SURFACE WAVE PARAMETRIC SIGNAL PROCESSING+

by

W. R. Shreve, G. S. Kino, and M. V. Luukkala

W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California 94305

New types of surface acoustic wave devices which utilize parametric interactions between surface acoustic waves to perform signal processing functions will be described. These devices can give real time convolution of two modulated rf signals. Similar devices can also be employed to time invert a modulated rf signal, so two devices can be used in combination to obtain the correlation between two rf signals[1-4]. As these are the basic signal processing functions required, the devices are also capable of performing fast Fourier transforms and pulse compression of chirped signals.

In the basic device, Rayleigh waves of velocity v and frequencies ω_1 and ω_2 and propagation constants $k_1 = \omega_1/v$ and $k_2 = \omega_2/v$ are excited by signals applied to interdigital transducers at opposite ends of a $LiNbO_3$ surface wave delay line. Because of nonlinearities in the substrate, a product signal is generated which has a frequency $\omega_3 = \omega_1 + \omega_2$ and propagation constant $k_3 = k_1 - k_2 = (\omega_1 - \omega_2)/v$. The electric field associated with this product signal can therefore be detected on an interdigital transducer with a finger pair spacing ℓ corresponding to $k_3\ell = 2\pi$. It will be seen then that the output transducer responds to any two input signals which have a difference in frequency $\omega_1 - \omega_2 = 2\pi v/\ell$. The amplitude of the output signal is proportional to the product of the input signals, and depends on an integration during the time when the signals overlap, i.e., an integration over the distance under the output transducer where the two signals overlap. Thus the system has the property that it takes the product and performs an integration which can be shown to be the convolution of the two input signal envelopes.

The device was first demonstrated using a metal film on each side of the substrate at the output transducer, with signals of identical input frequencies. Later, in order to increase the sensitivity, and to provide more bandwidth, a relatively coarse output transducer with a finger pair spacing of 100 μm was used to detect output signals in the range of 400 MHz-450 MHz, with input signals at approximately half this frequency.

With the original form of this device, it was necessary to use an output interdigital transducer spaced by an air gap from the substrate to inhibit scattering of surface waves to volume waves by the electrical shorting effect of the fingers of the output transducer. This air gap system has been replaced by a new type of device in which a layer of SiO_2 is used to separate the output transducer from the $LiNbO_3$ substrate. This reduces the Rayleigh wave scattering losses from 22 dB/cm to approximately 2 dB/cm, most of this loss being due to the silicon dioxide itself rather than the presence of the interdigital transducer. With this system the coupling of the product signal, which had a relatively long wavelength, was reduced at most by 1-2 dB, less than experimental error.

The system has also been used to obtain the time inversion of a modulated rf signal by applying an impulse of frequency at ω_3 to the center transducer while a signal of frequency ω_1 is propagating beneath it. This generates an idler at a frequency $\omega_2 = \omega_3 - \omega_1$ which is the time inversion of the input signal.

In all models the center transducer must be long enough to cover the entire interaction region. It is therefore highly capacitive, approximately 80 pF in this case. To match into it efficiently at frequencies on the order of 400 MHz, a strip line tuning circuit is used. A shorted strip line is connected across the transducer and its inductance is adjusted to resonate with the capacity of the transducer by varying the length of the strip line. A probe to the strip acts as a variable tap on the inductance. Using this system with 20 dBm input power levels, the peak output power was -47 dBm for one centimeter of interaction. This means that a device with a two centimeter interaction region and one watt input levels can give a .008 milliwatt output signal. Because of losses in the interdigital fingers, the output tuning had a low Q and did not limit the bandwidth of the system; this bandwidth was limited only by the bandwidth of the seven finger pair input transducers to approximately 30 MHz. Thus the time-bandwidth product of the present devices is approximately 180.

A system of this type with two different input transducers designed to have center frequencies at 200 MHz and 230 MHz, respectively, was used to observe the matched filter response of two coded signals. The use of amplitude modulated digital codes has produced results in agreement with theoretical predictions. We have also tested phase modulated Barker codes up to 13 bits, and obtained results in good agreement with theory.

At Stanford we have a number of experiments in progress to increase the output power by making use of the electric field nonlinearity associated with the carriers in a semiconductor rather than that associated with the acoustic medium. In our experiments we deposit a thin film semiconductor on the substrate in the region where the center transducer would normally be placed. Because the voltage developed across the depletion layer of a semiconductor is proportional to the square of the field normal to its surface, its characteristics are highly nonlinear. Hence this technique would be expected to strengthen the product signal. Preliminary results using a 0.5 μ layer of InSb and a solid plate center electrode ($k_1 = k_2$, $k_3 = 0$) indicate the output power is increased by 11 dB from the level with no semiconductor present.

References:

1. C. F. Quate, and R. B. Thompson, "Convolution and Correlation in Real Time with Nonlinear Acoustics," Appl. Phys. Letters 16, 494-496 (1970).

2. R. B. Thompson and C. F. Quate, "The Nonlinear Interaction of Microwave Electric Fields and Sounds in $LiNbO_3$," J. Appl. Phys. 42, 907-919 (1971).

3. L. O. Svaasand, "Interaction Between Elastic Surface Waves in Piezoelectric materials," Appl. Phys. Letters 15, 200-302 (1969).

4. M. V. Luukkala and G. S. Kino, "Convolution and Time Inversion Using Parametric Interactions of Acoustic Surface Waves," Appl. Phys. Letters 18, 393-394 (1971).

5. B. A. Auld, "Surface Wave Theory," Invited paper to be published in Proceedings of the 1970 IEEE Ultrasonics Sympoisum, Oct. 1971.

+ Paper based on work supported in part by the U.S. Army Electronics Command under