A 4-40 GHZ WIDE BANDWIDTH, MAGNETICALLY TUNED BANDPASS FILTER

David L. Harris

Tektronix, Inc.; Microwave and RF Instrument Division; Beaverton, Oregon

Abstract

In recent years, as microwave test equipment evolved, the need for a coaxial input/output bandpass filter that can tune from 4 to 40 GHz has become evident. This filter also needs a pass-band much wider than any of the previously available YIG filters. To meet these needs a special non-YIG ferrite filter was designed and built.

This article discusses the key problems and solutions in the development of this new microwave filter.

Introduction

As the need to use higher frequencies in communications and surveillance grows, test and measurement equipment such as sweep generators, network analyzers, and spectrum analyzers have evolved to meet the needs of the microwave industry. A key component, the magnetically tuned filter or YIG (Yttrium-Iron-Garnet) filter as it is commonly known, was a major stumbling block in the push to frequencies above 26 GHz. Use of coaxial transmission lines and connectors has, in recent years, advanced beyond 18 or 26 GHz to 40, 50, and even 60 Ghz. Except for a 26-40 GHz coaxial filter from Ferretec Inc., reports of YIG filters operating to 40 GHz or higher, have for the most part, been waveguide based filters with limited tuning range [2, 5]. A coax based, low hysteresis bandpass filter with a wide 4-40 GHz tuning range and a pass-band in excess of 100 MHz was unobtainable in the market place. Therefore, Tektronix undertook a research and development project to produce such a filter for use in a new spectrum analyzer.

Three problems had to be solved in order to increase the tuning range and bandwidth of the conventional 20 GHz YIG filter designs. First, the tuning range is limited by a gross tuning non-linearity due to saturation of the tuning magnet as the resonant frequency is pushed above 26 GHz. The second problem is the self-resonance of the filter's resonator coupling structure. The frequency of this self-resonance must be well above the highest

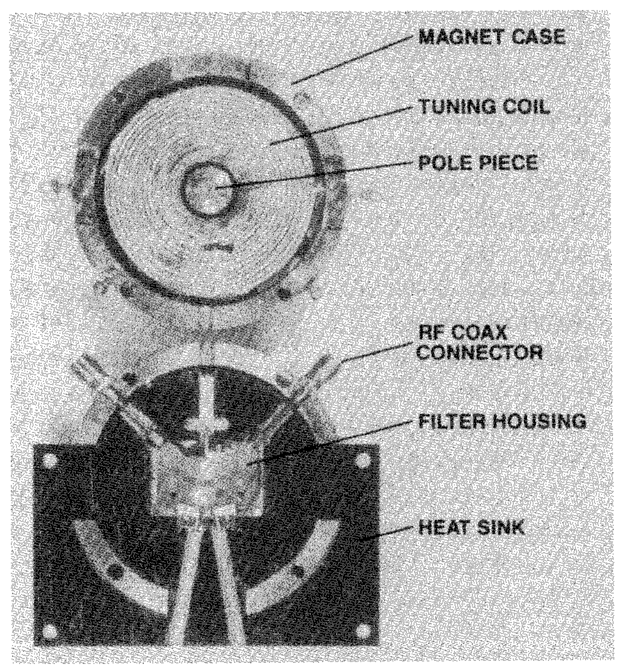

Figure 1: Interior view of the 4-40 GHz filter

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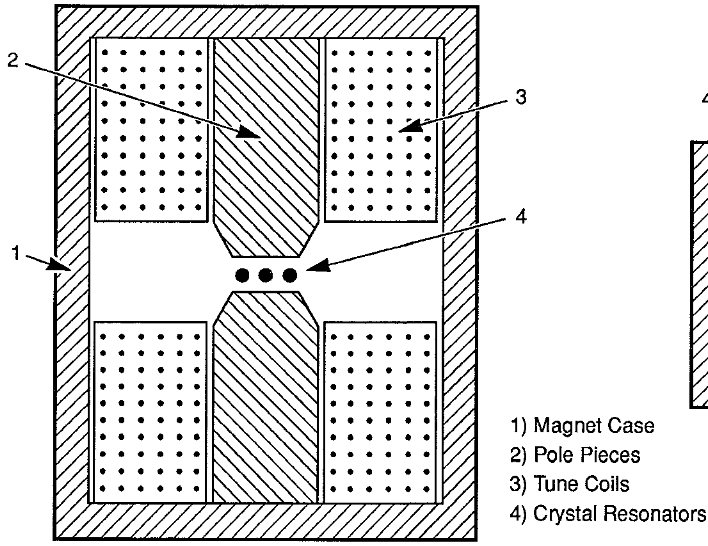

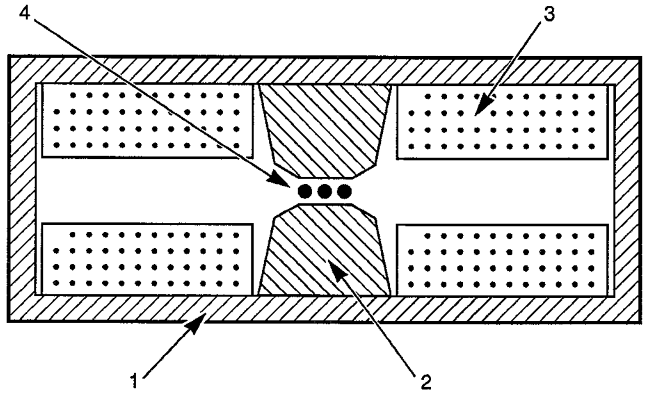

Figure 2: a) Traditional cylindrical pole magnet design. b) 40 GHz conical pole magnet design.

operating frequency of the filter. The third problem is to increase the pass-band from 20 or 30 MHz to 100 MHz or more at the lowest operating frequency without creating unacceptable spurious responses. Figure 1 shows the internal construction of the prototype 4-40 GHz filter.

Tuning Magnet Design

Tuning magnets for YIG filters have traditionally been similar to the one shown in figure 2a. They are constructed of a closed cylindrical outer shell of a low hysteresis alloy of nickel and iron and have internal pole pieces separated by a small air gap which contains the ferrite resonators and filter structure. This design works well for tuning to 20 or even 26 GHz, but for higher frequencies, tuning becomes non-linear as magnetic saturation begins to occur. A higher saturation point and higher frequencies may be obtained by using a cobalt-iron alloy but this will result in as much as 20 times the hysteresis of the nickel-iron alloy. Magnetic saturation should ideally occur simultaneously throughout the magnetic material if maximum flux density in the gap is to be achieved. This traditional design with long cylindrical pole pieces, does not allow this to

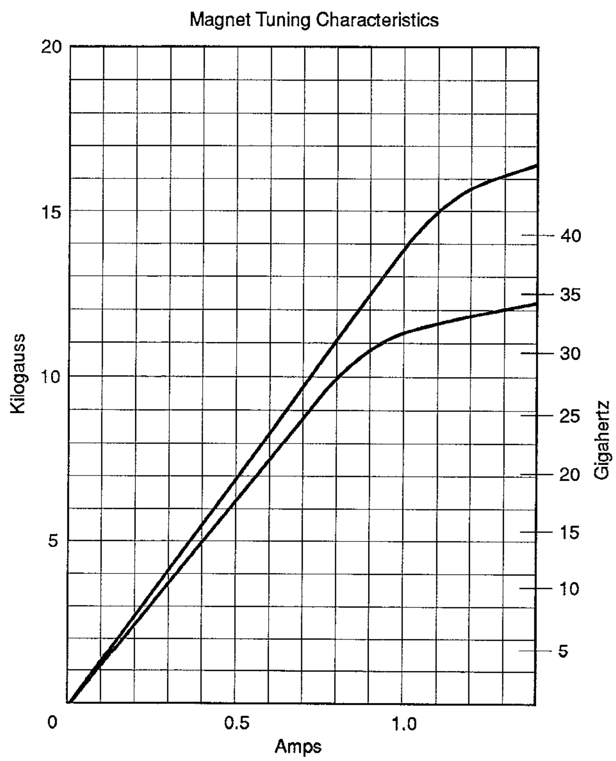

Figure 3: Magnet tuning linearity.

happen. Premature saturation of the magnetic material occurs at the bases of the pole pieces where they join the magnetic shell and therefore restrict the tuning range of the filter. In order to take full advantage of the magnetic limits of the nickel-iron alloy and thereby tune to higher frequencies, a critical modification to the old design must be made. In Figure 2b the long cylindrical pole pieces have been replaced by short double tapered conical poles. This shape prevents premature saturation and allows tuning to beyond 40 GHz to be achieved [1]. Figure 3 shows the tuning characteristics of the magnet designs from Figure 2. The upper curve is for the conical pole magnet and the lower curve is for the cylindrical pole magnet. As can be seen, the conical pole design allows linear tuning to 40 GHz.

Filter Design

The design of YIG filter coupling structures has been known for many years and has been extensively documented in the technical literature [3, 4]. The problem is two-fold. The filter's tune range must be extended from 20 GHz up to 40 GHz and at the same time the pass-band must be increased from the 20-40 MHz of the older design to 100 MHz or more.

The first part of the problem is the limitation to the filter's tuning range imposed by the self-resonance of the filter's coupling structure. In the case of the older 20 GHz filter design, this self-resonance occurs at about 25 GHz. Figure 4 shows the self-resonances of both the 20 GHz (left curve) and the 40 GHz (right curve) designs. This upward shift in frequency of the self-resonance was achieved by reducing the physical dimensions of both the filter's coupling structure and the diameter of the crystal resonator spheres as shown in Figure 5. Figure 5a shows the dimensions of an inter-stage cross section of a 20 GHz filter. Figure 5b shows the size reduction needed for operation at 40 GHz. Both filter housings are constructed from a high resistivity powdered metal alloy so that eddy currents induced by the tuning magnets are minimized.

The second part of the problem, that of increasing the bandwidth, required not only a change in the filter's coupling coefficients, but also a change to a resonator material with a much lower "Q" than the commonly used YIG. It was determined, through experimentation with various types of resonator materials, that the best compromise between bandwidth and insertion-loss is the use of LAF (Lithium-Aluminum-Ferrite) resonators. Figure 6 shows the pass-band response of the LAF filter at various frequencies. The bandwidth of the filter varies from about 100 MHz at 4 GHz to about 350 MHz at 40 GHz. Insertion-loss of the three resonator LAF filter is about 6-7 dB while the three resonator YIG filter is about 4-5 dB. LAF

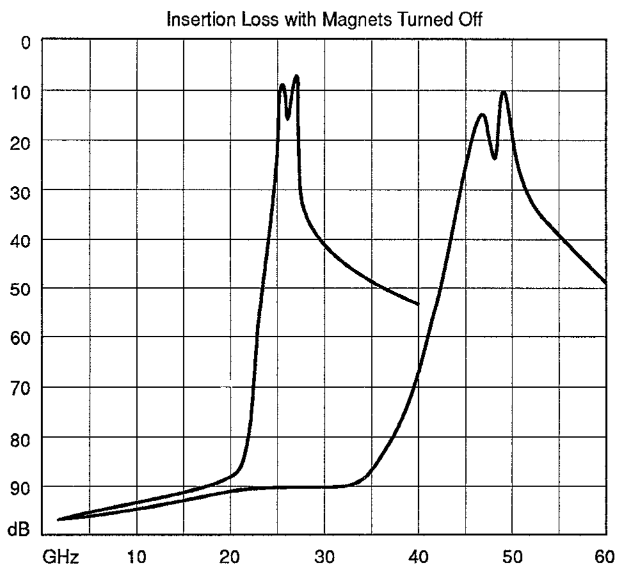

Figure 4: Self-resonance of Two Filters.

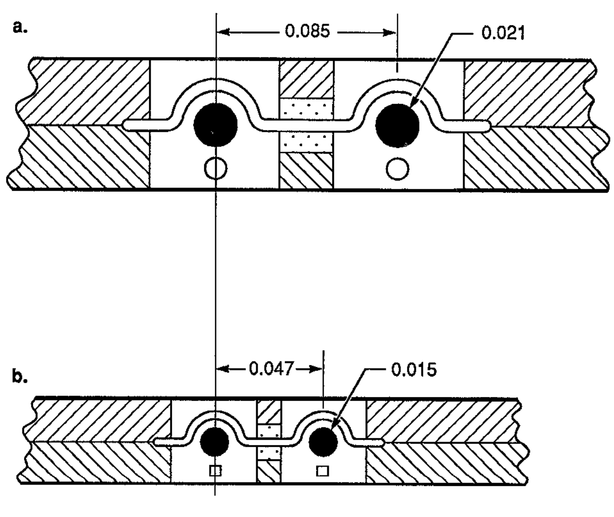

Figure 5: Filter Coupling

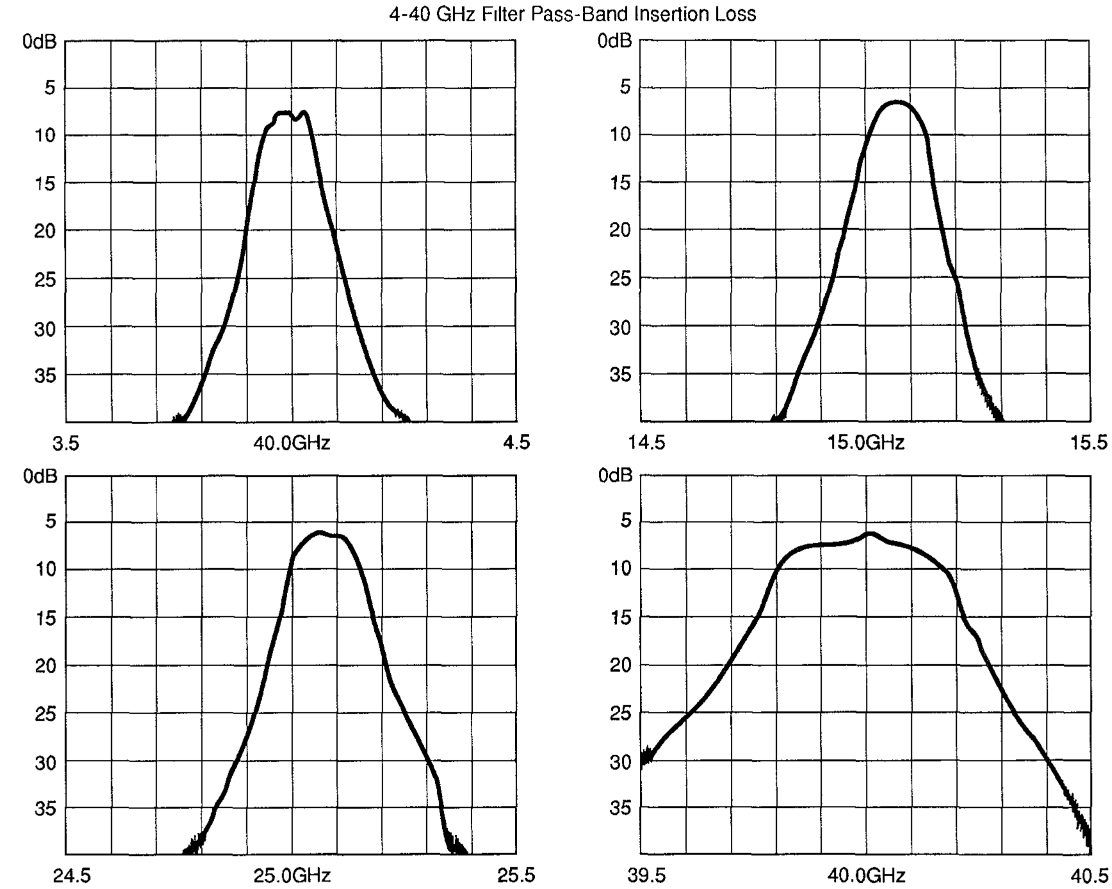

Figure 6: Pass-band response of the filter at various frequencies.

spheres with a magnetic saturation level of 2200 gauss were used to obtain filter operation down to 4 GHz. In the production version of this filter, however, the lowest required operating frequency is only 6 GHz. This allows the second resonator to be replaced with a 2600 gauss sphere in order to supress the 210 mode. The spheres were mounted on the 100 crystaline axis for good temperature stability.

Conclusions

A 4-40 GHz bandpass filter can be realized if the tuning magnet uses conical poles and the filter's coupling structure can be made small enough to prevent self-resonance from occurring below 40 GHz. Additionally, the pass-band bandwidth can be made greater than 100 MHz by using LAF resonators instead of YIG.

Acknowledgements

I would like to thank Hoa Nguyen, Don Backstrand, and Wolfgang Herr for their outstanding work in helping to make this filter a reality.

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