VIII-4 FREQUENCY MODULATION AND TRANSLATION WITH MAGNETO-ELASTIC WAVES IN YIG

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A magnetoelastic wave propagating in yttrium iron garnet (YIG) can be frequency translated or frequency modulated by pulsing the biasing magnetic field. Room temperature experiments of this kind are described here for a (100) rod of single crystal YIG, of 7.35 mm length and 2.94 mm diameter, axially biased into the magnetoelastic regime.[1] Spatially orthogonal shorted fine wire couplers are utilized for excitation and detection. A coil wound along the specimen permits the application of a pulse of magnitude δH to the biasing field, with rise time short compared with the relaxation of the magnetoelastic waves.

For the one port configuration it is convenient to consider five cases, according to the position of the wave packet when the field pulse is applied. These are shown in Fig. 1 as an outgoing spin wave region (1), a spin-acoustic region (2), an acoustic region (3), extending to the end face and back to the commencement of the incoming spin-acoustic region (4), and finally the incoming spin wave region (5).

Analysis[2] for the spin wave regions shows that pure frequency translations, given by $\delta\omega = \gamma\delta H$, occur. Figure 2 shows the results obtained by pulsing with $\delta H > 0$ in region 1 for an input frequency of 900 Mc/sec, at a biasing field of 585 gauss. Frequency determination was by retuning the local oscillator of a 5 Mc/sec wide superheterodyne receiver. Excellent rf pulse reproduction was achieved, providing the input signal was typically below −15 dBm, thus avoiding spin wave limiting. The narrow spatial extent of the rf pulse, typically 20μ, eliminates the need for extreme pulse field uniformity. The magnetoelastic delay changes by typically 100 nsec for a frequency translation of 250 Mc/sec. An important result is that, apart from conversion loss due to the finite rise time of the field pulse, upward translation leads to 'gain' and downward translation to "attenuation" in the ratio of output to input frequencies. This prediction was confirmed experimentally.

The qualitative behavior in region (2) for downward field pulsing, $\delta H < 0$, can be envisaged as follows. The leading edge (L) of the rf pulse, with time length T_p, receives no frequency shift but its output turning point, y_o, moves towards the rod center. This causes the leading edge round trip delay, T_L, to increase rapidly. The trailing edge (T) receives a downward frequency translation, as for spin waves, but its turning point remains fixed, causing the appropriate round trip delay, T_T, to decrease slightly. As the field pulse δH is increased the differential delay $T_L - T_T$ becomes larger and the output pulse, of length $T_{out} = |T_p - (T_L - T_T)|$, is initially compressed. This is followed by inversion, as T_{out} passes through zero, and eventually expansion, when $T_L - T_T$ becomes greater than $2T_p$. The expression given for T_{out} is only approximate near the point of inversion, where the pulse length passes through a minimum 3dB width[3] equal to $(\delta f)^{-1}$, where δf is the induced frequency modulation, rather than zero. For $\delta H > 0$ only limited expansion occurs. An approximate theory for this model has been developed, using a parabolic approximation to the internal field profile. The results are depicted in Fig. 3, where $B = H(y_i) - H(L/2)$ denotes the magnetostatic field difference from the initial turning point, y_i, to the rod center, $y = L/2$. Figure 4 gives oscillograms of the compression-expansion sequence. The upper traces show the amplitude of the downward field pulse on a vertical scale of 47 Oe per large scale division, the lower traces depict the output rf pulse. The operating frequency was 1230 Mc/sec, the input rf pulse length 0.2μsec, and the initial magnetoelastic delay 1.2 μsec. The normal echo is shown in Fig. 4a, the compressed echo in Fig. 4b and the inverted and expanded echo in Fig. 4c, all on a time scale of 50 nsec per large scale division. The compressed pulse is displayed again in Fig. 4d on a time scale of 10 nsec per large scale division. The 3 dB width is 13 nsec and the side lobe levels are 10 dB down. It was found that the lower the initial magnetoelastic delay the greater the compression ratio available. However, the optimum input pulse length was always about 0.2μsec. Further the time position of the field pulse was more crucial than its magnitude. Time-bandwidth products up to 35 were achieved. These observations were taken with no tuning at the rf output port and using a low noise octave bandwidth 55 dB gain TWT chain followed by a broadband crystal detector, with a response time of 1 nsec. Experimentally, field pulsing in region (4) is similar to pulsing in region (2) except that compression occurs for $\delta H > 0$, and expansion for $\delta H < 0$.

In region (3) the field pulse does not induce a frequency shift, unless δH is positive and of large amplitude. However, there is a change in round trip delay, T, since the output turning point, y_o, is shifted; T decreases for $\delta H > 0$ and increases for $\delta H < 0$. If the field pulse magnitude is negative and greater than B, the magnetostatic field difference from the initial turning point to the rod center, the output turning point is removed from the rod. The rod then becomes a pure shear wave line, with single transit time, T_a. Application of a second field pulse with the same magnitude but opposite sign at a subsequent time nT_a, where 'n' is an integer, allows an rf echo to be recovered in either a one port ('n' even) or two port ('n' odd) configuration. Experiments confirm these predictions, as L band rf pulses have been gated easily after ten round trips, corresponding to a maximum delay of 45μsec, with an initial magnetoelastic delay of 7μsec. The amount of delay was limited only by the drooping of the current step applied to the pulsing coil. Further, by modifying the biasing field and adjusting the timing of the first field pulse, whilst maintaining the input frequency constant, continuously variable delay over the range 1-45μ sec was achieved.

Double field pulse techniques have been applied in other regimes. By upward pulsing in region (2) followed by downward pulsing in region (4), a double expansion is affected. By pulsing down for compression in region (2) and up in region (4), a double compression effect is observed.

It is believed that the effects described here would be useful for: (1) synthesis of swept frequency pulses for matched filter testing of conventional magnetoelastic pulse compressors, and (2) construction of broadband two port delay lines with gating and wide variable delay.

Finally, it should be pointed out that the use of an abrupt field pulse is not essential. For instance an increasing field ramp applied throughout a spin wave region leads to pulse compression, and eventually inversion with expansion. This phenomena has also been observed.

References

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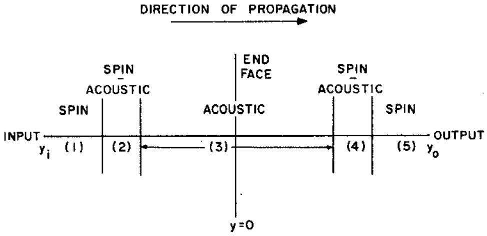
3. J.R. Klauder, A.C. Price, S. Darlington, and W.J. Albersheim, Bell System Tech. J. 39, 745 (1960).



UNFOLDED 1-DIMENSIONAL MAGNETOELASTIC DELAY LINE

FIG. 1

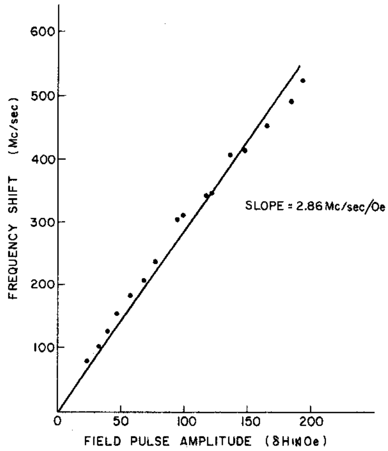
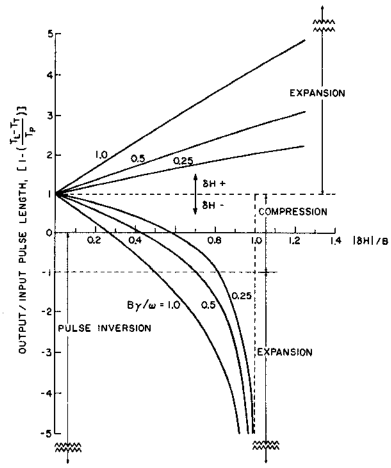
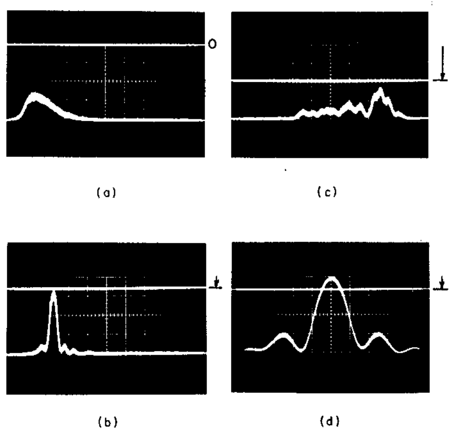


FIG. 2



OUTPUT/INPUT PULSE LENGTH vs |δH|/B WITH Bγ/ω AS PARAMETER

FIG. 3



OSCILLOGRAMS OF COMPRESSION-EXPANSION FOR PULSING DOWN IN REGION 2

TIME SCALE: 50 nsec PER LARGE DIVISION IN (a), (b) & (c)
10 nsec PER LARGE DIVISION IN (d)

FIG. 4