Bow-Tie Antenna for Underwater Wireless Sensor Networks

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Abstract

Within this paper the use of Wi-Fi in air and underwater environment using the channels around the 2.4 GHz frequency range that have been standardized worldwide, is presented through simulation and experimental work. Using a bow-tie shaped antenna we study the actual signal strength between underwater and air conditions, while changing the distance between two devices, wirelessly connected with each other.

Keywords — Bow-tie Antenna, Underwater Communications, Wireless Fidelity, Wireless LAN.

Biographies

Konstantinos N. Alvertos was born in Knoxville Tennessee USA in 1984. He is a Master of Science candidate at the National Kapodestrian University of Athens. He received his Bachelor of Electrical Engineering from the School of Pedagogical and Technological Education in 2014.

Evangelia A. Karagianni was born in Leros, Greece, in 1969. She received her B.Sc. degree in 1994 and the Ph.D. degree in 2000 from the Department of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Greece. In 2004, 2008, and 2016, she was elected Lecturer, Assistant Professor and Associate Professor, respectively, with the Hellenic Navy Academy, Sector of Battle Systems, Naval Operations, Sea Studies, Navigation, Electronics and Telecommunications. She was employed in Public Power Corporation Hellas and Intracom Hellas. She cooperates with the Microwaves and Fiber Optics Laboratory, NTUA as a researcher and with the National and Kapodistrian University of Athens, Informatics and Telecommunications Department as an Associate Lecturer in Microelectronics M.Sc. Program. She has authored 3 books related to Monolithic Microwave Integrated Circuits (MMIC) and RF electronics and has more than 40 publications in the fields of MMIC, RF Navy electronics, Numerical Methods for Telecommunication systems, Telecommunication in Navigation, Optical Communication Systems and Low Noise Amplifiers and Microwave Filters.

Biographies

Konstantinos D. Vardakis was born in Athens, Greece, in 1995. He joined the Hellenic Naval Academy in 2013 and now he is a 4th year's Combatant Naval Cadet to be a Deck Officer for the Hellenic Navy. He speaks and writes English and German languages.

Thomas K. Mpountas was born in Athens in 1987. He received the Engineer's Diploma, from the Department of Electrical and Computer Engineering, at University of Patras, in 2011. In 2015, he received the Master's Degree in Microelectronics at National and Kapodistrian University of Athens. He is a PhD student at ECE, NTUA, and Hardware Engineer at R&D Team of Prisma Electronics SA.

Dimitra I. Kaklamani was born in Athens, Greece, in 1965. She received the PhD degree from the National Technical University of Athens (NTUA) in electrical and computer engineering (ECE), in 1992. In April 1995, April 2000, October 2004, and February 2009, she was elected Lecturer, Assistant Professor, Associate Professor, and Professor, respectively, with the School of ECE, NTUA. She has over 300 publications in the fields of software development for information transmission systems modeling, microwave networks, mobile and satellite communications, and has coordinated the NTUA activities in the framework of several EU and National projects in the same areas. She is Editor of one international book by Springer-Verlag (2000) in applied CEM and reviewer for several IEEE journals.

INTRODUCTION

Underwater Wireless Sensor Networks (WSN) are sensors used to monitor environmental or physical phenomena in order to cooperatively disseminate the data through the network of sensors to a shore access point.

Wireless communication has been used underwater for many years under a variety of reasons such as:

- Research: Study of marine life and climate recording
- Military: Underwater defensive systems that need remote control
- Industrial: Instrument monitoring and pollution control for the oil industry

INTRODUCTION:
Specific Applications

Coastline protection

Off-shore oil/gas field monitoring

Oceanographic data collection

Autonomous or remotely operated underwater vehicles

Real-time guidance of an autonomous underwater vehicle (AUV)

INTRODUCTION:
Current problems

The current technology applied is based on acoustic technologies which includes a variety of issues:

- Poor performance in shallow water
- Limited bandwidth
- Negative impact on marine life
- Poor noise immunity

INTRODUCTION:
Options or Alternatives?

In order to rectify these problems and improve the use of wireless sensors underwater we could either apply a solution using Optical systems or RF systems

Optical Systems

- Great bandwidth (in the order of many Gbits/sec)
- Extremely susceptible to the presence of suspended particles
- -Line of sight conditions are required in order to achieve communication

RF Systems

- High bandwidth (not as high as an optical system but still more than enough to accommodate the needs of today's sensors) in the order of Mbit/sec
- -Immune to noise and suspended particles
- -No need for L.O.S
- -Range can be increased by decreasing the depth of operation.

RECENT RESEARCH

-Previous research has been focused in channel characterization and not in antenna design which influences its structural parameters as well as the changes in different environmental conditions.

-The great difference in designing an antenna when the propagation mean is water, is:

- The change of the medium’s density which limits our frequency options
- The presence of particles when heavy rain conditions are taken into account
- The increased conductivity our medium has compared to air or vaccum

ANTENNAS FOR THE 802.11 STANDARD:
Bands for the 802.11 Standard

Using the 802.11 standard by IEEE for underwater use gives us a great amount of benefits:

It is an ISM band which doesn’t need a licensing fee and can be used for free public use since the spectrums have been released for free public use.

Hardware is easy to be found, modified and purchased at very low cost

ANTENNAS FOR THE 802.11 STANDARD:
Bands for the 802.11 Standard

IEEE 802.11 is the current standard of WLAN (also referred to as Wi-Fi). There are four basic protocols:

IEEE 802.11a
IEEE 802.11b
IEEE 802.11g
IEEE 802.11n

-The 802.11a uses a frequency around 5 GHz while the rest use a frequency around 2.4 GHz
-Vendors use also the 802.11ac protocol which can combine multiple antennas and uses both frequencies to increase the bandwidth

ANTENNAS FOR THE 802.11 STANDARD:
Standard – Frequency – Data Rate

Standard	Frequency	Data Rate
IEEE 802.11b	2.4 GHz	11 Mbps
IEEE 802.11g	2.4 GHz	54 Mbps
IEEE 802.15.4	2.45 GHz (Worldwide)	250 Kbps
IEEE 802.15.4	868/915 MHz (N. America/Europe)	20/40/100 Kbps
IEEE 802.11a	5 GHz	54 Mbps
IEEE 802.11n	2.4/5 GHz	54 Kbps – 600 Mbps
IEEE 802.11ac	5 GHz	6.77 Gbps

ANTENNAS FOR THE 802.11 STANDARD:
Antenna Type Selection

Types of Antennas:

-Omnidirectional (Basic Dipole)

-Directional (Cantenna OR Yagi)

-Parabolic

-Corner Reflector

One method used to increase the distance between two nodes is the use of a directional antenna. With a directional antenna that is aimed at a WLAN Access Point we can extend our coverage to greater distances.

ANTENNAS FOR THE 802.11 STANDARD:
Antenna Type Selection

Our choice is the Bow-Tie Antenna

The bow-tie antenna is popular for frequencies ranging from Ultra High Frequency (UHF), from 300 MHz to 3 GHz, up to the millimeter wave range, from 30 GHz to 300 GHz. Its performance is not sensitive to small parameter variations, improving robustness to manufacturing tolerances and minor changes within its enviroment. Although the bow-tie antenna provides reasonable wide-band performance, this is not a high performance antenna; thus demanding applications may call for more complex designs. The resistively bow-tie antenna is a practical candidate for pulse radiation

WATER PROPERTIES:
Conductivity , Permittivity and Permeability

Conductivity of the water can value from 5.5 µS/m up to 4 S/m. To be more precise high quality deionized water values at around $5.5*10^{-6}$ S/m, drinkable water values from $5*10^{-3}$ to $5*10^{-2}$ S/m and salt water around 4 S/m.

The best media for electromagnetic waves propagation are insulators where the conductivity (σ) is zero in S/m, so they are called lossless media. If the conductivity of a medium increases, the attenuation of radio waves is also increases. The permittivity (ε) becomes complex with a value of:

$$\varepsilon = \varepsilon_r \varepsilon_0 - j\frac{\sigma}{\omega} = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - jtan\delta_\varepsilon)(\frac{\mathrm{F}}{m})$$

Where ε0 is the vacuum permittivity, σ is the conductivity of the medium, ω is the angular frequency and εr is the relative permittivity which varies from 55.720 up to 87.740 in water.

Since the water is a non-magnetic medium, the value of its relative permeability is μ_r=1, so, the permeability µ of the water is the same as that of free space μ_0. The conductivity of water is $\sigma=5.10^{-2}$.

UNDERWATER ELECTROMAGNETIC PROPAGATION

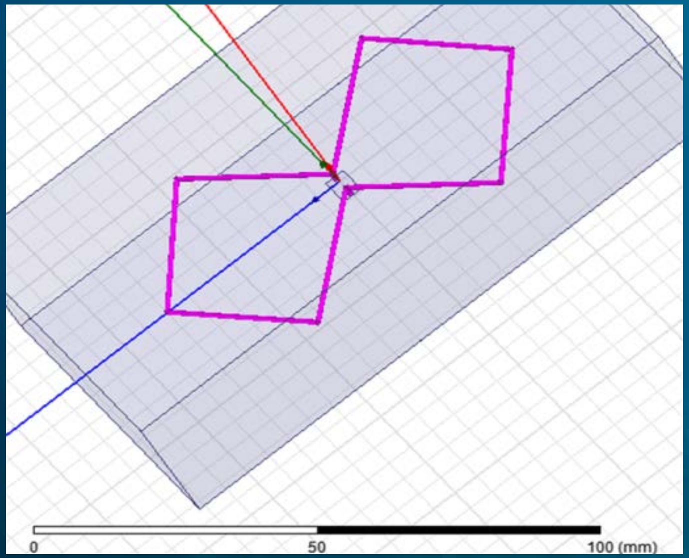
Intrinsic Impedance of Water $z = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$

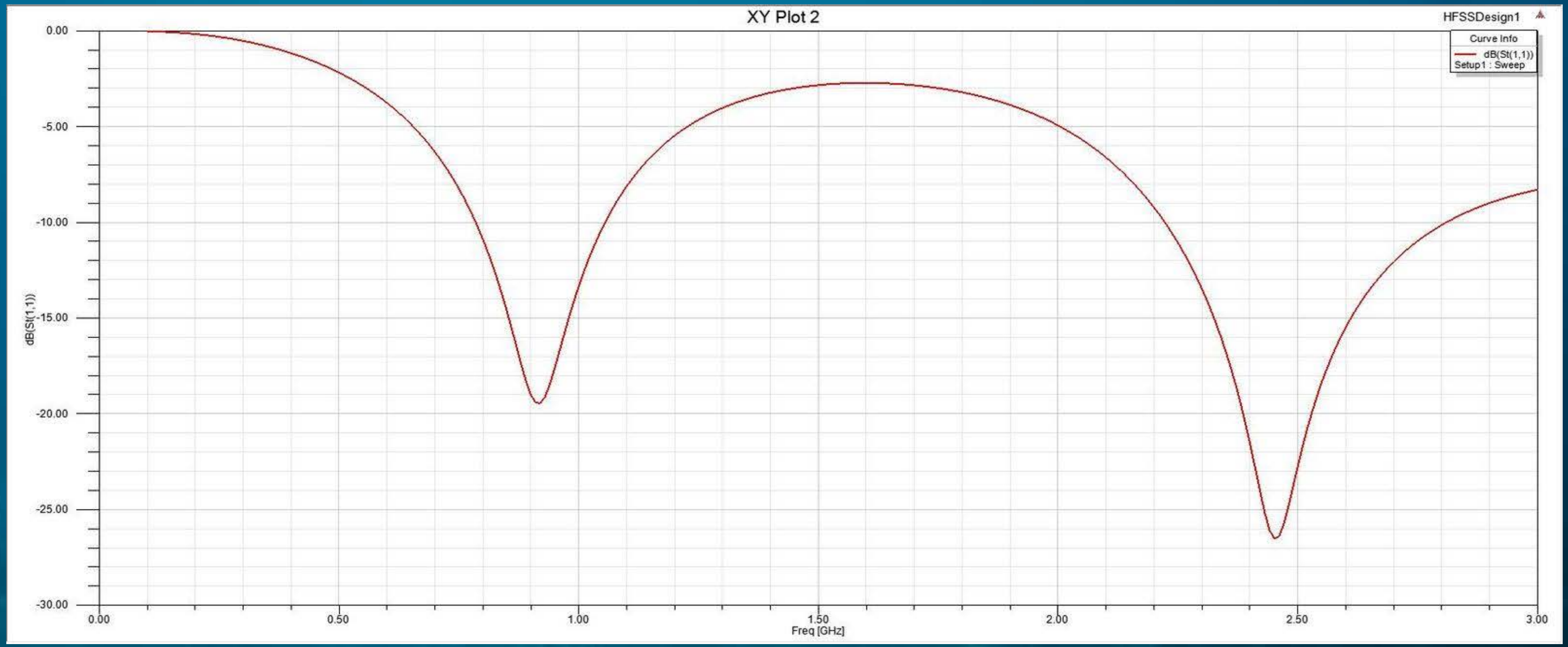
Propagation of electromagnetic waves: $\gamma = \omega\sqrt{\frac{\mu\varepsilon'(1 - cos\delta_\varepsilon)}{2cos\delta_\varepsilon}} + j\omega\sqrt{\frac{\mu\varepsilon'(1 + cos\delta_\varepsilon)}{2cos\delta_\varepsilon}}$

Underwater Path Loss: $\mathrm{L(dB)} = 20log\frac{4\pi d}{\lambda} + 20log\frac{\lambda_0}{\lambda} + 20loge^{\alpha d}$

SIMULATION RESULTS

When operated in the air, the antenna resonates at 2.45 GHz with S_{11}=-26dB and at 910 MHz with S_{11}=-20dB. When the environment is pure water the antenna resonates at 150 MHz with -10 dB reflection coefficient.





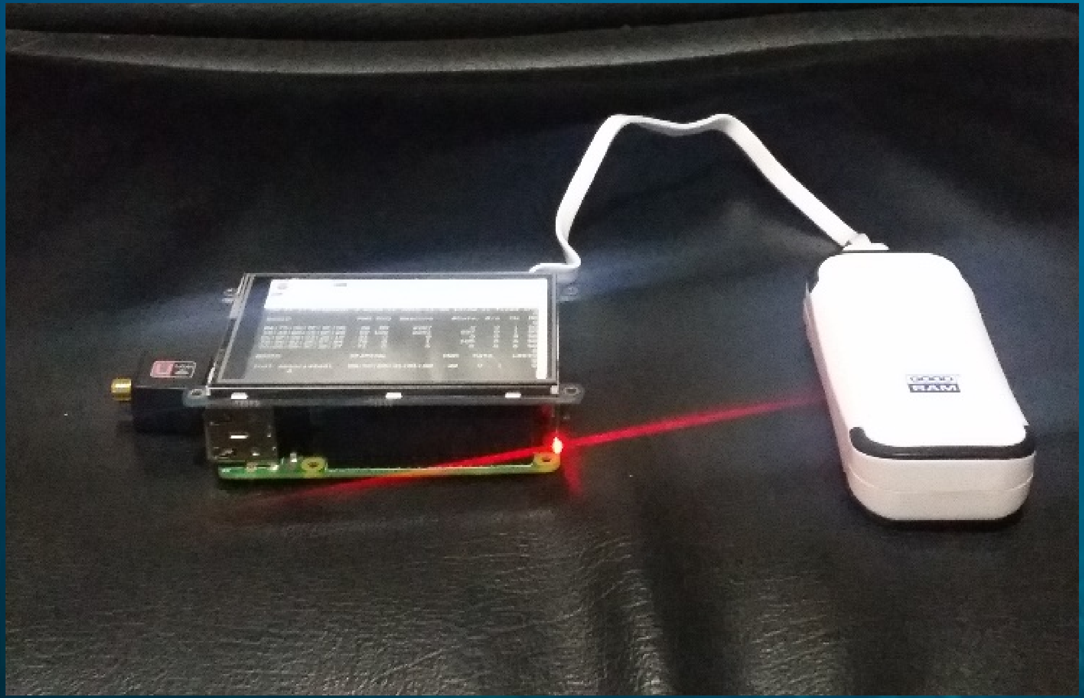
MATERIALS, EQUIPMENT AND MEASUREMENTS

Container: Capacity of 139 lt. (90cm x 48cm x 32cm)

Router attached to antenna: Custom made Bow-Tie Antenna connected to an ALFA AP121U router

Receiver of signal: Raspberry Pi 2 with an integrated TFT touch screen and a USB WiFi with an MT7601U chipset and 4400 mAh power bank

Raspberry Pi with its TFT screen, power bank and Wi-Fi antenna



Bow-Tie antenna with its insulation

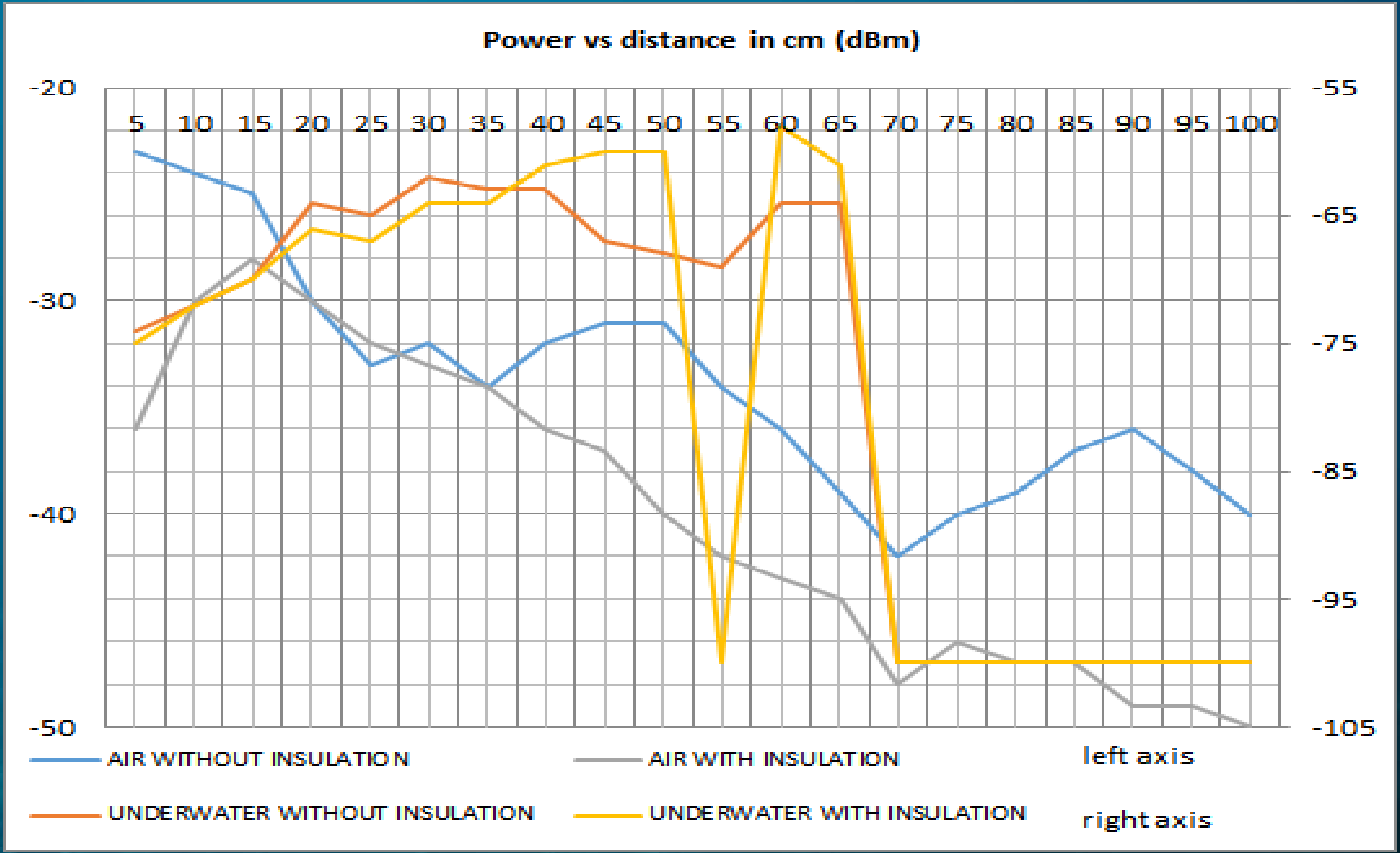
Bow-Tie antenna without its insulation

MATERIALS, EQUIPMENT AND MEASUREMENTS

The measurements as we can see differentiate greatly between the two mediums and there is a slight difference when the insulation is removed.

Bow-Tie Antenna Submerged

Measurements for the performance of the bow-tie antenna



CONCLUSIONS

- The non-insulated antenna has a very good performance (better than the insulated one) when working in air.
- The strength of the received signal fell almost linear of the order of 0.5dB/cm up to 70 cm.
- The best performance measured at 50 cm and 90 cm where the signal strength was -30dBm and -35dBm respectively.
- The insulated antenna has better performance for distances up to 38 cm which indicates the need to take into account the properties of the medium and in particular its conductivity, at the design stage.
- Our inability to test greater distances was based on the size of the container, which can also be concluded that the distance could be much greater for a bow-tie antenna.

The experimental results in freshwater agree well with those obtained through HFSS simulations, in terms of the transmission power. So we can conclude that it is possible to predict the operation of the antennas and improve their design.

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