Def Sci J, Vol 35, No 3, July 1985, pp 295-311

Optimising the Active Sonar System Design

PHILIP C GEORGE & A PAULRAJ

Naval Physical & Oceanographic Laboratory, Cochin-682004

Abstract. Designing an optimum sonar system for a given platform is based on analysing various parameters in their totality, establishing the constraints and assumptions relevant to the platform and the environment as well as on manipulating the design parameters to arrive at the sonar configuration that will maximise performance. In this paper, the design tradeoffs involved in the system design for an active sonar are discussed. A computer aided analysis for the 'first order' estimation of the sonar performance is presented. Typical results of the analysis in connection with the design for certain hypothetical systems are also included.

1. Introduction

Modern warships are considered to be reasonably equipped against aerial threats, under the umbra of sophisticated rader systems and long-range weapons. Most of them, however are quite vulnerable to underwater threats. This is because the detection of submerged targets is relatively difficult.

The low data rate in sonar (due to the low velocity of propagation of only 1.5×10^3 meters/sec) together with the highly varying and adverse influence of ocean on the propagation characteristics makes underwater detection an inherantly difficult task. Strong backscattering due to inhomogeneity in the medium (reveberation), absorption of acoustic energy by the medium as well as variations in velocity of propagation at different layers of water, resulting in complicated raypaths and shadow zones (Fig. 1) are problems peculiar to sonar. Hence the need for a fairly sophisticated system for underwater detection. The design must, however, be optimised, giving due consideration to the constraints on design parameters and resources.

The first step in the design of a sonar system is to configure a basic system model that is likely to meet the requirement. Then, the parameters of the sonar equation that is relevant to that model is manipulated to arrive at the optimum design. In actual practice, however, the system designer is faced with a number of constraints that prevent easy manipulation of these parameters. Some of these constraints are related to the plateform on which the sonar is to be installed. Some others are due to the environment in which the sonar is supposed operate The characteristic of the targets that are expected, tactical aspects and engineering considerations also provide constraints.

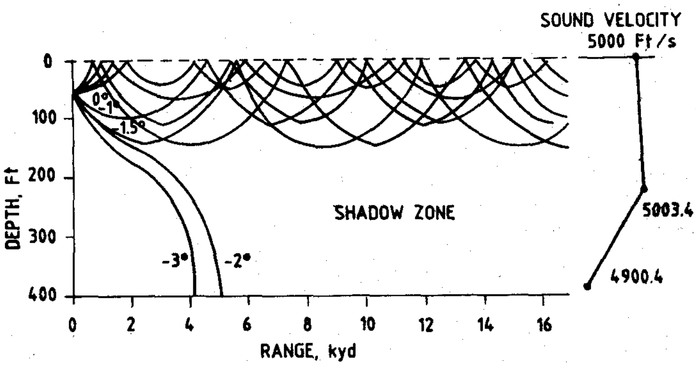

Figure 1. Ray diagram for sound transmission.

Design of an optimum sonar system for the given platform is based on analysing the above parameters and their interrelations in their totality, establishing the constraints/assumptions relevant to the plateform/environment and in manipulating judiciously the design parameters under one's control to arrive at the sonar configuration that will maximise performance. The design is finally completed through several computations and the intution and experience of design engineers

In this paper we discuss the tradeoffs in the design of a panoramic, hull mounted active sonar. The design of a hull mounted sonar is chosen since it is the most common type of sonar. It is chosen to be panoramic since a panoramic sonar has high data-rate. The approach can be easily adapted to other types of sonar also.

2. Factors Affecting the Sonar Design and the Tradeoffs Involved

A number of factors are to be taken into account while desiging a sonar system. A detalied analysis of these factors is beyond the scope of this paper. A list of some of the important factors is given in Appendix I.

These factors effect, either directly or indirectly, the parameters of the so called sonar equation. A brief discussion on the sonar equation, the influence of the above factors on the sonar equation and the tradeoffs involved are given in sequal.

The basic equation for an active sonar, for the noise limited case in given by

$$SL - 2TL + TS = NL - DI + DT \tag{1}$$

where

SL = Source level in dB
(refered to 1 micro-Pascal)

TL = Transmission loss in dB/Kyrds

TS = Target strength (Analogous to target cross section) in dB

NL = Noise level in dB (referred to 1 micro-Pascal)

DI = Directivity index in dB

DT = Detection threshold in dB

The left hand side of the above equation gives the echo level and the right hand side gives the noise masking level. The corresponding equation for the reverberation-limited case is given by

$$SL - 2TL + TS = RL + DT \quad (2)$$

where RL = Reverberation level in dB

(referred to micro Pascal)

The right hand side of the above equation is given the reveberation masking level.

It may be noted that parameters such as SL and DI are, to a great extent, within the control of the designer. DT and TL can atleast be controlled indirectly. NL and TS are beyond the hands of the designer, depending only on the platform and the target respectively. The tradeoffs involved in the proper choice of the above parameters and their dependence on the factors given in Appendix I are discussed briefly below.

2.1 *The Source Level*

The source level (SL) is given by the equation

$$SL = 171.6 + 10 \log P + DI \quad (3)$$

where 171.6 dB stands for the fact that 1 watt of acoustic power produces 171.6 dB at 1 Yard from a point source

P is the acoustic power radiated by the tranducer in watt.

DI is the directivity index.

It is obvious from, the sonar equation that the higher the value of the SL, the higher the echo level and hence the detection range. The source level can be increased either by inceasing the power P or by increasing the Directivity index during transmission. The power that can be applied is, however, constrained by factors such as :—

(a) Onset of cavitation,

(b) Available power on the platform, and

(c) Power handling capacity of the array

The caviation thereshold can be increased by increasing the static pressure on the array, and by operating it at greater depths. Alternatively, the surface area of the array may be increased so that the power fed to the array may be increased without increasing the surface power density. This, however, increases the size and weight of the array and hence machanical constraints on the platform may become the limiting factors. The source level may also be increased by increasing the *DI* during transmission, by beamforming techniques. The directive gain of an array is proportional to the frequency and the physical dimensions of the array. There are some pitfalls in increasing directivity index beyond a certain limit. A few of them are the following :—

(1) As the directivity index is increased the beamwidth reduces. The reduction in vertical beamwidth, however, results in loss of vertical coverage, especially when the platform rolls and pitches.

(2) More number of beams are needed in azimuth, during transmission, to insonify a certain sector. The transmission time is hence increased, resulting in more dead-range. The dead-range must be minimised due to tactical reasons.

(3) Increased number of beams in reception means more signal conditioning channels, and hence increased size, weight and cost.

The optimum choice of source level is hence rather difficult. A logical approach to the choice of source level could be as given below :—

(i) Estimate the maximum array dimention (i.e. the Radius R and the height H) that can be accommodated in the platform. The active area A available on such an array is given by

$$A = 2\pi RHa$$

Where

a is the ratio of the active area to the total area of the curved surface of the array.

(ii) At any frequency F corresponding to a wavelength λ in water, the vertical beam width is given approximately by

$$\theta v = \lambda / H \text{ Radians} \quad (5)$$

Ensure that the beamwidth is greater than or equal to the minimum permissible. If not reduce the value of H accordingly. The minimum permissible beamwidth is usually around 8 degrees, for platforms that experience roll of less than 5° in sea state 2. This could be as less as 4° for platform with stabilized transducer.

(iii) The cavitation threshold is usually 1/3 watt/cm². For pulsed signals it is customary to apply up to 1/2 watt/cm². Hence, by using equation (4), the power that can be radiated by the array is given by

$$P = A/2 = 2\pi RHa/2 = \pi RHa \quad (6)$$

For arrays operating at a depth of h meters, the power that can be radiated is given by.

$$P = \pi RHa\,(1 + h/10) \quad (7)$$

The corresponding electrical power required is

$$P = \pi RHa\,(1 + h/10)/\eta \tag{8}$$

where η is the efficiency

(iv) substituting equation (7) in equation (3) we get the source level in omni-mode of transmission as

$$SL(\text{omni}) = 171.6 + 10 \log RHa + 10 \log (1 + h/10) + DIv \tag{9}$$

where DIv is the directivity index (vertical)

(v) If ripple directional transmission (RDT) is used for increasing SL, select the number of simultaneous beams Nx used in transmission. The optimum value for Nx is 3. Reducing Nx simplifies the hardware for transmission control. This however, implies that more number of transmission will be needed to cover 360° azimuth and hence the dead range also increases. Increasing Nx will have the opposite effect on hardware and dead range. Also, the aperture area for each beam is reduced and the SL will also be reduced to that extent. The source level for RDT case can be computed as follows.

The power that is radiated by each aperture is given by

$$P = \pi RH.a(1 + h/10)/Nx \tag{10}$$

The aperture angle is given by

$$\theta_{Nx} = 2\pi/Nx \tag{11}$$

The corresponding aperature width is

$$A_{Nx} = 2R \text{ Sin } (\pi/Nx) \tag{12}$$

The transmission directivity DI is given by

$$DI = 10 \log (4\pi/(\theta v \times \theta H)) \tag{13}$$

where θv is the vertical beam width given by equation (5) and θH is the horizontal beam width given by

$$\theta H = \lambda/A = \lambda/2R \sin (\pi/Nx) \tag{14}$$

substituting these values in equation (13) we get

$$DI = 10 \log \{ (4\pi/\lambda^2)\, 2RH \sin (\pi/Nx)\} \tag{15}$$

therefore, the source level in RDT is given by

$$SL\,(\text{RDT}) = 171.6 + 10 \log \{(\pi RH \cdot a/Nx)\,(1 + h/10)\} + 10 \log \{(4\pi/\lambda^2)\, 2RH \sin (\pi/Nx)\} \tag{16}$$

2.2 *The Transmission Loss*

The transmission loss (TL) is the ratio in dB of the signal intensity at 1 yard from the source to the intensity at the target or at the receiver. The transmission loss has two components namely (i) The spreading loss, and (ii) The absorption loss.

The spreading loss depends upon the type of spreading. The usual assumption is spherical spreading given by 20 log r, where r is the range. When the energy is trapped between two boundaries such as in a duct or in shallow water, the loss is proportional to the first power of range and is given by 10 log r. In practice, however, a combination of the two types of spreading is observed. Initially for a certain range, till the wavefront encounters the boundaries, spreading follows spherical law and afterwards the cylindrical law. The spreading loss is independent of frequency.

The absorption loss is due to dissipation of energy in the medium. The coefficient of absorption 'α' varies with frequency, temperature, salinity, pressure (depth), etc. in a very complex manner. It shows a very strong dependence on frequency. A handy thumb rule for α, for Indian waters (assuming a temperature of 80° F) is

$$\alpha = 0.0036 \times f^2 \; dB/Km \tag{17}$$

where f is the frequency in KHz.

Because of this strong frequency dependence of α, the detection range depends greatly on frequency.

The combined expression for TL assuming spherical spreading is

$$TL = 20 \log r + \alpha . r + 60 \tag{18}$$

where the term 60 db stands for the fact that r is expressed in kiloyards instead of yards.

2.3 *Target Strength*

The target strength (TS) is defined as the ratio (in dB) of the echo intensity at 1 yard from the target to the incident intensity. This is a parameter dependent only on the geometry of the target and the aspect it offers to the sonar. The average value of TS is usually assumed to be + 15 dB, though smaller submarines such as Daphne may have a slightly lesser value.

If short pulses, say less than 15 m. Secs are used for transmissian, the target strength is likely to fall, in as much as a short pulse may fail to insonify the entire target. Also, for a target to length L at an aspect angle 0, the echo pulse is lengthened in duration by $T = 2L \cos(\theta)/C$. Multipaths also lead to increased pulse length which becomes comparable to the pulse length when the duration is small. Hence a parameter, collapsing loss given by

$$CL = 5 \log (0.015/T) \tag{19}$$

(where T is the actual pulse length)

is included, which is reduced from *TS*, for the purpose of calculating sonar ranges, when pulse lengths lower than 15 m. Secs are used in transmission.

2.4 *The Noise Level*

The noise level (NL) stands for the noise spectral density, defined as the noise intensity in 1 *Hz* band in *dB* with reference to one micro-Pascal. The ocean and the plateform are both noise sources. The ambient noise of the sea depends upon the sea state. The platform noise increases with the cruising speed of the ship. The noise spectral density usually falls at the rate of 6 *dB* per octage of frequency and hence the noise level influences the choice of the operating frequency, for optimum performance.

Both the ambient noise and the self noise are generally isotropic in nature. Hence a directional array picks up lesser noise compared to an equivalent nondirectional hydrophone and is given by $(NL - DI)$.

The integrated noise seen by the sonar depends on the bandwidth. For white noise, the integrated noise level is given by

$$NLW = NL + 10 \log w \tag{20}$$

where w is the bandwidth.

Hence the noise level seen by the sonar can be reduced by (i) Reducing the cruising speed, (ii) Increasing the *DI*, (iii) Incıeasing the frequency of operation, and (iv) Reducing the bandwidth.

Reducing the cruising speed reduces the search rate of the sonar. Hence it is advisable to optimise the sonar system at the normal cruising speed of the ship. The directivity index can be increased either by increasing the dimension of the array or, by increasing the frequency. The proper choice of *DI* is influenced by the factors as mentioned elsewhere also. Though the noise spectral density reduces with frequency at the rate of 6 *dB* per octave, the strong frequency dependence of absorption loss as given in Eqn. (17) has an opposite effect on the sonar performance. The combined effect is to give a peaked characteristic to the frequency verses detection range curve, giving the best performance at a particular frequency. While a small bandwidth will keep the integrated noise level low, a higher bandwidth is mandatory to cater for the Doppler shift due to the relative motion of the platform and the target. The ships own motion is usually nullified either in transmission, or in reception for keeping the bandwidth low in sonars. The Doppler shift ΔF is given by

$$\Delta F = + 0.69 \times v \times f \tag{21}$$

where v is the target velocity in knots and f is frequency in Khz.

A target speed of 40 knots can be taken as worstcase maximum for the purpose of fixing the receiver bandwidth.

To improve performance in reverberation, one is sometimes forced to increase the bandwidth of the transmission pulse by some kind of modulation. The receiver bandwidth will have to be increased correspondingly.

It may be remembered that the parameter NL in the sonar equation is the noise spectral density and not the integrated noise level over the band. The effect of bandwidth is, however, included in the Detection Threshold. Hence clear insight to the variation of DT with bandwidth is necessary for the correct choice of the bandwidth.

2.5 *Directivity Index*

Many aspects of directivity index (DI) were discussed in connection with the parameter SL and hence are not repeated here. In reception the DI is a measure of the discriminating power of the receiver against interfering noise from unwanted directions. The important factor in deciding DI is the aperture width for each receive beam. The optimum aperture for a receive beam using cylindrical arrays[1] is that formed by 1/3rd arch of the array. Under this condition Eqn. (15) may be modified to get DI in reception as

$$DI = 10 \log (4\pi/(\theta_V.\theta_H))$$

$$= 10 \log \{(4\pi/\lambda^2)\, 2RH \,\text{Sin}\, (\pi/3)\} \qquad (22)$$

2.6 *The Reverberation Level*

The reverberation level (RL) is the ratio in dB of the reverberation power at hydrophone to the reference intensity. The reverberation has three constituents namely the surface reverberation, the volume reverberation and the bottom reverberation. The major constituent for hull mounted sonars, working in the surface duct mode, is the surface reverberation.

The fundamental ratio on which the reverberation depends is called the scattering strength and is given by

$$S_s = 10 \log [I\,(\text{scat})/I\,(\text{inc})] \qquad (23)$$

where I(scat) is the intensity scattered by unit area or volume and I(inc) is the intensity of incident plane wave.

The corresponding plane wave RL for surface scattering is given by

$$RL_s = SL - 40 \log r + S_s + 10 \log [(CT/2)\theta.r)] \qquad (24)$$

where C is the velocity of sound

T is the pulse length

θ is the beam width in azimuth; and

r is the range

Similarly, the RL for volume reverberation is given by

$$RLv = SL - 40 \log r + Sv + 10 \log \{(CT/2)\psi.r^2\} \qquad (25)$$

where Sv is the volume scattering coefficient, and

ψ is the solid angle subtended by the beam

For isothermal water condition (surface duct mode), the surface reverberation is the predominent factor and hence the following empirical rule[2] for S_s will apply.

$$S_s = 521.4\,(v\sqrt[3]{F})^{-0.58} \log(\theta v/30)$$
$$- 42.4 \log\{158\,(v\sqrt[3]{F})^{-0.58}\} + 2.6\ dB \qquad (26)$$

where θv is the vertical beamwidth,

V is the wind speed in knots, and

F is the frequency

The reverberation masking level may be equated to the echo level, to calculate the range. Hence substituting Eqn. (23) in Eqn. (25) and remembering that $TL = 20 \log r + \alpha r + 60$, Eqn. (2) may be manipulated to get

$$10 \log r = TS - 120 - 521.4\,(v\sqrt[3]{F})^{-0.58} \log(\theta v/30)$$
$$+ 42.4 \log\{258\,(v\sqrt[3]{F})^{-0.58}\} - 2.6 - 10 \log\{(CT/2)\theta\}$$
$$- DT = K \qquad (27)$$

Therefore the reverberation limited range is given by

$$\text{Range } r \text{ in } Kms = 10^{k} \qquad (28)$$

Empirical formulae for different types of propagation conditions and scatterings are given elsewhere[2]. Necessary modifications to the range solution may be carried out to suit the specific case.

2.7 *The Detection Threshold*

The detection threshold (DT) is the ratio in *dB* of the signal power in the receiver bandwidth to the noise power in one *Hz* band, required for detection, at some pre-assigned probabilities of detection and false alarm. The *DT* value varies with the quality of detection (probability of detection and false alarm), a priori knowledge of the expected signal and noise characteristics and the type of receiver used

In the case of signals known exactly, the *DT* is given by

$$DT = 10 \log(d/(2.t)) \qquad (29)$$

where 'd' is the detection index and t is the signal duration

The detection index 'd' is the parameter that links *DT* to the required quality of reception. Once the probability of detection and false alarm are assigned, the value of 'd' can be read off from the so called Receiver Operating Characteristic (ROC) curves.

The optimum receiver for signals, known completely in gaussian background, is the matched filter[3] whose impulse response is the replica of the transmission signal, reversed in time. It may be noted that for signals, known completely, the DT is independent of the bandwidth where as DT improves with the signal duration 't'.

For the other extreme case of unknown signal in gaussian background, the DT is given by

$$DT = 5 \log (d\, w/t) \tag{30}$$

where 'w' is the bandwidth

The optimum receiver for the above type consists of a square-law detector preceded by a filter. This, assumes that the time canstant of the post detection filter T is the same as the signal duration t. If T is different from t, the DT increases and is given by

$$DT = 5 \log (d\, w/t) + | 5 \log (T/t)| \tag{31}$$

There are a number of possible cases in between the above two extreme cases, depending upon the level of knowledge about the signal and the type of receiver used. In these cases, the exact value of DT must be modified accordingly by including a parameter "additional processing gain/loss" in the sonar equation.

The DT in the case of unknown signals is inversely proportional to the signal duration. Reducing the bandwidth also reduces the DT, provided the signal power in the receiver bandwidth remains the same. For broadband signals, however, the signal power increases as 10 log (bandwidth) whereas the DT deteriorates (i.e. increases) at the rate of 5 log (bandwidth) and hence there is a net gain. This aspect is made use of in the reverberation limited case by deliberately increasing the signal bandwidth (by using modulation techniques) and thereby reducing the spectral density of the reverberation.

3. The Optimisation Procedure

The general procedure for arriving at the appropriate design is given below :

(a) Establish the constraints and assumptions relevant to the given plateform.

(b) Search for the optimum frequency and the sonar configuration that will maximise the noise limited range ensuring that the constraints are satisfied. This is a recursive, successive approximation process.

(c) Work out the reverberation limited range for this configuration If this range is less than the noise limited range, change the system configuration accordingly and go back to step (a). Repeat the process till the two ranges are about equal.

(d) Confirm that this range is in excess of the minimum required range, based on tactical consideration such as

(i) the detection range of the expected enemy vessels, (ii) killing range of the enemy weapons, (iii) Range of weapons on the ship, and (iv) The usual missions to be carried out by the ship etc.

If this condition is not satisfied go back to step (a) again and repeat the process. This result gives a 'first order' design which can be further improved, based on the experience of the designer. The whole process involves a number of recurring computations. The task can be simplified by employing a digital computer for the necessary computation and plotting.

3.1 *Frequency Plots*

The results of the above computations, for any fixed array dimensions, are best presented in the form of the following plots : (a) Frequency versus range plot (noise-limited), (b) Frequency versus power demand, and (c) Frequency versus vertical beamwidth.

A number of such plots, under various processing options, may be computed and the optimum frequency and configuration may be chosen intutively.

3.1.1 *Frequency versus range plot* : The computation of frequency versus range may be carried out on the following lines. The first step in the procedure is to compute the Figure of Merit (FOM) of the sonar at any arbitary frequency, say 10 KHz.

$$FOM = SL - (NL - DI + DT) \tag{32}$$

The values of SL, DI and DT may be computed using Eqn. 16, 15 and 30 respectively From the available knowledge of the value of NL at any frequency, the NL at 10KHz may be extraplotated by applying the 6 dB per octave law. Now compute the FOM at 10 KHz. Modify the FOM so computed by incorporating such factors as (a) Additional processing gain, to take care of improvement in DT depending on the knowledge about the signal and the type of processing, (b) Display gain, (c) Clipping loss, (d) ORing loss and (e) Collapsing loss, etc.

Compute the law governing the variation of FOM with change in operating frequency (This is in fact included in the expressions for the parameters of the sonar equation). Compute the FOM at the minimum frequency of interest.

The maximum allowable transmission loss at the operating frequency is given by :

$$TL = (FOM + TS)/2 \tag{33}$$

A target strength of 15 dB may be assumed and the TL value, may be computed The detection range and the transmission loss are related by the exact spreading law and the attenuation. Eqn. (18) may be used for all practical cases. Hence

$$TL = 20 \log r + 0.003 f^2 r + 60 \tag{34}$$

This equation may be solved in the computer, to estimate the detection range at this frequency. Since Eqn. (34) is an implict expression, the value of range 'r' may be computed iteratively by successive approximation method.

Now, the frequency variable 'f' may be incremented by a small step and the computation may be repeated. This process is continued till the range of frequency of interest is covered. The result may be plotted as frequency verses range plot.

The plot will usually be a peaked curve showing maximum range at a particular frequency. This frequency, where the maximum range appears, is called the optimum frequency for that particular configuration of the sonar.

3.1.2 *Frequency versus power demand plot* : The basic assumption in computing this plot is that the duration of a ping-cycle corresponds to the detection range obtained in para (a) above. The duration of a ping-cycle is given approximately by

$$T = 2r/C \tag{35}$$

where r is the range at any frequency and C is the velocity of propagation.

Hence the duty ratio for omni-transmission is given by

$$D = t/T \tag{36}$$

where t is the basic pulse length.

In case of *RDT* transmission, the duty cycle is

$$D = (t/T)\, 2\pi/\theta_H \tag{37}$$

where θ_H is the transmission beamwidth in azimuth given by Eqn. (14).

Now the average electrical power required may be computed from Eqn. (8).

In the case of omni-directional transmission, the average electrical power is given by :

$$P = \pi RH\, \mathrm{a}\, (1 + h/10)\, (1/\eta)\, (t/T) \tag{38}$$

where η is the overall conversion efficiency from electrical supply power to the transducted acoustic power.

In the case of *RDT*, the average electrical power is much more than the above and is given by .

$$P = (\pi RH/N_s)\, \mathrm{a}\, (1 + h/10)\, (t/T) \times (2\pi/\theta_H)\, 2R \sin (\pi/N_X)\, (1/\eta) \tag{39}$$

3.1.3 *Frequency versus vertical beamwidth plot* : This is a direct plot of Eqn. (5) as a function of frequency. Eqn. (5) may be re-written for this purpose as below :

$$\theta_V = (C/F) \times (1/H) \times (180/\pi) \text{ degrees} \tag{40}$$

where C is the velocity of sound and F is the frequency.

3.2 *Design of a Hypothetical Sonar*

We will now proceed with the design of a hypothetical sonar that could give an average detection range of 20 K yards. The block-schematic of a basic sonar model that may meet the requirement is given in Fig. 2.

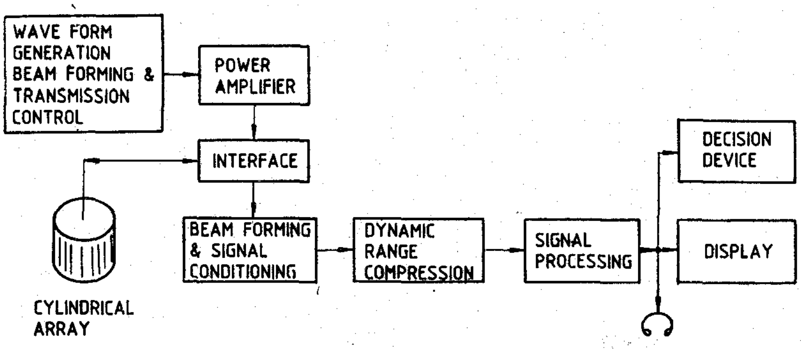

Figure 2. Block schematic of a basic sonar.

First of all, the following assumption/constraints are established :

(i)	Maximum possible radius of the array :	50 cm
(ii)	Maximum height :	150 cm
(iii)	Array depth :	8 meters
(iv)	NL of the platform at the normal cruising speed of 16 Knots :	60 dB/μ Pasc
(v)	Expected TS	+ 15 *dB*
(vi)	Minimum allowable vertical beam width	7°
(vii)	Maximum allowable dead range	3000 yds
(viii)	Average power/Peak Power limitation	20 kw average. 40 kw Peak (pulsed)
(ix)	Usual environment	Shallow water, sandy-bottom, 80° F water temperature, isothermal upto 50 yds, sea-state 2
(x)	Maximum target speed	± 32 knots

A number of computations, with changes in array height processing options, pulse length, FM sweep, number of beams in RDT, etc, were carried out. The results as given in Figs 3, 4 & 5 were obtained for three different combinations of parameters. The optimum configuration is taken as that corresponding to the result in Fig. 5. The parameters corresponding to Fig. 5 are given below, which helps in defining each block in the system model given in Fig. 2.

Radius of array	50 cms
Height	100 cms
Pulse length	150 cms
No. of RDT Beams	2

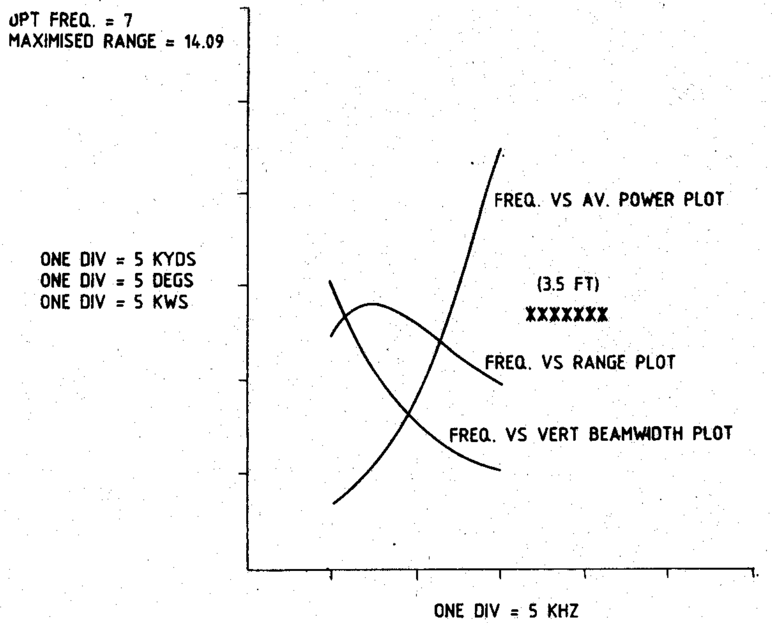

Figure 3. Range, Vert. beamwidth and power Vs frequency for various Sonar specifications.

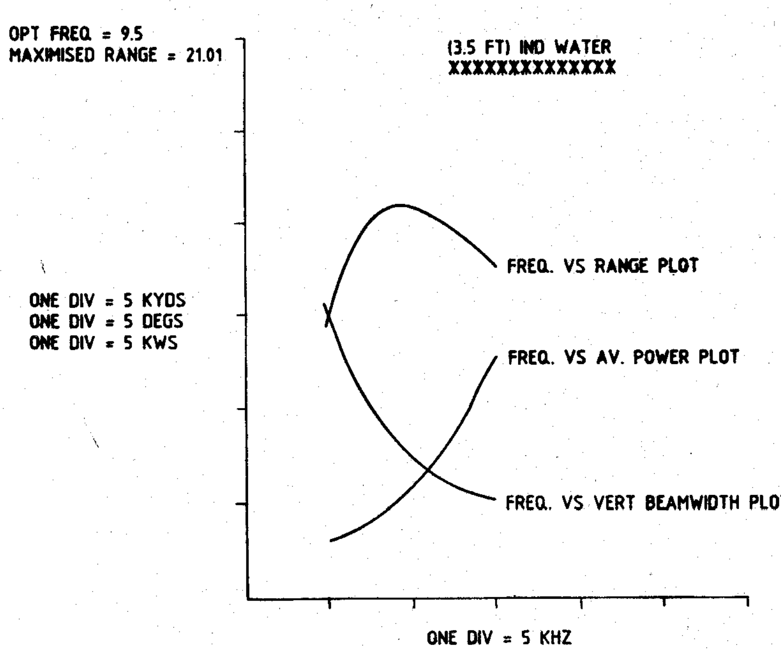

Figure 4. Range, Vert. beamwidth Vs frequency for various Sonar specifications.

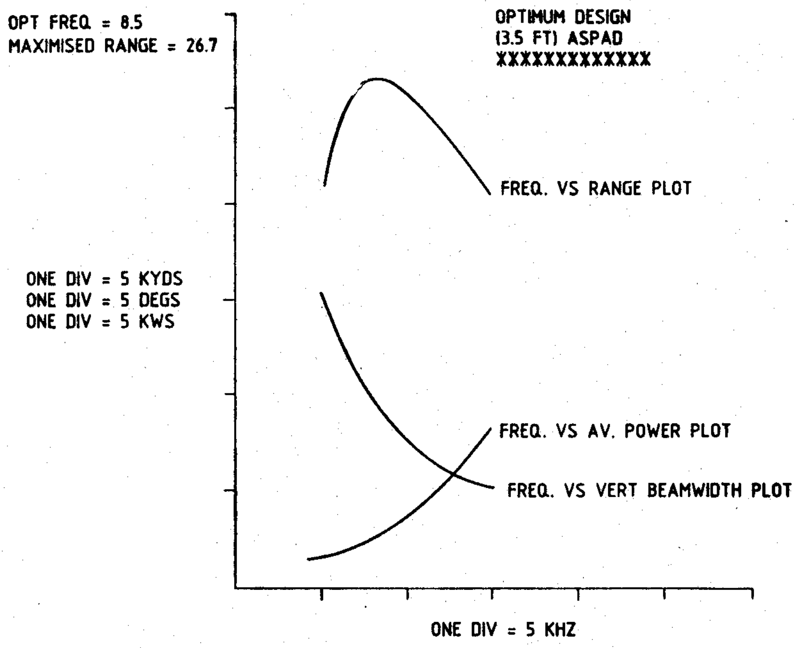

Figure 5. Range, Vert. beamwidth and power Vs frequency for various Sonar specifications.

Processing	Semi-coherent processing on clipped beam output
Display	Advanced refreshed display with multi-ping history.
Optimum frequency	8.5 khz
Maximum range	26.7 kyds
Wave form	L.F.M. with $\pm$ 250 Hz sweep
Verticle Beamwidth at optimum frequency	8°
Average transmission power	$<$ 5 kw

4. Conclusion

The design of an optimum sonar system is influenced by a number of factors. The tradeoffs involved are discussed briefly in the paper. The role of computer in the system design is discribed. The design of a hypothetical sonar system is also explained. It may be borne in mind that this approach can offer only a 'first-order' solution. Detailed system design taking into account 'second order' effects has to be carried out by the designer.

Acknowledgement

The authors wish to acknowledge with thanks the constant encouragement recieved from Capt. Datey. Thanks are also due to the Director, NPOL, for giving permission to publish this paper.

References

1. Cherian, John P., George, Philip C. & Paulraj, A. 'On beamforming for Opaque Cylindrical Arrays', Paper presented at the Baroda Symposium of the Acoustic Society of India, 1978.
2. Urick, Robert J. 'Principle of Underwater Sound' (McGraw-Hill), 1975.
3. Whalen, Anthony D. 'Detection of signals in Noise' (Academic Press, N. York), 1971.

APPENDIX - I

Factors effecting the sonar design

i. Array dimensions.
ii. Array depth.
iii. Power handling capacity of the array.
iv. Percentage of active area in the array.
v. Average power available on the plateform.
vi. Efficiencies of the transducer array, power emplifier.
vii. Cable loss, dome attenuation etc.
viii. Normal cruising speed of the ship.
ix. The spectrum noise level at the normal cruising speed.
x. Roll and pitch angles experienced by the plateform at various sea-states.
xi. Water temperature.
xii. Ambient noise level.
xiii. Depth of water in the normal operating areas.
xiv. Surface and bottom scattering strength in the normal operating area.
xv. Sound velocity profiles.
xvi. Presence of biological species and other inhorogeties in the medium.
xvii. Target strength of the expected target.
xviii. Reduction in target strength due to target break up.
xix. Expected maximum target speed.
xx. Processing gain/loss.

xxi. Display gain/loss.

xxii. Tolerable dead range.

xxiii. Tolerable minimum vertical beamwidth.

xxiv. Variation with frequency of the following factors.

(a) Source level
(b) Cavitation threshold
(c) Scattering strength
(d) Receiver bandwidth
(e) Attenuation
(f) Spectrum noise level
(g) Receiver directivity index

xxv. Size, Weight, Processing complexity and cost consideration.

xxvi. The detection threshold for the assumed statistics of detection and false alarm.