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Dynamic Model for Calculating the VHF Radio Horizon at Sea

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Preliminary comunication

Very High Frequency (VHF) range covers the range of radio frequency electromagnetic waves from 156 MHz to 162.025 MHz. Marine VHF communication devices have a wide application in navigation onboard convention and non-convention vessels. VHF communication is also partly used in inland waterways, rivers, and lakes. The varied application of the VHF technology implies performing regular and emergency communication during the operation of various services that ensure the safe flow of navigation process by exchanging Maritime Safety Information (MSI). As for their construction and design, marine VHF equipment may be classified as portable and stationary. Regulations provided by local registers of shipping apply to their technical features and design requirements in case of new-built vessels or subsequent fitting of the vessels with such equipment. Although these regulations go into details as they refer to the design and the exploitation of vessels, it can be noticed that they are not sufficiently elaborated in the area of using VHF marine communication devices in dynamic conditions. This paper discusses the impact of dynamic conditions on the range of marine VHF equipment and the development of feasible improvements onboard various types of vessels.

Keywords: *dynamic conditions, horizon, very high frequency, vessels*

Dinamički model za proračun VHF radiohorizonta na moru

Prethodno priopćenje

Područje vrlo visokih frekvencija (*Very High Frequency – VHF*) obuhvaća dio frekventnog spektra u dijelu od 156 MHz do 162, 025 MHz. Brodski komunikacijski uređaji u frekventnom opsegu vrlo visokih frekvencija primjenjuju se u pomorstvu na konvencijskim i nekonvencijskim brodovima. VHF se djelomice koristi i na unutarnjim plovnim putovima rijeka i jezera. Raznolika primjena VHF-a podrazumijeva provedbu redovitih i posebnih komunikacija u radu raznih službi bitnih u funkcioniranju plovidbenog procesa izmjenom pomorskih sigurnosnih informacija (*Maritime Safety Information – MSI*). U konstrukcijskom smislu brodski komunikacijski VHF uređaji mogu se podijeliti na prijenosne i stacionarne. U pogledu njihovih tehničkih karakteristika i projektnih zahtjeva u slučajevima novogradnje ili naknadnog opremanja brodova takvom tehničkom opremom primjenjuju se pravila područnih registara brodova. Ipak, može se reći da pravila nisu dostatno razrađena posebice u djelu korištenja VHF brodskih komunikacijskih uređaja u dinamičkim uvjetima. Ona kao takva se primjenjuju u projektiranju i eksploataciji brodova. U radu se možemo upoznati s utjecajem dinamičkih uvjeta na horizont VHF brodskih uređaja te razvojem mogućih poboljšanja na raznim vrstama brodova.

Ključne riječi: *brodovi, dinamički uvjeti, horizont, vrlo visoke frekvencije*

1 Design requirements and the horizon

The range of the marine VHF communication devices is calculated according to the radio horizon pattern derived from the calculation of the geometric horizon (Figure 1) [1, 2, 3]. The geometric horizon (G_h) for the values:

r – radius of the Earth ≈ 6378 km or 3440 NM
h_a – height of aerial above sea level
G_h – geometric horizon

is calculated according to the pattern:

$$G^2{}_h = (r + h_a)^2 - r^2 \Rightarrow G_h = \sqrt{(r + h_a)^2 - r^2} \tag{1.1}$$

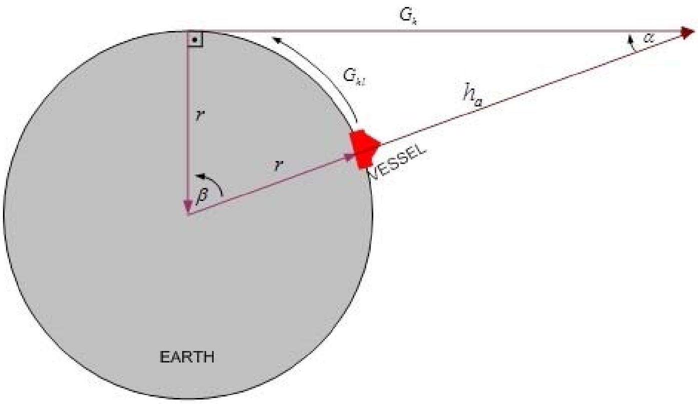


Figure 1 **Geometric horizon (G_h)**
Slika 1 **Geometrijski horizont (G_h)**

The procedure allows for a relatively accurate calculation of the geometric horizon. It is relatively accurate because the Earth is geoid shaped and its flattening is generalised in the calculation pattern. However, the geometric horizon differs from the radio horizon that is essential in marine VHF communication [4]. The difference also occurs due to refraction, the change in wave direction caused by the change in the speed of radio wave propagation through the areas of atmosphere having different density values.

That is why the practical applications consider the VHF radio horizon (R_{hVHF}) as larger than the geometric horizon (G_h) by 15% [1]. Hence, in practice, the radio horizon (R_{hVHF}) is calculated by increasing the value of the geometric horizon by 15%, according to:

$$\Rightarrow R_{hVHF} = \frac{3}{20} G_h + G_h \tag{1.2}$$

In case of measuring the value of the Earth radius (r) in km or NM, the value of the radio horizon (G_h) is calculated in km or NM accordingly. Marine communication devices with associated aerial systems are fitted to the vessels in line with their designed features and are practically considered as stationary [5, 6]. Their radio horizon is therefore calculated according to (1.2.), without informing the end user, e.g. the master or officer of the watch, that the calculation has been made on the basis of ideal weather and other prevailing conditions. It should be noted that the calculation contains a relatively small error, as the distance to horizon is assumed to be the distance from the aerial height to horizon. Hence, when transferring onto the sea chart, the length of a part of the Earth's circumference should be taken and considered as the horizon along the arc of the curvature (G_{hl}). After obtaining the geometric horizon *(G_h)*, the angle (β) is calculated according to:

$$\sin\beta = \frac{G_h}{r + h_a} \qquad (1.3)$$

or

$$\cos\beta = \frac{r}{r + h_a} \qquad (1.4)$$

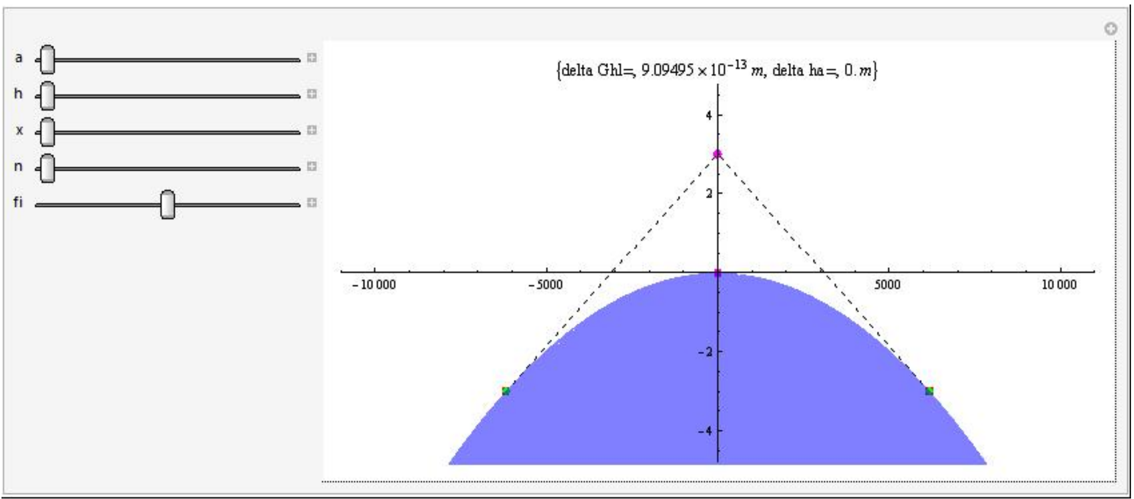
So the final calculation of the horizon along the arc of the curvature (G_{hl}) is calculated:

$$G_{hl} = \frac{r \cdot \Pi \cdot \beta}{180^o} \qquad (1.5)$$

Calculating the horizon along the curvature arc (G_{hl}) according to 1.5. allows for the correction of the relatively small error contained in the generally accepted model for calculating the horizon, as expressed by (1.1.)

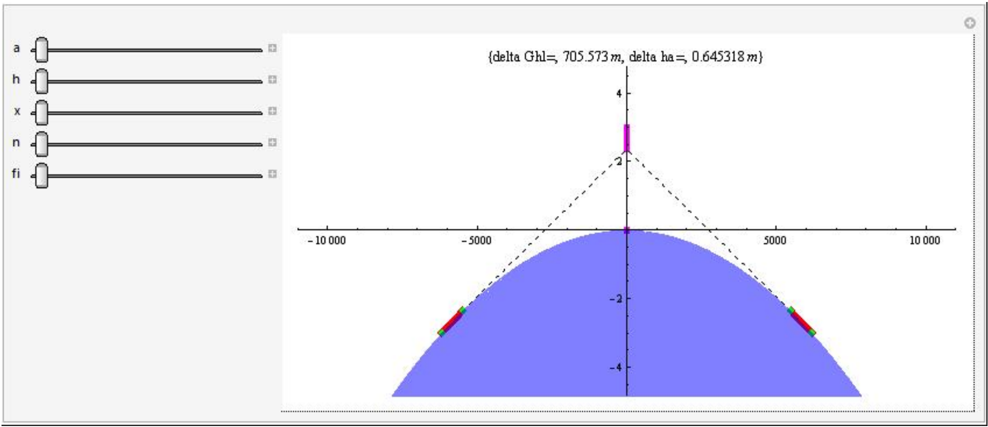
2 Dynamic conditions and the horizon

In all navigation areas the motion of vessels is greatly affected by weather and sea conditions. Various vessel motions may be classified as translation and rotation motions. Translations include *sway* (linear side-to-side motion), *heave* (linear up/down motion) and *surge* (linear front/back motion). Rotations include *pitch* (rotation of a vessel about its transverse i.e. side-to-side axis), *yaw* (rotation of a vessel about its vertical axis) and *roll* rotation of a vessel about its longitudinal i.e. front/back axis). Hence, a vessel sails under dynamic conditions. The impact of vessel's rolling on the horizon can be presented by the models for vessel's rolling and influence of the vessel's motion on the vessel's aerial, designed by the software Wolfram Mathematica 7.0 (Figure 2 and Figure 3.).



G_{hl} – horizon along the curvature arc; h_a – height of aerial; Δh_a – change of height of aerial on the vessel's mast, relative to the sea level; α – angle of rolling

Figure 2 **Simulation model (*α = 90°*)**
Slika 2 **Simulacijski model (*α = 90°*)**



G_{hl} – horizon along the curvature arc; h_a – height of aerial; Δh_a – change of height of aerial on the vessel's mast, relative to the sea level; α – angle of rolling

Figure 3 **Simulation model (*α = 60°*)**
Slika 3 **Simulacijski model (*α = 60°*)**

The model reveals considerable changes in the onboard communication aerials relative to the sea level, directly degrading the respective radio horizons and ranges. Table 1 shows the impact of rolling on the radio horizon degradation of the marine VHF.

Table 1 **Impact of rolling**
Tablica 1 **Utjecaj valjanja**

R (km)	**h_a (m)**	**α (°)**	**$h_t = h_a$ sin (m)**	$G_h = \sqrt{(r+h_t)^2 - r^2}$ **(m)**	$\sin\beta = \frac{G_h}{r+h_a}$	$\cos\beta = \frac{r}{r+h_a}$	**β (°)**	$G_{hl} = \frac{r\cdot\pi\cdot\beta}{180°}$ **(m)**
6378	3	90	3	6186.114208	0.000969913	0.999999529	0.0556	6189.230743
		85	2.98858	6174.328708	0.000968066	0.999999531	0.0555	6178.099033
		80	2.95442	6138.940462	0.000962517	0.999999536	0.0552	6144.703903
		75	2.89778	6079.81003	0.000953246	0.999999545	0.0545	6066.781933
		70	2.81908	5996.681749	0.000940213	0.999999558	0.0539	5999.991673
		65	2.71892	5889.189248	0.000923359	0.999999573	0.0529	5888.674574
		60	2.59808	5756.832028	0.000902607	0.999999592	0.0518	5766.225764

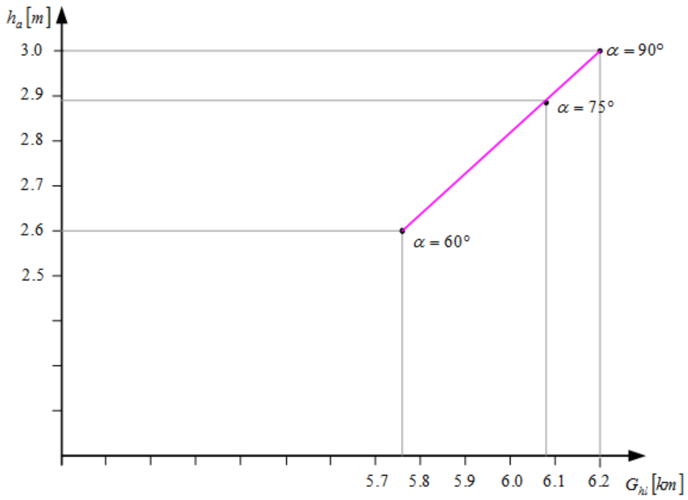
It should be noted that the horizon may be adversely affected by sailing with or towards high seas, so that the described model should be upgraded in practical application. At any rate, changes do exist and the master or the officer of the watch have no real-time information about them. The issue deserves discussion and suggestions for solutions.

3 Suggested solution

In practical maritime affairs it is deemed important to know the accuracy of a device in use, i.e. its error [7]. With regard to marine communications based on terrestrial connections, this can be achieved by developing:

- a system of marking the radio horizon dynamic characteristics under real conditions of the ship exploitation (DKR_{hVHF}), and
- an automated system of real-time warning about the dynamic characteristics of the radio horizon under real conditions of the ship exploitation ($AutDKR_{hVHF}$).

Marking the radio horizon characteristics under dynamic conditions can be done by setting up the compulsory typical graphic shape featuring the dynamic characteristic of changes in the radio horizon caused by dynamic conditions, for the designed height of the aerial mounted on an individual vessel (Figure 4).



G_{hl} – horizon along the curvature arc; h_a – height of aerial; α – angle of rolling

Figure 4 **Graphic marking of the radio horizon (*DKR_{hVHF}*)**
Slika 4 **Grafičko označavanje radiohorizonta (*DKR_{hVHF}*)**

When developing an automated system of real-time warning about the dynamic characteristics of the radio horizon under real conditions of the ship exploitation, an algorithm-defined approach is suggested (Figure 5).

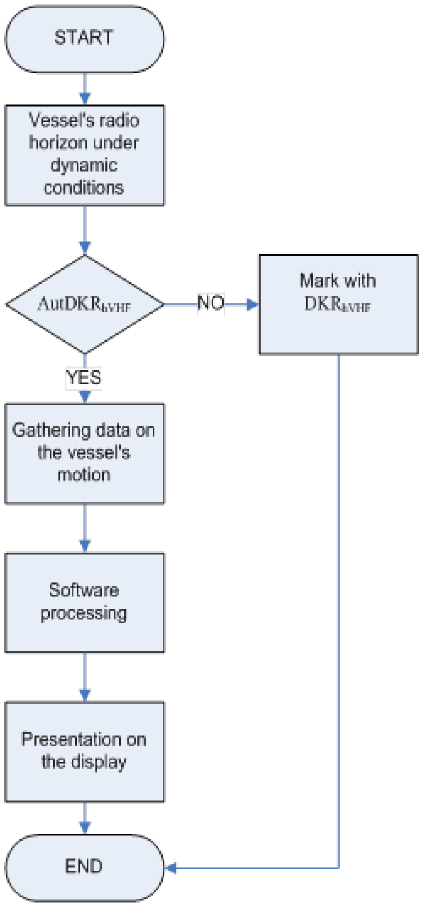


Figure 5 **Algorithm for operation of the automated system (*$AutDKR_{hVHF}$*)**
Slika 5 **Algoritam rada automatiziranog sustava (*$AutDKR_{hVHF}$*)**

By applying the automated system of real-time warning about the dynamic characteristics of the radio horizon under real conditions of the ship exploitation, the deck officers are provided with the maritime safety information on the actual radio horizon and the range of their marine VHF communication equipment. In case of emergency, this ensures additional possibility to achieve the desired radio horizon of the marine communication equipment by, for example, altering the course and/or speed. In certain critical situations, this model's application may considerably improve the safety of navigation as regards the use of the marine VHF communication devices.

4 Conclusion

Regulations provided by local registers of shipping referring to the use of marine VHF communications are partly insufficient. For instance, the generally accepted model for calculating the VHF radio horizon contains a relatively small error. Therefore, the radio horizon calculation can be more accurate if it relies on the suggested calculation based on the horizon along the curvature arc (G_{hl}). Furthermore, setting up various VHF electronic devices onboard vessels does not sufficiently take into account the dynamic conditions of the vessel exploitation. This paper presents the mathematical and simulation models showing the potential dangerous effects of such an approach. After upgrading the model with other horizon-affecting vessel's motions, the suggested solutions can be used regarding the way of marking the radio horizon characteristics under real conditions (DKR_{hVHF}) and the introduction of an automated system of real-time warning about the dynamic characteristics of the radio horizon under real conditions of the ship exploitation ($AutDKR_{hVHF}$). Further development and application of the suggested models and suggestions might considerably improve the safety of navigation as regards the technical and technological issues associated with some aspects of the design and exploitation of various types of vessels.

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