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TECHNICAL NOTE NO. 1

WIDE BAND ELECTRONICALLY

TUNABLE FILTERS

Covering the period

1 July to 30 September 1962

PUBLICATION REVIEW

This report has been reviewed and is approved.

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K. L. Kotzebue

and

A. W. Shaw

Watkins-Johnson Company
3333 Hillview Avenue
Palo Alto, California

Contractor's Report No. W-J 62-609R5

Contract No. AF 30(602)-2625

October 1962

Prepared for

Rome Air Development Center
Air Force Systems Command
United States Air Force
Griffiss Air Force Base, New York

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ABSTRACT

Work on hysteresis, linearity and temperature compensation in YIG filters is discussed and measurements are reported for hysteresis using both core iron and hypernik pole piece in a WJ-501 filter (2-4 Gc reciprocal bandpass filter). Hysteresis amounts to about 0.1 percent of the tuning range for hypernik pole pieces. Linearity and temperature compensation measurements are reported for core iron pole pieces. Linearity is ± 2 mc and resetability ± 3 mc. With the filter adjusted for minimum temperature coefficient at 3 Gc the temperature coefficient at 4 Gc was maximum of 0.1 mc/oC.

A four stage X-band bandpass filter and a 2 stage X-band band-reject filter are described. The X-band bandpass filter suffers from band distortion above 11 Gc as also does the band-reject filter. Even below 11 Gc some improvement of the X-band bandpass filter will be necessary to meet the objectives of the program. The X-band band-reject filter gave the required 50 db rejection at single frequencies but the two resonators gave tracking difficulty. Initial studies of strip line circuits for use below 8 Gc are also outlined.

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INTRODUCTION

Purpose and Scope of Investigation

The purpose of this work is to conduct research and development to advance the state-of-the-art in the field of wide band electronically tunable filters employing magnetically tunable resonators such as Yttrium Iron Garnet (YIG). The work is to culminate in the development of a series of bandpass filters covering the frequency range 1-18 Gc, a series of bandreject filters covering the frequency range 1-12 Gc, a multiple bandreject filter with four independently tunable reject band in the filters through its entire tuning band, linearly, at a rate which can be varied continuously from 0 (manual sweep) to 1000 cps. The frequency range covered by the bandpass filters will be divided as follows: 1-2, 2-4, 4-8, 8-12, and 12-18 Gc, with 18 to 30 Mc bandwidth in the passband. The frequency range covered by the bandreject filters will be divided as follows: 1-2, 2-4, 4-8, 8-12 Gc with a 50 db rejection bandwidth of greater than 3 Mc and a 3 db bandwidth of less than 30 Mc. All the filters are to be nonreciprocal (greater than 20 db), temperature compensated, magnetically shielded, and ruggedized.

Background and Method of Approach

Nonreciprocal bandpass filters have been developed previous to this contract at Watkins-Johnson, in the frequency range 8-12 Gc. These filters are not temperature compensated, shielded, etc., so some work will be required to meet the objectives of this contract. Since the filters are in waveguide, the nonreciprocity is easy to obtain. The higher frequency bandpass filter, 12-18 Gc, can also be made in waveguide and should be a simple scaling of the X-band filter. Below 8 Gc both size and tunable bandwidth preclude the use of waveguide. In this range stripline will be used and nonreciprocity becomes difficult to achieve. The bandreject filters can be achieved by modifying suitable bandpass filters, or by specially designed bandreject filters. No previous work aimed at nonreciprocal bandreject filters has been done at Watkins-Johnson.

Work Reported

The first part of the discussion deals with magnetic circuit and environmental problems. The problems of hysteresis, linearity, and temperature compensation are discussed and work accomplished this quarter toward solving the problems, using a WJ-501 bandpass filter (2-4 Gc reciprocal filter) as a test vehicle, are outlined. The last part of the discussion describes the work on X-band bandpass filters, X-band bandreject filters, and nonreciprocal filters below X-band which has been accomplished this quarter. The conclusion summarizes the results of this quarters work. Work contemplated next quarter is mentioned throughout the report and summarized in the recommendations.

DISCUSSION

Magnetic Circuit and Environmental Studies

The tuning of YIG filters is accomplished by changing a magnetic field which is in a direction perpendicular to the microwave magnetic fields. This tuning field can be supplied by an electromagnet, a permanent magnet, or a combination of both. The most linear tuning field will be obtained with an air-core solenoid supplying the field, for then there can be no nonlinearity or hysteresis in the field as a function of current. In most cases, however, such a tuning method is not practical because excessive tuning power is required. The minimum tuning power is in most cases obtained by using a permanent magnet which supplies a magnetic field to tune the filter to the middle of its frequency range. The field is then changed through use of tuning coils in series with the permanent magnet.

Hysteresis and Linearity Measurements

If such a magnetic circuit is to be useful, it is highly desirable that tuning nonlinearity and hysteresis be held to a minimum. A study was made to determine experimentally to what extent these undesired characteristics could be minimized. The test vehicle used in this study was a modified WJ-501 filter, which is a single tuned bandpass filter designed for operation in the 2 to 4 Gc range. A cross section of this filter is shown in Fig. 1. With no current applied, the filter tunes to 3 Gc. The application of approximately +400 ma of current tunes the filter to 4 Gc, while -400 ma tunes it to 2 Gc. The hysteresis is defined as the frequency change at zero current which is measured after the application of +400 ma of current and then -400 ma of current. The results for different magnet and pole piece materials are given below in Table I.

On the basis of these measurements it has been decided that hypernik pole pieces and Alnico 5 magnets are most suitable. With this combination the hysteresis should amount to about 0. 1 percent of the tuning range.

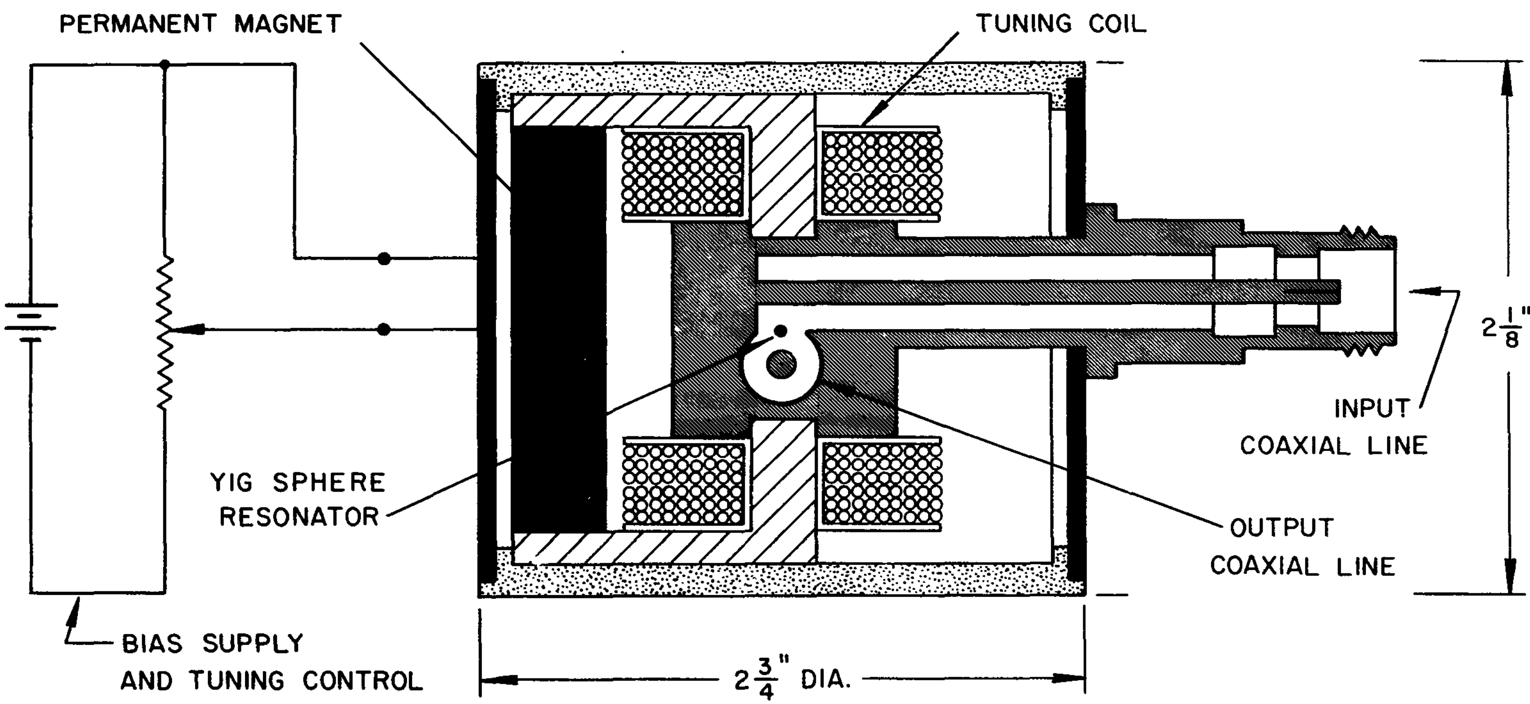

Fig. 1 - Cross-section of the single-tuned YIG bandpass filter used in the linearity and hysteresis measurements.

TABLE I

Hysteresis Measurements

Magnetic Circuit	Hysteresis, Mc
Un-annealed core iron pole pieces and Alnico 5 magnets	20
Annealed core iron pole pieces and Alnico 5 magnets	8
Annealed core iron pole pieces and Alnico 8 magnets	8
Annealed hypernik pole pieces and Alnico 5 magnets	2
Annealed hypernik pole pieces and Alnico 8 magnets	2

Linearity of resonant frequency with applied current is also of importance. Shown in Table II are the results of linearity measurements made on a filter which used annealed core iron pole pieces and Alnico 5 magnets.

The current increments used in the linearity measurement were chosen so that the change in frequency averaged 100 Mc per current increment. In this manner the maximum deviation from linearity can thus be readily seen in the frequency measurements. In a single measurement, the measured tuning curve was within ± 2 Mc of linearity, with measured re-setability of within ± 3 Mc.

The linearity should be even better with the utilization of hypernik pole pieces. This experiment will be performed at a later date.

TABLE II

Linearity Measurements

Control Current		Resonant Frequency, Gc	
ma	Initial measurement	1 hour later	18 hours later
-391. 0	1. 994	1. 990	1. 994
-351. 9	2. 092	2. 089	2. 092
-312. 8	2. 192	2. 188	2. 192
-273. 7	2. 291	2. 289	2. 290
-234. 6	2. 390	2. 388	2. 390
-195. 5	2. 491	2. 489	2. 490
-156. 4	2. 592	2. 590	2. 590
-117. 3	2. 690	2. 689	2. 690
- 78. 2	2. 791	2. 788	2. 790
- 39. 1	2. 891	2. 890	2. 891
0	2. 990	2. 990	2. 992
39. 1	3. 092	3. 092	3. 090
78. 2	3. 192	3. 192	3. 191
117. 3	3. 292	3. 290	3. 290
156. 4	3. 392	3. 391	3. 392
195. 5	3. 492	3. 491	3. 491
234. 6	3. 591	3. 591	3. 590
273. 7	3. 693	3. 692	3. 692
312. 8	3. 792	3. 792	3. 791
351. 9	3. 893	3. 890	3. 891
391. 0	3. 991	3. 991	3. 990

Temperature Compensation

The excellent tuning linearity characteristics which can be obtained cannot be fully utilized unless steps are taken to temperature compensate the filter. The major effect of a change in temperature of a YIG filter is to shift the resonant frequency. This shift in resonant frequency is due to:

1. A change in magnetic field with temperature.
2. A change in the YIG material with temperature.

A change in magnetic field with temperature can result from dimensional changes, changes in the strength of the permanent magnet, and changes in the permeability of the pole piece material. These changes, however, are generally small compared to the changes in the YIG resonator, provided that Alnico magnets and iron-alloy pole pieces are used in the magnetic circuit.

The variation of resonant frequency with temperature of the YIG resonator itself is a consequence of crystal anisotropy. Artman[1] gives relations specifying the resonant frequency of such a crystal along its three principal axes:

$$\frac{\omega}{\gamma} = H + 4/3 \left| H_a \right| \qquad [111] \text{ direction}$$

$$\frac{\omega}{\gamma} = \left[H - \left|H_a\right|\right] \left[H + 2\left|H_a\right|\right]^{1/2} \qquad [110] \text{ direction}$$

$$\frac{\omega}{\gamma} = H - 2\left|H_a\right| \qquad [100] \text{ direction}$$

where ω is the resonant frequency, γ is the gyromagnetic ratio, H is the applied field and H_a is an equivalent anisotropy field. Thus, we see that the anisotropy field can either increase or decrease the resonant frequency, depending upon the orientation of the sphere. Also, since H_a is a function of temperature, it follows that the resonant frequency is a function of temperature. It is an experimental fact that the anisotropy field H_a decreases with increasing temperature. It therefore follows that along the [111] direction (which is the easy axis) the resonant frequency will decrease with increasing temperature, while along

[1] Artman, Joseph O., "Microwave resonance relations in anisotropic single crystal ferrites" Proc. IRE, Vol. 44, pp. 1289-1293; October 1956.

the [100] direction (the hard axis) the resonant frequency will increase with increasing temperature. Since these variations are not discontinuous, there must exist an orientation which gives rise to a zero temperature coefficient at a given magnetic field.

The question, then, is how does one quickly and accurately determine this orientation? One method which has been proposed is to use a rather involved magnetic alignment technique[2] which allows one to mechanically place the sphere at any desired crystal axis orientation. This approach was investigated and the conclusion was reached that an impractical degree of mechanical precision was required. An alternate technique was therefore devised which is much simpler mechanically, and which has yielded excellent results. This method uses the following approach:

1. The temperature coefficient is a function of orientation, which we may express as

$$\frac{\Delta f}{\Delta T} = F(\theta)$$

2. The resonant frequency at a given magnetic field is also a function of orientation

$$f = G(\theta)_{H\,=\,\text{constant}}$$

3. Therefore, the temperature coefficient can be expressed as a function of the resonant frequency as the orientation is varied in a constant magnetic field.

$$\frac{\Delta f}{\Delta T} = J\left[f(\theta)\right]_{H\,=\,\text{constant}}$$

[2] Matthaei, G. L., Young, L., and Carter, P. S. Jr., "Microwave filters and coupling structures," Fifth Quarterly Progress Report, Contract DA 36-039 SC-87398, Stanford Research Institute, Menlo Park, California, pp. 101-107; May 1962.

The procedure is then to experimentally determine that value of f the resonant frequency in a fixed magnetic field, which makes $\frac{\Delta f}{\Delta T} = 0$. It is then possible to quickly determine the proper orientation of <u>any</u> sphere which has been <u>randomly</u> mounted on a dielectric rod by simply rotating the rod until the sphere resonates at the pre-determined proper frequency.

This procedure has been employed in the WJ- 501 filter configuration to pre-set spheres to yield temperature coefficients of less than 0. 1 Mc/^{o}C, - 20^{o}C $<T<$ 80^{o}C, without need of lengthy temperature runs.

As the magnetic field is changed to a value other than that which is used in the temperature compensating procedure, it is to be expected that the temperature coefficient will change. This effect was measured on a WJ-501 filter over the frequency range 2 Gc to 4 Gc. The results of this are shown in Fig. 2. With a slight adjustment in sphere position the temperature coefficient could be "centered" better as indicated in the figure.

It appears to be possible to reduce the change in temperature coefficient with frequency by means of a simple "trick." This method makes use of the fact that the measured variation in temperature coefficient with frequency is exactly identical with a change in tuning slope with temperature. We can compensate for this temperature dependence of the tuning slope by placing a resistive shunt across the tuning coil with just the right temperature coefficient. This procedure will be evaluated shortly.

<u>RF Circuit Studies</u>

One of the major objectives of the present study is to obtain bandpass filters with high selectivity and good suppression of spurious response. It is desired that the bandwidth at the 3 db points be between 18 and 30 Mc, together with a 50 db bandwidth of 110 Mc or less. This degree of selectivity requires the use of a four-resonator structure. Narrow-band multi-stage filters are well known to be difficult to align properly because of the interaction between the various resonators. In the case of YIG resonators the problem is further compounded by the small dimensions of the resonators, making mechanical tolerances critical. Anisotropy and temperature effects add further complications to the tuning problem. Because of these anticipated difficulties, the design approach that is being used is to cascade two relatively simple double-tuned units. Such cascading is not practical with reciprocal filters. for the inter-action between resonators which are separated by a length of transmission line not small compared to a wavelength results in frequency-sensitive

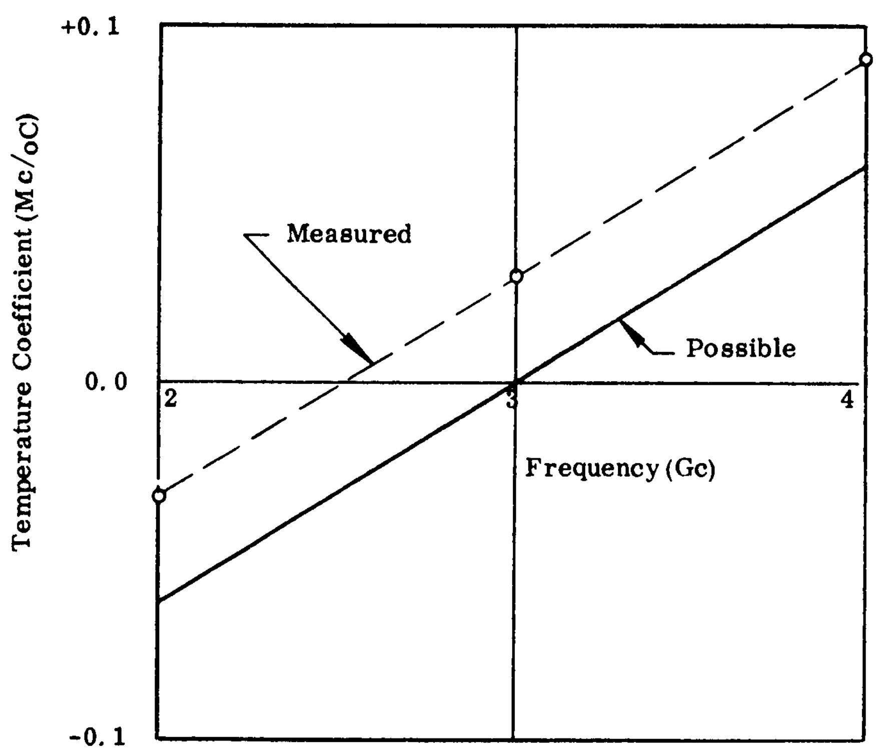

Fig. 2 - Variation of temperature coefficient with frequency for a WJ-501 filter (2-4 Gc reciprocal bandpass) adjusted for minimum temperature coefficient at 3 Gc. Actually a better adjustment would give a temperature coefficient of 0. 0 at 3 Gc.

passband distortion and the generation of spurious responses. When nonreciprocal filters are used, however, this interaction is eliminated, and stages can be cascaded without deleterious effects. The situation is quite analogous to a multiple-stage vacuum tube amplifier, where the tuned circuits are separated and isolated by the tubes. Such circuits are much easier to construct and adjust.

X Band Bandpass Filter

The prime pre-requisite for nonreciprocal operation is that the RF magnetic field be nearly circularly polarized. Since waveguide possesses a point of such circular polarization, nonreciprocal operation is obtained in a straightforward manner. Because of prior success in the development of double-tuned waveguide nonreciprocal filters, the first RF circuit to be investigated was at X-band. The circuit consists of two cascaded double-tuned units as shown schematically in Fig. 3. Shown in Fig. 4 is a photograph of the disassembled filter structure. Coupling between spheres is by means of small circular irises in the dividing plate.

The minimum insertion loss measured was about 4 db at 10 Gc with a 3 db bandwidth of 20 Mc. The experimental set-up used in this initial measurement had a useful dynamic range of only about 50 db; no observable spurious response was noted within this range. Likewise, the directivity of the filter was greater than 50 db, for no signal could be observed in the reverse direction. The bandwidth at the 50 db points was approximately 120 Mc.

The major problem encountered in this first test circuit was the presence of interfering magnetostatic modes which cross through the main response, thereby distorting the passband. This passband distortion is vividly illustrated by the three photographs of passband shape shown in Fig. 5. The most severe distortion occurs at around 11 Gc. A major effort will be made in an attempt to reduce magnetic field nonuniformities which give rise to the excitation of these modes.

X Band Bandreject Filter

Two different designs are being considered for the X-band nonreciprocal bandreject filter. One of the designs makes use of a single YIG sphere critically coupled to and positioned in the guide so that all the energy at the resonant frequency of the sphere is absorbed. This type of filter is difficult to build because trimming adjustments are not readily incorporated. It will probably have the advantage of less distortion in the

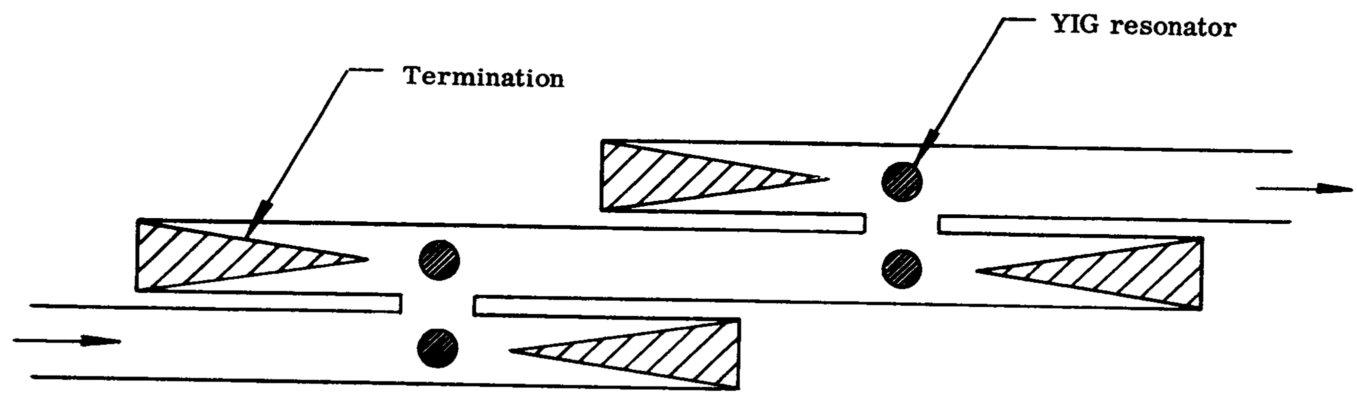

Fig. 3 - Schematic illustration of the four resonator bandpass filter waveguide circuit under investigation. All resonators are located at the plane of circular polarization.

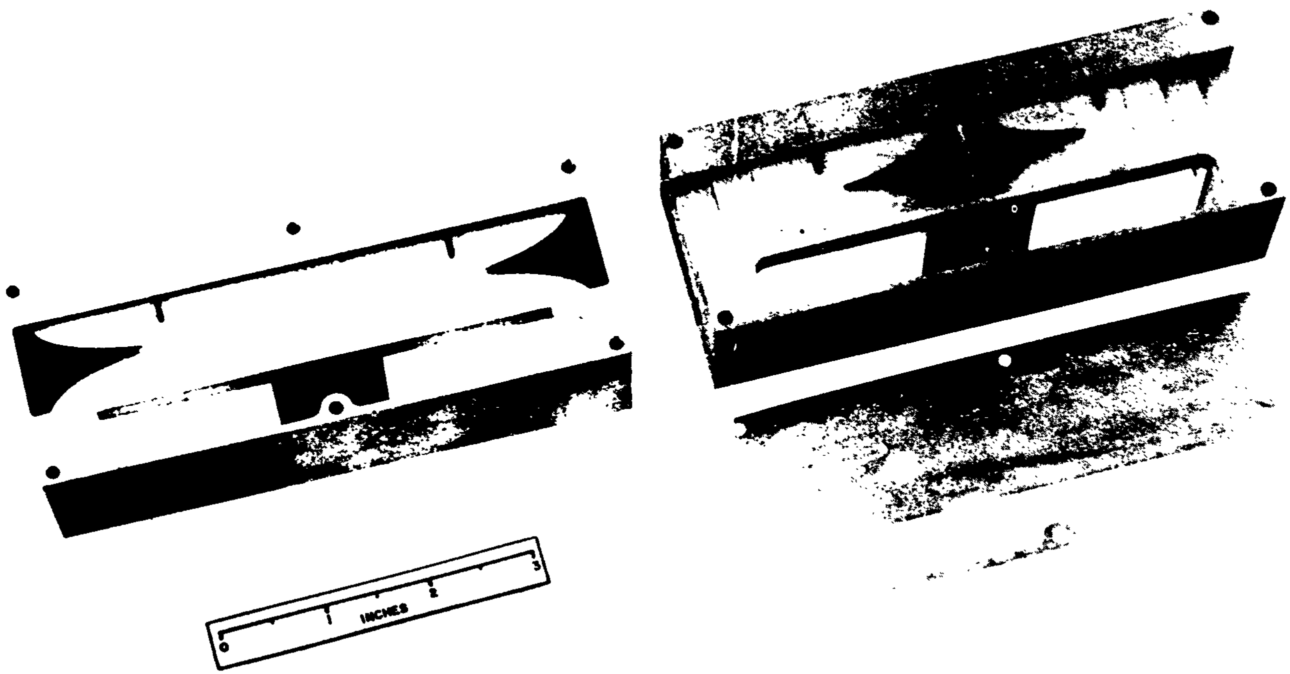

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Fig. 4 - X-band 4 stage bandpass filter disassembled to show interior.

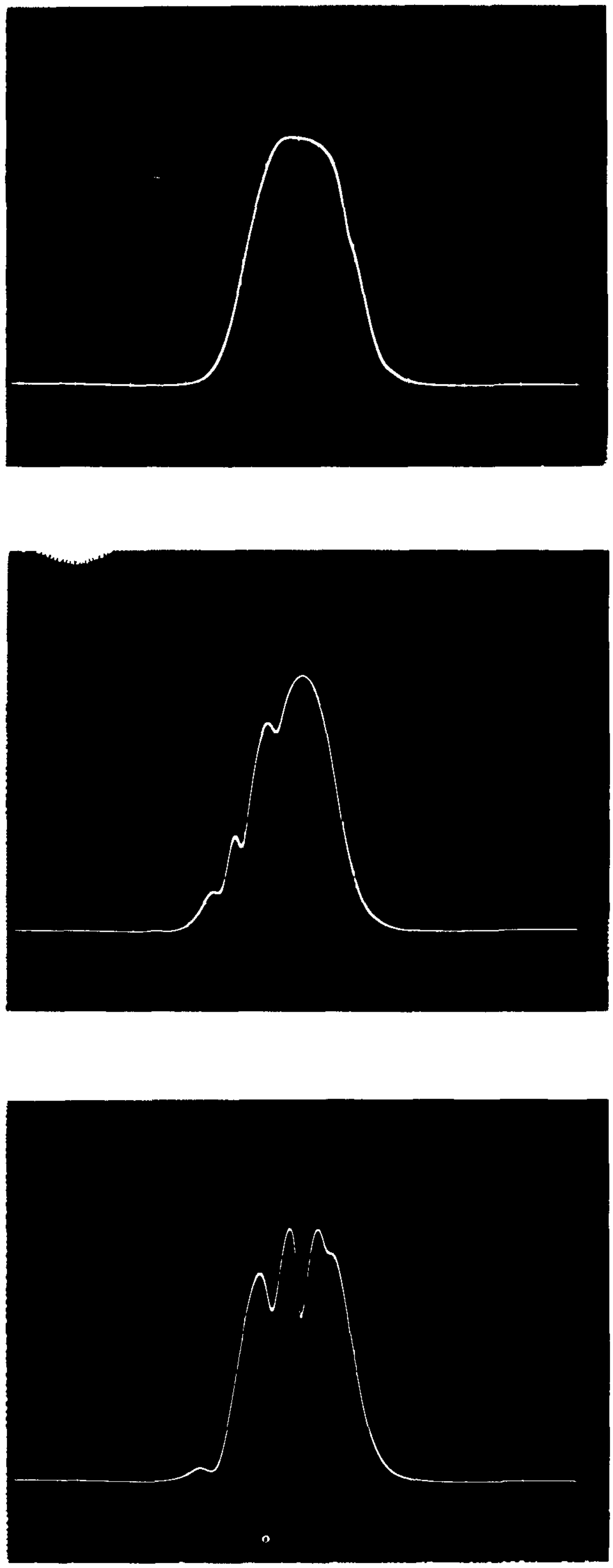


Fig. 5 - Distortion of the passband as it tunes through interfering magnetostatic modes.

band due to magnetostatic modes. A filter using this design has not been tested to date. The other design uses a standard nonreciprocal double-tuned bandpass filter with the output and terminated arms interchanged so as to give the band-reject characteristic. This design has the advantage of the previous work on bandpass filters and is readily adjusted.

The scatter matrix of a single YIG sphere placed in a waveguide has been found by Anderson[3] and others. From the scatter matrix he has calculated how the rejection varies with the sizes of YIG sphere and its position in the guide. Theoretically, if a low-loss YIG sphere is placed in the position in the guide shown in Fig. 6 and is of such a size as to critically couple to the guide, total rejection will be obtained at the resonant frequency of the sphere. The size for critical coupling, neglecting anisotropy, is given by Anderson:

$$d^3 = 0.608 \frac{\Delta H}{Ms} a^2 b$$

where d is the diameter of the YIG sphere, ΔH is the linewidth, Ms is the saturation magnetization, a is the width of the guide, and b is the height of the guide. The only factor in the above formula which is frequency dependent is ΔH. Since ΔH is relatively insensitive to frequency, the filter should have a broad tuning range. This filter will be nonreciprocal because the YIG sphere is in a region of circularly polarized magnetic field with the sense of polarization dependent on the direction of power flow in the guide.

The other type of filter, which uses a double-tuned configuration, can be easily understood from Fig. 7. This figure shows how energy is transfered to a double-tuned filter configuration. For a bandreject filter arms two and three are terminated and the output is taken from arm four. As can be seen, energy in the reject band is coupled off into arm three and disipated in the load, while energy at all other frequencies is passed straight through to arm four. The filter is nonreciprocal because the spheres

[3] Anderson, L. K., "Ferrimagnetic relaxation measurements and microwave circuit properties of ferrite ellipsoids," M. L. Tech. Report No. 880, Microwave Laboratory, W. W. Hanson Laboratory of Physics, Stanford University, Stanford, California, pp. 24-33; February 1962.

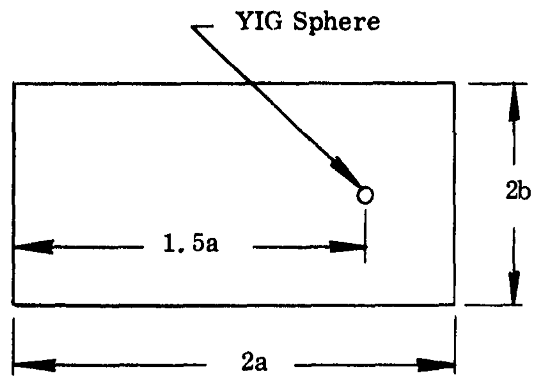
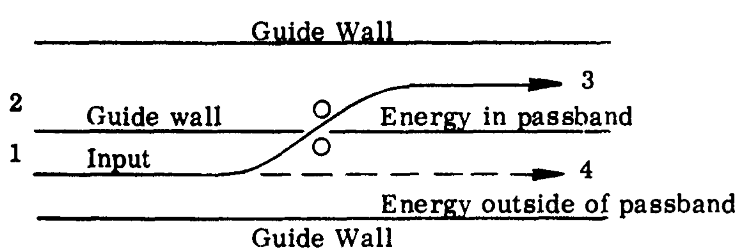


Fig. 6 - Position of YIG sphere in a wave guide to produce a broad tuning band bandreject filter. The position is independent of frequency.



Cross Section Through Guide

Fig. 7 - Energy transfer in a double tuned filter. For a bandpass filter arms 2 and 4 are terminated and the output is taken from are 3. For a bandreject filter arms 2 and 3 are terminated and the output is taken from arm 4.

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are mounted in a region of circularly polarized magnetic field with the sense of polarization dependent on the direction of power flow in the guide.

A bandreject filter of this type has been constructed and partially evaluated. Fig. 8 is a photograph of this filter disassembled to show the interior. The YIG spheres can be seen at the center of the guide near the upper wall in each section. The terminations for arms two and three are in the left section. The right section contains two step transformers, one at each end, to regular X-band guide. When the filter is assembled the shim in the lower right of the photograph is placed between the two halves of the filter and forms the other wall of the waveguide for each. The coupling hole is near the center of this shim.

The rejection of the filter has been measured from 8. 3 to 11 Gc. Above 11 Gc serious distortion of the reject band occurs due to magnetostatic modes which couple to the uniform precession mode. In this region no measurements were taken. If the filter is retuned for maximum rejection at each frequency, rejection of greater than 50 db is obtained over the entire band. Fig. 9 is a photograph of the rejectband. Note that it is slightly skewed at the top. This was necessary to obtain maximum rejection and is due to a slight overcoupling which can be easily corrected in the next design. The bandwidth was measured at 10. 9, 10. 3, 9. 5, 8. 9 and 8. 3 Gc to be 32 Mc. The principal spurious rejection which can be seen to the right of the reject band in Fig. 9 measured 1 db with the filter tuned to 10 Gc. The reverse rejection at 10 Gc is 1. 3 db. The rejection of the filter was also measured as a function of frequency after adjusting for maximum rejection at one frequency. Fig. 10 shows curves for the filter rejection when maximized at 8. 3, 9. 5, and 10. 9 Gc. The reason for the deterioration away from the adjustment frequency is the imperfect tracking of the two spheres. If one of the tuning coils in the filter is shorted with a compensating resistor the field at the two spheres will differ slightly and the tracking error can be decreased. The best performance of the compensated filter is also shown in Fig. 10. In the compensated filter the rejection is greater than 30 db from 8. 3 to 11 Gc. To make this filter useful above 11 Gc coupling to the magnetostatic modes must be reduced. This problem is being attacked in the X-band bandpass filter and any results will be directly applicable to the bandreject filter.

Strip Line Studies

In all of the strip line filters, the nonreciprocity is difficult to obtain because unlike waveguide which has a region of circular polarization, strip line propagates TEM waves

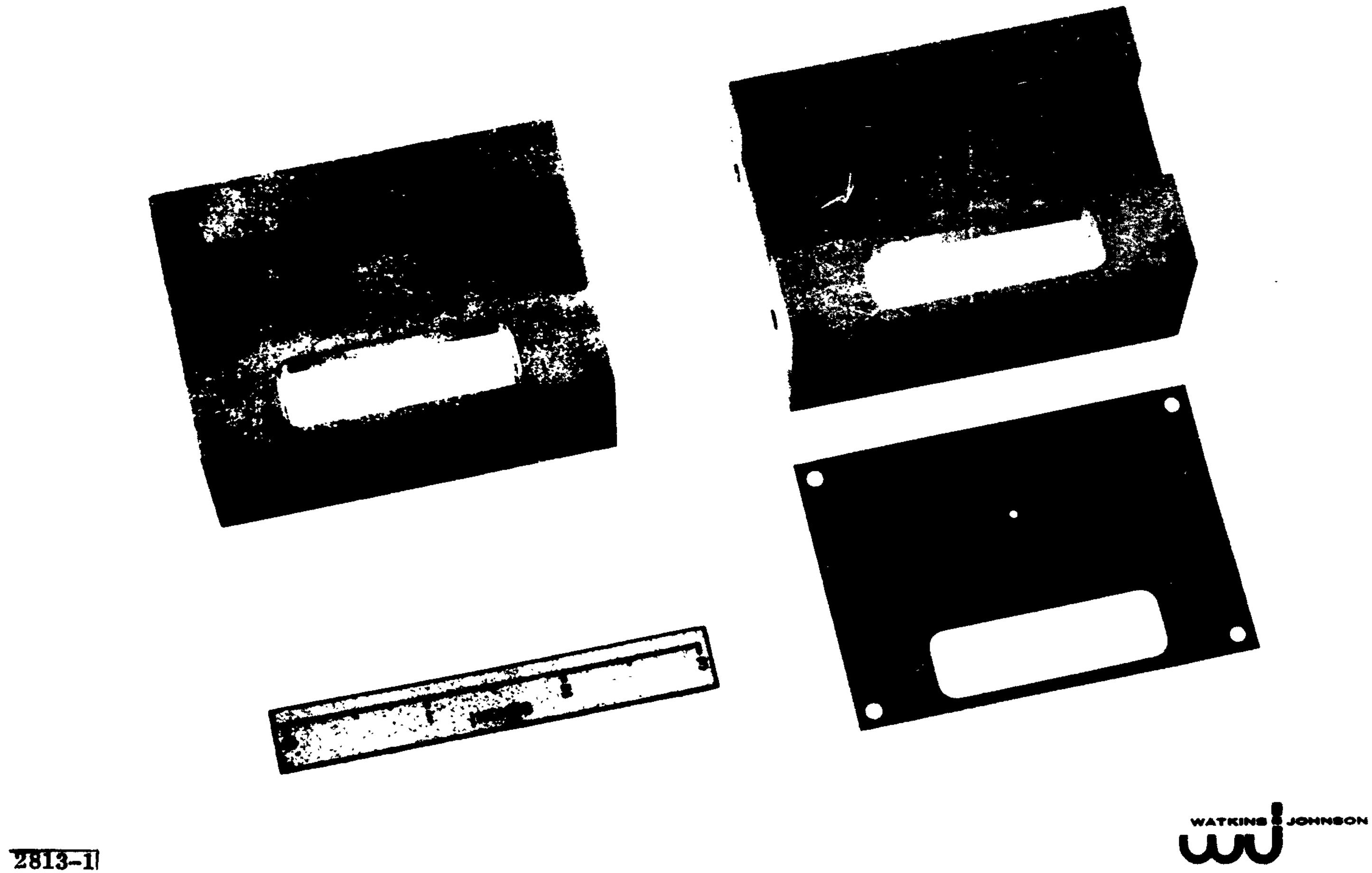

Fig. 8 - X-band bandreject filter disassembled to show interior construction.

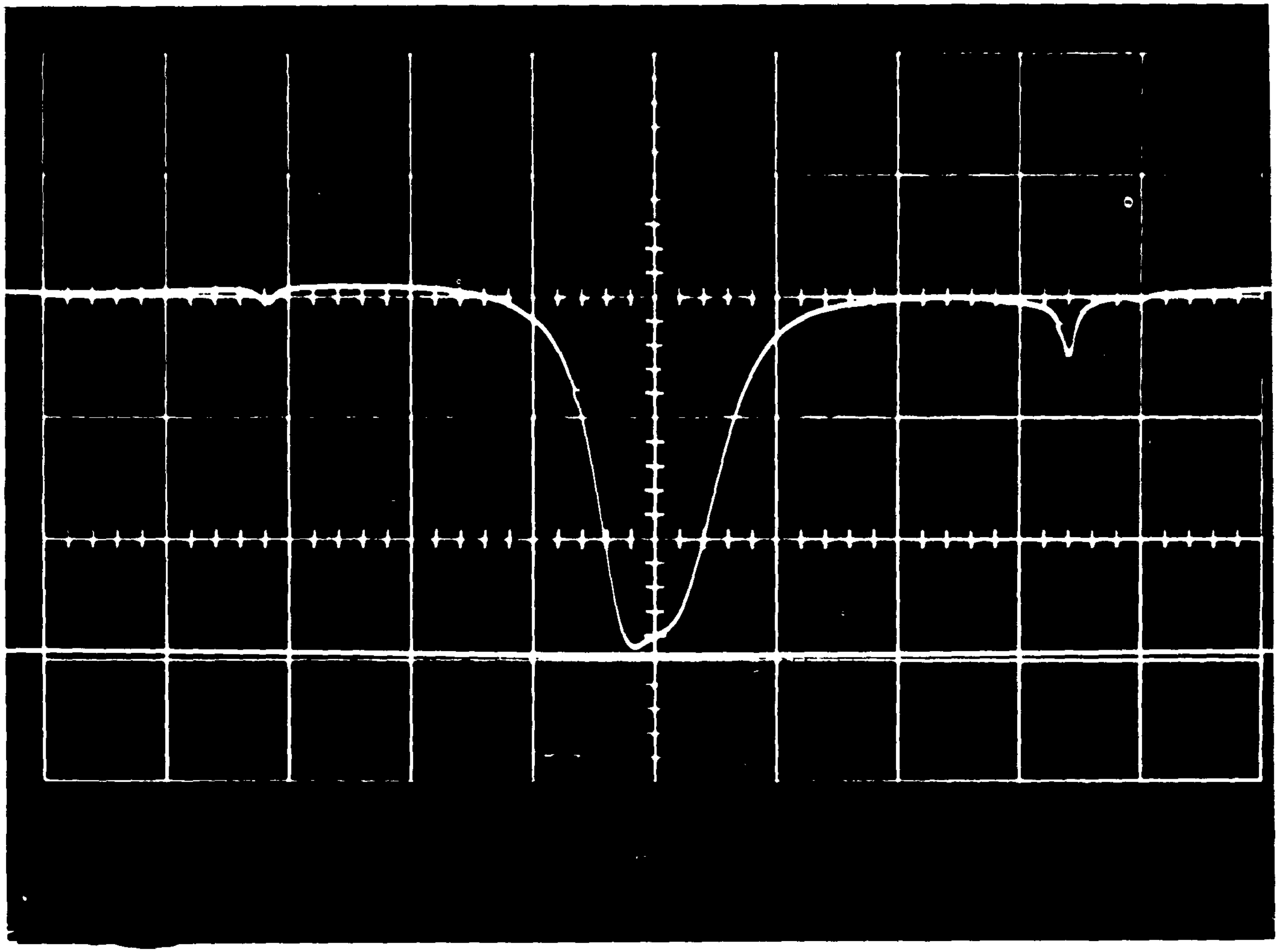

Fig. 9 - Reject band of the X-band double tuned bandreject filter.

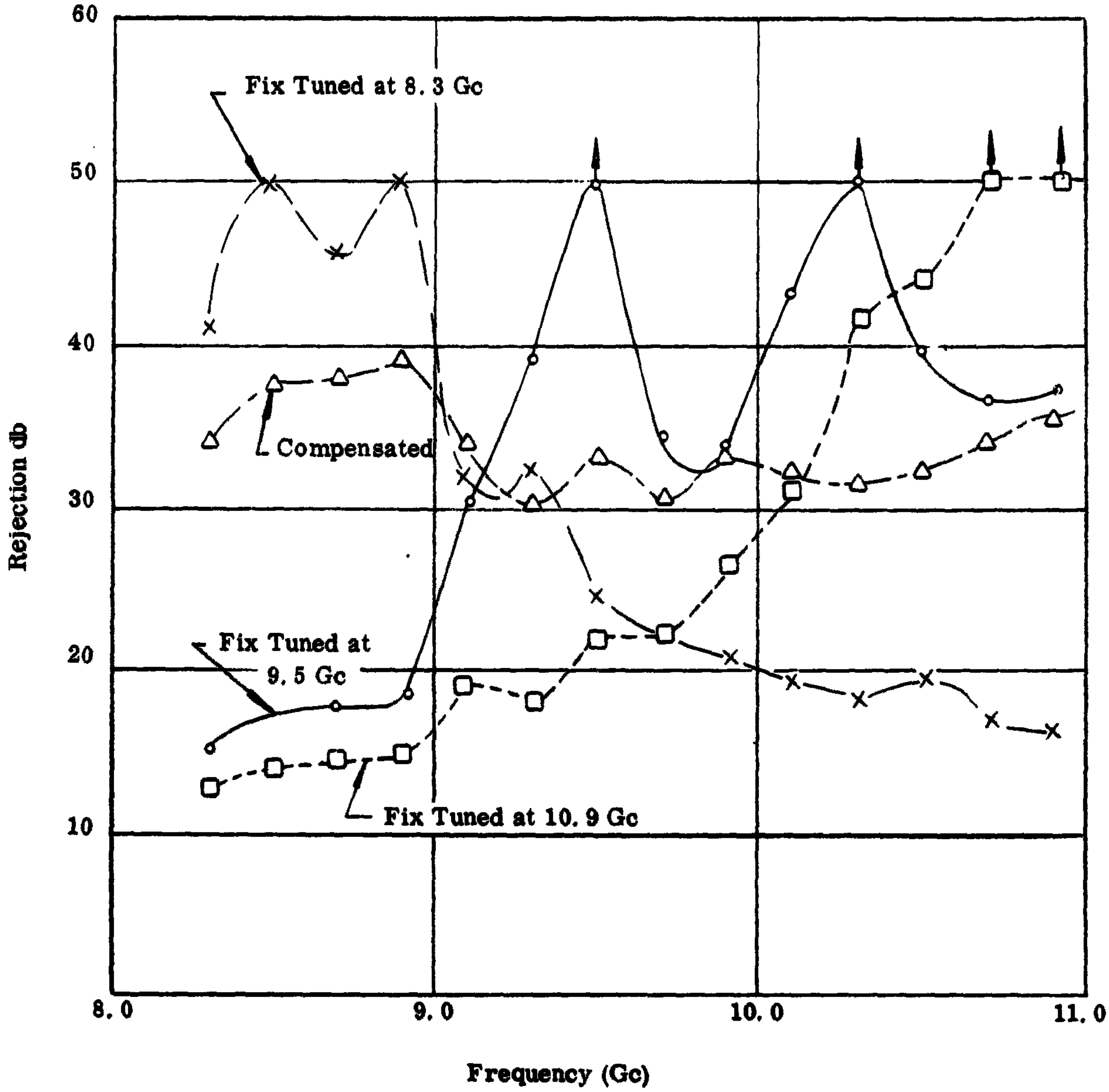

Fig. 10 - Rejection of an X-band double tuned filter for various fixed tunings and compensated to give best over-all performance. Rejection was > 50 db when maximized at each frequency.

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which are linearly polarized. To obtain nonreciprocal operation it is necessary to perturb the TEM mode to produce near circular polarization. Fleri and Hanley[4] analyze one method of making this perturbation. The strip line configuration they use is shown in Fig. 11. In this configuration true circular polarization is not obtained, but at the interface of the dielectric near-circular polarization is obtained.

Two parameters are defined for the strip line:

$$D = w + \frac{2b}{\pi} \ln 2$$

$$d = \frac{w}{2} + \frac{b}{\pi} \ln 2 - t$$

and curves are plotted by Fleri and Hanley of polarization factor $|Hy \quad Hy|$ as a function of $\lambda/2d$ with $|D/d|$ and dielectric constant ϵ as parameters. Best results are obtained around $\lambda/2d = 2$ independent of $|D/d|$ and almost independent of ϵ. However, increasing either $|D/d|$ or ϵ extends the range of $\lambda/2d$ for good polarization to longer wavelengths (lower frequencies). Table III gives the upper limit of $\lambda/2d$ for a polarization factor of less than 1. 2 (20db reciprocity).

TABLE III

$\lambda/2d$ must be greater than 2 and less than the value given below for $|Hy \quad Hz|$ to be less than 1. 2

$\lvert D/d \rvert$	ϵ	$\lambda/2d$
2	10	5. 5
3	5	4
3	10	8. 6
3	15	11. 7
4	10	10. 3

[4] Fleri, D. and Hanley, G., "Nonreciprocity in dielectric loaded TEM mode transmission lines," IRE Trans. on MTT, Vol. MTT-7, pp. 23-27; January 1959.

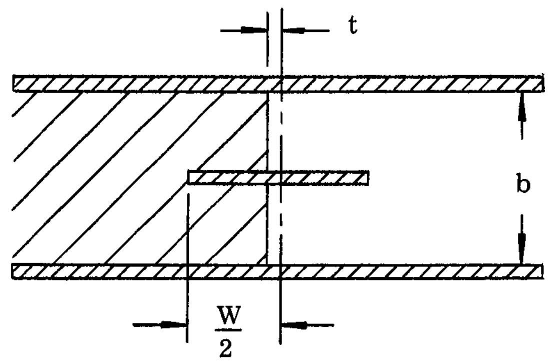

Fig. 11 - Strip line loaded with dielectric

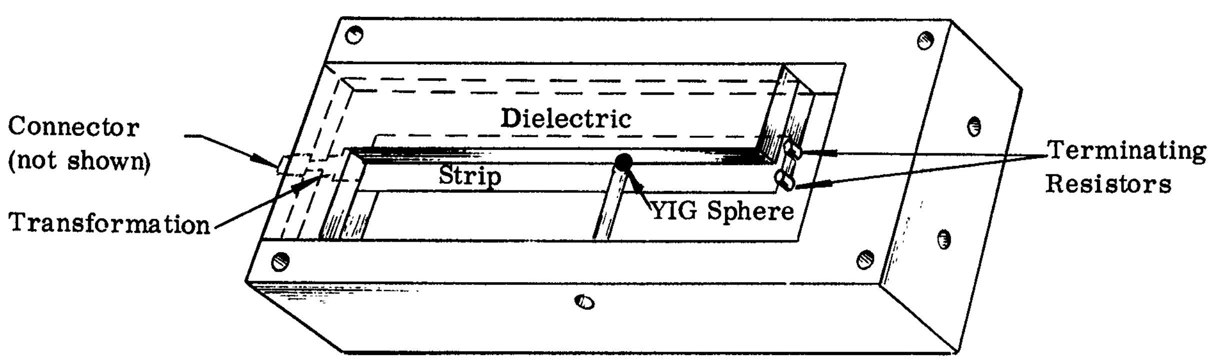

Fig. 12 - Half of a strip line filter. The other half is identical and fits on top of this one with the connector at the opposite end. A thin shim which contains the coupling hole separates the two parts. No provisions for the magnet have been made in the initial design. A large electro magnet which fits over the entire filter is used.

The design of a filter now becomes a compromise between obtaining adequate loading on the YIG sphere, satisfying the conditions for good polarization, and obtaining an impedance which is not so low as to make matching to 50 Ω coax impossible. Both the loading on the sphere and the line impedance decrease with strip width (w). On the other hand d and hence w (b is set by air gap requirements) must be large to satisfy the conditions for good polarization at the wavelengths being considered. Also, since d must be large t should be taken equal to zero. If $t = 0$ then $D/d = 2$, so dielectric constant is the only remaining parameter. For C-band a good compromise can be reached. Using $\epsilon = 25$ and $b = 0.235$, the strip width is 0.480 which should give good coupling to the sphere. The impedance is 25 Ω which can be matched to 50 Ω using a step transformer. Below C-band the problem becomes more acute and perhaps a line loaded on one side with $\epsilon = 10$ material and on the other side with $\epsilon = 100$ material will have to be used. This will help the coupling and the size but the impedance may be very low.

Fig. 12 is a sketch of half of a strip line filter. One filter of this type has been built and tested at L-band. It has provisions for testing two different loading materials as shown in Fig. 13. Only about 3db of reciprocity was obtained with both loadings. This is not supprising since at 1 Gc

$$\frac{\lambda}{2d} \approx 24 \quad \text{for the first configuration}$$

$$\frac{\lambda}{2d} \approx 36 \quad \text{for the second configuration}$$

both of which are much too large for good polarization. This initial filter had no transformation since the strip line was 50 Ω and required only one terminating resistor. With $\epsilon = 25$ a spot check at 4 Gc and 7.5 Gc gave a reciprocity of 10 db and 13 db, respectively. At these frequencies the matching was poor. A filter for C-band is being constructed based on the calculations outlined in the previous paragraph. This filter will be identical to the figure and should give better results. A cross section of the line used in this filter is shown in Fig. 14. For this filter

$$\frac{\lambda}{2d} = 8$$

at the lowest frequency.

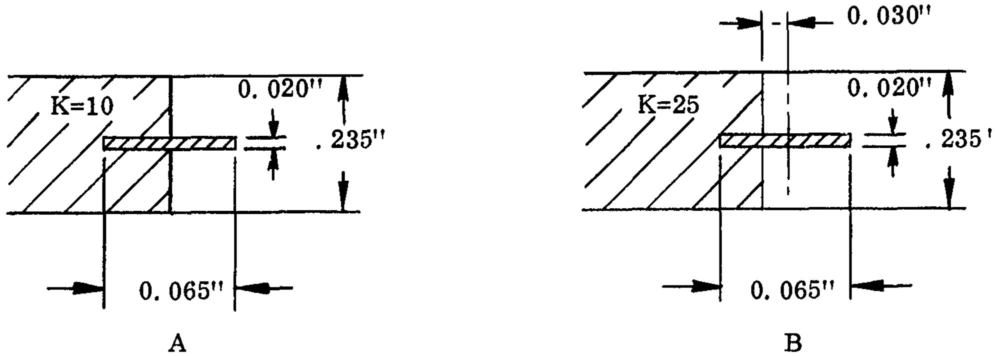

Fig. 13 - Configurations of strip line used in initial test filter

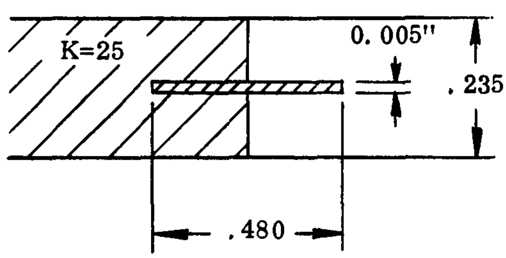

Fig. 14 - Configuration of strip line used in C-band filter

CONCLUSIONS

Work on the magnetic circuit indicates that the specifications for resetability and linearity can be met with hypernik pole pieces and Alnico 5 magnets. Temperature compensation to the extent desired also appears reasonable. The bandpass filter at X-band has pointed up the problem with magnetostatic mode interference in the frequency range 11 to 12 Gc but otherwise gives every indication of meeting specifications. The bandreject filter at X-band has a problem with tracking of the two spheres. If this problem could be overcome the desired 50 db rejection could be accomplished in two stages. Work below 8 Gc where stripline is necessary may be most difficult. Tests next quarter should indicate the extent of the problem.

RECOMMENDATIONS

The following work should be attempted next quarter:

1. Start work on magnetic shielding.
2. Additional temperature and linearity measurements using hypernik pole pieces.
3. Work on distortion reduction at 11 - 12 Gc in X-band filter.
4. Build and test an X-band bandreject filter using a single YIG sphere as per Anderson.
5. Build and test a K_u-band bandpass filter scaled from X-band filter.
6. Assemble and test a C-band filter in strip line.
7. Design S-band and L-band filters in strip line.
8. Look at the possibility of S-band and L-band filters using circuits other than strip line.

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