Simulation of Slanted Shipboard VHF Antenna Radiation Pattern

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Abstract—**Slanted shipboard VHF half-wavelength antenna simulations in NEC were presented in paper. The effects of antenna height above sea surface and slanted antenna elevation angle on radiation characteristics were studied. Change in the antenna height affected the number of lobes and thus redirected maximums and nulls along the elevation angle. The pattern envelope was not affected. Antenna slanting did not cause the slanting of its pattern.**

Keywords-marine shipboard VHF antenna; slanted elevated antenna; antenna over sea surface (ground plane); NEC simulation

I. Introduction

In the last several years we are witnesses of increasing marine traffic density especially considering the recreational marine traffic. Most of these vessels are equipped with marine VHF radio working in frequency range from 156 MHz to 176 MHZ. Recreational vessels can be divided into two groups: sailboats and motorboats. These two groups have completely different characteristics considering antenna mounting and vessel behavior on the sea. Sailboat antennas are always vertically mounted and slanting appears due to sailboat heeling. Motorboat antennas are usually mounted with backwards tilt (stern direction) for esthetic reasons. Expression "heeling" is characteristic for sailboats and refers to specific slanting toward one side during sailing. "Rolling" is more characteristic for motorboats and refers to alternate slanting of vessel toward each side. Heeling usually implies larger angles than rolling. The purpose of this paper is to analyze the possible effects of vessel rolling or heeling and antenna elevation on radiation pattern. Effects of ground plane and conductive sailboat structure on radiation pattern forming were discussed in [1]. To our best knowledge, no studies have been published on analysis of slanted shipboard antennas. Similar problems were mainly studied for military applications on large conductive platforms [2–4]. All these papers observe antenna parameters on vessels above sea surface but none of these observes possible effects of slanted antennas. Slanted antenna above mobile vehicular platform was simulated in [5]. Commonly in manufacturers' publications and literature the marine VHF antenna radiation pattern is presented as perfectly shaped eight-figured diagram without taking into account the presence of ground plane (sea). Sea has a large impact on radiation behavior. The eight-figured diagram is cut in half horizontally because there is no radiation into the lower half-space. Despite the perception that maximum gain is directed exactly to the horizon, due to finite conductivity of the sea surface, null occurs in the direction of the horizon and the maximum is slightly elevated [6]. Furthermore, at antenna heights of $\lambda/2$ and more above ground plane, the main radiation lobe starts to split and the effect is known as *splitting, lobing* or *scalloping,* analytically discussed in [6] and verified with NEC simulations in [1]. Incorrect or deficient information about marine VHF antennas presented a motivation for writing this paper in order to remedy possible obscurities. The main obscurity is whether the antenna slanting would cause the slanting of whole radiation pattern.

All simulations were done using NEC (Numerical Electromagnetic Code) [7–9] based on Method of Moment (MoM). Basic simulations were done with single antenna in free space and above the sea surface (σ = 5 S/m, ε = 81) with different antenna heights and elevation angles. These were followed by the simulations done with full sailboat model.

Antenna used in simulations was a marine VHF half-wavelength end-fed dipole antenna. All models were simulated at 156.8 MHz (λ = 1.91 m), which commonly serves as the reference frequency for marine VHF antenna characteristics (marine channel 16).

II. Impact of Antenna Height on Radiation Pattern

Antenna height presents one of the major contributions to the radiation characteristics. "Antenna height" or "antenna elevation" used throughout this paper refers to the height i.e. elevation above the sea surface. It should not be confused with the length of a monopole antenna. If an antenna is placed above ground plane at a height $\lambda/2$ or more, the lobing effect appears and changes the perfectly shaped horizontally cut eight-figured diagram into a lobed one with characteristic nulls and maximums in pattern.

Change in the antenna height changes the number of lobes, moving the maximums and nulls along the elevation angle. At a certain frequency, the number of lobes depends on antenna height [6]:

$$number\ of\ lobes = \frac{2h}{\lambda} + 1 \qquad (1)$$

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Considering the antenna use on sailboats, it is obvious that antenna height is more than λ/2 at 156.8 MHz. Even on motorboats, the antenna is elevated more than λ/2 above the sea level and lobing effect should be present. It is important to emphasize that sailboat antenna is not constantly on the same height; as sailboat heels, the antenna height changes. Those changes in height are not negligible. In our case where sailboat mast is approximately 12 m long, the alterations of antenna height can reach 2λ (approximately 4 m) for the heel of 45°. Motorboats do not lean as much, and the antenna is originally placed at a lower height (typically 3 – 5 m), so rolling does not produce significant change in height.

According to image theory, single vertical VHF marine antenna at distance *h* above ground plane can be observed as system of two identical symmetrically placed antennas separated by *2h* (Fig. 1). Field produced by a system of real and virtual sources is given by:

$$E_{total} = E_1 + E_2 = \left(E_0 \frac{e^{-j\beta r_1}}{r_1} + E_0 \frac{e^{-j\beta r_2}}{r_2} \right) \cdot \left| F_{dipole} \right| \qquad (2)$$

Applying far-field approximation and expression for radiation diagram of half-wavelength dipole, total electric field is shown in Fig. 2 and equal to:

$$E_{total} = 2E_0 \frac{e^{-j\beta r}}{r} \cdot \frac{\cos\left(\beta h \cos\vartheta\right) \cdot \cos\left(\frac{\pi}{2}\cos\vartheta\right)}{\sin\vartheta} \qquad (3)$$

At this point, the simulations with vertical antenna placed in z axis at different height above sea surface will be presented. Bearing in mind that this case is not real and that antenna angle is also changed with antenna elevation, the emphasis here is explicitly on antenna height effects. Intention of these simulations would be to verify the agreement with relation (1) and to analyze how antenna height affects the number of lobes.

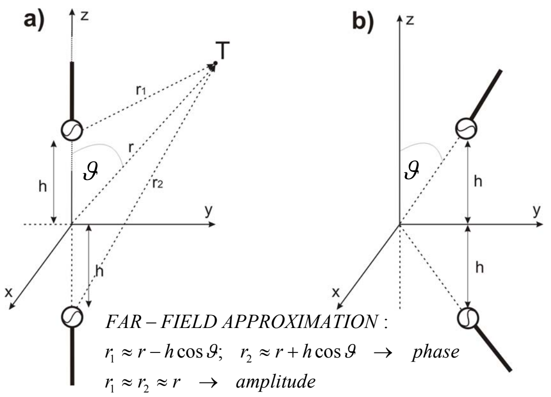

Figure 1. Antenna above ground plane and its image under the ground a) vertically positioned; b) slanted

In Fig. 3 radiation patterns of sailboat shipboard antenna are presented for different antenna elevations starting from 12 m (approximately 6λ) and lowering every 2 m. Figures show the decrease in the number of lobes with the antenna elevation lowering, according to relation (1). Fig. 4 presents the radiation pattern of motorboat antenna placed 3 m above sea level.

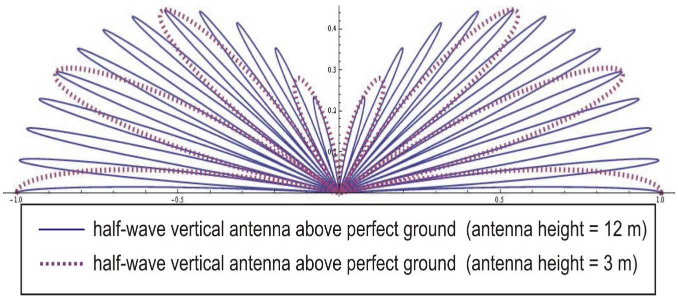

Figure 2. Lobing effect of half-wave vertical antenna above perfect ground plane

Another interesting characteristic of radiation pattern is that the first maximum is not directed toward horizon as would occur if the ground plane were infinitely conductive. Instead, it is elevated by approximately 5° upwards, as seen in figures. This is due to presence of sea surface, which is not a perfect electric conductor [6].

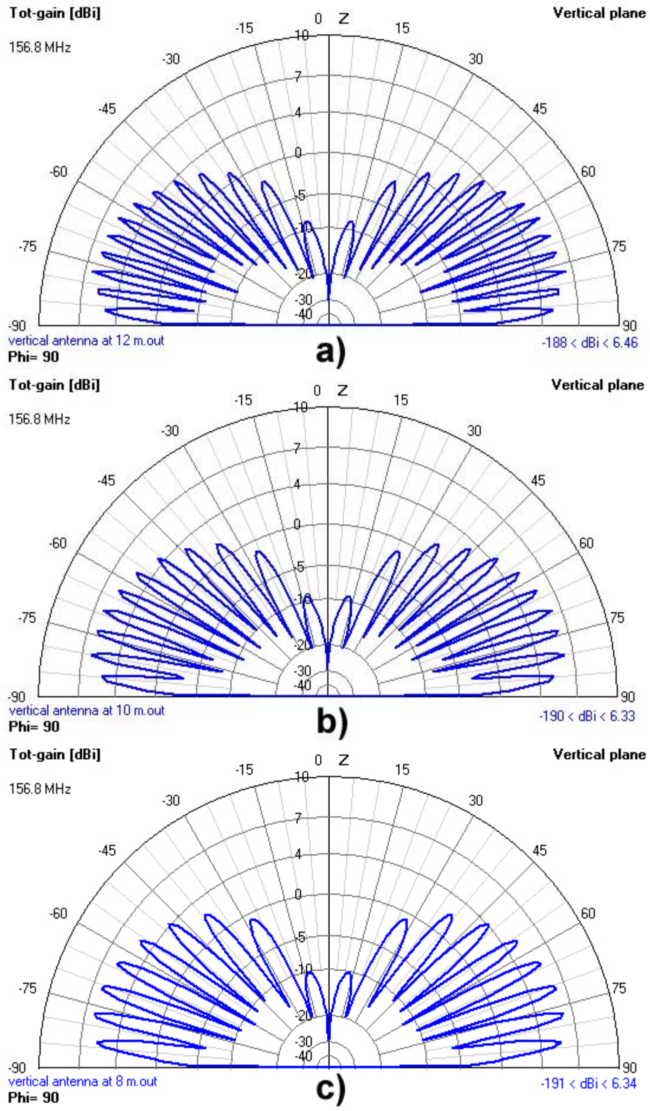

Figure 3. Radiation pattern of vertical VHF marine antenna in *yz*-plane elevated at: a) 12 m; b) 10 m; c) 8m

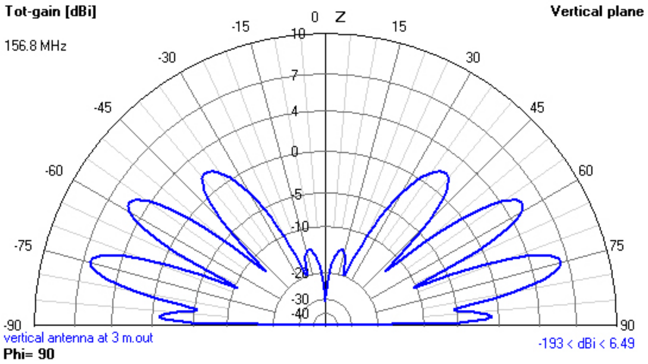

Figure 4. Radiation pattern of vertical VHF marine antenna elevated at 3 m in *yz*-plane

III. Impact of Antenna Elevation Angle on Radiation Pattern

Further step would be to verify the effect of antenna slanting on radiation diagram. Considering motorboats, antennas are usually mounted on the highest position (e.g. flybridge), initially tilted from the vertical position in the stern direction by an arbitrary angle. Rolling of a motorboat can additionally slant the antenna. On the other hand, the sailboat antenna is mounted vertically on the top of the mast. However, heeling of the boat while sailing causes the antenna to slant, typically up to 30°, even up to 45°.

A slanted antenna in free space will have a slanted radiation pattern. This leads to the wrong perception that the slanted shipboard antenna will also show a slanted radiation pattern: one side directed downwards to the sea, and the opposite side upwards to the sky. However, the sea surface, acting as a ground plane, forms a symmetrical virtual source placed under the ground level (Fig. 1 and 5a). The resulting radiation pattern (Fig. 5b) is not slanted because it evolves as a combination of two symmetrically slanted radiation patterns.

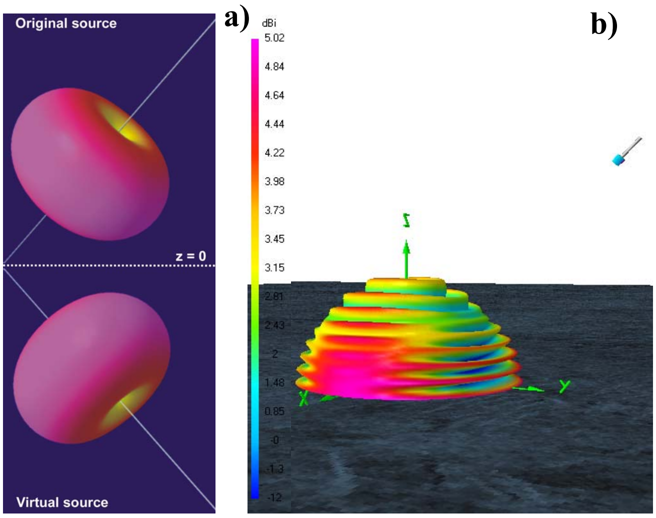

Figure 5. 3D radiation pattern of VHF marine antenna slanted by 45°
a) separate patterns of symmetrical antennas above and under the ground;
b) aggregate pattern of symmetrical antennas above and under the ground

In Fig. 6 radiation pattern of VHF marine antenna above sea surface is presented for different boat heel angles. These radiation patterns show that heeling does not cause slanting of radiation pattern. Changes appear in number of lobes, which is mainly contributed by the change of antenna height that occurs during heeling. Those changes in height can vary from several centimeters to several meters and therefore cause changing of positions of maximums and nulls in radiation pattern. Considering motorboats, vessel rolling cannot cause changing of maximums and nulls directions, they remain constant.

Previous calculations were done using simplified models, without sailboat conductive structures. According to [1], the simplified models should yield almost the same results as the complete model of the sailboat. This was verified by NEC simulations of complete model (Fig. 7 and 8).

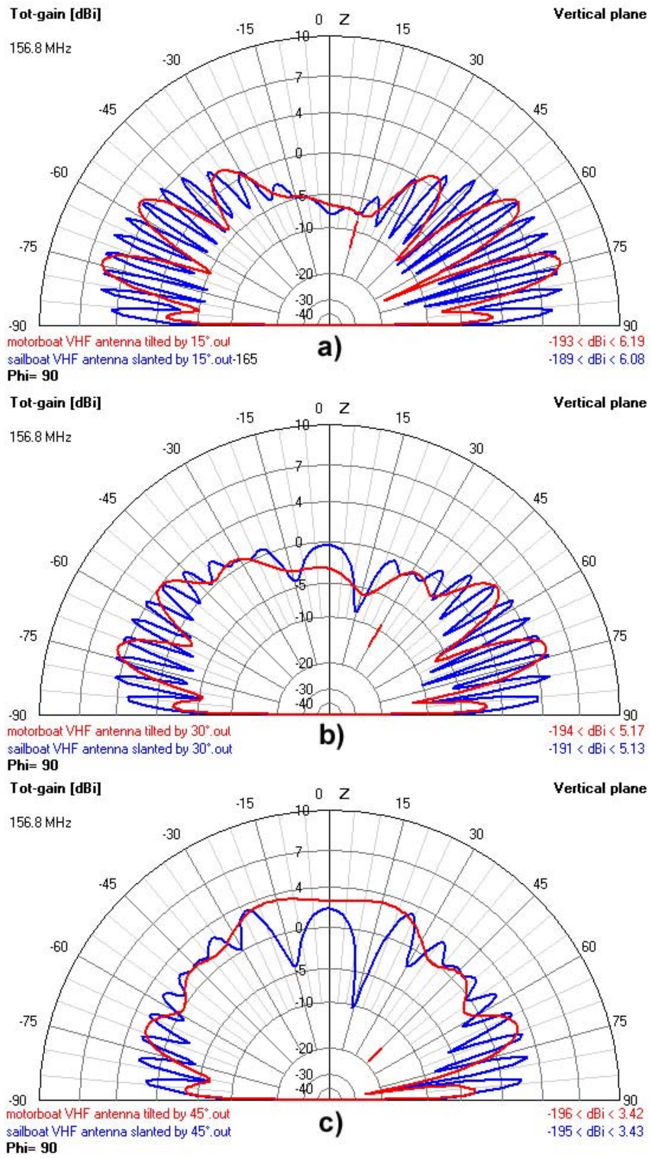

Figure 6. Radiation pattern of sailboat (blue bold line) and motorboat (red bold line) VHF marine antenna above sea surface in *yz*-plane slanted by:
a) 15°; b) 30°; c) 45° toward *y*-axis

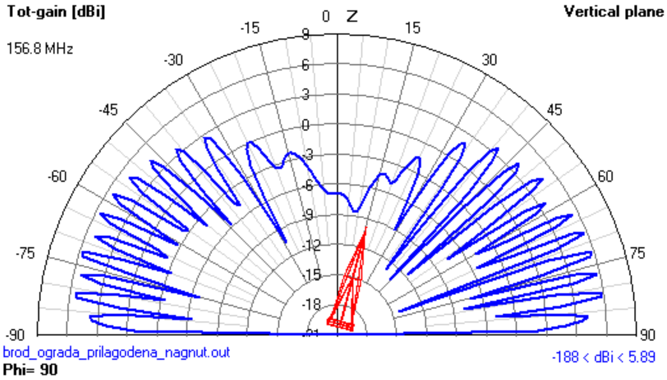

Figure 7. Radiation pattern of VHF marine antenna with full sailboat structure in *yz*-plane heeled by 15° toward *y*-axis

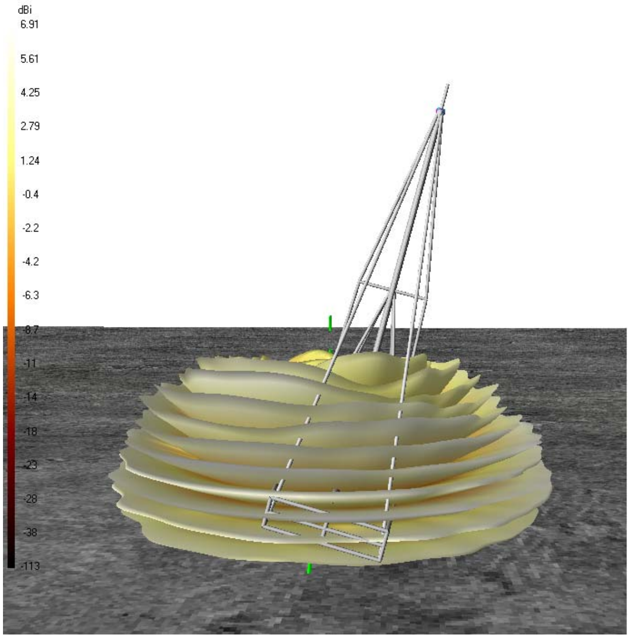

Figure 8. 3D radiation pattern of VHF marine antenna with full sailboat structure heeled by 15° toward *y*-axis

IV. Conclusion

The results of NEC simulations concerning impact of antenna height above the sea surface and impact of antenna slanting on radiation characteristics were presented in this paper. These two factors are inevitable in real environment.

It was observed that the antenna height played significant role in the forming of the radiation pattern. Change in the antenna height changed the number of lobes in the radiation pattern. This caused the redirection of maximums and nulls along the elevation angle, however not affecting the envelope of the pattern.

Simulations showed that antenna slanting did not cause the slanting of the pattern itself. The pattern preserved most of its symmetry.

These results present a good basis for further analyses concerning different platforms, various types of ground and more complex antenna structures.

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