# Ferrite Tuned Millimeter Wave Bandpass Filters With High Off Resonance Isolation

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## Abstract

By combining four hexagonal ferrite spheres under the same magnet structure, magnetically tuneable bandpass filters may be built in waveguide yielding increased off resonance isolation, while keeping insertion loss to a reasonable value. Examples of these filters in A, Q, U, and V bands are presented with typical O.R.I. >70 dB and I.L. <13 dB for full band tuning.

## Introduction

The advantage of using hexagonal ferrite spheres instead of YIG spheres for magnetically tuneable filters in the millimeter wave region is that they have a large internal anisotropy field (Ha) which reduces the applied magnetic field needed to achieve resonance ($f = 2.8$ MHz/oe $(H_a + H_{applied})$). By reducing the required magnetic field, problems with electromagnet heating, hysterisis, tuning linearity, and maximum tuning frequency may be reduced.

Two sphere magnetically tuneable bandpass filters fabricated in waveguide (Figure 1) utilizing hexagonal ferrite spheres have been previously reported, (1,2,3) and have been demonstrated to cover full waveguide bandwidths up through W band (4) as shown in Figures 2,3, and 4. The characteristics of these filters in the mm wave region are similar to the characteristics of two sphere loop coupled YIG filters below 26 GHz. In cases where more off resonance isolation (ORI) is desired, loop coupled YIG sphere filters can be extended to 3 and 4 sphere versions in a straightforward manner, gaining an extra 20-30 dB of off resonance isolation per sphere. The extension of the two sphere iris coupled waveguide filter to a 3 or 4 sphere version for increased off resonance isolation is not obvious, however.

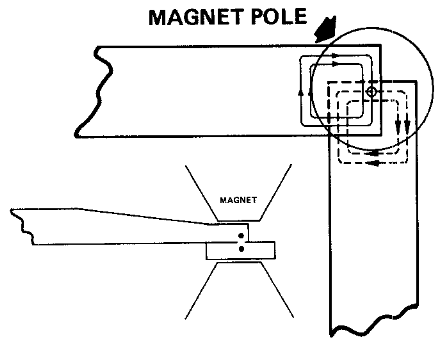


**Figure 1:** Two sphere waveguide bandpass filter.

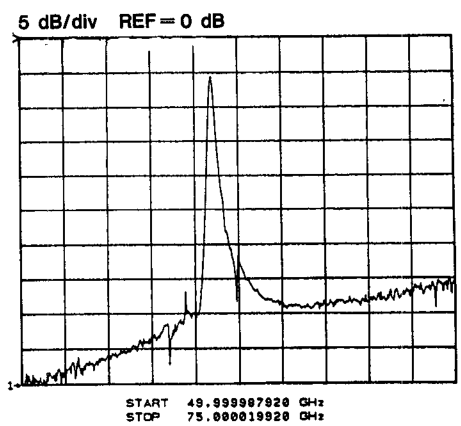


**Figure 2:** Typical two sphere filter response.

J.A. Sweschenihow et al (2) developed a three sphere bandpass filter utilizing hexagonal ferrite spheres (Figure 5). The addition of the third sphere did not increase the insertion loss significantly, but only improved the O.R.I. by ~12 dB while spreading the magnet pole tips farther apart.



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In this paper a new magnetically tuneable four sphere bandpass filter utilizing hexagonal ferrite spheres in waveguide is reported that greatly increases the O.R.I. without increasing the separation of the magnet pole tips. This filter gives similar performance to two cascaded two sphere filters without having to have two separate magnet structures. The filter configuration has shown successful full band performance in A band (26.5-40 GHz), Q band (33-50 GHz), U band (40-60 GHz), and V band (50-75 GHz).

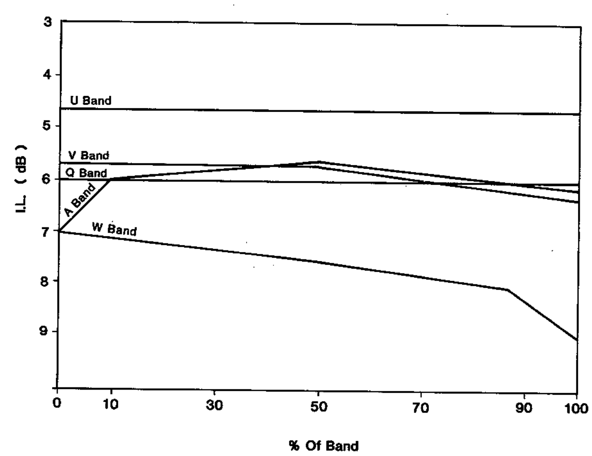


**Figure 3:** Insertion loss vs % of band, two sphere filters.

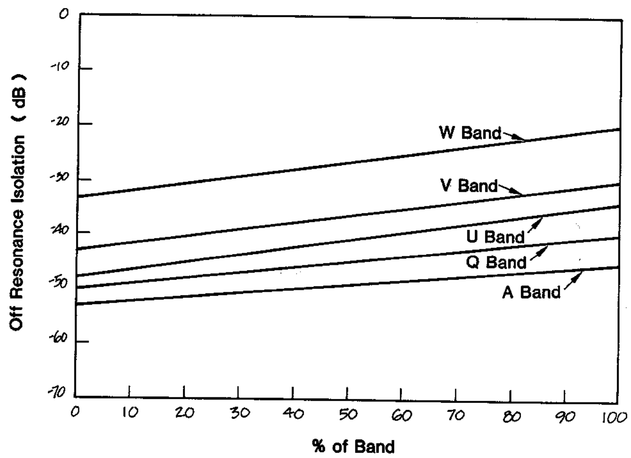


**Figure 4:** Off resonance isolation vs % of band, two sphere filter.

## <u>Filter Design</u>

A schematic of the new four sphere filter configuration is given in Figure 6. The design is basically a pair of two sphere filters connected by a short "transfer" waveguide of reduced height, allowing all four spheres to fit under one magnet pole tip. The spacing of the two sets of spheres from each other is about one waveguide width which becomes a reasonably small figure in the millimeter region. This allows fairly compact magnets to be used. The input and output waveguides use a linear taper to transition from reduced height under the magnet pole tip to standard height waveguide at the connecting flanges. The waveguides which are connected to each other by an iris are kept at $90^0$ angles as in the previous two sphere filters to create magnetic field mode mismatches between the top and bottom guides to increase ORI. The size of the spheres in relation to the waveguide, and the sphere to sphere separation (top to bottom) were set so as to give a maximally flat filter response to avoid ripples in the pass-band.

From the similarity of this four sphere design to two cascaded two sphere filters, the ORI should be double (in dB) the figure for a similar two sphere filter. The I.L. of the filter should also be about double (in dB) the amount for a two sphere filter, but by eliminating one set of input and output transitions the I.L. should be .5-1 dB less than a simple doubling. The one significant difference that was expected from this design was the possibility of cavity resonances in the transfer guide (shown for a V band filter in Figure 7). Calculations indicated the $\lambda g/2$ mode would occur at 48.9 GHz and the $\lambda g$ mode at 69. 3 GHz. At these frequencies the short length of transfer guide will act as a bandpass filter, degrading the ORI.

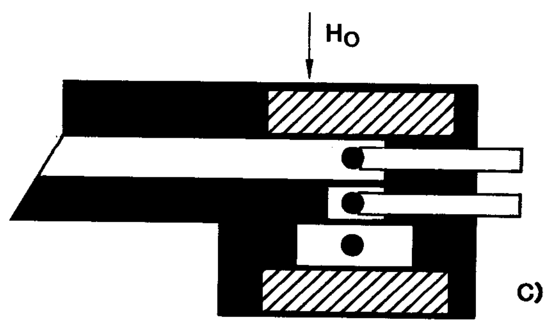


**Figure 5:** Three sphere waveguide bandpass filter.

## Experimental Results

Figure 8 gives a typical four sphere filter response. It can be seen that the insertion loss is slightly less than twice that (in dB) of two cascaded V band filters. The $\lambda g$ cavity mode which was expected to appear at 69.3 GHz actually appears at 67.5 GHz due to the dielectric loading effects at the ferrite spheres in the transfer guide. The "normal" $\lambda g/2$ mode is below the bottom of the band (50 GHz) as expected. The off resonance isolation is about twice (in dB) that of the V band two sphere filter. These results are similar for the A, Q and U band four sphere filters also, W band filters having not yet been built.

The excess feedthrough caused by the $\lambda g$ resonance can be greatly decreased by introducing a small amount of loss in the transfer guide. This loss can be introduced either by an attenuating vane in the transfer guide, or by placing a thin (25$\mu$) sheet of dielectric under the backshorts in the transfer guide. An introduction of 1-2 dB of loss in the guide gives about 15-20 dB of attenuation in the cavity mode induced feedthrough (Figure 9). In addition to the "normal" cavity modes which can occur many GHz away from the filter passband, there are also $\lambda g/2$ and $\lambda g$ modes which are perturbed by the large permeability (both positive and negative) which occurs near resonance and tend to follow within a few hundred MHz of the passband as it is tuned. With no loss introduced in the transfer guide these perturbed cavity modes can put ripples in the passband, but with the introduction of loss these irregularities are greatly reduced.

If the degradation in ORI due to the "normal" $\lambda g$ cavity mode is unacceptable for certain applications, even after it has been reduced by 15-20 dB with the introduction of loss in the transfer guide, it can be eliminated completely by the following technique. By offsetting the spheres from the center of the input and output waveguides so that they are slightly closer to each other, the

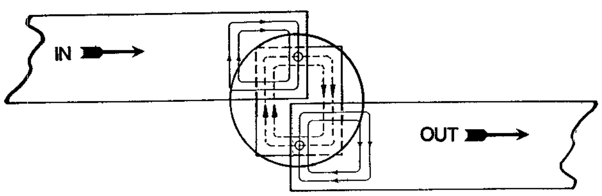


**Figure 6:** Four sphere filter.

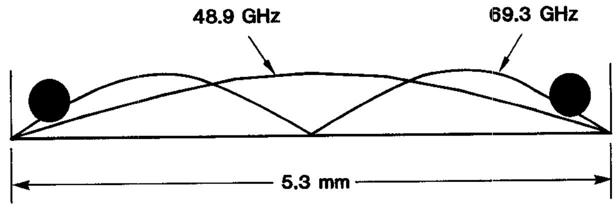


**Figure 7:** Transfer guide resonances.

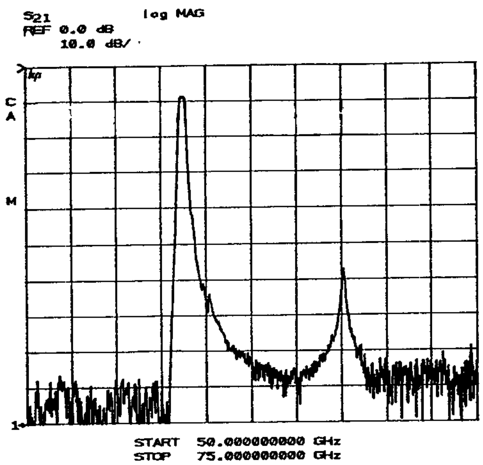


**Figure 8:** Typical four sphere filter response, no transfer guide attenuation.

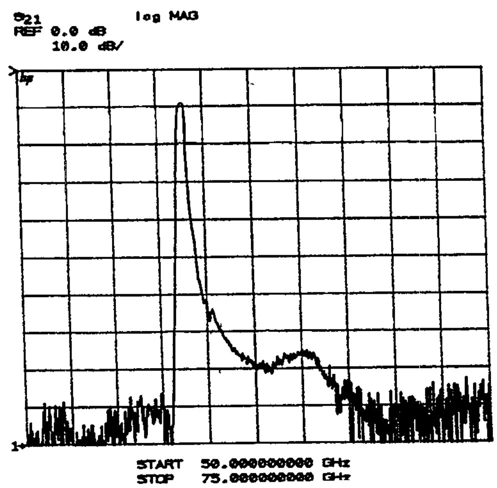


**Figure 9:** Filter response with loss in transfer guide.

transfer guide can be shortened enough to push the λg mode out the top of the band. Shortening the transfer guide will now bring the λg/2 mode in near the bottom of the band, but it's frequency can be reduced below band again by placing a piece of dielectric midway between the two spheres in the transfer guide. The point midway between the two spheres in the transfer guide is an E field null for the λg mode so that it's frequency is not affected and both "normal" modes are now out of band. An example of this technique is shown in a Q band filter response in Figure 10.

A performance summary for these four sphere waveguide filters is given in Figure 11 showing the similar performance obtained in the different bands. All results are for filters with loss introduced in the transfer guide for cavity mode suppression.

## Conclusion

A series of four sphere magnetically tuneable bandpass filters fabricated in waveguide utilizing hexagonal ferrite spheres as tuning elements has been reported. These filters have been built in A, Q, U and V bands with typical ORI >70 dB and insertion losses <13 dB.


## Acknowledgements

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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, September 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. D. Nicholson, "A High Performance Hexagonal Ferrite Tuneable Bandpass Filter for the 40-60 GHz Region", 1985 IEEE MTT-S International Microwave Symposium Digest, pp. 229-232.
4. D. Nicholson, unpublished.


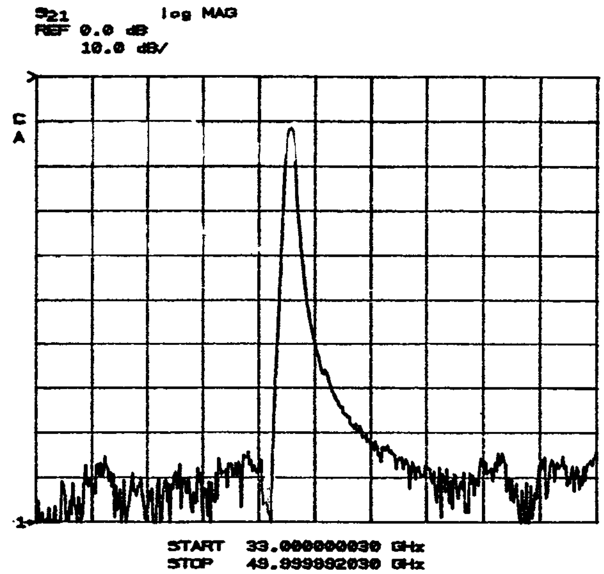


**Figure 10:** Elimination of "normal" cavity modes.

| BAND | INSERTION LOSS (dB) | | O.R.I. (TYPICAL) | 3 dB BANDWIDTH (MHz) | | MAGNET POWER (WATTS) | |
|---|---|---|---|---|---|---|---|
| | MINIMUM | MAXIMUM | | MINIMUM | MAXIMUM | MINIMUM | MAXIMUM |
| A (26.5-40) | 11.0 | 14.0 | >75 dB | 120 | 200 | .27 | 4.7 |
| Q (33-50) | 10.0 | 13.0 | >75 dB | 180 | 260 | .28 | 7.1 |
| U (40-60) | 8.0 | 12.0 | >75 dB | 180 | 270 | .28 | 8.4 |
| V (50-75) | 8.0 | 12.0 | >70 dB | 190 | 300 | .35 | 12.0 |

**Figure 11:** Four sphere filter parameters.