De-Embedding of Directivity Index of a Hydroacoustical Antenna on the Idealized Model of its Directivity Pattern

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ABSTRACT

In this paper will be presented a new universal procedure of calculating of directivity index dependent of the measured directivity pattern of a SONAR antenna. The procedure derives from an idealized model of directivity pattern. It is directly and universally applicable on any contemporary sonar antenna. Analytical expressions in general form are particularly appropriate for graphical presentation of functional dependence of directivity index on given parameters. Presented graphs of functional behavior in a two-dimensional system and especially in a three-dimensional coordinate system are an excellent base for standardization and quality evaluation of an antenna. With this model and with given mathematical expressions mathematical standards for applying hydroacoustic measurements of directivity pattern in the equations of hydrolocation are founded.

Key words: *hydroacoustic antenna, sonar, equation of hydrolocation, idealized model of beam patterns, suppressed minor lobes, directivity pattern, directivity index.*

1. INTRODUCTION

Directivity index *DI* is one of the important parameters of sonar (hydroacoustical) equation. *DI* is special and repeatedly significant via level of the signal/noise relation in presenting its influence on the range and resolution of underwater targets with the same conditions by monostatic and bi-/multistatic sonar systems. Therefore, from the level of the system analysis through the sonar equations we have additional requirements for antenna manufacturers in the phases of constructions. Keeping in line with the construction conditions of sonar antenna, we have many expressions in theory as unusable in practical applications. It is a special important for directivity index DI_R in the receive. It is all the same with active and passive systems to the given expresses to the bidirectional active system in literature [8, 12, 14, 28, 30], we have equations of bi-static system:

$$TL_{TT}+TL_{TR}=SL+TS-(NL-DI_R)-DT \tag{1}$$

$$TL_{TT} = 20\cdot\log(r_{TT}) + \alpha\cdot r_{TT}\ , \tag{2}$$

$$TL_{TR} = 20\cdot\log(r_{TR}) + \alpha\cdot r_{TR}\ , \tag{3}$$

$$SL = 10\cdot\log P_e + 10\cdot\log\eta_{ea} + DI_T + 171.5 \tag{4}$$

$$NL = N + 10\cdot\log B, \tag{5}$$

$$LN = NL - DI_R, \tag{6}$$

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where is:

α(dB/m) – absorption coefficient in sea water (defined by parameters of the sea,

SL(dB re 1µPa//1m) – Sound Level on 1 m of surface of antenna, to equation (4) Fig. 1,

DI_T(dB) – Directivity Index in the Transmit, (defined with the construction parameters of the sonar antenna, with amplifications of the output amplifiers and different conditions of the systems),

η_{ea}(1) – efficiency power factor of the sonar antenna $\eta_{ea}=P_a/P_e$, (defined with parameters of the construction),

P_e(W) – power on the electrical input of sonar antenna, (defined with the construction parameters of transmitter output amplifier),

TL_{TT}(dB) – Transmission Loss of sound in the sea from transmitting antenna to target as function of range r_{TT} and α to (2), symbolic showed in Fig. 1,

r_{TT}(m) – range of sonar systems in transmit, distance from the transmit antenna to target,

TL_{TR}(dB) – Transmission Loss of sound in the sea from target to the receive antenna as function of range r_{TR} and α to (3), symbolic showed in Fig. 1,

r_{TR}(m) – range of sonar (hydroacoustical) systems, distance from target to the receive antenna, Fig. 1,

B(Hz) – band with of frequency, (defined with conditions of filters, input electrical preamplifiers and duration of hydroacoustical and electrical impulse τ),

τ(s) – duration time of hydroacoustical impulse, (defined with detection conditions of the hydroacoustical targets),

DI_R(dB) – Directivity Index in the Receive, its character and value we have given in (1) and (6) and in graphical presentation in Fig. 2.

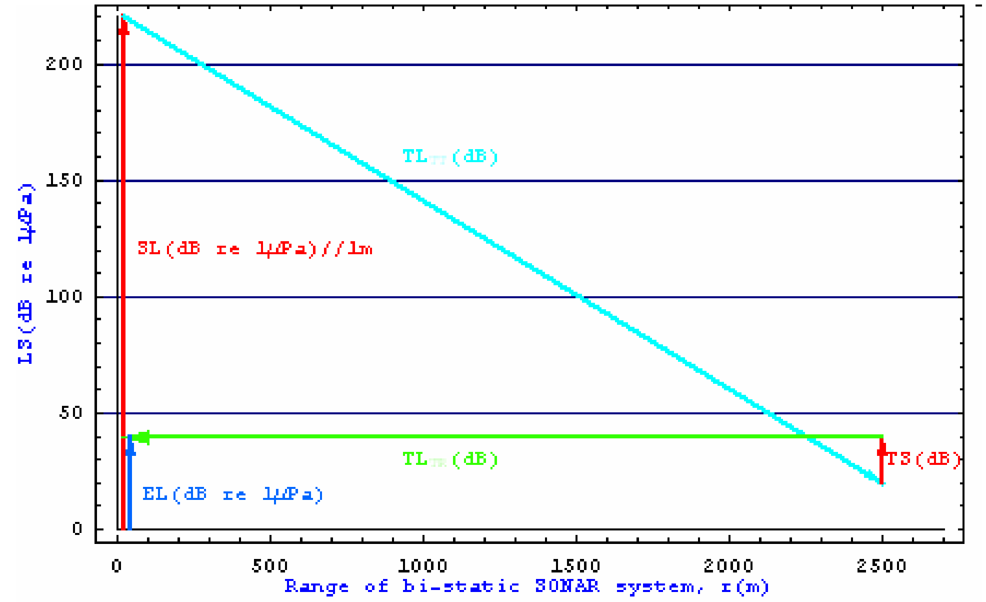

Fig. 1. Graphical presentation of levels by bi-static sonar systems in the sea from transmit antenna to the target and back from the target to the antenna in the receive.

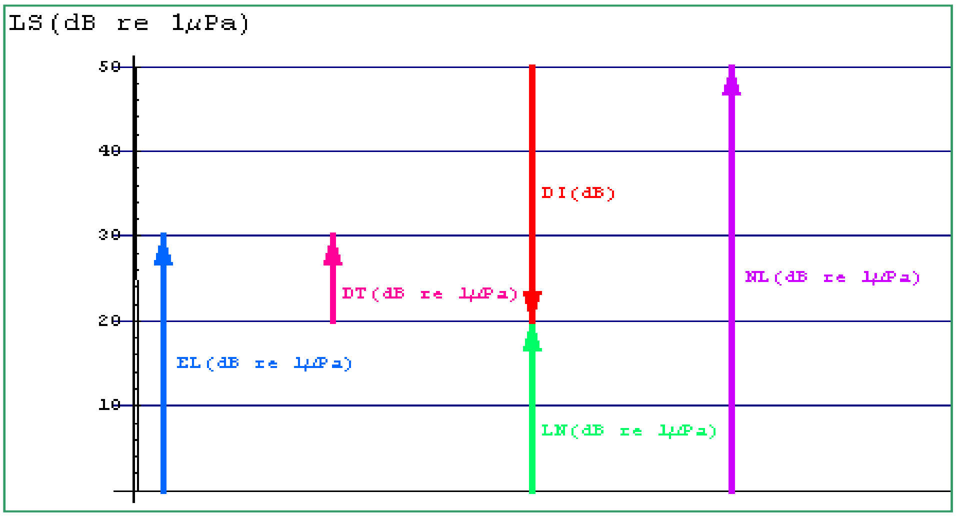

Fig. 2. Graphical presentation of the difference levels on hydroacoustical input of sonar antenna in the receive.

Therefore, value of directivity index in the receive DI_R is one of the important parameter in the bi-static sonar systems. Keeping in line with the tactical and technical conditions on the bi-static sonar systems, the range as parameter is direct depend of DI_R and we can point out it as center of our analyses and activity. Therefore, the value of this parameter we need to de-embed very safe and calculate very precisely.

De-embedding of DI_R of antenna on the idealized model of its measured directivity pattern can give better access in good detection of targets. On the other hand, this model will get better compare of quality of different bi-static sonar systems to the higher range.

Keeping in line with the tactical and technical conditions on the bi-static sonar systems we need to point out the range as parameter in very direct dependence of DI_R. Therefore, we have one choice and the solution in the hydroacoustical measurements of receive pattern characteristics, Fig. 3.

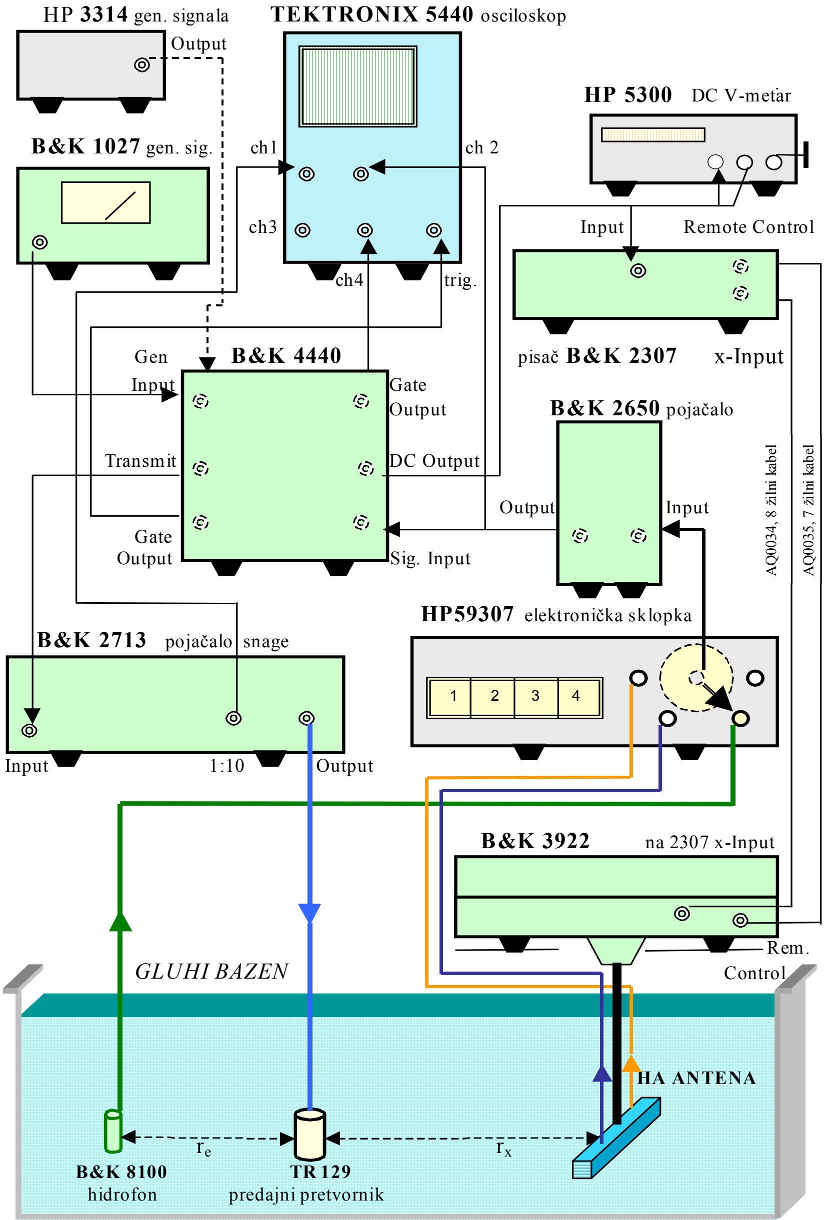

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Fig. 3 Block schema for measurement of directivity pattern of hydroacoustical antenna.

Mainly, many expressions in literature based on standard theory are unusable in practical applications. Using the expressions of idealized model on measured directivity pattern of antenna of measured data, Fig. 4, we can precisely calculate the value of DI_R and de-embed minimal conditions for maximal range. It is very important as the usable operative data for security and underwater long range monitoring.

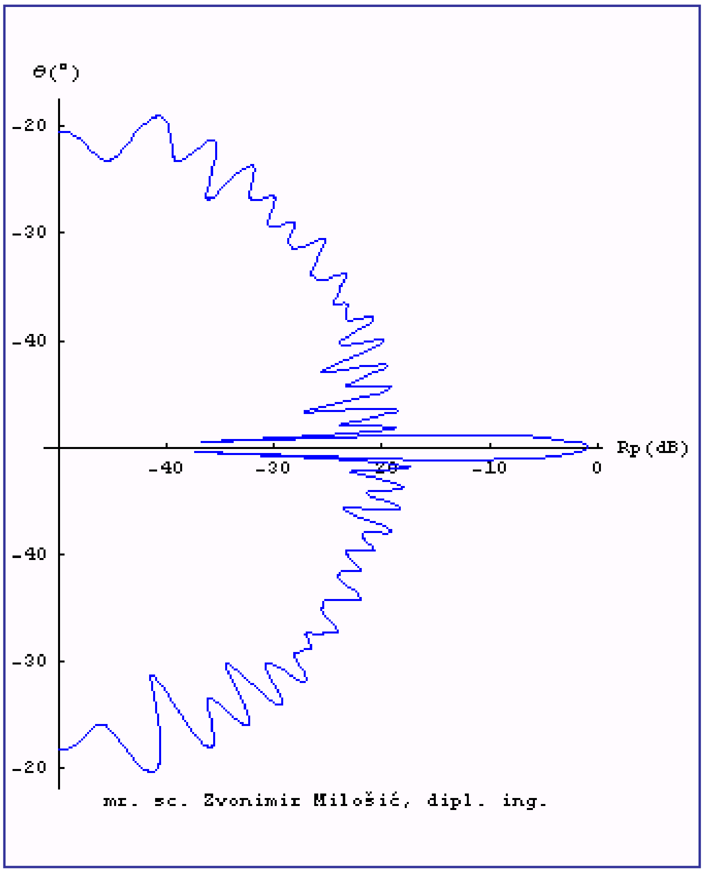

Fig. 4. Measured or simulated directivity patterns of sonar HA antenna, where we have in azimuth θ_{-3dB}=0.5° and in elevation angle φ_{-3dB}=15° and with b=-20 dB we have DI=19.7 dB.

2. IDEALISATION OF DIRECTIVITY CHARACTERISTIC WITH A NEW ORIENTATION OF THE ANGLES OF INTEGRATION

Keeping in line with the illustration in Fig. 5 basic elements should be set for the procedure of conducting correct integration as the basic factor of a mathematical definition of directivity index of hydroacoustic transducers and antennas. It follows that:

$$S_I = \int_S R_I(\theta,\varphi)dS \tag{7}$$

where we have

θ (rad) – integration angle by azimuth

φ (rad) – integration angle by elevation

dS (m^2) – elementary surface according to Fig. 5 is defined by the expression (8) in accordance with [19]

$$dS=r^2 \cos\theta \, d\theta \, d\varphi \tag{8}$$

R_I (1) – directivity size of sound intensity in the spreading media (water) as a dimensionless figure which by azimuth has θ=0 (rad) and φ=0 (rad), that is

$$R_I(\theta=0, \varphi=0)=1$$

S_I (m^2) – the sphere surface which is under the weight activity of the directivity characteristic $R_I(\theta, \varphi)$ and sound intensity $I(\theta, \varphi)$.

Using the new coordinate system in Fig. 5 and the idealized characteristics of the measured directivity patterns as in Fig. 4. to the models in Fig. 6., Fig. 7. or Fig. 8., we can give relatively simple mathematical expression of directivity index. The conditions for process of integration to the general definition are given in expressions (9), (10), (11) and (12).

$$R_I\left(\begin{matrix}\theta > +\dfrac{\theta_{-3\mathrm{dB}}}{2} \\ \theta < -\dfrac{\theta_{-3\mathrm{dB}}}{2}\end{matrix}\right) = R_b \tag{9}$$

$$R_I\left(\begin{matrix}\varphi > +\dfrac{\varphi_{-3\mathrm{dB}}}{2} \\ \varphi < -\dfrac{\varphi_{-3\mathrm{dB}}}{2}\end{matrix}\right) = R_b \tag{10}$$

$$R_I\left(\begin{matrix}\theta < +\dfrac{\theta_{-3\mathrm{dB}}}{2} \\ \theta > -\dfrac{\theta_{-3\mathrm{dB}}}{2}\end{matrix}\right) = 1 \tag{11}$$

$$R_I\left(\begin{matrix}\varphi < +\dfrac{\varphi_{-3\mathrm{dB}}}{2} \\ \varphi > -\dfrac{\varphi_{-3\mathrm{dB}}}{2}\end{matrix}\right) = 1 \tag{12}$$

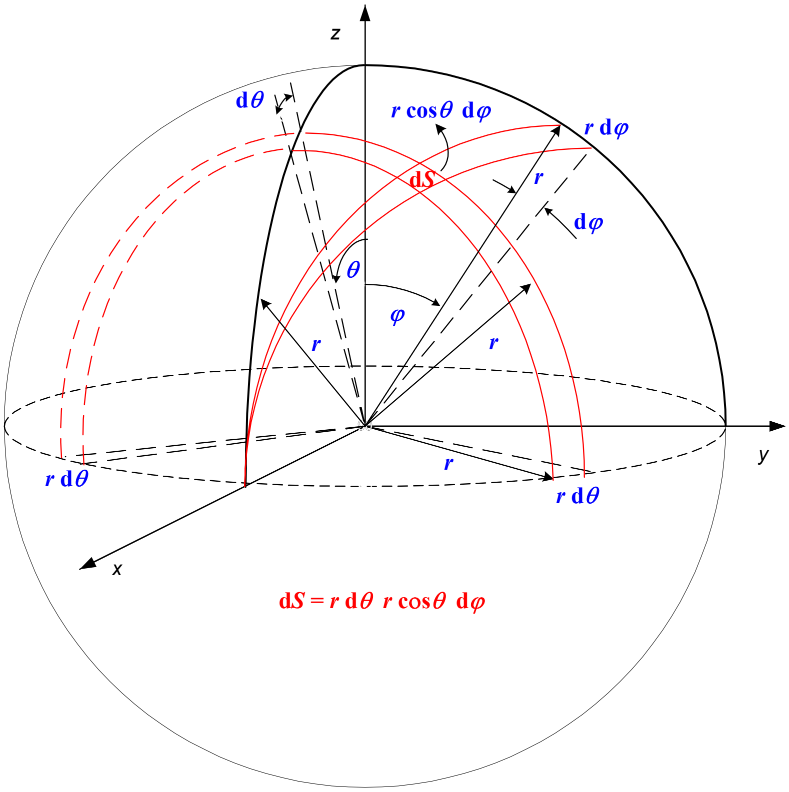

Fig. 5. This model of coordinate system for de-embedding of any parameters the new modern sonar antennas is not in use by the contemporary theory in hydroacoustics generally.

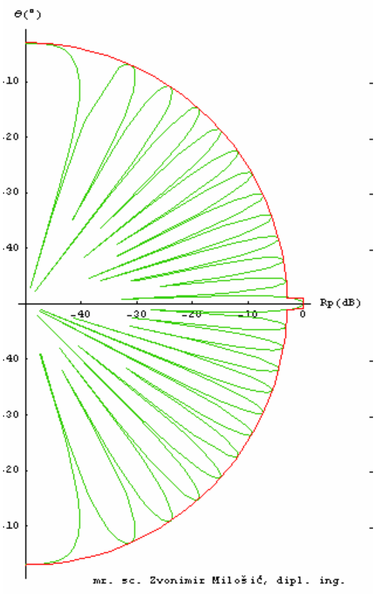

Fig. 6. Directivity patterns of the theoretical sonar antenna with azimuth angle for example θ_{-3dB}=0.5° and elevation angle φ_{-3dB}=15° and *b*=-3 dB we have *DI*=3 dB.

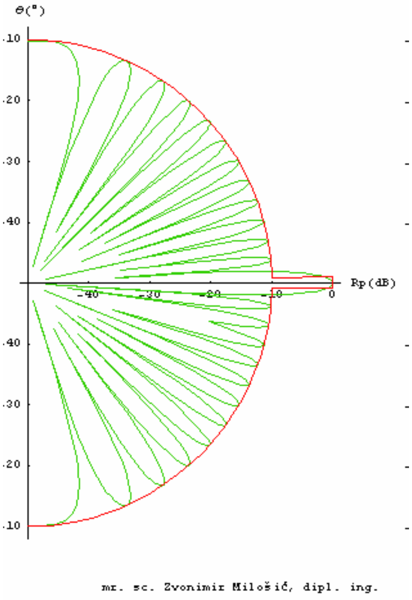

Fig. 7. Directivity patterns of sonar antenna in azimuth and elevation in this example θ_{-3dB}=0.5° and elevation angle φ_{-3dB}=15° and with suppression of minor lobes *b*=-10 dB we have *DI*=10 dB

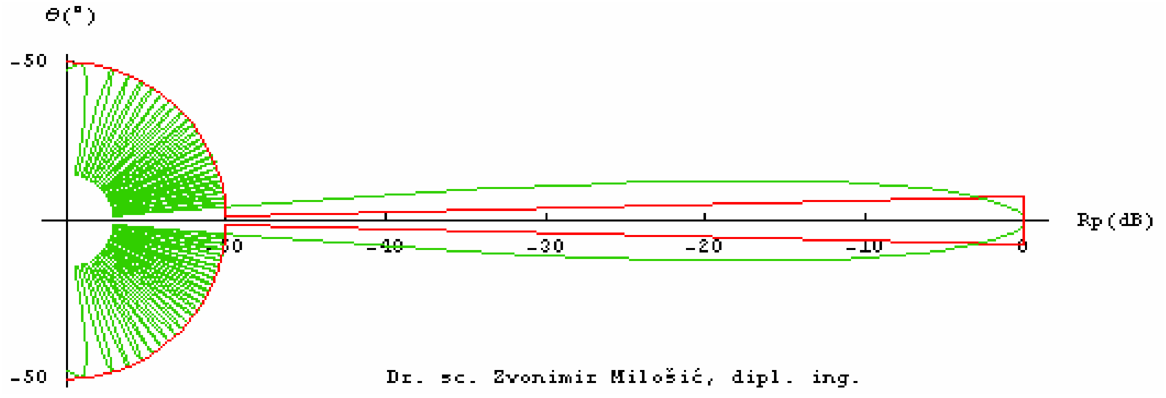

Fig. 8. Directivity patterns of sonar antenna in azimuth where we have θ_{-3dB}=0.5° and elevation angle φ_{-3dB}=15° then with suppression of minor lobes *b*=-50 dB we have *DI*=41.5 dB.

In practice the term of suppressing level of minor lobes b (dB) is often used and it often shows the level of the maximum of suppressed minor lobes below the maximum of the major lobe on the directivity characteristic. The connection of numerical data of the minor lobe amplitude, the sign R_b and the value of suppressing level are determined by the expression

$$R_b = 10^{\frac{b}{10}} \tag{13}$$

where is

$\theta_{-3\,\mathrm{dB}}$ (rad) – sensitivity angle of hydroacoustic antenna by azimuth,

$\varphi_{-3\,\mathrm{dB}}$ (rad) – sensitivity angle of hydroacoustic antenna by elevation,

R_b (1) – amplitude size of suppressed lobes, that is, of secondary lobes on the directivity characteristic of sound intensity, this size is a dimensionless number.

b (dB) – suppression of minor lobes size in relation to the peak of the major lobe which lies in the acoustic axis of an antenna with $R_I(\theta=0,\ \varphi=0)=1$, level of suppressing b comes as a negative value in relation to 0 dB in the axis, so that we write b=-30 dB, b=-50 dB, so that the value is $R_b \le 1$.

$R_I(1)$ – direction of sound intensity is a dimensionless number in the integrational equation of the directivity index definition and if it is shown in form of the level of directivity characteristic it has a decibel dimension (dB).

The size R_b shown in expressions (9) and (10) shows the directivity values of sound intensity R_I outside the sensitivity angle. The graphical illustration of this condition is in Fig. 6. and Fig. 7, which from definition (14) passes over into a form of influencing the suppressing level of minor lobes on D_f. According to that, we have that the directivity factor D_f according to definitions from literature [5, 9, 12, 23, 25, 28, 32] is shown in dependence to three variables as follows

$$D_\mathrm{f} = \frac{I(\theta,\varphi,b)}{I_0} \tag{14}$$

$$I(\theta,\varphi,b) = \frac{P_\mathrm{a}}{S_I(\theta,\varphi,b)} = \frac{P_\mathrm{a}}{\iint\limits_S R_I(\theta,\varphi,b)\mathrm{d}S} \tag{15}$$

$$I(\theta,\varphi,b)=\frac{P_{\mathrm{a}}}{\iint\limits_{S} R_I\left(\pm\frac{\theta_{-3\mathrm{dB}}}{2},\pm\frac{\varphi_{-3\mathrm{dB}}}{2}\right)\mathrm{d}S+4\pi r^2R_b-\iint\limits_{S} R_b\left(\pm\frac{\theta_{-3\mathrm{dB}}}{2},\pm\frac{\varphi_{-3\mathrm{dB}}}{2}\right)\mathrm{d}S}$$

$$D_{\mathrm{f}}=\frac{\dfrac{P_{\mathrm{a}}}{\iint\limits_{S} R_I(\theta,\varphi,b)\mathrm{d}S}}{\dfrac{P_{\mathrm{a}}}{4\pi r^2}} \quad \text{and} \quad D_{\mathrm{f}}=\frac{4\pi r^2}{\iint\limits_{S} R_I(\theta,\varphi,b)\mathrm{d}S} \tag{16}$$

Applying conditions (9) to (12) we can write that is

$$D_{\mathrm{f}}=\frac{4\pi r^2}{\iint\limits_{S} R_I\left(\pm\frac{\theta_{-3\mathrm{dB}}}{2},\pm\frac{\varphi_{-3\mathrm{dB}}}{2}\right)\mathrm{d}S+4\pi r^2R_b-\iint\limits_{S} R_b\left(\pm\frac{\theta_{-3\mathrm{dB}}}{2},\pm\frac{\varphi_{-3\mathrm{dB}}}{2}\right)\mathrm{d}S} \tag{17}$$

With the given conditions and the application of mathematical analysis of expression (1) we reach the understanding that the directivity value, according to the conditions (9) to (12) as the first member of sub-integral function in the denominator is equal to $R_I=1$ and the value of the first factor of the sub-integral function of the third member in the denominator equals to R_b. If we insert the value of differential surface $\mathrm{d}S=r^2\cos\theta\mathrm{d}\theta\mathrm{d}\varphi$ into expression (17) and if we shorten r we can write that

$$D_{\mathrm{f}}=\frac{4\pi}{\int\limits_{-\frac{\varphi_{-3\mathrm{dB}}}{2}}^{+\frac{\varphi_{-3\mathrm{dB}}}{2}}\int\limits_{-\frac{\theta_{-3\mathrm{dB}}}{2}}^{+\frac{\theta_{-3\mathrm{dB}}}{2}}\cos\theta\cdot d\theta\cdot d\varphi+4\pi R_b-R_b\int\limits_{-\frac{\varphi_{-3\mathrm{dB}}}{2}}^{+\frac{\varphi_{-3\mathrm{dB}}}{2}}\int\limits_{-\frac{\theta_{-3\mathrm{dB}}}{2}}^{+\frac{\theta_{-3\mathrm{dB}}}{2}}\cos\theta\cdot d\theta\cdot d\varphi} \tag{18}$$

that is, after eliminating the double integral, we have

$$D_{\mathrm{f}}=\frac{4\pi}{\left(1-R_b\right)\cdot\int\limits_{-\frac{\varphi_{-3\mathrm{dB}}}{2}}^{+\frac{\varphi_{-3\mathrm{dB}}}{2}}\int\limits_{-\frac{\theta_{-3\mathrm{dB}}}{2}}^{+\frac{\theta_{-3\mathrm{dB}}}{2}}\cos\theta\cdot d\theta\cdot d\varphi+4\pi R_b} \tag{19}$$

The expression (19) is sufficient for graphical interpretation with assistance of modern mathematical software. With the stated initial condition for the given model a further integration procedure is possible.

The solution to the double integral in the denominators is reduced to the known solution from the previous chapter, so that

$$D_{\mathrm{f}}=\frac{2\pi}{\left(1-R_b\right)\cdot\varphi_{-3\mathrm{dB}}\sin\left(\dfrac{\theta_{-3\mathrm{dB}}}{2}\right)+2\pi R_b} \tag{20}$$

Substituting the expression (13) for R_b with a computing of the decadal logarithm of directivity factor, we can as well determine and scientifically analyze the behavior of the directivity index function on the most important parameters of modern hydroacoustic antennas.

Finally, we have that the directivity index is

$$DI = 10 \cdot \log \frac{2\pi}{\left(1 - 10^{\frac{b}{10}}\right) \cdot \varphi_{-3\text{dB}} \sin\left(\frac{\theta_{-3\text{dB}}}{2}\right) + 2\pi \cdot 10^{\frac{b}{10}}} \tag{21}$$

and graphical presentations in Fig. 9 and in tree dimension on Fig. 10.

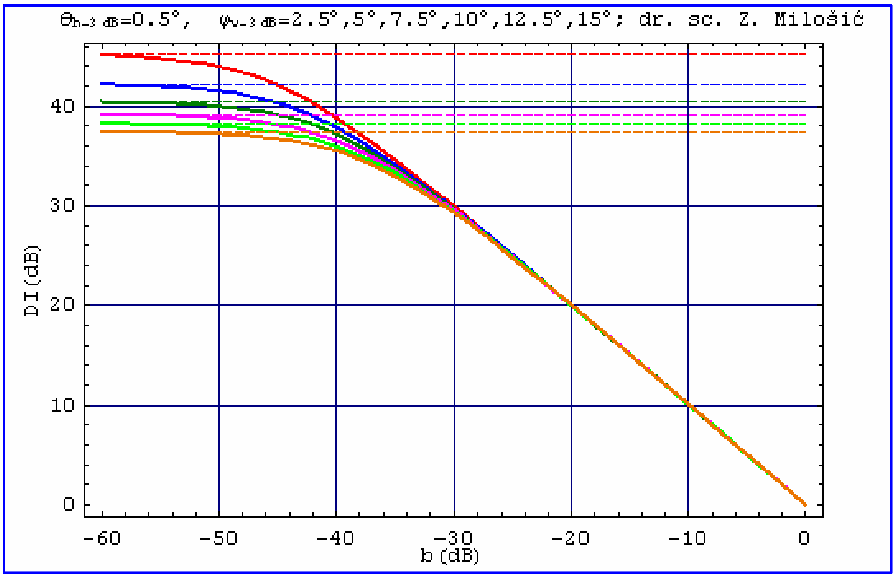

Fig. 9. Graphical presentation *DI* as function of: θ_{-3dB}, φ_{-3dB} and suppression of side lobes *b* of the sonar antenna.

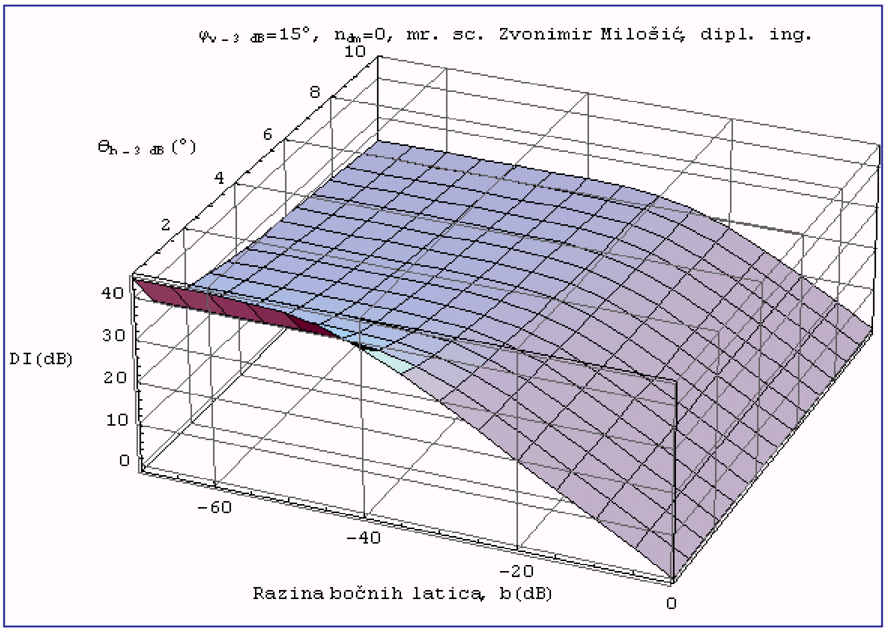

Fig. 10. Graphical presentation *DI*(θ_{-3dB}, φ_{-3dB}, *b*) in three dimensions have a special meaning by comparison of different sonar systems.

Using expression (21) a graphical illustration of directivity index dependence is obtained showing, according to the given idealized model of directivity characteristics, huge differences in decibel amount particularly in the used area of minor lobe suppressing up to 30dB.

Introducing the condition of a small angle by azimuth, mathematically $\theta_{h\text{-}3\text{ dB}}$ it is valid that the size sin ($\theta_{h\text{-}3\text{ dB}}/2$)≈ ($\theta_{h\text{-}3\text{ dB}}/2$) and the expression (16) is simplified so that we have

$$DI = 10 \cdot \log \frac{4\pi}{(1 - R_b)\varphi_{-3\text{dB}}\theta_{-3\text{dB}} + 4\pi R_b} \tag{22}$$

Using expression (13) with the condition with ideal model of minor lobe suppressing, b=-∞ dB, we have R_b=0. With the substitution of this value of R_b in (21) we get very simple expression (23).

$$DI = 10 \cdot \log \frac{2\pi}{\varphi_{-3\text{dB}} \sin\left(\frac{\theta_{-3\text{dB}}}{2}\right)} \tag{23}$$

In the same way by using (22) we get the simplest expression (24), which is usable only in above mentioned unreal conditions.

$$DI = 10 \cdot \log \frac{4\pi}{\varphi_{-3\text{dB}}\theta_{-3\text{dB}}} \tag{24}$$

3. THE USE OF DIRECTIVITY INDEX OF IDEALIZED MODEL DIRECTIVITY PATTERN IN DE-EMBEDDING OF IMPORTANT CHARACTERISTICS OF BI-STATIC SONAR SYSTEMS

Using above mentioned mathematical expressions of directivity index, for DI_{Rmz} in *idealized* conditions (21) or (22) and DI_{R} in *ideal* conditions (23) or (24), on bi-static sonar systems, in development of the expressions (1), (2) and (3), we can see great differences on the range r as follows,

$$TL_{\text{TT}}+TL_{\text{TR}} = SL+TS-(NL-DI_{\text{R}})-DT \tag{25}$$

The introduction of new conditions on the receive antenna, with a new value of directivity index DI_{Rmz}, has no influence on any parameters in the chain from transmitter to target. Therefore we have the same values of TL_{TT} and we can write

$$TL_{\text{TT}}+TL_{\text{TRmz}} = SL+TS-(NL-DI_{\text{Rmz}})-DT \tag{26}$$

If we make subtraction of expressions (25) and (26) on the left side, then is

$$\Delta TL=TL_{\text{TT}}+TL_{\text{TR}}-TL_{\text{TT}}-TL_{\text{TRmz}}$$

$$\Delta TL= TL_{\text{TR}}-TL_{\text{TRmz}} \tag{27}$$

Using the simplification of expression (2) and (3) on low frequencies without $\alpha \cdot r_{\text{TT}}$ and $\alpha \cdot r_{\text{TR}}$, we have

$$TL_{\text{TR}} = 20 \cdot \log(r_{\text{TR}}) \tag{28}$$

$$TL_{\mathrm{TRmz}} = 20\cdot\log(r_{\mathrm{TRmz}}) \qquad (29)$$

and then it is

$$\Delta TL = 20\cdot\log(r_{\mathrm{TR}}) - 20\cdot\log(r_{\mathrm{TRmz}}) \text{ and } \Delta TL = 20\cdot\log(r_{\mathrm{TR}}/r_{\mathrm{TRmz}}) \qquad (30)$$

On the other hand, using the subtraction of expressions (25) and (26) on the right side, we have

$$\Delta TL = SL + TS - NL + DI_{\mathrm{R}} - DT -$$

$$- SL - TS + NL - DI_{\mathrm{Rmz}} + DT = DI_{\mathrm{R}} - DI_{\mathrm{Rmz}}$$

$$\Delta TL = DI_{\mathrm{R}} - DI_{\mathrm{Rmz}} \qquad (31)$$

If we equalize the expressions (30) and (31) we get direct correlation ratios of the ranges

$$m_z = r_{\mathrm{TR}}/r_{\mathrm{TRmz}} \qquad (32)$$

and differences of the directivity indexes ΔDI

$$\Delta DI = DI_{\mathrm{R}} - DI_{\mathrm{Rmz}} = \Delta TL \qquad (33)$$

as follows

$$m_{\mathrm{z}} = 10^{\frac{\Delta DI}{20}} \qquad (34)$$

where is

DI_{Rmz}(dB) – Directivity Index of the idealized model of directivity pattern of antenna in the receive mode of bi-static sonar system, given in expressions (21) and (22),

DI_{R}(dB) – Directivity Index of the ideal model of directivity pattern of sonar antenna in the receive mode of bi-static sonar system, expressions (23) and (24),

ΔDI(dB) – difference of ideal and idealized DI value, $\Delta DI = DI_{\mathrm{R}} - DI_{\mathrm{Rmz}}$

TL_{TRmz} (dB) – Transmission Loss from target to the receive antenna by the bi-static sonar system in the conditions of DI_{Rmz},

TL_{TR}(dB) – Transmission Loss from target to the receive antenna by the bi-static sonar system in the ideal conditions of DI_{R},

ΔTL(dB) – differences of transmission losses from target to the receive antenna by the bi-static sonar system, equation (27),

r_{TRmz}(m) – range by the conditions of idealized characteristic of directivity pattern and DI_{Rmz},

$r_{\mathrm{TR}}(\mathrm{m}) = r_{\mathrm{TRideal}}(\mathrm{m})$ – range by ideal characteristic of directivity pattern and DI_{R},

$m_{\mathrm{z}}(1)$ – ratio of the ranges $r_{\mathrm{TR}}/r_{\mathrm{TRmz}}$, merit of influence of the difference $\Delta DI = DI_{\mathrm{R}} - DI_{\mathrm{Rmz}}$ on the range to Fig. 11.

$m_{\mathrm{mz}}(1)$ – ratio of the ranges $r_{\mathrm{TRmz1}}/r_{\mathrm{TRmz2}}$, merit of influence of the difference of directivity index $\Delta DI_{\mathrm{Rmz}} = DI_{\mathrm{Rmz1}} - DI_{\mathrm{Rmz2}}$ on the equal suppressed minor lobe b with different angles of sensitivity in azimuth $\theta_{\mathrm{h1\text{-}3dB}} = 0.3^{\circ}$ and $\theta_{\mathrm{h2\text{-}3dB}} = 3^{\circ}$ to Fig. 12.,

ΔDI_{Rmz}(dB) – difference of two directivity indices of idealized values DI_{Rmz1} and DI_{Rmz2} where we have

$$\Delta DI_{\mathrm{Rmz}} = DI_{\mathrm{Rmz1}} - DI_{\mathrm{Rmz2}}$$

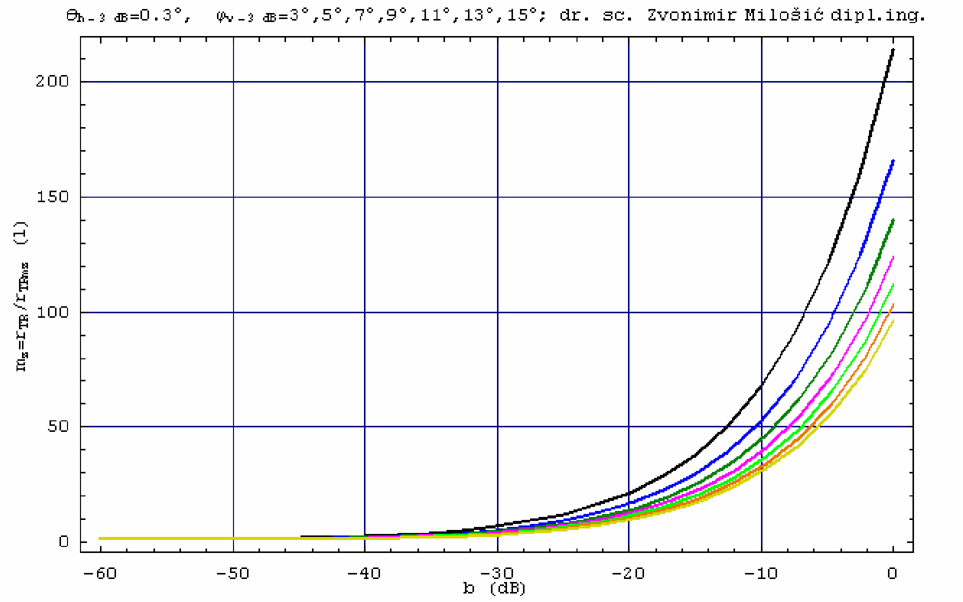

Fig. 11. Graphical presentation of the dependence of the ratio of ranges $m_z = r_{TRideal}/r_{TRmz}$ of b (dB) by differences of $\Delta DI = DI_R - DI_{Rmz}$ and $\theta_{h\text{-}3dB}$=0.3° with $\varphi_{v\text{-}3dB}$=3°, 5°, 7°, 9°, 11°, 13° and 15° as parameter.

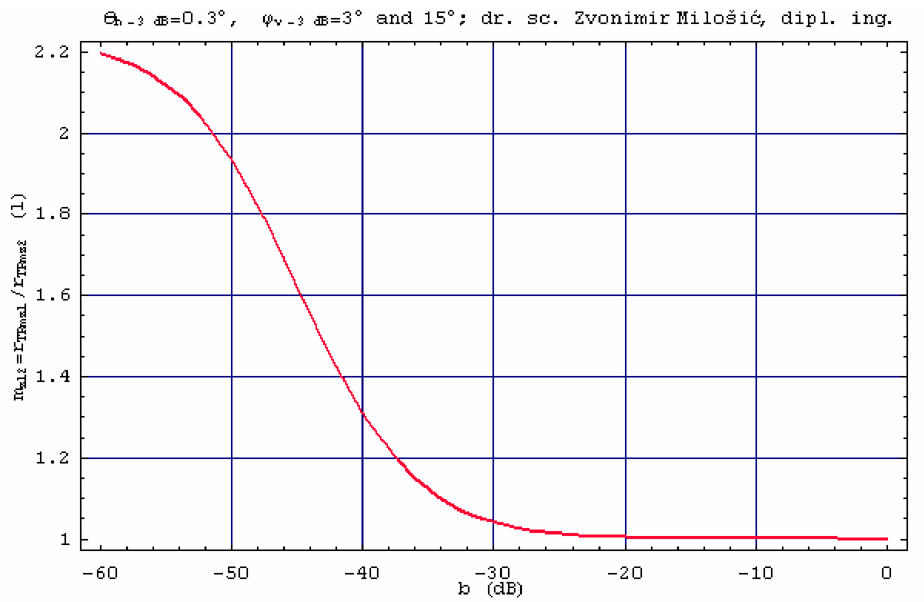

Fig. 12. Graphical presentation of the functional dependence of $m_{mz} = r_{TRmz1}/r_{TRmz2}$ of b where is angle $\theta_{h1\text{-}3dB}$ =0.3° by angle $\varphi_{v1\text{-}3dB}$ =3° and angle $\varphi_{v2\text{-}3dB}$ =15° we have on b=-50dB ranges r_{TRmz1}=1.93× r_{TRmz2} in bistatic sonar systems. We compare the ranges by two sonar systems with $\theta_{h1\text{-}3dB}$ =0.3° for both in azimuth and with two angles in elevation, 5° and 15°.

Then we can calculate ranges to the equations (25) to (34) or graphical de-embed to Fig. 11 in bi-static sonar systems.

On the one hand, it is of special importance for buyers and operative forces in the phase of C*ontract with the Specifications* on the level: buyers–manufacturers, NATO factories of professional equipment. On the basis of measurements and expert analyses of data, the buyer expert teams have the guarantee for the agreement with specification of system. Keeping in line with the illustration in Fig. 9 and special in Fig. 10 with basic parameters in three dimensions we have main elements for conducting the procedure of control of many parameters in specification.

In the graphical presentation in Fig. 9 we can see too great values of differences in directivity index DIR. The ranges with colored horizontal lines in Fig. 9 given by (23) or (24) are too optimistic and they are incorrect for b>-50 dB.

Using the mentioned figures, Fig. 9 and Fig.10 for example, by the value of b=-20 dB we have differences ΔDI=20 dB.

In bi-static sonar systems to the expressions (31), (32), (33) and (34) we have also the difference of transmission losses ΔTL≈20dB and it is too much of the range rTR in the systems made by different manufacturers.

Using given mathematical expressions (21) and (22) for the mentioned idealized model of directivity pattern we can control the value of one of the important parameters for de-embedding of the bi-static sonar range in its specification.

On the other hand, it is of special importance for the manufacturers of the bi-static sonar systems too. They can control many important parameters in the phase of building the sonar antenna, Fig. 13 and Fig. 14.

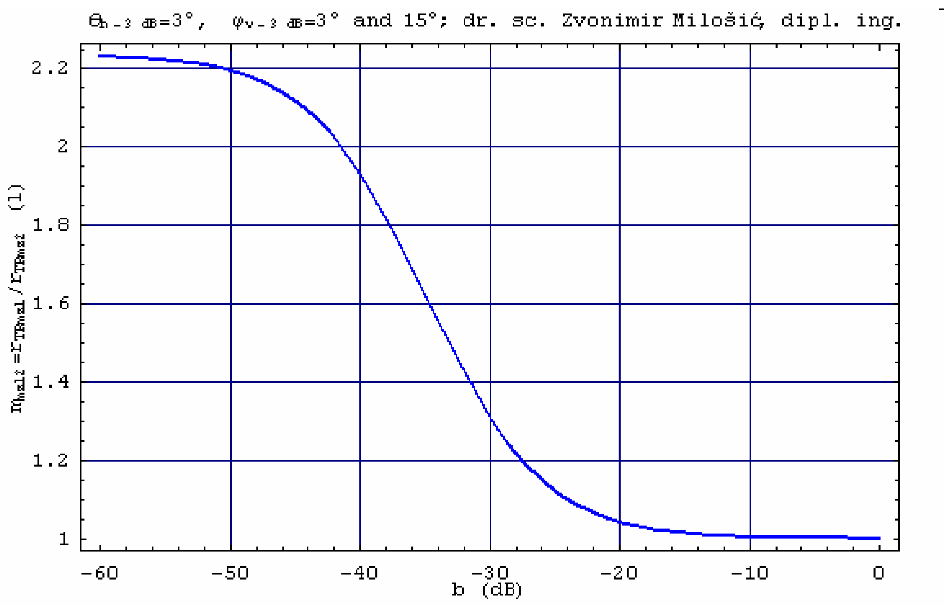

Fig. 13. Graphical presentation of the functional dependence of m_{mz}= r_{TRmz1}/r_{TRmz2} of *b* where is angle $\theta_{h\text{-}3dB}$ =3º by angle $\varphi_{v1\text{-}3dB}$ =3º and angle $\varphi_{v2\text{-}3dB}$=15º we have by suppressing *b*=-50dB ranges r_{TRmz1}=2× r_{TRmz2} in bistatic sonar systems. We compare the ranges by two sonar systems with $\theta_{h1\text{-}3dB}$ =3º for both in azimuth, and with two angles in elevation, 5º and 15º.

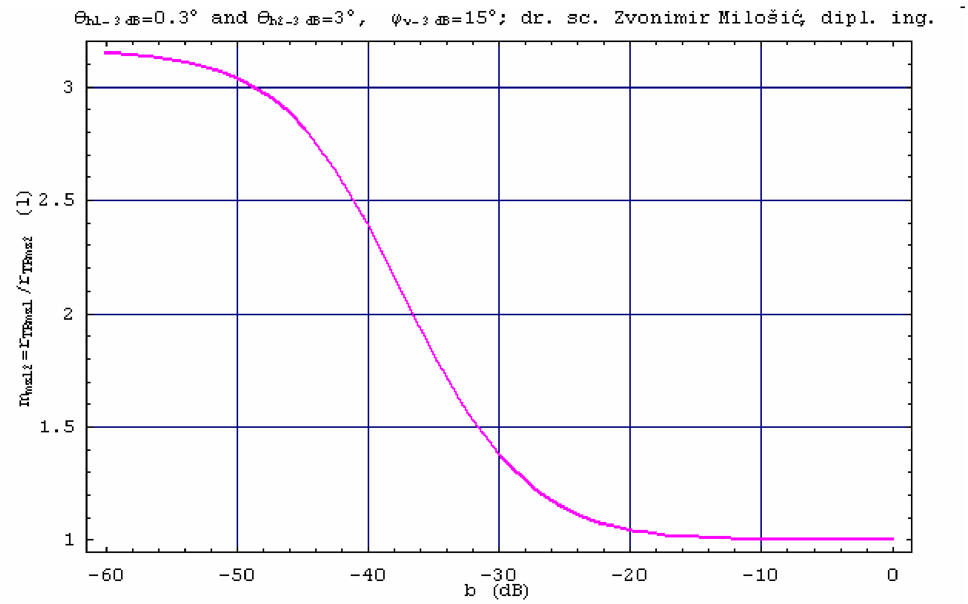

Fig. 14. Dependence $m_{mz}= r_{TRmz1}/r_{TRmz2}$ of b where are angles $\theta_{h1\text{-}3dB}$=0.3° and $\theta_{h2\text{-}3dB}$=3° by angle $\varphi_{v\text{-}3dB}$ =15° we have by suppress b=-50dB ranges r_{TRmz1}=3.05× r_{TRmz2} in bistatic sonar systems. We compare two sonar systems with two different angles in azimuth, 0.3° and 3°, on the range level with 15° in elevation for both.

And in the end, we have mathematical tools for good analyses of quality of bi-static sonar systems in the phase of producer bids of sonar systems for potential buyers.

4. CONCLUSION

De-embedding of Directivity index DI_{Rmz} and ranges on undersea targets according to the conditions in this paper, makes possible a better evaluation of given parameters:

- for buyers with contracts with specifications,
- in the research and development R&D of bistatic sonar systems in the combat against the undersea terrorism,
- in academies of security and
- on the operative levels for users of bi-static sonar systems.

In the accordance with the equations in this paper, de-embedding of directivity indexes of the receive antennas of bistatic sonar systems and ranges of detection of underwater targets are:

1) SIMPLE (because there is one equation of *DI* for all the models of bi-static SONAR antenna systems)
2) FAST (due to calculations with the simplest calculator of basic functions)
3) RELIABLE (physical dimensions and other building and constructing components of antennas are not necessary in calculation process)
4) ACCURATE (*DI* is not only the function of angles θ_{-3dB} and φ_{-3dB}; the result of calculation is in direct connection with measured and real characteristics of bi-static sonar HA antenna)
5) WIDELY USUABLE IN ALL SONAR SYSTEMS AND IN OTHER SYSTEMS OF MONITORING (in ultrasound scanners in medicine with the equation of body-location)

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