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Magnetoelastic Rayleigh Wave Convolver

William P. Robbins
University of Minnesota

Mark S. Lundstrom
University of Minnesota, lundstro@purdue.edu

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William P. Robbins and Mark S. Lundstrom

Department of Electrical Engineering, University of Minnesota, Minneapolis, Minnesota 55455
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An epoxy-bonded $LiNbO_3$-YIG-$LiNbO_3$ composite structure has been constructed and operated as a magnetoelastic Rayleigh wave convolver with 50-MHz input signals. The acoustic signals were propagated on a (110) YIG surface and the convolution characteristics were studied as a function of the magnitude and direction of the applied magnetic field. Nonuniform demagnetizing fields limited convolution pulses to less than 1.5 μsec duration. Relatively efficient operation was observed corresponding to an internal efficiency F_{int} of −53 dBm.

Little attention has been given to the possible use of magnetoelastic surface waves for convolution. Bulk magnetoelastic waves possess the highly nonlinear characteristics required for efficient convolution and on this basis it might be expected that the same conditions hold for surface magnetoelastic waves. But theoretical calculations by Parekh and Bertoni[1] and confirming experimental measurements by Daniel[2] and others[3,4] show that the magnetoelastic interaction for surface waves is substantially smaller and more lossy than for bulk waves. However, the interaction is still a strong one by the standards of piezoelectric interactions. Parekh and Bertoni estimate that the surface wave velocity changes by several percent in the vicinity of the cross-over field[1] and we have measured changes of 0.4% for a YIG sample biased with a parallel field.[3] Hence the nonlinearities in the magnetoelastic interaction may still be large enough to permit efficient convolvers to be built.

The epoxy-bonded $LiNbO_3$-YIG-$LiNbO_3$ composite structure shown in Fig. 1 was used to investigate the behavior of magnetoelastic Rayleigh waves and to assess their potential for convolution. The YIG portion of the structure was a 0.5×0.5×0.125-in. single-crystal YIG sample with a (110) plane as the propagating surface. The $LiNbO_3$ samples were *YZ* single crystals the same size as the YIG sample. The $LiNbO_3$ and YIG pieces were bonded together with Hysol 0151 epoxy using techniques described elsewhere.[5] The resultant bond widths were 0.8 and 2.5 μm. The interdigital transducers had a center frequency of 50 MHz, a bandwidth of 6 MHz, and were fabricated by the liftoff technique.

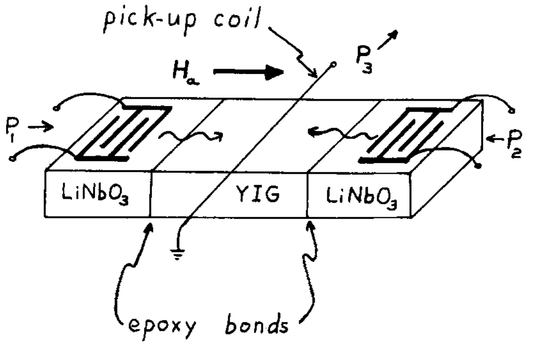


FIG. 1. Magnetoelastic Rayleigh wave convolver with perpendicular convolution pick-up coil and parallel magnetic field bias. P_1 and P_2 are the input signals and P_3 is the convolution output.

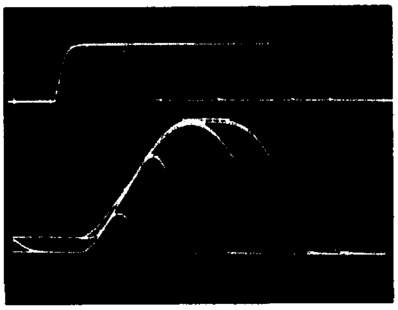
In zero magnetic field, the device had an insertion loss of 32 dB when operated as a tuned delay line. At large fields the insertion loss was 4 dB smaller. This variation is attributed to interactions with domain walls.[2] The remaining 28 dB of loss is composed of 19 dB transmission loss through the two epoxy bonds and 9 dB of loss (determined by impedance measurements) in the two interdigital transducers. Signal propagation was reciprocal for all field magnitudes and orientations examined.

The convolution of a series of variable-width 50-MHz pulses using the geometry of Fig. 1 is shown in Fig. 2. This convolution is observed over a narrow range of applied field values which appears to correspond to the internal field varying over the magnetoelastic bulk wave spectrum, in agreement with theory.[1] (Nonuniform internal fields cause the position in the sample where convolution occurs to be dependent on the applied field as described below which in turn makes this estimate difficult.) The largest convolution signal is observed at applied field values corresponding to the internal field at the cross-over value where the largest linear magnetoelastic effects are observed.[3,4]

The present device is limited to input pulse lengths of about 1.5 μsec or less because of spatially nonuniform demagnetizing fields. Pulses whose duration is longer than the propagation time across the interaction region where the internal field is at the cross-over value produce a saturation or flattening of the signal such as is shown in Fig. 2. However, the effect can be used to estimate the length of the interaction region when P_1 and P_2 are timed to enter the interaction region simul-

Input

Convolution



0.5 μsec/div.

FIG. 2. Behavior of the convolution output signal as a function of input pulsewidth. The leading and trailing slopes of the convolution triangle differ because the input signals do not enter the interaction region simultaneously due to asymmetric placement of the input transducers with respect to the YIG.

TABLE I. Summary of convolver performance for various field and coil orientations. Input power $P_1=P_2=1.7$ W for all configurations and pulse durations set for maximum convolution signal magnitude without producing saturation. Variations in the coupling to the convolution signal between the different coils is estimated to be less than 4 dB.

Field direction	Coil orientation	Relative convolution magnitude P_3/P_1 (dB)	Applied field magnitude H_a (G)
parallel	perpendicular	−70	263
	parallel	−82	250
perpendicular	perpendicular	−96	700
	parallel	−95	1450
$\perp k$, ∥ YIG	perpendicular	−99	125
(Love bias)	parallel	−87	150
20 °K, ∥ YIG	perpendicular	−59	250
	parallel	−67	250

taneously. For example, the interaction length for the bias arrangement of Fig. 1 is 0.4 cm.

The nonuniform field also means that the position of the interaction region in the sample varies with the magnitude of the applied field. In Fig. 1 the demagnetizing factor is smaller at the center of the sample than at the ends. Hence as the applied field is increased, the interaction region first appears at the sample center. Further increases in H_a cause the interaction region to split into two separate regions both of which move towards their respective ends of the sample and eventually disappear. Evidence of this behavior is furnished by the fact that two convolution pulses are observed when P_1 is a single pulse and P_2 is a properly timed double pulse. Proper timing requires that P_1 and the first pulse in P_2 overlap in one interaction region and P_1 and the second pulse in P_2 overlap in the second region.

A convolution signal 70 dB down from the 1.7-W 1.5-μsec duration input signal ($P_1=P_2$) was observed using the parallel bias geometry of Fig. 1 and also using the perpendicular pick-up coil shown in Fig. 1. Rotating the coil by 90° so that its plane was parallel to the YIG surface decreased the convolution magnitude by 12 dB. This indicates that the nonlinear magnetization component parallel to the applied field is the largest component. Decreasing the area of the parallel pick-up coil also improved the convolution magnitude because the smaller coil intercepted more of the total flux generated by the nonlinear interaction, i.e., the coil fill factor was larger. This is also further evidence of the limited spatial extent of interaction region.

The magnitude of the convolution signal for other field and coil orientations is summarized in Table I. Little change in the convolution magnitude was noted as the field was rotated from parallel to perpendicular bias in the sagittal plane until about 20° from perpendicular where the signal level dropped abruptly. No significant change was noted as the field was rotated from parallel to the YIG surface and perpendicular to the wave vector k to perpendicular to k and in the sagittal plane. As the field was rotated in the plane of the YIG from parallel bias, a sharp maximum in the convolution magnitude was noted when H_a and k were at an angle of about 20°.

The observation of a weak convolution signal with the Love bias was an unexpected result because the linearized equations of motion do not have any magnetoelastic coupling terms. Moreover, the field at which the convolution is observed does not correspond to the internal field being at the cross-over point for the 50-MHz input signals. Linear delay line measurements with the same bias arrangement and at the same field show a substantial change in the surface wave velocity. This behavior is attributed to the morphic effect where the elastic constants of the material change in magnitude because of lattice distortions caused by magnetostrictive coupling to changes in the saturation magnetization direction.[4,6]

The best result was obtained for the 20° bias listed in Table I where the convolution was 59 dB down from the input signal. This corresponds to a bilinearity factor F_T ($F_T=P_3/P_1P_2$) of −91 dBm. The corresponding internal bilinearity factor F_{int} is −53 dBm or an insertion loss $P_{3int}/P_{1int}=-35$ dB. The difference between F_{int} and F_T is the 28-dB loss of the input transducers and an estimated 10-dB loss in the output transducer due to impedance mismatch and a small fill factor for the pick-up coil.

In spite of its present limitations with respect to input pulse time duration, the magnetoelastic surface wave convolver is a viable device. Although its F_{int} is 20–30 dB poorer than the $LiNbO_3$-semiconductor convolver ($F_{int}=-30$ dBm),[7] it is 20–30 dB better than the piezoelectric convolver by itself ($F_{int}=-80$ dBm).[7] Investigations of this interaction in other materials and crystalline orientations may reveal stronger nonlinearities which would then allow improved convolver performance. Improvements in the internal field uniformity are possible either through field shaping by means of external magnetic shunts or by shaping or the YIG itself, both of which would permit longer duration input signals to be convolved.

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[1]J.P. Parekh and H.L. Bertoni, J. Appl. Phys. **45**, 434 (1974); **45**, 1860 (1974).
[2]M.P. Daniel, J. Appl. Phys. **44**, 1404 (1973).
[3]M.S. Lundstrom and W.P. Robbins, Ultrasonics Symposium, Milwaukee, Wisconsin, 1974 (unpublished).
[4]M.S. Lundstrom, M.S. thesis (University of Minnesota, 1974) (unpublished).
[5]M.T. Wauk and R.L. Zimmerman, Electron. Lett. **8**, 439 (1972).
[6]B.A. Auld, Proc. IEEE **53**, 1517 (1965).
[7]G.S. Kino, *Workshop on Acoustical Micro-electronics* (Stanford University, Stanford, California, 1973), p. 51.