International Council for the
Exploration of the Sea

CM 1986/B:8
Fish Capture Committee
Session 4: (Acoustic Methods)



# SIMPLE CALIBRATION OF A SPLIT-BEAM ECHO-SOUNDER

by

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## SUMMARY

The split-beam echo-sounder is used to measure the in-situ target strength of fish. Calibration of this instrument requires sensitivity measurements throughout the cross-section area of the beam A calibration technique is described which requires few measurements to achieve sufficient accuracy. For the ES400 echo-sounder, measurements at 30 points in the beam determine the mean sensitivity to ±0.5 dB or better. The sensitivity measurements varied over a 3 dB range. Reasons for this unexpected variation are discussed.

## INTRODUCTION

There are well established methods for calibrating the sensitivity of the conventional echo-sounder for targets on the acoustic axis (Foote et al., 1986). In the case of the split-beam echo-sounder, however, it is insufficient to determine the on-axis sensitivity alone. This equipment is used to measure the target strength (TS) of isolated targets which may be detected at any position in the beam (Foote et al., 1985). It is therefore important to know how much the sensitivity, expressed as the indicated TS of an isotropic target, varies with the target position in the beam.

The correct interpretation of TS data collected from a split-beam echo-sounder requires the average sensitivity to be known. When many targets are detected, they are expected to be randomly distributed in the beam cross-section. The appropriate average is therefore an area-weighted integral over the beam cross-section. If $\sigma(\hat{r})$ is the indicated acoustic cross-section of a reference target in direction $\hat{r}$, and $d\Omega$ is a solid angle element around $\hat{r}$, then the average sensitivity is

$$\bar{\sigma} = \int \sigma(\hat{r})\, d\Omega / \int d\Omega \qquad \text{------------} \quad (1)$$

where the integrals are taken over the downward pointing hemisphere. In the usual decibel notation, the mean indicated target strength is

$$Tav = 10 \text{ Log } (\bar{\sigma}/4\pi) \qquad \text{------------} \quad (2)$$

If the known target strength of the reference sphere is Tref, then a correction term K = Tref - Tav must be added to the indicated TS values of single fish targets detected by the echo-sounder.

Ideally, K would be estimated from detailed measurements of the beam pattern, following the method of Simmonds (1984) or similar. However, this method is time consuming and it is not practical when the transducer is mounted on the ship's hull.

In this paper we consider how K may be estimated from a few measurements and we describe how to perform the calibration at sea. The main requirement is that the ship should be anchored in sheltered water at least 25 m deep. An example is given from measurements performed on the SIMRAD ES400 split beam echo-sounder which is installed on the Norwegian Research Ship "GO Sars".

## THEORY

The beam pattern of the split-beam transducer has the usual central and side lobe structure. The phase differences in the signals received by the four transducer sections are used to determine the target direction and hence to correct the signal level for the change in transducer sensitivity. In the case of the ES400, this correction is performed by the program in a read-only-memory (ROM) microcircuit within the instrument. The signal from the reference target must be measured at two points in the ES400. Firstly, the output signal gives the indicated cross-section $\sigma$. Secondly, the signal V is measured at a point before the phase correction is applied. The size of V varies with the target position and may be used to determine the angle $\Theta$ of the target relative to the acoustic axis. The procedure for computing $\Theta$ as a function of V is described in the next section.

For the purpose of estimating the mean senstivity, the beam cross-section is partitioned into seven equal areas as shown in Figure 1. The acoustic axis is at the centre of the acceptance circle defined by $\Theta = \Theta_{max}$. Targets at angles greater than $\Theta_{max}$ from the acoustic axis are ignored by the instrument. The division of the acceptance circle into six peripheral segments and one central area is particularly convenient when the calibration is performed with the target suspended on three lines.

The angular limit of the central area Ao is $\Theta_{cen} = \Theta_{max}/\sqrt{(7)}$. The radial lines separating the six segments are equally spaced by 60 degrees in azimuth. The central area is included in addition to the segments because there will usually be several measurements near the acoustic axis. These should be given the same weight as the off-axis measurements.

Suppose that a number of measurements are taken by moving a reference target through all sub-areas of the beam. $N_i$ measurement sets are taken in area i, namely sensitivities $\sigma_{n,i}$ corresponding to angles $\Theta_{n,i}$ for $n = 1 - N_i$.

It is preferable that the $N_i$ should all be the same, so that all areas are sampled equally, although some differences in sampling intensity may be accepted with little effect on precision. Ideally, the samples should be located randomly in each area. In practice, however, it is expedient to collect the data along radial transects such as the port-starboard line shown in Figure 1, since the target can be made to move along a transect by adjusting one of the support lines.

To achieve the best coverage of the beam, the samples should be taken at positions such that each sample represents the same area. This implies that the samples should be spaced along the transect as follows

$$\Theta_{n,i} = [(n-\tfrac{1}{2})(\Theta_{max}^2 - \Theta_{cen}^2)/N_i + \Theta_{cen}^2] \text{ ---------- } (3)$$

If it is not possible to position the target precisely, so that the $\Theta_{n,i}$ are at arbitrary positions on the transect, each $\sigma_{n,i}$ should be weighted in proportion to the area it represents. Since the cross-section area is proportional to $\Theta^2$, the samples are weighted by elemental areas bounded by the mean $\Theta^2$ of adjacent samples, or the inner/outer segment boundary in the case of the first/last samples in a radial transect. The mean sensitivity for segment i is

$$\langle\sigma_i\rangle = (\sum_n \sigma_{n,i} W_{n,i})/(\Theta_{max}^2 - \Theta_{cen}^2) \text{ ---------- } (4)$$

and the weights $W_{n,i}$ are

$$W_{1,i} = (\Theta_{1,i}^2 + \Theta_{1,i}^2)/2 - \Theta_{cen}^2 \text{ ------------ } (5a)$$

$$W_{n,i} = (\Theta_{n+1,i}^2 + \Theta_{n,i}^2)/2, \text{ for } n = 2 \text{ to } N_i-1 \text{ ---------- } (5b)$$

$$W_{N_i,i} = \Theta_{max}^2 - (\Theta_{N_i}^2 + \Theta_{N_i-1}^2)/2 \text{ -------- } (5c)$$

If the $\Theta_{n,i}$ are those given by (3), the elemental areas are equal and $W_{n,i} = 1$. The angles of measurements in the central area are disregarded and a simple average is calculated in this area.

$$\langle\sigma_o\rangle = (\sum_n \sigma_{o,n})/N_o \text{ ------------ } (6)$$

The final result is $\hat{\sigma}$, an estimate of the $\bar{\sigma}$ defined in (1). It is obtained as the average over the seven sub-areas.

$$\hat{\sigma} = \{\sum_{j=o}^{6} \langle\sigma_j\rangle\}/7 \text{ ------------ } (7a)$$

The standard deviation of $\hat{\sigma}$ is

$$s = \sqrt{\{\sum_{j=o}^{6} (\langle\sigma_j\rangle - \hat{\sigma})^2/42\}} \text{ -------------- } (7b)$$

95% confidence limits on $\hat{\sigma}$ are estimated as $\pm 2.4$ s using student's t parameter for six degrees of freedom.

## Experimental Method

The equipment required is the same as that used to calibrate conventional echo sounders, namely a reference sphere of known TS and some means of suspending the sphere on three lines below the transducer (Foote et al., 1986; Simmonds et al., 1984). In the case of measurements on the hull-mounted transducer of "GO Sars", the reference target is a 60 mm diameter copper sphere. The support lines run from three small winches attached to the sides of the ship, two on the starboard side and one on the port. The sphere is suspended about 18.5 m below the transducer. The length of each line may be adjusted to move the sphere in different directions. Further details of this equipment will be found in Foote et al. (1986).

An oscilloscope is connected to a suitable point (CAL OUT or equivalent) in the echo sounder to measure the transducer signal V. The line lengths are adjusted until V is at its maximum value, Vo. The sphere is then on the acoustic axis. The output of the echo-sounder is now recorded to give the first measurement of $\sigma$ in the central area.

The line to the port side winch is now pulled in, causing the sphere to move through area A1 (Fig. 1). At the same time, the signal V is observed. It should decrease as the sphere moves away from the acoustic axis. The angle Θ corresponding to the ratio V/Vo is determined from the beam pattern of the transducer. In the case of the ES400 transducer, the relationship is shown in Table I which has been compiled from information supplied by the manufacturer. The sphere is moved until V/Vo corresponds to the angle required for the next measurement.

When the required number of measurements in A1 has been collected, the port side line is released so that the sphere moves to A3 and further measurements are made. Then the sphere is returned to the central area Ao and a measurement may be taken there if required.

The above procedure is repeated while the other two support lines are adjusted, thus collecting measurements in all the sub-areas Ao-A6. The final measurement should be taken in the central area when the sphere is returned to its initial position. $\hat{\sigma}$ and the corresponding estimate of Tav are now calculated using equations (4-7) above.

While the sphere is at the final position on the acoustic axis, the echo-sounder gain may be adjusted to increase the indicated TS of the sphere by (Tref - Tav). The echo sounder should then indicate the correct mean TS for a large number of targets randomly distributed in the beam. However, if the gain is adjusted, it would be advisable to repeat the complete calibration procedure.

## RESULTS AND DISCUSSION

A preliminary investigation of the sensitivity of the ES400 was made on board the Research Vessel "Fridtjof Nansen" in August 1985. This indicated significant changes in sensitivity over the beam. More detailed measurements on another echo-sounder of the same type were obtained during a cruise of "GO Sars" in November 1985. Two calibrations were performed. The results from the first calibration are shown in Figure 2 and Table II(a). Each peripheral graph in the Figure shows the measurements in one section of the beam corresponding to the adjustment of one support twine. The measurements in the central area Ao were collected at intervals during the calibration.

Following alterations to the echo-sounder, including the installation of a new lobe ROM, the second calibration was performed and the results are shown in Figure 3 and Table II(b).

The difference in mean sensitivity between the two calibrations is not significant because the gain of the echo-sounder was changed during the adjustments. However, it is seen from Figures 2 and 3 that the variation about the mean sensitivity is similar. In particular, there is a consistent anomaly in area A1 where the sensitivity suddenly increases by more than 2 dB over a small change in Θ. We are unable to explain this effect, but we note that the ES400 transducer is installed on the port side of the ship, while area A1 is on the starboard side of the beam. It is possible that the keel of the ship, being close to the ray path between the transducer and the targets in A1, might influence the echo phase to some extent. Of course, these results do demonstrate that significant changes can occur in the sensitivity of the split beam echo-sounder, and that appropriate calibration procedures are necessary to correct the measured target strengths.

We observed more variation during the second calibration. This is reflected in the slightly wider confidence limits, ±0.6 dB as opposed to ±0.5 dB on the indicated TS. Some of the variation may be measurement error, for example when fish swim close to the target. Interference from fish will usually be indicated by a large fluctuation of V. Should this happen, do not continue the measurements. Wait until the fish go away, or find another place to do the calibration.

The difference between the two calibrations might indicate real changes in sensitivity, since the sphere would be unlikely to move along exactly the same transects in the two cases. More painstaking measurements would be necessary to investigate this possibility.

## CONCLUSIONS

The split beam echo-sounder may be calibrated by the same equipment as is used to calibrate conventional echo-sounders. Measurements are required of the echo from a reference target at various positions in the transducer beam. Given about 30 measurements, the mean sensitivity can be determined to better than ±0.5 dB at the 95% confidence level. The calibration will be more accurate if more measurements are made.

## REFERENCES

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TABLE I

Target direction as a function of the signal amplitude for the "GO Sars" ES400 transducer. Θ is the angle between the target direction and the acoustic axis. BW is the beamwidth between 3 dB down points. Results are given for targets in two planes parallel to the acoustic axis and mutually perpendicular.

| | BW = 7.5 degrees (fore-aft plane) | | BW = 8.2 degrees (port-stbd plane) | |
|---|---|---|---|---|
| Θ (deg) | V/Vo | dB | V/Vo | dB |
| 0.0 | 1.000 | 0.00 | 1.000 | 0.00 |
| 1.5 | 0.901 | -0.90 | 0.917 | -0.75 |
| 1.8 | 0.860 | -1.31 | 0.882 | -1.09 |
| 2.0 | 0.830 | -1.62 | 0.856 | -1.35 |
| 2.2 | 0.797 | -1.97 | 0.828 | -1.64 |
| 2.4 | 0.763 | -2.35 | 0.798 | -1.96 |
| 2.6 | 0.727 | -2.77 | 0.767 | -2.31 |
| 2.8 | 0.689 | -3.23 | 0.734 | -2.69 |
| 3.0 | 0.651 | -3.73 | 0.700 | -3.10 |
| 3.2 | 0.611 | -4.28 | 0.665 | -3.55 |
| 3.4 | 0.571 | -4.86 | 0.629 | -4.03 |
| 3.6 | 0.531 | -5.49 | 0.593 | -4.54 |
| 3.8 | 0.491 | -6.17 | 0.556 | -5.10 |
| 4.0 | 0.452 | -6.90 | 0.520 | -5.69 |
| 4.1 | 0.432 | -7.28 | 0.501 | -6.00 |
| 4.2 | 0.413 | -7.68 | 0.483 | -6.32 |
| 4.3 | 0.394 | -8.09 | 0.465 | -6.65 |
| 4.4 | 0.375 | -8.51 | 0.447 | -6.99 |
| 4.5 | 0.357 | -8.95 | 0.429 | -7.34 |
| 4.6 | 0.338 | -9.41 | 0.412 | -7.71 |
| 4.7 | 0.321 | -9.88 | 0.394 | -8.08 |
| 4.8 | 0.303 | -10.37 | 0.377 | -8.47 |
| 4.9 | 0.286 | -10.87 | 0.360 | -8.87 |
| 5.0 | 0.269 | -11.40 | 0.343 | -9.29 |

TABLE II

Results from two calibrations of ES400. The receiver gain was adjusted between the calibrations.

| (a) First Calibration | | | | (b) Second Calibration | | |
|---|---|---|---|---|---|---|
| Sector | Θ (deg) | σ (cm²) | σ (cm²) | Θ (deg) | σ (cm²) | σ (cm²) |
| $A_0$ | - | 45.2 | 51.87 | - | 128.7 | 127.6 |
| | - | 55.4 | | - | 126.5 | |
| | - | 55.0 | | | | |
| $A_1$ | 2.5 | 109.9 | 74.81 | 1.9 | 122.6 | 159.6 |
| | 3.7 | 62.7 | | 2.6 | 202.5 | |
| | 4.4 | 54.8 | | 3.2 | 186.1 | |
| | 4.8 | 47.9 | | 3.7 | 162.1 | |
| | | | | 4.4 | 148.5 | |
| | | | | 4.8 | 116.9 | |
| $A_2$ | 2.6 | 53.8 | 58.77 | 2.6 | 155.0 | 149.2 |
| | 3.7 | 65.5 | | 3.7 | 150.9 | |
| | 4.4 | 59.9 | | 4.4 | 154.5 | |
| | 4.7 | 55.0 | | 4.8 | 122.1 | |
| $A_3$ | 2.6 | 67.5 | 59.40 | 2.6 | 164.7 | 153.2 |
| | 3.7 | 67.5 | | 3.7 | 167.2 | |
| | 4.4 | 61.5 | | 4.4 | 145.9 | |
| | 4.8 | 56.1 | | 4.7 | 111.1 | |
| $A_4$ | 2.6 | 53.9 | 54.64 | 2.6 | 146.9 | 147.4 |
| | 3.7 | 55.3 | | 3.7 | 154.4 | |
| | 4.4 | 55.4 | | 4.4 | 148.0 | |
| | 4.8 | 53.7 | | 4.8 | 131.6 | |
| $A_5$ | 2.6 | 63.3 | 67.04 | 2.6 | 242.0 | 212.3 |
| | 3.7 | 68.2 | | 3.7 | 219.8 | |
| | 4.4 | 75.2 | | 4.4 | 182.5 | |
| | 4.7 | 62.4 | | 4.8 | 171.4 | |
| $A_6$ | 2.6 | 62.4 | 61.05 | 2.6 | 170.5 | 174.0 |
| | 3.7 | 61.6 | | 3.7 | 208.4 | |
| | 4.4 | 62.4 | | 4.4 | 161.3 | |
| | 4.7 | 55.4 | | 4.8 | 127.0 | |
| Mean sensitivity (cm²) | | | $61.1 \pm 5.8$ | | $160.5 \pm 24.3$ | |
| Indicated target strength (dB) | | | $-33.1 \pm 0.4$ | | $-28.9 \pm 0.6$ | |

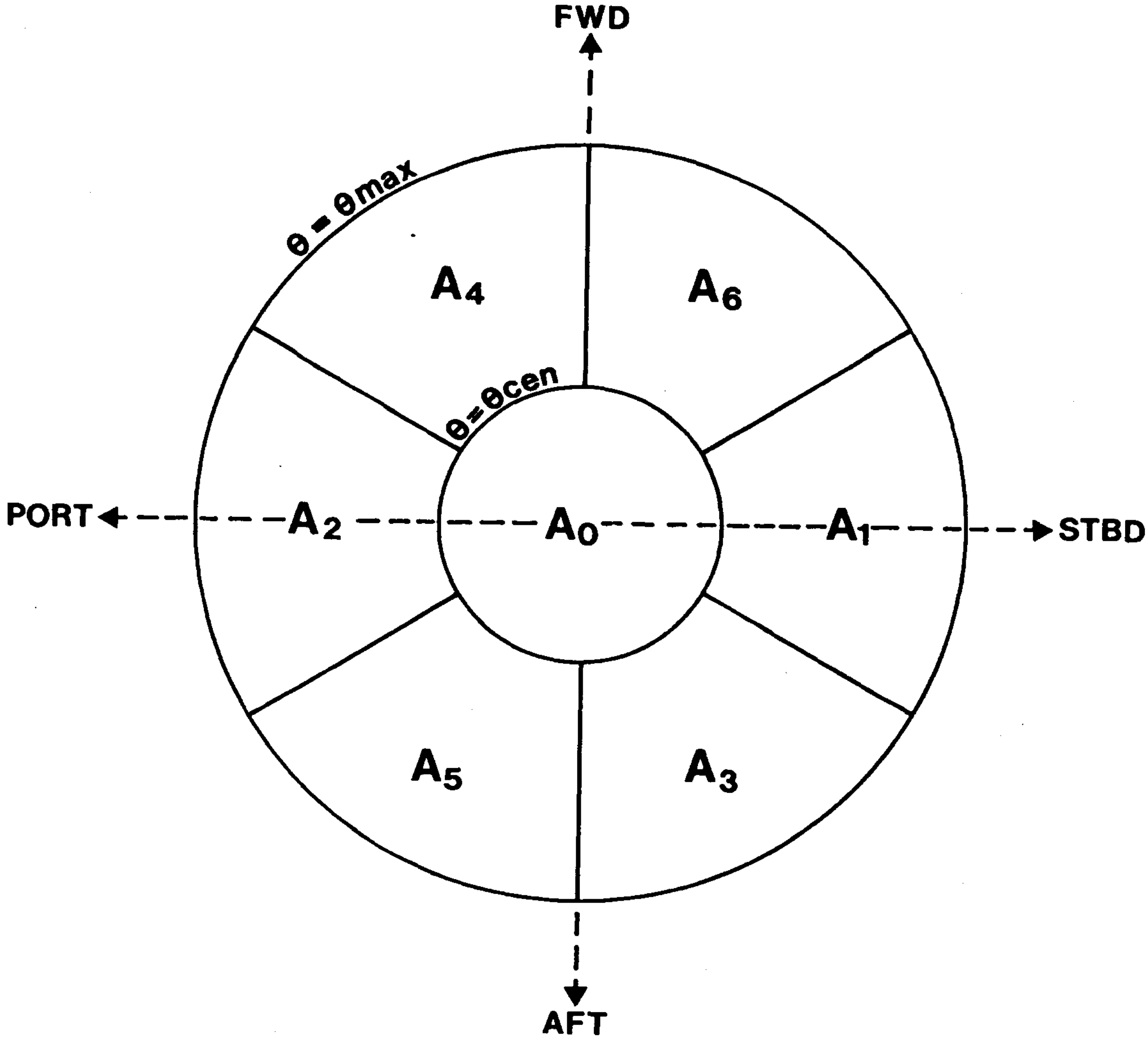


fig 1. Division of the beam cross–section into seven equal sub–areas

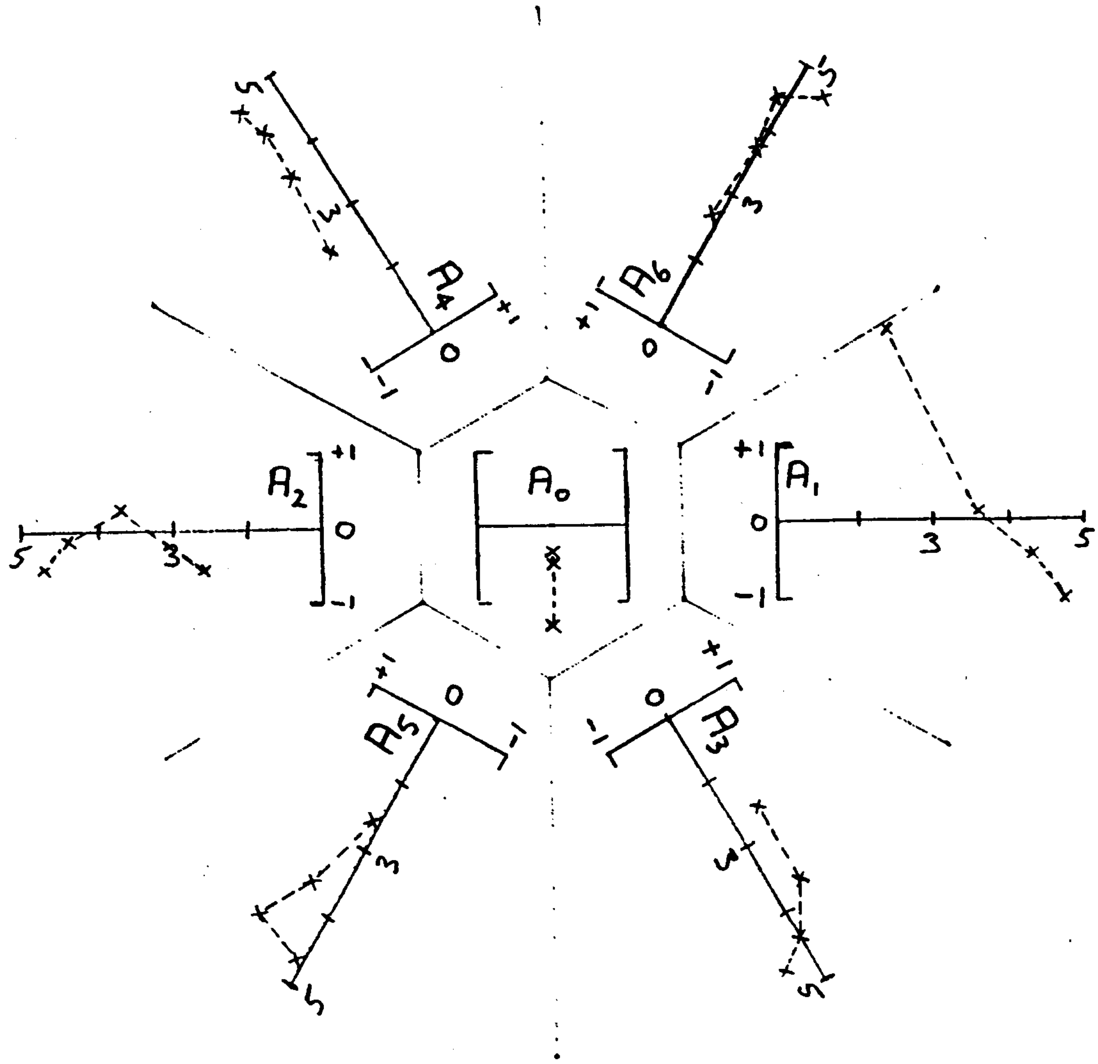


Figure 2. Indicated TS as a function of the target position in the beam. Measurements from the first calibration are shown by sub-area. Radial axes - target direction relative to the acoustic axis, degrees; azimuthal axes - indicated TS, dB relative to the mean TS from Table II.

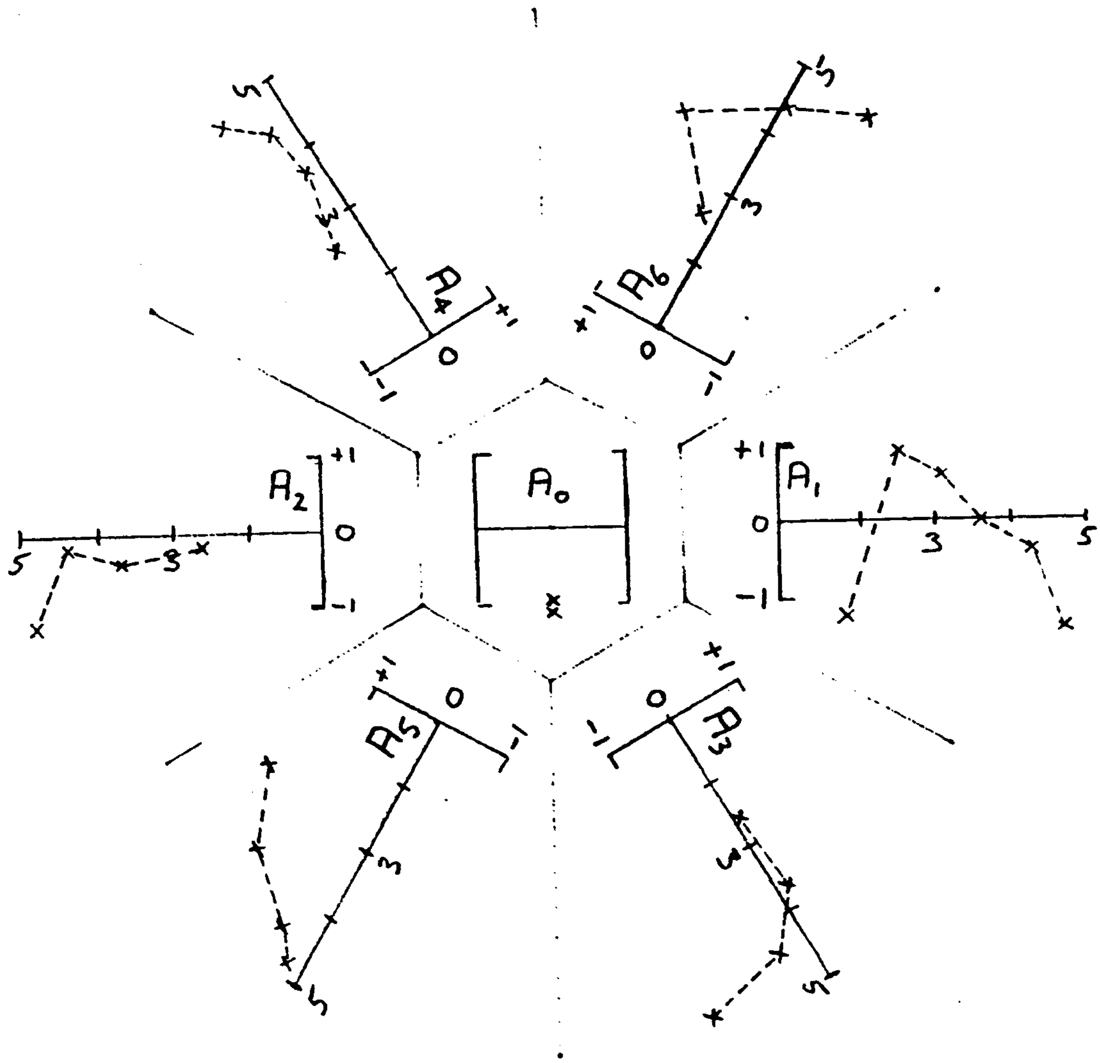


Figure 3. Indicated TS as a function of the target position in the beam. Second calibration. Measurements are shown by sub-area. Radial axes - target direction relative to the acoustic axis, degrees; azimuthal axes - indicated TS, dB relative to the mean TS from Table II.