YIG-FILTER RECOVERY AFTER EXPOSURE TO HIGH POWER
and
X-BAND FREQUENCY-STEPPED YIG FILTER

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Abstract

The physical processes that determine the recovery of YIG filters after exposure to high-power signals are investigated. Results include predictions concerning nonthermal detuning due to spin-wave instability and concerning delayed emission after termination of the incident pulse.

A novel YIG filter is described in which resonators can be detuned some 300 MHz in a 50 nanosecond time interval. When detuning is synchronized with a transmitter pulse the component can perform as a T.R. switch in addition to its normal selective function. A substantial amount of the incident rf power is reflected, providing a measure of protection for the filter and following receiver components.

Part A, YIG-Filter Recovery after Exposure to High Power (E. Schloemann)

When a YIG filter is exposed to a high-power pulse of rf energy at a frequency within the pass band the filter will be temporarily incapacitated. Several physical processes contribute to the deterioration of the filter's performance and to the recovery that occurs after the termination of the incident pulse. Three important processes may be distinguished: 1) "thermal" detuning; 2) "non-thermal" detuning; 3) delayed emission (sometimes known as the "kick-back" effect).

Thermal detuning is caused by the change in temperature of the sphere resonator. This effect occurs primarily when the sphere orientation differs from an axis of temperature compensation. Thermal detuning is usually due to the cumulative effect of many microwave pulses and is therefore significant only at relatively high duty rates.

Nonthermal detuning is induced by a single rf pulse when the power level exceeds the threshold for spin-wave instability. Under these conditions a significant fraction of the energy absorbed by the sphere resonator is rapidly transferred to certain spin waves, which thus become excited far in excess of their usual thermal level. After the pulse these spin waves decay with a relatively long relaxation time (typically of the order of 100 nsec). As long as they remain excited the uniform mode of the sphere resonator is detuned by an amount proportional to the energy stored in the spin waves.

The delayed emission or "kick-back" effect is the emission of energy by the filter after termination of the incident pulse. Such emission occurs in any narrow-band filter even at low power levels, but nonlinear effects due to spin-wave instability modify the emission process significantly. In the linear regime (i.e., at low power levels) the power emitted by the filter decays exponentially with a decay time inversely proportional to the bandwidth of the filter. In the nonlinear regime (i.e., after the onset of spin-wave instability) the power emitted has a more complicated time dependence. At first it decays exponentially with a decay time considerably shorter than the decay time in the linear regime. The decay time is shorter because energy is still being transferred from the uniform mode of the sphere to the spin waves even after the termination of the incident pulse. After the initial decline the emitted power increases again as energy is now transferred from the spin waves to the uniform mode, giving rise to a delayed emission spike as first reported by Clark and Brown.[1]

Detailed calculations of nonthermal detuning and delayed emission have been carried out based on the theory of parametric excitation of spin waves previously developed.[2,3] A typical result of the calculations is shown in Fig. 1. Here the level of signal emitted by the filter after termination of the incident pulse is plotted as a function of reduced time for various power levels of the incident signal. It may be seen that a peak in the emitted signal occurs at approximately 2.5 to 3.5 on the reduced time scale. The peak power of the emitted signal is quite small at moderate levels of the incident signal (less than 25 dB above the spin-wave instability threshold) and becomes significant only at very high levels of the incident signal (approximately 30 dB above threshold or more).

Calculations of the saturation and recovery behavior of YIG filters have also been carried out assuming that the high power signal differs from the resonant frequency of the filter. The results show that for sufficiently large detuning the filter is substantially protected from the deleterious saturation effects described above.

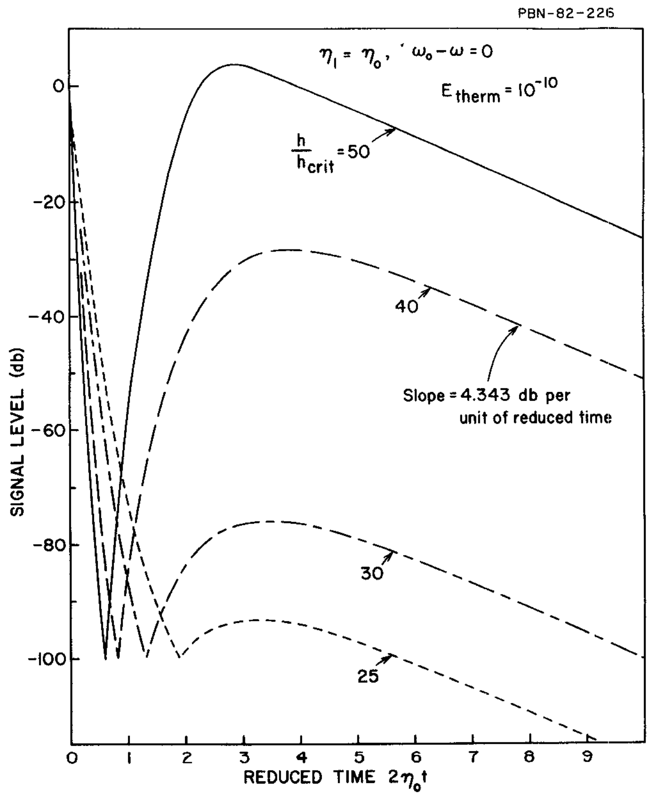

FIG. 1. Calculated time dependence of signal emitted by filter after termination of the incident pulse.

Part B, X-Band Frequency-Stepped YIG Filter (R. E. Blight)

The YIG filter, as a receiver front end component, provides a microwave system with a high degree of selectivity. Recent developments at X-band show that this component when redesigned can in addition provide a measure of protection for itself and the receiver during the transmit period of a pulsed radar system. The merit in this filter's dual performance lies in an improved system noise figure made possible by the removal of redundant rf limiter stages.

When an rf signal is applied to a single-stage YIG filter at an off-resonance frequency the amounts of reflected and absorbed energy are determined by the resonator's unloaded Q and the external loading imposed upon it doubly by the input and output circuitry. Under similar conditions for a dual-stage filter, resonators are essentially decoupled from one another in the region of interest and tend to be singly loaded by external rf circuitry. A typical curve of absorbed power by a singly loaded resonator shows (Fig. 2) that for a 300 MHz offset the level is approximately -33.5 dB. This is a clear situation for a C.W. signal; however, under pulsed rf conditions with energy distribution in the frequency domain dependent upon pulse shape, the total amount of power absorbed is less obvious.

Energy stored in a filter's YIG resonator due to the application of a low-level CW signal which is then fast tuned in frequency, is shown in Fig. 3 to be dissipated while changing frequency. This phenomenon raises the possibility of some transmitter pulse sidelobe energy being stored in a frequency stepped, or detuned resonator and then being converted to the receiver passband frequencies when the filter is restepped for echo reception. The small signal visibility close in to the transmitter pulse has been observed with a frequency stepped dual-stage filter in a simulated system environment with Tx peak power levels up to 20 W. Figure 4A is a block diagram of the setup used showing the position of major components. Receiver protection was guaranteed by a pulse modulator placed after the YIG filter. The width of a video pulse applied to this modulator was adjusted to reveal the Tx pulse trailing edge at a very low amplitude and its "cut on" point served as a time reference for the scope display.

The delayed small signal pulse was calibrated and served as a reference power level. Figure 4B shows the system visibility with the reference pulse set to -65 dBm and for a 200 nanosec Tx pulse at a peak power of 1 mW and 1 W.

The fast tuning characteristics of a YIG resonator are determined to a large extent by the applied A.C. magnetic field. In two microstrip filter designs to be described, this field is produced locally and from high current flowing through a low inductive conductor path. The first design (Fig. 5) shows a dual-stage filter fabricated with circuitry delineated on three substrates which share a common, enclosed, thin film ground plane. Filter stages are identical and have coupling regions defined by circular apertures in the ground plane conductor. Apertures are 60 mil in dia. and concentric to 25 mil dia. holes shown drilled through two substrates. YIG spheres are positioned midway in these holes with their centers coplanar with the ground plane. Input and output bifurcated coupling line structures are equally spaced on opposite sides of the spheres and orthogonal to each other. Open circuit transmission line stub lengths produce rf short circuits midway along the coupling lines in the absence of YIG resonators and provide tight magnetic coupling with spheres in place. Filter stages are quarter-wave coupled with a transmission line section.

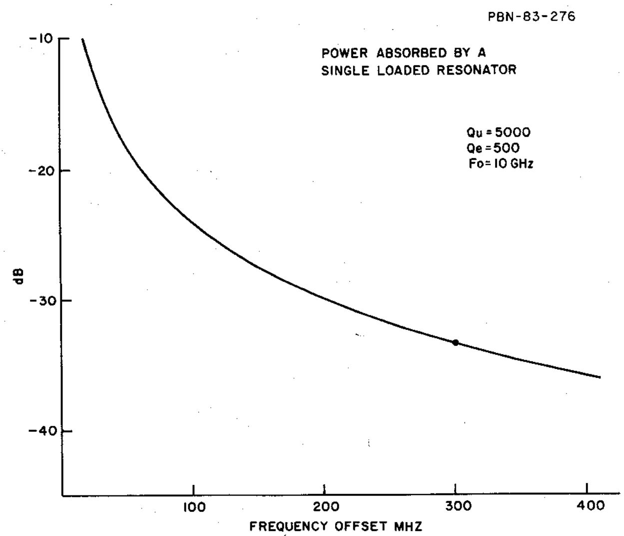

FIG. 2. Power absorbed by singly-loaded resonator as function of frequency offset.

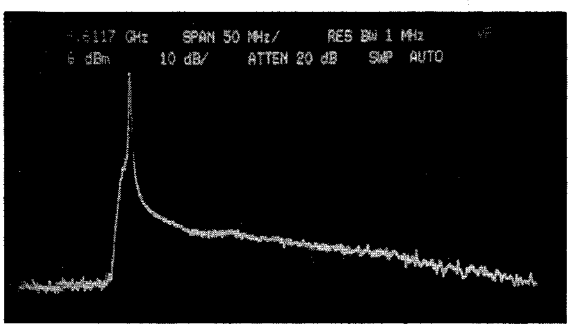

FIG. 3. Energy distribution in the frequency domain observed with a frequency-stepped YIG resonator.

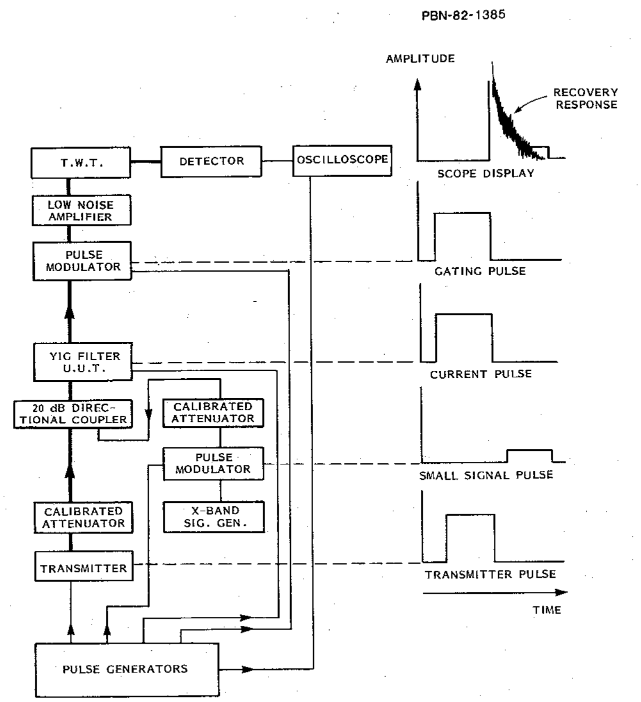

FIG. 4A. Block diagram of microwave system used for measurements on frequency-stepped YIG filters.

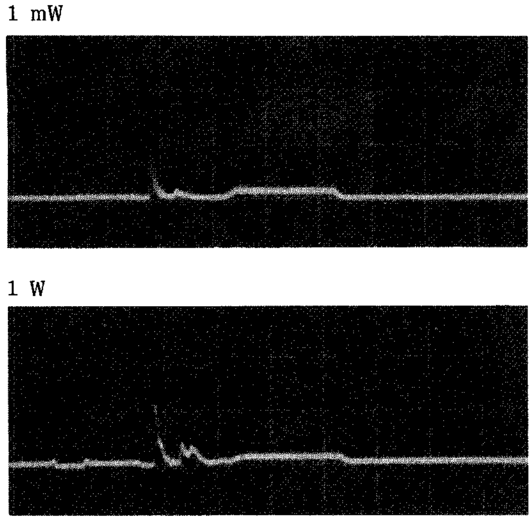

FIG. 4B. Small signal visibility close in to transmitter pulse. Horizontal scale: 200 nsec per division.

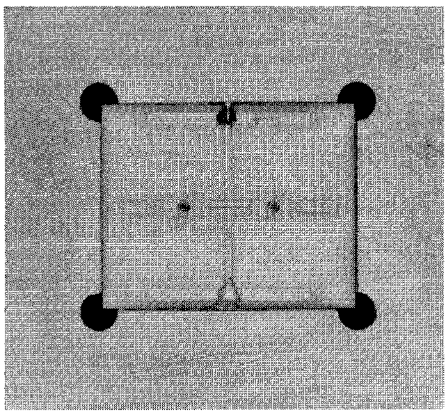

FIG. 5A. Interstage transmission line of a two-stage frequency-stepped filter. In this design the interstage line is also used as a single-turn coil for generating the magnetic field which frequency-steps the filter.

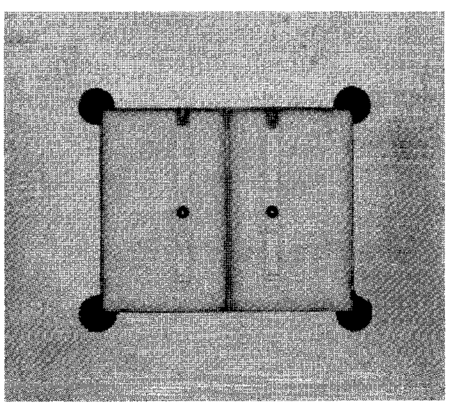

FIG. 5B. Same filter as in Fig. 5A viewed from the opposite side, showing input and output transmission lines.

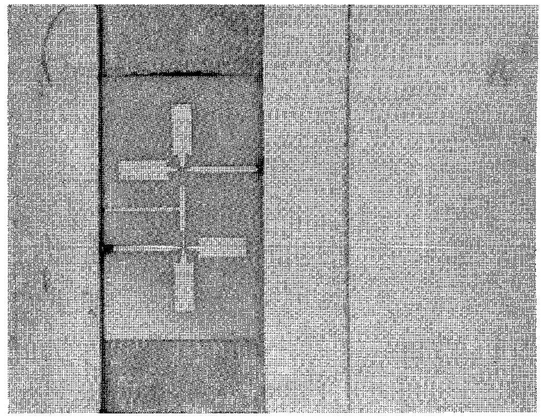

FIG. 6A. Rf coupling structure of another frequency-stepped filter. In this design, input line, output line and interstage line are formed on the same side of a dielectric substrate.

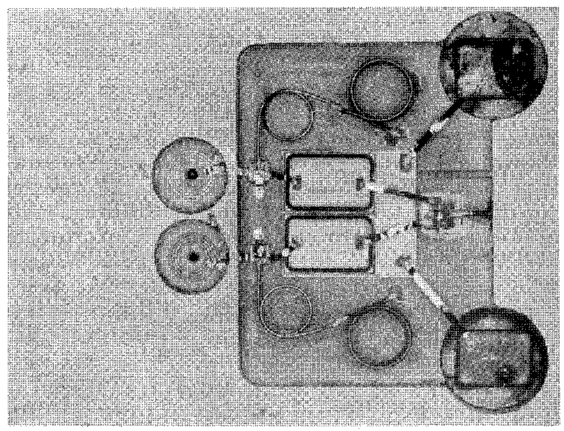

FIG. 6B. Same filter as in Fig. 6A viewed from opposite side, showing 4-turn coils, transistors and damping circuits.

The interstage rf bifurcated coupling lines are also used as single turn coils to create the desired localized A.C. magnetic fields. RF decoupled terminals for these coils are of a conventional circuit design using $\lambda/4$ stubs. In this particular configuration pulse current directions drive resonators in opposite frequency directions.

The second dual stage filter (Fig. 6) is a similar rf design on a single substrate. Rf couplings by single line cross-over structures are made through ground plane apertures. Spheres are located concentric to apertures and touching the substrate bottom surface. The A.C. magnetic fields are produced by current flow through four-turn planar coils formed on 7 mil circular substrates. Each coil is driven by a power MOSFET chip switched by a voltage pulse from an external supply. Again, resonators are frequency stepped in opposite directions.

References

1. J. Clark and J. Brown, "The gyromagnetic coupling limiter at C-band," IRE Trans. MTT-10, pp. 84-85 (Jan. 1962).

2. H. Suhl, "The theory of ferromagnetic resonance at high signal power," J. Phys. Chem. Solids, Vol. 1, p. 209 (1957).

3. E. Schloemann, "Ferromagnetic resonance at high power levels," Raytheon Tech. Report R-48 (Oct. 1959).