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Design of Wide Band Antenna for Ocean Communication: Review

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Abstract

In this review paper, the design and implementation of antenna types in wide band frequencies for ocean communication are analysed. This work mainly concentrates on designing a high frequency wide band antenna which has high directivity, omni directional radiation pattern, small size and good time domain performances.

Keywords

UWB Antennas, Electro Magnetic Waves, HED, VLF

1. Introduction

Ultra-wideband (UWB) is a radio transmission technology which occupies an extremely wide bandwidth, i.e. > 500MHz or at least 20% of the centre frequency [1], is also a revolutionary approach for short-range high-bandwidth wireless communication. Differing from traditional narrow band radio systems (with a bandwidth usually less than 10% of the centre frequency) transmitting signals by modulating the amplitude, frequency or phase of the sinusoidal waveforms, UWB systems transmits information by generating radio energy at specific time instants in the form of very short pulses thus occupying very large bandwidth and enabling time modulation. The transmitting power consumption of UWB systems is extremely low in comparison with that of traditional narrow band radio systems [2] .UWB technology is widely employed in many applications such as indoor positioning, radar/medical imaging and target sensor data collection. Since the release by the Federal Communications Commission (FCC) [1],[2] of a bandwidth of 7.5GHz (3.1GHz to 10.6GHz) for ultra wideband (UWB) wireless communications. Omni directional property in radiation pattern is in demand for UWB antenna.

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Hence low directivity is desired and the gain should be as uniform for different directions. Radiation efficiency is also an important application. Since the power transmitted into space is very low, the radiation efficiency required is high. The antenna designed should be capable of operating over an ultra-wide bandwidth as allocated by the FCC. Antennas designed for use in air are unsuitable for use in water, because of the different electromagnetic properties of water and air. Electromagnetic under water has a nominal speed of 33,333,333m/s,power loss, 28dB/Km/100MHz,MHz bandwidth and a 10m effective range with less than 0.5 m antenna size [41]. Ultra Wideband antenna has high radiation efficiency, linear phase, offers low dispersion, and a VSWR$\leq$ 2 throughout the entire band with relatively small size. In this proposed work different antennas are investigated in detail in order to understand the parameters that lead to the wide band characteristic and also obtain some quantitative guidelines for designing this type of antenna. Very little work has been done in undersea communications. In seawater the conductivity is nominally σ=5 S/m and a good conductor should satisfy the condition $\sigma/\sqrt{\varepsilon\omega} >>1$, so seawater is a good conductor at 7 to 30 MHz .The attenuation constant is approximately, $\alpha=\beta\approx\sqrt{\pi\sigma\mu f}$ [34].

The propagation of electromagnetic waves in water is very different than in the air, because of its high dielectric constant and the attenuation is much higher in water, causing a limitation on the transmission distance which cause variation of the impedance of the antenna. This change in return loss implies a completely variation when immersed in water. Thus, as the frequency increases, the attenuation also increases and the propagation distance decreases, so water is a better conductor at lower frequencies [10]. Therefore seawater is a good medium at frequencies around 10 MHz’s. So an antenna should be designed with low frequency, high gain, omnidirectional radiation pattern, small size, constant group delay and gain across the whole band. The design parameters for achieving optimal operation of the antennas should be analysed extensively in order to understand the antenna operations.

2. Literature Survey

Undersea communications include driver monitoring systems [12], underwater autonomous vehicles (AUV)[17],[18],underwater acoustic networks[19], unmanned underwater vehicle (UUV) [20], underwater gliders[29],observatories[42], detection of underwater mines, disaster prevention etc. Though the proposed omni directional antenna is mainly based on undersea communication, very few works are done in this area. Moreover very few works are done with electromagnetic waves in water due to the high dielectric constant. These types of antennas are mainly used for establishing communication between underwater sensors, using electromagnetic signals. Electromagnetic propagation in water is 1/9 times of free space and the lesser Doppler shift provides command latency and better networking protocols in underwater communications [22].EM wave propagation is possible through the water column at useful distances in the lower unlicensed Industrial, Scientific and Medical bands(ISM) [25].The main disadvantage of radio communications is that it suffers from heavy attenuation due to the skin depth and water's conductivity [30]. The return loss depends on the reflection coefficient, г. A return loss level less than -10 dB means that the energy is radiated is more than 90%. The antenna radiation pattern is defined as the spatial distribution of a quantity which characterizes the electromagnetic field generated by an antenna [10][13]. The level of this parameter is related with feeding power. The directivity in a direction measures the power density that an antenna radiates in a specific direction, relative to the power density radiated by an ideal isotropic radiator antenna radiating the same amount of total power. This parameter is related with the radiation power, and is used to know the antenna efficiency. The antenna size should be less than 5cm of radius [8]. The antennas in water are prone to corrosion, so an insulated antenna is preferred to one made of bare metal [24].The attenuation is less in low frequencies and our work mainly concentrate on lower wide band frequencies [15].In earlier works acoustic waves are used for the communication in undersea, but the low speed and time varying properties make the acoustic frequencies less preferable in modern communications. In acoustic the bandwidth is undesirably limited [39], although used for long distance communications. Conductivity, dielectric constant and permittivity are the important factors in the undersea communications where they change with frequency and temperature [7], [8].Impedance increases with frequency, but decreases with the conductivity. Impedance matching is an important aspect in any antenna design commonly uses a matching circuit for designed antenna in air. But due to the high dielectric property of water, matching circuit in circuit may suffer from complete signal loss [26].The problem with this radio communication is that water readily absorbs radio frequencies around the 2.4 GHz region, which is why microwave cooking units operate at 2.45GHz [30]. Moreover the dielectric constant does not vary within the 10 MHz-1 GHz frequency range [8].

This work mainly concentrated on antenna design in undersea communications. Previous work includes loop antennas[24],long wires, bow-tie[26] and dipoles[8].To design specific antenna the design parameters such as gain, directivity, return loss and radiation pattern should be taken into account to satisfy different physical size and electrical specifications. The software tool for antenna design is HFSS software. In the application that we study, we need simulations in water with a permittivity of 81.In our work the study range of frequencies are selected to be 10 MHz-1 GHz, because the frequencies in water are 9 times lower than in air[25]. For the antenna to operate in UWB range, BW should be greater than 500 MHz feeding is also an important aspect in antenna design. In 1967, Richard K Moore [38] studied very low frequency (VLF) and suggested that due to strong attenuation in the sea, very low frequencies are required for undersea communication. He made the first theoretical treatment of end fed dipole and considered all four dipole combinations (Vertical, Horizontal, electric and magnetic) in undersea communications. In 1973, M.Siegel [40] studied dipole antennas theoretically and experimentally. In this the received signal is extremely or for modern equipment's. These antennas suffer are limited to short range and low frequency application. In 1976, Momma et al [11] proposed an underwater communication with reduced power and increased range by electric current. This method is an alternative to acoustic wave communication but results in high power consumption. In 2004, Al demonstrated that transmit and receive antennas, improve launching efficiency, coated with insulating material enabled signal propagation over hundreds of meters in shallow water. Their results indicate propagation loss of 100dB in the antenna near-field and 1 to 3 dB in far field with loss out to 100 m. In 2005, Ted et al [31] proposed two antennas for swarm robots in underwater; the two new antennas were a Parabola antenna with an 8dB gain and a Yagi with a 9dB gain. In this study the Yagi antenna performed worse than expected at all depths compared to the omni directional antenna. The parabolic antenna performed better than the omni directional antenna, Also the three antennas gave steady results when depth is increased up to the bottom of the pool, where the omnidirectional antenna signal dropped off. A new type of ionic liquid (salt water) antenna was proposed by Ewananovil et al[45].In this two salt solutions one with salinity 35 parts per thousands and conductivity 4.7 S/m at 17.5"C and the other with the salinity doubled at 70 ppt and 8.4 S/m at 17.5 "C. The resonant frequency was found inversely proportional to salt solution column height and bandwidths. In 2006, A. Shaw et al [36] studied the electromagnetic wave propagation through seawater at MHz frequencies. He conducted different class experiments in a fibre tank with dipole, loop, double loop and folded loop antennas. In the same year, Ram et al [37] derived a physically realistic model for the frequency variation of the relative permittivity of seawater for varying salinities and temperatures. In this study they measured no conductivity change for small electric fields (12 and 1.5 μV/m) at frequencies of 50 KHz and 1 MHz respectively. In 2007, Fielding et al [21] analysed a method for maintaining vertical dipole antenna alignment for subsea towing, where horizontal dipole antennas were used in EM transmission. In 2008, Peter Smith investigated [28] a single resonant coil antenna, an array of twin resonant coils, a stacked column of twin resonant coils with 2.5 kHz operating frequency, which gives a wavelength of ~30 m for typical seawater electrical characteristics ($\varepsilon r = 81$, $\sigma = 4$ S/m). These antennas can serve the purpose of maximizing the magnetic flux while maintaining a manageable drive circuit. A resonant antenna design reduces the power requirement of the drive circuit with high Q. He combined stacked and array antennas to increase the transmitted magnetic moment. In 2009, Conessa et al [33] designed an active antenna to measure electromagnetic fields in water. It combines a differential wideband amplifier and a dipole, which provide constant gain on the bandwidth of the antenna and small size of the dipole. In this a symmetrical reception antenna in the frequency range of 100 MHz to 1 GHz was introduces with few disturbances. This dipole can be used as a wideband matching network and ideal balun when connected to a differential amplifier. The sensitivity is better for high frequencies. In the same year Liu et al [35] proposed a horizontal electric dipole (HED) in which vertical electric field component produced by a HED in a sea of finite depth is much weaker than the horizontal components, and may be neglected generally in ELF band. Horizontal components are more sensitive to the change of seabed conductivity than other field components. In a shallow sea, the field strength from a HED would decay slower with the distance than that in a deep-sea, thereby providing a favourable condition for underwater communication. The field strength produced is not sensitive to frequency change in ELF band. A submerged HED at the seabed can substantially change the electromagnetic field distributions produced. It can only be applied to determinate the apparent conductivity at seabed surface. In the same year, an electromagnetic signal in the form of a linear chirp signal (1 kHz to 29 kHz over a period of 42.6 ms) of range 27ms was proposed by Robin et al[46].In this Line antenna, magnetic loop, surface contour antenna, conformal 2D disc antenna were analysed theoretically and practically.

In 2010 Dale [12] suggested in situ data extraction from underwater sensors with moderate transmission rate. According to him undersea communications, control and command signals usually does not require high data rates.ie in acoustic modems the amount of information gathered over a period of time, is lost in between transmission in high speed modems [19]. In the same year Kenneth et al [24], suggested a mussel based insulated (copper) dipole isotropic antennas were more effective than loop antenna that are under study. In the very near field (near field 2 inches and far field 6 inches), the insulated loop performs better than any other antenna, but the received power falls off very rapidly. In 2011, Waheed et al [32] designed very low frequency (VLF) antenna for undersea communications. They used copper wires which are rewound just like a transformer core in either direction. In this a low power modulated and amplifier circuit was designed for short distance communications between two submarines. In the same year Zhang et al [34] proposed a vibrator antenna which provides better performance than loop antenna. A vibrator antenna may have a reduced signal to noise ratio, and it can be employed over greater distances. Hector et al [42] introduced a buffer for reducing the transmission loss in underwater communications. In this work, the reflection coefficient obtained was -25.98dB in 2.38GHz (without cover) and -34.25dB in 2.58GHz (with glass cover).When glass cover is used the antenna bandwidth reduced from100 MHz to 70 MHz, due to the permittivity of glass.In 2012, Lu et al [4] proposed a two planar monopole (elliptical and swan) with cutting slots on ground plane and produce strong coupling between slots and ground plane modes on FR4 substrate with a dimension of 32 mm × 15 mm for the elliptical monopole and 25 mm × 9 mm for the swan monopole. The proposed antenna slots had very little effects on the frequency and time domain performances. In the same year Abdurrahman et al [23] proposed a circular micro strip antenna for underground communications. In this he analysed the underground signal propagation and reflection from ground interfaces. The frequency effects on the path loss for different values of distance between sensors using different soil types are studied. In the same year Jurianto [39] proposed a new type of antenna for undersea communication with less power consumption. In this the antenna comprised of first radiating element or connecting to a first potential level and second radiating element for connecting to second potential level with both first and second field shaping structure for controlling field propagation in first and second direction. The propagation direction is defined by field pathway and substantially perpendicular to at least one of the first or second directions. The related works done so far are shown in table 1.1. In 2013, Liang et al [3] proposed a wideband monopole antenna for Bluetooth and UWB application. He used lower pass band-U shaped parasitic strips bilaterally beside feed line on a FR4 substrate with dimensions of 18×32×0.8mm3.He analysed the reflection coefficient by changing length and feed gap. The peak gain at Bluetooth band of 1.6dB. Chang et al [5] proposed an inverted F antenna for a 3-13 GHz short range (<10m) UWB indoor, wireless communication. In this a planar monopole is top loaded with a rectangular patch attached to two rectangular plate, one shorted to ground and other suspended on a FR4 substrate with a dimension of 20×10×7mm3.In the same year Mingjian Li et al [6]proposed a differential fed magneto-dielectric dipole which provides unidirectional radiation pattern and a gain of 8.25±1.05dBi on a Duroid 5870 substrate with a dimension of 65×65×9.8mm3.This antenna claimed to have an impedance bandwidth of 114% for frequencies from 2.95 to 10.73 GHz range. In this the radiation patterns in E and H planes are well behaved up to 9.4 and 8.9 GHz, respectively, after which side lobes appear due to the high order modes radiation. Arash et al [7] proposed a couple line fed planar, (patch antenna) which has a dual band notch with two integrated monopoles that attempts to integrate the UWB technology with Bluetooth and Global System for Mobile Communications (GSM) at 900 MHz. Kwai et al [13] [16] proposed a magneto electric dipole for UWB application that can be easily printed on Duroid 5880 substrate for 60 GHz frequency. In this a horizontal bowtie electric dipole with an impedance bandwidth of 110%, with SWR ≤ 2 was analysed from 3.08 to 10.6 GHz. Li et al [14] grouped UWB antennas based on Time domain or Frequency domain and low gain or high gain .He analysed ringing, group delay, signal fidelity and differentiation parameters. A matched Bow tie antenna designed by Abdou et al [25] shows that, a RL of -16dB at 433MHz which means that more than 95% of the power is transmitted in air and the simulation presents a sharp valley at low frequencies of 154MHz with a high value -43dB of RL and bandwidth of 90MHz in undersea. In this the antenna is fully waterproofed with glue. Brian et al [48] proposed broadband antennas (balanced coaxial loop antennas with a bazooka Balun) with insulation (TiO2) using OFDM, advanced space frequency and iterative decoding for low SNR The experiments were carried out with moderate data rates upto 100 Mps. A comparison between different communication systems is shown in table 1.2.In unmanned underwater vehicles(UUV),UUV's must surface to enable the dorsal antenna to get above the waves to communicate, which requires extra energy to back to depth and be on track. So a buoyant tethered antenna was proposed by Brooke Ocean Technology USA, which will support two-way RF communication, including Wi-Fi, Iridium, and a camera and GPS reception [27].

Table 1.1: Techniques used so far

Antenna Used	Frequency Band
Bow tie,[26]	433MHz ISM
Coaxial loop [48]	3-18 MHz
Magneto Electric Dipole [48]	3.08-10.6 GHz
Monopole [49]	433MHz ISM
Electrodes[39]	VLF
microstrip [42]	2.4 GHz
Dipole,loop,folded dipole[24]	315-433MHz ISM
Resonant coil[28]	2. 5KHz
Loop[36]	50Khz-1MHz
Lonline,magnetic loop[46]	10-100KHz
Loop antennas[47]	10Hz-1GHz
Coaxial antenna [44]	VLF
Dipole antenna[50]	100KHz-14 MHz

3. Electromagnetic Waves

The EM field behaviour in freshwater and seawater is entirely different. In salt water, positive and a negative ion may be bonded to each other through water molecules that are hydrogen bonded (extremely weak and easy to break) to each other. Therefore at high electric field strengths, with forces acting in opposite directions on positive and negative ions, these bonds might be broken apart and would get free positive and negative ions. The propagation speed *c* can be expressed as in equation number (1).

$$c = 1/\sqrt{\mu\varepsilon} \qquad (1)$$

Where ε is the dielectric permittivity and μ is the magnetic permeability. The relative permittivity of air is about one [3]-[7].Since εr (relative permittivity)for water (saline and fresh alike) is about 81, the speed of underwater EM waves is slowed down by only a factor of 9 of the speed of light in free space. The absorption coefficient α for EM propagation in freshwater can be calculated as in equation (2).

$$\infty \approx \frac{\sigma}{2}\sqrt{\mu/\varepsilon} \qquad (2)$$

Where σ is the electric conductivity. Seawater is a *high-loss medium*. In highly conductive media, both the propagation velocity and the absorptive loss of EM waves are functions of carrier frequency. The propagation speed as well as absorption loss can be expressed as in equation (3) and (4) respectively.

$$c = \sqrt{4\pi f / \sigma\mu}\ , \qquad (3)$$

$$\infty = \sqrt{\sigma\mu\pi f} \qquad (4)$$

For a given medium, the ratio of the electric conductivity and the dielectric permittivity, σ/μ, referred to as transition frequency, defines the border of the behaviour of an electromagnetic (EM) field in that medium [43].If the frequency of an EM field is lower than the transition frequency, it behaves mostly like a diffusion field; if the frequency is higher than the transition frequency, the EM field is mostly like a propagating wave. For seawater, the conductivity is about 4 Siemens/meter, and the dielectric permittivity is 81×10^9= (36π). These values yield a transition frequency of about 4 × 36π× 10^9= (2 × 81π) = 888 MHz This means that if a carrier working on the frequency of 10 MHz in seawater, which is much lower than seawater's transition frequency, then the EM field basically is not a wave anymore and it rather behaves like a diffusion field. On the other end of the spectrum, if a carrier with frequency of 1 GHz is used, the EM field will mostly behave like a wave. However, the EM wave can hardly propagate due to the high absorption of seawater. The field components for submerged horizontal electric dipole in submerged conditions are well noted by Blare [44] in 1962.

4. Electromagnetic Propagation in Seawater

The propagation constant is a factor that determines the changes in an electromagnetic wave as it propagates in a given direction and the propagation constant [36] is expressed by equation (5).

$$\gamma = \sqrt{j\omega\mu(j\omega\varepsilon + \sigma)} = \alpha + j\beta \qquad (5)$$

$$\alpha = \beta = \omega\sqrt{\mu\varepsilon\sqrt{0.5(\sqrt{1+(\sigma/\omega\varepsilon)^2 - 1})}} \qquad (6)$$

Where ω is the angular frequency, μ is the magnetic permeability, and ε is the electric permittivity [9]. The propagation constant has a real attenuation constant α(m^{-1}) (Helmholtz equation)and an imaginary phase constant β .The attenuation constant depends on rate of decay and the phase constant depends on the rate of phase change in EM propagation. Sea water dissipates energy as heat when an electromagnetic wave propagates through them [8].Intrinsic impedance η, is the ratio of the transverse electric and magnetic field. In sea water propagation η determines power transfer. The propagation constant and intrinsic impedance are approximately those of a lossless dielectric $\beta = \omega\sqrt{\mu\varepsilon}$ and $\eta = \sqrt{\mu/\varepsilon}$

Because the permittivity of water is about 9 times that of air, the intrinsic impedance is about a 1/9 that in air and the propagation constant is about 9 times that in air. The wavelength λ, $\lambda = 2\pi/\beta$ in water is about a 1/9 that in air. The attenuation,α(dBm-1 derived from Neper m-1),velocity of propagation (ms-1), skin depth ,δ (m), wavelength ,λ (m), and intrinsic impedance, η (Ω), versus frequency, (Hz),can be easily obtained directly from the relationships[46].

1. Design

The design approaches are mainly classified into four. They are class A, B, C, D .In class A approach both the transmitter and receiver antenna are in direct contact with the sea water. For class B sea water is contained in an insulating container while the antennas are placed close to the container. In class C, both the antenna is coated with insulator are placed in sea water and vertical transmissions are analyzed in class D. The design approaches are as shown in figure 1.1. The antennas are usually made of thick copper sheet and FR4 glass reinforced epoxy laminate sheet. The main aim of this work is to design an antenna for class C transmission.

2. Fabrication

Photolithography is the process of transferring geometrical shapes from a photo-mask to a surface Antennas are printed on the FR4 epoxy glass laminates by photolithography. The CAD drawing of the antenna is printed on a high quality butter paper with a high resolution laser printer. The copper clad of suitable dimension is cleaned with a suitable chemical like acetone to remove any chemical impurities. A thin layer of photo resist material is then applied over the copper clad using a high speed spinner. A negative mask of the designed antenna geometry is created. An oxide removed single/double sided copper clad lamination of suitable dimension is dipped in the negative photoresist and dried to get a thin film of the photo resist on the laminate. UV radiation exposure through the negative mask is given for 2 minutes. The layer of photoresist material in the exposed area hardens and immersed in the developer solution for agitation. To remove the unwanted metal portions, it is then washed in Ferric Chloride ($FeCl_3$) solution.$FeCl_3$ dissolves the copper parts except underneath the hardened photo resist layer. Finally, the laminate is washed in Acetone solution to remove the hardened negative photo resist.

3. Testing and Equipment's

The antenna under test is used with PVC containers. The frequencies ranges for analysis are generated using oscillators [36].The receiver antenna can be identical or some reference dipole antennas. The receiver antenna is directly connected to a HP spectrum analyser via a RG58 cable and a narrow band filter. The propagation of antennas in sea water is tested with a tank filled with sea water with conductivity of 4S/m .The antennas (TXR and RXR) are mounted with movable support to provide different measurable distance. The experiments conducted by Ahmed et al [36] analysed loop, dipole, double loop, and folded dipole shows different attenuation in different classes.

Figure 1.1: Different underwater design approaches

An experimental set up was created to measure the conductivity of salt water which was proposed by ram et al in 2006 [37].For measuring S11 (S11 is the reflection coefficient expressed in dB) parameters, the insulated antenna is immersed in sea water tank and connected to a network analyser. The frequency at which the return loss value minimum is taken as the resonant frequency of the antenna. The network analyser is calibrated before performing the measurements. For measuring S12 parameters an electronic circuit is connected to provide impedance matching. The specific port of the analyser should be calibrated for the frequency range of interest using the standard open, short and matched load, prior to the measurement. The S11 values of the antenna in the entire frequency band can be stored on a computer.

5. Conclusion

In this work, we are analysing different type of antennas that are used for undersea communication. The peak gain, return loss, directivity, radiation pattern are analysed as per the requirement and will be able to design an antenna for undersea wide band applications using HFSS or CST MS simulation software.

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