TIME-VARIED-GAIN CORRECTION FOR DIGITAL ECHOSOUNDERS.

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ABSTRACT

Time-varied-gain (TVG) is indispensable feature in sonars used in fisheries research in order to compensate for transmission loss and make the echo level independent of a target range. In digital processing of data acquired from modern digital echosounders, the sample by sample compensation is applied, assuming that each echo envelope sample was received from the range determined by its time delay with reference to the sounding pulse. However, as the sounding pulse used for generation of acoustic wave lasts for a certain period of time, the compensation should be made rather on echo waveform basis than on sample basis.

In the paper the new algorithm for digital TVG correction was introduced, which allows for more accurate echo level adjustment than conventional "20logR" or "40logR" formulae. The developed algorithm was investigated experimentally on sonar echoes obtained from the standard sphere targets. The results may explain the possible source of errors encountered in the field studies, especially in a shallow water.

INTRODUCTION

The time-varied-gain feature of a sonar removes the range dependence of echo level. Two kinds of TVG are commonly used, viz.: so called „*40logR*" function, which applies for single targets and „*20logR*" which applies for distributed or multiple targets like fish schools or seabed. Both functions provide exact compensation only for the case of infinitely short sounding pulse or at infinite range. These terms express the spherical spreading loss in logarithmic scale for two-way transmission to range *R* and are additionally extended for compensation of absorption losses "$2\alpha R$" where α is an absorption coefficient expressed in decibels per meter.

For single targets "*40logR*" range dependent function *G(R)* expressed in decibels and *g(R)* in linear scale as [1]:

$$G\,(R) = 40\log R/R_0 + 2\alpha R$$
$$g(R) = (R/R_0)^2 e^{\alpha_0 R} \tag{1}$$

where R_0 reference distance (typically 1m) and α_0 absorption coefficient expressed in nepers per meter.

Typical approach of expressing TVG function as a function of time uses simple substitution $R=ct/2$, what leads to (omitting R_0=1m):

$$g(t) = (ct/2)^2 e^{\alpha_0 ct/2} \tag{2}$$

where c is speed of sound. Fig. 1 shows transmission loss along time-varied-gain function as a function of time as given by Eq. 2. In digital echosounders not like in its analog counterparts (where TVG function was implemented in hardware) there is no restriction on dynamic range of these functions and their range. However, Eq. 1 describing gain function as a function of range is inconsistent with Eq. 2 as a function of time due to the echo formation process [2].

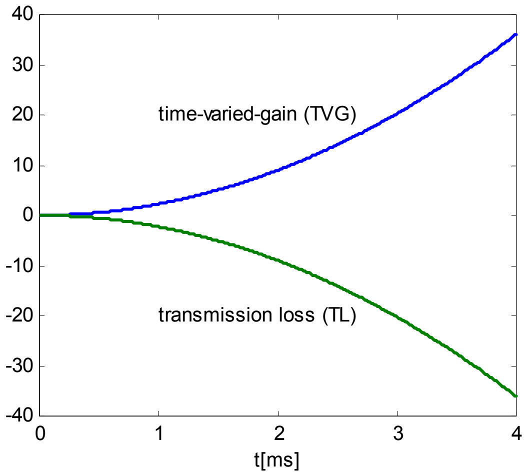

Fig.1. Transmission loss and classical time-varied-gain function.

TIME-VARIED-GAIN FUNCTION THEORY

More accurate approach distinguishes between the range and time dependent TVG functions. According to MacLennan's definition [2], the range dependent TVG function $g_R(R)$ is expressed as a weighted average of time dependent TVG function $g_t(t)$:

$$g_R{}^2(R) = \frac{\int_0^\infty |V_0(R,t)|^2 \, dt}{\int_0^\infty \left| \frac{V_0(R,t)}{g_t(t)} \right|^2 dt} \tag{3}$$

Exact range dependant TVG functions for a single target echo can be expressed as $g_R(R)=R^2 exp(\alpha R)$ and the echo voltage after TVG correction is:

$$V_o(R,t) = g_t(t) \frac{e^{-\alpha_0 R}}{R^2} V(t-\tau) \tag{4}$$

where $V(t)$ is a normalized echo waveform observed at the receiver output (before correction) and $\tau = 2R/c$ is a propagation delay of an echo.

Exact time dependant TVG function must fulfill the integral relationship, which guarantees obtaining the same value at the echo integrator output (energy) for the same target at different ranges:

$$\frac{\int_{-\infty}^{+\infty} g_t{}^2(t'+\tau) |V(t')|^2 \, dt'}{\int_{-\infty}^{+\infty} |V(t')|^2 \, dt'} = kc^4 \tau^4 e^{\alpha_0 c \tau} \tag{5}$$

where k is an arbitrary constant.

The solution of Eq. 5 is given as

$$g_{40\log R}(t) = (ct)^2 e^{\alpha_0 ct/2} \sqrt{1 + a_1(T/t) + a_2(T/t)^2 + a_3(T/t)^3 + a_4(T/t)^4} \tag{6}$$

where T is sounding pulse length and coefficients a_i can be expressed using moments I_m (normalized to pulse length T) of the signal $|V(t)|^2$:

$$I_m = \frac{\int_{-\infty}^{\infty} t^m e^{\alpha_0 ct} |V(t)|^2 dt}{T^m \int_{-\infty}^{\infty} e^{\alpha_0 ct} |V(t)|^2 dt} \tag{7}$$

respectively $a_1=-4I_1$, $a_2=-6I_2+12I_1^2$, $a_3=-4I_3+24I_1I_2-24I_1^3$, $a_4=-I_4+8I_1I_3+6I_2^2-36I_1^2I_3+24I_1^4$.

The same approach for distributed or multiple targets (e.g. fish schools or sea bottom) gives:

$$g_{20\log R}(t) = (ct)e^{\alpha_0 ct/2}\sqrt{1 + b_1 T/t + b_2 (T/t)^2} \tag{8}$$

with $b_1=-2I_1$, $b_2=2I_1^2-I_2$. Eq. 8 can be approximated by delayed TVG function:

$$g_a(t) = c(t - T_0)e^{\alpha_0 ct/2} \tag{9}$$

with $T_0=T_1+2R_0/c-\{(2R_0/2)^2-T_2^2\}^{1/2}$, where $T_1=I_1T$ and $T_2=T(I_2-I_1^2)^{1/2}$, which shows that not exact approach may be partly corrected introducing a delay T_0 in TVG function which always lies between T_1 and T_1+T_2.

As T_1 and T_2 still depends on acquired echo envelope some echosounder manufacturers uses another approximation assuming flat frequency response of the target in flat receiver frequency bandwidth and an ideal rectangular pulse delayed by echosounder hardware (t_0) for which $T_1=t_0+T/2$ and $T_2=T/\sqrt{12}$. More adequate approach incorporates bandpass approximation of receiver bandwidth. In this case normalized moments of the echo signal (and consequently T_1 and T_2), depend on the product BT of bandwidth B and pulse length T. Fig.2 shows that *20logR* TVG function introduces decreasing error until 10m range, giving over 1.5dB error at 1m range for $BT=2$. Approximation of exact TVG function (see Fig.3) can be used for ranges greater than 1m. This approach, however, still can not take into account target frequency response, which depends on target properties.

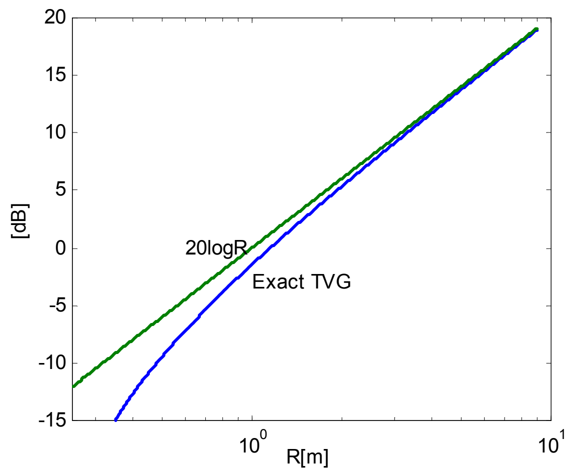

Fig.2. Theoretical *"20logR"* TVG function compared with exact $g_{20logR}(t)$ TVG function for receiver bandwidth B=5kHz and pulse length T=0.4[ms].

SAMPLE DATA ANALYSIS

In this paper another approach is proposed for calculation of an exact TVG function, which uses shape of the echo envelope. As modern echosounders instead of using analog TVG ramp, use software correction of digitized echo, it is convenient to extend calculation of values of echo samples. The calculation can include time-varied-correction derived from the echo waveform moments exactly as proposed by Eq. (6) or Eq. (8). This procedure requires target detection algorithm to precede the TVG correction phase and involves addition computational cost.

All sample echos presented in the paper were acquired with BioSonics DT series digital echosounder operated at the frequency of 200kHz

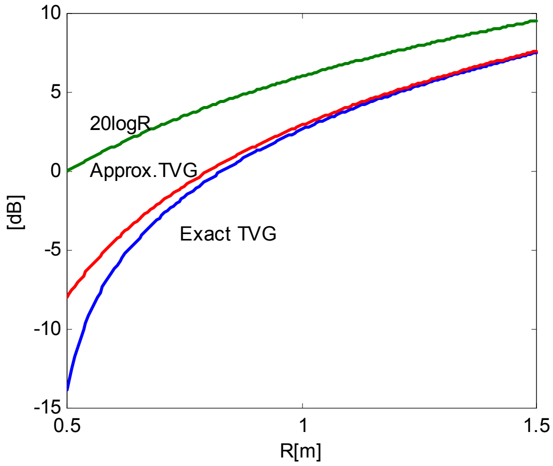

Fig.3. Exact TVG function $g_{20logR}(t)$, its delayed approximation $g_a(t)$ along with *20logR* function (receiver bandwidth *B*=5kHz and pulse length *T*=0.8[ms]) in a short range.

Fig.4 shows the echo pulse modeled as the echo from the target with flat frequency response acquired by receiver with simple LCR bandpass filter:

$$V(t) = \begin{cases} 1 - e^{-\pi Bt} &, \quad t < T \\ (e^{-\pi BT} - 1)e^{-\pi Bt} &, \quad t >= T \end{cases} \tag{10}$$

where *B* is the receiver bandwidth and *T* is transmitting pulse length. It is compared with actual normalized echo reflected from standard target ball. In Table 1 the normalized moments used for calculation of exact TVG function are presented.

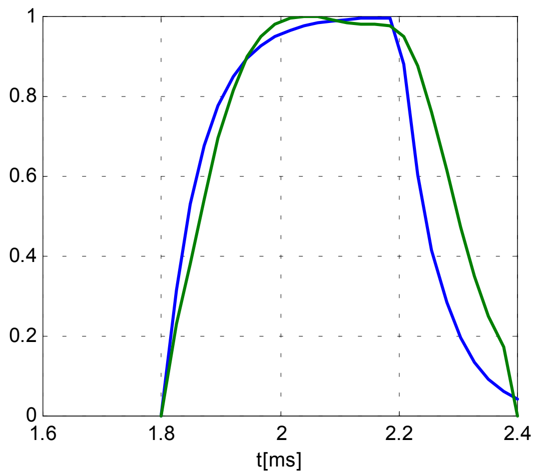

Fig.4. Model of the echo pulse from the target with flat frequency response acquired with a simple LCR bandpass filter compared with actual normalized echo reflected from a standard target sphere.

Tab.1. Normalized moments I_m used for calculation of exact TVG function for ideal wideband pulse, system modelled with bandpass receiver and for actual shape of echo from standard target.

normalized moments	I1	I2	I3	I4
ideal wideband pulse and ideal receiver	0.5	0.333	0.250	0.200
system modelled with bandpass receiver (Eq.7)	0.576	0.407	0.320	0.268
actual shape from standard target ball	0.711	0.591	0.544	0.535

The results obtained for three different locations of standard target positioned on a beam axis of transducer are illustrated in Fig. 5, whereas their corresponding echo level calculation are presented in the Table 2. It is evident that when the shape of the echo should be preserved, continuous time varied function can not be used in the ranges below 10m, as the end of echo is artificially amplified. When the peak value of the echo envelope is used echo level calculation it leads to another source of error in target strength estimation. It is easily seen that for actual case all the moments are greater than modeled. Hence for simple delayed approximation (Eq. 6) the delay $T_0=0.5T$ (half of the pulse length) should be increased up to $T_0=0.7T$ for this case.

In Fig. 6 and in Fig. 7 the echo envelopes acquired at the very short distances (0.7m and 1m) from standard target located on-axis of the system for three different values of pulse length T (0.1ms, 0.3ms, 0.5ms) are presented. The y-axis in these figures is scaled in 24-bit analog-to-digital converter values as acquired by digital echosounder. By comparison of its peak value it is evident that they does not fulfills $1/R^2$ (*40logR*) law as for 0.7m range the amplitude should be around two times ($1/0.7^2$) larger than for 1m range. This error may be explained also by operation in the distance, which is close to theoretical near field range defined by Rayleigh distance $r_0=ka^2/2$, where k is the wave number and a transducer radius. Also in the integral sense (echo energy) the TVG function differs from delay approximation what agrees with theoretical curves shown in Fig. 3.

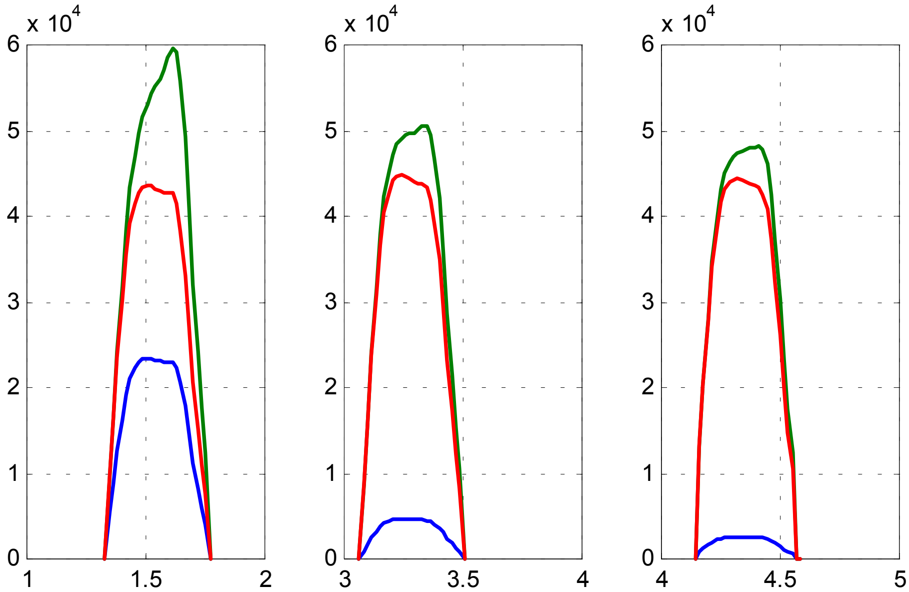

Fig.5. Sample echoes acquired from standard target located on axis at 1.5m, 3m and 4m, along with classical "*40logR*" correction and correction clamped at target range (linear scale x-axis in meters, y-axis in AD converter samples).

Tab.2. Echo level *EL* of standard target located on beam axis in logarithmic scale.

range *R [m]*	1.5[m]	3[m]	4[m]		mean(EL)	std(EL)
classical *40logR* correction [dB]	-38.70	-40.12	-40.54		-39.79	0.96
correction fixed at target range [dB]	-41.41	-41.17	-41.26		-41.28	0.12

CONCLUSION

In the paper some problems of time-varied-gain correction are presented in the context of its application in the digital echosounder. Theoretical calculations show that "classical" *20logR* and *40logR* functions introduce error, which is greater in short distances and monotonically decreases up to around 10m range. It is shown that in shallow water applications exact TVG function or its delayed approximation should be used rather than classical function calculated by *R=ct/2* substitution.

For some application including target recognition or bottom classification where the shape of the echo envelope need to be preserved it is very important to introduce nonlinear time-varied-gain function fixed at target range for a time interval equal to the of pulse length. For a narrow band systems, this allows to calculate target strength or scattering strength using peak value of the echo. The sample number of the peak value is shifted in relation to target range due to bandpass properties of echosounder hardware. It explains the approximation of exact TVG function by delayed TVG function.

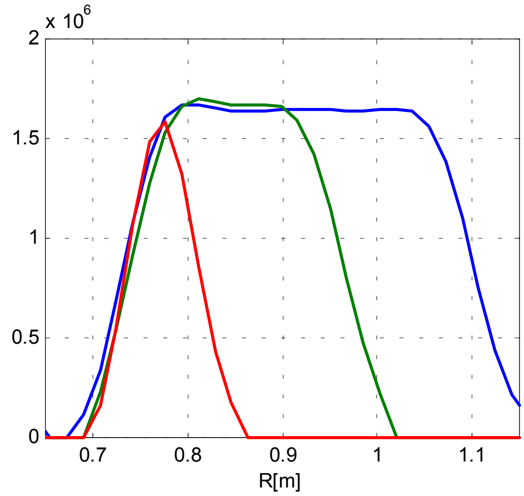

Fig.5. Echoes acquired from standard target located 0.7m from transducer for three different values of pulse length (*T*=0.1[ms], 0.3[ms], 0.5[ms]).

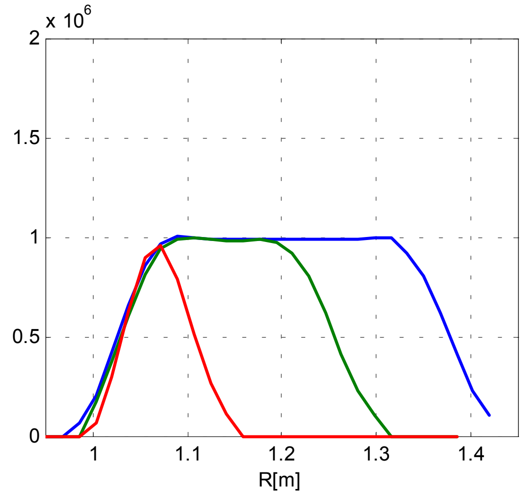

Fig.6. Echoes acquired from standard target located 1.0m from transducer for different values of pulse length (*T*=0.1[ms], 0.3[ms], 0.5[ms]).

For short pulses due to bandpass properties of the transducer the transmitted pulse does not reach its maximum value measured during calibration stage with longer pulses so additional correction is required. For a very short distances (i.e. fish tracking applications) the echo strength calculated for different target ranges does not fulfill exactly the spherical spreading rule, so although it is beyond theoretical near field Rayleigh distance additional corrections are also required.

REFERENCES

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