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High Performance Underwater UHF Radio Antenna Development

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Abstract

This study presents the development of a UHF radio antenna for underwater transmissions in order to rapidly transmit large size files and real-time video.

1. Introduction

New developments of underwater observatories involve an increase of the transmission data rate between autonomous mobile subsystems and fixed platforms. Actual acoustic or optical wireless transmission technologies in this context do not meet the requirements concerning both relative low cost and several tens of Mbit/s. The work under development is ongoing within the perspective of responding to those needs over short distances, also for deep underwater observatories, thanks to the support of the French "Pôle Mer Bretagne" actions (axis 5). After a comparison between electromagnetic models of the seawater needed for antennae simulations, we present the conception of an innovative radio antenna compatible with common UHF WLAN standards. We relate first experimental results at 2.4 GHz.

2. EM modeling of the seawater

2.a. Electromagnetic model of the seawater

In the liquid state, the evolution of the relative dielectric permittivity ϵ_r of the water according to the frequency yields to a first order Debye equation (1). For seawater, salinity is due to the presence of various ionic components. It induces conductivity σ (S/m), depending on location, depth, temperature...

$$\epsilon_r = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 - i2\pi\tau f} + i \frac{\sigma}{2\pi\epsilon_0 f} \quad \text{Eq (1)}$$

The typical parameters of the model are the static permittivities ϵ_s , asymptotic ϵ_∞ , and relaxation time τ . In published literature, simple empirical formulas are proposed for these parameters [1]. Moreover, a rigorous model based on the electrophysiology of seawater [2] demonstrates an excellent correspondence between simulations and measurements. Unfortunately, the calculation of the rigorous model involves substantial experimental characterization, thus considerably reducing the possibilities of use. Fig. 1 illustrates that for standard conditions of underwater medium, variations of predictions between the two models (empirical [1] and rigorous [2]) could induce a significant impact on the

attenuation assesment in seawater of electromagnetic waves at around 2.4 GHz frequency.

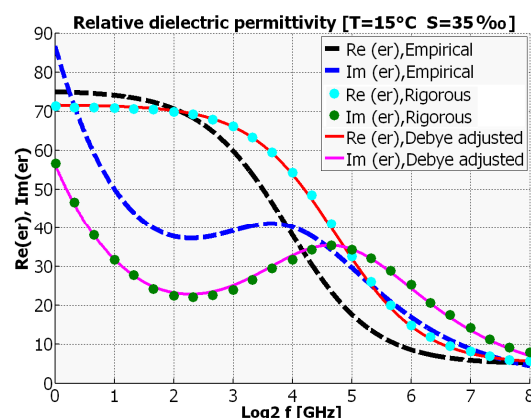


Fig. 1. Comparison of the dielectric permittivity models of seawater

Furthermore, Fig. 1 also demonstrates that the empirical model can be adjusted (Debye adjusted) to obtain an excellent correspondence with the rigorous model

2.b. Attenuation

The expression of the linear attenuation α (m^{-1}) for the plane wave in a medium is calculated from the homogeneous Helmholtz equation. It leads to:

$$\alpha = \omega \sqrt{\mu \epsilon'} \left[\frac{1}{2} \left(\sqrt{1 + \tan^2(\delta)} - 1 \right) \right]^{1/2} \quad \text{Eq (2)}$$

where ϵ' is the real part of the dielectric permittivity and $\tan\delta$ the loss tangent which integrates the conductivity contribution. Considering the frequency at 2.4 GHz, while the rigorous model predicts an attenuation of 7.2 dB / cm, the empirical model provides an additional 4 dB / cm, notably due to a difference in the imaginary parts.

Significant uncertainties remain in the theoretical evaluation of the attenuation of radio waves according to the different compared models. Moreover, special care to the sensitivity of the antenna's performances will have to be taken, due to the natural electrical properties variability of the sea water regarding the various local conditions.

3. Ongoing study of the underwater antenna

3.a. Specification of constraints and objectives

There is a need for fast wireless transmission of large computer video files, or even real-time video using an antenna system integrated in underwater mobile module.

Another important requirement is the effective low cost. Moreover, there are some constraints concerning biofouling and hydrostatic pressure, bearing in mind that the oceanic trenches are a part of the objectives of operational implementation.

3.b. Antenna solution for transmission

In the context of air radio transmissions through biological tissues, the solutions combining radiating elements and element protection (buffer) have been successfully developed [3]. In this way, the additional use of circular polarization was firstly suggested to overcome any constraints regarding the azimuthal alignment between transmitter and receiver. But the usual shapes of underwater equipment led us to consider a cylindrical buffer. The study of eigen modes in this buffer demonstrates that the resonant frequency of the TM_{010} mode does not depend on the height and results in an azimuthal symmetry; thus this obviates the complexification added for a circular polarization while maintaining the advantages of lack of constraint concerning azimuthal alignment.

The electromagnetic simulations and optimizations were made by using ANSYS/HFSS © software (implementing the finite element numerical method FEM). The proposed antenna system is very insensitive to variations of seawater electrical properties dispersions. As shown in Figure 2, we conducted the first experiments which demonstrate the very good abilities to match the system in seawater. Indeed, the return loss (S_{11}) is close to -20 dB, while we verified that the water level variations in the buffer do not shift the working frequency of 2.370 GHz.

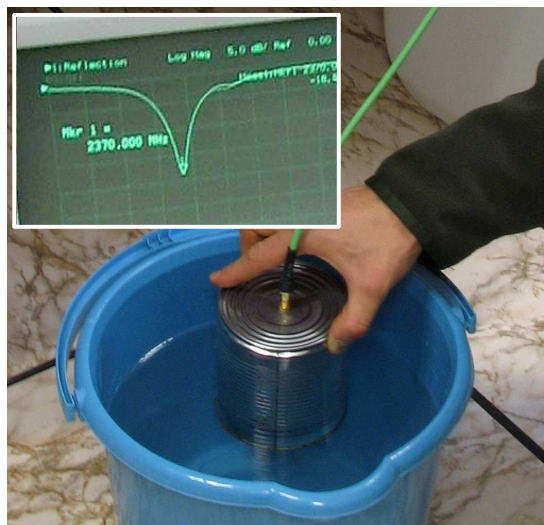


Figure 2. Matching measurements on prototype at 2.4 GHz.

4. Conclusion

A first prototype of underwater antenna at 2.4 GHz has been developed with a very good return loss of -20 dB. The experiment confirms the specific properties selected for applications in various seawater conditions (temperature, salinity, depth ...) without the requirements imposed by azimuthal alignment between the transmitter and the receiver. The experimental study of the transmission is in progress and will permit to verify the hypothesis of the medium modeling and permit to measure the reachable distance of the transmission. For instance it is expected to reach about 10 cm to 15 cm with wireless Wi-Fi conventional systems.

5. Bibliography

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