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CODING FOR TRANSMIT BEAM SONAR SYSTEMS

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1. Introduction

Wide band, high resolution, narrow beam sonars have been a subject of interest for many years. Specifically the advantage of a wide band sonar lies in increased bandwidth which can be used either to assist in target recognition or to more accurately determine the position of an object in range and bearing.

The Electronic and Electrical Engineering Department of Birmingham University has been building a transmit scanned sonar system in which the receiver is tuned to the difference frequency obtained from the interaction in the water of the two transmitted frequencies. This transmitter will provide a relatively wide bandwidth and a narrow beamwidth which is independent of frequency over the bandwidth. It is the signal design for this system which will be discussed in this paper. A narrow transmitted beam is to electronically scan the bearing sector of interest. Since it is the transmitted beam which sweeps the sector, each bearing within the sector must be uniquely identified by the signal transmitted on that bearing. The receiving transducer has a wide beamwidth which covers the entire sector of interest.

The simplest means to achieve this is to transmit a signal on one bearing, await returns from the maximum range and then transmit the same signal on an adjacent bearing. However, the time necessary to scan the sector using this technique may be unacceptably long, particularly from the point of view of scan to scan integration which enhances detection capability.

Alternatively, to reduce the time necessary to scan the sector, a different signal can be transmitted on each bearing. One transmitted signal from which target bearing and range information can be obtained is a linear F.M. signal. As the frequency changes the signal phase between array elements alters and the narrow transmitted beam sweeps the sector of interest. The theoretical resolving capability in range and bearing of such a system is a function of the time-bandwidth product and has been discussed in detail by Berktay[1].

An alternative coding system for the electronically scanned transmitter which has been investigated will be discussed. Each signal or code word, sent into a different segment of the sector must insonify that segment in such a way that the receiver can identify the segment from which the signal is received by deciding which code word of the group of possible code words has been received.

The codes investigated consist of B code words, each of which is a sequence of A pulses, and each pulse is a CW pulse using one of N frequencies within the transmitted bandwidth.

In order to obtain maximum resolution capability each code word must utilise as much as possible of the system bandwidth. Furthermore, each code word must be as different as possible from each other code word to simplify the receiver recognition problem and reduce detection errors. These two requirements may conflict and the design of codes becomes a compromise.

2. Receiver Processing

The receiver which must identify the code words consists of a bank of N parallel filters corresponding to the N possible pulse frequencies. Each pulse of the received sequence passes through one of the N filters and is rejected by the other (N-1) filters. Pulses are then demodulated. Depending upon whether or not the demodulated pulse amplitude exceeds the first threshold a "one" or a "zero" is sent to a shift register consisting of A bistables. By tapping the N shift registers in the appropriate places and summing the tapped outputs, the summed output on one of the B bearing channels will correspond to the autocorrelation between the received code sequence and one of the B stored sequences. The other (B-1) summed outputs correspond to the cross-correlation between the received code sequence and the remaining (B-1) stored sequences. When all A pulses of a code sequence are in the shift registers, the sum of the taps corresponding to the received sequence will be equal to A. If the first threshold is set too high, the sum of the taps corresponding to the received sequence will be less than A. A second threshold comparator has a preset value, T, equal to or less than A. When the second threshold is exceeded the bearing of the received signal is identified. It can be shown that a two threshold receiver is the best way to identify the received signals for the codes being considered.

3. Code Design

Various constraints can be imposed on the code parameters A, B and N depending on the circumstances in which it is proposed to use the sonar. Having selected the values of A, B and N, the aim of the code design is to minimise the cross correlation between all sets of two code words, when the code words are either in phase with each other (k=0) or out of phase by up to $k = \pm(A-1)$ pulses. The designer does this by selecting the maximum acceptable cross correlation, R_M, between any two code words and then generates as many code words as possible for the given values of A and N. If B such code words cannot be achieved either A, N or R_M must be altered. Figure 1 shows some codes designed in this manner.

As an example, the range-bearing response plane for one code word as it passes through the receiver is shown in Figure 2. The code word belongs to the second code shown in Figure 1.

1		2	3	4
B = 26		B = 10	B = 7	B = 10
N = 5		N = 5	N = 4	N = 4
A = 6		A = 6	A = 8	A = 5
R_M = 3		R_M = 2	R_M = 3	R_M = 2
132451	313254	212345	11423234	14322
135412	331245	254231	12314323	23314
143253	351142	331245	12442431	24341
145523	352314	414523	22134412	24413
151423	414523	425314	34332411	31241
153542	422513	432415	43132124	31324
212345	425314	544132	44312143	32114
215234	432415	553421		33421
221453	441235	315224		41123
241355	513412	114352		42213
243512	534512			
254231	543215			
313425	544132			

Figure 1 - Code Examples

Bearing j \ Range k	-5	-4	-3	-2	-1	0	1	2	3	4	5
1	0	1	1	1	0	1	0	0	2	1	0
2	0	1	0	1	2	1	0	1	0	1	0
3	0	0	1	0	2	0	2	2	0	0	0
4	0	1	0	1	1	0	2	1	1	0	0
5	0	0	1	0	0	(6)	0	0	1	0	0
6	1	0	0	1	0	2	2	1	0	0	0
7	0	1	0	0	2	2	1	1	0	0	0
8	0	1	2	0	2	1	0	0	0	2	0
9	1	0	1	1	0	1	1	0	0	1	1
10	0	1	0	2	0	1	2	0	1	1	0

N = 5, A = 6, B = 10, R_M = 2 Target Return 425314

Figure 2 - Range Bearing Response Field for One Target Returns at the Receiver

4. Code Rotation

One method of reducing the unwanted spikes in the range-bearing response plane is to use code rotation; that is to send each code word into a different bearing segment on each transmission. The receiver must be programmed for this. However, the technique will ensure that higher unwanted spikes appear in different range bearing cells on successive transmissions and the net result over a number scans is reduced peak spikes relative to the signal peaks.

5. Performance of Codes with Additive Gaussian Noise

The performance of the codes described has been studied in the presence of additive Gaussian noise. For a two threshold receiver, the optimum value of T, the second threshold has been studied by Schwartz[2] and others.

Because of the possibility of false alarms resulting from a combination of unwanted spikes in the range-bearing response plane and Gaussian noise, the optimum setting of T, for $4 \le A \le 10$, was found to be T A-1 instead of the value found by Schwartz, T 1.5 A. Simulations, carried out with the receiver described, confirmed the fact that for a false alarm rate, set from Gaussian noise considerations alone, the probability of false alarms resulting from range-bearing response spikes and noise combined increased in a predicted fashion as the signal-to-noise ratio increased.

6. Improved Bearing Resolution

Using the coding method described it is possible to achieve improved bearing resolution in a transmit scanned sonar by shifting the transmitted beam less than one complete beamwidth for each code word transmitted. For example, if the transmitter beam is shifted one-half beamwidth after each code word is transmitted, then bearing resolution is improved by a factor of two. It is necessary to receive two code words in order to obtain the improved bearing resolution but in so doing it can be shown that one also obtains a signal processing gain.

7. Comparison with Other Sonars

The time bandwidth product of a system transmitting A pulses into a segment is $W_T A\tau$ where W_T is the system bandwidth and τ the duration of each pulse. The system using the codes described has the same time-bandwidth product; however, the duration of each pulse is increased by a factor N. Thus, in a fast scanning system, in order to be resolved, two targets must be separated by N times the range necessary for a system which awaits all returns before insonifying a different segment. On the other hand, the scanning rate is independent of the maximum range.

The compromise imposed on the receiver to reduce the deteriorating effect of spikes in the range-bearing response plane is to make it a two threshold receiver, and alter the setting of the second threshold from what is regarded as optimum for the situation where such spikes do not exist. However, the loss in processing gain for $A \leq 10$ is of the order of 3 dB or less over a one threshold system employing video integration for probabilities of detection between 0.5 and 0.9 and probabilities of false alarms of the order 10^{-3} to 10^{-10}, the ranges investigated.

In terms of array gain a transmitter scanned sonar may offer an improvement over a receiver scanned sonar for the situation where noise is correlated between receiver elements.

Finally using the coding techniques described, the performance of a transmitter scanned sonar should be comparable to that of an F.M. scanner, cheaper to construct, and capable of greater diversity.

References

1. H.O. Berktay 1967. "Some Proposals for Underwater Transmitting Applications of Nonlinear Acoustics", J. Sound Vib. 6(2) 244-254.

2. M. Schwartz 1956. "A Coincidence Procedure for Signal Detection", IRE Trans. Inf. Theory IT-2(4) 135-139.