ACOUSTIC SURFACE WAVE BURST CORRELATOR*

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Abstract

A doppler resolution filter is described which utilizes two acoustic-surface-wave tapped delay lines to perform an important radar signal processing function. The (-1 dB) bandwidth is 50 MHz and the delay increment for each tap is 5.0 μsec, for a total of 16 taps. A novel $LiNbO_3$ temperature stabilization technique is reported for controlling the 80 μsec delay line stability to $\pm 2 \times 10^{-7}$ over an ambient $10^{o}F$ range.

Introduction

There are frequent requirements in modern acquisition and tracking radars for high resolution in range and velocity, but both of these, in general, cannot be realized independently. For example, in order to improve range resolution, the radar pulse width might be shortened. Since decreasing the pulse width causes broadening of the spectrum, the determination of small doppler shifts, corresponding to high velocity resolution, becomes increasingly difficult. More desireable range/velocity characteristics are obtained when a pulse burst, rather than a single pulse, is utilized. The pulse burst is a train of coherent pulses of time duration that is much larger than the single pulse width. (In our application the inter-pulse delay is a constant 5.0 μsec and the number of pulses is 16.) For a pulse burst, it can be shown that within certain limits on range and velocity difference, the range resolution is characteristic of a single pulse while the velocity resolution is characteristic of the duration of the entire burst.

The acoustic-surface-wave tapped delay lines described below are utilized as matched filters or "correlators" for a uniform burst waveform. The analog signal processing function performed by the surface wave devices is easily visualized. Consider the burst return from a single stationary target introduced into the tapped delay line. As each burst passes under a tap, it produces an electrical signal at the tap terminals. At the instant the entire burst is within the delay line and there is one pulse under each tap, the tap output signals add coherently to reach their peak value. Clearly, the total output signal is extremely sensitive to spurious phase shifts, since a slight change in tap delay can result in a π phase shift, causing cancellation rather than additions. For this reason, temperature stabilization of the tap delays is a crutial requirement for the success of the processor.

In practice, the radar engineer would prefer to obtain peak correlation for returns from moving rather than stationary targets. Since the return of a uniform burst from a moving target no longer has constant pulse to pulse separation, it will not correlate with the uniformly spaced taps in the surface wave delay line. However, rather than summing the tap outputs directly, introducing them individually into a set of tapped delay lines adds important versatility to the processor. The set of (16 tapped delay lines performs the doppler filter function. The tap spacings in these lines are adjusted to cancel the delay variations in the burst caused by the target mov ing at specified velocities. The taps corresponding to each velocity are then summed, so that each will correlate the return from a particular velocity, just as the basic 80 μsec uniform tapped delay line would do for a stationary target. A block diagram of the complete burst correlator - doppler velocity filter combination is shown in Fig. 1.

Acoustic-Surface-Wave Filter Design

The two surface wave filters required for the processor were developed under separate programs. Because of the technical difficulty in realizing the large number of tapping transducers required in the velocity filter, its bandwidth of 20 MHz and center frequency of 150 MHz were chosen more conservatively than for the burst correlator, for which the corresponding values are 50 MHz and 210 MHz. The burst correlation is discussed in detail below.

In addition to achieving 50 MHz (-1 dB) bandwidth for each of 16 taps uniformly spaced by 5.0 μsec, there exist the requirements of maximum cw insertion loss of 50 dB to any tap and minimum of 40 dB spurious signal rejection at all taps. These specifications constrained the substrate material to be strong coupling YZ $LiNbO_3$, in spite of its relatively large temperature coefficient of delay (TCD) of $+47 \times 10^{-6}$ per ^{o}F. Moreover, we found that regardless of the choice of substrate, tapping transducers could not be designed to be compatible with 50 dB insertion loss and 40 dB double transit echo suppression when the taps were placed colinearly, as depicted in Fig. 1. When arranged in the parallel double transit echo, all requirements could, in principle, be achieved. The input transducers contain six constant overlap (double) electrodes spaced on periodic centers of 8 μm. The tapping transducers contain eleven periodic (double) electrodes including two phase-reversed, apodized sections at the ends. The overall photolithography requirement of producing 2.0 μm electrodes over a pattern area of six square inches is representative of the present state of the art.

As shown in Fig. 2, the first 8 tap outputs (5-40 μsec) are obtained in one pass through the delay line. The remaining eight (45-80 μsec) are achieved by amplifying the 40 μsec tapped output and inserting it into a second tapped delay located on the same substrate. In this manner, the entire delay line could be temperature controlled with one oven.

Temperature Stabilization

In as much as the required delay stability of $\pm 2 \times 10^{-8}$ per ^{o}F and the constraint of using lithium niobate substrates place the required thermal control ($\pm 4 \times 10^{-4}$ ^{o}F) well beyond the state of the art for ovens, a novel control loop was implemented in order to provide long term stability. As shown in Fig. 2, thin film resistive heaters are deposited between adjacent taps and a separate surface-wave delay channel is

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included on the substrate. The primary stability is held to approximately $\pm 4 \times 10^{-2}$ °F using thermistor controlled thermo-electric coolers on the bottom surface of the substrate. The fine-scale secondary stabilization is achieved by applying controlled heating uniformly to the substrate through the strip heaters. The amount of heating is controlled by monitoring any phase shift through the auxiliary delay channel. Thus, the heat applied to the surface of propagation in order to stabilize delay variations is controlled by the delay variation itself. Although no attempt was made to distribute the surface heat uniformly, it was found that the overall delay was indeed, stabilized uniformly between taps.

Filter Performance

Two burst correlator tapped delay lines have been tested in order to demonstrate the feasibility of realizing the desired performance and stability. One unit contains the full 16 taps with an amplifier (as in Fig. 2) in order to demonstrate the bandwidth, loss and spurious signal characteristics of the 80 μsec tapped delay line design. The second unit, which contains only eight taps, has been installed in the TEC controlled chamber and has been used primarily for temperature stability measurements. Figs. 3 and 4 show the measured insertion loss for the 10 μsec and 80 μsec taps, respectively. These results are typical of 14 of the 16 taps. Severe fabrication defects led to the degradation of performance of the other two. In most taps, the mid-band dip is slightly deeper than 1 dB, therefore, the required 1 dB bandwidth has not been realized. However, since the -3 dB bandwidth is greater than 70 MHz in all taps, the use of a slightly rounded broadband filter at the input would be sufficient to bring the tap pass bands within specification. The insertion losses were measured to be in the range of 47 to 55 dB, with the effects of propagation and diffraction loss being virtually negligible. Aside from one easily corrected problem, spurious echoes were below the noise. The primary problem resulted from acoustic leakage between the two sets of 8 taps. This leakage can be prevented by the use of sufficient acoustic absorber between the transducers which are to be isolated. The temperature stabilization has proved effective by achieving typically $\pm 3 \times 10^{-7}$ stabilization, in comparison to the goal of $\pm 2 \times 10^{-7}$, over a 10°F range in temperature. This stability is realized several minutes following a step-function change in temperature. The control system does have a transient overshoot which is approximately twice the steady state error. In order to realize this stability in all taps, it was necessary to place the acoustic temperature control delay channel in the center of the substrate. When the control channel was placed near the edge of the crystal the steady state errors increased by a factor of five.

Conclusions

The results of this development effort have proved the feasibility of realizing an acoustic-surface -wave burst processor of effective time-bandwidth product of 4,000. Because of the elaborate hardware associated with temperature stabilization, the burst correlator, shown in Fig. 5 does not fall into the class of "inexpensive" surface-wave components. It is, however, capable of performing an analog signal processing function which is highly impractical, if not impossible to accomplish with present day digital processors.

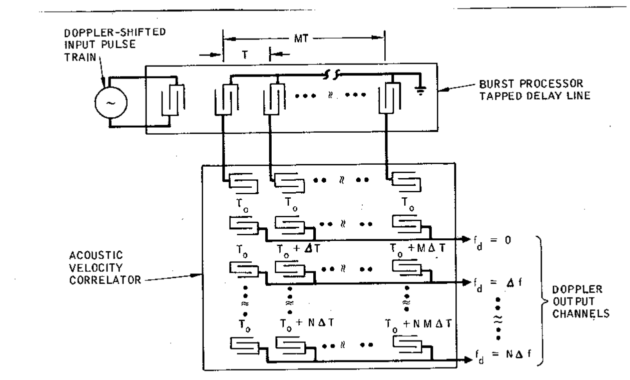

Fig. 1. Block Diagram of Burst Processor/Doppler Velocity Filter

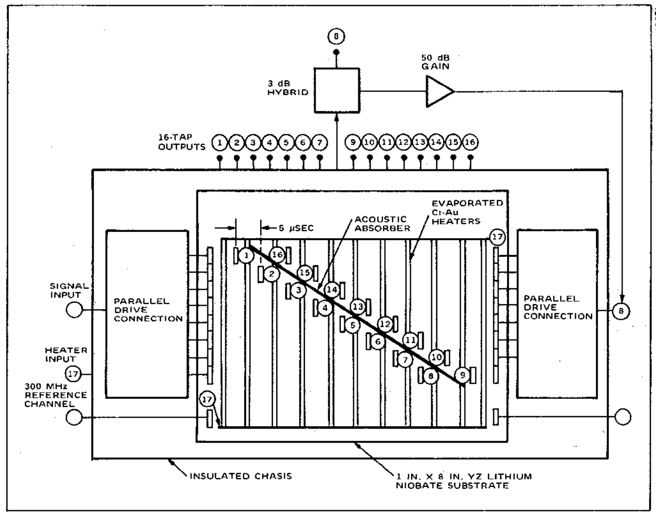

Fig. 2. Schematic of 16-Tap Burst Correlator Tapped Delay Line

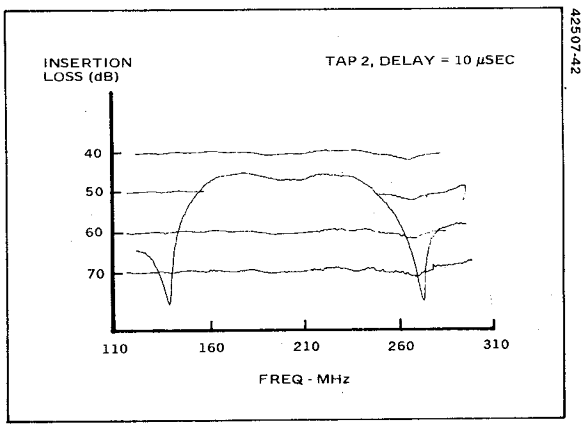

Fig. 3. Measured Insertion Loss vs Frequency for 10 μsec Tap

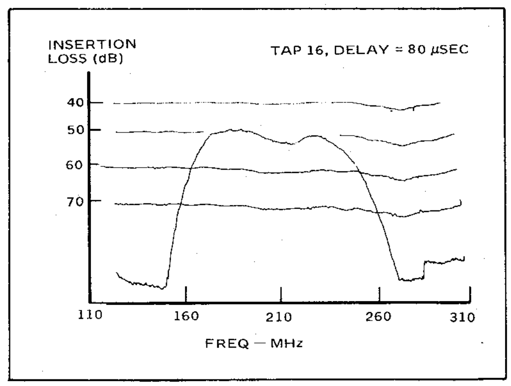

Fig. 4. Measured Insertion Loss vs Frequency for 80 μsec Tap.

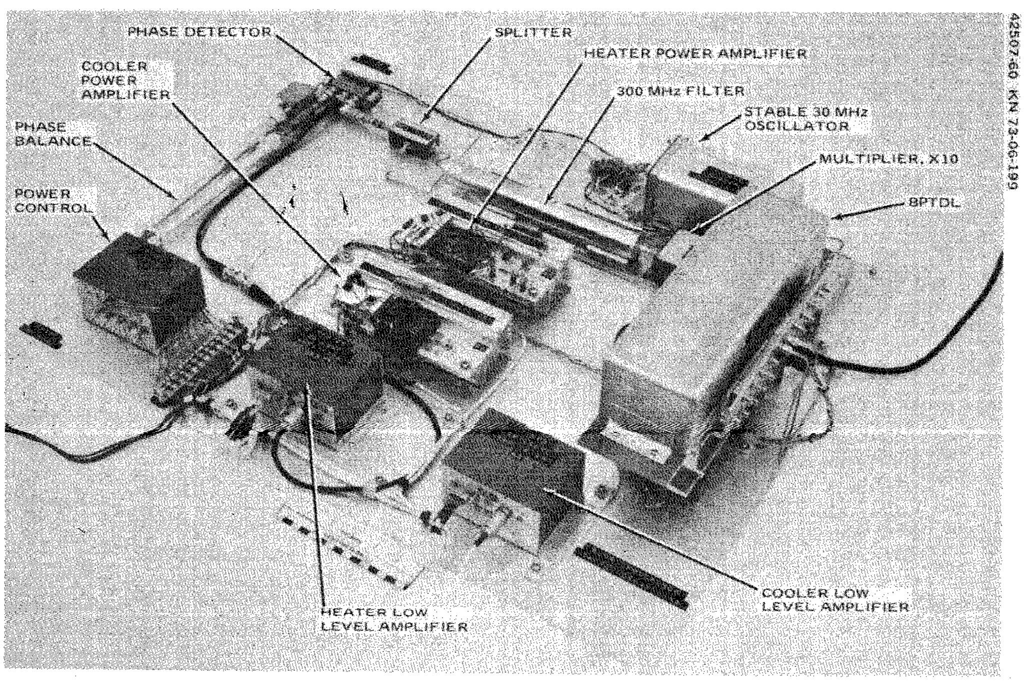

Fig. 5. Photograph of Burst Correlator Tapped Delay Line (BPTDL) Showing Auxiliary Hardware Required for Temperature Stabilization