# PRINCIPLES OF COMPUTING AND DISPLAYING THE RESULTS OF DETECTION BY UNDERWATER SYSTEMS AS PART OF SOUND VELOCITY MEASUREMENTS

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*The paper presents the upgraded system for measurements of sound velocity profiles and for computing and imaging the terms of detection in different hydrolocation and hydrocommunication systems. Three types of computations made by the system's processors are discussed. The most interesting task is to link the propagation routes and ray density with the parameters of the hydroacoustic system to obtain the desired display of the conditions to detect the signal from the background noises. Presented discussion of methodology of determining detection conditions using different forms of range equation gives a more detailed description of this task. In the next part of this paper the software's display function and necessary settings are specified and discussed. In the end two examples of computed detection conditions images (for active and passive sonar) are shown.*

## INTRODUCTION

Over the last decade or so measurement devices have been designed to measure and display hydrological conditions in bodies of water, and to be exact, to study the distribution of sound velocity as a function of depth. Knowledge of these conditions combined with the knowledge of the essential parameters of a hydrolocation system or an underwater communications system is the basis for computing the conditions of detection, expressed as a function of the variance between the useful signal and the receiver's own electric noises or sea noise.

Recently, new software has been developed to run the device. The improvement was necessary to keep up with the recent developments in computer technology, as the new operating systems do not allow the use of DOS based software. Another reason for the upgrade was that new functions were added. Detection must now be conducted in a variety of underwater acoustic systems, including passive and active sonars, with hull-mounted or variable depth antennas, and in audio and digital communications systems. The previous software was upgraded as new applications were introduced. The transparency of use and structure, however, suffered. New processors were added meaning that the process of computing propagation routes and acoustic field intensity as system's range increased, had to be improved as well [1].

The new software is WINDOWS based. The structure and software of the single chip processor in a submergible measurement cylinder remained unchanged. Consequently, the method of measuring hydrological conditions did not change, either.

## 1. TYPES OF COMPUTATIONS MADE BY THE SYSTEM'S PROCESSORS

Generally speaking, the system's processors perform three tasks. First, the processor in a submergible measurement cylinder together with the appropriate system for measuring sound velocity and hydrostatic pressure sensor, collects measurement data and forms them into files that are stored and are ready to be transmitted to an external computer. The collecting itself is not a simple task as it allows for complications such as unintended upward and downward cylinder moves (e.g. as the helicopter hovers) which are quite troublesome at water surface or when the cylinder is lowered too quickly or too slowly.

The second task is to compute propagation routes of the numerous rays whose variable density in unit cross-section of the water represents sound intensity which changes as the range changes. Consequently, the level is computed using the so called ray density method [2]. The important thing is that the display shows the cross-section (two rather than three-dimensional) of the variance between the levels of sound intensity and noise level, therefore changes in intensity (ray density) as the range changes are computed and displayed as one-dimensional (linear density in a specific range), while spatial aspects are taken into account by using three-dimensional shapes of the beams – the transmitting beam for determining (or measuring) the system's source level and the receiving beam for determining the level of sea noise at receiver input.

The causes of the variable sound intensity level (usually decreasing as range increases) include losses incurred as the signal's energy is distributed in a divergent beam, wave attenuation and displacements and reflections from water surface and bottom caused by gradients of sound velocity in the water. To reduce the time of the computations, despite the powerful computers, some reasonable optimisations are used with regard to the thickness (and consequently the number) of water layers (by checking for actual, significant gradients of sound velocity in various depths) and with regard to geometrical approximations of the phenomenology of the displacements [1].

The third task is to link the propagation routes and ray density with the parameters of the hydrolocation or hydrocommunication system to obtain the desired display of the conditions to detect the signal from the background noises. This task needs a more detailed description.

## 2. METHODOLOGY OF DETERMINING DETECTION CONDITIONS

The way detection conditions are determined and displayed in underwater acoustic systems linked with the measurement device in question is that a decibel scale of colours is used on vertical sections of the body of water to mark the variances between the level of the useful signal (echo from a target or a signal transmitted by another, remote source) and the level of interference. One hundred and seventy two colours were used covering a dynamics of variances equal to 60 dB. There are three types of underwater acoustic systems: active hydrolocation, passive hydrolocation and hydrocommunication. Noise from the sea or electric noise from the system is treated as disturbance.

Let us introduce a certain formalistic approach, based on known range equations used for designing hydroacoustic systems. We get the following logarithmic form [3], [4]:

$$C(d,r) = SiL + PG - NL \tag{1}$$

where:

- $C(d,r)$ is the distribution of the display colours as the function of depth $d$ and range $r$,
- $SiL$ [dB] – level of the useful signal received from various signal ranges (signal level),
- $PG$ [dB] is the processing gain in the system's receiver and gives us an idea of any improvements of the signal to noise ratio at receiver output with regard to its input as a result of special operations on special signals (matching filtration of broadband signals, e.g. 'chirp' type); with no such operations the gain is 0dB [4],
- $NL$ [dB] - noise level.

The signal level $SiL$ can be one of the following:

- in active hydrolocation systems – the level of the received echo $EL$ [dB] from the target,
- in passive hydrolocation systems – the level of the received signal $SiL_p$ [dB] from the source that generates the signal level (source level) $SL_p$ [dB] (e.g. noise-like),
- in communications systems (audio or digital) – the level of the signal $SiL_c$ [dB] from a transmitter where source level is $SL_c$ [dB].

The expressions that determine the level $SiL$ take this form:

- the level of the signal received (echolocation):

$$EL = SL + TS - 2TL \tag{2}$$

where:

- $TS$ [dB] is the target strength and for large submarines the value is assumed at about 0 dB, for mines –20 dB, for big fish –30 dB,
- $TL$ [dB/m] are transmission losses of signal in the water that depend on the range (here counted twice – as the sounding signal goes to the target and back), a more detailed description is given further on,
- $SL$ [dB] is the source level (system transmitter) determined as follows:

$$SL = 48 + 10\log P_t + 10\log\frac{41000}{\alpha_t \cdot \beta_t} \tag{3}$$

where:

- $Pt$ [W] is the acoustic power emitted by the transmitter (electric power reduced by the transducer's limited electroacoustic efficiency, usually in the range of 50%),
- $\alpha_t$ and $\beta_t$ [$^0$] are the beam width (vertical and horizontal) of the transmitting transducer's while the whole factor defines, in a simplified way, the directivity index on the transmitting side $DI_t$ $DI_t$ (this approximation is effective for angels $\alpha,\beta < 90^o$ and for omnidirectional transducers $DI_t = 0$dB),
- factor 48dB is the result of the necessary normalisation introduced as we change from the geometric to the decibel form of range equations, equation (1) is the special form of these; the usual value of the factor at 51dB was reduced by 3dB, under the assumption that the target is not necessarily found on the acoustic axis of the transmitting transducer.

- the level of the signal received in the case of passive bearing:

$$SiL_p = SL_p - TL \tag{4}$$

where:

- $SL_p$ [dB] is the level of the detected signal source and its value is usually unknown; consequently, for 'loud' submarines the assumed value is 20dB and for 'quiet' ones it is 0dB,
- $TL$ was defined in formula (2) (here: transmission losses one way only).

- the level of the signal received when systems communicate:

$$SiL_c = SL_c - TL \tag{5}$$

For two-way communication between different systems to occur, the parameters of the 'worse' system must be taken into account.

The level of noise $NL$ can be one of the following:

- the level of electric noise at system receiver input $NL_e$:

$$NL_e = 20 \log u_{nrin} - 20 \log v_r \tag{6}$$

where $u_{nrin}$ [$V_{rms}$] is the voltage of noise at receiver input, and $v_r$ [V/Pa] is the sensitivity (voltage response) of the system's receiving transducer,

- the level of sea noise $NL_s$:

$$NL_s = SPL + 10 \log B - 10 \log \frac{41000}{\alpha_r \cdot \beta_r} \tag{7}$$

where:

- $B$ [Hz] is the system's receiver bandwidth,
- $\alpha_r$ and $\beta_r$ [°] are this time the beam width (vertical and horizontal) of the receiving transducer and the whole factor defines, in a simplified way, the directivity index on the receiving side,
- $SPL$ [dB] is the spectral power level defined by experimentally produced Knudsen's curves; it is determined by the higher value from among the level of thermal sea water noise and the level of wave noise (with the sea state as the parameter); it is analytically approximated with the following formulas:

$$SPL_{term} = -135 + 20 \log f \tag{8}$$

$$SPL_w = x - 20 \log f \tag{9}$$

where:

- $f$ [kHz] is the mid frequency of receiver bandwidth,
- value $x$ depends on the sea state as follows:

| State of sea [°] | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $x$ | - 75 | - 65 | - 58 | -56 | -54 | -50 | - 43 |

The above analysis shows that transmission losses $TL$ are the only factor in the equations that is dependent on the range. As mentioned before, the source of the losses is wave spread leading to reduced wave intensity and wave attenuation. This effect can be formally presented as follows:

$$TL = 20 \log r + ar \tag{10}$$

where $r$ [km] is the range and $a$ [dB/km] is the logarithmic wave attenuation ratio. Its value can be determined from Schulkin – Marsha empirical formula:

$$a = 2{,}03 \cdot 10^{-5} \frac{s \cdot f_T \cdot f}{f_T^2 + f^2} + 2{,}94 \cdot 10^{-5} \frac{f^2}{f_T} \tag{11}$$

where:

- $s$ [$^o/_{oo}$] is water salinity (in the Baltic about $7^o/_{oo}$, in oceans about $35^o/_{oo}$),
- $f_T$ [kHz] – so called relaxation frequency:

$$f_T = 2{,}19 \cdot 10^{6 - \frac{1520}{273+T}} \tag{12}$$

- $T$ is water temperature [°C] (usually at the average temperature of 10 °C),
- $f$ [kHz] is the receiver's mid frequency.

## 3. THE DISPLAY FUNCTIONALITY OF THE SYSTEM'S EXTERNAL PROCESSOR SOFTWARE

The basic operation the software performs is producing the above relations in a colour display. The imaging is done using hydrological data retrieved from the measurement cylinder and data about the underwater system which are input by the operator or pre-defined in the software's memory. It needs to be stressed again that apart from transmission losses *TS* all other parameters in the relations once input and computed, do not depend on the range and are, as a result, constant values. For smaller ranges the variances between the levels of usable signals and noise levels are sometimes greater than 60dB – those are marked with red corresponding to 60dB (this variance is treated as perfect); thanks to that the dynamics of the display remains within reasonable limits.

The software's display function is to:

- 'locate' the transducer with the pre-defined angle of vertical cross-section of the beam at the right depth (variable depth antenna) or at the right tilt (hull-mounted antenna),
- compute ray density at 1m away from the source (following the above normalisation rules) and assign the density a value equal to [dB]:
  $SL + TS + PG$ (for the active location system),
  $SL_p + PG$ (for the passive location system),
  $SL_c + PG$ (for the communications system);
- compute level $NL$ ($NL_e$ or $NL_s$);
- compute the shape of the trajectories of the rays including any bends, reflections and transmission losses $TL(r)$,
- compute the value of ray density in units of cross-section for the different ranges, assign it a value in dB, check the value of the variance from level $NL$ and assign the right colour to the variance.

## 4. THE SETTINGS

Operating the software is very easy and for a number of commonly used underwater systems, you only need to select that system's name from the list. If you select *other* system from the list, you can input its parameters. Even when selecting a system from the list, you can still change its parameters, but after the new parameters are input, a message will appear to say that a change has been made and to ask the user whether the previous parameters should be restored or saved on the list under a new system.

When new settings are to be input (especially the settings of a new system), obtaining all the necessary information from the documentation may be problematic. The information you will most frequently find missing is the source level. To help the user with this problem, the source level is interchangeable with the transmitter power and beam width of the transmitting transducer, as you can use this information to compute the source level using formula (3). The noise level, which is the reference level in the display, can be selected automatically, as the higher of the two, i.e. electric noise or sea noise (poorer conditions), provided you know the voltage of the electric noise at receiver input, sensitivity of the receiving transducer and receiver bandwidth. Should any of these parameters be unknown, you can use one type of noise only (the levels are usually comparable), you can also select *reference level -60dB*, treated as a roughly typical value.

You need to be careful with the coefficient of wave reflection from the bottom and surface though. The default zero values are usually the right values in terms of target detection capability, since finding the echo or proper communication signals in a signal after reflections is highly unlikely, and the levels of reflected signals should really be seen as information about the relative (compared to the level of sea noise or electric noise) level of reverberation rather than the relative level of the useful signal.

The field *Accuracy of computation* allows you to select the density of 'emitted' rays, i.e. the number of rays used for the computations in $1^o$ of the section of the system's transmitting beam. The default value is set at 0.001 and stands for 1000 rays $/1^o$ and can be increased to 10000 making the computation time longer, or reduced, e.g. for several rays you obtain a clear, textbook display of the routes of individual rays in a cross-section of the water.

With the settings and computations complete, the images of six different situations will appear on the monitor for varying depths of antenna submersion, different tilts or ranges (when the antenna is neither tilted nor submerged). The different antenna depths on the images are the result of a division into 6 segments of the maximal depth of the profile measured (maximal depth of cylinder during measurement) less the initial value. Similarly, the varying antenna angles in the individual displays are the result of an automatic division, after rounding up, of the angle $90^o$ into 6 parts less the initial value of incidence. The values of maximal ranges in the six individual displays (occurring when the antenna is neither tilted nor submerged) are the result of successive multiplication of the rounded up automatic division by 6 of the pre-defined system *Range*. Figure 1 show an interesting, spectacular sound speed profile and figures 2 and 3 show images for a sonar operating in this hydrological conditions in the active and passive mode.

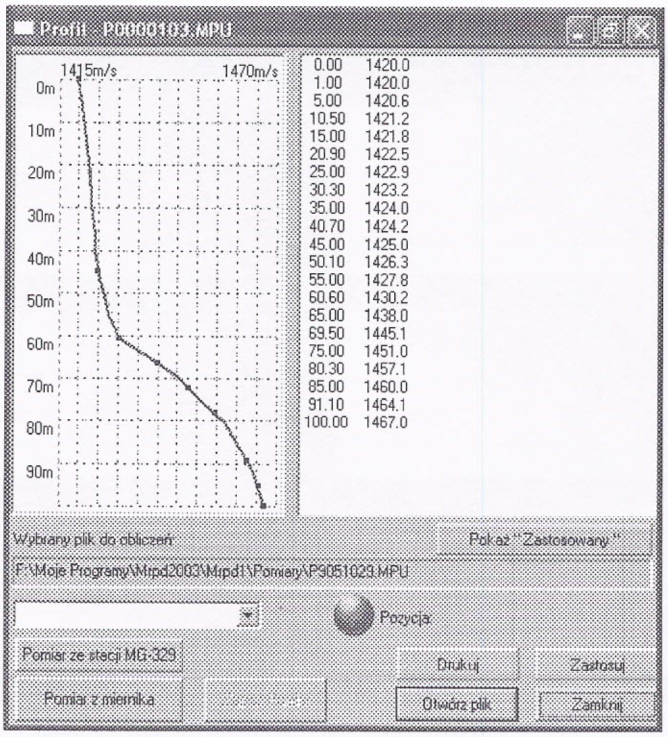


Fig. 1. Sound speed profile

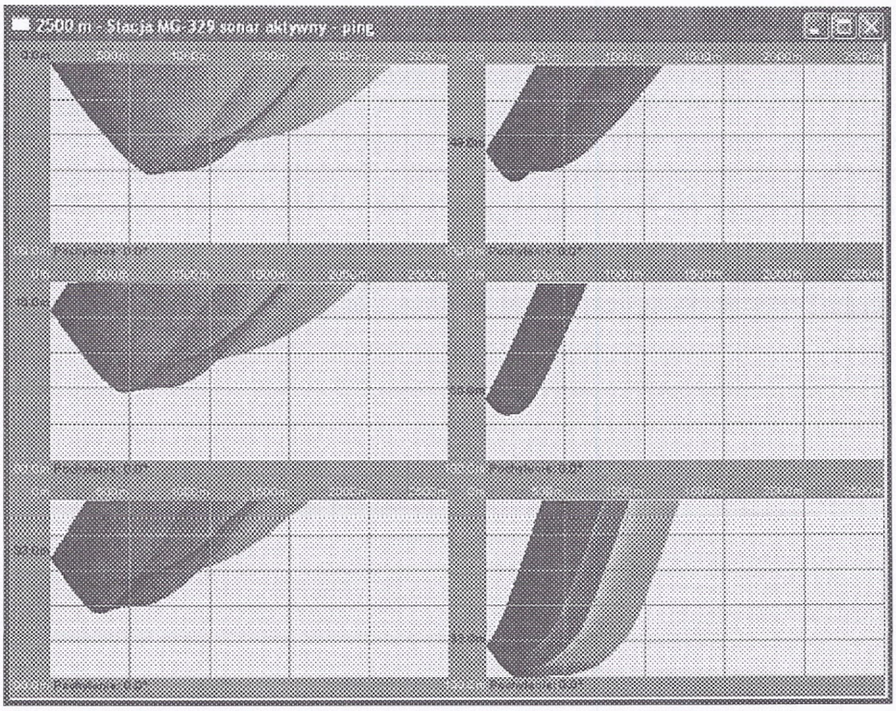


Fig. 2. Image of detection conditions for active sonar.

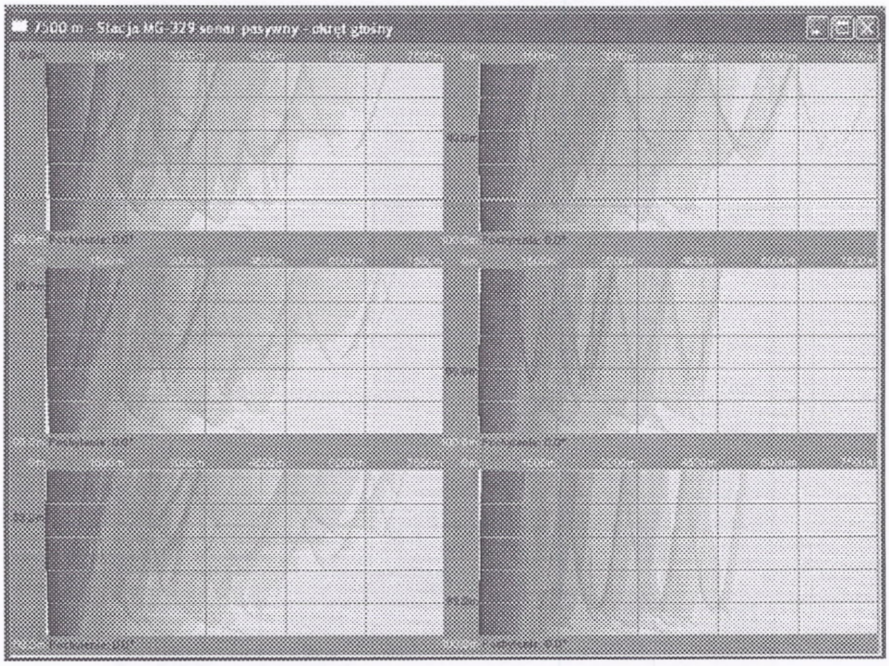

Fig. 3. Image of detection conditions for passive sonar.

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