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DISTRESS BUOY SYSTEM ANALYSIS

Howard C. Salwen

PROTEON ASSOCIATES, INC.
24 Crescent Street
Waltham MA 02154

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16. Abstract

This report presents a brief analysis and comparison of two candidate approaches to the implementation of a multiple access Emergency Position Indicating Radio Beacon (EPIRB) system for maritime use. One approach, implemented by the Federal Republic of Germany and tested by the European Space Agency (ESA) during the 1974-1975 ATS-6 tests, uses frequency-shift-keyed (FSK) audio tone pairs for user identification, with detection employing a bank of narrow-band filters. False alarm probabilities and other parameters are calculated for this approach. An alternative to this approach, promising improved performance in the presence of multiple interfering EPIRBs, is also described. This alternative uses orthogonal Pseudo-Noise (PN) spread-spectrum sequences to identify each EPIRB uniquely. These sequences are easily generated using linear shift registers, and the resulting receiver structure is comparable in complexity with that needed for the FSK approach. It is concluded that the acquisition and detection performance of the two approaches is about equal, but that the spread-spectrum method has advantages in a multiple-access environment.

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Emergency Position Indicating Radio Beacon (EPIRB)
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PREFACE

A signaling technique for Emergency Position Indicating Radio Beacons (EPIRBs) using FSK modulation, with detection employing a bank of narrow-band filters, was designed and implemented by the Federal Republic of Germany for ESA tests with the ATS-6 satellite. An alternative signaling scheme using spread-spectrum pseudo-noise (PN) modulation with phase-locked loop demodulation and correlation detection was felt to give improved performance in a multiple EPIRB environment. This report presents a description and comparative analysis of the two designs.

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1. INTRODUCTION

This report analyzes an existing L-band distress buoy design, and recommends alternative designs which should be considered.

where P_d is the probability of detection on one of the baseband filters. It should be noted that one filter sees only half of the received signal power assuming a reasonably balanced binary message as should be produced by the use of Miller encoding.

In order to create a false alarm due to noise, two filters with the appropriate spacing, say, 240 Hz, must erroneously indicate the presence of a pair of signals. Assuming 48 channels and a 4-channel separation between Mark and Space frequencies, the probability of false alarm, P_F, is approximately

$$P_F = 44 \; (P_f)^2 (1 - P_f)^{46},$$

where P_f is the probability of noise causing the threshold to be exceeded in a given channel filter. The expression above is approximate, in that it excludes the possibility that more than 1 pair of filters exceeds the threshold due to noise.

Now, the received carrier-to-noise density, C/N_o, worst case, is on the order of 20 dB Hz. This assumes the link budget given in Table 1.

The link budget of Table 1 does not include a multipath loss. This effect will be considered as part of the detection analysis.

2.2 DETECTION ANALYSIS

In the absence of multipath fluctuations, the received signal-to-noise ratio (S/N) in a 75-Hz bandwidth filter is

$$S/N = 24 \text{ dB} - 3\text{dB} - 18.75 \text{ dB} = 2.25 \text{ dB}.$$

The 3-dB reduction is due to the fact that the signal is at each of the two FSK frequencies only half the time.

Now assuming a Rician fading signal with carrier-to-multipath ratio (C/M) of about 6 dB, and assuming that the fading is correlated over most of the detection integration, there is a loss due to signal fluctuation on the order of 2 dB.(2) This means that the available S/N per received bit is on the order of 2.25 dB-2.00 dB = 0.25 dB.

Next, the loss through the envelope detection process must be estimated. Given an 0.25 dB S/N at the input to the detector, the output S/N per bit is roughly -1.5 dB.(3) But 32 bits are integrated, on the average, over a 1-sec interval. Thus, the S/N at the output of the integrator is -1.5 dB + 15.0 dB = 13.5 dB where 15 dB expresses the enhancement provided by the 32 bit integration.

At that level, detection probabilities and false alarm rates on the order of those shown in Table 2 are achievable.(4)

TABLE 2. RECEIVER OPERATING CHARACTERISTICS

Probability of Detection (P_d)	Probability of False Alarm (P_f)
0.95	1×10^{-6}
0.995	1×10^{-4}

Using the second set of values in Table 2, it is found that the probability of detection, P_D, of the FSK distress signal is

$$P_D = (0.995)^2 = 0.99,$$

and the probability of false alarm, P_F, is approximately

$$P_F = 44(10^{-4})^2 \; (1 - 10^{-4})^{46} = 4.38 \times 10^{-7}.$$

At one detection decision per second, this implies a false-alarm rate of 1 per 264 days. Note that this detection performance is achieved at C/N_o = 24 dB Hz.

2.3 PERFORMANCE EVALUATION

The basic detection-false alarm performance of the system is quite satisfactory. Following detection; i.e., the determination that a distress signal is present, the outputs of the two baseband

3. ALTERNATIVE DESIGN APPROACHES

Alternative design approaches were investigated to determine if high reliability distress buoy operation could be achieved when more than one buoy is in operation at the same time.

A number of techniques were considered. The constraints on the design are that (a) the transmitter system remain as simple or simpler than the basic design discussed above, and, (b) high reliability detection and data demodulation performance are obtained when two or more buoys are operated simultaneously.

3.1 THE PN-PSK TECHNIQUE

The pseudo-noise phase shift key (PN-PSK) approach has achieved wide acceptance as a spread spectrum-multiple access technique for satellite communication systems. It should be considered for the distress buoy application because it has the potential for meeting the design constraints defined above.

3.1.1 PN-PSK Transmitter Design

A block diagram of one possible distress buoy-transmitter implementation is shown in Figure 1. The system is somewhat simpler than the basic FSK design, and will provide a more stable carrier frequency because it uses a fixed crystal oscillator rather than a Voltage Control Oscillator (VCO) as its frequency reference.

The operation of the device is as follows: The crystal oscillator output is multiplied up to L-band and mixed with the L-band VCO output in a phase detector. The output of the phase detector, with the PN-PSK baseband signal, is passed through a loop compensation network, and applied to the voltage control input of the L-band VCO to close the loop. The PN-PSK baseband signal is added to the phase error output, so that the L-band VCO output is phase-modulated by the PN-PSK data stream. Phase

TABLE 3. MESSAGE FORMAT

Data Rate	64 bits/sec
Message Length	64 bits
Message Repetition Rate	1/sec
Number of Synchronization Bits	22
Number of Information Bits	42
Pseudo-Noise Sequence Length	127 bits

Each bit is represented by a 127-bit PN sequence, so that the actual transmitted bit rate is 64 X 127 = 8128 bits/sec. The phase modulation deviation is chosen so that there is considerable carrier power in the transmission. In particular, the deviation is set at ± 45 degrees. Thus, residual carrier power is 3 dB down from the total transmitted power output.

3.2 ACQUISITION PROCEDURE

The first step in acquiring the distress message is the detection of the presence of a carrier component at the receiver. Given that the worst-case C/N_o = 20 dB Hz as before, the residual carrier power-to-noise density will be 17 dB Hz, worst case.

Let us assume that the search for the residual carrier is accomplished by a phase-locked loop (PLL). The maximum sweep rate ω_{max} for a 90 percent probability of detection is approximately$^{(5)}$

$$\omega_{max} = [1 - \sqrt{\frac{N_o B_n}{C}}]\, B_n^2 ,$$

where B_n is the double-sided noise bandwidth and C/N_o is the pulses at the distress message code rate, 64 bits/sec. These can be detected to produce the distress message. The message format given in Table 3 is such that there is insufficient energy-to-noise density per received distress message bit to ensure reliable detection of the message bits. In particular, the data power-to-noise density is equal to the residual carrier-to-noise density, assuming 45 degrees PSK deviation. Therefore, C_d/N_o = 17 dB, and the energy-to-noise density per bit is

$$E_b/N_o = C_dT/N_o = 17 \text{ dB} - 18.06 \text{ dB} = -1.06 \text{ dB}$$

where T is the bit duration.

Reliable bit detection requires E/N_o on the order of 10 to 12 dB. To achieve this level, the outputs of the correlation detectors can be integrated using digital techniques. For example, an 11 dB E/N_o can be achieved by integrating 30 received data bits each of which has E_b/N_o = -1.06 dB; i.e., there is an integration loss of roughly 2.5 dB.

3.4 DESIGN ALTERNATIVES

Thus far, we have assumed a basic message format similar to that of the FSK distress buoy system. However, by slowing the message bit rate down, we can gain two advantages. First, the 2.5 dB integration loss can, for the most part, be avoided. Second, the use of a slower data rate makes it easier to implement the entire data detection process (except for the PLLs) in digital computer software.

For example, a 2 bit/sec distress message data rate will provide E/N_o on the order of 17 dB - 3 dB = 14 dB, which is more than enough for reliable detection. The 2.5 dB integration loss will be avoided, provided that coherent detection is employed, and this can be done given a sufficiently low data rate.

The PN code bit rate is 2 X 127 = 254 bit/sec assuming a 2 bit/sec data rate and a 127 bit code. The PN encoded data signal must be digitized at a rate which provides roughly 5 samples per

4. SYSTEM COMPARISONS

The PN-PSK distress message system described here provides code division-multiple access capability. This added capability provides for a lower probability of mutual interference when two or more buoys are in operation simultaneously, relative to that achieved with the FSK apporach.

Of course, the added modulation complexity necessitates a more complicated receiver structure. However, the detection performance achievable with the PN-PSK technique is very similar to that achievable with the FSK approach.

The added complexity of the ground station is not considered a serious disadvantage because only a few ground stations are contemplated for the system. The additional costs of the electronics required are negligible compared with overall ground station costs. Moreover, the additional cost of the ground station electronics for the PN-PSK approach is certainly negligible compared with overall system costs.

Overall system costs are critically dependent on transmitter costs because many transmitters will be deployed in the system. The PN-PSK approach results in a transmitter configuration which is somewhat simpler than that of the FSK approach, given that crystal-stabilized frequency operation is required. In particular, it is relatively easy to phase modulate a fixed tuned crystal oscillator output, while frequency modulation requires either a voltage controlled oscillator which has poorer frequency stability or an additional up-conversion operation.

Table 4 shows a comparison of the performance factors of the FSK and PN-PSK approaches.

5. CONCLUSIONS AND RECOMMENDATIONS

The PN-PSK approach offers the potential for better data performance, better multiple transmitter capability, and slightly simpler transmitter configuration. These performance advantages were obtained by increasing the complexity of the transmitted waveform, and hence increasing ground station receiver processing complexity.

The PN-PSK system design presented here was tailored for ease of comparison with the existing FSK system design. It is recommended that further consideration be given to the PN-PSK approach in order to (a) optimize performance for the distress buoy mission, and (b) adapt the design for complete digital computer signal processing of the received distress messages.