A HIGH PERFORMANCE HEXAGONAL FERRITE TUNABLE BANDPASS FILTER FOR THE 40-60 GHZ REGION

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Abstract

The first ferrite tuned bandpass filter, tunable with hexagonal ferrite spheres over the whole of U band (40-60 GHZ) is described. This filter has an insertion loss of 4.5 ± .5 dB, typical bandwidth of 325 MHZ, and a maximum tuning current of 350 mA (at 24 volts) at 60 GHZ, giving it better performance than any previously reported hexagonal ferrite bandpass filter.

Introduction

YIG tuned bandpass filters perform very well as preselectors, postselectors, and tunable receivers at frequencies below 40 GHZ, and are commercially available. YIG filter limitations at frequencies above 40 GHZ are twofold, high power dissipation in the magnet coils in the 40-60 GHZ region giving thermal problems, and saturation of magnetic pole tip materials above 60 GHZ.

Previous researchers have designed and built filters which utilized the large anisotropy (Ha) of the hexagonal ferrites to reduce the magnetic field required to achieve resonance (f = 2.8 MHZ/oe.(Ha + Happ.)). Loop coupled filters have been built covering the 26.5-40 GHZ (1) region with an insertion loss of 7.5 dB and B.W. of about 250 MHZ, iris coupled waveguide filters have been built covering the 32-40 and 46-55 GHZ (2) regions with insertion losses of 6-12 dB, and B.W. of about 300 MHZ, and iris coupled waveguide filters have also been built in the 53-80 GHZ (3) region with insertion loss of 5-8 dB, and B.W. of about 325 MHZ.

The filter which will be described in the following article is a hexagonal ferrite tuned, two sphere, cross waveguide, iris coupled filter tunable over the 40-60 GHZ band with better performance than any previously reported filter utilizing hexagonal ferrites.

Ferrite Resonator Selection and Linewidth Testing

Hexagonal ferrites of the proper composition were grown and processed into polished spheres of .3-.4mm diameter. The ΔH of these spheres was measured with the apparatus shown in Fig. 1 and a corrected form of I. Badys linewidth equations (4).

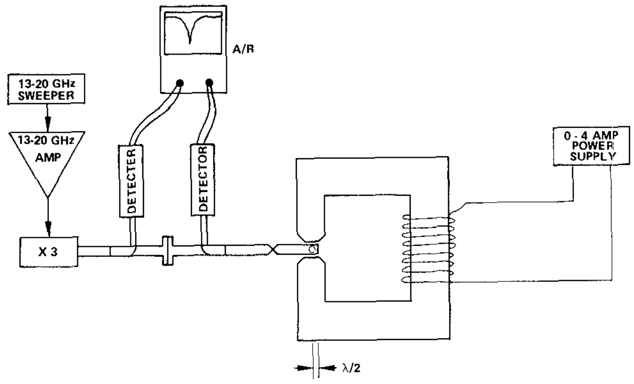

Fig. 1. Ferrite Linewidth Measuring Apparatus

Data taken at 44,51, and 57 GHZ indicates ΔH increase linearly with frequency such that Qu stays essentially constant at 660 for our spheres from 40-60 GHZ. The Ha of the sphere is important to determine so that the spheres resonant frequency for a given applied field is known. The Ha values were obtained by measuring the magnet coil current needed to tune each sphere to 57 GHZ, then calculating using a simple equation.

Filter Design

The high frequency (53-80 GHZ) ferrite filter work done by Lemke and Tolksdorf (3) served as a starting point for our filter design. Their two sphere, iris coupled filter utilized crossed input and output waveguides to produce rf magnetic fields perpendicular to each other in the two waveguides to reduce out of band leakage through the coupling iris (Fig. 2a). A linear taper was used to reduce the height of the waveguide to allow a smaller gap between the magnet pole tips (Fig. 2B).

This design had also been used at lower frequencies with YIG (5). Loop coupling to the spheres was considered due to the narrow pole tip gap possible with this design. Waveguide to sphere coupling was decided on due to its lower insertion loss and the possibility of keeping the magnet gap

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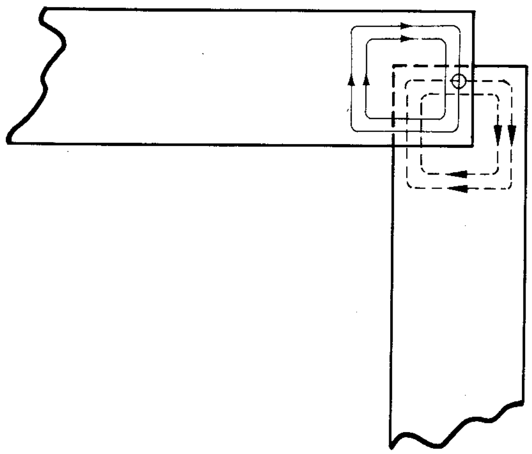

Fig. 2a. Magnetic Field Mode Mismatch

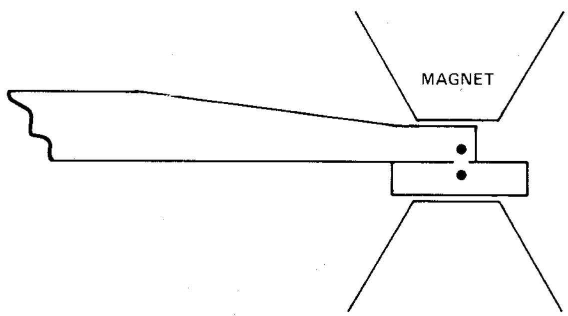

Fig. 2b. Side View of Two Sphere Filter

nearly as small as with loop coupling.

A first pass filter shown in Fig. 3 was built which showed the feasibility of this design concept. A second pass filter was then built (Fig. 4) which had the spheres hard mounted on ceramic rods that slipped into positioners, allowing accurate alignment of the spheres in relation to the iris. The magnet and waveguide were also integrated to form a single unit.

Filter Performance

Using previously derived formulas for insertion loss versus Qu (unloaded Q) and Ql (loaded Q) for a two resonator filter (6) we can express our expected insertion loss as a function of the Ql that we desire from the filter and the available unloaded Q of the resonators. This expression is:

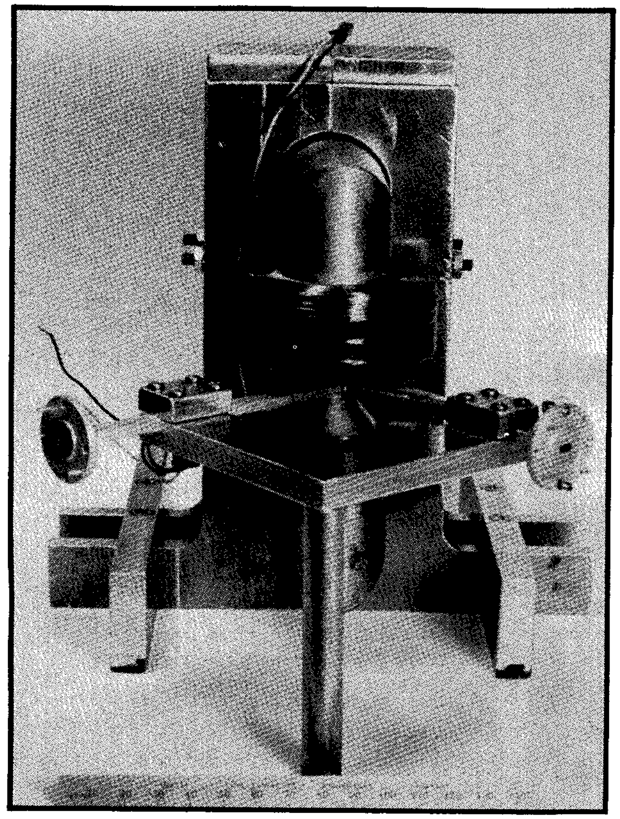

Fig. 3. First Generation Filter

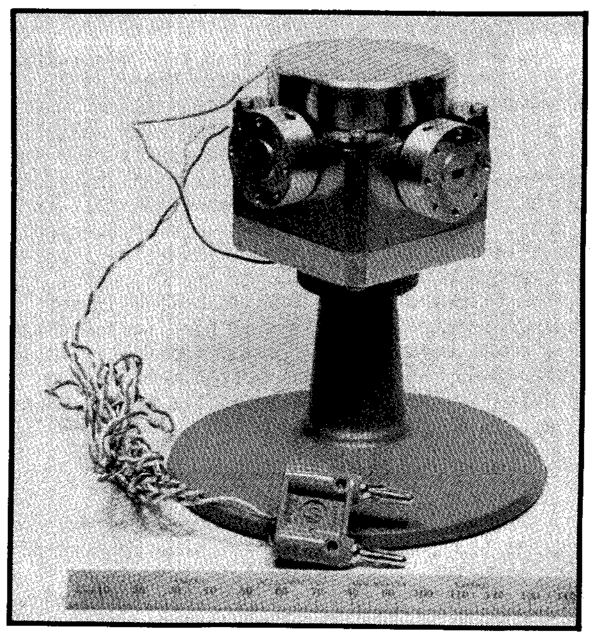

Fig. 4. Second Generation Filter

$$\frac{\text{Transmitted Power}}{\text{Incident Power}} = \frac{Ql^2}{(Qe - Ql)^2}$$

with the stipulation that $Qe = \frac{2}{(1/Ql - 1/Qu)}$,

$$Ql = \frac{\text{Operating Freq.}}{\text{3 dB B.W.}}$$

With the above formulas, the theoretical insertion loss can be plotted and compared to the actual insertion loss measured at 7 different frequencies (Fig. 5). A typical filter response is shown in Fig. 6. The Ql used for the insertion loss plot was 150, as this gave the best fit to the measured 3 dB bandwidth of the filter (Fig. 7).

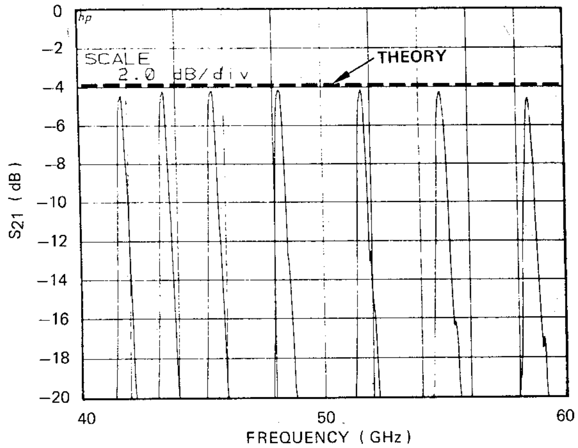

Fig. 5. Filter Insertion Loss Vs. Frequency

The power handling capability of the filter was tested from -10 to +27 dBm at 41 and 44 GHZ, and no change in insertion loss or bandwidth was noted. The current needed to tune the filter to 60 GHZ was 350 mA at 25 volts, giving a maximum power dissipation of 8.5 watts.

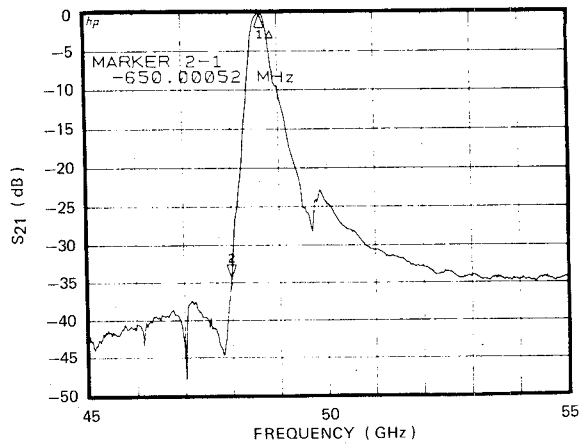

Fig. 6. Typical Filter Response

Discussion

Looking at Fig. 5 it can be seen that we have achieved a very low insertion loss of 4.5 +.5 dB across the entire 40-60 GHZ frequency region, with a typical bandwidth of about 325 MHZ. These figures are significantly better than any reported previously for a hexagonal ferrite filter, although they do agree well with what is theoretically obtainable with our material (Fig.s 5,7). The reason for our filters improved performance versus previously reported results is probably due to more accurate positioning of the spheres, since previous authors have used spheres with similar or higher Qu's (2,3).

The 8.5 watts of power dissipated in the magnet coils of the filter at 60 GHZ is equal to that dissipated in YIG filters at 40 GHZ. For all other factors being equal, the power dissipated in the magnet coils goes up as the square of the frequency for YIG, so that a YIG filter similar to the ones tunable to 40 GHZ would dissipate 18 watts at 60 GHZ. The lower power dissipated in the magnet coils of a filter using hexagonal ferrite spheres instead of YIG spheres should prove useful in avoiding undue heating of the filter structure. The ability

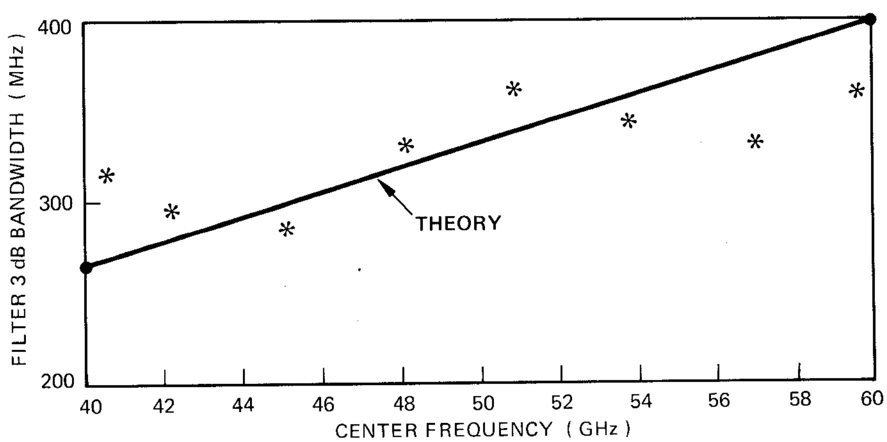

Fig. 7. 3dB Bandwidth vs. Filter Frequency

to produce low insertion loss filters tunable through the 40-60 GHZ band will allow more accurate spectrum analyzer measurements to be made due to preselection in front of the mixer.

Projections for Future Hexagonal Ferrite Use

The design of the crossed waveguide, iris coupled hexagonal ferrite filters seems extendable to cover full waveguide bands in both V (50-75 GHZ) and W band (75-110 GHZ) with performance similar to that of the 40-60 GHZ filter reported here. The hexagonal ferrites for these frequencies can be grown (7), and have Q's similar to that of the 40-60 GHZ material used for our filter.

Tunable oscillators using hexagonal ferrite spheres as the tuning element have already been built by Lemke (8) in the 62.5-65.7 GHZ region using a Gunn Diode as the active device. As techniques to broadband the negative impedance of the Gunn Diode in the oscillator circuit progress and as mounting parasitics are eliminated, this kind of oscillator looks promising for wideband applications up to 110 GHZ by using GaAs and InP Gunns. Alternatively, millimeter-wave transistors may be developed with useful gain up through W band, and these devices could be used as the active elements in hexagonal ferrite tuned oscillators.

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References

(1) F. Reisch et al, "Magnetically Tuned Zn_2Z filters for the 18-40 GHZ Range," IEEE Trans. Magnetics, vol. Mag-11, pp. 1256-1258, Sept. 1975.

(2) J.A. Sweschenikow, E. K. Merinow, and B. P. Pollak, "Bandfilter aus Hexaferriten im Mikrowellenbereich," Nachrichtechnik Elektronik,26, pp. 262-264, 1976.

(3) M. Lemke, W. Hoppe, "Barium Ferrite- A Material for Millimeter Waves," Mikrowellen Mag., vol. 7, pp. 286-290, 1981.

(4) I. Bady, "Measurement of Linewidth of Single Crystal Ferrites by Monitoring the Reflected Wave in Short-Circuited Transmission Line," IEEE Trans. Magnetics, vol. Mag-3, pp. 521-526, Sept. 1967.

(5) G. Matthaei, L. Young, and E.M.T. Jones, Microwave Filters, Impedance Matching Networks, and Coupling Structures, Massachussets: Artech House, 1980, pp. 1069.

(6) J. L. Altman, Microwave Circuits, New York: D. Van Nostrand Company, 1964, pp. 260-263.

(7) P. Röschmann, M. Lemke, W. Tolksdorf, and F. Welz, "Anisotropy Fields and FMR Linewidth in Single-Crystal Al,Ga, and Sc Substituted Hexagonal Ferrites With M Structure", Mat. Res. Bull., vol. 19, pp. 385-392, Feb. 1984.

(8) M. Lemke, "A Millimeter-Wave Gunn Oscillator, Tunable With A Barium-Ferrite Sphere," Proc. of the 9th Eur. Microwave Conf., 1979 pp. 617-620.