VI-3. DELAY SPECTRA OF SINGLE CRYSTAL FERRIMAGNETICS WHEN LOADED BY POLYCRYSTALLINE FERRITES

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Magnetostatic, magnetoelastic and elastic wave propagation in magnetically saturated single crystal round and square cross-section rods of yttrium iron garnet (YIG), possessing non-ellipsoidal geometry, has been extensively studied. However, the resulting delay characteristics versus dc applied magnetic field and frequency are necessarily non-optimum for certain microwave applications. The object of this paper is to demonstrate the feasibility of polycrystalline ferrite loading for modifying and controlling magnetoelastic delay spectra. This technique has the advantage that sample geometry, which determines the internal magnetostatic field configuration, can be adjusted simply and cheaply without disturbing the single crystal specimens in which the magnetoelastic propagation takes place. Further, if necessary, experiments can be conducted on a minimal volume of single crystal material. The discussion is restricted to the axially magnetized arrangements shown in Figure 1. More sophisticated geometries are currently under consideration. Figure 1 A depicts a single crystal ferrimagnetic round rod, of saturation magnetization $4\pi M_1$, loaded with a polycrystalline sleeve, of saturation magnetization $4\pi M_2$. Figure 1 B depicts a single crystal rod ($4\pi M_1$) backed by a polycrystalline ferrite ($4\pi M_2$) of identical cross-section.

Results of investigations made on the geometry pictured in Fig. 1 A are depicted in Figures 2 and 3, where the inserts represent plots of the normalized axial demagnetizing fields, $H_d/4\pi M_1$, with polycrystalline YIG loading and the following dimensions: $2L = 10$ mm, $a = 1.5$ mm, $b = 2.5$ mm. In Fig. 2, $2\ell = 1.27$ mm and $s = 2.5$ mm, while in Fig. 3, $2\ell = 3.5$ mm and $s = 0$. The principal plots in these figures depict the observed and theoretical one-port delay characteristics at room temperature and a frequency of 2800 MHz. Delay monotonically decreases with increasing applied magnetic field. Two spin-elastic branches generally exist separated by a gap in applied field. Two values of applied field can give rise to the same delay. Explanations for these gap regions can be made by applying the paraxial ray equations for magnetoelastic waves. Briefly, in the observed regions of propagation, for both geometries, the alternation of signs of the first and second derivatives of the axial demagnetizing field lead to a focussing action. In Fig. 3 (insert) points B and C correspond in first order theory to inflection points in the internal magnetostatic field, and in the region B - C the first derivative has the same sign, and the second derivative the opposite sign, to corresponding values in regions A - B and C - D. Theoretically, region B - C can lead to defocussing of magnetoelastic energy. The results shown in Fig. 2 can also be explained in this manner.

A number of experiments have been carried out at 3000 MHz also, with sleeves having a saturation magnetization of 3150 gauss. Besides the double branch behavior, it is commonly observed that the low field branch exhibits a constant delay over a field range of several hundred gauss. This is interpreted as arising from a large magnetostatic field gradient over a small axial region within the crystal.

Polycrystalline loading can conveniently be used to diagnose the regions of power flow for radial ($\pi/2$) magnetoelastic waves in axially magnetized discs. Figure 4 (A - E) shows the geometries employed, all dimensions being in millimeters. The shaded portions denote polycrystalline material. Single crystal geometries A and B both propagate $\pi/2$ magnetoelastic waves and in addition geometry B propagates axial magnetoelastic waves. By artificially thickening geometry A, with polycrystalline YIG, the axial mode is induced. However, the radial mode is then suppressed, indicating a concentration of energy for this mode close to the central plane of the sample. Reducing the saturation magnetization of the loading to 670 gauss moves the radial mode energy upward into the single crystal region, giving weak propagation.

The inherently large time-bandwidth product of magnetoelastic waves makes them attractive from the standpoint of compressing microwave pulses, providing secondary echoes can be suitably suppressed. For this application a linear dependence of delay time with frequency is desirable, implying a linear dependence of delay time with magnetic field at constant frequency. A constant magnetic field gradient throughout a significant axial region of the single crystal ferrimagnetic material is required. The arrangement of Fig. 1B, with $M_2 > M_1$, is useful for this purpose. By expanding the axial demagnetizing field as a polynomial in z about the plane end face of the single crystal, an expression is derived for eliminating the quadratic term. The appropriate loci (p, q) are shown in Figure 5, where $p = L/b$, $q = \ell/b$, and $\mu = M_2/(M_2 - M_1)$. The following parameters were used in the experiments:

$4\pi M_1$ = 1750 gauss	b = 1.5 mm
$4\pi M_2$ = 3150 gauss	ℓ = 0.81 mm
	L = 1.8 mm

The results are shown in Figure 6. The agreement between theory and practice at 2160 MHz for the delay-field slope, over a field range of 450 gauss, is good, although significant discrepancies occur at higher frequencies. Using precision alignment techniques an approximately exponential pulse train has been observed over a wide range of applied field. This has allowed the measurement of delay time by injecting long pulses and noting the frequency deviation between successive magnetoelastic resonances, while maintaining the applied field constant. The constant field gradient geometry is interesting, since the paraxial ray equations for magnetoelastic waves can be integrated analytically. Further, the one-dimensional differential equation for the spin wave magnetization can be solved. A correction term is obtained for the delay time formula previously given in the literature.

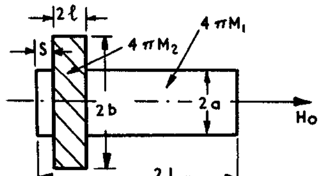


FIG. 1A.

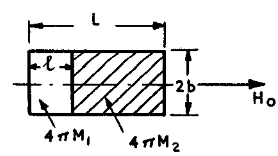
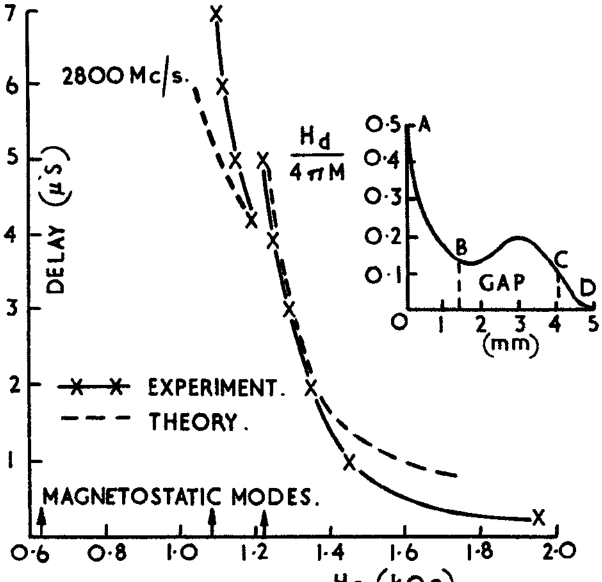
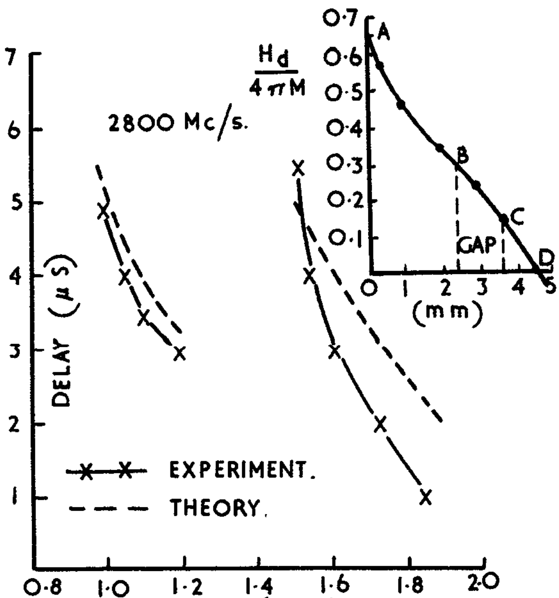


FIG. 1 B.



2800 Mc/s.
DELAY (μS)
$\frac{H_d}{4\pi M}$
A
B
C
D
GAP
(mm)
EXPERIMENT.
THEORY.
MAGNETOSTATIC MODES.
Ho (kOe)

FIG. 2.



2800 Mc/s.
DELAY (μ S)
$\frac{H_d}{4\pi M}$
A
B
C
D
GAP
(mm)
EXPERIMENT.
THEORY.
Ho(kOe)

FIG. 3.

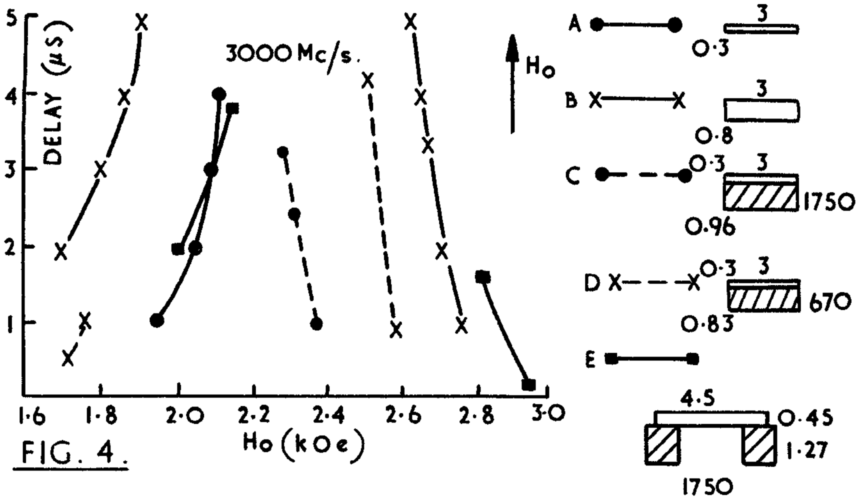


FIG. 4.

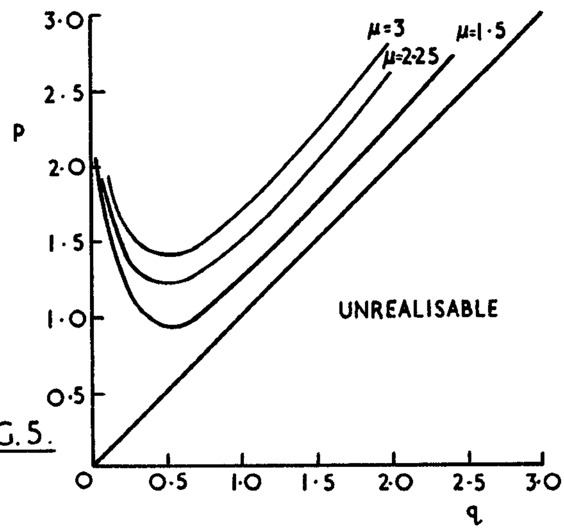


FIG. 5.

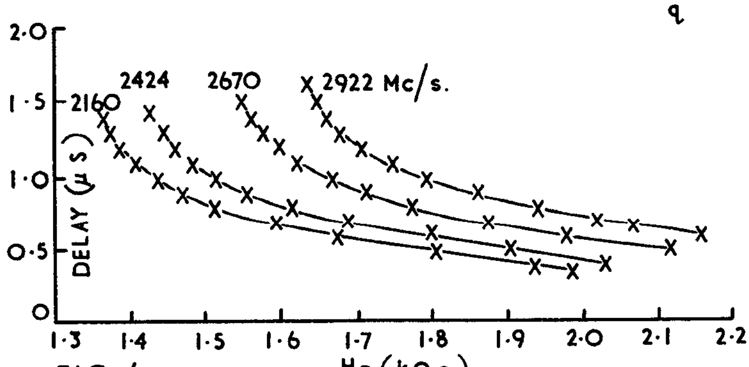


FIG. 6.