Abstract — The analysis and prediction of a radio signal level in the maritime environment depends on measurements in a specific frequency and its influence on the measured signal. The sea has typical characteristics, including the level of the tides and waves that affect the intensity of the received signal. This article presents the results of the analysis of radio frequency (RF) signal measurements performed in the maritime mobile radio in a narrow band channel in the coastal region of Macaé city, Rio de Janeiro State. Such analysis was carried out in terms of signal level, coverage, fast and slow variability.

Index Terms — maritime environment, propagation, radio waves, slow fading, signal variability.

I. INTRODUCTION

Several authors [1]-[3] describe the propagation models for different frequency bands and environments with distinct characteristics. However, the advance of the technology, with the use of frequency bands and higher transmission rates, requires field measurements for validation or creation of new models that can be used in new frequency bands, rates and various locations so it would be possible to guarantee a desirable accuracy and performance [4]. Field trials allow a better understanding of the signal behavior in the environment and with the measurement of that signal it is possible to verify the initial signal shape, which then helps to predict what kind of perturbation there is going to be present in that environment. Traditionally a field trial is first made with both transmitter and receiver in fixed positions, evolving to fixed transmitter and mobile receiver or vice versa, and them, not so common, both transmitter and receiver in movement.

With the measured results, a channel modeling can be achieved for that specific location and conditions as an empirical model. On the other side other theoretical or empirical models could have validation for that environment, thus strengthening that model as it would help to predict the measured values. It is worth to note that only with reliable measured data it is possible to understand and verify a phenomenon, make supposition, and proposition of a way to deal with it.

An initial analysis in a narrow band of frequencies, as a performed in a maritime environment, allows an assessment of the channel in terms of signal level, coverage and variability, providing better
understanding of the channel behavior for further analysis in broadband, more adequate for digital transmission.

With a narrow band analysis it is possible to access the initial channel conditions and get to some important parameters such as: signal level, path loss, small and large scale variability pdf and some second order statistic like level crossing rate and average duration of the fade.

In terms of setup, a narrow band field trial requires less and cheaper equipment and processing data compared with a broadband one. That is suitable for a first approximation especially in more aggressive conditions like the one where the test was performed. Once all the equipment had been installed minutes before the beginning of the test on the vessel or watercraft, there were problem of electrical energy, place for the correct fixture of the antennas and so on.

The field trial, with some of the results are presented in this paper. It was carried out in a maritime environment with a fixed transmitter in land and a mobile receiver installed in a watercraft. The main objective was to acquire the signal level and then to perform a narrow band analysis.

After this brief introduction (section I), this article is organized as follows: section II describes the environment and the route taken in the propagating tests, the measurement system (setup), the data processing and the results obtained. Section III presents some relevant results from the signal measured in a narrow band analysis and a comparison with Two Ray model. Section IV presents the main conclusions.

II. ENVIRONMENT, SETUP AND DATA PROCESSING

In the next subsections the environment and others relevant conditions to obtain and to process the data used for analyses of the signal will be described.

A. Maritime Environment

The maritime environment studied is located at the coastal region of Macaé city in Rio de Janeiro State, in the region of the Santana archipelago. At this location, there are usually small and medium watercrafts (many of them are of the tug type) anchored or in movement, representing a typical scenario, on a small scale, of a harbor region. The measurements were carried out in the morning of a sunny day (December 12, 2009, from 08:00 h to 12:00 h) with temperature around 26.5 °C (79.70 °F) and relative air humidity of 86 %. The sea was slightly wavy with estimated winds force equal to 2 made for the shipmaster of the watercraft, on the Beaufort scale (light breeze – with speed between 7 to 12 km/h) and the sea with slight undulations up to 30 cm, with crests, but without surf) as sown in Fig 1.
Fig. 1. Sea with slight undulations in the test day with a partial view of Santana archipelago

The routes used for the measurements are shown in Fig. 2 in segments of thick blue line. Each segment represents a stretch measured, from which data were obtained for analysis purposes. In this figure it can be identified: the position of the transmission antenna – TX on the Engenheiro hill; the visibility region; the partial obstruction region; the total obstruction region; the total obstruction region by the islands of Santana archipelago and the region of watercraft anchoring. The three thick white dashed lines, numbered as 1, 2 and 3, show the approximate radial analyzed to obtain the results presented in this article.

Fig. 2. General vision of the measurement environment and used routes

B. Measuring system setup

In order to carry out the measurements, a transmission system was mounted where a signal generator provided a RF signal of 3.515 GHz, with 7 W output power. The antenna used was an arrangement of vertical dipole mounted in a single structure, with 11 dBi gain. The setup was installed
on the Engenheiro hill at 42 m high above mean sea level in the point indicating as TX in Fig. 2.

The received system was composed of a vertical monopole antenna with 5 dBi gain, installed on the outside top of the watercraft at 5.5 m height above mean sea level, a low-noise amplifier (LNA) with 15 dB gain, a Spectrum Analyzer (zero span and 300 kHz BW), a GPS receiver and an analog-to-digital (A/D) converter module with sampling rate of 4000 samples per second (sps). A portable microcomputer was used to control the Spectrum Analyzer, to capture the position sending by GPS and storage of the acquired data from the A/D converter module. This system was installed in Propriá I watercraft and its speed, for the purpose of measurements, was maintained at about 9 knots (18 km/h).

As briefly mentioned before, the equipment used to compose the setup had to be mounted just minutes before the beginning of navigation. The mounting of the transmission side was a little fast once it required less equipment e.g. power source, radio frequency generator, antenna support and transmitter antenna. In the receiver side however thinks were more complicated due the limited space available to install the equipment as well as the amount of connections antenna fixture in the appropriated place, cable transit, electrical energy availability and plug connection among others minors complications that have to be anticipated and solved between the harbor and the beginning of the test while the watercraft initiate their navigation.

C. Data acquisition and processing

For the purpose of processing and analysis of the data acquired, three types of files were created: the first one with the signal level measured at the Spectrum Analyzer video out, the second one with signal level measured by Spectrum Analyzer through a command sent by the portable microcomputer control program, and the third one with the records of the latitude and longitude positions sent by the GPS. Each file with the signal level measured at video out corresponded to a period of 5 minutes of record, generating a total of 1,200,000 samples. A tag of time was attached to the data sampled so that it would be possible to later determine accurately the spatial location of each sample obtained. Altogether, 24 files were generated of the three types mentioned, where each group of three types of file corresponded to a stretch.

After processing, only the data obtained in the region of visibility were considered, in which three thick white dashed lines, as shown in Fig. 2.

III. Data Analysis

A. Level signal measured and coverage

Once the narrow band signal was measured there are some analyses that can be performed. Traditionally it is determined, from the signal level, the fast fading and the slow fading and its respective pdf. This pdf are in general and for urban environment Rayleigh and Rice for the fast fading and lognormal for slow fading. Others more specific pdf can be obtained and has been reported in the specialized literature for specific places. Fig. 3 show the spatial signal level measured during all
It is possible to observe in red the stronger signal and blue the weak one. Also could be observed a variation on the signal level that becomes strong and weak in routes 1, 2 and 3.

A regression curve was calculated by the method of least squares [5] and [6], to retrieve the attenuation factor \( n \) using the equation:

\[
P_r = P_r(d_0) - 10n \log_{10}\left(\frac{d_i}{d_0}\right)
\]  

(2)

where:

- \( n \): attenuation factor;
- \( P_r \): received power in dBm;
- \( P_r(d_0) \): estimated power at \( d_0 \) distance;
- \( d_i \): distance between transmission point to the \( i \)-th measured sample.

It was observed that the attenuation factor \( n \) was equal to 2 that mean that a free space loss (FSL) can represent the mean attenuation for the environment:

- Route 1: attenuation factor = 1.97;
- Route 2: attenuation factor = 2.52;
- Route 3: attenuation factor = 2.17.

Fig. 4 shows a comparison between the measured signal and a free space loss.
The coverage evaluation was done true to the level signal measured compared with the signal that would be obtained if one of the path loss model were utilized.

It was possible to verify that the SUI/Erceg [7] model show a pessimistic prevision in relation to the signal level measured, the same happened to the Hata-Okumura [8] and Hata COST231 [9] models.

The graphic of the Fig. 5 show a comparison of the signal measured with SUI/Erceg model. Although there is not recommendation to use this model to maritime environment a comparative analyses permit to evaluate de degree of adherence or discrepancy of this model to the model in study. It is important to note that this model it is indicated by WiMAX Forum for Urban areas where, in general there is propagation without visibility (NLOS).

**B. Comparison and analysis with the Two Ray model**

Also for result analysis purposes, the signal levels measured in each radial were compared with the Two Ray model for the Flat Earth [1], with vertical polarization, because the sea surface behaves as
an almost perfect reflector for the signal in this frequency range, particularly in the situation of calm sea. The Fig. 6 presents the comparative results of radial 1 with the Two Ray model for the Flat Earth. This same typical behavior was observed in the radial 2 and 3.

![Fig. 6](image)

Fig. 6. (a) Signal level received and theoretical curve obtained by the Two Ray model (b) Traditional geometry of the Two Ray model.

For the traditional Two Ray model shown in Fig. 2, the following equation was used [1]:

\[
PL = \left[ \frac{\lambda}{4\pi d} \right]^2 e^{-jk_1} + \Gamma(\theta_2) \frac{e^{-jk_2}}{r_2} \right]^{-1}
\]

where:
- \( \Gamma(\theta_2) \): Fresnel reflection coefficient for vertical polarization;
- \( k = 2\pi/\lambda \): wave number;
- \( \varepsilon_r \): dielectric constant for the sea (\( \varepsilon_r = 81 \));
- \( d \): distance between base and mobile stations;
- \( h_b \): transmitter (base) antenna height;
- \( h_m \): receiver antenna height (mobile);
- \( r_1 \): direct ray distance;
- \( r_2 \): reflected ray distance;
- \( \theta_1 \): normal to direct ray angle;
- \( \theta_2 \): normal to reflected ray angle.

Also it is possible to conclude from Fig. 6 that the Two Ray model for the Flat Earth can be employed for simulation and prediction coverage of a base station placed in the sea or closed to then. However, a high variation in the signal level measured, even after removing the fast fading was observed in all radials. A possible explanation for this phenomenon is the influence of the sea surface roughness which affects the antenna position, especially its height due to the watercraft movement.
C. Fast fading

The fast fading was separated from the measured signal and it is shown in Fig 7. In the Fig 8 it is shown the pdf where the variability obtains Rice in most part of the trip. That was not surprised once there is a direct sight and a reflected one diffused by the random sea surface.

![Fig. 7. Fast fading](image1)

![Fig. 8. pdf of the fast fading](image2)

For the slow fading the variability of the received signal did not present a good fit to the lognormal curve, as commonly presented in the technical literature [1]-[3] for urban environment. The Fig. 9 shows a typical variation of the received signal and its pdf.
Based on conditions of the sea, in the day where the measurements were carry out it is possible to better describe the main element that could influence and explain de variation of the signal not presented in the two ray model that it is based on the geometry shown in Fig. 8.

The main element mentioned in the previous paragraph are waves that affect the reflected signal, and the effect of the waves in the watercraft that change the position of the received antenna, mainly the height or heave of the ship, and therefore the compound received signal both direct and reflected ones.

Others effects that also could be explain the signal variation are the motion of watercraft like sway, surge, pitch roll and yaw, that will also affect the antenna position and consequently the signal received. It is worth to mention, although it was not present in the test day, the physical condition of the water surface of the sea like foam, wave crest, bubble and surf.

IV. CONCLUSIONS

With the result of the measurements carried out it was possible to conclude that the attenuation of
the received signal level follows, in general, the Two Ray model for the Flat Earth, although they have presented variations that were not contained in that model, which deserved further analysis in terms of slow variability and its relation to the characteristics of the environment. It has been found, however, that the slow variability measured did not provide good adhesion with the model commonly used in terrestrial environments (lognormal pdf) and it seems to have a Laplace shape what might be also investigated in further work. Anyway, the variation of the signal previously mentioned could be explained as being the result of the random sea wave conditions and this effect on the watercraft position that affect the level of received signal by the antenna, mainly the height.

Even with this preliminary results some improvements could be suggested to the design of maritime system that can be operated in this frequency and environment for example the use of special and frequency antenna diversity as a way to minimize the fading observed as due movement of the antenna.

REFERENCES