A Conformable Design of Hemispherical Helical Antenna for Ocean Monitoring

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***Abstract*–Floating wireless sensor networks present unique communication challenges. Monopole and loop antennas have been used in seawater. However, a hemispherical antenna has the advantage of small size, robust and low profile structure with increased efficiency and directivity. This paper presents the design of hemispherical helical antenna which operates at the frequency of about 0.75 GHz - 1.25 GHz and is designed by using High Frequency Structure Simulator (HFSS) software to analyze the antenna parameters. The material combination of copper and lead forms a new composite material and it is used for gain improvement and better electric field distribution. The proposed antenna is intended to radiate in the end fire direction and produces a good circular polarization. The antenna modeling shows a return loss of – 5.3 dB and a maximum gain of above 9dB. This antenna finds application for wireless sensor network, where the antenna can be used in coastal areas.**

***Keywords* – Gain; Directivity; Return loss; End fire direction; Circular polarization.**

I. INTRODUCTION

Antenna was first invented by German physicist Heinrich Hertz in 1888. It is a metallic device which forms an interface between free - space and guiding device. Antennas usually work in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distance.The concept of helical antenna was first introduced by John D. Kraus in 1947. It is a three dimensional structure of which linear and loop antennas are the special cases. It is basically a simple broadband VHF and UHF antenna. It consists of a thick copper wire wound in the form of a screw thread forming a helix.

The helix of a helical antenna combines three different geometric shapes like straight line, circle and a cylinder. It can operate in many modes but the two important modes are normal mode and axial mode. The axial mode of the helical antenna is the most widely used mode to achieve circular polarized waves over extremely wide bandwidth. In general helical antenna is fed with co-axial transmission line in which the central conductor is connected to the helix at the feed point. The benefits of using hemispherical antennas are robust construction, low cost, high directivity, and wide bandwidth [1].

The paper is organized as follows: Section II deals the literature review. Section III describes the design methodology of the proposed antenna. Section IV illustrates with analysis of simulation results. Finally, Section V concludes and summarizes the work.

II. LITERATURE REVIEW

Marine environment systems are vulnerable to the effects of human activities related to industrial, tourist and urban development and it is important to monitor the salinity, conductivity and temperature of the seawater. Monitoring the seawater by an oceanographic research vessel is expensive, time-consuming and has a low resolution both in time and space and hence wireless sensor networks (WSN) based approach is used to improve the access to real time data covering long periods and large geographical areas in [2], [3]. The experiments conducted at ISM band (6.7 MHz, 433 MHz and 2.45 GHz) showed that the propagation through seawater is only possible at 6.7 MHz [4]. A hemispherical helical antenna at 433 MHz was designed for coastal monitoring applications and this antenna can perform efficiently in a partially submerged condition [5]. A planar helical antenna operated at a center frequency (f) of 10 GHz and wide impedance bandwidth with a good circular polarization in the end fire direction was obtained [6]. The size reduction of 5-14 % was achieved at the expense of a slight decrease in gain, front-to-back ratio (≥ 14 dB) and axial ratio. The impedance and radiation pattern at L-band quantified the impact on the quality of the radiation pattern over a bandwidth of 28% [7]. The stepped-width arms with meander feeding network was employed to size reduction and dual-band operation with no significant degradation in radiation gain and pattern and the antenna was suitable for dual-band GPS applications [8]. A five turn hemispherical helical antenna with a stable power gain of 9 dB was obtained and the radiation pattern had large main lobe without any side lobes and found application in mobile satellite communication [9]. A hemispherical antenna of 4.5 number of turns (*N*), 20 mm of radius (*a*) and strip width (*w*) of 2 mm with side fed provided circular polarization and the radiating element replaced with metal strip yielded maximum directivity of 9 dB and it was attractive for high speed wireless communication systems [10]. A low-profile hemispherical helical antenna array with only four elements fed by a simple network produced a gain of 9 dB and a radiation pattern with a side lobe of 20 dB and it was designed for INMARSAT satellite reception [11]. An array configuration of 32 - element with cosine squared pattern provided a maximum array directivity, 92 % efficiency and peak gain of 7-8 dBi [12]. The single branch helical antenna (SBHA) element did not have sufficient power capacity so cavity-backed dual branch helical antenna (DBHA) was presented, it had not only high power capacity but also little mutual coupling [13]. A composite helical - spiral antenna with one turn helix was operated at a center frequency (*f*) of 12.25 GHz and the angle of maximum radiation remain unchanged between 28° and 34° and it was designed for Ku-band operation [14]. By applying quadrifilar arms with a sequential feeding network, the characteristics of antenna was improved with 43 % of size reduction [15]. Compared to the existing system [1-15], the proposed antenna is compact in size and provide high gain and high directivity and radiates in the end fire direction with a good circular polarization.

III. DESIGN METHODOLOGY

A hemispherical antenna is a modified form of spherical helix antenna and it has the advantage of compact size and stable structure. The spacing between the windings is constant. The structure of the helical antenna can be fully defined by the number of turns and the radius of the hemisphere and its resonant frequency is controlled by changing the radius of the sphere. By increasing the number of turns (*N*), the size of the antenna gets reduced at the cost of a decreased bandwidth [16].

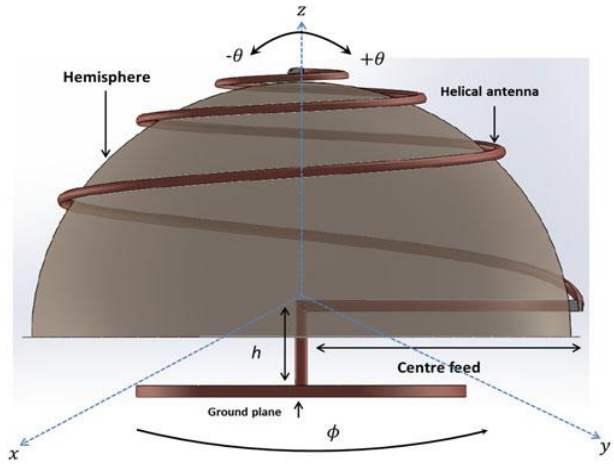

Fig. 1. Geometry of 3.5-turn hemispherical helical antenna.

A three and a half turn hemispherical antenna with a conducting ground plane is shown in above Fig. 1. The geometrical parametric equations that represent the helical wire in spherical coordinates (r, θ, φ) are described by the following equations [9]:

$$r = a,\ \theta = cos^{-1}[\pm(\frac{\phi}{2\pi N} - 1)],\ 2\pi N \leq \phi \geq 4\pi N \qquad (1)$$

where a is the radius of the hemispherical surface encompassing the antenna and N is the number of equally spaced turns of the helix. The "+" and "−" signs represent the right and left hand helix respectively. The radius of hemisphere (*a*) is 9.3 cm and number of turns (*N*) is 3.5. The length of the helical wire (*L*) can be calculated by integrating the following equation: The diameter of the wire is 0.22cm and the diameter of the helix is 18.6cm.

$$L = \int_0^{\pi} a \sqrt{1 + (N\pi)^2 sin^4\ \theta d\theta} \qquad (2)$$

The length of the helical wire (*L*) forming the hemispherical antenna is 105.1 cm and it is defined by the radius of hemisphere and number of turns. If the number of turns is constant, decreasing the radius of the hemisphere would decrease the length of the helical wire, which would tune antenna to a higher resonant frequency. The antenna is made from the composite material of copper and lead. The diameter of the wire (*d*) is 0.22cm and the diameter of the helix (*D*) is 18.6 cm. The coaxial feed has 50 *Ω* characteristic impedance. A center feed is given to the antenna because it brings symmetry from origin.

To design the antenna using HFSS software, it investigates several parameters like number of turns, length of the helix and radius of hemisphere. The design parameters are listed below in Table I.

TABLE I
PARAMETERS OF AN ANTENNA

Parameter	Value
Number of turns of helix (*N*)	3.5 turns
Radius of the hemisphere (*a*)	9.3 cm
Length of helix (*L*)	105.1 cm
Operating frequency (*f*)	0.75-1.25 GHz
Spacing between two turns (*S*)	5 cm
Diameter of helix (*D*)	18.6 cm
Diameter of wire (*d*)	0.22 cm

IV. SIMULATION RESULTS

The hemispherical helical antenna resonates at 1.25 GHz. The results are analyzed in terms of antenna parameters like gain, directivity, return loss and radiation pattern and they are listed below in Table II.

TABLE II
SIMULATED RESULTS

Description	Values
Gain RHCP	9.26 dB
Gain LHCP	9.29 dB
Directivity	8.60 dB
Return Loss	-5.3 dB

The gain of an antenna is a measure of power radiated in a particular direction to the actual power input to the antenna.

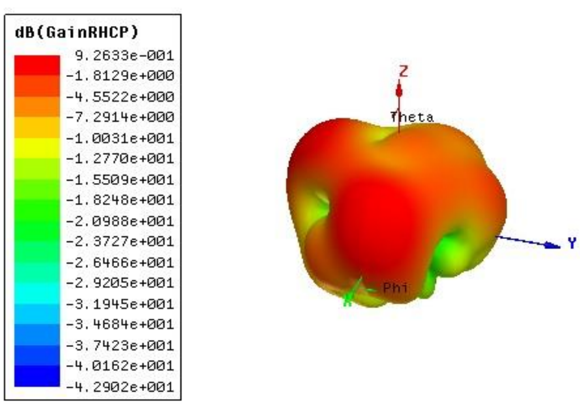

Fig. 2. Simulated Gain RHCP Value

The gain due to Right Hand Circular Polarization (RHCP) is 9.26 dB and Left Hand Circular Polarization (LHCP) is 9.29 dB and it is shown in Fig. 2 and Fig. 3. It is a key performance which combines the antenna's directivity and electrical efficiency.

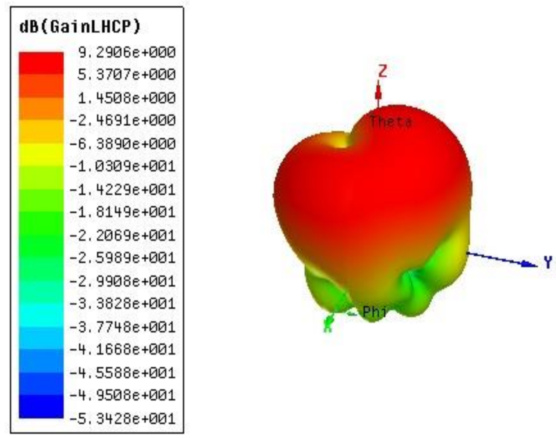

Fig. 3. Simulated Gain LHCP Value

The directivity of an antenna is the ratio of the radiation intensity in a particular direction and the radiation intensity averaged over all directions. The helical antenna has the advantage of high directivity and the simulated directivity value is 8.6 dB and it is shown in Fig. 4.

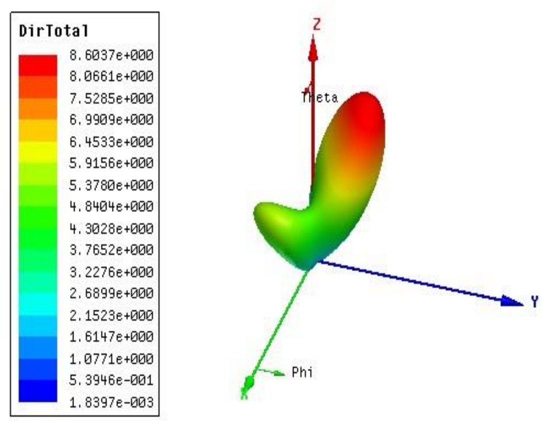

Fig. 4. Simulated Directivity Value

The return loss indicates the proportion of radio waves arriving at the antenna input that are rejected as a ratio against those that are accepted. Reflection coefficient is also known as return loss. The helical antenna has the return loss about -5.3 dB at 1.25 GHz and it is shown in Fig. 5.

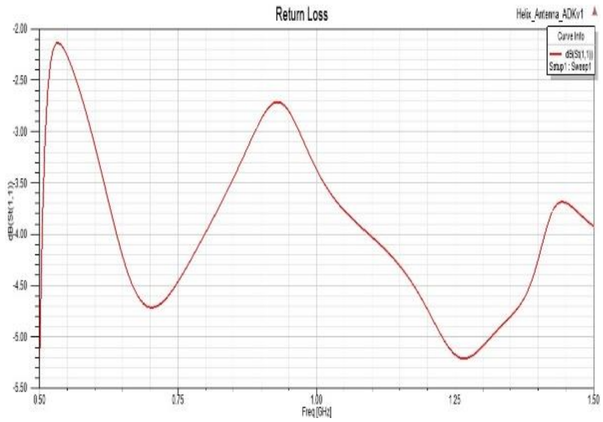

Fig. 5. Simulated Return Loss Value

The radiation pattern indicates the distribution of energy radiated by an antenna in the space. The radiation of the helical antenna is maximum in the end fire direction and it is known as end fire mode or axial mode and it is shown in Fig. 6.

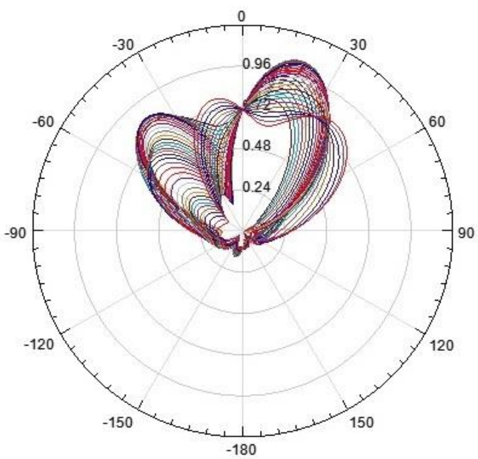

Fig. 6. Radiation Pattern

In this paper, seawater is used as an infinite ground plane and the size of the ground plane influences the radiation characteristics of the antenna. Impedance matching is performed by introducing a small section of wire with length h=32 mm (see Fig.1). By adjusting h, the antenna can be matched to 50 Ω at a desired frequency.

V. CONCLUSION

A new improved hemispherical helical antenna design for ocean monitoring has been presented. The proposed antenna resonates at 1.25 GHz. The main beam (radiation pattern) is oriented towards the end-fire direction achieving a maximum realized gain RHCP of 9.26 dB, gain LHCP of 9.29 dB and directivity of 8.6 dB respectively. The circular polarization property has been improved with end fire mode. Due to the use of a new composite material, the antenna produces a better electric field distribution. In future enhancement, the size of the antenna may be reduced, the number of turns can be increased and gain may be increased which can be frequently used for satellite and space probe communication.

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