# TIME VARIABLE GAIN FOR LONG RANGE SONAR WITH CHIRP SOUNDING SIGNAL


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*The main purpose of applying Time Variable Gain (TVG) in active sonars with digital signal processing is to reduce dynamic range of echo signal and adapt it to the dynamic range of the analogue to digital conversion. With high transmission losses level, the dynamic range of the input signal in long range sonars can be very high and even exceed 200 dB. When chirp sounding signals with matched filtration are used, sonars can reach very long ranges. The article presents optimisation of TVG control for long range sonars. It also looks at the influence of chirp sounding signal compression, the result of digital matched filtration, for the TVG controlling. The examples of obtained results are presented.*


## INTRODUCTION

When Time Variable Gain (TVG) is used in classic analogue active underwater acoustic systems, the objective is to compensate for transmission losses, reduce signal dynamic range and adapt it to the dynamic range of the indicator. Depending on why the sonar is used, gain is controlled to ensure the same echo level off an object regardless of the distance or to obtain a constant background of surface reverberations. Digital signal processing systems use analogue TVG to obtain the best possible match between signal dynamic range and analogue to digital conversion resolution. Any further signal processing for usable signal or interference level normalisation can be done digitally. Other important aspects to be considered when designing for TVG include identical level of echo off an object when observation ranges are changed and a good signal level when types of TVG control are changed.

## 1. TRANSMISSION LOSSES FOR LONG RANGE SONARS

Transmission losses 2TL in active long range sonars can be described logarithmically using the equation below:

$$2TL = n \times 10\, log\, R + 2\alpha R \tag{1}$$

where R is distance, $\alpha$ coefficient of acoustic wave attenuation in water.

Depending on the model of acoustic wave propagation coefficient $n$ takes on these values:

$n$ = 2 – for a cylindrical model of acoustic wave propagation for shallow waters;
$n$ = 4 – for a spherical model of acoustic wave propagation to ensure a constant level of echo off a point target regardless of the distance;
$n$ = 3 - for a spherical model of acoustic wave propagation to ensure a constant background of interference caused by surface reverberations.

When TVG systems use adjustable amplifiers with gain expressed in decibels proportional to the controlling voltage (e.g. Analogue Devices AD600), the signals generated can be described directly with relation (1). When the sonar operates in low frequencies with a low attenuation coefficient $\alpha$, the wave attenuation component is frequently overlooked and the TVG is referred to as 20logR, 30logR or 40 log R type.

Fig. 1 shows some typical TVG control characteristics. To ensure a more efficient use of the analogue to digital conversion dynamic range and avoid having to make significant manual control gain changes following a TVG type of change, it is advisable to normalise the control curves. Good engineering practice suggests that the normalisation should not be done at a 1 m distance, typical for a logarithmic range equation, but for half the gain control range (in example in Fig. 1 for a 40dB gain at full control range at 80 dB).

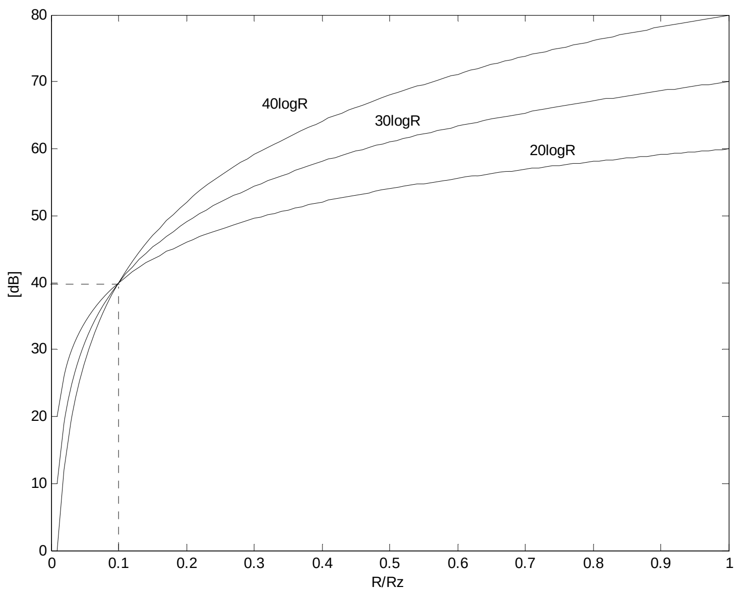


Fig.1 Characteristics of range control of sonar gain
(R – distance, R – range: 4, 8, 16, 32 km)

When designing how the TVG will be controlled, there are some negative aspects of using TVG to be considered. When echo signal, regardless of the distance, is set to be constant, the echo signal to detection threshold relation no longer depends on the distance. Consequently, the detection rate of low target strength objects does not increase as the distance decreases. Precision TVG control only makes sense in short range devices used for measuring, e.g. when estimating fish biomass. In long range devices, on the other hand, TVG should only be optimised to improve detection and make interference stationary.

The control curves given in Fig. 1 have the same shape for different ranges. As a result, TVG can be controlled at different speeds and maximal control gain can be obtained at the extreme ends of distances. In the example the only exception are ranges less than 4 km. For ranges of 1 km, 2 km and 4 km the same speed of control was used, reduced to a half or one quarter of the range, to prevent over-control of the receiver input for large echo signals over short distances.

## 2. ASPECTS OF TVG CONTROL FOR CHIRP SOUNDING SIGNALS

For longer ranges at a limited power of the sounding pulse, signals with frequency modulation type chirp are used. When combined with matched filtration, which produces the pulse compression effect, sounding signals of this type ensure improved range resolution by the product of frequency bandwidth and pulse duration. It also increases the echo signal to noise ratio, which grows in proportion to the extended pulse duration. Fig. 2 shows an example of the pulse's spectrum. $W$ frequency spectrum band ensures a range resolution $\Delta R$, which is independent of the pulse duration and equal to:

$$\Delta R = \frac{c}{2W} \tag{2}$$

where $c$ is the velocity of sound in water.

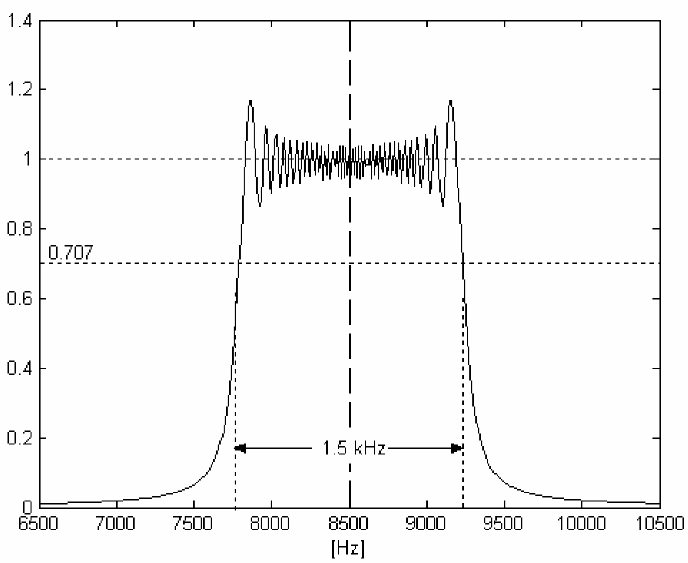


Fig.2 Spectrum of a chirp sounding signal

Digital matched filtration and pulse compression for double the duration of the chirp sounding signal, turn doubles the echo amplitude, while the noise level remains unchanged. On the other hand as sounding pulse duration increases, so does the dead zone $R_0$ equal to:

$$R_0 = \frac{cT}{2} \tag{3}$$

To keep the dead zone relatively small and improve long range detection, different sounding pulse times are used for different ranges.

When echo signal amplitude changes as a result of matched filtration following new sounding pulse durations for a specific distance, the output echo signal level for 20logR type control (as described in section 1) does not change when distances are changed. In the case of 30logR, 40logR control and for shorter ranges using 20logR control, the same echo signal levels for varying distances can only be kept if normalisation coefficients are used. Table 1 presents the values of the proper coefficients. For comparison, the table also gives normalisation coefficients for ping sounding signals. Because pulse compression does not occur in this case, the lack of an echo amplitude increase should be compensated with a much higher normalisation coefficient. (Obviously, increasing the result of the computation will not improve actual detection, which for ping signals for very long ranges can only be achieved when sonar source level is significantly increased.)

Tab.1 Normalisation coefficients for different ranges

| pulse type | TVG type | sonar range [km] | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 4 | 8 | 16 | 32 |
| | | pulse time duration [ms] | | | | | |
| | | 50 | 100 | 200 | 400 | 800 | 1600 |
| | | dead zone [m] | | | | | |
| | | 37.5 | 75 | 150 | 300 | 600 | 1200 |
| | | normalisation coefficient | | | | | |
| chirp | 20logR | 4 | 2 | 1 | 1 | 1 | 1 |
| | 30logR | 4 | 2 | 1 | $\sqrt{2}$ | 2 | $2\sqrt{2}$ |
| | 40 logR | 4 | 2 | 1 | 2 | 4 | 8 |
| ping | 20logR | 4 | 4 | 4 | 8 | 16 | 32 |
| | 30logR | 4 | 4 | 4 | $8\sqrt{2}$ | 32 | $64\sqrt{2}$ |
| | 40 logR | 4 | 4 | 4 | 16 | 64 | 256 |

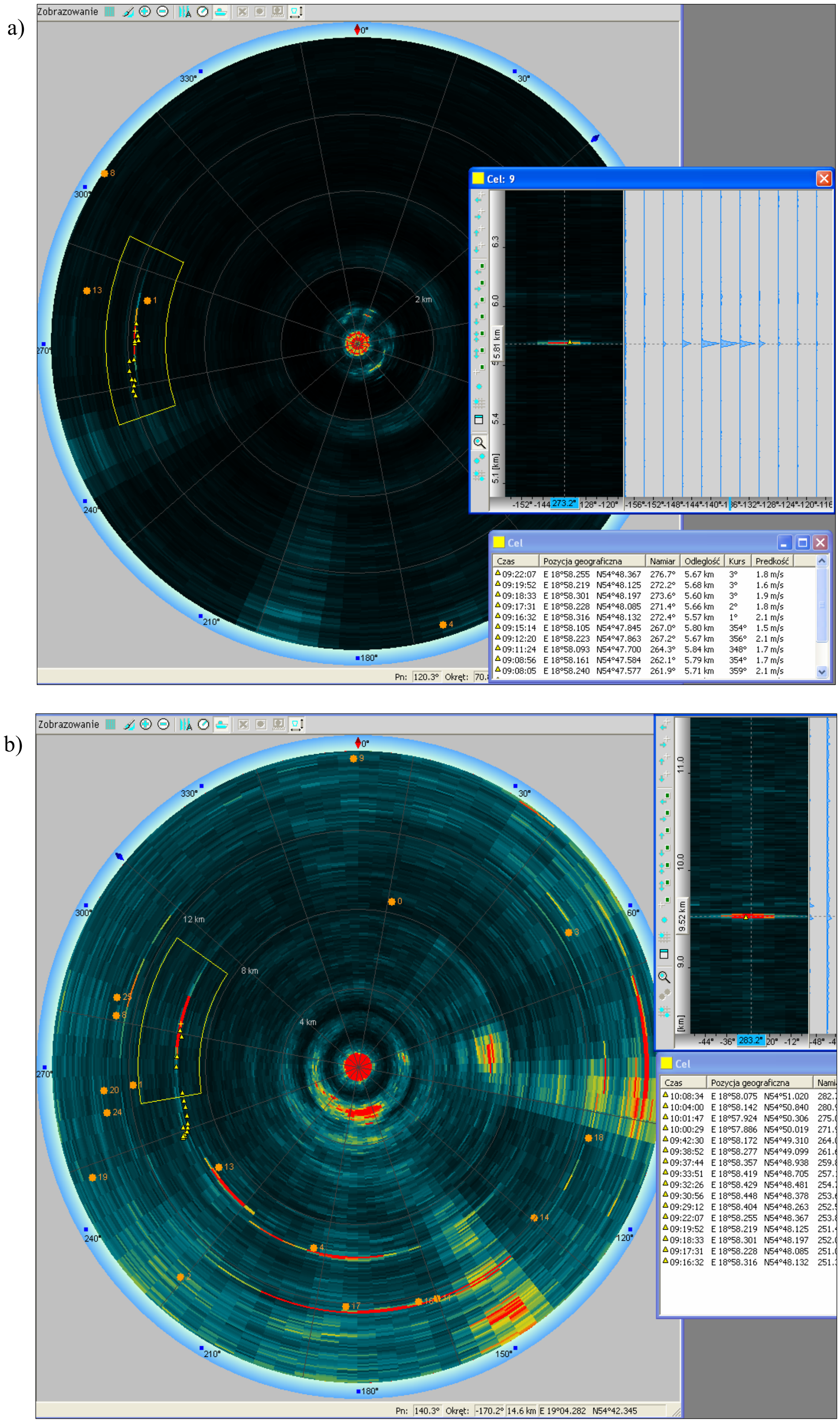

Fig.3 The examples of sonar display with reverberation interference background level made stationary for submarine tracking a) 5.67 km away at 273° bearing and ship's head at 49°; b) 9.94 km away at 282° bearing and ship's head at 306°

## 3. CONCLUSIONS

The considerations presented above are the result of a long standing practice of the Department of Marine Electronic Systems, Gdansk University of Technology, designing underwater acoustic systems. The examples illustrate work on improving a long range sonar operating at less than 10 kHz, where a chirp sounding signal was applied. The solutions for controlling TVG work very well for detecting and tracking submarines. The benefits include a good match between the dynamic range of echo input signals and the analogue to digital converter range of operation as well as a constant level of echoes when distances change. When TVG control type is changed, there is no need for manual gain adjustments. Examples of sonar operation for different ranges and TVG settings are given in Fig. 3. Earlier work and experiments with this type of sonar suggest that TVG control should be used:

- 40logR – for relatively small distances (4km maximum) for significant depths and a good signal to noise ratio;
- 30logR – for medium distances (4 - 8 km) for medium depths;
- 20logR – in situations where a cylindrical wave propagation model is more appropriate, i.e. for very long distances (16 - 32km) or for shorter distances for low depths.

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