Multiple Terminal Acoustic Communications System Design

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Abstract—**A design is presented for a system providing highly reliable command and control acoustic communications between a mother ship and a number of small fast submersibles. The small submersibles may be employed for underwater mining, exploration, bottom mapping, or military surveillance. Modulation and coding design is presented; the techniques discussed provide multiple protection against multipath and fading, high reliability, acceptable transmitted signal total time duration, simplicity, and economy. The required decision point signal-to-noise ratio (SNR) for Rayleigh fading conditions is derived for the modulation and coding design. Particular attention is paid in the receive signal processing to the Doppler (relative velocity) and Doppler variation (relative acceleration) problems inherent in a scenario with mobile endpoints. A Figure-of-Merit (FOM) calculation is provided for typical geometrical and environmental parameters. It is shown for a realistic source level that the required SNR can be achieved at long range with considerable endpoint relative motion.**

I. INTRODUCTION

THE EXPLOSIVE growth of undersea vehicles which followed development of North Sea oil and gas discoveries of the late sixties and early seventies continues. While the diver still dominates commercial underwater activities, the role of manned submersibles and remotely controlled vehicles progressively increases. The largest U.S. submersible commitments at present are in the academic and military communities. The U.S. Navy has a total of seven manned submersibles and seven unmanned vehicles in operating condition at the moment. They are based on both coasts and in Washington, DC; their largest concentration is in the San Diego area.

Most of the U.S. Navy vehicles have a capability for TV viewing and video taping. Most have a manipulator and are constructed to carry 35-mm or 70-mm still cameras with a light strobe. Configuration, dimensions, weight, complexity, and depth capabilities vary from vehicle to vehicle, as does work instrumentation and vehicle attitude monitoring instrumentation. At present, Navy vehicles operate within a relatively confined radius of the mother ship and up to depths of about 20 kft. It is desirable for future U.S. and other Navy oceanographic and military operations to equip the submersibles with sophisticated active and passive sonar equipment and have them operate at ranges up to 100 nmi from the mother ship and at speeds of up to 10 knots.

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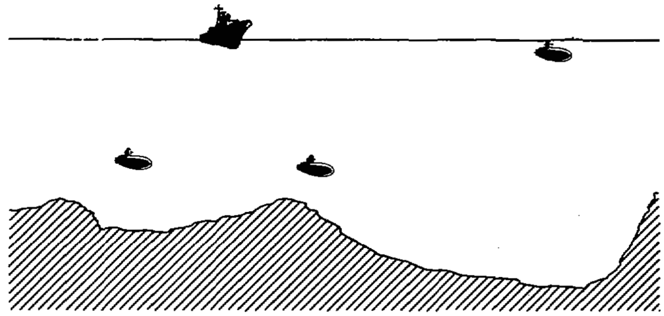

Fig. 1. Small submersible scenario.

Fig. 1 illustrates the scenario of interest. A surface ship with an acoustic transmit array, generally at a shallow-to-intermediate depth, communicates with a submersible equipped with an acoustic receive array, generally at an intermediate-to-deep depth, the objective being to provide command and control information to the submersible. The acoustic information transfer is treated here as being strictly from ship-to-submersible and the amount of message information that must be transmitted is small. We assume that any data gathered by the summersible can be retrieved at a later time, either physically or via EM means, although a submersible-to-ship communications link (utilizing data compression, if necessary) is possible. Since there may be more than one submersible, the message must contain destination information as well as the actual command and control information. It is anticipated that the above message information can be conveyed by an 8-bit block.

The minimum operational range is established as 100 nmi. This operational range capability permits a substantial operating radius about the surface ship. The reliability of the communications system is described by two (conditional) error probabilities: 1) Pr $\{M_i \neq m_i \mid m_i\}$, the probability that a message m_i destined for the ith submersible is not received and decoded correctly as M_i, and 2) Pr $\{M_j = m_j \mid m_i; i \neq j\}$, the probability that a message m_i is received and decoded as a valid message by the (incorrect) jth submersible. The communications system is designed to conform to the following error probabilities per message:

$$\Pr\{M_i \neq m_i \mid m_i\} = 10^{-6} \tag{1}$$

$$\Pr\{M_j = m_j \mid m_i; i \neq j\} = 10^{-12}, \quad i, j = 1, 2, \cdots, N_S \tag{2}$$

where

$$N_S \times N_T \leqslant 2^8.$$

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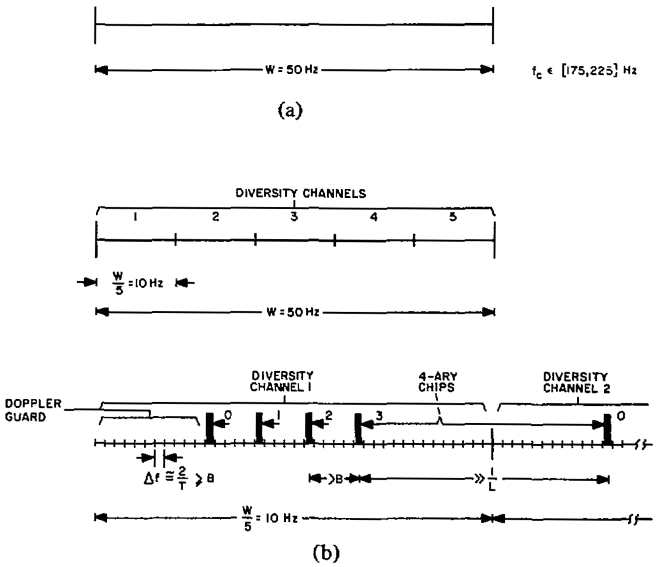

Fig. 2. Modulation and diversity design. 1. There are ≅80 spectral bins per diversity. 2. Time duration of minimum signal element (denoted by shaded areas). T = 16 s. (a) Signaling center frequency and bandwidth. (b) Modulation design parameters.

The quantity N_S is the number of submersibles within operational range and N_T is the command and control information.

II. MODULATION AND CODING DESIGN

The modulation and coding design proposed here provides the following features:

Multiple protection against multipath and fading
Low (conditional) error probabilities [cf. (1) and (2)]
Acceptable transmitted signal total time duration
Simplicity
Economy.

The last point above is a matter of extreme practical importance; the proposed modulation and coding design can be easily implemented utilizing *existing* communications system technology.

Several considerations, foremost among them being the capability of existing communications system hardware, the minimum operational range requirement of 100 nmi and associated standard path loss to the receiver, and the relative absence of commercial and military traffic lines, have led to a signaling center frequency f_c in the range [175, 225] Hz and a signaling bandwidth W of 50 Hz, as shown in Fig. 2(a). The geometry of surface ship and (any one) submersible, depicted in Fig. 1, allows multiple reflections, caustics (surface ship projector in surface duct), and ray path refraction. The severity of these effects depends (environmentally) on the ocean depth, season, nature of the boundary inhomogeneities, and vertical and horizontal sound velocity gradients. In general, there will be degradations suffered by the transmitted signal, due to multipath cancellation and fading; the source of these degradations is conveniently described by the medium time dispersion L and frequency dispersion B. NISSM II and other theoretical models were utilized with a surface ship projector (source) depth S = 30 ft (9.1 m), receiver array depths R = 300 ft (91.4) and R = 1000 ft (304.8 m), and frequency f_c = 200 Hz to obtain the following interval estimates for L and B:[1]

$$L \mathrel{\tilde{\in}} [0.5, 2.4] \text{ s} \tag{3}$$

$$B \mathrel{\tilde{\in}} [.02, 0.2] \text{ Hz.} \tag{4}$$

The lower limit on L is valid for the important range increment 100-200 nmi; the upper limit on L is obtained only at the shorter ranges on the order of 10 nmi. The lower limit on B applies to volume dispersion (i.e., purely refracted propagation paths) and an endpoint relative motion of 30 knot at a range of 100 nmi; the upper limit on B includes the effects of surface and bottom scattering with the standard deviation of the boundary undulations assumed to be 1.4 m (SS3) and 0.2 m, respectively. The upper limit on B is believed to be quite pessimistic.

The basic design philosphy is to use minimum signaling elements well suited to the acoustic communication channel and any existing equipment, further improve the bit error rate performance by diversity to achieve a moderately low bit error rate, and employ error correcting coding to obtain the final error rate. The proposed callup communications system employs 4-ARY FSK (M = 4), a simple modulation technique which is efficient in terms of the available bandwidth W, facilitates recognition of fades and receiver AGC adjustments, and allows an acceptable transmitted signal time duration [1]-[3]. Multiple protection against multipath and fading is provided. First, by use of a long-time duration T for the minimum signaling element (tonal pulse), i.e., we choose

$$T = 16 \text{ s} \tag{5}$$

which reduces intersymbol interference in time (the transmitted time separation $T \cong T + L$) and generally assures temporal and spectral coherence of the received pulse ($T < (1/B)$ and $w = (1/T) < (1/L)$, respectively). Second, by a receive tone spacing sufficiently large, i.e., we choose the receive frequency resolution Δf as

$$\Delta f \cong \frac{2}{T} = 0.125 \text{ Hz} \tag{6}$$

which reduces intersymbol interference in frequency (the transmitted frequency separation $\Delta f \cong (1/T) + B$). Third, by the redundancy offered by fivefold frequency diversity with diversity-to-diversity channel spacing much greater than the fading correlation width of $1/L$, to insure statistical independence in frequency. It is obvious that the above selections do not protect against the entire range of channel parameters in (3) and (4); however, they do provide a starting point from which specific changes for specific channels can be made. These selections leave sufficient unused bandwidth to accommodate realistic Doppler shifts associated with the down-link endpoint relative motion. The long tonal time duration and

[1] Bottom class and sound velocity profile (SVP) employed were those associated with the acoustic province MGS3 (57 N, 40 W) and the summer season.

the redundancy act to increase the SNR at the decision point for the transmission bits. The modulation and diversity design parameters are depicted in Fig. 2(b).

The low (conditional) error probabilities of (1) and (2) may be met by an encoded message format consisting of two codewords, each carrying the same eight information bits. As previously mentioned, the eight information bits specify which of the N_S submersibles is being targeted, in addition to specifying the command to the submersible. Thus, for example, three of the eight bits specify which of eight submersibles is being sent information, with the remaining five bits specifying one of 32 commands. Upon reception, the codewords are decoded separately and the eight information bits accepted as valid *only* if both codewords decode identically. Mathematically, we may express the ith encoded message x_i in the following manner:

$$x_i \triangleq [f_1(m_i), \quad f_2(m_i)] = (c_{1i}, \ c_{2i}) \tag{7}$$

where $f_1(\cdot), f_2(\cdot)$ denote linear transformations on the message m_i, and (c_{1i}, c_{2i}) are the two aforementioned codewords concatenated. The probability of message error may be written as[2]

$$\begin{aligned}\Pr\{M_i \neq m_i \mid m_i\} &= 2\Pr\{M_{li} \neq m_i \mid m_i\} \\ &\quad - \Pr\{M_{li} \neq m_i \mid m_i\}^2 \\ &\cong 2\Pr\{M_{li} \neq m_i \mid m_i\}, \qquad l = 1, 2\end{aligned} \tag{8}$$

where M_{1i} and M_{2i} represent the received and decoded messages associated with the codewords c_{1i} and c_{2i}, respectively. Since the probability of message error is to be maintained at 10^{-6} (cf. (1)), the probability of a codeword error, from (8) must be held to

$$\Pr\{M_{li} \neq m_i \mid m_i\} \cong 5 \times 10^{-7}, \qquad l = 1, 2. \tag{9}$$

The false message error probability of (2) is related to the probability that both codewords (c_{1i}, c_{2i}) contain the *same* error, i.e.,

$$\begin{aligned}\Pr\{M_j = m_j \mid m_i; i \neq j\} &= \Pr\{M_{1j} = m_j \mid m_i; i \neq j\} \Pr\{M_{2j} = m_j \mid m_i; i \neq j\} \\ &\leqslant \frac{1}{N}[1 - \Pr\{M_{lj} = m_i \mid m_i; i \neq j\}]^2, \\ &\qquad l = 1, 2.\end{aligned} \tag{10}$$

The upper bound is obtained by assuming that each codeword has N nearest neighbors[3] which are equally likely to decode in error. The bracketed complementary probability is numerically equal to that of (9). For a particular 8-bit block of information bits, there are eight nearest neighbors; thus $N = 8$ and

$$\Pr\{M_j = m_j \mid m_i; i \neq j\} \leqslant 3.1 \times 10^{-14} \tag{11}$$

which is substantially less than the error probability requirement of (2). An upper bound on the probability that any one *or more* vessels have a false message is given by

$$\begin{aligned}1 - [1 - \Pr\{M_j = m_j \mid m_i; i \neq j\}]^{N_s} &\leqslant N_s \\ \cdot \Pr\{M_j = m_j \mid m_i; i \neq j\} &\leqslant 1.0 \times 10^{-12}\end{aligned}$$

by invoking the Union bound and assuming that $N_s = 32$.

We now turn to the detailed code structure. The code must be capable of correcting at least two errors so that received bits of moderate quality will not affect proper response, and must admit economical and simple encoding and decoding. The latter requirement demands that the codeword length be as short as possible. The number of linear code alternatives that satisfy the practical requirements is small; namely, we have the (21, 11; 2, 6) difference-set and the (24, 12; 3, 7) (overall parity check) extended Golay code [4]. Constant weight codes [5] may find some suitability to an application of this type, but are not considered here. The difference-set code corrects up to two errors in the 21-bit codeword and is relatively simple to decode; the fact that it is a Projective Geometry cyclic code also guarantees that is can be (1-step) majority-logic decoded. The Golay code corrects up to three errors and is capable of detecting the existence of a fourth error in the 24-bit codeword. The Golay code is moderately hard to decode; however, much recent work on efficient implementation and block synchronization techniques make it the more desirable choice. To use the Golay code, we shorten it to a (20, 8; 3, 7) code in order to accommodate the eight information bits. Note that the shortened code retains the same distance and error correcting features of the original code [6].

Assuming the codeword error of (9), we may compute the error rate per coded bit for the shortened Golay code, and then the required SNR per tone at the decision point. The interleaving and unanimity count on the transmission bits acts to guarantee the statistical independence of coded bit errors; therefore, the coded bit error rate P may be found from the expression

$$\begin{aligned}\Pr\{M_{li} \neq m_i \mid m_i\} &= 5 \times 10^{-7} \\ &= \sum_{n=4}^{20} \binom{20}{n} P^n (1-P)^{20-n} \\ &= \binom{20}{4} P^4, \qquad l = 1, 2\end{aligned} \tag{12}$$

and

$$P \cong 3.2 \times 10^{-3}. \tag{13}$$

The transmission bit error rate p may be determined from the

[2] We assume that the occurrence of codeword errors are statistically independent, justified by the fact that the codewords will be separated in time by greater than the average fade duration $1/B$.

[3] In the Hamming metric sense.

expression

$$P = p^3 + 3p^2(1-p)$$
$$\cong 3.2 \times 10^{-3} \tag{14}$$

and

$$p \cong 3.3 \times 10^{-2}. \tag{15}$$

Finally, the transmission character error rate P_e for $M = 4$ FSK signaling is related to the bit error rate of (15) by

$$P_e = \frac{2(M-1)}{M}\, p$$
$$\cong 5.0 \times 10^{-2}. \tag{16}$$

The character error rate is directly related to the required SNR at the decision point. For $M = 4$ FSK signaling, ideal detection, and fivefold frequency diversity, the shortened Golay coding scheme requires the following SNR value *per tone* for (Rayleigh) fading conditions [7]

$$\frac{S}{N} = 4.5 \text{ dB}. \tag{17}$$

The *total* required SNR is 11.5 dB, taking into account the fivefold diversity. Under fading conditions, an additional allowance of 2.0 dB is necessary to allow for nonideal filters, timing error, waveform distortion in the medium, and AGC and noise shifts in the receiver. The required S/N per tone is then 6.5 dB to meet the (conditional) error probabilities; this is a most reasonable figure for the operational range requirement, as shown in Section IV.

In concluding the modulation and coding design, we must mention the total transmitted signal time duration. We transmit two codewords for a total of 40 bits with the time duration of a minimum signaling element equal to 16 s; thus the total time duration is 10.7 min. We must also allow approximately 1.0 min for a preamble segment to alert the receiver and provide real-time bit synchronization, and 2.0-min propagation time for a 100-nmi range.

III. RECEIVE SIGNAL PROCESSING

The receive signal processing is that commonly associated with M-ARY FSK supplemented by Doppler processing to accommodate the endpoint relative motion. It is required that the initial Doppler be estimated and that any Doppler variations be estimated throughout the transmitted signal time duration of approximately 10.7 min.

To aid the initial Doppler estimation, a two-phase preamble is proposed. Each phase consist of a predefined burst of no more than five tonals with time duration $T = 16$ s; thus the entire preamble time duration is a mere $2T = 32$ s. The preamble and (encoded and modulated) message time allocations are shown in Fig. 3. The preamble tonals for each phase are

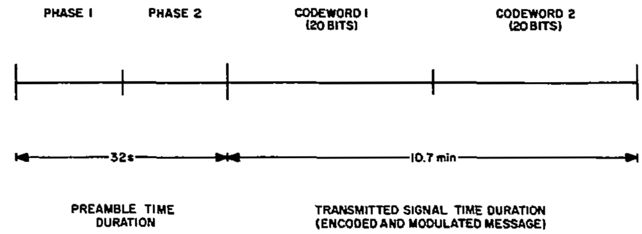

Fig. 3. Premable and message time allocation.

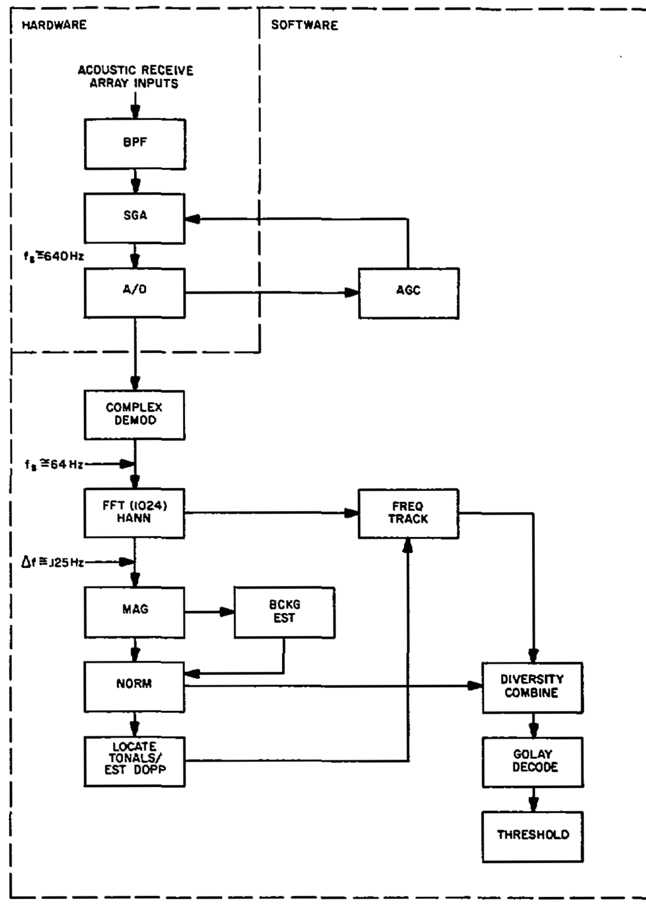

Fig. 4. Receive signal processing.

located utilizing the processing shown in Fig. 4; tonal detection/location unanimity is required for the two phases.[4] The initial Doppler estimate so obtained is then employed to assign a total of 20 phase-difference frequency trackers to the anticipated message spectral bins (four per diversity, fivefold diversity). Shortly after the transmitted signal onset, 15 of the trackers may be disabled, with the remaining five tracking the encoded and modulated message bits.

As shown in Fig. 4, the tracked encoded and modulated message bits are diversity combined, Golay decoded, and thresholded, resulting in the desired 8-bit block of information bits.

[4] The same reliability philosophy is employed here as is in using two codewords to transmit the message and requiring that both be identically decoded.

A matter of concern is the capability of the frequency trackers to deal with the expected frequency slew rate. Exceedingly worst case CPA dynamics calculations indicate that the slew rate s is bounded as follows:

$$s \leqslant 1.7 \times 10^{-3} \text{ Hz/s}. \tag{18}$$

The slew rate of (18) is computed using a relative endpoint range rate of 30 knots, a closest point of approach of 10 nmi, and a frequency of 200 Hz. The simple phase-difference tracker algorithm envisioned for the receive signal processing is capable of a slew rate of 3.1×10^{-3} Hz/s at a SNR of 3 dB/spectral bin (a spectral bin $\Delta f = 0.125$ Hz; cf. Fig. 2). We note that this SNR figure is less than the 4.5 dB of (17), required for acceptable (ideal) detection/decoding. No problem is then anticipated with tonal tracking during the transmitted signal time duration.

IV. PERFORMANCE PREDICTION

Up to this point, we have considered the dispersive nature of the acoustic channel in the sytem design. Now we relate that design to the noise and transmission loss estimated for the channel in order to ascertain overall system feasibility. A convenient means of condensing the many parameters of interest is the (communications) Figure of Merit (FOM), which equals the maximum allowable one-way transmission loss for a specified character error rate. The FOM minus the transmission loss then equals the signal excess (SE), which must be positive for the actual communications character error rate to be at least as good as that value specified. There should be sufficient design margin in these calculations to account for the fact that parameters such as ambient noise and transmission loss are best modeled as stochastic variables with certain standard deviations.

The (FOM) is given by

$$\begin{aligned} \text{FOM} = L_s - \{&[L_A - (\text{DI} - \text{DA})] \\ &\oplus [L_{\text{SN}} - L_{\text{SNR}} - D_N)] - (\text{DT} + DS) \end{aligned} \tag{19}$$

where L_A is the ambient noise spectrum level, DA is the degradation to the theoretical acoustic receive array directivity index DI, L_{SN} is the self noise level, L_{SNR} is the theoretical acoustic array discrimination against self noise, D_N is the degradation to the L_{SNR}, DT is the detection threshold, and DS is the processing system loss. The symbol $\oplus$ denotes power level addition.

The total background noise spectral level L_N (bracketed term of (19)) has been measured at the broadside beam output of a representative receive array for several speeds and a frequency of 200 Hz.[5] The values obtained are shown in Table I.

[5] The ambient noise spectral level included in the total background noise spectral level is consistent with that of the acoustic province MGS 3(57 N, 40 W), S = 30 ft (9.1 m), R = 300 ft (91.4 m), and the summer season.

TABLE I
TOTAL BACKGROUND NOISE SPECTRAL LEVEL FOR SEVERAL SPEEDS, 200 Hz

SPEED (KN)	L_N(DB//1μPA/HZ)
3	57.0
6	58.8
8	62.0
10	68.0
15	79.1

TABLE II
FOM AND SIGNAL EXCESS AT 100 nmi FOR SEVERAL SPEEDS, 200 Hz

SPEED (KN)	FOM (DB)	SE(DB)
3	134.5	15.5
6	132.7	13.7
8	129.5	10.5
10	123.5	4.5
15	112.4	-6.6

The transmitted source level per tone is taken to be

$$L_S = 188.0 \text{ dB//1 } \mu\text{Pa} \cdot \text{m} \tag{20}$$

implicitly assuming an omnidirectional projector. The value of (20) is also selected as a value achievable by existing equipments.[6] The detection threshold per tonal may be calculated from the relation

$$\text{DT} = \text{MDL} + 10 \log (\Delta f) - \text{RG} \tag{21}$$

where $\Delta f = 0.125$ Hz is the receive frequency resolution, MDL is the minimum detectable level per tonal, and RG is the redundancy gain. The MDL is obtained from (17) plus 2.0 dB to account for nonideal detection; thus the MDL = 6.5 dB/tone. We assume RG = 1.0 dB, nominally associated with redundancy factor of from 2 to 4. Inserting the above values into (21), we obtain

$$\text{DT} = -3.5 \text{ dB}. \tag{22}$$

Contribution to the factor DS principally arises from operator loss. We assume the operator loss is zero; accordingly, we set $DS = 0$ dB in the ensuing calculations.

Based on the above discussion and the data presented in the form of Table I and (20) and (22), we compute the FOM values of Table II. To complete the picture, transmission loss calculations have been made utilizing the FACT and NISSM II models with coherent multipath combination and the geome-

[6] More precisely, the total required source level L_s + 10 log 5 is achievable by existing equipments.

trical and environmental parameters previously mentioned. The peak transmission loss in a 50-nmi window centered about 100 nmi was computed as approximately 119 dB. The signal excess SE at 100 nmi is also shown in Table II. We see that it appears possible to provide reliable command and control capability out to the desired range of 100 nmi for submersible speeds up to approximately 10 knots.

V. CONCLUSION

A design has been presented for command and control acoustic communications between a surface ship and a number of small moderately fast submersibles. The design offers a reliable command and control capability out to the desired range of 100 nmi for submersible speeds up to 10 knots, in addition to a simplicity and economy of implementation. It is felt that the results presented here will prove useful to the command and control of commercial submersibles devoted to mining, exploration, and bathymetry tasks and to military submersibles dedicated to coastal protection and enemy surveillance activities.

REFERENCES

[1] P. Hearn, "Underwater acoustic telemetry," *IEEE Trans. Commun. Tech.*, vol. COM-14, pp. 839–843, Dec. 1966.

[2] C. S. Miller and C. E. Bohman, "An experiment in high rate underwater telemetry," in *Proc. Oceans 1972 Conf.*, pp. 34–38, 1972.

[3] A. Quazi, D. Viccione, M. Lackoff, E. Gannon, and R. Kurth, "Results of high data rate underwater acoustic communication experiments," presented at the 9th Int. Cong. Acoust., Madrid, Spain, July 4–9, 1977.

[4] W. W. Peterson and E. J. Weldon, Jr., *Error Correcting Codes*. Cambridge, MA: MIT Press, 1972.

[5] J. Proakis, R. R. Reed, J.K. Wolf, and J. F. Pieper, "The Design of Efficient Coding for Rayleigh Fading Channels," *IEEE Trans. Inform. Theory*, vol. IT-24, pp. 457–468, July 1978.

[6] E. R. Berlekamp, *Algebraic Coding Theory*. New York: McGraw-Hill, 1968.

[7] A. H. Nuttall, "Error probability characteristics for orthogonal multiple alternative communication With D-fold diversity," NUSC/NL TR 4769, June 19, 1974.

Portable Acoustic Tracking System for Divers (PATS)

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Abstract—**A portable acoustic tracking system (PATS) has been developed for the Navy to track underwater construction teams in water depths to 200 ft. The tracking system can be deployed and operated by the divers and is intended for use in remote areas and for nearshore survey, maintenance, and construction work. A self-calibrating system provides a geographically justified track for up to eight divers. Diver position coordinates are computed from acoustic measurements at periodic intervals and displayed for control purposes. The positions are also recorded for future reference.**

I. INTRODUCTION

LATE IN 1975, the Naval Facilities Engineering Command requested that the Applied Physics Laboratory design a system for locating and mapping underwater cable runs to aid the maintenance and repair of underwater cables and electronics. The result of the study was a set of requirements and an operating method for a diver-tracking range called the PATS (portable acoustic tracking system). In essence, the divers locate the underwater object to be tracked, and the PATS locates and maps the positions of the divers.

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The basic requirement governing the design was that it be portable and readily usable at remote field sites by Navy underwater construction teams. Specific requirements that evolved during the study were:

a) Be deployable from boats as small as 20 ft in length,
b) Be capable of continuously tracking up to eight targets,
c) Contain no single subassembly with a weight greater than 60 lb,
d) Be suitable for operation in water depths of up to 200 ft,
e) Be suitable for use in a relatively noisy nearshore environment,
f) Have a range of approximately 1 mi,
g) Have a circular probable error of 5 ft,
h) Include plotting equipment to provide a permanent record of target track,
i) Be suitable for immersion periods of 60 days on station,
j) Include a radio frequency link which would permit monitoring, plotting, and controlling the system at points up to 5 mi from the tracked object,
k) Include nonmagnetic diver-carried acoustic transmitters.

The deployment and utilization of the PATS would generally proceed as follows. The PATS, along with the underwater construction team, would be deployed to the work site where the system would be removed from portable shipping con-

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