SELECTION OF OPTIMUM FREQUENCY FOR SONAR ECHOES FROM UNDER WATER TARGETS

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ABSTRACT

Method is given for selecting optimum frequency for detection of echoes from targets using underwater sound. Attenuation of sound in water increases with frequency while diffraction spreading of the echo decreases. The frequency has also to be chosen so that the estimated strength of the echo is above the observed reverberation level.

Introduction

In location of mines under the surface of the sea, sonar echoes can give great assistance provided the frequency of sonar is rightly chosen depending upon the expected size and distance of the mine and propagation conditions of the sea. The transmitter and receiver are usually identical. Distance of the target is expressed in kilo-yards. The sonar signal attenuates due to three causes, viz., inverse square spreading, refraction effects and absorption in sea water, the latter two are frequency dependent. The reflected intensity will depend on the size and the reflecting power of the target, the latter will depend on frequency, also the reflected beam will have a spread from diffraction effects and the intensity per unit area in the reflected beam will depend on frequency on that account too. The observed echo will also depend on the size of the transducer and the transmitted intensity, the latter has a dependence or frequency. In the text below, the echo strength will be determined as a function of frequency, given other parameters and from the calculation given below, the optimum frequency can be selected so that there is best chance of observing the echo against a particular reverberation background.

Intensity of Echoes in a Non-absorbing Homogeneous Medium

Let the target be assumed to present a square cross-section of length l. The diffraction effects in the reflected beam cause it to show alternate maxima and minima when proceeding from centre to outwards along its square cross-section.

The central maxima has width 2θ given by λ/l and at distance D of receiver from the target, it is spread over an area δ^2 where $\delta = \lambda D/l$. If the energy of the source is I_o, energy per unit area at the target is I_o/D^2 neglecting refraction effects

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and effect of absorption in sea-water. Assuming a reflection coefficient K for the target the reflected energy $KI_o l^2/D^2$ is spread in area δ^2 at the receiver. The energy per unit area on average is $(KI_o l^2/D^2)$ $(l^2/D^2\lambda^2)$. So energy entering receiver of radius a would be $I_r = \pi a^2 . KI_o \frac{l^4}{D^4} \frac{1}{\lambda^2}$. Actually the energy is somewhat concentrated in the central position and so the energy received in the small receiver will be somewhat larger than that shown by a simple ratio of areas as above. Lumping all constants and noting $\lambda \propto 1/n$ where n is frequency and replacing l^4 by square of Area of cross section A

$$I_r = Ca^2A^2 \frac{I_o}{D^4} n^2 \qquad \text{.. .. .. ..} \qquad (1)$$

Similar relation will hold for an object which does not present a rectangular cross-section.

Intensity in an Absorbing Medium

The equation (1) can be corrected for absorption in sea-water as follows. Intensity at target is not just $\frac{I_o}{D^2}$ but $\frac{I_o}{D^2} \exp\left\{-\cdot 23\alpha D\right\}$ where α is Attenuation constant in db/kyd $\left(= \frac{\text{Transmission Anomaly}}{D}\right)$. Since α is frequency dependent it can be replaced by f (n) thus

$$I_r = Ca^2 A^2 \frac{I_o}{D^4} n^2 \exp\left\{-0.46D.f(n)\right\} \qquad \text{..} \qquad (2)$$

The refraction effects can be neglected for short ranges of practical interest.

Conditions for optimum Echoes

From equation 2, the condition for optimum echo strength where frequency n is varied can be obtained by differentiation.

Case (i)

If intensity of source is constant for all frequencies. The condition is

$$1 = .23nf'(n)D$$

$$\text{or } \frac{1}{D} = .23nf'(n) \qquad \text{.. .. .. ..} \qquad (3)$$

Case (ii)

Intensity of source is given by $I_o \propto n^2$ (This being the condition found in general for same power consumption), we get

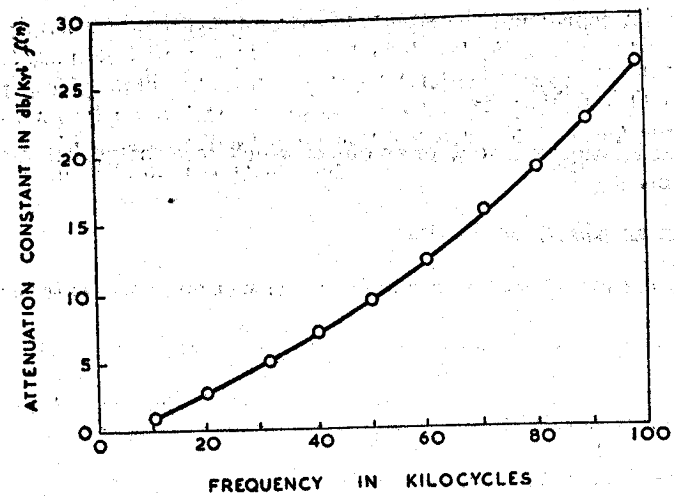
$$\frac{1}{D} = .115n\, f'(n) \qquad \text{.. .. ..} \qquad (4)$$

Case (iii)

Intensity of source is given as a general case by $I_o \propto n^p$

$$\frac{1}{D} = \frac{.46}{(2+p)} nf'(n) \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

In practice the variation of attenuation constant with frequency for isothermal conditions can be experimentally found out and a curve of f(n) or attenuation anomaly against n plotted. Figure 1 gives an experimental curve from data given in the National Research Council Publication (Physics of the Underwater Sound—1949). From this, f'(n) can be known for all values of 'n'.



Thus the values on the right hand side of the equations (3) to (5) can be determined and another curve plotted in general between $\frac{\cdot 46}{(2+p)}$ n f'(n) against 'n' where p is given the proper value. From this graph the frequency for which echo strength is maximum for any value of the range D can be easily determined by finding the value of 'n' corresponding to $\frac{\cdot 46}{(2+p)}$ nf' (n) equal to 1/D. Since $\frac{1}{D^4}$ due to inverse square law does not occur in these equations, the present treatment will apply also for non-point sources. The reflected intensity for optimum n can now be determined by evaluating equation (2) for this value of n.

Reverberation

The echo has to stand out against background of reverberation. One has to determine the relation between the amount of reverberation and the frequency for appropriate intensity of source. Thus reverberation strength plotted against frequency will give the background at any frequency and one can then determine how much the echo level is above the reverberation level. This reverberation curve can be determined experimentally. Research workers elsewhere have shown that the reverberation is independent of frequency when the intensity of source is kept constant. Thus for the usual case (*ii*), the reverberation is proportional to n^2.

Conclusion

Experimentally for the typical water of interest, variation of attenuation constant with frequency is to be determined and also the reverberation level for source of known intensities at various frequencies is to be obtained experimentally. Then as outlined above, the optimum frequency can be determined and theoretical strength of echo for that frequency can be determined. If this echo strength is higher than the observed reverberation level at that frequency for the expected intensity of source, then the same frequency or a neighbouring frequency for which an oscillator can be arranged conveniently can be used in an optimal sense.

In the simple treatment outlined above the diffraction of a parallel beam of sound by a plane perpendicular obstacle is considered. In actual usage the beam will be slightly divergent (negligible) and the obstacle will present a sloping surface. This will only limit the effective return to the first half zone in Fresnel type construction, i.e. the effective dimension l will be somewhat reduced but dependence on frequency will have to be considered practically in the same manner as above.