #1) Fort Monmouth, New Jersey	1
Advisory Group on Electron Devices 346 Broadway New York 13, New York	2

	Copies
Commanding Officer U. S. Army Electronics Research and Development Laboratory Attn: SELRA/TNR Fort Monmouth, New Jersey (For RETRANSMITTAL TO ACCREDITED BRITISH AND CANADIAN GOVERNMENT REPRESENTATIVES)	3
Commanding General U. S. Army Combat Developments Command Attn: CDCMR-E Fort Belvoir, Virginia	1
Commanding Officer U. S. Army Combat Developments Command Communications-Electronics Agency Fort Huachuca, Arizona	1
Director, Fort Monmouth Office U. S. Army Combat Developments Command Communications-Electronics Agency Building 410 Fort Monmouth, New Jersey	1
AFSC Scientific/Technical Liaison Office U. S. Army Electronics Research and Development Laboratory Fort Monmouth, New Jersey	1
Commanding Officer and Director U. S. Navy Electronics Laboratory San Diego 52, California	1
Commanding Officer U. S. Army Electronics Research & Development Laboratory Fort Monmouth, New Jersey	
Attn: SELRA/PEM (Dr. I. Bady)	1
Attn: SELRA/PRM (Mr. J. Carter)	1
Attn: SELRA/PEM (Mr. E. Freibergs)	11
Commander Rome Air Development Center ATTN: Mr. P. Romanelli (RCLRA-2) Griffiss Air Force Base, New York	1

	Copies
Chief Bureau of Ships Attn: Mr. Gumina, Code 68182 Department of the Navy Washington 25, D. C.	1
Airborne Instruments Laboratory Attn: Mr. S. Okwit Deer Park, Long Island, New York	1
Mr. Gustave Shapiro, Chief Engrg Electronics Section National Bureau of Standards Washington 25, D. C.	1
USAELRDL Liaison Office Rome Air Development Center ATTN: RAOL Griffiss Air Force Base, New York	1
Commanding Officer U. S. Army Electronics Research & Development Laboratory Fort Monmouth, New Jersey	
ATTN: SELRA/PE (Dr. E. Both)	1
ATTN: SELRA/PEM (Mr. N. Lipetz)	1
ATTN: SELRA/PE (Division Director)	1
ATTN: SELRA/PEM (Mr. E. Freibergs)	7

AD

Sperry Microwave Electronics Company, Division of Sperry Rand Corporation, Clearwater, Florida.
MICROWAVE FERRITE DEVICES (OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS). By J. W. Simon, G. A. Burdick, W. C. Heithaus. Fourth Quarterly Report - 15 January 1963 to 15 April 1963. 57 pp Inc. Illus-Graphs, refs. (Report No. SJ-224-0041-4)

Contract DA-36-039-SC-89214 Unclassified Report

As part of the theoretical study, the effects of introducing a nonzero linewidth in the equations for μ_{eff} are considered for the first time. Some interesting results are reported which are in agreement with earlier empirical data.

A substantial increase in bandwidth has been achieved in the 400 - 800 Mc band through the use of reduced strip width and puck heights.

Octave bandwidths have been achieved in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc circulators through the use of improved microwave parameters and matching techniques. The circulators for the remaining two bands, 1.5 - 3.0 Gc and 4.0 - 8.0 Gc, are currently being modified to reflect similar changes.

UNCLASSIFIED

1. Octave Bandwidth Y-Junction Circulators
2. Circulators
3. Ferrite Devices
I. Microwave Ferrite Devices
II. J. W. Simon
III. G. A. Burdick
IV. W. C. Heithaus
V. U. S. Army Electronics Research and Development Laboratory, Ft. Monmouth, N.J.
VI. Contr. DA-36-039-SC-89214

UNCLASSIFIED

AD

Sperry Microwave Electronics Company, Division of Sperry Rand Corporation, Clearwater, Florida.
MICROWAVE FERRITE DEVICES (OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS). By J. W. Simon, G. A. Burdick, W. C. Heithaus. Fourth Quarterly Report - 15 January 1963 to 15 April 1963. 57 pp Inc. Illus-Graphs, refs. (Report No. SJ-224-0041-4)

Contract DA-36-039-SC-89214 Unclassified Report

As part of the theoretical study, the effects of introducing a nonzero linewidth in the equations for μ_{eff} are considered for the first time. Some interesting results are reported which are in agreement with earlier empirical data.

A substantial increase in bandwidth has been achieved in the 400 - 800 Mc band through the use of reduced strip width and puck heights.

Octave bandwidths have been achieved in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc circulators through the use of improved microwave parameters and matching techniques. The circulators for the remaining two bands, 1.5 - 3.0 Gc and 4.0 - 8.0 Gc, are currently being modified to reflect similar changes.

UNCLASSIFIED

1. Octave Bandwidth Y-Junction Circulators
2. Circulators
3. Ferrite Devices
I. Microwave Ferrite Devices
II. J. W. Simon
III. G. A. Burdick
IV. W. C. Heithaus
V. U. S. Army Electronics Research and Development Laboratory, Ft. Monmouth, N.J.
VI. Contr. DA-36-039-SC-89214

UNCLASSIFIED

AD

Sperry Microwave Electronics Company, Division of Sperry Rand Corporation, Clearwater, Florida.
MICROWAVE FERRITE DEVICES (OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS). By J. W. Simon, G. A. Burdick, W. C. Heithaus. Fourth Quarterly Report - 15 January 1963 to 15 April 1963. 57 pp Inc. Illus-Graphs, refs. (Report No. SJ-224-0041-4)

Contract DA-36-039-SC-89214 Unclassified Report

As part of the theoretical study, the effects of introducing a nonzero linewidth in the equations for μ_{eff} are considered for the first time. Some interesting results are reported which are in agreement with earlier empirical data.

A substantial increase in bandwidth has been achieved in the 400 - 800 Mc band through the use of reduced strip width and puck heights.

Octave bandwidths have been achieved in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc circulators through the use of improved microwave parameters and matching techniques. The circulators for the remaining two bands, 1.5 - 3.0 Gc and 4.0 - 8.0 Gc, are currently being modified to reflect similar changes.

UNCLASSIFIED

1. Octave Bandwidth Y-Junction Circulators
2. Circulators
3. Ferrite Devices
I. Microwave Ferrite Devices
II. J. W. Simon
III. G. A. Burdick
IV. W. C. Heithaus
V. U. S. Army Electronics Research and Development Laboratory, Ft. Monmouth, N.J.
VI. Contr. DA-36-039-SC-89214

UNCLASSIFIED

AD

Sperry Microwave Electronics Company, Division of Sperry Rand Corporation, Clearwater, Florida.
MICROWAVE FERRITE DEVICES (OCTAVE BANDWIDTH Y-JUNCTION CIRCULATORS). By J. W. Simon, G. A. Burdick, W. C. Heithaus. Fourth Quarterly Report - 15 January 1963 to 15 April 1963. 57 pp Inc. Illus-Graphs, refs. (Report No. SJ-224-0041-4)

Contract DA-36-039-SC-89214 Unclassified Report

As part of the theoretical study, the effects of introducing a nonzero linewidth in the equations for μ_{eff} are considered for the first time. Some interesting results are reported which are in agreement with earlier empirical data.

A substantial increase in bandwidth has been achieved in the 400 - 800 Mc band through the use of reduced strip width and puck heights.

Octave bandwidths have been achieved in the 600 - 1200 Mc, 1.0 - 2.0 Gc, and 2.0 - 4.0 Gc circulators through the use of improved microwave parameters and matching techniques. The circulators for the remaining two bands, 1.5 - 3.0 Gc and 4.0 - 8.0 Gc, are currently being modified to reflect similar changes.

UNCLASSIFIED

1. Octave Bandwidth Y-Junction Circulators
2. Circulators
3. Ferrite Devices
I. Microwave Ferrite Devices
II. J. W. Simon
III. G. A. Burdick
IV. W. C. Heithaus
V. U. S. Army Electronics Research and Development Laboratory, Ft. Monmouth, N.J.
VI. Contr. DA-36-039-SC-89214

UNCLASSIFIED