VIII-6 WIDEBAND PULSE COMPRESSION USING MAGNETOELASTIC WAVES IN YIG RODS

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I. Introduction

Single crystal YIG dispersive delay lines show great promise as pulse compression filters. Very large bandwidths can be obtained by using magnetoelastic waves in axially magnetized YIG rods. Bandwidths up to 250 MHz have recently been reported in the literature.[1-3].

The dispersion of a YIG rod is nonlinear, but it can be linearized by suitably shaping the internal magnetic field. By bonding YAG quarter-wave plates to the ends of the YIG rod, the filter can be changed from a reflection mode to a transmission mode of operation, with a substantial reduction of direct undelayed leakage. Theoretical and experimental results on these aspects of magnetoelastic pulse compression filters will be described in this paper.

II. Magnetoelastic Wave Propagation

The propagation characteristics of magnetoelastic waves in an axially magnetized YIG rod are well known.[4] The waves travel from a "turning point", where generation and detection take place, to the nearer end face and back. The turning point moves from the middle of the rod toward the end with decreasing frequency; hence, the delay time decreases with decreasing frequency at a fixed field.

The relation between the delay time and the frequency ω is given by:

$$T = L\left[\frac{1-x_T}{c_t} + \int_{x_C}^{x_T} \frac{dx}{2\gamma D^{1/2}\left[\frac{\omega}{\gamma} - H_i(x)\right]^{1/2}}\right] \qquad (1)$$

where the first part is the elastic wave contribution and the second part represents the spin wave contribution. $H_i(x)$ is the internal field in the rod equal to the applied magnetic field H_0 reduced by the demagnetizing field $H_d(x)$. $H_d(x)$ is given as a function of the normalized coordinate $x = z/L$ by the well-known Sommerfeld relation.[5] The positions of the turning point x_T and the crossover point x_C are determined by

$$H_d(x) = H_0 - \frac{\omega}{\gamma} + a \qquad (2)$$

where $a = 0$ for $x = x_T$ and $a = D\,\omega^2/c_t^2$ for $x = x_C$. For YIG, $D = 5.17 \times 10^{-9}$ Oe cm^2, $c_t = 3.84 \times 10^5$ cm/s, and $\gamma = 2.8$ MHz/Oe s. A plot of T vs ω taken with H = 1030 Oe is shown in Fig. 1. It is immediately obvious that the dispersion is nonlinear. It varies from 1000 MHz/μs at short delay to 40 MHz/μs at long delay. Thus, given a particular input pulse, a large variation in dispersion is possible, and the choice depends on the required time – bandwidth product.

III. Linearization of the Dispersion

In many pulse compression systems, it is desirable to linearize the dispersion, for instance when complementary filters are required or when large Doppler shifts are expected.

According to Auld and Strauss,[6] the required variation of turning point for a prescribed delay dependence is given by:

$$y = \frac{1}{I(h)} \int_0^h I(h)\ B(h)dh \quad , \tag{3}$$

where $I(h) = \exp\left[\int \Omega^{-1} dh\right]$, $B(h) = c_t T/2\Omega$, $\Omega = \omega/\gamma = H_e + h$. Here y is the distance of the turning point from the end of the rod, H_e is the internal field strength at the end of the rod, and h is the difference between the internal field at the turning point y and that at the rod end, $h = H_i(y) - H_e$. For linear dispersion, we impose the condition $T = T_o + a(\Omega - \Omega_o)$. Evaluating I(h) gives $I(h) = \exp \int dh/(H_e + h) = \exp \ln(H_e + h) = H_e + h$. Thus,

$$y = (H_e + h)^{-1} \int_0^h (H_e + h) \frac{c_t}{2\Omega} \left[T_o + a(\Omega - \Omega_o)\right] dh$$

$$= (H_e + h)^{-1} h \frac{c_t a}{2} \left[H_e + \frac{1}{2}h + \frac{1}{a}(T_o - a\Omega_o)\right] \tag{4}$$

$$= \frac{c_t a}{2} \left(\frac{H_e' + \frac{1}{2}h}{H_e + h}\right) h \quad ,$$

where $H_e' = H_e + \frac{1}{a}(T_o - a\Omega_o)$ is a constant for a specified operating frequency and delay slope. Inversion of this result, together with the requirement that $h = 0$ at the end of the rod, yields the field distribution for linear delay dispersion:

$$h(z) = \left(\frac{2z}{c_t a} - H_e'\right) + \left[\left(H_e' - \frac{2z}{c_t a}\right)^2 + \frac{4zH_e}{c_t a}\right]^{1/2} \quad , \tag{5}$$

where z is now the distance from the rod end. This is a relatively simple field distribution, consisting primarily of a linear variation with distance plus a parabolic component. As an example, consider the case for which $T_o = 0$ and $\Omega_o = H_e$. Then the required field reduces to

$$h = H_i(z) - H_e = \frac{2z}{c_t a} + \left[\left(\frac{2z}{c_t a}\right)^2 + \left(\frac{2z}{c_t a}\right) 2H_e\right]^{1/2} \quad . \tag{6}$$

If we consider a linear dispersion of 100 MHz/μs, then $a = 2.8 \times 10^{-8}$. For $H_e = \Omega_0$ at a frequency of 2 GHz: $H_e = 715$ Oe. Substituting these values in Eq. (6) gives the required field distribution:

$$H_i(z) - H_e = 186z + \left[3.46 \times 10^4 z^2 + 2.66 \times 10^5 z\right]^{1/2} \quad .$$

This is plotted in Fig. 2.

IV. Experimental Arrangement

A block diagram of the experimental arrangement is shown in Fig. 3. If the BWO is swept by a linear voltage sweep, its frequency is nonlinear and matches approximately the dispersion of the magnetoelastic waves. This arrangement has been found adequate for bandwidths up to 150 MHz.

For higher bandwidths, a more accurate sweep control by means of a tapped delay line waveform generator is required. For operation in a reflection mode of operation, the two orthogonal fine wires at the end face of the rod provide input and output coupling with 36 dB isolation. A compressed pulse obtained at L band with this arrangement is shown in Fig. 4. Insertion loss was 11 dB; thus the compressed echo was 25 dB above the direct leakage. Input pulsewidth was 1μs, swept over 150 MHz, resulting in a compressed pulse of 7 ns.

V. Transmission Mode of Operation

It has recently been reported that YIG rods can be operated in a transmission mode rather than in the usual reflection mode by optical-contact bonding of quarter-wave plates to both ends of the rod.[7] For certain applications this is a distinct advantage, mainly because the undelayed direct feedthrough can be suppressed to a much higher degree than in a crossed wire configuration. The purpose of the YAG quarter-wave plates is to reverse the sense of circular polarization of the elastic waves on reflection at the end surface, so that no interaction with the magnetic system is possible and the elastic waves propagate through the entire length of the rod. At the far end, the YAG plate reverses the sense of circular polarization back to that required for interaction with the spin waves, and detection is then accomplished at the far end turning point. The result of a pulse compression experiment using this YAG-YIG-YAG assembly is shown in Fig. 5. The undelayed direct leakage at the output wire was 72 dB below the input pulse and the insertion loss was 28 dB at $\sim 5\mu$s delay; thus the compressed pulse was 44 dB above the undelayed leakage.

The frequency was swept from 1075 to 925 MHz and input pulse was 1μs; thus a compression ratio of 150 was obtained.

VI. Conclusions

Magnetoelastic waves in axially magnetized YIG rods provide a very attractive means of obtaining large bandwidth pulse compression. Bandwidths of up to 250 MHz have been reported and a two- or three-fold increase in bandwidth is technically feasible.

REFERENCES

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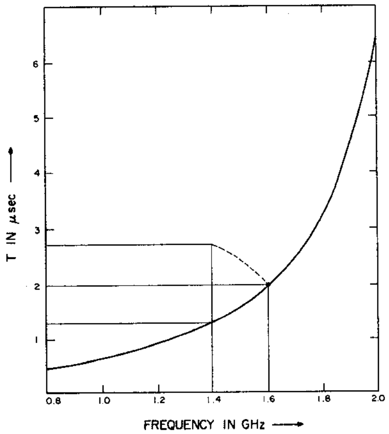

FIG. 1 - Delay time T vs frequency at H_0 : 1030 Oe for an axially magnetized YIG rod with aspect ratio D/L: 0.3. The dotted line shows the frequency sweep that is required if a 0.7 μs-wide input signal swept from 1.6 to 1.4 GHz is to be compressed to 5 ns at 2 μs delay.

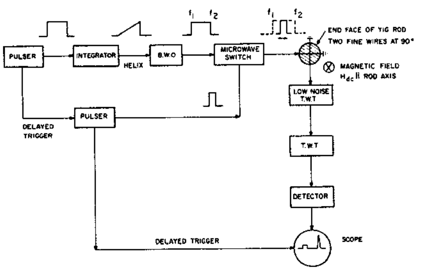

FIG. 3 - Block diagram of equipment used for pulse compression experiments.

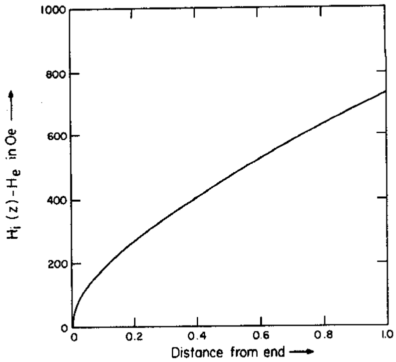

FIG. 2 - Internal magnetic field required to obtain linear dispersion 100 MHz/μs in an axially magnetized YIG rod.

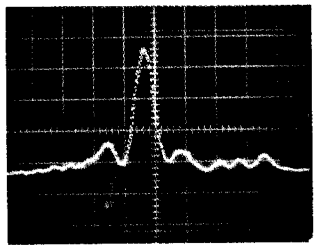

FIG. 4 - Compressed magnetoelastic wave echo in reflection mode.
Frequency: 1125 to 975 MHz
Input pulse: 0.8 us (at 2.1 us delay)
Compressed pulsewidth (4 dB points) 7 ns

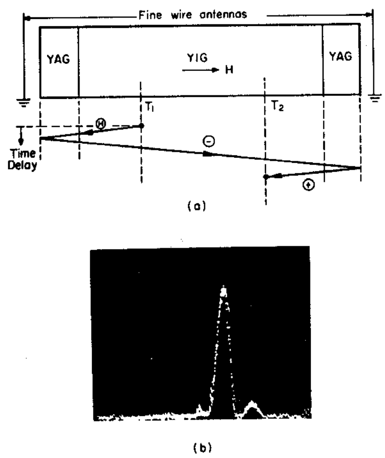

FIG. 5 - (a) YAG-YIG-YAG assembly and schematic representation of magnetoelastic wave propagation
(b) Compressed pulse in transmission mode of operation Frequency: 1075 to 925 MHz, H : 750 Oe
Input pulsewidth: 1 μs
Compressed pulsewidth: 7 ns