To be presented at Intermag 2018, April 26, 2018, Singapore.

TITLE: A Magneto-elastic Correlator Using Acoustic Wave Pumping of Spin Waves

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ABSTRACT BODY:

Digest Body: The group velocity of both acoustic waves and spin waves in crystals are orders of magnitude less than those of electromagnetic waves. As a result, complex analog signal processing tasks that span multiple periods of a signal can be implemented more compactly with acoustic or spin waves than with electromagnetic waves. Acoustic wave devices have thus become common in RF communications circuits, realizing complex linear filter functions in a compact and efficient manner. Although spin-wave-based devices could, in principle, perform many of the same functions as acoustic wave devices, the much higher losses and non-linear effects have limited the practical application of spin wave signal processors. However, we propose that for *nonlinear* signal processing functions, such as signal correlation, the combination of acoustic and spin wave signals in a single device may prove advantageous.

We have developed a magneto-elastic device that exploits the nonlinear interactions between acoustic waves and spin waves to implement a microwave signal correlator. The device, illustrated schematically in Fig. 1a, uses an acoustic wave signal generated by a piezoelectric transducer to parametrically pump [1-3] a signal spin wave launched into a thin-film yttrium-iron-garnet (YIG) waveguide by an antenna. The resulting idler spin wave is picked up by an output antenna. The frequencies of the three waves are related $f_p = f_s + f_i$. In our experiments, the acoustic pump signal is at a frequency of f_p=2.4 GHz while the signal and idler spin wave frequencies, f_s and f_i, are a few MHz above and below 1.2 GHz.

It can be shown that if the microwave input signal and pump signal are modulated with signals S(t) and P(t) respectively, the generated idler signal is modulated by the combination of the two signals as $I(t)=\int_0^{t_o} S(2\tau-t)P(\tau)\, d\tau$, thus implementing a signal correlator. The correlation time window, t_o, depends on the length of time that the spin wave transits the pumping region. The correlation signal processing is used to increase the signal-to-noise ratio of weak signals in a presence of an interference. In our proposed scheme the weak signal is used to generate spin-waves via the input spin-wave transducer, while the “reference” code is applied to the pumping acoustic transducer. We created a theoretical formalism, which allows us to predict the characteristics of the output idler signal taking into account the features of the magneto-elastic parametric interactions, magnetic damping and the non-linearities in spin-waves associated with the pumping process. As an example we calculate the distribution of the spin-wave amplitude under the transducer for two orthogonal Walsh codes, while the pumping signal is modulated with one these codes. Fig. 2a demonstrate the distribution of two “signal” spin-waves, while Fig.2b shows the corresponding two “idler” spin-waves under the influence of the the pumping signal. Our simulations show, that i) the output idler power is enhanced when the signal spin-wave code matches the reference and suppressed otherwise, ii) the non-linearity introduced by a relative high pumping amplitude does not spoil the correlation

process, and iii) the spin-wave damping does not spoil the correlation processing.
We have fabricated such a device, and sample results of its operation with a continuous pump are shown in Fig. 1b. The input microwave pulse of duration t_s = 30 ns on the signal channel generates an idler pulse that appears after some delay at the output. Since the pump is continuous, the output spans a time $t_s + t_o$, where t_o is approximately 200 ns, the time required for the pulse to traverse the 2 mm long device. We are currently implementing the ability to modulate the pump signal as well, so that the convolution of two signals, such as in Fig 2, can be demonstrated.
Such a signal correlator could be used to great advantage at the input to a code division multiple access (CDMA) communications receiver, such as a cellular telephone, to de-correlate the incoming code sequence in the analog domain. Shifting this function to the analog domain could result in significant power savings and may improve the receiver's resilience to interfering signals.

References: [1] P. Chowdhury, A. Jander, and P. Dhagat, *"Nondegenerate Parametric Pumping of Spin Waves by Acoustic Waves,"* IEEE Magnetics Letters, v. 8, 3108204, (2017); doi: 10.1109/LMAG.2017.2737962.
[2] P. Chowdhury, P. Dhagat, and A. Jander, *"Parametric Amplification of Spin Waves Using Bulk Acoustic Waves,"* IEEE Transactions on Magnetics, v. 51, no. 11, 1300904, (2015); doi: 10.1109/TMAG.2015.2445791.
[3] I. Lisenkov, P. Dhagat and A. Jander, *"Inhomogeneous Parametric Pumping of Spin-waves by Acoustic Waves in an Yttrium-iron-garnet Film"*, presented at the IEEE International Magnetics Conference, Dublin, Ireland, Apr. 2017.

KEYWORDS: Correlator, Spin wave, Acoustic wave, Parametric pumping.

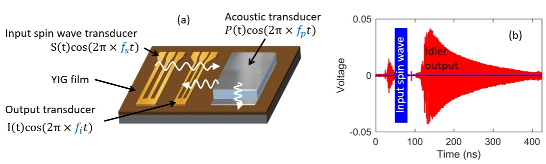

Fig.1. (a) Illustration of the magneto-elastic correlator. (b) Experimental results showing generation of a parametrically generated idler pulse from an input signal pulse.

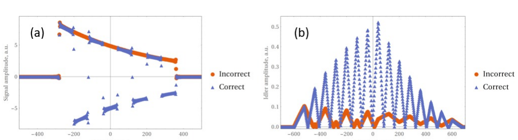

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IMAGE CAPTION:
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