A SWEPT DELAY CORRELATOR

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ABSTRACT Charge-transfer devices can be used as low-loss analogue delay lines of variable length extending up to many msec. This can be exploited to provide a very simple auto-correlator suitable for examining stationary signals. By controlling the clock frequency so that its period is swept linearly, a gradually increasing delay can be inserted into the signal path. The mean product of the delayed and undelayed signal represents the estimated auto-correlation (strictly the autocovariance) function of the signal and this can be obtained very simply using an analogue multiplier followed by a integrator with a time constant chosen to match the sweep rate of the delay.

INTRODUCTION

It is sometimes important to establish the decorrelation times of random or quasi-random signals, for instance radar echoes from sea waves. In other cases it may be required to detect and measure the period of repetitive components in a signal without foreknowledge of their shape and when they may be masked by other, perhaps larger, components. Problems of this type call for a knowledge of the auto-correlation properties of the signal s, expressed by the autocovariance function

$$\phi\ (\tau) = \int s(t)\ s(\tau+t)dt$$

which if normalised to make ϕ (0) = 1, becomes the auto-correlation function (acf). In practice the integral is over a finite interval of time, t so that ϕ is statistically estimated only. τ specifies the time displacement or lag across which the signal correlation is measured.

When the signal statistics change slowly enough for stationarity to be assumed, sequential methods of estimating ϕ for different values of τ are applicable with consequent savings in hardware compared with systems which simultaneously measure ϕ for all time lags of interest. A simple real time implementation of this approach is possible using charge transfer devices (CTD). Fig 1 shows how a CTD can be used to provide the time displacement τ and a four-quadrant analogue multiplier to derive the product

$$s(t)\ s(t+\tau)$$

which is integrated to form an estimate of ϕ using a simple time constant.

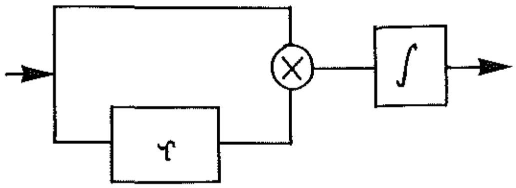

Fig 1 CTD Autocorrelator

DESIGN CONSTRAINTS

Some care is necessary in obtaining meaningful estimates of $\phi(\tau)$ for a fluctuation s(t). The integrator time constant T must be long enough for sufficient independent samples of the product $s(t)\ s(\tau+t)$ to be integrated to allow a given fractional accuracy f to be obtained. The sweep rate of the clock period P must also be low enough for the change $\Delta\phi$ due to the changing τ (= NP for an N-sample delay) also to be kept smaller than $f\phi$.

If the variable sampling rate of the CCD is always kept below Nyquist, all the products integrated will be independent and the attainment of a fractional accuracy f requires approximately $1/f^2$ samples to be integrated so that

$$T = P/f^2 > 1/(2Bf^2)$$

fixes a lower bound for T where B is the bandwidth of s.

The sweep rate $\frac{dP}{dt}$ causes a change in ϕ over a time T of

$$\phi' \; N \frac{dP}{dt} T$$

where ϕ' represents the slope of $\phi(\tau)$. Keeping this error also down to the fraction f requires

$$\frac{dP}{dt} < \frac{f}{NT} \Big/ \left(\frac{\phi'}{\phi}\right)$$

which becomes important with the sharply peaked acf's exhibited by wideband signals. These arguments apply only if we do not exceed the Nyquist sampling rate. This limits the minimum delay attainable to N/2B. Below this value of τ, we must increase T and reduce the sweep rate to maintain accuracy.

In practice ϕ' is not known in advance and it is easier to experiment with the integration time constant and sweep rate to make sure that sensible measurements are being obtained.

EXPERIMENTAL RESULTS

The hardware equivalent of Fig 1 was realised as in Fig 2 using a pair of bucket brigade circuits connected in series to form the delay element. A total of 26 samples were stored at any time and a sample-hold circuit was used to derive a

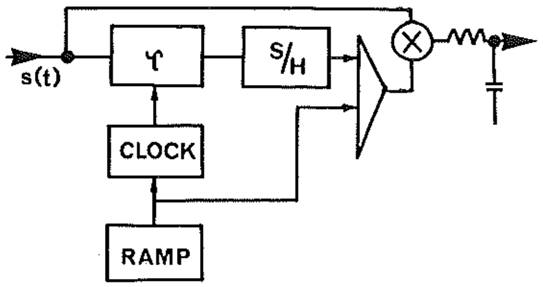

Fig 2 Compensated correlator

staircase output waveform, free of clocking transients. The two-phase clock was arranged to have a period increasing linearly with time by deriving it from two ramp functions, the faster of which is reset when it crosses the slower as indicated in Fig 3. The end points and sweep rate of the clock frequency are set by suitably choosing the slopes of the two voltage ramps. The bipolar bucket brigades,

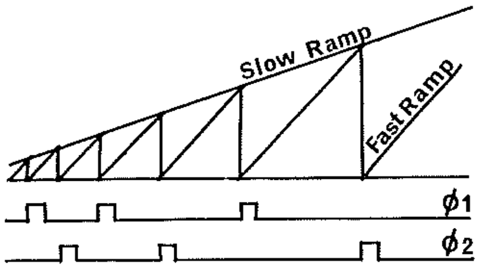

Fig 3 Linear clock period generator waveforms

normally used with MHz clock rates, were here required to store data for delays τ as long as 120 ms and under these circumstances the output showed a τ-dependent voltage offset which caused a significant error in the correlation output. This was approximately corrected by adding to the bucket brigade output a fraction of the slow ramp signal which determines the sweep rate of

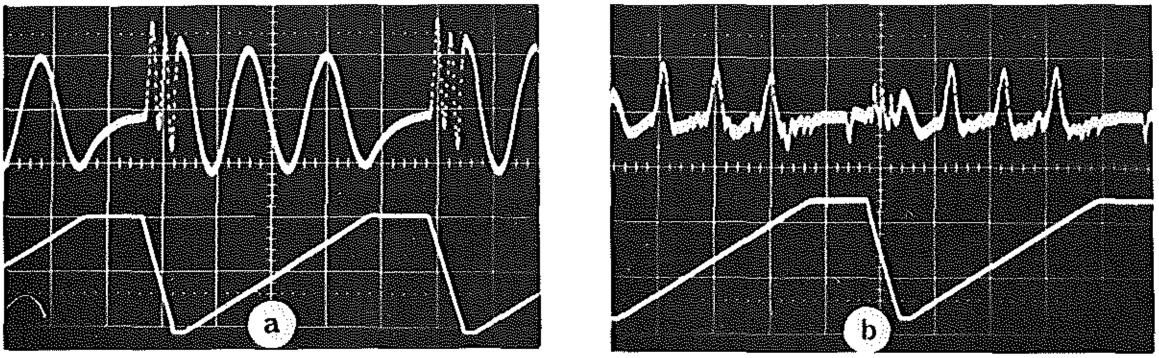

Fig 4 Correlator waveforms (2.5 s/div)

the clock period. Fig 4 shows some representative waveforms on simple test signals. In each case the integration time constant is 1s and the auto-correlation lag τ is swept from 6ms to 120 ms (with extreme clock frequencies of 4 kHz and 200 Hz) in a time of approximately 8 sec. 4(a) shows the approximately cosinusoidal acf obtained with a 20 Hz sine wave input. The lower trace shows the ramp controlling τ. During the ramp flyback the acf is retraced in reverse with poor accuracy because of the high sweep rate. Fig 4(b) illustrates the auto-correlation of a 30 Hz pulse waveform with 15% duty ratio. In both cases the measured acf is substantially correct, the chief distortion being due to the voltage offset error in the bucket brigade. Because this varies non-linearly with storage time it is difficult to remove completely. The effect is to contribute a proportion of the undelayed signal to the multiplier output. In spite of this effect, the correlator is adequate for certain purposes even when time lags of the order 100ms are required.

CONCLUSION

A simple auto-correlator, which can readily be generalised to cross-correlate different signals by supplying the separate signals to the delayed and undelayed channels, can be built around a charge transfer device used as a variable delay line. Its chief restriction, apart from being applicable only to stationary signals, is the requirement that samples stored for times up to the longest lag to be measured are not appreciably attenuated or offset in voltage compared with those stored for the shortest lags.

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