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Signal Threshold in Echointegration

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Abstract.

The equivalent two-way beam width is evaluated when a threshold is applied to the signal before integration.

It is found that the effect is dependent on system parameters, depth, target strength of the reflecting object and density of the scatters.

The correction to the equivalent two-way beam width is found for TS = - 40 dB, Cs = SL + VR - TVG = 65 dB, depth = 50 m and 0.0001 fish per m^2 as a function of the threshold. The system parameters resembles those for the SIMRAD EK 400 system on the R/V DANA. The target strength is that of a medium size cod. The correction is found to be neglible for threshold below 100 mV but increases sharply for threshold above 200 mV.

Similar results are obtained for target strength = - 50 dB, a small herring, by dividing the threshold axis by 10 (- 10 dB)

Observed Sv values obtained by integration will consequently depend on the target strength and density of scatters.

Introduction

Ignoring signals below some limit on the output signal from an echosounder before integration is used to suppress noise. This is called applying a threshold to the signal. A further use could be to filter out signals from marine organisms not under investigation such as copepods, éuphaûsids, jelly fish. Also reflections from halo- or thermoclines could be suppressed using a threshold.

Introducing a threshold in signal processing will effect three elements in the echointegration proces

1) The minimum target strength detectable will increase.
2) The equivalent beam angle will decrease for a given scatter and in general become dependent on target strength of the scatter, depth and apparatus constants.
3) Noise influence will decrease (maybe insignificantly)

This paper discusses the first two of these aspects.

Theory

The output signal from the echosounder measured in energy unit is the echolevel, el, which at any particular time is related to the reverberation of a half sphere shell of thickness $c\ \tau/2$ (c:soundspeed in seawater, τ: pulse length). The volume of this shell is $\Delta V = 2\pi\ r^2\ c\tau$ where r is the distance between scatter and transducer.

The theory is given below when all scatters have the same back scattering cross section σ^2. Further it is assumed that a TVG gain, $\exp(2\ \alpha\ r)*\ r^2$ or in dB ûnits $20 \log r + 2\ \alpha\ r$, with the absorption coefficient α is applied to the signal and that this amplification matches the transmission loss perfectly.

It is assumed throughout that the scatters within an ensonied volume are randomly distributed and therefore their phases are at random. Therefore the echolevel is the sum of the contributions from each scatter.

It is further assumed that the beam patterns for transmission and receiving are identical $b(\theta, \phi)$.

Equivalent Beam Angle without Threshold.

Let us consider n scatters each with spherical coordinates $(r, \theta_i, \phi i)$. These n scatters each have a backscattering cross section σ^2 and are in the volume ΔV at distance r. The echolevel el is after TVG amplification with $20 \log r + 2 \alpha r$

$$el = c_s \frac{\sigma^2}{r^2} \sum_{i=1} b^2 (\theta_i, \phi_i)$$

where $b^2 (\theta_i, \phi_i)$ is the directivity function for scatter no. i. c_s is an apparatus constant (source level + voltage respons - TVG constant attenuation). The stochastic parameters are the position of scatter i, θ_i, ϕ_i (spherical coordinates) and the number of scatters n in the ensonified volume.

The average echolevel, el, is

$$\overline{el} = c_s \frac{\sigma^2}{r^2} E_n (n E_V(b^2))$$

$$= c_s \frac{\sigma^2}{r^2} \overline{b^2} * \rho \Delta V$$

where ρ is the mean density (no/m³) of scatters in the sea at this distance, r. The ensonified volume ΔV is $2\pi r^2 c \tau/2$ and the definition of the equivalent beam angle Ψ is $2 \pi b^2$. This then leads to the usual sonar equation (in logarithmic units)

$$EL = (SL + VR - TVG_c) + S_v + 10 \log \Psi + 10 \log \frac{c\tau}{2}$$

Introduction of Threshold

Signals below some threshold u V (peakvalue) (e.g. 20 mV) are now excluded from the integration. The echolevel without a threshold is el° and is el after a threshold has been applied.

$$el = el^\circ * I \left\{ el^\circ > \frac{u^2}{2} \right\}$$

where I (B) is an indicator function

$$I(B) = \begin{cases} 0 & B = \text{false} \\ 1 & B = \text{trúe} \end{cases}$$

For simplicity let

$$T = \frac{u^2}{2}$$

$$b_i = b(\theta_i, \phi_i)$$

When there are exactly n scatters in the sampling volume the echolevel is called el_n.

The averaging process is

$$\overline{el} = c_s \frac{\sigma^2}{r^2} E_n \left(E_v \left(\sum_1^n b_i^2 * I \left\{ el_n > T \right\} \mid n \right) \right)$$

where E_n is the mean over the number of scatters and the second expection operator is over the sampling volume $(2\pi\ r^2\ c\ \tau/2)$.

The inner expectation E_v is

$$n * E \left(b^2 * I \left\{ el_n > T \right\} \mid n \right)$$

since all scatters have the same distribution in the sampling volume.

This mean is

$$\frac{1}{(2\pi)^n} \int_0^{2\pi} d\theta_1 \int_0^{\pi/2} d\phi_1\ b^2\ (\theta_1, \phi_1)\ \sin\ \phi_1 \int_0^{2\pi} d\theta_2 \int_0^{\pi/2} d\phi_2\ \sin\ \phi_2\ d\phi_2\ d\theta_2 \ldots$$

$$\ldots \int_0^{2\pi} d\theta_u \int d\phi_n\ \sin\ \phi_n * I \left\{ \sum_1^n b^2\ (\theta_i, \phi_i) > \frac{T\ *\ r^2}{\sigma^2\ *\ c_s} \right\} \equiv \overline{b_t}^2\ (n)$$

This mean is only dependent on the threshold $t = Tr^2/(\sigma^2 * c_s)$ and the number of scatters.

Backsubstitution gives

$$\overline{eI} = c_s * \frac{\sigma^2}{r^2} * E_n(n\,\overline{b_t^2}(n))$$

In order to have the same sonar equation as when no threshold is applied

$$\overline{eI} = c_s \frac{\sigma^2}{r^2} * \rho r^2 \frac{c\,\tau}{2} \Psi_t$$

the equivalent beam angle should be defined

$$\Psi_t = 2\pi \frac{E_n(n\, b_t^2(n))}{\overline{n}}$$

Where $\overline{n}$ is the mean number of scatters in the sampling volume

$$\overline{n} = \rho \frac{c_t}{2} * 2\pi\, r^2$$

This equivalent beam angle Ψ_t depends on the target strength and the distribution of the scatters as well as the threshold and other apparatus parameters and settings.

Circular Piston Transducer.

For simplification the remaining analysis is restricted to a circular piston transducer with the directivity function

$$b\ (\theta,\ \phi) = \left[\frac{2\ J_1\ (ka\ \sin\phi)}{ka\ \sin\phi} \right]^2$$

where J_1 (z) is the Bessel function of 1 st order, k is the wavenumber and a radius of the transducer.

The formula for the equivalent beam angle then reduces to

$$\Psi_t = 2\pi \frac{1}{n} E_n \left(n \int_0^{\pi/2} b^2\ (\phi_1\ )\ \sin\phi_1\ \ d\phi_1 \int_0^{\pi/2} \sin\phi_2\ \ d\phi_2 \ldots\right.$$

$$\ldots \int_0^{\pi/2} \sin\phi_n\ I \left\{ \sum_1^n\ b^2\ (\phi_i\ ) > t \right\}$$

Approximation of $b_t{}^2$ (n)

Direct calculation of $\overline{b_t}^2$ (n) is time consuming to the point of not being feasible. Instead an approximation of this integral was found as follows.

The calculations are splitted into two. First the inner integral $V(t - b^2(\phi_1),\ n,\ ka)$

$$V = \int_0^{\pi/2} d\phi_2 \sin\phi_2 \ldots \int_0^{\pi/2} d\phi_n \sin\phi_n \; I \left\{ \sum_2^n b_i^2 > t - b^2(\phi_1) \right\}$$

was evaluated for all combinations of

n = 2, 5, 10, 20
ka = 8, 11.3, 16, 22.6, 32, 45.3, 64 and 90.5
t = 0.0004, 0.0039, 0.03, 0.39, 3.9

using standard NAG routines for evaluation of multidimentional integrals.

This dataset was then approximated by

Call $t - b^2(\phi_1) = \zeta$

$$V = 1 - \exp\left(- 0.0093330487 * \frac{n-1}{(ka)^2 \sqrt[3]{\zeta}} + 0.0014690730 * \frac{(n-1)^2}{(ka)^2 \sqrt{\zeta}} - 0.7268206667 * \frac{n-1}{(ka)^2 \sqrt[3]{\zeta}} \right)$$

For $t - b^2(\phi_1) \geq 0$

$V = 1$

For $t - b^2(\phi_1) \leq n - 1$

$V = 0$

This approximation was then introduced in the formula for $\Psi(t)$ derived in the preceeding section.

$$\Psi(t) = 2\pi \frac{1}{\bar{n}} \sum_{n=1}^{\infty} n\, p(n) \int_{0}^{\pi/2} b^2(\phi_1) \sin\phi_1\, V(t - b^2(\phi_1), n-1, ka)\, d\phi_1$$

where p(n) is the probability of finding n scatters in the sampling volume $2\pi\, r^2 \frac{c\tau}{2}$.

Evaluation of the equivalent two-way beam angle for
ka = 18, u = 50 mV, TS = - 40 dB and Cs = 65 dB
resulted in that the approximated integral and the exact formulation agreed within 4 significant digits. The approximation breaks down when Ψ declines rapidly.

Results.

The calculations were carried through for target strength -40 dB, depth = 50 m, SL + VR -TVGc = 65 dB and ka = 18. These parameters more or less resemble the system on R/V DANA. The abundance of scatters (fish) was taken to be poisson distributed with mean = 0.0001 fish per m² or with the given depth about 1 fish per ping, this is a low abundance. The changes in 10 log Ψ as function of the threshold are shown on fig. 1 and on fig. 2 with the threshold in dB.

The effect is modest for small thresholds but can become important. It is not recommended to remove say jelly fish by a threshold which for the system on R/V DANA should be around 300 - 500 mV.

Fig 2 can be used to evaluate the effect for other depth,TS and C_s. Let u be the threshold and $\Delta(20 \log r - TS - C_s)$ the change in parameters from the 50 m depth TS = - 40 dB and C_s = 65 dB (or 9 dB). Then u_0 will be the corresponding threshold for these standard parameters which should be used as entry on fig. 3.

$$20 \log(u) = 20 \log(u_0) + \Delta(20 \log r - TS - Cs)$$

However the density effect is not linear in the logaritms but the effect decreases with increased density of scatters.

The application of this theory is related to evaluation of acoustic surveys when a conglomerate of fish are investigated. Conventionally a standard equivalent two-way beam width is applied but as discussed above this lead to significant errors, specifically when weak scatters are investigated.

The effect of density will be investigated in a later paper.

Relative Equivalent

Two - Way Beam Width

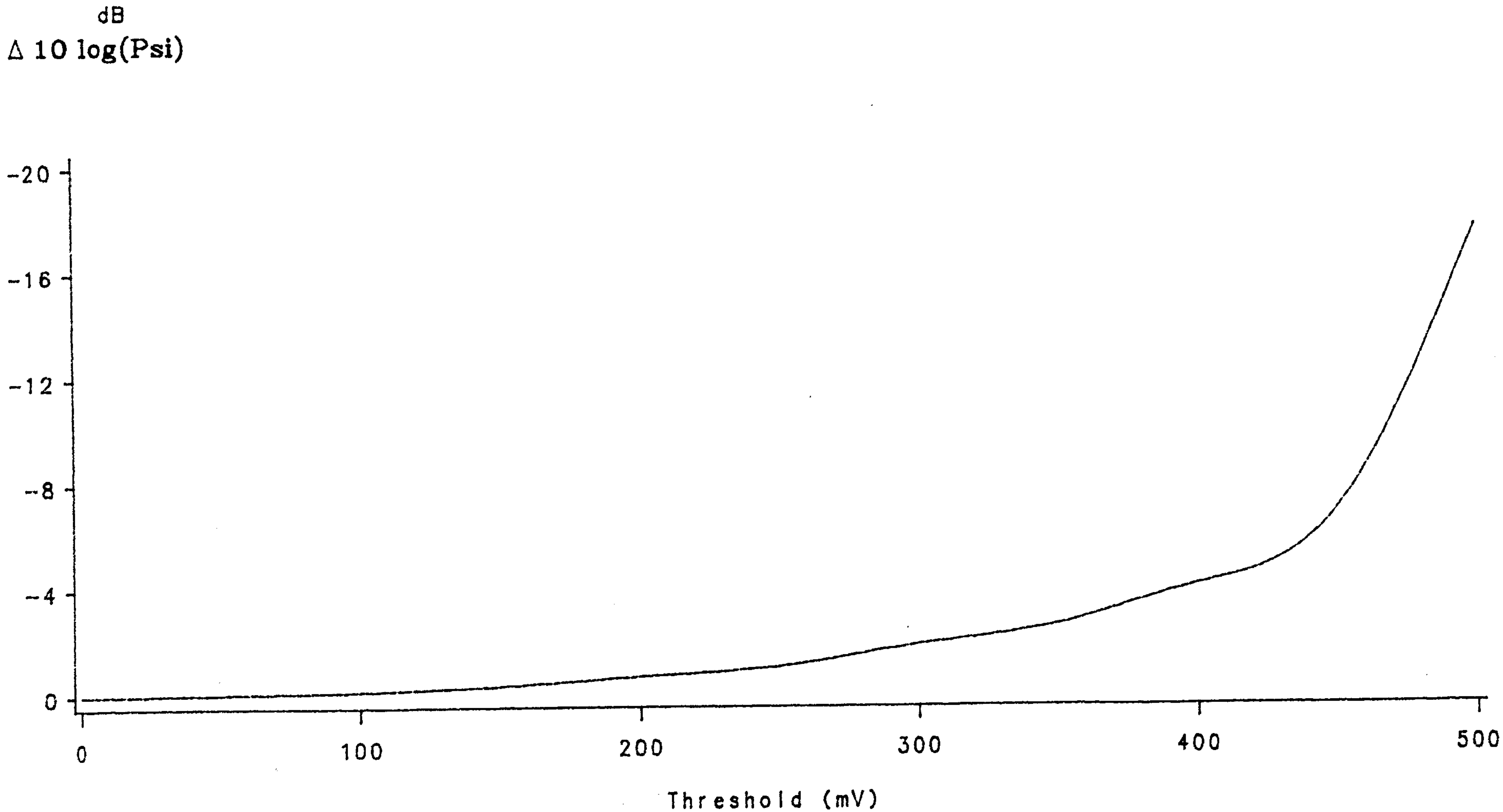

Fig.1 Calculated for 50m depth and a noise free system

Ks = 18 Fish per m**3 = 0.0001 Target Strength = -40 dB

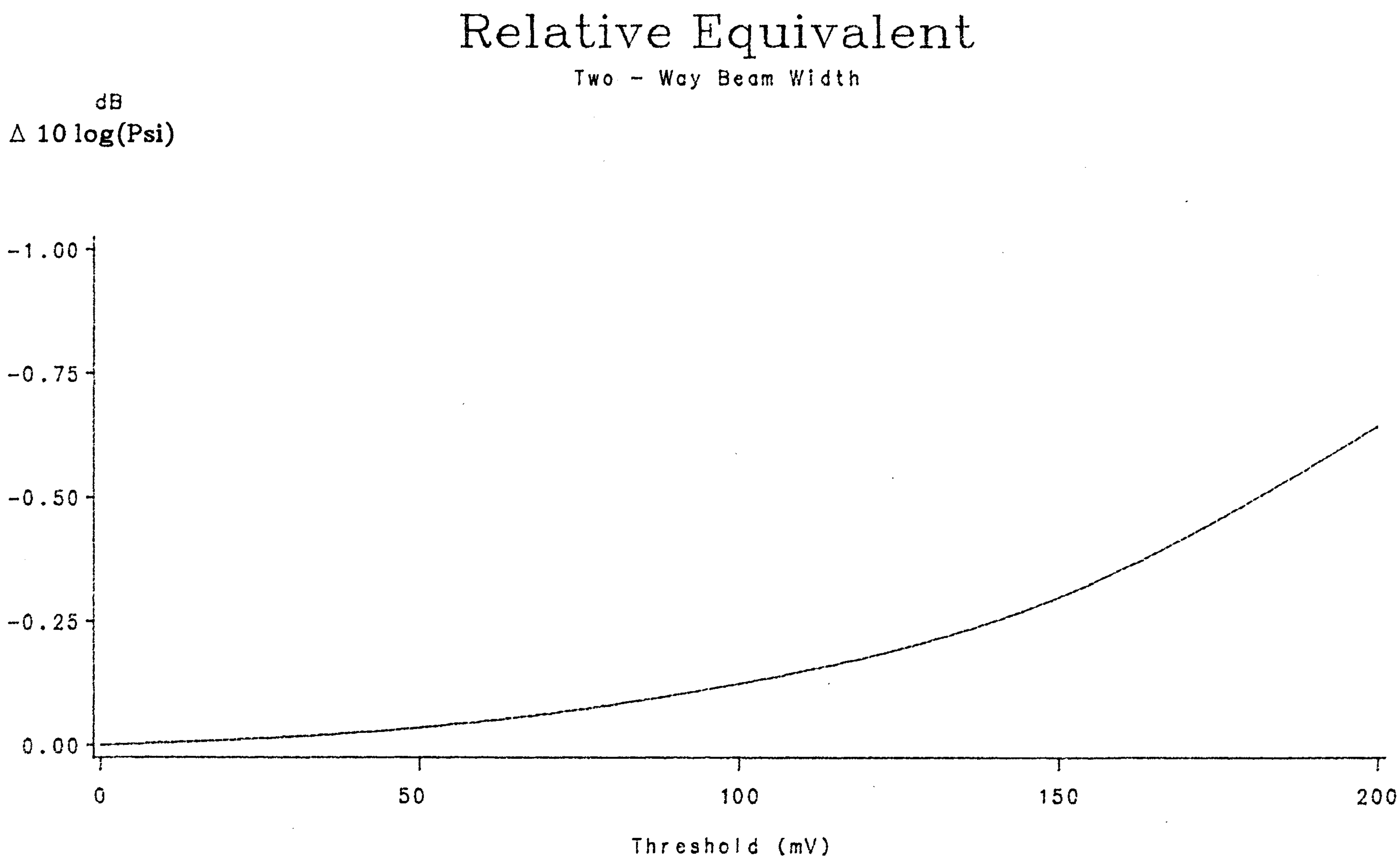

Fig.2 Calculated for 50m depth and a noise free system
Ks = 18 Fish per m**3 = 0.0001 Target Strength = -40 dB

Relative Equivalent

Two - Way Beam Width

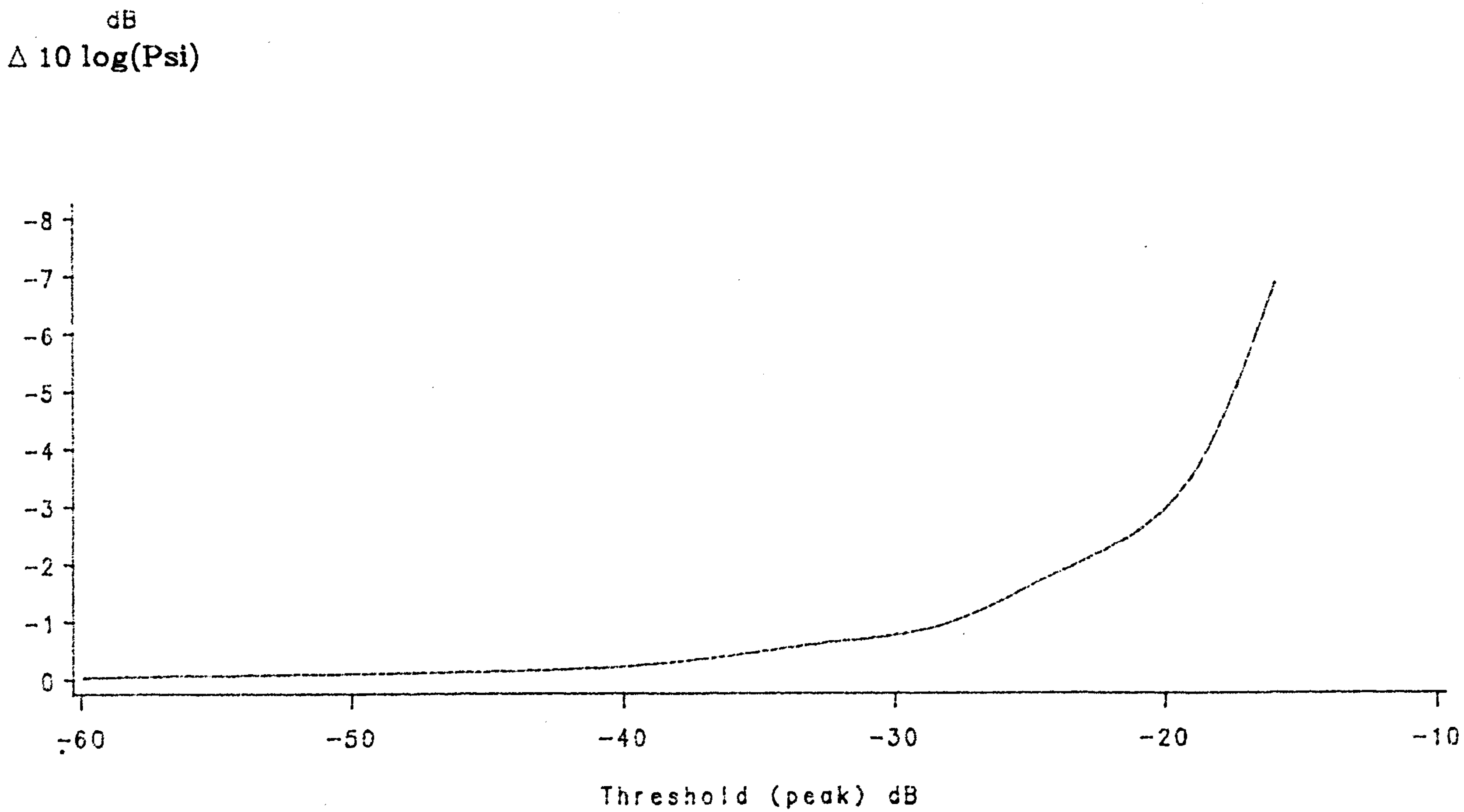

Fig.3 Calculated for 50m depth and a noise free system
Ka = 18 Fish per m**3 = 0.0001 Target Strength = -40 dB