PRACTICAL ACTIVE SONAR RECEIVER SYSTEMS USING FAST FREQUENCY-DOMAIN CORRELATION.

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1. Introduction

Active sonar systems require good angular and range resolution to localise targets and to combat reverberation [1,2].

Range resolution can be achieved using short transmission pulse lengths (ie with simple PCW transmissions, range resolution equates to effective transmitted pulse length). However, the peak acoustic power delivered by the transmit array is limited by cavitation, so to achieve the high transmit energies needed for long range detection, long transmit pulses must be used. Consequently, to provide the high energy transmissions for long range together with the good range resolution to combat reverberation, coded transmission waveforms are usually employed.

Typical waveform types [2] used in active sonar include linear period FM (LPFM) chirps which provides a 'Doppler invariant' range-doppler ambiguity function, linear frequency FM chirps with limited Doppler discrimination and pseudo random noise (PRN) with a 'thumb-tack' range-doppler ambiguity response. Typically these waveforms use time-bandwidth (BT) products of the order 1000 and the receive processing detection system consists of a collection of matched filters, using Doppler shifted versions of the transmitted waveforms to implement a multi-beam, multi-doppler channel replica correlator system.

For transmission waveforms with good range-doppler performance (eg PRN), the number of Doppler shifted replicas necessary to cover the receive Doppler window can be high: typically upwards of one hundred individual correlation channels each with a different Doppler shifted reference is required to cover the Doppler range met in practical applications.

For systems with modest angular resolution, with say around 3 degree beamwidths, this receive correlation processing must be provided on around one hundred beams simultaneously, if full all-round surveillance cover is needed. Consequently maybe ten thousand individual correlation channels need to be processed simultaneously (ie one hundred Doppler channels on each of one hundred beams). Even taking into account the relatively modest bandwidths used in sonar applications, the total processing load to provide this processing is daunting and correlation rates ranging from a few million to a few tens of million correlations per second are typical. Using conventional time domain correlation techniques, each correlation point requires around four thousand multiply-accumulate operations (for real arithmetic), so the processing load equates to a throughput of a few tens of giga-operations per second.

Until recently, this processing power has been difficult to provide in a cost effective way and the required throughput was often minimised by using, for example, Doppler invariant transmission waveforms: but even with the reduction in Doppler channels this produces, it was difficult to provide the necessary processing throughput in compact systems.

Typical DSP-based implementations have been developed using high-density random access memory (RAM) and bit-slice multiplier-accummulators (MACCs) to provide multi-channel delay time compression (DELTIC) replica correlator systems [3] but these processors have often only been able to process a few channels per processor card.

Sampled analogue data systems have also been investigated using charge-coupled devices (CCDs) and surface acoustic wave (SAW) and acousto-optic technologies [4,5]. Whilst these provide a reasonable processing bandwidths (as they are essentially parallel correlator implementations) but the architectures available with these technologies were not easy to adapt to multi-channel systems: because of their parallel architectures, they were better at providing wide-bandwidth, single channel systems. Available devices were also limited in the data storage times that could be realised and, more importantly in active systems, in useful dynamic range.

The dynamic range required from the correlator system was minimised by including automatic gain or time varying gain control (AGC/TVG) circuits in the receive processing chain, prior to correlation. However these suffered from the effects introduced by modulating the received signals with the AGC/TVG control voltages. Spurious image signals could be generated by this modulation, particularly with the fast acting gain control needed to maintain signal levels in active systems in reverberation limited conditions, which, after correlation, produce false echoes, degraded detection performance and increased false alarm rates.

With recent advances IC fabrication technology and computer aided design [6], application specific integrated circuits (ASIC) and high density memories have reached the stage were very wide dynamic range analogue to digital convertors and high performance, compact frequency domain correlation systems can be produced cost effectively. The following paragraphs outline the development of these types of correlation systems: analogue to digital conversion techniques to provide wide dynamic range for active sonar applications are discussed in Reference [7].

2. Practical Frequency Domain Correlation Systems.

The systems outlined below all use 32-bit complex vector processor (CVP) ASIC [8,9], high-speed dual port memory and a writable control store architecture to provide sustained data throughputs up to 25 million correlation points per second. This is sufficient for many sonar (and indeed some radar) applications. Two basic systems are outlined, one a single 6U PCB system using a single CVP for lower throughput systems, the other a two board, 8 CVP systolic pipeline processor supporting throughputs up to 25 million correlation points per second. The block schematics for these two basic systems are shown in Figures 1 and 2.

2.1 Frequency-domain Correlation Algorithms.

The processing algorithm used with both of the systems outlined above is the standard overlap-save technique described in Reference 10. The basic algorithm flow is as follows: data is block processed using 4k data blocks (ie 4k real samples) overlapped by 2k samples. Processing consists of a 4k real forward FFT, multiplication of the frequency-domain transformed input data with the complex conjugate of the transformed 2k point real time domain replica (zero padded to 4k points to avoid circular convolution effects), followed by inverse transform to generate 4k correlation points, of which 2k points are valid.

In practice, the frequency-domain data is multiplied and inverse transformed for each of the required Doppler replicas in turn and this process repeated for the required number of beams. The whole sequence is repeated when a further 2k input samples have been gathered, so that consecutive 4k point input blocks, offset by 2k points, are processed.

2.2 Practical System Performance

For the single CVP system (Figure 1), the forward and inverse transforms each require 12k clock cycles (equates to 490 microsecs at 25 Mhz clock rate), whilst each frequency-domain multiplication takes a further 82 microseconds. Hence data can be processed at around 570 microseconds per Doppler reference, with a forward transform overhead of around 490 microsecs per beam. Using 256k*4 VDRAMs for the writable control store, up to around one hundred Doppler references can be processed sequentially, if required.

For the systolic implementation (Figure 2), one CVP is used for the forward transform, one for the frequency-domain multiplication and six for the pipelined inverse FFT. This provides throughputs of 82 microsecs per Doppler reference and since each inverse transform generates 2k correlation points, this equates to approximately 25 million correlation points per second. Again up to one hundred different Doppler references can be held in the writable control store if required. If only one Doppler reference per beam is required, for example for processing LPFM, the systolic pipe can be extended to improve the forward transform speed.

All of the processing outlined above is carried out to 32-bit precision (with 40-bit precision internal to the CVP): magnitude data can be generated on the final stage of the inverse transform if needed.

References

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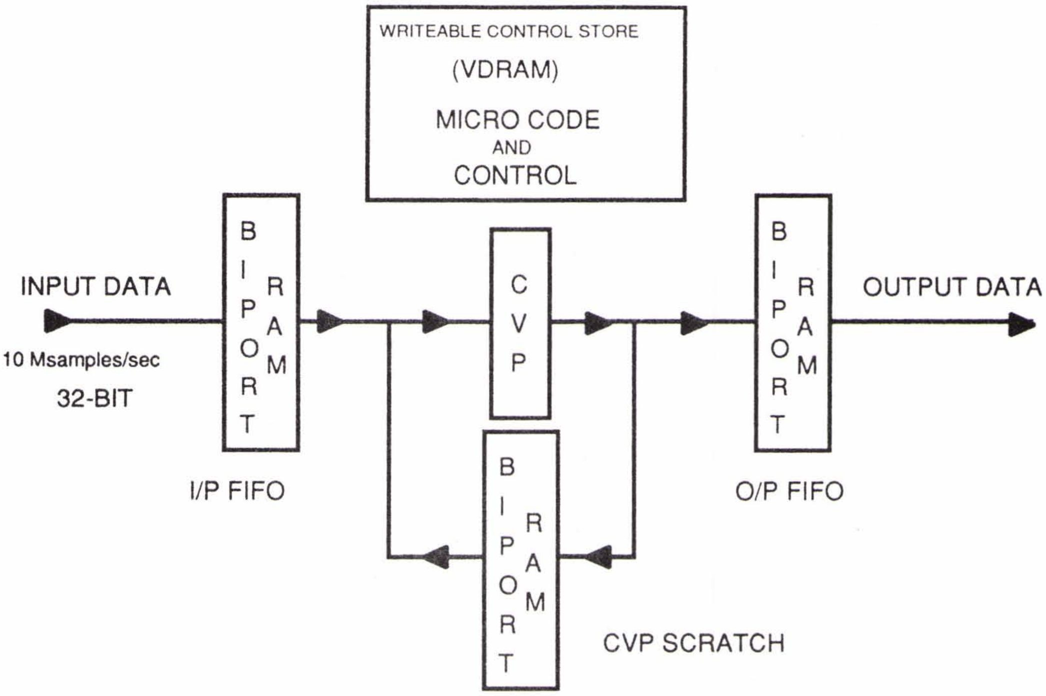

FIGURE 1(A) - SINGLE CVP FFT ENGINE - (TOP LEVEL SCHEMATIC)
TRANSFORM SPEED - 1024 Point Complex, 205 uSec.

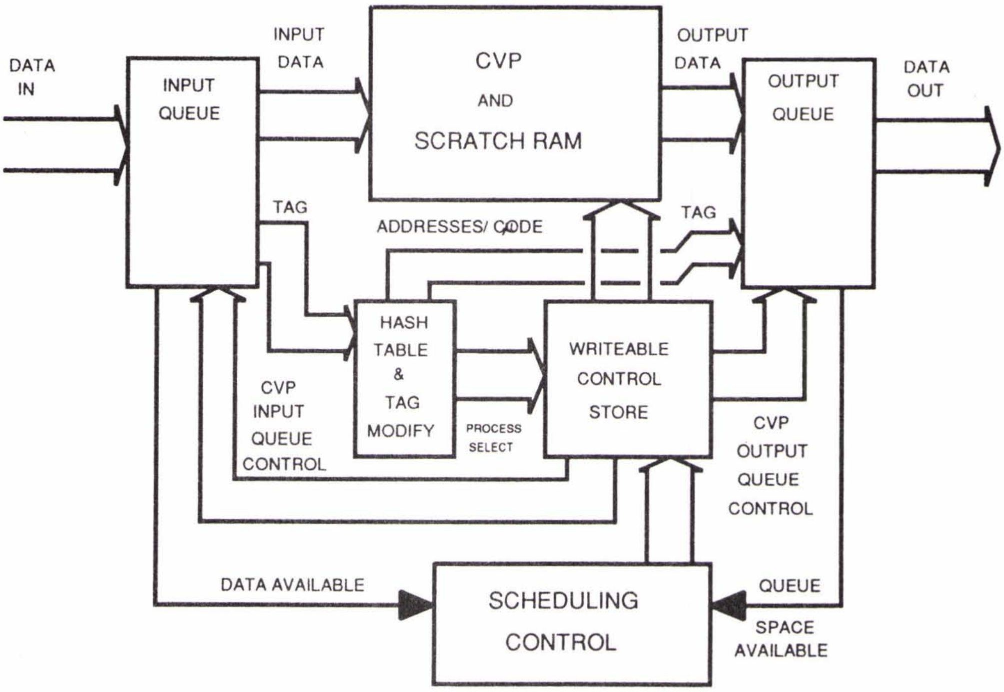

FIGURE 1(B) - PROCESSOR CONTROL SCHEMATIC

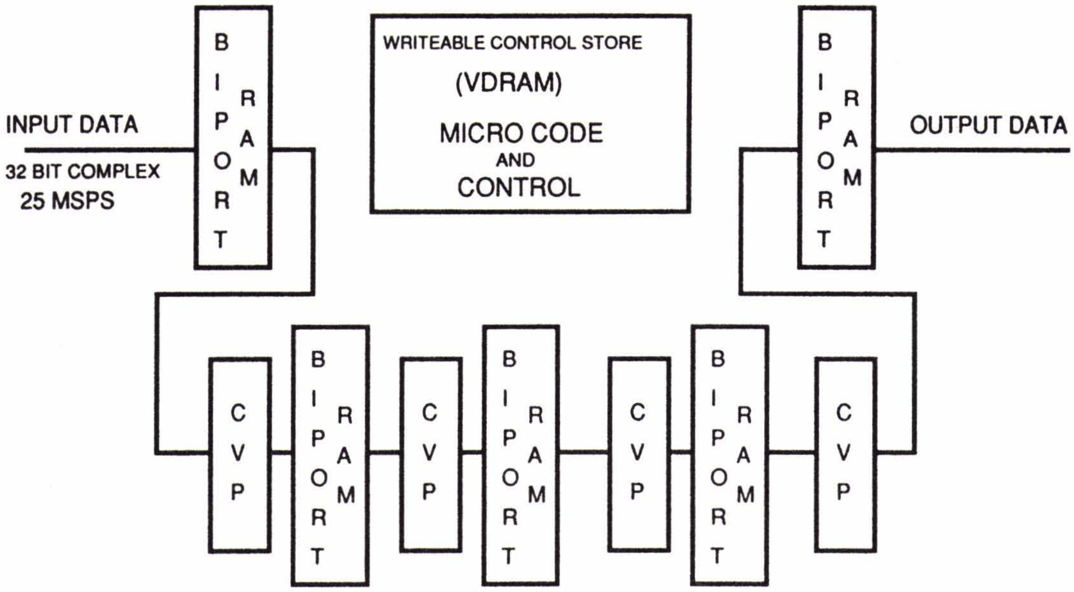

FIGURE 2 - "SYSTOLIC" FFT ENGINE
USING LSI CVP

Transform speed - 1024 pts complex, 41 microsecs.