ELECTRONICALLY VARIABLE CHIRP SIGNAL CORRELATION WITH THE DIODE-CORRELATOR*

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Abstract

The application of the Diode-Correlator to electronically variable chirp signal correlation is described. Theory and experiments for this nonlinear tapped delay line device are presented which show that input chirp signal bandwidth may be arbitrarily variable up to a maximum specified by the tap sampling frequency.

Introduction

The Diode-Correlator is a new type of nonlinear delay line correlator that provides relatively low insertion loss and practical device construction using hybrid microelectronic techniques. Previous papers[1,2] have discussed the physical operation and conditions for achieving low insertion loss. Here, we describe the application of the Diode-Correlator to electronically variable chirp signal correlation.

Circuit Arrangement Used for Chirp Signal Correlation

The Diode-Correlator makes use of nonlinear signal mixing in a forward biased, semiconductor diode array which is connected to the piezoelectric wave interaction region of a tapped, surface wave delay line. Of the several possible diode-tap circuit arrangements, the parallel configuration shown schematically in Fig.1 has been found most suitable for large time-bandwidth signal processing.

In present experiments, the device is used to perform the convolution of modulated signals $V_1(t)\exp(j2\pi f_1 t)$ and $V_2(t)\exp(j2\pi f_2 t)$ which are applied to the signal and reference input ports. The convolution signal appears at the output port as a modulated voltage, $V_3(t)\exp(j2\pi f_3 t)$, developed across R_L. In common with other types of nonlinear delay line devices,[3] the input and output carrier frequencies must satisfy[1]

$$f_3 = f_1 \pm f_2 \qquad (1)$$

$$nf_s = f_1 \mp f_2 \qquad (2)$$

where n is an integer, and $f_s = 1/\Delta T$ is a tap sampling frequency defined by the reciprocal of inter-tap acoustic transit time. For sum frequency operation (i.e., $f_3 = f_1 + f_2$), the output voltage waveform is proportional to a form of serial product convolution[4] between the input and reference signal waveforms

$$V_3(t) = A \sum_{p=1}^{P} V_1(t_p)\, V_2\, [2(t - t_d) - t_p]. \qquad (3)$$

Here, t_d is the time delay between the input or reference signal port and the center of the delay line while $t_p = t - z_p/v$ may be regarded as the effective waveform sampling time for waves crossing the p^{th} tap. For difference frequency operation ($f_3 = f_1 - f_2$), the convolution output is essentially the same as Eq.(3) except that the conjugate waveform, V_2^*, replaces V_2. Further, if V_1 and V_2 are band limited to frequencies less than half the tap sampling frequency f_s, the serial product convolution reduces to the integral convolution form observed in continuous interaction region devices.[3]

Chirp signal correlation may be accomplished in the Diode-Correlator with either sum or difference frequency operation. Chirp signals with identical time duration (T) and bandwidth (B) are applied to the signal and reference input ports with carrier frequencies centered at f_1 and f_2, respectively. For sum frequency operation, the frequency slope of these signals must be opposite, but equal slope signals are used for difference frequency operation since, in the latter case, hetrodyne inversion is performed automatically by the Diode-Correlator. Difference frequency operation also has the special advantage that a simple low pass filter can be used to separate the correlation signal from other undesired nonlinear signals obtained at the output port. In either case, for unweighted chirp inputs, the correlation waveform output is found to have a $\sin 2\pi Bt/2\pi Bt$ variation near the central correlation peak. Note that within the limitations set by transducer and output circuit bandwidth, delay line interaction region length, and tap sampling frequency, the input chirp signal parameters can be completely arbitrary and can be electronically varied from pulse to pulse.

Experiments with an 80 Tap Diode-Correlator

For electronically variable correlation of large time-bandwidth chirp signals, it will be clear from the above discussion that small tap spacings and large tap sampling frequencies are desirable. Current models of the Diode-Correlator use a YZ lithium niobate delay line and a custom designed silicon-on-sapphire diode array. Diode spacing as small as 0.127 mm has been reliably achieved. In typical devices, the diode array is small enough to be mounted with epoxy directly on the delay line surface. Connections between the diodes and corresponding delay line taps are made with 0.025mm Al wire bonds. Since the Z-directed wave velocity on YZ lithium niobate is 3488 m/s, the present 0.127 mm tap spacing corresponds to a tap sampling frequency of 27.5 MHz.

Experiments are currently being performed on an 80 tap Diode-Correlator designed for signal input at 67.6 MHz and reference input at 97.5 MHz. Difference

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frequency output is obtained at 30 MHz with the aid of a LP filter whose 3 dB cutoff frequency is 40 MHz. With a total diode bias of 0.8 ma, this 80 tap device achieves a minimum signal to output port insertion loss of 35 dB with 20 dBm reference input level. With constant reference input level, the insertion loss is constant to ± 1 dB over an 80 dB dynamic range.

Figure 2 shows input-output signal photos for chirp signal correlation with the 80 tap device. The input chirp duration was set at 2 μs, and the bandwidth was varied from 0 up to 10 MHz, the maximum 3 dB bandwidth available at the 67.5 MHz signal input port. Fig.2b - 2d demonstrate the electronically variable correlation response expected from Eq.(3).

Chirp Bandwidth Limit Due to Tap Sampling Frequency

The bandwidth limitation due to tap sampling frequency has some interesting consequences which can be theoretically investigated by evaluating Eq.(3) for specific examples. Consider the case where the chirp TB product is equal to P, the number of interaction region taps. This corresponds to $B = f_s$. Here, as predicted from sampling theory, the chirp bandwidth should be large enough to cause considerable correlation distortion. Fig.3 shows the output computed from Eq.(3) and stored on a CRT display for devices with TB = P = 100, 200, and 300 and T = 10 μs. Compared to the desired $\sin 2\pi Bt/2\pi Bt$ time response, the major distortion seen in Fig.3 is the appearance of enhanced time sidelobes near the edges of the correlation interval. Experimentally, correlation edge sidelobes have been seen for $B = f_s$ in Diode-Correlators with 8 and 12 taps.[5]

In the usual case where Gaussian or Taylor weighting is used to suppress near-in time sidelobe interference, we can also expect that substantial attenuation of correlation edge sidelobes will be achieved. Fig.4 shows the effect of Gaussian weighting on the correlation output of Eq.(3) assuming the same TB parameters used in Fig.3. We see that all time sidelobes are now attenuated below - 40 dB and that better sidelobe suppression can be expected for devices designed for larger TB products. With proper waveform weighting, we conclude that electronically variable chirp correlation should be possible with the Diode-Correlator for chirp bandwidths up the tap sampling bandwidth, f_s.

Conclusions

In summary, we have shown that the Diode-Correlator is capable of performing electronically variable chirp signal correlation with time bandwidth products as large as P, thé number of interaction region taps. This corresponds to a maximum chirp bandwidth equal to the tap sampling frequency, which for current devices is 27.5 MHz. The hybrid construction using lithium niobate delay lines and silicon-on-sapphire diode arrays has been found to provide a rugged and viable experimental configuration. Devices constructed to date with 8 to 80 taps have demonstrated relatively low insertion loss, good two-port linearity, and usable dynamic range in excess of 60 dB. Devices are now under construction to demonstrate this technology with 300 taps.

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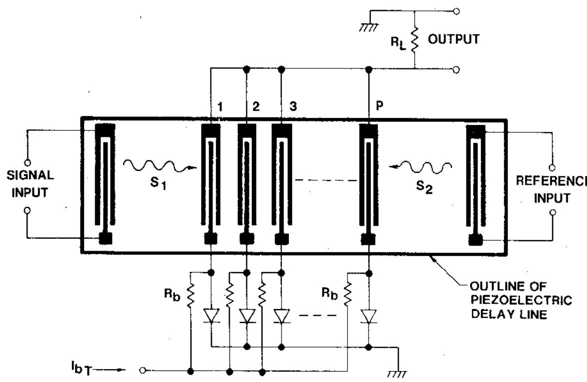

Fig.1 Schematic view of the parallel configuration Diode-Correlator

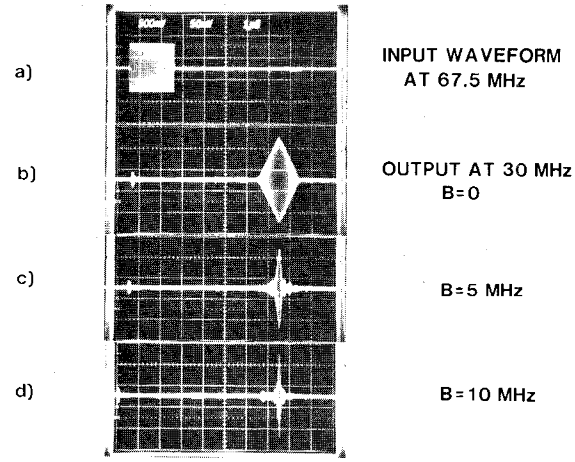

Fig.2 Input-output waveforms showing electronically variable chirp signal correlation with an 80 tap Diode-Correlator

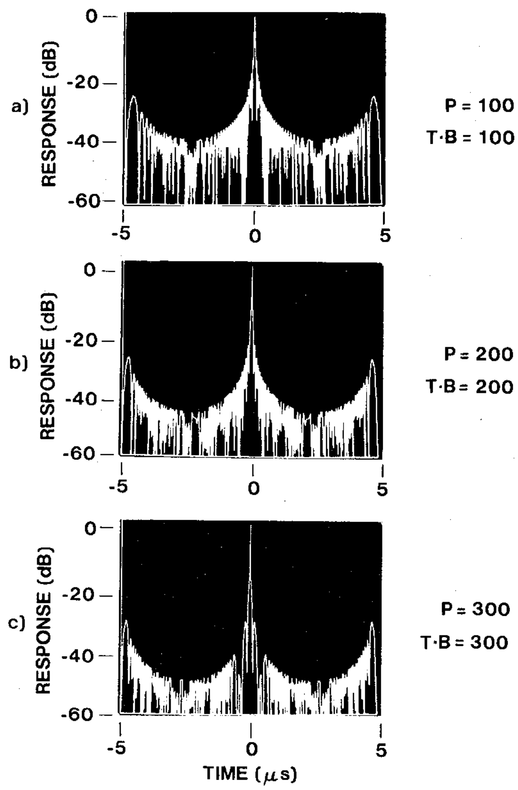

Fig.3 Theoretical correlation output calculated from Eq.(3). Input waveforms unweighted.

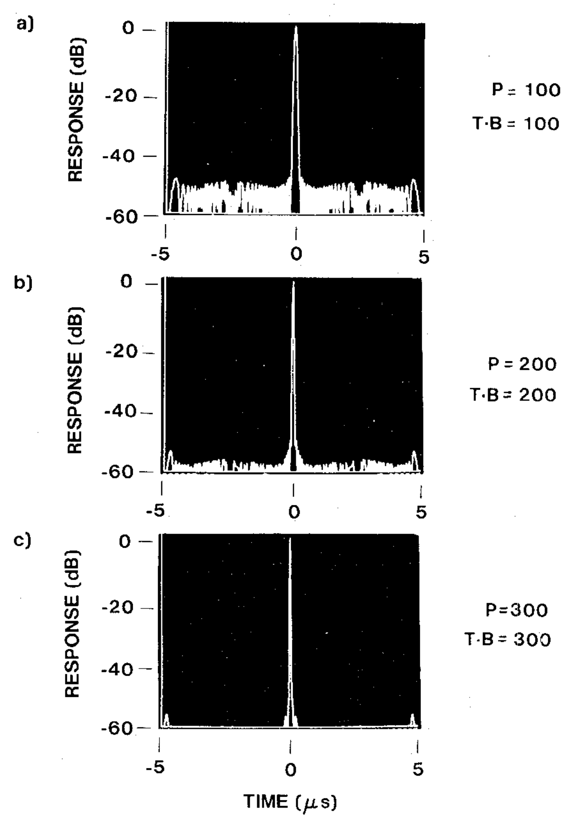

Fig.4 Theoretical correlation output calculated from Eq.(3). Input waveforms Gaussian weighted.