MTI FILTERING FOR RADAR WITH CHARGE TRANSFER DEVICES

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ABSTRACT

The use of CCD and bucket brigade devices in radar moving target indicator filter applications is discussed. A three pole Chebychev analogue filter is described in which charge coupled devices are used as the delay elements.

INTRODUCTION

The purpose of a radar moving target indicator (MTI) filter is to reject signals from stationary objects while passing those from moving targets. For this the Doppler effect is used. The frequency of the returned radar signal is compared with that transmitted. The beating between the two shows up as an amplitude fluctuation at the Doppler frequency.

One of the first applications of charge transfer device analogue delay lines in radar is likely to be in MTI filters. The reasons for this are summarised by the following device parameters:-

a) Signal storage and delay times up to $\approx$ 100ms.
b) Dynamic range hopefully >40dB.
c) ~ 100 stored samples.
d) Clock rates up to 10MHz.
e) Serial access to data is simple.
f) Simpler, faster, smaller and potentially cheaper than digital systems.
g) Delay is variable and can be accurately controlled.

Because of the suitability of both bucket brigade and CCD devices for this application, experimental filters have been assembled using both types of device. Some aspects of their performance are compared and discussed in this paper. Firstly the application of CCDs to a simple MTI cancelling filter is described and then the results obtained with the more ideal Chebychev type of filter are given.

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SIMPLE CANCELLING FILTER

Fig 1 shows a simple cancelling filter incorporating a time delay element T, (ref 1). It has a frequency response as shown in Fig 2 in which cancellation occurs at frequencies which are a multiple of f_r where $f_r=1/T$. Such a filter can be used as a coherent moving target indicator (MTI) for a pulse radar system if T is the pulse repetition interval (p.r.i.) of the radar transmitter (ref 2). Thus in such a radar set the reflected return signals at radio frequency are mixed with a reference signal at the transmitter frequency. If the target giving the reflection is moving there will be a change in phase of the returned signal between consecutive transmitter pulses, due to the changing path length and hence the mixer output shows beating at the Doppler frequency. If this signal is applied to the filter of Fig 1 an output will be obtained only for moving targets because the subtraction cancels signals which are stationary pulse to pulse. Thus clutter signals from stationary targets are cancelled. Targets with speeds corresponding to Doppler frequencies which are multiples of f_r are also cancelled.

It can be seen how charge transfer devices such as CCDs and BBDs can be utilised in an MTI filter since they act as shift register delay lines which can transfer digital or analogue signals. Only analogue operation is considered here since this has the advantages of avoiding expensive A/D signal conversions and requiring simpler circuitry than multibit digital systems.

If an N element CCD is used for the delay line, clocked continuously at a rate f_1 then $T=N/f_1$. Fig 3(a) shows a linear CCD with the signal input applied to the input diode. The CCD samples the incoming signal during phase 1 of the clock ($\emptyset_1$) only and delivers it as a series of discrete pulses during the $\emptyset_1$ period at the output [see Fig 3(b)]. The precise moment at which the I/P signal is sampled depends upon the circuitry used to feed the signal into the CCD. Application of the signal to the input gate rather than to the diode together with a means of linearising the CCD input/output characteristic has been proposed (ref 3). In the present work a circuit has been used which applies to the input diode a voltage proportional to the average of the incoming signal over the $\emptyset_1$ "on" period. The input gate is kept strongly turned on by a DC voltage equal to the peak phase voltage used.

A reset MOST is used to give the square pulse O/P in Fig 3(b). This is turned on by the reset pulse $\emptyset_2^1$ which is derived from $\emptyset_2$. Due to gate to drain capacitance in the reset MOST there is a $\emptyset_2^1$ feedthrough onto the O/P.

Using these waveforms the simple canceller in Fig 1 gives the required output only during the $\emptyset_1$ "on" periods since this is when the delayed signal output of the CCD is subtracted from the incoming signal. Thus a sample and hold circuit must be used on the output of the canceller with its sample period adjusted to occur during $\emptyset_1$ "on" so that only the required output is obtained.

Furthermore if the CCD input signal is time varying during $\emptyset_r$ "on" this output sampling instant ought to be adjusted to correspond to the precise time at which the CCD takes its input sample so that correct operation of the filter is obtained. Since the instant at which the CCD takes its input sample can vary, depending on the method of signal input used, the timing of the output sampling instant becomes far less critical if the filter is preceded by an input sample and hold circuit arranged so that its hold period spans $\emptyset_1$ "on" and thus the filter input is constant during this time interval. In practice the limits imposed by the minimum sampling time required by the sample and hold circuits must be considered.

CCDs may also be used with interrupted clocking, see Fig 3 (c). The clocks are stopped for a rest period t_r during which $\emptyset_3$ remains on and during which the analogue information in the CCD remains stored under the $\emptyset_3$ electrodes. In this case T is given by equation (1) where f is the clocking frequency.

$$T = t_r + N/f \quad \ldots\ldots\ldots\ldots \quad (1)$$

Fig 3(c) shows the clock waveforms for an 8 element CCD. A variation whereby storage is under the $\emptyset_2$ electrodes could also be used.

A CCD simple canceller using an N element CCD takes N samples of the incoming waveform every pulse repetition interval thus it can cover the acquisition of targets in N range elements (range gates).

CHEBYCHEV MTI FILTER

The three pole Chebychev analogue filter shown in Fig 4 has been implemented using CCD delay lines, as described below and also using MOS bucket brigade devices as described in ref. 5.

The advantage of the Chebychev MTI filter (refs 1, 2) over the simple MTI canceller is that the frequency response is better matched to real clutter which has a finite spectral width and also shows a more uniform passband response and hence probability of detection, for targets with Doppler frequencies outside the rejection notch.

The numbers in Fig 4 refer to the signal weightings fed into the summing amplifiers which are 15MHz bandwidth I/C operational amplifiers. An 8 element 3 phase surface P channel CCD is used for each delay. These have common 3 phase clocks and interrupted clocking is used for which f is 330 kHz, t_r is 2 μsec and T is 26μsec.

Fig 5 shows the low frequency response of the filter to a 0.4 V peak to peak sine wave input with a swept frequency. The response minima shown occur at 0, 38.4 and 76.8 kHz. The filter cancellation ratio at 38.4 kHz is -32 dB compared with the maximum output.

With these filter parameters we have simulated an MTI radar with a prf of 38.4 kHz. The filter should cancel repetitive pulses occuring at this frequency which correspond to radar clutter. To show MTI action, the input signal shown in Fig 6(a) was used. It consists of a square simulated clutter pulse that is locked to the interrupted clocking rate, ie its repetition rate is 38.4 kHz. The clutter pulse spans three range gates, ie three of the CCD $\emptyset_1$ clock pulses. Superimposed on the clutter pulse is a simulated moving target spanning one range gate and having a 20 kHz Doppler frequency, and there is a similar moving target adjacent to the clutter pulse.

The filter output waveform Fig 6(b) shows that the clutter pulse is cancelled and only the "moving target" signals pass through. The spiky transients are caused by logic breakthrough in the sample and hold circuit when this samples the filter output during the $\emptyset_1$ "on" period. As with the bucket brigade circuit, (ref 5) there is some smearing of the moving target into the following range gate. This is just visible in Fig 6(b) and is caused by the inefficiency ε of the charge packet transfer along the CCDs (ref 6). For the CCDs used in the present case ε is estimated to be $\sim 1\text{X}10^{-3}$ per transfer. As in ref 5, this smearing effect is found to increase when the Doppler frequency is near the edge of the filter passband. Thus for a Doppler frequency of 34 kHz a smeared amplitude of up to 20% of the target occured but smearing did not appear to extend further than the first following range gate.

Computer calculations have been used to predict the smearing. It is found that this is a non linear function of the ε value and is also a function of the signal weightings used in the filter design. The effect is magnified when the signal weightings are altered to increase the steepness of the edge of the filter passband. Fig 7 shows the results of calculations made for the filter shown in Fig 4 for the case in which charge transfer devices are used which each have 32 transfers with an inefficiency of 2.1×10^{-3} per transfer. Curve g_s is the frequency response for the signal range gate and curves g_{s+1} and g_{s+2} show the frequency response of the smeared signals in the first and second following range gates respectively. These signals peak at the edge of the filter passband where they reach 43% and 15% respectively of the amplitude of the wanted signal.

APPLICATION OF CCDs TO PRACTICAL MTI FILTERS

In practice MTI filters usually operate with several hundred range gates and with a p.r.i. of the radar of 1 ms so that the use of a linear or serial-parallel-serial CCD delay line is appropriate. The total required delay T could be several milliseconds, depending on system requirements, which is within the limits imposed by thermal generation of minority carriers which adds charge to the charge packets as they transfer through the CCD.

To minimise target smearing the ε value must be kept small. Its allowed value will depend upon the number of range gates, the type of CCD and the practical frequency response required. A rough estimate from the above results would be that ε ought to be less than 10^{-4} per transfer when using a 3 phase, 100 element linear CCD (300 transfers).

The linearity of the CCD output as a function of its input is important as it determines the cancellation ratio attainable. Operational amplifier bandwidth and settling time parameters must be carefully chosen when clocking speeds in excess of 1MHz are contemplated.

APPLICATION OF BBDs TO MTI FILTERS

Bipolar BBDs are faster than MOS BBDs and operate at clock rates in excess of 5MHz. They have the disadvantages relative to CCDs in that the chip area per element is greater and also that ε values are greater typically by an order of magnitude. Thus they are unlikely to be able to compete with CCDs as very long storage arrays. Nevertheless as their storage time, dynamic range and maximum clocking frequency are comparable with CCDs and as their clocking requirements are simpler, systems with up to 100 range cells can conveniently use BBDs.

Fig 8 shows a BBD MTI system which is being developed for a radar application which calls for 4MHz clock rate and 100 range cells. The filter has the same configuration as that in Fig 4 but the delay sections each comprise ten bipolar BBDs in parallel each having ten storage cells. The BBDs are clocked directly from TTL logic gates in sequence so that 100 range cells are available. An ε value of $< 10^{-3}$ per transfer is anticipated and should keep spurious signals due to smearing below 17 dB.

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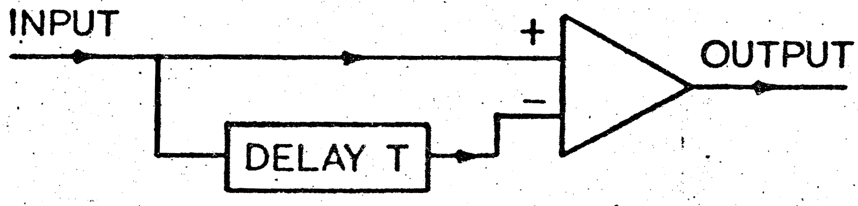

Fig 1 Simple cancelling filter.

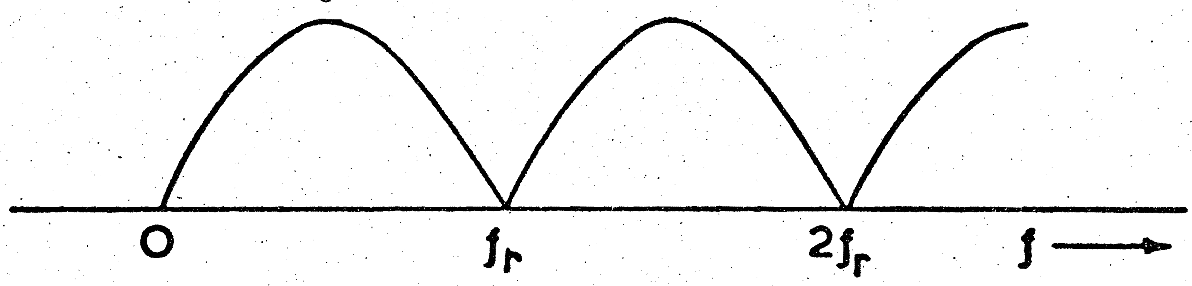

Fig 2 Frequency response of simple cancelling filter.

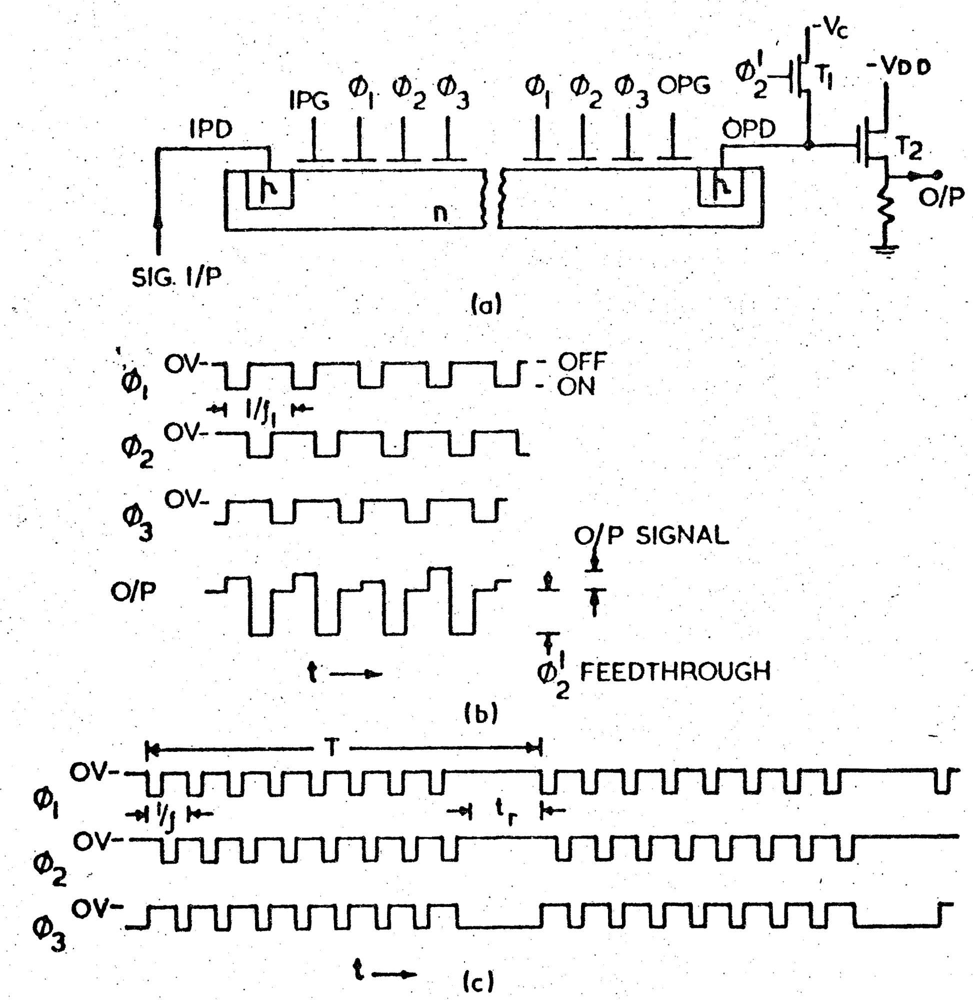

Fig 3 (a) N Element three phase linear p channel CCD.
IPD = I/P diode, OPD = O/P diode, IPG = I/P gate, OPG = O/P gate.

T_1 = reset MOST, T_2 = source follower MOST.

(b) Phase and O/P waveforms for continuous clocking.

(c) Interrupted clocking phase waveforms for N = 8.

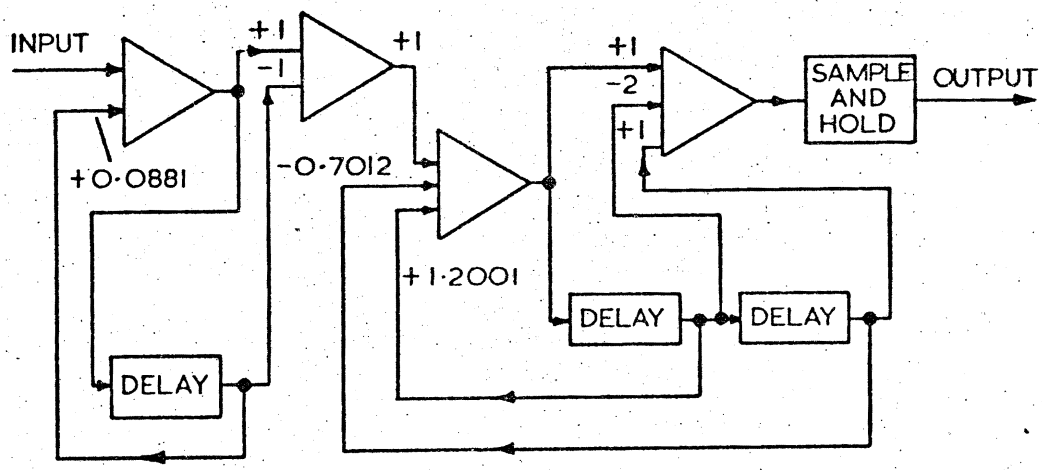

Fig 4 Three pole recursive filter.

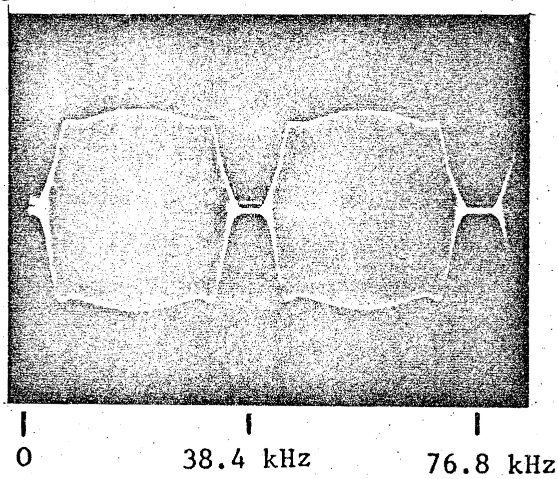

Fig 5 Frequency response to 0.4 V peak to peak sinewave

Vertical scale: filter output amplitude $\simeq$ 0.25 V/division

Horizontal scale: input frequency.

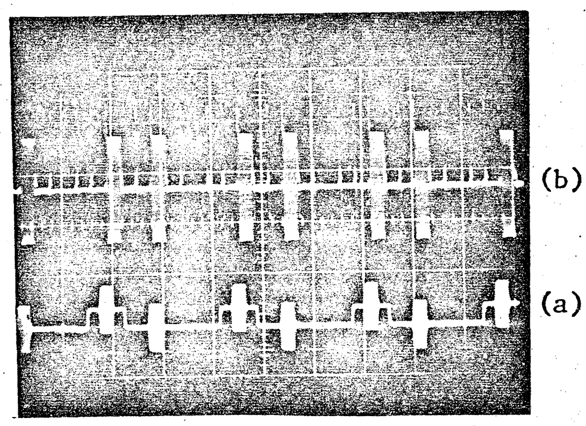

Fig 6 Simulated clutter cancellation

(a) Filter input waveform

(b) Filter output

Vertical scale: 0.5 V/division

Horizontal scale: 10μs/division

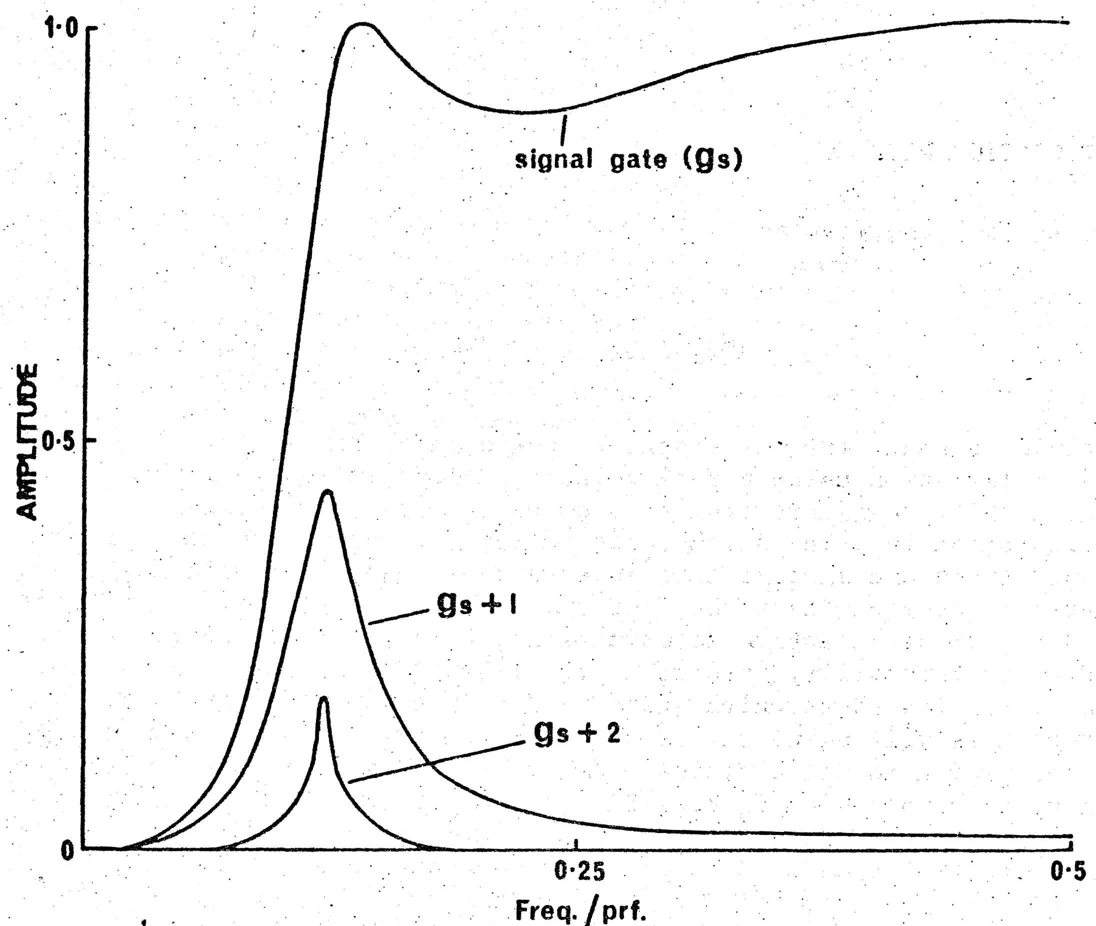

Fig 7 Frequency response of smearing amplitude.

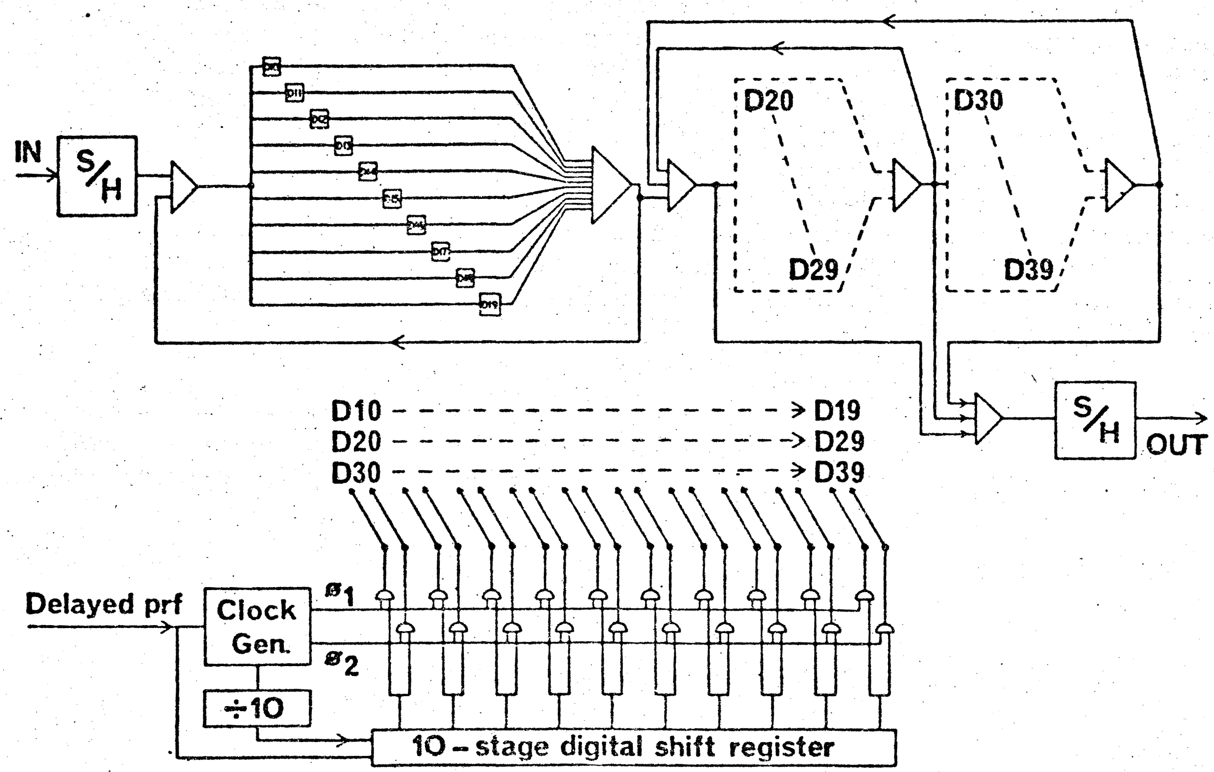

Fig 8 100 Range gate MTI utilising 10 element BBDs in parallel.