LARGE PULSE COMPRESSION RATIO OBTAINED WITH NONLINEAR INTERACTION OF BULK ACOUSTIC WAVES IN $LiNbO_3$

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Abstract

We report here on increased bandwidth in bulk wave parametric convolvers, and demonstrate a new approach to cancellation of the inherent signal distortion in time inverters. A 6 ns compressed pulse has been generated in the convolver by autoconvolution of a 7 µs V-FM chirp signal (center frequency of 1.2 GHz), using the nonlinear interaction of longitudinal waves in $LiNbO_3$. Time inversion of microwave signals has been demonstrated with uniform output for signal lengths up to 5 µs, by compensating for the signal distortion resulting from delay line attenuation.

Much development is being done on acoustic wave devices which produce the convolution of two signals via a nonlinear interaction in a delay line. While most of this work uses surface acoustic waves, bulk wave devices are also of interest because of their potential for high operating frequencies and correspondingly high bandwidths. Early observations[1] demonstrated that convolution could be done in the gigahertz frequency range. In the present state of the art, the practical utilization of this device requires further developments in the convolver itself, and development of a suitable time-inversion device which will allow the convolver to function as a correlator.

With regard to the bulk wave convolver, the limitation on the bandwidth is found to be connected with the output circuit of the device. The required time-inversion function can also be accomplished in an identical device as a separate function. One of the principal problems with the time-inverted signal is the distortion which results from the basic attenuation of the acoustic signal in the delay line.

We report here on advances toward achieving sufficient bandwidth in the bulk wave convolver, and we demonstrate a new approach to cancellation of the basic signal distortion in the time inverter.

When appropriate microwave signals are introduced into opposite ends of a $LiNbO_3$ acoustic delay line, the resulting polarization current created by the nonlinear interaction of the so-called "input" and "reference" acoustic signals appears as a compressed pulse. In our continuing effort to compress 10 µs signals with 100 MHz bandwidths we have achieved compression of a 7 µs pulse to a width of 6 ns which implies a useable input time-bandwidth product of about 600. The pulse width ratio is twice the input time-bandwidth product because the "input" and "reference" both move with the acoustic velocity.

The device used for the pulse compression results in this paper (Fig. 1) is similar to one illustrated in an earlier publication.[2] Thin film zinc oxide transducers are used to generate the longitudinal acoustic waves which move in opposite directions along the 6.2 cm (2.447 inch) X-axis length of the $LiNbO_3$ delay line. The delay line has a 2.5 mm (0.100 inch) square cross section. The bandwidth of the delay line including amplifiers and matching networks can be readily estimated from the result shown in Fig. 2. This swept-frequency measurement was made by taking the gated output of a sweep oscillator (1.10 - 1.30 GHz), amplifying this signal with a traveling wave tube (TWT) and transmitting through the delay line including double stub tuners at each transducer for electrical matching and passband shaping. Finally, the delayed signal was amplified with another TWT, detected, and displayed. The amplitude ripple, mainly due to the TWT's, is less than 1 dB over a 100 MHz bandwidth. It should be noted that for the compression experiment, the second TWT was reversed so that signals could be applied to both ends of the delay line.

The significant difference between the current device and the one reported earlier is that the delay line is no longer clamped in a resonant cavity with a loop-coupled output, but it is now clamped between reentrant metal ridges crosswise in a 6.23 cm (2.447 inch) wide by 0.457 cm (0.180 inch) high waveguide. One end of the reduced-height waveguide is closed by a sliding short. The other end is flanged to a 28 cm taper to standard S-band waveguide. The result is a greatly reduced loaded Q and much wider bandwidth when compared to the loop coupled device.

For the pulse compression experiment, identical 7 µs V-FM chirps with adjustable bandwidths were applied to the "input" and "reference" acoustic ports.[3] The compressed output pulse was amplified with 2-4 GHz amplifiers, then rectified and observed with a sampling oscilloscope. The best result, shown in Fig. 3, was 6 ns wide at the 3 dB points, indicating an output bandwidth of about 160 MHz.

Further work has also been done on time-inversion[2] using the earlier loop-coupled device. By applying a short, high-power rf pulse across the crystal in the cavity, an acoustic wave propagating within the crystal can be reversed and will come out backwards in time (time-inverted) at the acoustic port. Even if the cavity shape is adjusted so that the resonant electric field distribution is uniform along the useful length of the crystal, the inverted signal will still be attenuated nonuniformly depending on how far the signal propagates in the crystal before recall. Figure 4 shows 7 dB variation in the inverted version of an originally flat pulse. (The inverted pulse is preceded by an incidental gating transient and leakage from the input signal.)

Because the time-inverted signal is attenuated exponentially within the delay line, one can compensate for this variation externally using a diode modulator which also has an inherent, exponential characteristic. By applying a linear current ramp, with the proper slope, to a PIN diode modulator in synchronization with the recall spike, the result shown in Fig. 5 was obtained. Here the output is flat like the input. Figure 5 shows an accurate time-inverted reproduction of the input whereas Fig. 4 does not. If we use time-inversion in conjunction with convolution to obtain correlation, then the time-inverted signal must be really accurate; else the correlation experiment will have unacceptable spurious sidelobes.

The time-inverting behavior of the device is further illustrated in the multiple exposure shown in Fig. 6. Here, the recall spike was left unchanged, and as the input pulse was moved forward, the inverted pulse moved backwards in time. Variable delay can be achieved by leaving the input fixed and moving the recall spike.

For the results shown, the modulator immediately followed the time-inverter. For optimum signal-to-noise ratio, an amplifier would be placed between the time-inverter and the modulator.

In addition to using the devices for V-FM pulse compression and time-inversion, a variety of digital signals has been processed.[4] This adaptability, the large pulse compression ratio, and the demonstrated compensation for attenuation in time-inversion make this an increasingly promising device.

References

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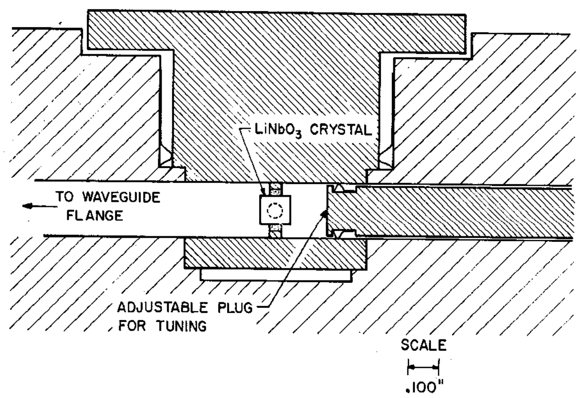

FIG. 1--Cross section view of pulse compression device. Dimensions are given in the text.

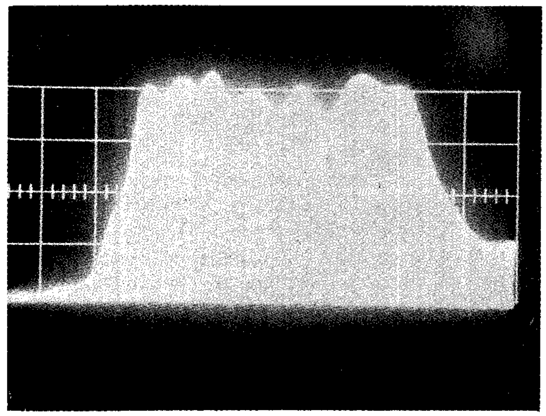

FIG. 2--Transmission through acoustic delay line and associated circuitry as a function of frequency from 1.10 to 1.30 GHz. Ripple on 100 MHz passband is 1 dB. Horizontal scale: 20 MHz/div.

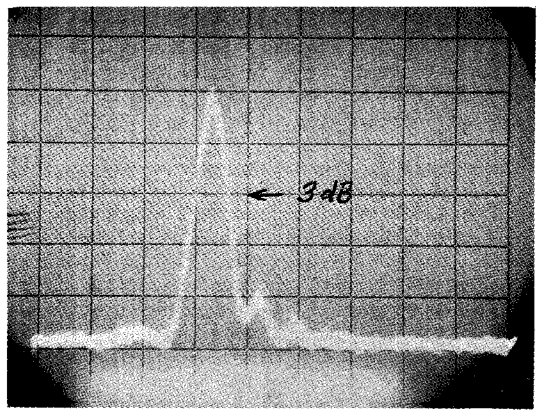

FIG. 3--Result of pulse compression (auto-convolution) of a 7 μs V-FM chirp. This output signal is 6 ns wide at the 3 dB points. Horizontal scale: 10 ns/div.

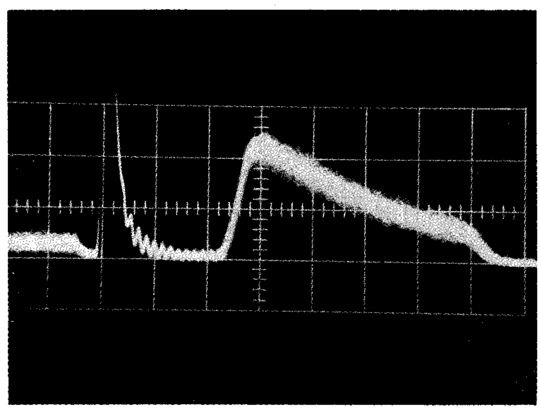

FIG. 4--Time inverted output from a uniform amplitude input (preceded by incidental gating transient and leakage from input pulse). There is an exponential variation of 7 dB across the pulse. Horizontal scale: 1 μs/div.

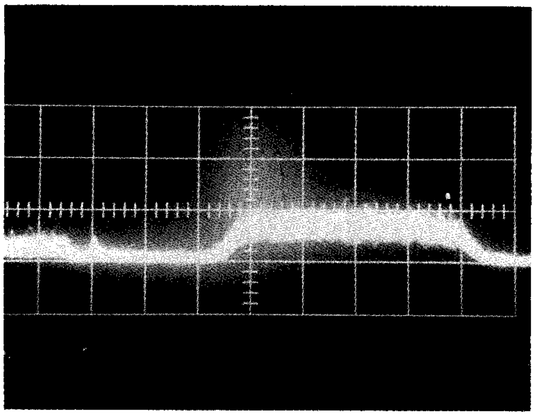

FIG. 5--Same as in Fig. 4 except that an external diode modulator has been used to compensate for the amplitude variation in the time-inverted signal.

FIG. 6--Multiple exposure shows the time-inverting property of the device after leveling. The time-inverted pulses on the right move in the opposite direction from the input signals shown as leakage on the left. Horizontal scale: 1 μs/div.