EM Technical Note

Date: **January 7th, 2000**
Author: **Erik Hammerstad**

Subject: Backscattering and Seabed Image Reflectivity

1. Introduction

The Simrad EM multibeam echo sounders all have beam backscattering strengths and optionally seabed image reflectivity as part of their data output. These data may be used for bottom classification, provided that how the data is collected and processed is clearly defined. This note will describe how this is done in the Simrad multibeam echo sounders. It will also show what corrections may be made in postprocessing these data to remove the bathymetry dependent part of the data. Finally a comparison will be made with ordinary sidescan sonars and some other multibeam echo sounders having imagery output.

2. Theory

The echo level, EL, of the signal backscattered from the bottom, may be derived from the sonar equation:

$$EL = SL - 2TL + BTS$$

Here SL is the multibeam echo sounder's source level, 2TL is the two-way transmission loss, and BTS the bottom target strength. The transmission loss consists of two parts, one due to spherical spreading of the signal, the other due to absorption loss in the water:

$$2TL = 2\alpha R + 40 \log R$$

Here R is the range and α the absorption coefficient in dB/m.

The bottom target strength will depend both on the reflective property of the seabed, but also on the extent of the bottom which contributes to the backscattered signal at any time. It is therefore usual to define a bottom backscattering coefficient, BS, given in dB/m^2, as the characterizing quantity for the bottom reflectivity. The backscattering area will be bounded by the beam geometry, as defined by θ_x and θ_y, at normal incidence (0° incidence angle or 90° grazing angle) while in other directions it will be bounded by the alongtrack beamwidth, θ_x, and the transmit pulse length, τ.

$$BTS = BS + 10 \log \theta_x \theta_y R^2 \quad for \varphi = 0°$$

$$BTS = BS + 10 \log \frac{c\tau}{2 \sin \varphi} \theta_x R \quad for\ \varphi > 0°$$

How the backscattering coefficient varies with incidence angle, φ, is of course an important part of seabed characterization and in determining the type of material which is on the seabed surface.

The receivers of the multibeams have limited dynamic range and a time variable gain (TVG) is therefore run during the ping to avoid overload or having the echo return buried in noise. The TVG must be predicted before reception, and must be devised so that the average signal level in the receiver is at an optimum level so as to be able to cater for random variations in bottom reflectivity. The limiting factor here is the A/D converters which with 12 bit as in most systems have 66 dB dynamic range. An additional reason for running such a TVG is that it will flatten the beam sample amplitudes. This is beneficial for bottom detection, but also important for display of the seabed image, where one is primarily interested in reflectivity contrasts, which resolvability is strongly limited by the number of colors or gray shadings available (or discernable) in today's printers.

When the EM 12 was designed in 1990, an investigation of the literature was done to get an idea of how backscattering coefficients varied with incidence angle. Unfortunately, most of the reported results dealt with low grazing angles, i.e. outside the region of interest. The conclusion that was drawn was that for incidence angles larger than about 25° a good approximation for most conditions would be to assume that a uniform flat bottom is characterized by a mean backscattering coefficient, BS_O, and that angular variation is given by Lambert's law, i.e.:

$$BS = BS_O + 20\log(\cos\varphi)$$

A paper (by Gensane in IEEE JOE Jan. 89) described measured backscattering coefficients versus grazing angle also gave data near normal incidence. The paper did show deviations from the Lambert's law, very little though for incidence angles from 40° to 80° but somewhat larger between 25° and 40° (but the data given in Urick's standard underwater acoustics book fits Lambert's law well also in this region). For smaller incidence angles, a reasonable fit to the data could be achieved by the simple scheme of assuming that the backscattering coefficient changes linearly with incidence angle from BS_N at 0° to BS_O at 25°. Thus, after recognizing that an incidence angle of 25° is equivalent to about $R = 1.1R_I$, and replacing the trigonometric functions by the equivalent expressions in R and R_I, the full model is:

$$BTS = BS_N + 10\log\theta_x\theta_y R^2 \quad for R \leq R_I$$

$$BTS = BS_O - 5\log(R/R_I)^2[(R/R_I)^2 - 1] + 10\log\frac{c\tau}{2}\theta_x R \quad for\ R \geq 1.1R_I$$

$$\begin{aligned} BTS = {} & BS_N + 3.162\sqrt{R/R_I - 1}(BS_O - BS_N) - 5\log(R/R_I)^2[(R/R_I)^2 - 1] \\ & + 10\log\frac{c\tau}{2}\theta_x R \quad for\ R_I < R < 1.1R_I \end{aligned}$$

From later literature no reasons for changing the above model has been found, with one exception. The crossover angle between the two regions has been shown to be quite variable depending on material type, and can be anywhere in the 5-30° region.

3. Implementation

The TVG law run in the Simrad multibeam echo sounders is based upon the above model with a fixed crossover angle between the two regions of 25°.

1) Based on previous pings, the range to normal incidence, R_I, and the backscattering coefficients at normal and oblique incidence, BS_N and BS_O, are estimated.

2) The fixed gain is set to provide an echo level maximizing dynamic range.

3) The gain is varied in time or equivalently range according to the above model.

In the gain setting, nominal values are used for source level and receiver sensitivity. After beamforming, the sample amplitudes are corrected for processing gain, and beam pointing angle dependent variations in source level and receiver sensitivity (for the deep sea systems corrections are also applied for the different frequencies used in different transmit sectors). Finally the used BS_O is subtracted which gives correctly scaled backscattering strengths in the area outside of normal incidence, but still with the ususal normal incidence peak flattened to the same level as outside.

After bottom detection further corrections are applied to take into account any errors in the estimate of the range to normal incidence and any lack of gain at the extreme ranges or too much gain applied at the lesser ranges (the latter may occur due to limitations in the dynamic range possible in the TVG circuitry).

The data which are provided in the seabed image datagrams are picked from the beam amplitude samples in such a way that when fitted together the total array of samples represent a continuous set along the bottom with a fixed interval in range according to the range sampling rate of the multibeam echo sounder and the mode it is used in. Due care is taken for beams with a lesser detected range than its neighbor closer to the nadir beam, and to some extent data is picked to avoid holes due to beams lacking valid detections. The sample corresponding to the detected range in a beam is identified in the datragram to allow correct placements of the imagery samples on the bottom. The used absorbtion coefficient, R_I, BS_N and BS_O are stored with the data to allow a user to fully take into account the model used and apply any corrections required. Furthermore on the latest systems (excepting the EM 12, EM 950 and EM 1000) the data are corrected according to an operator settable angle for where the crossover from the normal incidence to Lambert’s law region is to take place (this angle is also logged with the data).

The BS values given in the depth datagrams are an average value of the sample amplitude values. Short averaging lengths are used and the maximum average level within a beam is chosen to represent the beam BS. However when the echo in a beam is very short the maximum sample amplitude is chosen (usually near normal incidence in shallow waters). In contrast to what is done in the seabed imagery datagrams the backscattering strengths around normal incidence are corrected for the TVG law used in this region, and the effect of the Lambert’s law assumption taken out. Thus the BS values in the depth datagrams are correctly scaled at all angles.

The result of the implementation is that the measured seabed image amplitudes are “correct”, i.e. they are the seabed's backscattering coefficients, or at least these are recoverable in postprocessing. An inherent uncertainty in the values due to variation in transducer sensitivities may be estimated to be typically ±1 dB, but this may be larger on a specific system, and for a specific sample at least ±3 dB (especially in the EM 950/1000 due to transmit pattern ripple and less overlap between receive beams, which again can be corrected in postprocessing).

4. Postprocessing

For seabed classification it seems reasonable to assume that the beam backscatter coefficients will be sufficient, especially when equidistant beam spacing is used. As all incident angle dependence and backscattering level assumptions have been removed from this data, the only parameter used in the real-time calculations which may need to be corrected is the scattering area which will not be correct if the bottom is not really flat. The areas used are:

$A = \psi_T \psi_R R^2$ around normal incidence

$A = \frac{1}{2} c\tau \, \psi_T R / \sin\phi$ elsewhere

Here c is the sound speed, τ the pulse length, and ψ_T and ψ_R are the transmit and receive beamwidths respectively. The first equation for the area is valid until the bottom incidence angle is larger than the largest of the following two angles, given by:

$$\cos\phi_{L1} = \left(1 + \frac{c\tau}{2D}\right)^{-1}$$

$$\sin\phi_{L2} = -\frac{\Psi_R D}{c\tau} + \sqrt{\left(\frac{\Psi_R D}{c\tau}\right)^2 + 1}$$

The above equations assume the bottom to be flat, and may require a slight revision when the bottom has a significant slope in any direction, i.e.

$$A_r = 10 \log \frac{\theta_x \theta_y R^2}{\cos\varphi_x \cos\varphi_y}$$

$$A_r = 10 \log \frac{c\tau \theta_x R}{2\cos\varphi_x \sin\varphi_y} \quad (\varphi_y \neq 0)$$

For the seabed imaging data there are a number of things that can be done with depending on what one is looking for. Some possible corrections are the removal of the Lambert's law, corrections for actual bottom slope, calculation of true backscatter coefficients (i.e. reinsertion of angular dependence), application of a different model for backscatter variation with incidence angle (such as using Gesand's suggestion to model incidence variation by $\gamma_0 - 10 \log(\sin^2\varphi \mathrm{tg}\varphi)$ for incidence angles larger than 30°, γ_0 being chosen to give a smooth transition to the model). Note that as many corrections are small and vary little with angle, perhaps except near normal incidence, quite often they need only be calculated and applied beam by beam.

Lambert's law removal can be done by adding 20 log(R/R_I) to all data points. Correcting for erroneous R_I (such as could occur when the central beams do not have valid detections) would involve calculating and applying the difference between the applied TVG and the correct TVG. Correcting for non-flat bottom involves removal of used Lambert's law and replacing it by 20 log(sine of 2D incidence angle) plus the same area correction as described above for the beam backscatter coefficients. Use of a different model would likewise involve removal of used Lambert's law, correction for area, and subtraction of model's backscatter using the actually encountered 2D incidence angle. To obtain true backscatter coefficients involves removal of used Lambert's law, area correction, and then correction for used backscatter coefficient in the flattening process near normal incidence.

It should be emphasized that the seabed image data are not corrected for beam pattern variations in the receiver beams. This may be required where the beams are not strongly overlapping, such as in the middle of the swath when running equidistant beamspacing when the number of beams is low such as on the EM 1000. It may also be required when the coverage of a beam has been extended due to a failed detection in a neighboring beam, or in the extreme outer part of the outermost beams. The beam pattern variation with angle is given in most textbooks on sonar technology or radio antennas or radar, and is generally in the form of a sinc function (sinx/x), but note that the pattern is not symmetrical with angle when appreciable beam steering has been applied such as on the EM 12.

5. Comparisons

The major differences between the seabed imagery derived from a Simrad multibeam echo sounder and an ordinary sidescan sonar are:

- The sidescan sonar does not measure calibrated backscattering strength, but only amplitudes with an unknown absolute level and only compensated by a 20/30/40 logR TVG.
- The sidescan sonar data may be slant range corrected, but only presuming a flat bottom and cannot thus be correctly scaled taking into account actual variation in bottom slope.
- The sidescan sonar is usually towed closed to the bottom and most data is collected at low incidence angles for shadow detection purposes. In contrast, most of the multibeam data is collected at higher incidence angles for classification purposes.

Finally it must be observed that the resolution of a sidescan may be better as it is cheaper to provide a sidescan sonar with narrower alongtrack beamwidth and higher range sampling rates than a multibeam echo sounder, allthough the specifications of the newer Simrad systems are quite good in this regard.

Other multibeam echo sounders (Seabeam, Atlas) are also to some extent capable of providing imagery data. However, as far as we know, the logged data of these systems are not such that they allow the postprocessing to absolute levels, resolution or correct geographical scaling as for the Simrad systems. The records provided seem to be of the same data as would usually go to a greyscale recorder of an ordinary sidescan sonar. Thus the number of points is limited, the scaling is not correct, and there seems to be limited knowledge provided with repsect to how the data is acquired and what the internal processing has done with the data.