

# Submarine Based Communication over Years: A Review

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**ABSTRACT:** Submarine Antenna technology was started in 1890's and used in World War I and World War II. From the Second World War the Submarine Antenna technology has become increasingly important in our Country. At present for the combined operations and Network Centric Warfare (NCW) concepts, the design of Submarine based antennas is a challenging issue. For an antenna to be successfully adopted for Submarine use, it must satisfy numerous requirements, which are generally competitive in nature, such as the ability to with stand hydrostatic pressure, severe constraints on the physical size, a low weight and a large bandwidth to accommodate multiple functions and the ability to operate in a sea water environment [46]. In this paper, we have presented the overall literature review, a brief history of Submarine based communication antennas and types of antennas with suitable frequency ranges starting from the year 1919 to 2016. Also we have studied the EM wave propagation in air and sea water, current trends in Submarine based communication antennas and limitations on the mast mounted antennas at the end.

**KEYWORDS:** UWB Antennas, Submarine based Antennas, mast mounted antennas, Properties of EM wave in air and sea water.

## I. INTRODUCTION

Now a day's Submarines plays an important role in Defence force. Submarines are prominent in our Military because they allow a stealth way to enter into enemy waters and possible attack. In the time of war the Submarines can be used to attack enemy Submarines and surface ships. Nuclear power Submarines are also used to launch the missiles which can be destroyed in land enemy targets, even thousands of miles away. To perform the above mentioned operations by using Submarines they have to operate for continuous stretch of time spanning over many months away from shores and in the deep sea water. To perform the successful operation by the Submarines, these must be able to receive communication from their base stations without exposing themselves to the danger of detection. Submarines can be used as research tools for doing research in the deep sea water. Submarines also allow the Scientists to travel up into the sea and study the water life and also use them for tourism purpose. The Federal Communication Commission (FCC) of the United States officially released the Regulation for Ultra-Wideband (UWB) Technology in 2002. The Spectrum in this Regulation from 3.1 GHz to 10.6 GHz (a fractional bandwidth of 110%) is allocated and the Equivalent Isotropically Radiated Power (EIRP) is less than -41.3 dbm/MHz for the unlicensed Indoor UWB Wireless Communication System. UWB technology is based on transmitting ultra-short pulses with duration of only a few nanoseconds or less has recently received great attention in various fields for the short distance (<10m) Wireless Communication. The benefits of UWB technology are high data rate, low power consumption, compact, low cost, excellent immunity to multipath interference and reduced hardware complexity. Due to the benefits of UWB technology, the UWB Antenna plays an important role in Industry and Academics. One Ultra Wideband antenna can be used to replace multi narrow-band antennas, which can effectively reduce the antenna number. There are the two conditions of Ultra Wide band technology.  $BW \geq 500 \text{ MHz}$  or  $BW/f_c \geq 0.2$ , where  $f_c$  is the central frequency and BW is the bandwidth. UWB was originally developed for Military Communication and RADAR. UWB Antennas have high radiation efficiency, linear phase and offers low dispersion throughout the entire bandwidth.

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## II.LITERATURE REVIEW

In 1919, Willoughby and Lowell conducted the experiments with an objective of developing a system for the detection of Submarines. In that system they found that radio signals could be received by means of loop antennas in water. They achieved successful communication between two Submarines running at full speed and entirely under water at about 20 km apart with a wavelength of 952 [1]. In 1919&1920, Loop Antennas were used for the communication between two Submarines and incorporated at the hull of the Submarine as part of the Antenna System [1-3]. In 1919, U.S. Navy Lieutenant - Commander Taylor conducted the underwater experiments using long wire antenna up to 153m at Navy station in Washington and a Submarine base [2]. In 1951, Ronald K. Moore was the first person worked out on EM theory of submerged antennas [4]. In 1952 to 1957, Wait studied the magnetic dipole, finite wire, insulated loop and Hertzian dipole antennas in a conducting medium. Out of these four antennas, the Hertzian dipole was investigated in sea water by putting the antenna perpendicular to the surface of water and just above the surface. He concluded that the field attenuated at least 20dB with respect of the field on the surface for the distance of 30m into the water using an operating frequency of 30 KHz [5-8]. In 1958, Wheeler analysed the performance of VLF antennas, located under the surface of seawater and mounted on Submarine. The direction of propagation is tilted downward and a fraction of the power is directed into the water. So the vertical propagation downward in the water is provided by horizontal crossed electric and magnetic fields [9]. In 1959, after World War II, the Naval Research Laboratory developed a cross-loop antenna, which was embedded in a plastic in a streamlined configuration. This antenna which was used in the Submarine mast [10]. In 1960, W.L. Anderson conducted an experiment based on the consideration of seawater as medium and magnetic dipole as a source of EM field. In this experiment he calculated the power propagation at various distances from the source. Finally he concluded that the propagation downloaded into the water is proportionally as  $1/r^2$  and  $1/r^3$  for electric and magnetic fields respectively [11]. In the same year, M.B. Kraichman conducted an experiment by using dipoles and loops as EM sources in pool. The pool was filled with a concentrated sodium chloride solution [12]. In the same year, Saran and Held conducted the experiments and measured the field strengths of monopoles and loop antennas at different depths in a Lake up to 304.8m. They had used transmission frequency of 18.6 KHz and measured the Lake conductivity as 2.66ms/m. For different antennas, the experiments and theoretical results illustrated that, the field strength attenuates exponentially with depth in fresh water [13]. In 1962, the investigation of air to undersea communication gained importance in Military application such as helicopter to Submarine Communication. One suggested solution consists of a vertical electrical dipole in air with a horizontal electric dipole in sea at 10 KHz to 100 KHz frequency based on the field strength considerations. This showed the changes in wave length with respect to the medium of propagation at different frequencies [14]. In 1963, R.C. Hansen had analysed the three types of antennas in lossy medium such as loops, dipoles and an insulated long wire with end electrodes based on the merit factor like relative Gain. For only one antenna in lossy medium, the relative Gain factor was useful in system calculation. He had concluded that among the three types of antennas the most effective antenna element was the long wire antenna [15]. In the same year, R.K Moore analysed the antennas in air and conducting medium. He had differentiated the two parameters like antenna Gain and Radiation pattern between the two mediums. He had also investigated the bi conical, loop and two forms of straight wire antennas. Finally he had concluded that the Gain and Radiation pattern were affected by the dissipation of energy in the medium [16]. In 1967, Richard K. Moor's did a broad examination of the radio communication in the sea. He had concluded that communication ranges are limited by the effects of depth attenuation and atmospheric noise [17]. In 1971, Marvin Siegel and Ronald W.P. King presented the mathematical formulas for the EM fields of linear antennas submerged in the Atlantic Ocean. The EM fields were measured in a medium by using three ranges such as horizontal range, the near field range and the intermediate range. They had performed the antenna patterns using Computer Simulation and which were compared with the experimental results. Finally they concluded that the experiments of measured fields in the near and intermediate ranges were agreed well with the fields predicted using mathematical formulas in lossy medium [18]. In 1972, M.L. Burrows and C.W. Niessen developed the design principles for the ELF Communication System. For that system they used the horizontal dipoles, grounded at each end as the antennas. The ten parallel 100km long conductors, spaced 10kms apart can communicate at a data rate of one bit per second with receivers' up to 10mm away and as deep as 80m below the surface of the Ocean. The required power was used for the transmitter about 4mw and the current in conductor was about 100A and the operating frequency was 75Hz [19]. After World War II, the most significant challenge was to communicate with Submarine at sea in 100m under water. In 1959, the U.S Navy started the secret Sanguine Project to develop

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communication system for submerged Nuclear Submarines and Submarine stations. The project was made public in 1971 [20]. In 1973, Marvin Siegel and Ronald W.P. King conducted the experiments between the antennas submerged in the Atlantic Ocean. They measured the electric field strength; antenna current distribution and antenna input impedance. They compared their measurements with the theoretical results and obtained the good agreement between them. They used short dipoles at 100 GHz and 14 MHz submerged at 0.15m. They measured electric field strength at -10.9dB/m and -128dB/m for 100GHz and 14MHz respectively [21]. In 1974, Steven L. Bernstein and their co-authors said that the efficiency of the antenna can be raised to tolerable levels by the use of very long antenna, broken up into an array of parallel dipoles and driven at moderate current levels [22]. In the same year, for the underwater antennas, a buoyant cable antenna of 610m was designed and attached to the Submarine [23]. In the same year, the Sanguine ELF operating frequency of 300Hz implies that a half wave dipole antenna would be thousand kilometres long. This was clearly impractical and the designers had to settle for antennas that were very small compared to the ELF wavelength. Different configurations were proposed for the both surface and underwater station antennas. Some of the surface antennas considered was helicopter suspended wires and mountain loops [24]. In the same year, an experiment between a radio station located at the North Carolina and Nuclear Submarine at 3200km range using an antenna near keel depth was conducted using ELF [25]. In the same year, James R. Wait briefly discussed the developments on ELF communications [26]. In the same year, the Sanguine Project's main goal was to provide one way radio communication with Submarines at depth anywhere into the world. In that Project they used VLF band [27]. In 1976, H. Momma and T. Suchiya found that the effective range is not a function of power but function of current. Based on this property they conducted the experiments and obtained the results for Voice Communication System. They noticed that the range can be expanded only by increasing the current output without increasing the power output [28]. In the same year, Shen, King and Sorbello conducted the experiment and measured the field patterns of submerged antennas in the Mystic Lake in Massachusetts at 144MHz. They used a travelling wave antenna for transmitter, which was constructed using a 0.32cm diameter brass wire insulated by an air-filled Plexiglas tube. The arms of the antenna were the length of one wavelength in air namely 2.08m. The transmitter antenna was placed 17.5cm below the surface of the water. They had used two receiving antennas, one inside the lake, which was a bare dipole antenna with length of half wave length in water. The other receiving antenna used for measuring the field strength outside the water, was a dipole antenna of approximately quarter wavelength at its operating frequency in air. Therefore the experiment was set such that they had two dipoles, one in air and another that went deep into the water (50m). The third antenna which is the antenna under test, was the travelling wave antenna that was barely into the water and fastened below to their floating structure. They computed the theoretical data for the electric field pattern and measured the electric field pattern with the setup described. Their computed and measured electric field pattern shapes are similar. They concluded that an insulating travelling wave antenna is suitable for Subsurface Communication in Lake Water at a frequency of 144MHz [29]. In 1977, James R. Wait had designed a Project which was seafarer, had stimulated a great deal of research on how ELF waves in the range from about 1Hz to 1 kHz to propagate. They reviewed some of the fascinating developments and especially in investigation of Nicola Tesla. ELF wave's research had been a fertile field of investigation for many years. The very long wavelength had meant that the dependence of the signal characteristics on the medium was very stable compared with high frequencies [30]. In the same year, John R. Davis had developed a Super Conducting ELF receiving antenna which used a triaxial array of Super Conducting Quantum Interference Devices (SQUIDS). The Authors had demonstrated that a SQUID has the potential capability to serve as an extremely sensitive ELF radio frequency receiving element on a mobile platform. Moreover the ability of the SQUIDS to operate at a 100m depth below the Ocean surface and tested based on the measured buoy tow test data [31]. In 1979, R.J. Decesari had designed a prototype communication system to provide VHF Communication from a stationary or moving body or Submarine at depth. This designed system allows to be towed as well survive storms and high waves. In this design, Slot antenna was used for Submarine based Communication [32]. In the same year, Hafez, Chudo biake and Wight investigated the attenuation in freshwater by using co-axial line instruments to verify the possibility of developing a VHF RADAR System capable of sensing the depth of shallow freshwater (<10m) for remote sensing applications. They concluded that, it is possible to develop an airborne VHF RADAR system, capable of sensing the depth and/or detecting large objects in shallow fresh water [33]. In 1981, Michael B. Callahan had studied the various communication techniques for Submarine Communication. He had also compared all the communication techniques based on their advantages and disadvantages [34]. In 1984, Gleun Smith developed a procedure to analyse for directive transmission in to half-space. The antennas half-space directive properties are pattern function, gain and directivity. They presented the theoretical

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results for infinitesimal electric and magnetic horizontal dipole antennas in a dielectric half-space. He had compared the theoretical and experimental results for dipole and loop antennas in a half-space and these results showed good agreement between theoretical and experiment results. Moreover, he concluded that the directivity increases with ratio of height and  $\lambda_0$  [35]. In the same year, Mario D. Grossi conducted the experiment on the long vertical wire as self-powered ULF/ELF radiators for Space borne applications. He had addressed the advantage of the Space borne placement for the ULF/ELF radiators compared with the traditional ground based placement, may be the avoidance of the potential environment threat posed by the conventional sitting [36]. In 1985, ranges in tens of kilometres were possible with bandwidth restricted to order of 1Hz, using trailing-wire antennas and transmit powers of tens of kilometre for antennas submerged within 5m of the surface of water [37]. In 1987, Lloyd Butler answered for some questions which are how far can we communicate under waters in the sea or in a Lake? How large is the signal attenuate? What frequency can be used? Could we use 1.8MHz? [38]. In 1993, H.B. Singh and Rajendra Pal summarized the various communications methods which were used to send messages to Submarine while crushing at various depths. They also proposed that there was a need to equip all Submarines with multi-channel receivers along with trailing wire/trailing buoy type of antennas [39]. In 1994, R.M. Durbar analysed the different types of antennas like magnetic loop antenna, electric field antenna, short electric dipole antenna, long line antenna and disc monopole antenna based on their characteristics. He also investigated the full scale flat and cylindrical antennas in a harbour area [40]. In 1996, B. Ben habiles studied a simple and closed-form expression for the electric field in sea water and derived from the two physical models such as the surface wave theory and the Fresnel formula. Three configurations of immersed receiving antennas were investigated by means of Computer Simulators. They also focused on two dominant antenna parameters such as the impedance and the voltage measured between the wire terminals. The parameter, voltage can be improved by doing modifications of the shape of the immersed antenna [41]. In 1997, Ronald W.P. King analysed and designed a horizontal travelling wave antenna of the Beverage type with the frequency range from 10 KHz to 30 KHz. The designed antenna was uni directional and maintains a large field out over and into the sea and only a very weak field over land [42]. In the same year, Ronald W.P King analysed and designed a horizontal trailing-wire receiving antenna which was used in the frequency range of 14 KHz to 30 KHz for radial distances up to 10,000km along the spherical surface of the earth or sea. Apart from this, the field radiated by such an antenna was Omni directional [43]. In 1999, James E. Brittain discussed Trans-Oceanic Communication and Alexanderson radio alternator [44]. The Defence Advanced Research Projects Agency and the Navy were investigated the advanced Buoyant Cable Antenna Technology. They had mentioned that Submarine based Communication could be enhanced at speed and depth using Buoyant Cable Antenna Technology [45]. In 2001, David F. Rivera and Rajeev Bansal had studied the past and present antennas and presented their merits and demerits. They had proposed that the antennas for the future work were novel Omni directional antennas, wash-over mitigation, new dielectric composites with designed special characteristics and adaptive array techniques [46]. In the same year, Bob Aldridge had completely studied about ELF radio signals at different cases [47]. In 2002, The Federal Communication Commission [FCC] has been released the Regulation for UWB technology in 2002. The Spectrum in this Regulation from 3.1GHz to 10.6GHz and the band width must be greater than or equal to 500MHz [48]. In 2003A. Monin had proposed the electromagnetic model for the floating antenna which was used by Submarine and suggested the frequency range was VLF. He presented the description of the floating antenna and analysed its electrical characteristics. The current in the horizontal wire induced by the lateral wave was computed and suggested a model that gave a non-rational transfer function. Parallel-extended Kalman filter was proposed and validated on the real data based on a Parameter Estimation Algorithm [49]. In 2004, Ahmed AI – Shamma'a, analysed the horizontal propagation through the sea water at a frequency range from 1 MHz to 66 MHz over a distance of 85m. They were used dipole, loop, double loop and folded dipole antennas for propagation through sea water [50]. In the same year, Anders Karlsson analysed the antennas in a lossy medium in terms of the radiation efficiency, the directivity and the power gain. Moreover he had derived the optimal values for these quantities in a lossy medium. Finally he conducted that the most radiation efficiency antenna was the magnetic dipole [51]. In the same year, David F. Rivera and Rajeev Banal discussed the different types of towed antennas like buoyant cable antenna, hull-terminated wire antenna and the floating wire antenna for Submarine based Communication. They had presented their advantage and disadvantages for ELF reception. They also proposed the Wideband antennas for Network Centric Warfare Concepts [52]. In the same year, John W. Beeman, Cam Grant and Philip V. Haner were measured the radiation patterns of three versions of Underwater radio telemetry antennas and compared the reception ranges in the horizontal and vertical planes. They also discussed detection ranges and these can be maximized by



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choosing an appropriate antenna after consideration of the location, relation between transmit and receive antenna orientations, radiation patterns and overall antenna efficiency[53]. In 2005, R. Tames had evaluated the mutual coupling between ship borne antennas in order to establish power and frequency restraints on the corresponding equipment [54]. In the same year, the authors Ben Allen, Tony Brown and Katja Schwinger reported on the state of the art of UWB Wireless Technology and highlighted key application areas, technological challenges, Spectrum operating zones and future drives. They noticed the future UWB developments for 4G Communication Networks [55]. In the same year, Nader Behdad and kamal Sarebandi presented the compact UWB antenna and they had achieved UWB operation through the proper magnetic coupling of two adjacent sectorial loop antennas in a symmetrical arrangement. The maximum bandwidth was achieved by a large number of coupled sectorial loop antennas with different geometrical parameters [56]. A. Shaw and D. Toal conducted the experiments for electromagnetic wave propagation through the seawater and 5MHz RF signal was transmitted over a distance of 90M in sea water [57]. In 2008, X.-T. Liu and C.-W. Su fabricated a wideband monopole antenna using cross-shaped metal plate and achieved Omni directional characteristics. They had successfully implemented that antenna for IEEE 802.16e operation in the frequency range 2 GHz to 6 GHz [58]. In the same year, Frank Plonski and Charles M. Gyenes developed the new small HF antenna using HI-Q antenna unique tuning mechanism and extremely short HF radiating element [59]. In 2009, Rakesh Singh Kshetrimayum studied an UWB communication system and their advantages, disadvantages and applications [60]. In the same year, Werner Wiesbeck was presented the basic properties and design principles of UWB antennas. They characterized the antennas by parameters in time and in frequency domain [61]. In the same year, V.C. Misra studied the different types of antennas such as shared aperture antennas, smart antennas, fractal antennas and photonic array antennas for the Electronic Warfare Applications [62]. In the same year, Liu C. Zheng and Li Y.-P had derived the formulas based on an air-water-seafloor three layer model for ELF electromagnetic fields generated in a sea of finite depth by a submerged horizontal electric dipole. They studied the effects of frequency, sea depth, seabed conductivity and depth of submerged transmitting horizontal electric dipole on the EM field distribution in a sea [63]. In the same year, Robert Headrick had studied the developments in Underwater Communication [64]. In the same year, Ying Cai and Rui Ding designed a super conducting antenna which is made up of super conductor material. This Antenna was compared with trailing-wire antennas in the frequency range of ELF. After comparison, they had noticed that the designed super conducting antenna has huge advantages over trailing wire antenna [65]. In the same year, Brain Austin studied the signals to Submarines at ELF and developed a practical antenna, consists of a ten parallel wire, each 100km long and spaced by 10km [66]. In the same year, Robin M. Dunbar and His Co-authors discussed the variation of electromagnetic propagation parameters with frequency and conductivity. They had examined various antennas such as line antenna and magnetic loop antenna based on environmental electromagnetic noise and its limitation on the Underwater Communication range [67]. In the same year, Rogue Zhou and Hailing designed, fabricated and measured the results in terms of Return loss of a Dielectric Resonator antenna. This Dielectric Resonator antenna is made up of distilled water with high dielectric constant and low loss. They also analysed the resonant mode and resonant frequencies of the Dielectric Resonator antenna using the dielectric resonator model [68]. In the same year, C. Christophe and Alain Joisel had designed a new active Wideband antenna for Under water tomography(1GHz) and frequency range is 100MHz to 1GHz [69]. In the same year, Alian Garcia Miquel had mentioned in his Doctorate thesis about bow-tie antenna (standard shape) antenna. It was better than diamond shape bow-tie antenna for Under water Communication. He had also noticed that circular loop and bow-tie antennas are the most suitable for underwater applications. He designed a new antenna based on the combination of circular loop and bow-tie antennas [70]. In 2011, Ahmet Cemal Durgun and Constantine A. Balanis designed, simulated, fabricated and tested the different novel flexible bow-tie antennas. They analysed their characteristics in terms of return loss and radiation patterns and also compared their results with the conventional bow-tie antennas [71]. In the same year, Zhang Hao and Aaron Gulliver analysed the impact of Antenna design and frequency on Underwater Wireless Communication and designed the Vibrator antenna, which provides better performance than a loop antenna in terms of greater distances [72]. In the same year, Hector Fabian Guarnizo Mendez and Francois Le Pennec developed a preliminary prototype of an underwater radio antenna at frequency of 2.4MHz and bandwidth of 70MHz has been developed for a Wi-Fi Communication [73]. In the same year, Mohd Anzor Bin Yusof and Shahid Kabir studied the different underwater Communication Systems such as Underwater SONAR Communication System and Underwater Electromagnetic Communication system. They had compared those two communication systems and noticed the advantages and disadvantages. The SONAR Communication modes are not practical for air-water Trans-boundary communication due to the greatly amplitude

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attenuation as they cross the air – water interface. Alternatively EM Communication Systems are practical for cross – boundary air – water Underwater Communication with almost without any limitation of speed and amplitude attenuation [74]. In the same year, M. Waheed-uz – Zaman and M.A.K. Yousuf Zai conducted the experiment and designed a new VLF antenna. They tested and measured to calculate the proper size of the new VLF antenna [75]. In 2012, Adil M. Karim, Stephen J. Stafford and R. Benjamin Baker examined the design of fiber–optic signal transport link for a Buoyant Cable Antenna which receives signals from the Global Positioning System. They have discussed the advantages of fiber optics over co-axial remoting. Low noise antenna remoting over extended distances can be obtained by using fiber optics which is particularly important over the long length of the Buoyant Cable Antenna [76]. In 2013, Zhi Ning Chen studied the advantages and challenges of UWB Antennas. He was demonstrated the planar antennas and their merits such as broad bandwidth, stable phase response, easy fabrication, small size, light weight, miniaturization and multiple functions [77]. In the same year, Ritu Rani Singh and Harshlata Sinha discussed the concept of UWB Communication Technology, application areas, Technological challenges, Spectrum operating zones and future aspects of the technology. Mainly they focused on the state of the art of UWB technology as it is today likes practical application in present era and in the nearer future [78]. In the same year, A A Abdou, and Ashaw designed a broadband bow – tie antenna at a frequency of 433 MHz and experimented it in air and water without a matching circuit. This antenna was also used in a two way communication sensor system [79]. In the same year, M. Bellec, and S. Avrillon measured the fields of surface wave propagation along sea water path in the HF band and were compared with theoretical models like Norton’s model and King’s models. They had presented the measurement results at three frequencies 10MHz, 20MHz and 30MHz. They obtained smoothly attenuation at 10MHz and were correlated with the theory [80]. In 2014, Brian Kelley and Krishna Naishadham presented a loop antennas matched to sea water in the HF band for the shallow Underwater Ocean zone. They analysed the data rate of EM radio communication which was 1000 times that of Acoustics [81]. In the same year, Majid Manteghi and Ali Ahmed Younis Ibraheem studied the near – field radiation characteristics of electric and magnetic antennas like implanted antennas and Submarine or Underground Communication antennas in a lossy dielectric media such as human tissues, minerals or salt water. They found that magnetic antennas are better than electric antennas in a lossy medium [82]. In the same year, Nisha George and Ganesan had reviewed many Wideband antennas for Ocean communication[83]. In the same year the authors have developed a new small loop antenna at a 40MHz frequency range for Underwater EM wave propagation [84]. In 2015, Dona Mary George and Ranjitha Rajan designed a rounded edge bow – tie antenna for widening the bandwidth and achieved bandwidth of 200MHz with a maximum gain of 3.588dB at 400MHz. They also proposed a slotted bow – tie antenna and bandwidth of 200MHz with a gain of 3.762dB at the central frequency. Moreover they proposed one more antenna such as wired bow – tie antenna which covers 86% power transfer and gain of 4.407dB [85]. In the same year, the author developed a system with an array of directional antennas which were autonomously controlled in order to save the transmission power required in one to one communication. The authors also said that antenna’s direction can be controlled based on the location of the receiving unit [86]. In the same year, Evangelia A. Karagianni analysed the dielectric properties of the sea water and mathematical models for sea water dielectric constant, propagation speed, wavelength when EM wave at a frequency of 2.4 GHz, propagates through seawater were presented. He had designed a dual – band antenna with arc–shaped circular slots at 2.4GHz and 5.1GHz for WLAN Communications [87]. In the same year, the authors proposed a model of a vertical electrically small antenna located underground with SLF or ELF. They derived the expressions of the electric field excited by an Underground antenna and obtained the current distribution and electric field based on the Numerical method [88]. In the same year, Ruben Lianas developed the spiral antennas in his Doctoral thesis and those antennas were curved in two dimensions for use in underwater (fresh water) communications. He said that the developed spiral antennas will be used in mussel backpacks. Moreover backpacks are compact electrics that in corporate sensors and a small radio operate around 300 GHz frequencies. For mussel related research, Researchers attach these backpacks in freshwater [89]. In 2016, the authors proposed a sea–water monopole antenna at VHF band. This proposed antenna has higher efficiency due to an efficient feeding structure [90].

### III. SUBMARINE BASED COMMUNICATION ANTENNAS

To communicate with submerged Submarines, several antennas such as VLF and ELF antennas are used. VLF radio waves can penetrate sea water up to a depth of 8 to 10 meters, whereas ELF waves can penetrate seawater to the depths of 100 meters, but data rate is very low. Submarines use frequencies in the HF, VHF and UHF ranges to carry

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information by raising the antenna above the surface of the water. HF antennas are used when the Submarine is operating far away from the shore. VHF/UHF antennas are used when it is within the line of sight distances. Generally Submarine based antennas can be divided into three types of antennas. First type of antenna which can be used as the buoyant cable antenna. It is nothing but a long insulated with buoyant material. When a Submarine is cruising at a keel depth of several tens of meters, it may reel out its buoyant cable which then trails behind the Submarine, floating on the ocean surface. The following figure1 shows that Submarine based Wire antenna. This wire antenna consists of material like buoyant or Ferromagnetic core solenoid.

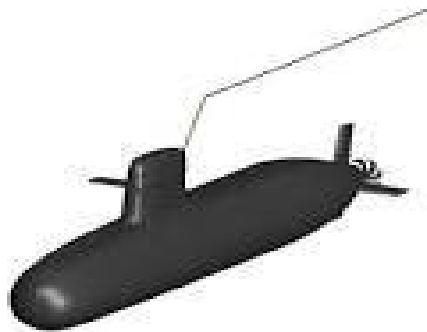


Figure 1: Submarine based Wire antenna

Second type of antenna which is the towed buoy or “swimming fish” antenna. It can be used for underwater reception of HF, MF, LF and VLF signals. The towed buoy antenna consists of a buoyant, stream lined, submersible housing, which contains a very sensitive Omni directional antenna. The disadvantage of this “towed buoy” antenna is limited frequency range of reception and cannot be used for transmission. For suppose if it is used for transmission, it requires a very powerful transmitters. Third type of antenna is the multifunction of mast mounted antenna. It is used to carry information by raising the antenna above the surface of the Submarine. The multifunction of mast mounted antenna is needed for high speed connectivity with Satellites, air and surface orbits as well as land stations. This mast consists of various antennas and provides the RF Communication for the Submarine to cover the VLF, MF/HF, VHF, UHF frequency bands with GPS and IFF functions. To improve the performance of the various antennas, located in the Submarine mast, the bandwidth has to increase their antennas to support multiple RF frequency bands or the Gain has to increase their antennas to support high data rates. The following figure2 shows the Submarine based multifunction of mast mounted antennas



Figure 2: Submarine based multifunction of mast mounted antennas

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### IV. TYPES OF ANTENNAS WITH FREQUENCY RANGES COVERED

Year	Antenna Used	Frequency Band
1952	Wire Antenna[5]	VLF
1952	The Magnetic dipole antenna[6]	VLF
1953	Hertzian Dipole[7]	VLF
1957	Loop antenna[8]	VLF
1958	Horizontal electric and magnetic dipole antennas [9]	VLF
1959	Mast antenna (Combined HF-UHF-IF assembly) [10]	HF-UHF-IF
1963	Loop, dipole and long wire antennas [15]	LF/VLF
1971	Short bar dipole and a series of insulated antennas[18]	HF
1972	Trailed Electrode pair antenna[19]	ELF
1973	Dipole antenna[21]	100KHz & 14MHz
1974	Single Horizontal Wire Antenna[22]	ELF
1974	Buoyant cable antenna with helical electrodes [23]	ELF
1974	Vertically polarized E-field antenna [24]	ELF
1976	Dipole Antennas and Travelling Wave Antennas [29]	VHF
1977	Horizontal wire antenna [30]	ELF
1977	Squid antenna [31]	ELF
1979	Fully assembled Buoyant module and original design slotted antenna cylinder [32]	VHF
1984	Long vertical wire antenna [36]	ULF/ELF
1993	Trailing Buoy Type of Antennas [39]	VLF
1996	Wire antenna [41]	VLF
1997	Long horizontal wire antenna [42]	VLF
1997	Horizontal trailing wire antenna [43]	VLF
2003	Wire antenna [49]	VLF
2004	Loop, multiple loop, dipole and folded dipole antennas [50]	1MHz to 66MHz
2004	Buoyant cable antenna and UHF Spoke antenna[52]	VLF, ELF and UHF
2005	Sectorial Loop Antennas [56]	UWB
2008	Wide Band Monopole Antennas[58]	2GHz to 6GHz
2008	Hi-Q Antenna [59]	HF
2009	Horizontal electric dipole [63]	ELF
2009	Super conductor antenna [65]	ELF
2009	Parallel Wire Antennas[66]	ELF
2009	Rectangular DR Antenna [68]	150MHz to 300MHz
2009	Bi conical antenna[69]	100MHz to 1GHz
2009	Circular loop & Bow-tie antennas [70]	100MHz to 1GHz
2011	loop antenna and vibrator antenna[72]	10MHz
2011	Preliminary Prototype antenna[73]	UHF
2011	Wire antenna with different materials[75]	VLF



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2013	Planner Antennas[77]	UWB
2013	Bow-Tie Antenna[79]	433MHz
2013	DAR antenna and loop antenna[80]	HF
2014	loop antenna[81]	HF
2014	small loop antenna[84]	HF
2015	Different types of Bow-Tie Antennas[85]	HF
2015	Micro strip patch antenna[86]	UHF
2015	Bow-Tie Antenna[87]	2.4GHz to 5.1GHz
2015	small wire antenna[88]	SLF and ELF
2015	Spiral Antennas[89]	300MHz
2016	Monopole antenna[90]	VHF

### V. EM WAVE PROPAGATION IN AIR AND SEA WATER

EM wave in water is different than in the air because of water has high dielectric constant and attenuation. Due to high attenuation, there is a limitation on the transmission distance, which causes variation of the impedance of the antenna. Moreover changes in the return loss will also affect the propagation of EM wave in water. There is an inter relation between frequency, attenuation and propagation distance. If the frequency increases, the attenuation will also increase and the propagation distance decreases, so that water is a better conductor at lower frequencies. The velocity of EM wave in any medium is given by the equation  $v = 1/\sqrt{\mu\epsilon}$ , where  $v$  is the speed of EM wave,  $\mu$  is the permeability and  $\epsilon$  is the permittivity. The velocity of EM wave in air or free space is given by  $v = 3 \times 10^8$  m/sec. The intrinsic impedance of any medium is given by the equation  $\eta = \sqrt{\frac{jw\mu}{\sigma + jw\epsilon}}$ , where  $\mu$  is the permeability,  $\epsilon$  is the permittivity,  $w$  is the frequency and  $\sigma$  is the conductivity. The intrinsic impedance for air or free space can be obtained by considering  $\sigma = 0$  and it is 377ohms. Seawater is a good conductor so that it has very high conductivity. The propagation constant is a main factor that determines the changes in an EM wave as it propagates in a given direction. For good conductor  $\alpha$  and  $\beta$  are equal. The impedance decreases with the conductivity, but increases with the frequency. The speed of EM wave in water is about 9 times lower than in air or free space. The intrinsic impedance for pure water is 42Ω. The conductivity of water is dependent on its concentration of dissolved salts and other chemical species which tend to ionize the solution. The conductivity for the pure water is low and depends on the temperature. The typical values of water conductivity are ultra-pure water: 5.5 X10-6 S/m, Distilled water: 0.001S/m, Drinking water: 0.005 -0.05 s/m, Sea water: 4-5.3s/m, Great salt Lake, USA: 15.8 s/m. The relative dielectric permittivity of air or free space is 1 and for water is 81. The water has high permittivity and it has significant impact on the EM wave propagation.

### VI. LIMITATIONS ON MAST MOUNTED ANTENNAS

In the mast, there are several antennas to support various bands like L-band, Ku-band and S band [10]. Therefore the space available in the mast is compact and is currently fully utilized by mast mounted structure. The limited space available in the mast will limit the gain and bandwidth of the existing antennas. Due to this limitation, the Submarine's ability will be limited to support high data rate communication or to support the multiple RF frequency bands. The solution for this limitation is to use erectable antennas or radome embedded antennas or multiband antennas or steerable antennas. In this research work, it is proposed to design Multiband antennas for Submarine based Communication. Multiband antenna means that the same antenna is used for multiple frequency bands. By using the multiband Antenna in the mast, the number of antennas located in the mast can be reduced to less number of antennas. Due to the reduction of antennas in the mast, the space will be freed up and it will be used for the other important functions.

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## VII. CURRENT TRENDS INSUBMARINE BASED COMMUNICATION ANTENNAS

Many exotic types of antennas have been developed for the purpose of Submarine based Communication. But the current trend in Submarine based communication is to use wideband antennas to communicate with Satellites, Aero plans and land stations. For this purpose, the selection of antenna is a challenging issue. Wire antennas are commonly used antennas in the field of Submarine based communication. The current trend has made it possible to simulate and analyse the wire antennas having different configurations of interest. Monopole, dipole and helical antennas are few examples of the wire antennas family. A large amount of research work has been done on these antennas for analysis of different parameters like gain, axial ratio, bandwidth and polarization. Helical antennas are suitable for their research work to improve above mentioned parameters since helix offers unique characteristics as compared to monopole / dipole.

Helical antennas have been widely used in a various applications due to their low weight and low profile conformability, easy and cheap realization. Radiation properties of these antennas can be examined with theoretically and experimentally. The wide bandwidth, simplicity, highest directivity and circular polarization of helical beam antenna have made it indispensable for Space Communication. Helical antenna is frequently used for Satellite and Space probe communication. It has particularly applications in Space telemetry at the ground end of the telemetry link with ballistic missiles, satellites at HF and VHF bands. The circular polarization is useful in their applications. Circular polarization is important in Space communication as well as in terrestrial applications because the favourable relations orientation between linearly polarized transmitting and receiving antenna is not guaranteed. Moreover for space applications Faraday rotation through the Ionosphere is generally unpredictable. Magnetized plasma in the ionosphere rotates the direction of linear polarization but has no effect on circular polarization. Due to this reason, it is likely that linear polarized antennas would experience deep signals fades from these effects, making communication unreliable.

Helical antenna can be operated in two modes such as normal mode and axial mode. In Normal mode of radiation, the radiation field is maximum in the direction normal to the helix axis and polarization is circular polarization. Normal mode of radiation is obtained if the dimensions of the helix are small compared with wave length. Because of its small size compared with the wavelength it has low efficiency and narrow bandwidth. In axial mode of radiation, the radiation field is maximum in the end fire direction and the polarization is circular or nearly circular. This mode occurs when the helical circumference and spacing are appreciably of the order of one wavelength. The dimensions of the helix in axial mode are not critical and can be obtained greater bandwidth by changing the dimensions. This end fire axial mode is most practical as it can achieve circular polarization over a wide bandwidth and it is more efficient. Moreover the axial mode helical antenna is suitable for GPS applications. The characteristics of the helical antenna can be varied by controlling the size of the geometrical parameters relative to the wavelength. With regard to the far field, improved performance can be achieved by adding more helix arms and feeding them with the appropriate phase relationships. Adding more arms also reduces the radiation in the back direction.

The helical antenna can be modified into various forms such as Bifilar helical antenna (BHA), Resonant Quadrifilar helical antenna (RQHA), Printed Quadrifilar helical antenna (PQHA) and Counter-wound Quadrifilar helical antenna (CQHA). If the helical antenna consists of a single wire element like an ordinary spring then the helical antenna is called as monofilar helix. If two such springs are intermeshed with their centre lines coincident, then a bifilar helix is obtained. The design parameters of mono filar and bifilar are same. The only difference is the additional arm which is positioned directly opposite to the first filament. The second arm is fed with the same amplitude but with a phase difference of  $180^\circ$ . If the four springs are used with  $90^\circ$  separations, then QHA will be obtained. Different types of helical antenna are used for different applications like Low- Earth Orbit Satellite Communication and Mobile Communication based on their characteristics.

Bifilar and Quadrifilar helical antennas are the most widely proposed antennas in Satellite and Space Communication because of their characteristics such as circular polarization, good axial ratio and wide bandwidth. Backfire Bifilar helical antenna is mostly used for LEO satellite communication. It has advantages such as high efficiency, convenient size at S band and extreme simplicity. This backfire bifilar helical antenna can also be used as a better feed element for parabolic reflector. Resonant QHA is widely used on hand held receivers for GPS and for some Mobile Communication System. The significant advantages of this type of antenna have compact size, cardioids-shaped pattern, excellent circular polarization and high axial ratio. The disadvantage of RQHA is it requires balun and

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quadrature hybrid circuits. Bifilar helix is not a resonant and it does not require quadrature hybrid circuits. The applications of RQHA are portable applications due to its compactness and ease of integration with mobile system. The CQHA helical antenna can be obtained by adding a second set of windings that would be in a sense opposite that of the first as in the QHA. The CQHA is more useful for the Subsurface RADAR applications.

## VIII. CONCLUSION

In this work we have analysed the different types of antennas for Submarine based Communication. It is concluded that a lot of work has been done on Submarine based Underwater antennas, but a little work has been done on Submarine based mast antennas. Moreover, now a day's modern Submarines are required to communicate with Satellites, Aero planes and land stations. So that Bifilar antennas or Quadrifilar antennas are the suitable and they are proposed for Submarine based Communication because of their multiband characteristics. HFSS Software or CST MS Simulation Software will be used for designing Multiband antennas.

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