SAMPLED-DATA PROCESSING WITH CHARGE TRANSFER DEVICES

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ABSTRACT

Charge transfer devices employing both the charge-coupled and bucket-brigade principles are now available to the design engineer. These devices provide the designer with a relatively simple, cost-effective way of obtaining and controlling the delay of an analog signal with negligible degradation. The area of signal processing most suited for exploitation by charge-transfer devices will be discussed.

Charge-transfer devices will be reviewed describing not only the basic functional differences that may be employed but also showing the practical range of applications for devices of varying architectures. Also, a family of devices designed to perform correlation between either two analog signals or between an analog signal and a binary sequence will be described. The ability to field program, i. e., change the correlation sequence, greatly expands the variety of applications for which these devices are useable.

I. INTRODUCTION

Until recently, signal processing involving successive time delays was implemented either by use of physical analog delay elements, such as acoustic or electric transmission-line delay elements, or by conversion to digital format for processing, then reconverting the processed results to an analog output. Wholly analog systems are cumbersome, expensive, and sensitive to environmental factors. On the other hand, conversion to wholly digital format is often unnecessary and penalizes the system in terms of cost, complexity, speed, and power.

A very attractive alternative is discrete-time processing of analog samples. Time is quantized, but relative amplitudes are preserved. Delay is accomplished by transferring samples from cell to cell in shift-register fashion, while preserving relative amplitudes. Discrete-time systems combine many of the best features of both digital and analog systems: speed as well as the freedom from quantization effects of analog systems are combined with the time precision and flexibility of digital systems.

II. THE TAPPED ANALOG DELAY

The Tapped Analog Delay is the basic building block of the transversal filter. The transversal filter represents one of the most effective applications of charge transfer devices to sampled-data signal processing. The signals that appear at each tap of the TAD are weighted and summed by the technique shown in Figure 1. The ability to control externally the weight on each tap allows the user to design a wide variety of filter functions all based on the same basic component, and by switching in different tap-weight functions it becomes possible to program in a predetermined way a desired set of filters. For example, a time-multiplexed filter bank could be realized using one TAD and multiplexing the taps to several tap-weight functions, each derived with resistors.

Figure 2 shows the performance of a 32-tap TAD (TAD-32) operated as a low-pass filter. The impulse response of this filter is very nearly a Hamming window; therefore, one would expect the peak side lobes to be suppressed by -43dB relative to the center lobe or passband. The experimental results of Figure 2 for a sample rate of 120KHz indicate that -41dB was achieved. The width of the main lobe at -20dB is 12KHz, which compares favorably with theory. It is apparent that band edge rates in excess of 80dB/octave are possible.

This picture shows the spectral response or filter characteristic obtained for two inputs differing by 40dB. The background response curve is for an input level 20dB below the maximum level, thus from this picture one must conclude that nearly 60dB of input dynamic range is possible while still realizing a -40dB stopband to passband ratio. From this we must agree that the performance attainable from the TAD-32 exceeds by far most other approaches.

III. WHY BUCKET BRIGADE

This devices uses a bucket-brigade structure. We have all known that charge-transfer devices are very suitable for analog signal processing. However, most people immediately conclude that using charge-coupled devices is the only way to do the job. If you say that you are going to use a bucket-brigade device, immediately they ask: "Why not use charge-coupled?" Well, probably the most important single reason is that bucket-brigade devices use standard MOS processing. This means that they can be processed on a standard production line using existing technology, which in turn results in higher yield, and more cost-effective components. Another advantage, which is often overlooked, is that being compatible with existing MOS processes means that a wealth of circuitry used in making ROM's, RAM's, PROM's, and micro-processors is all available to the charge-transfer device designer. This allows the designer to build such things as flip-flops, clock drivers, shift registers, and even programmable memory onto the same chip with the charge-transfer device. Another advantage of bucket-brigade devices is the ease with which the clocks may be generated. There are no tricky multi-phase clocks; a simple two-phase complementary square-wave clock is all that is required. The output circuitry is equally simple, allowing one to do either capacitive sampling of the bucket such as in a split electrode transversal filter, or to use source followers which are directly driven by the buckets and in turn act as current sources to the outside world. Modern n-channel bucket-brigades are capable of sampling at rates up to 5MHz. Contrary to popular belief, bucket-brigades can be made with transfer efficiency equal to surface channel CCD. Transfer inefficiency curves are shown in Figure 3 for two n-channel structures using a two layer poly-silicon MOS technology. A commercially available p-channel device is shown as a comparison.

Bucket-brigade devices are most suitable for sample rates below 5MHz, for delays not exceeding 5,000 transfers (2,500 stages), or when simplicity of associated circuitry for peripherals, etc., is a major consideration. There is also no advantage to using the alternative CCD (which does allow higher packing density) when packing density is only secondary, such as when peripheral circuitry or when pads determine the size of the chip and not the charge-transfer device itself. In such cases no real advantage can be obtained by using charge-coupled devices. Bucket-brigade devices are a natural in audio delays up to about 2,000 stages. For more than 2,000 stages one runs into transfer-efficiency problems, as well as into an increasing noise floor, both functions of the number of stages in a bucket brigade.

With the addition of some on-chip circuitry the tapped analog delay can be made into a binary analog correlator, as shown in Figure 4. This device has an on-chip static shift register which may be loaded with any desired binary sequence which then controls the (positive or negative, one or zero) tap weights from the BBD delay-line taps. This device permits 32-point real-time binary (or P-N) sequence correlation with an analog input signal. It may be used in applications requiring correlation, convolution, code generation, decoding, filtering, or other types of signal processing where an analog signal operates on a variable binary pattern or where two continuous signals - one analog, the other binary - operate on each other.

Figure 5 shows 29-bit P-N sequence correlation as performed with a 32-point binary-analog correlator (BAC-32).

Figure 6 shows a schematic representation of a 32-point analog-analog convolver (AAC-32) which uses two of the 32-tap lines with adjacent pairs of taps connected to four-quadrant multipliers whose outputs are summed in a common output line. This device will perform real convolution between two analog signals, a function which is fundamental to all time invariant linear systems.

IV. TRANSVERSAL FILTERS

The three devices which have been discussed may be considered programmable since the impulse response of each is under the control of the user. This external control requires accessory components and becomes a disadvantage if one develops a large volume requirement for devices all possessing the same impulse response. This requirement can be better satisfied by a mask programmable structure such as the split electrode structure. A 64-tap transversal filter which can be programmed at the mask level by modifying a single layer of the structure has been developed. A tap accuracy of 0.5% is attained at the mask level and the structure is completely insensitive to mask alignment. Furthermore, the sensing structure is unclocked and "full wave", therefore eliminating the need for additional signal processing in order to extract a useful signal from the clock noise. Figure 7 shows the raw output from a low-pass filter with only a differential amplifier (ua 733) as the output circuit.

This split-electrode structure has been used to produce a family of filter functions. Figure 8 shows the spectral characteristics of three general-purpose linear-phase filters, a low-pass and two band-pass filters. The low-pass filter has a corner frequency which is 10% of the sampling frequency, and a stop-band rejection of 45dB. The edge rate is about 100dB/octave. The two band-pass filters have similar edge rates and stop-band rejection; however, their pass bands are different, one having a narrow pass band 2% of the sampling frequency centered at 25% of the sampling frequency, the other having a wide band of 15% f_s centered at 17.5% f_s.

Other tap weight functions have been implemented using this structure. These include a set of linear fm chirps for implementing the chirp Z transform algorithm and a Hilbert Transform pair for broad band quadrature generation.

V. CONCLUSION

In the discussion of the TAD-32 it was demonstrated how novel discrete-time analog signal devices of this type are opening new and exciting possibilities in the area of signal processing. Complex tasks like convolution, matched filtering, correlation, etc., may be done with these large-scale integrated devices at a high speed. Signal processors, so far only realizable with complex, power consuming digital computers, can now be built on one board. Thus, sophisticated equipment may be constructed with the new devices at reduced size and power consumption, leading to higher reliability. The low cost will also enable the hobbyist to realize many of his ideas with the novel approach.

Among other discrete time analog devices, the TAD and the BAC are unique in the respect that their window function may be changed at a high rate. This makes them useful in adaptive type applications requiring real-time alteration of the window function. These devices also allow one to experiment with different operations and patterns, making it useful as an educational tool. Concepts expressed with complicated formulas or simulated on digital computers may be demonstrated, requiring only a simple TAD or BAC and some peripheral circuitry and one oscilloscope.

For large quantity requirements of a fixed filter function, the mask programmed structure offers the additional advantage of lower cost through volume production.

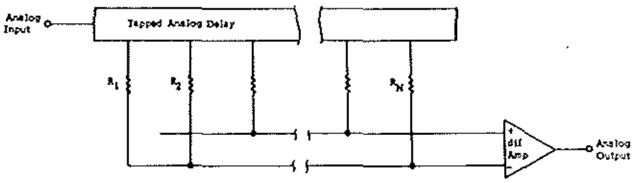


Figure 1. Block diagram representation of a transversal filter using a Tapped Analog Delay and resistor weighting of the taps.

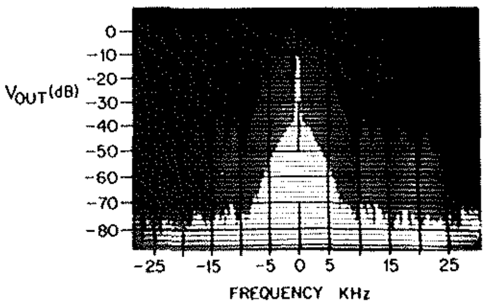


Figure 2. Spectrums obtained at two input levels from a 32-tap transversal filter whose impulse response was a Hamming window function.

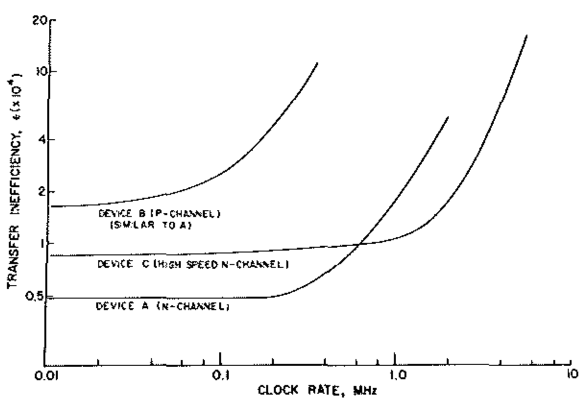


Figure 3. Transfer inefficiency versus sample rate of a modern n-channel bucket brigade device.

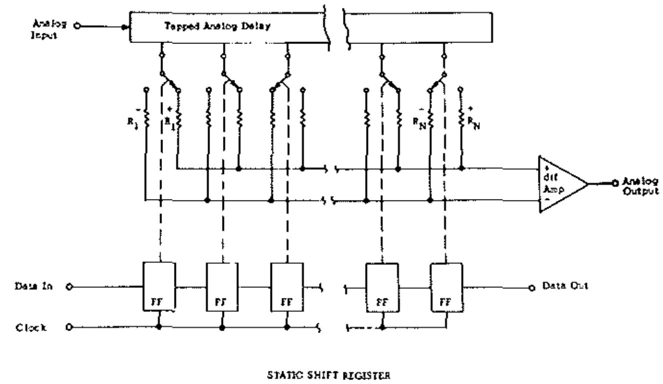
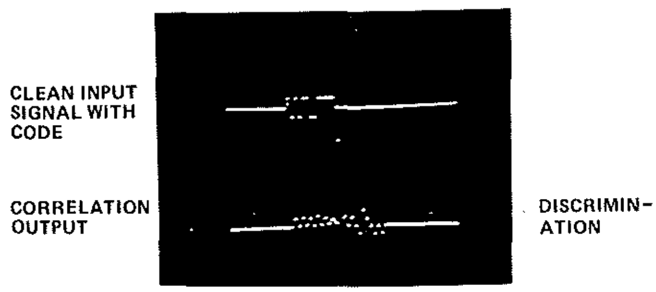
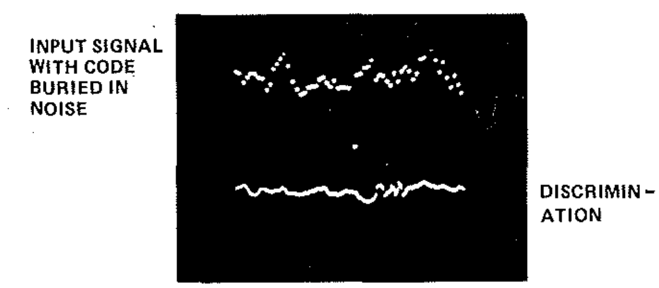


Figure 4. Block diagram representation of a Binary-Analog Correlator.



a) Input Signal Contains Code Only



b) Code In Input Signal Is Buried In Noise

Figure 5. Correlation Output obtained by correlating signal with high discrimination code with some code stored in digital shift register.

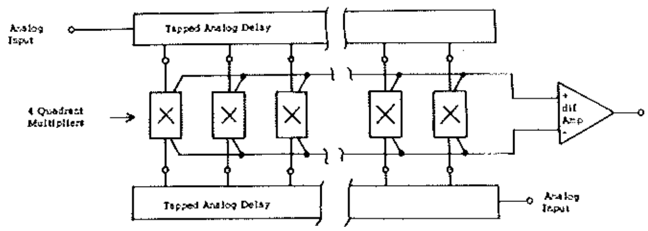


Figure 6. Block representation of an Analog-Analog Convolver.

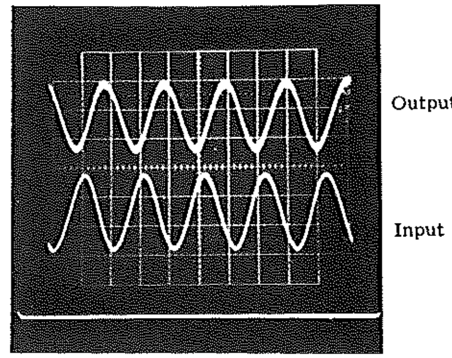


Figure 7. Waveforms showing the input and the unfiltered output from a 64-tap BBD transversal filter.

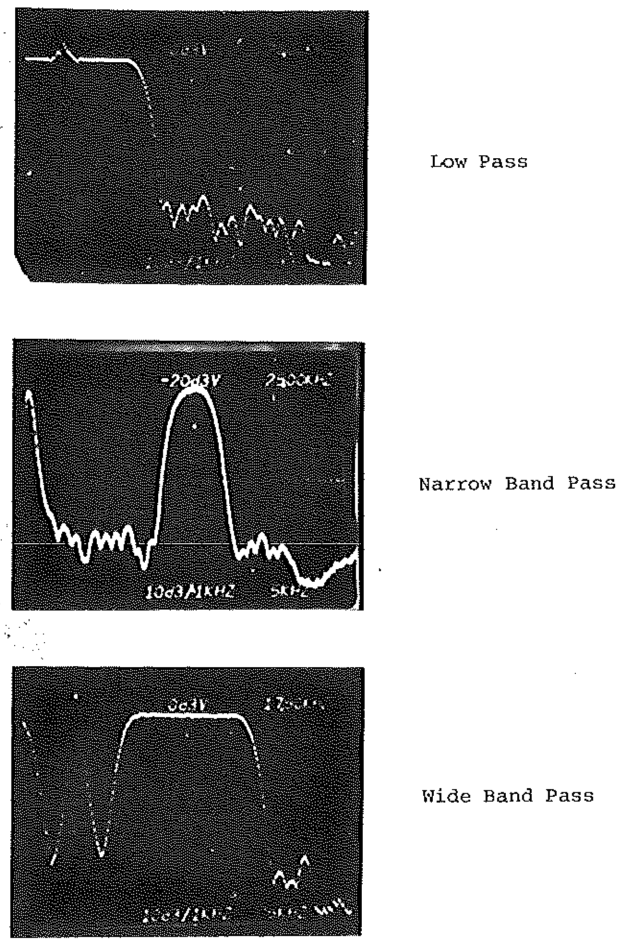


Figure 8. Spectral responses from three 64-tap transversal filters implemented by a BBD structure.