NRL REPORT S-3467

FACTORS INFLUENCING THE DESIGN OF LONG-RANGE ECHO-RANGING EQUIPMENT

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May 16, 1949

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ABSTRACT

Advantages of echo-ranging in obtaining long detection ranges are pointed out. The mutually independent equipment parameters -- frequency, transducer area, power output, and recognition differential -- are consecutively discussed; and the bases of decisions regarding the choice of these parameters presented. The parameters obtainable for the first equipment are 10-kc frequency, 10-kilowatt power, 3-ft-diameter transducer, and -23 db recognition differential, with 5-kc equipment following as soon as feasible. Conclusions are drawn regarding ranges to be anticipated with the first equipment operating under various water conditions.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem S07-12R

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INTRODUCTION

Long contact ranges by low-frequency listening have been reported not infrequently. For example, ComSubRon 6 has reported listening from submarines to the noise output of 10-knot schnorkelling submarines at ranges greater than 30,000 yards. In the Pacific for all 250 rpm runs, an average range of 20,647 yards in October, January, and March has been reported by Submarine Division 32. If such ranges could be obtained by echo-ranging, many advantages of this mode of operation over listening would be realizable. Foremost, echo-ranging would not require a noisy target but would permit detection of a quiet, creeping target equally well. Echo ranges are not decreased to the same extent as listening ranges by background noise: Echo-ranging could therefore give improved ranges in a high sea state or with own ship generating considerable self-noise. Finally, echo-ranging would yield range as well as bearing.

The only reason why echo-ranging has not yielded long ranges to date appears to be that properly designed low-frequency equipment has not been tried. It seems likely that echo-ranging equipment, properly designed for long range, should give ranges of not less than 30,000 yards when used under the conditions which yielded 8,000 yards with WCA equipment in the ComSubRon 6 tests. There is also the definite possibility that properly designed echo-ranging equipment can operate over a skip-distance.

The first long-range search equipment has been planned and is under way. It is intended that this equipment be installed in a submarine in order to permit experimental work at a variety of transducer depths. The objectives in this problem are to develop a system to the stage of operating in the field, to evaluate the performance of this system, and to study low-frequency echo-ranging potentialities. This report presents the reasoning which led to the selection of design parameters and presents the planned parameters.

METHOD OF ANALYSIS

In order to show clearly the effect of any echo-ranging-equipment parameter on equipment performance, it is necessary to use a set of parameters which are mutually independent. A convenient choice is the following set:

Frequency
Transducer area
Power output
Recognition differential

A good design for long range detection must approach optimum values of all these parameters as closely as feasible.

While there is no intention of becoming involved here in the details of mathematical analysis, the form which the echo-ranging equation takes for the above set of parameters may be of interest to some readers and will serve to substantiate certain curves which will be presented. The equation is

$$10 \log P + 20 \log A - \delta - 1.5 \times 10^{-4} f^{1.3} R + 60 \log f + 102 = \text{Divergence loss and Bending loss at range } R \tag{1}$$

in which

P is power output of the transducer in kilowatts
A is transducer area in square yards
δ is recognition differential
f is frequency in kilocycles
R is range in yards at which the probability of detection is 50%

The equation assumes limitation by the self noise of a 20-knot destroyer with a conventional dome, and a target strength of 10 db.

FREQUENCY

With all other equipment parameters held constant, the left side of equation (1) may be computed as a function of range for different frequencies. The resulting curves plotted in Figure 1 show the equipment merit (left side of equation (1)) as a function of range for each frequency chosen. These curves are relative to that at 10 kc at 1 kiloyard.

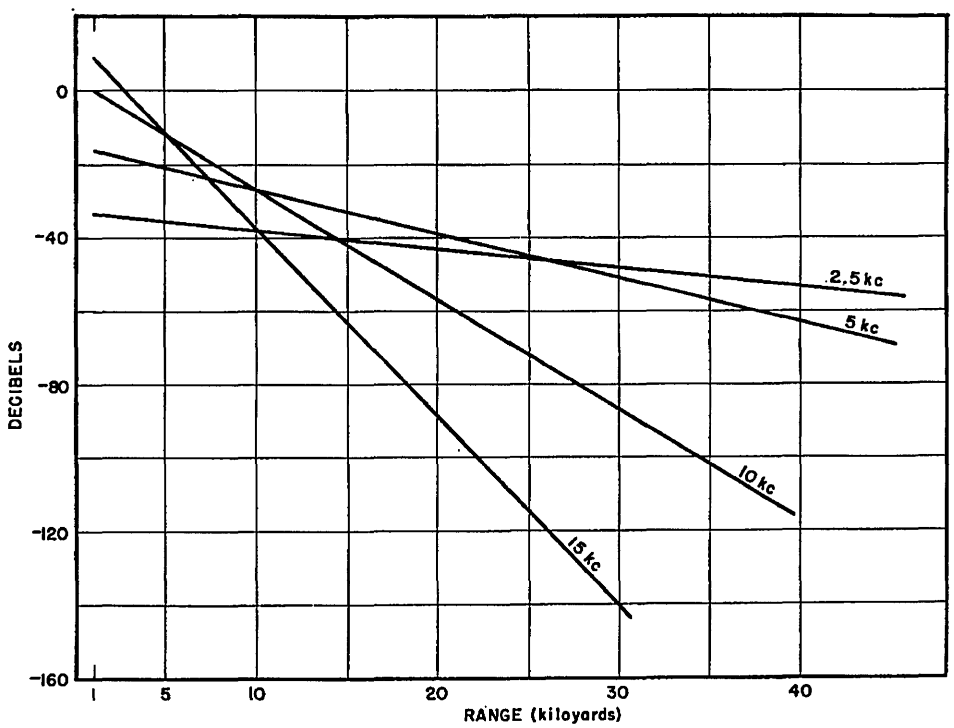

Fig. 1 - Equipment merit as a function of range (relative to 10 kc at 1 kiloyard)

The most striking fact presented in Figure 1 is that different frequencies are optimum at different ranges. Therefore, if it is desired to exploit most fully the rare occurrences of optimum water conditions with a sacrifice in shorter ranges under poorer conditions, a very low frequency such as 2.5 kc should be chosen; while to get the most out of conditions permitting a 10- to 25-kiloyard range, 5 kc is optimum. The ranges between these latter limits are those on which most emphasis is being placed in this problem, and 5 kc is a natural choice of frequency.

The difficulties in producing and handling a 5-kc transducer are considerable. In fact, it has been estimated that about twice as much time will be required to produce the 5-kc transducer, as to produce a 10-kc transducer. Therefore the use of 10 kc as a first step has been carefully considered, with the conclusion that 10 kc should provide a very significant advance, and that its development is therefore warranted. By studying a 10-kc equipment first and then a larger, higher-power 5-kc equipment, much more significant data will be obtainable with only a moderate increase in over-all time.

The remainder of this report pertains to designs in general but especially to the proposed 10-kc equipment.

TRANSDUCER AREA

Equation (1) indicates that transducer area is the most important equipment parameter after frequency, insofar as single-ping range is concerned. From a performance standpoint, larger area is more desirable up to the point where the sharper beam width begins to cut down search rate. While 15-degree beam width in the horizontal plane and 7-degree in the vertical plane would seem not too sharp for a submarine installation, a greater vertical width would be desired to accommodate pitch and roll in a surface ship installation for which this equipment may, in an emergency, serve as a prototype. Considerations of handling problems also weigh in favor of a broader sound beam. A 1-yard-diameter transducer has been chosen and the beam width will be 18 degrees.

The transducer will be divided into two sections for binaural reception, noise balancing, and SSI. These sections will overlap to provide improved beam patterns of each. All active elements of the transducer will be equally weighted to give maximum power output and maximum directivity index.

The transducing material will be ADP crystals, one-quarter-wavelength long, assembled in the NRL Unit Design which provides mechanical as well as electrical isolation of the sections and affords advantages in fabrication, testing, and control of performance.

POWER OUTPUT

The power output of the transducer is limited by cavitation at very shallow depth, but only by the transducer's own power-handling capacity below 50 feet. The design is intended to permit 2 watts/cm^2 output, or about 10 kilowatts for the whole area. This is about 20 db above outputs of searchlight transducers now in the fleet, a substantial increase. Near the surface, the full output may cause cavitation, necessitating operation at reduced power.

Reference to equation (1) shows that moderate changes in power, such as 100% increase are scarcely significant. Therefore, it is hardly worth considering the use of still higher power unless a large step, such as going to 50 kw output, is taken. Such a step would be extremely costly, especially in time, since quarter-wavelength ADP crystals will not handle anything approaching 10 watts/cm^2 output with long pulses. Such a step would result in improvement only in operation at considerable depth, where the high power could be used without causing cavitation.

RECOGNITION DIFFERENTIAL

The recognition differential, δ, is the ratio of the signal having a 50% probability of detection to the noise in a band 1,000 ~ wide which includes the signal. Noise is used here to include reverberation. Improvement of the recognition differential means reaching down into the noise background to detect a weaker signal.

The ear, or an equivalent circuit, will detect a minimum energy signal of duration 1 second and of intensity about 15 db below the noise level in a 1,000-cycle band which includes the signal. For pulses of say 50 to 1,000 milliseconds in length, increased pulse length is just as effective as increased average power during the pulse in improving the signal-to-noise ratio, the improvement from increasing the pulse length appearing in equation (1) in δ. For this reason, long pulses will be used, at least up to 0.5 second long. This lengthening of the pulse, as far as it can be carried profitably, is a more practical procedure than further increasing the power, because of the greater difficulty in producing and handling the higher power.

The use of the full proposed high energy per pulse will improve the recognition differential only if some 30 decibels discrimination against reverberations can be obtained. Such discrimination appears possible provided that the signal from a target on the beam where the maximum frequency-spread occurs carries a Doppler shift of at least 10 cycles corresponding to a target speed-component of 1.5 knots. This is a likely situation. The method of discrimination proposed is to compensate for own-Doppler in the outgoing frequency so that reverberations lie in a band centered always at the same frequency; then to reject this frequency band by filters. When two frequencies are transmitted simultaneously both will be shifted for compensation of own-Doppler and both reverberation bands will be rejected. Additional means of discrimination against reverberations which may find use are noise balancing in azimuth with a long time constant, and the use of two signal frequencies to produce noncoherent reverberation envelopes and coherent signal envelopes with detector discrimination against the former.

With noise background limiting, design considerations must depend upon the equipment-operator link. Consider first a presentation to the ear. Since the ear is equivalent to a band-pass filter, a rectifier, and a low-pass filter, in cascade; and since the average characteristics of all these elements are known; it becomes a simple task to compute the improvement effected in δ by placing other known circuit elements ahead of the ear. For example, the advantage of passing a long 800-cps signal plus the background noise through a five-cycle-wide band-pass filter ahead of the ear has been observed experimentally by NRL to be 4 db. This result is in general accord with theory because a part of the noise reduction which this filter affords ahead of the rectifier in the ear would have been removed in any event by the low-pass filter after the rectifier. It is somewhat impractical to provide so narrow a filter before detection and even if this were done, the gain of 4 db would be but small reward.

An approach to the problem may be found in putting to use characteristics of the ear itself which at present are ignored in sonar presentations. True binaural detection utilizing two transducers spaced the same (or a greater) time difference apart in water as the ears are in air, with each transducer feeding a channel to one ear, would be expected to yield several decibels gain in δ. The required spacing of at least 27 inches is costly but may be attempted in a later step of the problem. However, any realizable advantage of the lesser spacing of the proposed two transducer sections feeding different ears will be determined in the first step. In addition, the advantage of shifting the electrical phase at one ear relative to that at the other as a function of frequency within the band which the ear receives will be studied.

At present, it appears that the following system will be one of those used. Two frequencies, own-Doppler compensated, will be transmitted. Reverberations will be suppressed. The two signals in the echo will be fed into two channels, each will be filtered and amplified, and the two will then be fed into a detector to produce a sum frequency which will be heterodyned to audibility, amplified, and fed directly to one ear and to the other through a phase shift depending on frequency. A recognition differential as low as -20 db relative to noise and -30 db relative to reverberations seems probable.

For presentation to the eye, very great improvement in range-recorder recognition differential is being sought. The following equipment offers an improvement of about 8 db relative to present amplifier-recorder systems at 25 kc. Two frequencies, transmitted with own-Doppler compensation and provided at reception with reverberation suppression, feed separate amplifier channels before being fed into a detector to produce a difference frequency. This difference frequency of 800 cps plus or minus a target Doppler of at most 8 cps is passed through a filter 16 cps wide before feeding the range recorder. In practice, it is planned to use two such amplifier systems, alike in all respects, one for each half of the transducer, each amplifier being provided with a detector, with detector outputs bucking, to give noise balancing in azimuth. Eighteen-db improvement relative to the present recorder-amplifier equipment seems likely with the noise balancing added. In addition, experimental work at NRL aimed at improving recording paper appears promising. This equipment may be the most sensitive detector of the system.

Other displays for the eye include SSI with a 14-db improvement over present 25-kc SSI by virtue of sharper filters and partial time integration. Multiple parallel filters with scanned outputs appear to offer performance comparable to that of the range recorder.

Finally, electronic triggering of an alarm is planned as insurance against loss of detection because of reduced operator alertness.

CONCLUSIONS

The design parameters which are planned will give this equipment superiority over QGA (used merely as a reference standard) of 25 db at 2,000 yards, 35 db at 4,000 yards, and 80 db at 8,000 yards, a tremendous improvement which offers a chance for substantial increases in range.

With isovelocity water (a very good condition, but not the best since channelling sometimes occurs and is responsible for most of the really long listening ranges that have been reported) approximately 14,000 yards range is predicted with noise limitation by a state 2 sea. At 15 knots, it is predicted that this range will be reduced to 11,000 yards. Under excellent channelling conditions, ranges as long as 30,000 yards may occasionally be obtainable.

With poor water conditions, improved equipment parameters can add very little. When QGA gives 400 yards, the 10-kc equipment may give 600 yards by the direct path. However, with the 10-kc equipment the possibility of echo-ranging via the bottom exists and provision for trial will be made. It appears not unlikely that a range of 6,000 or 8,000 yards can be obtained consistently by this method.

PLANS

Completion of the new system, ready for installation in a submarine, is planned for July 1, 1950. Once the installation is completed, and shakedown including training of operators has been carried out, the evaluation and propagation studies can be undertaken. These should afford checks on theoretical computations which should give a fairly clear indication of the direction in which further progress can be made.

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