AN ALIGNMENT TECHNIQUE FOR MULTIPLE BALL YIG BANDPASS FILTERS OPERATING OVER MULTI-OCTAVE FREQUENCY BANDS

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ABSTRACT

To date, the alignment of a multi-sphere YIG bandpass filter for multi-octave frequency bands has been designated as a "Black Art" performed by a rare breed of highly skilled and patient individuals. The intent of this paper is to bring YIG filter alignment out of the realm of "tweaking and hunting", thereby significantly reducing the cost per unit. A logical step by step alignment procedure applicable to any YIG or Ga YIG multi-sphere bandpass filter is presented. The validity of the technique has been verified by many successfully aligned complex filters.

INTRODUCTION

The past decade has produced many papers and company pamphlets describing the design of multi-sphere YIG bandpass filters. However, very little, if anything, can be found in the literature pertaining to the actual alignment of a multi-sphere YIG filter. This very important aspect of the YIG filter appears to be a deep dark secret known only to the alignment technician. In effect, each "aligner" has developed his or her own "tweaking" technique; consequently, for a given filter design, the time for alignment will vary (by a considerable amount) for each technician. This large variation in alignment time causes great difficulty in estimating the cost per unit and can play havoc with a production run.

It is obvious that a methodized alignment technique would alleviate the need for specialized personnel and significantly reduce the time and cost for the realization of a completed YIG filter. It is to that end, this paper is presented.

Dual Channel Preselector Form Factor

The unit used to describe alignment technique is a dual channel YIG preselector (two (2) four-ball YIG filters tuned via a common electromagnet). This is a "worst case" example, since both four-ball filters must exhibit (within specification tolerances) the same insertion loss, instantaneous bandwidth, selectivity and VSWR, with the added constraint of channel tracking over the range 2.0 to 18.0 GHz. A schematic of the preselector is shown in Figure 1a and a typical bandpass response indicating pertinent characteristics e.g., insertion loss, bandwidth, in and out of band spurious responses is in Figure 1b.

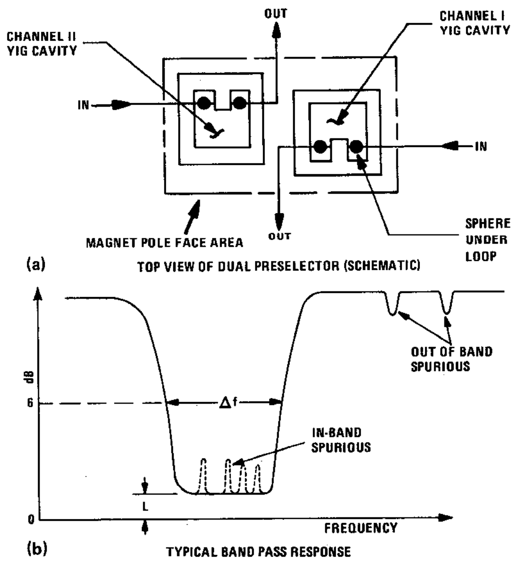


Figure 1. Form Factor — Dual Preselector

Alignment Procedure

The alignment technique described herein is a step by step procedure which can be divided into three (3) pertinent phases, i.e., Phase I and II are preparation phases and Phase III is the actual alignment of the filter.

NOTE: The basic premise is that the filter design is valid.

PHASE I: Inspection of Filter Structure and YIG Spheres

1. Mechanical and optical inspection of YIG plate (housing) and coupling loops for conformance to specifications.
2. Mechanical inspection of electromagnet in terms of gap spacing, flatness of pole faces and parallelism between pole faces.
3. Mechanical and optical inspection of YIG spheres in terms of diameter and sphericity.
4. Determine linewidth (ΔH) of YIG spheres. The linewidth is directly related to the unloaded Q (Q_u) of the sphere.

Determination of YIG Sphere Linewidth (ΔH). The linewidth (ΔH) of each YIG sphere is measured via the standard cavity perturbation technique[1]. In essence, an S-band waveguide cavity designed to resonate at 3.73 GHz is placed in a large Varian electromagnet. The YIG sphere is placed in a quartz test tube which is inserted into the center of the cavity. The sphere is free to orient itself along its easy axis. The cavity operates in the TE_{104} mode; thus, with the sphere positioned at the cavity center, it is at zero electric field and maximum magnetic field. In effect, the measurement is executed by using a swept rf source to resonate the cavity and adjusting the magnetic field to resonate the YIG sphere at the same frequency causing the YIG to absorb energy from the cavity resonance response. The depth of the absorption dip is measured in db by a precision attenuator using the cavity resonance response as a reference. The absorption dip in db is used in the following equation to calculate the linewidth.

$$\Delta H = \left[\frac{4\,Q_L\left[1-\left(\frac{\lambda_o}{\lambda_c}\right)^2\right]}{\left[\log^{-1}\frac{db}{20}\right]-1}\right] \times \frac{\text{Vol sphere}}{\text{Vol cavity}} \times 4\pi\, M_s$$

where: Q_L = loaded Q of cavity

$4\pi\, M_s$ = 1785 gauss for pure YIG

and the unloaded Q (Q_u) of the YIG sphere can be found from[2]

$$Q_u = \frac{f_o\ (10^{-6})}{2.8\ \Delta H}$$

A photograph of the linewidth measurement test set is shown in Figure 2. Note the cavity resonance response and the absorption notch due to the YIG resonance.

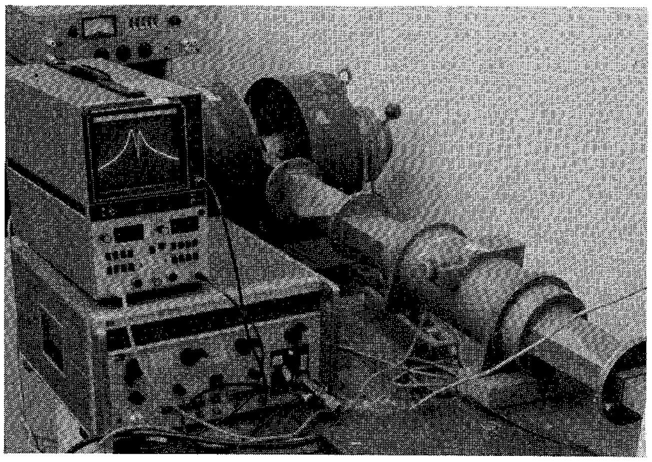


Figure 2. S-Band Cavity Test Set to Determine ΔH of YIG Spheres

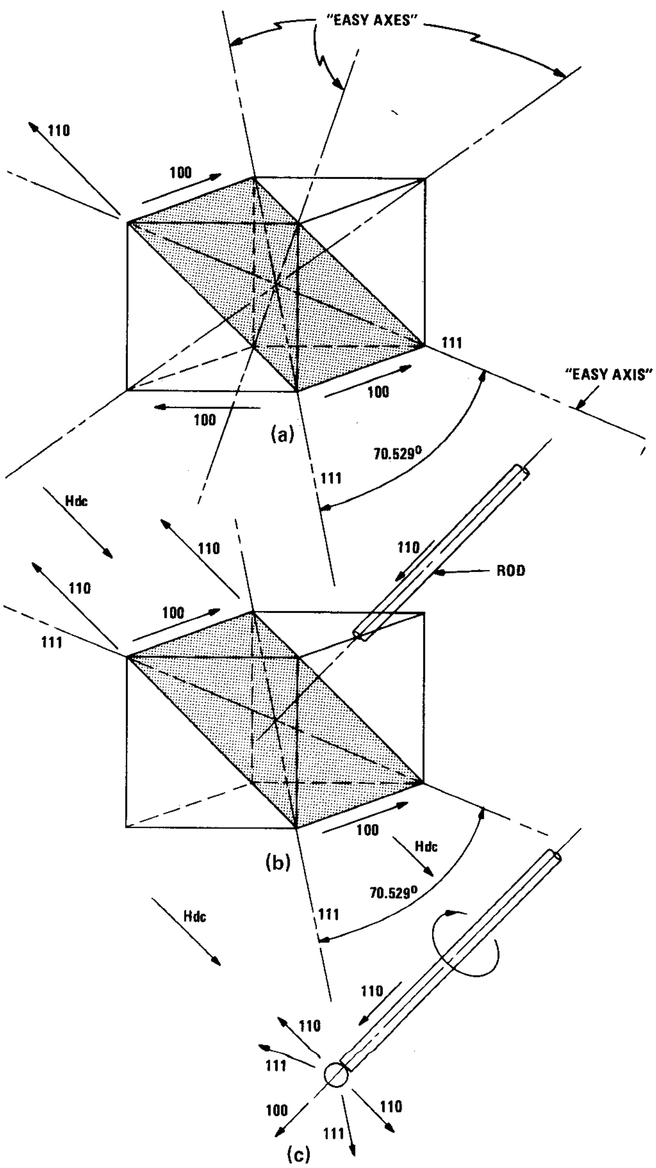


Figure 3. Sphere-to-Rod Alignment and YIG Crystal Geometry

PHASE II: Mounting of YIG Sphere to Tuning Rod

The key to the alignment technique is in the mounting of the YIG spheres to their respective tuning rods. All spheres must be mounted with the same (YIG) crystal axis parallel to the tuning rod. Figure 3a illustrates the cubic crystal structure of the YIG and its pertinent axes, i.e., 111, 110 and 100. In this case, all spheres are mounted with the 110 axis parallel to the tuning rod as shown in Figure 3b. Figure 3c illustrates the YIG sphere mounted to the tuning rod and how the axes would appear to the perpendicular applied magnetic field H_{dc} with rod rotation. If all spheres are so mounted, they will exhibit a similar "response factor", i.e., applied perpendicular H_{dc} field versus degree rotation of sphere.

The sphere-rod mounting procedure has been described in the literature [1,2,3]. The technique can best be understood by referring to Figure 3b. Note that the shaded area contains two easy axes (111) 70.53 degrees apart. Therefore, if two sets of electromagnets were set at 70.53 degrees apart in a horizontal plane with the YIG sphere placed in a very low friction mount centered between the magnets, the activation of each pair of magnets (one at a time, via a switch) would align the two easy axes. Then a preglued rod brought in perpendicular to this plane would mount the rod parallel to the 110 axis of the sphere. A photograph of the sphere orienting fixture is shown in Figure 4.

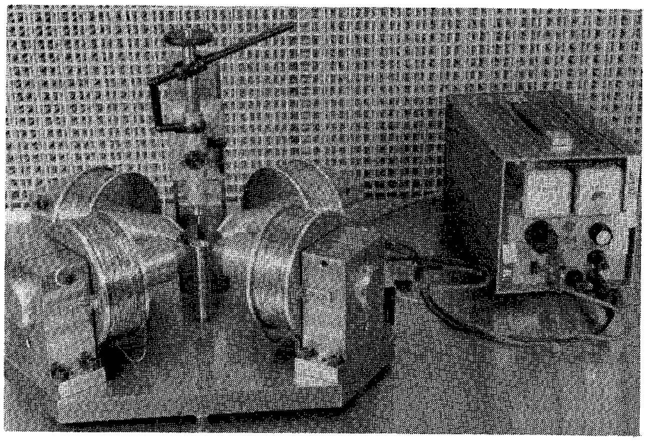


Figure 4. Sphere Orienting Fixture

The "response factor" is achieved by placing each rod-sphere assembly into a single sphere (loop coupled) plate and for a fixed rf frequency input, the required H_{dc} field (to maintain YIG resonance at fixed input rf frequency) versus degree rotation of the YIG sphere is plotted[2]. This variation of applied H_{dc} versus rotation of the sphere is due to the anisotropy variation within the sphere and can be described by the following (for 110 axis parallel to rod) equation,

$$H_{dc} = \frac{f_0(\text{MHz})}{2.8} - \left(2 - \frac{5}{2}\sin^2\theta - \frac{15}{8}\sin^2 2\theta\right) K_1/M_s$$

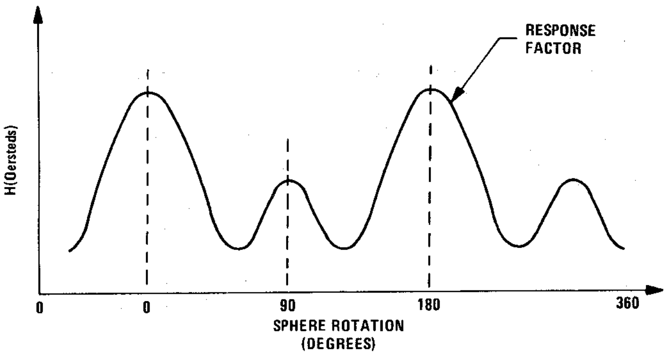
where H_{dc} = applied magnetic field (oersteds)

f_0 = resonant frequency

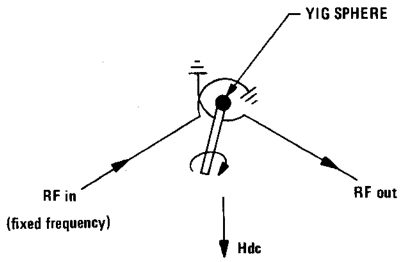
θ = degree sphere rotation

K_1/M_s = first order anisotropy constant (for YIG, K_1/M_s = -43 oersteds)

The response factor and method of test is shown in Figure 5a and 5b.



(a) RESPONSE FACTOR



(b) SINGLE BALL PLATE

Figure 5. Response Factor and Single Ball Plate

Since all spheres are mounted in a similar manner, they will exhibit the same "response factor" and an "apples and apples" situation is achieved.

PHASE III: Alignment

As previously stated the unit to be aligned is a dual channel preselector, each channel utilizing four YIG spheres and both channels are tuned via a single electromagnet. The composite unit is placed in an alignment fixture as shown in Figure 6. This fixture permits the longitudinal and rotational movements of the YIG sphere to be manipulated in a precise manner with a mechanical readout of exact position for each sphere.

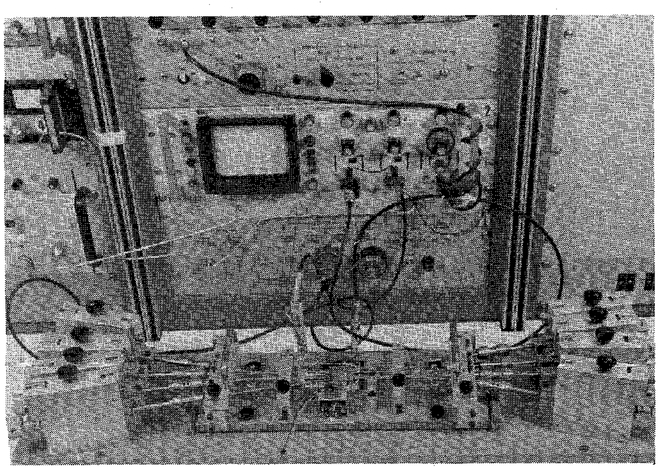
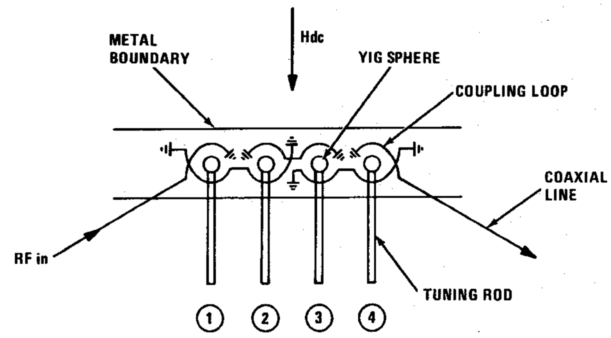


Figure 6. Alignment Fixture For Dual Preselectors

For the purpose of discussion a schematic view of a four-ball filter is shown in Figure 7a. For a fixed rf frequency input of 3.0 GHz:

a. Insert sphere ④ under loop (centered) and place 15 dB coupler in line as shown in Figure 7b for a reflected power response on dual trace scope (no other spheres in structure). Now rotate sphere to largest peak on "response factor", i.e., highest H_{dc} field for resonance at input frequency (0 degree point on "response factor" as shown in Figure 5). Lock sphere ④ in place.

b. Repeat step a. for sphere ① under opposite loop and rotate ① until response is similar to sphere ④ on dual trace scope (Figure 7c). Lock sphere ① in place. Note that spheres ① and ④ have been tuned to the same resonant frequency with the same H field. This in essence, is the prime reason for mounting spheres to exhibit the same "response factor".



(a) FOUR-BALL PRESELECTOR (SCHEMATIC VIEW)

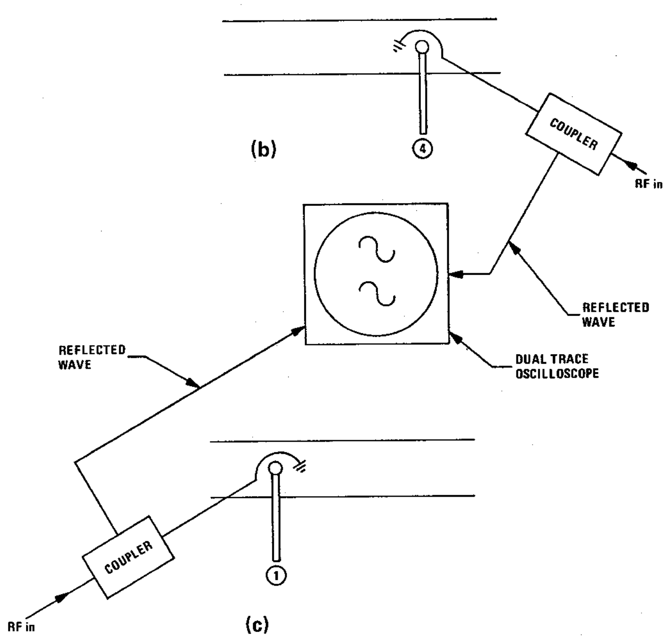


Figure 7. Measurement Instrumentation (Schematic)

c. Insert sphere ③ next to ④ as shown in Figure 8 and rotate to yield the shown reflected response. Lock rotational movement of ③, note its longitudinal position and retract from structure.

d. Insert sphere ② next to ① and repeat step c. for these two spheres (Figure 8b) for similar response on dual trace scope.

e. Re-insert sphere ③ to same longitudinal position as in step c. (Figure 9a.)

f. Connect filter for conventional transmission mode (Figure 9b) and for a fixed frequency input of 10.0 GHz manipulate center spheres ② and ③ for optimum bandwidth and insertion loss. Note: Spheres ① and ④ remain locked in place.

g. In transmission mode, slowly scan the entire frequency band, 2.0 GHz to 18.0 GHz, to ascertain conformance to specifications.

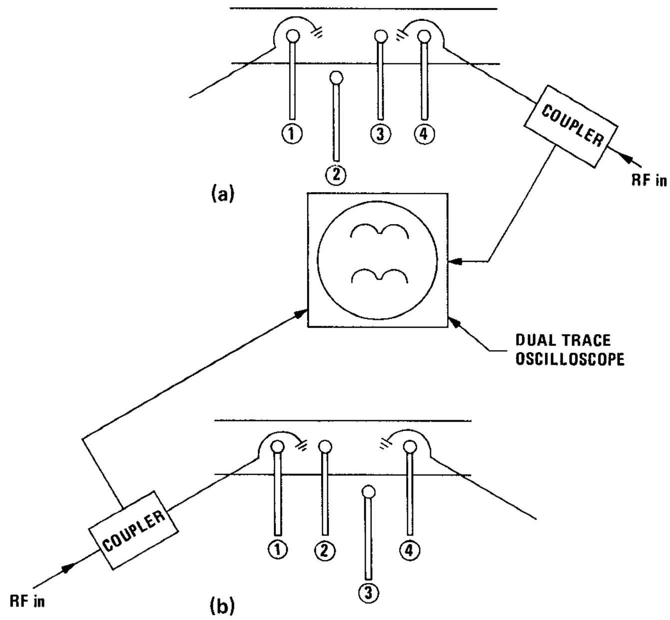


Figure 8. Multiple Ball Filter Alignment — Initial Adjustments

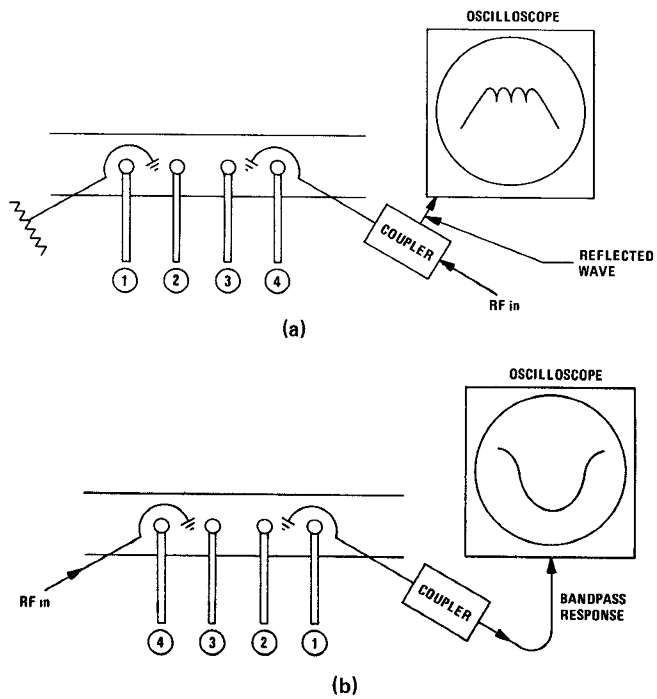


Figure 9. Multiple Ball Filter Alignment — Final Adjustments

h. If the amplitude of the in and out of passband spurious responses are too high (in amplitude) spheres having higher values of ΔH (i.e., lower Q_u) should be used and steps a. through g. repeated.

In the actual alignment of the dual channel preselector, spheres ① and ④ of both preselectors were tuned to the same point on the "response factor", this insured channel tracking to within 5 MHz over the entire frequency range.

To insure spurious response and insertion loss spec conformance, the end spheres required linewidths of ΔH = 0.7 and the center spheres, ΔH = 0.9. Therefore, for production run, only those spheres having the required linewidths need be mounted.

Conclusions

A step by step alignment procedure has been presented. The salient features of the technique are:

- All YIG spheres exhibit the same "response factor" when placed in a magnetic field, (H_{dc})
- The required linewidths (ΔH) of spheres can be determined during the initial alignment
- Once set, the end spheres remain locked in place, hence, only two spheres in a four-sphere filter are manipulated
- Channel tracking is assured for dual channel filters over multi-octave bands
- Uniform procedure for all alignment personnel
- Significant cost reduction per unit
- Applicable (with some initial modifications) to all YIG or Ga YIG multi-sphere filters

The simplicity of the procedure makes the thought of computer-controlled alignment feasible.

Acknowledgements

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