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RESEARCH ARTICLE

Design of a very high frequency stretchable inverted conical helical antenna for maritime search and rescue applications

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Abstract
The design of a stretchable inverted conical helical antenna (SICHA) applicable to maritime search and rescue is proposed, and the gain and the reflection coefficient are obtained at a resonant frequency of 156 MHz. The optimized top and bottom diameters of the SICHA are 36 and 18 mm, respectively, and its height is 115 mm, which is much shorter than a quarter-wavelength monopole. Finally, we simulate the outdoor propagation of electromagnetic waves with the SICHA; both the simulated and measured received power intensities are similarly reduced as the distance between the two antennas increases.

KEYWORDS
helical antenna, maritime antennas, maritime wave propagation, search and rescue antennas, VHF antennas

1 | INTRODUCTION

Maritime distress warning systems (MDWSs) and associated communication devices to rescue incident survivors have been proposed,[1,2] and various antennas that can be mounted in these systems have also been developed.[3-5] A flexible and lightweight meander-type wearable antenna that can be attached to a life jacket has been proposed, operating at two target frequencies within the Cospas-Sarsat bands, namely 121.5 and 406 MHz.[3] Elsewhere, a fractal antenna, also attachable to a life jacket, has been reported with consistent performance observed even if the antenna is bent.[4] In addition, an extendable wound antenna has been proposed which is folded in nonemergency situations and stands straight in an emergency.[5] However, these antennas are all relatively large in size and not easily attached to life jackets, often preventing survivors from moving freely. Therefore, it would be especially useful in such applications if a relatively short stretchable antenna could be mounted on life jackets. Coil or helical antennas[6-8] have the spatially efficient advantage of being able to reduce in size and be stored away in small spaces when not required.

In this article, we propose a stretchable inverted conical helical antenna (SICHA) operating in the very high frequency (VHF) band,[9] specifically at 156 MHz. This helical antenna shrinks in normal circumstances and is stretched to the required length for resonance at 156 MHz in an emergency situation. In a conventional helical antenna,[10] the top and bottom diameters of the helix are the same, resulting in low space efficiency when the wire is stacked in nonemergencies. However, when the top and bottom diameters are different, a helical antenna can be contracted without overlapping the wire and, therefore, with higher space efficiency. Furthermore, the reflection coefficient and antenna gain with different diameters are better than those of a conventional helix.

The proposed antenna is made of spring steel with high tensile strength, which allows it to extend to the required length during an emergency. The MDWS module has a function to detect incoming water; when water is detected, the module's cap, normally the lid, is detached and the SICHA is automatically stretched by assuming an emergency situation. Finally, we examine the outdoor propagation of electromagnetic waves as a function of the distance between the transmitting and receiving antennas using commercial numerical simulation software, and the results are compared with the measurements, including when the helical antenna is immersed in water.

2 | GEOMETRY AND MEASUREMENT OF THE HELICAL ANTENNA

To operate an MDWS at the VHF band,[9] an antenna should resonate at around 156 MHz. For this, well-known fundamental types of monopole or dipole antenna could be suggested. However, if a monopole or dipole antenna is employed in this system, it becomes too large to fit on a life jacket. Alternatively, a smaller helical antenna, while slightly reducing gain, could be compressed and shrunk to an even smaller size outside of emergency situations; spatial efficiency is improved. Figure 1A,B illustrates the conceptual geometries of the proposed SICHA that could be applied in an MDWS to find maritime survivors. The proposed SICHA shrinks in normal circumstances and is stretched to the length required for resonance at 156 MHz in an emergency situation.

When the upper and lower diameters are equal, the wire of the retracted helical antenna overlaps which causes low space efficiency for mounting it on life jackets. Therefore, the proposed upper and lower diameters of the helical antenna are different so that the SICHA can be easily contracted without overlapping the wire to provide better spatial efficiency. As described in Figure 1A, the upper (D_t) and lower (D_b) diameters are optimally configured at 36 and 18 mm, respectively; the number of helix turns is 8.3. The height (h) of the SICHA is 115 mm, and the height of the support fixture (p) is 10 mm. The ground plane of the perfectly electric conductor is square, and the length (G) of one side is 135 mm. The SICHA is made of nickel-plated spring steel to prevent corrosion by seawater and improve soldering efficiency. The conductivities of the spring steel and nickel are 1.5×10^7 and 1.4×10^7, respectively, therefore the effective conductivity of the SICHA can be assumed to be 1.45×10^7. We have simulated and designed the SICHA by sweeping parameters such as D_t, D_b, h, and the number of turns to resonate at 156 MHz where the FEKO commercial software[11] is used. Figure 1C shows the fabricated SICHA using optimized design parameters. The simulated and measured results for reflection coefficient and boresight gain are investigated in order to verify the performance of the proposed SICHA. At 156 MHz, the simulated and measured reflection coefficients in Figure 2 are −5.90 and −11.19 dB, respectively; the resonant frequencies are almost the same. Figure 3 presents the measured and simulated boresight gains at 156 MHz of −3 and −8.5 dBi, respectively, and the overall trends of the two are similar. We have examined the performance degradation when the SICHA is not fully stretched by simulation. When the height of the SICHA is 115 mm, a resonant frequency of 156 MHz

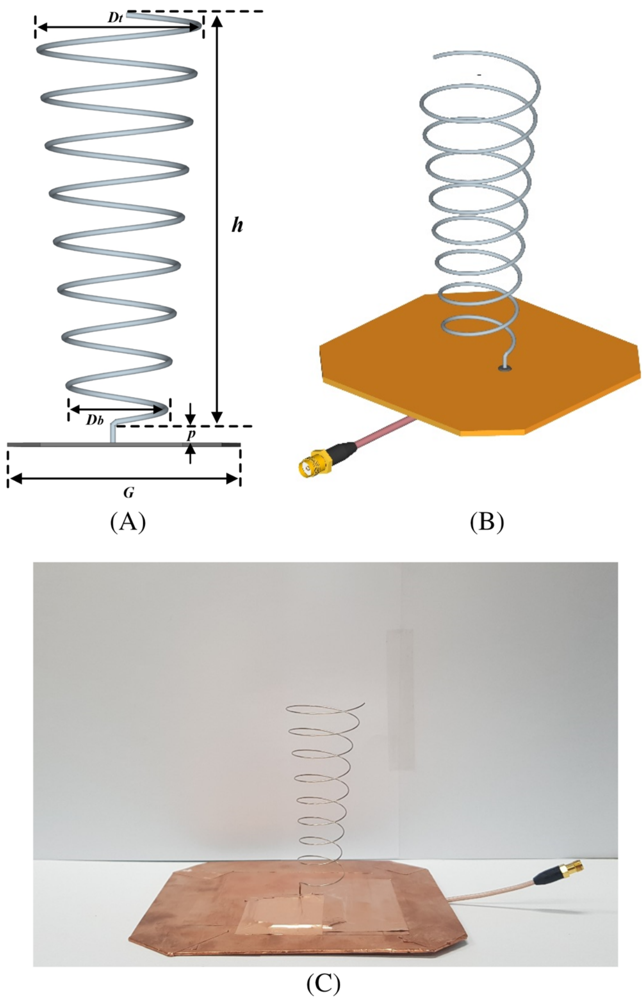

FIGURE 1 Configuration of the proposed SICHA: A, side view; B, perspective view; and C, fabricated antenna. SICHA, stretchable inverted conical helical antenna [Color figure can be viewed at wileyonlinelibrary.com]

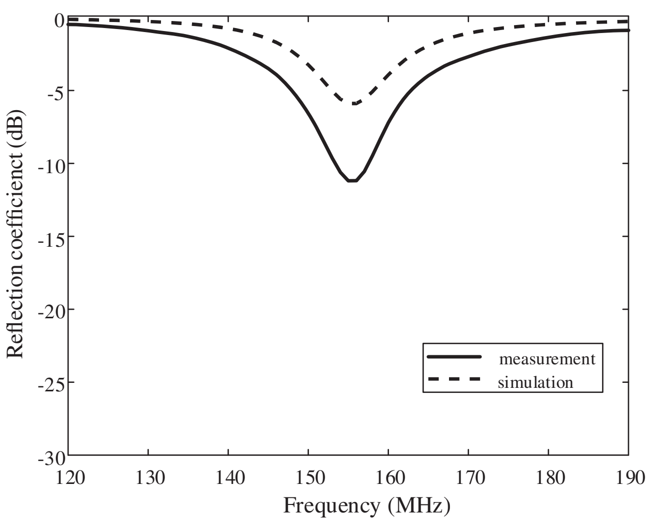

FIGURE 2 Simulated and measured reflection coefficients of the proposed antenna

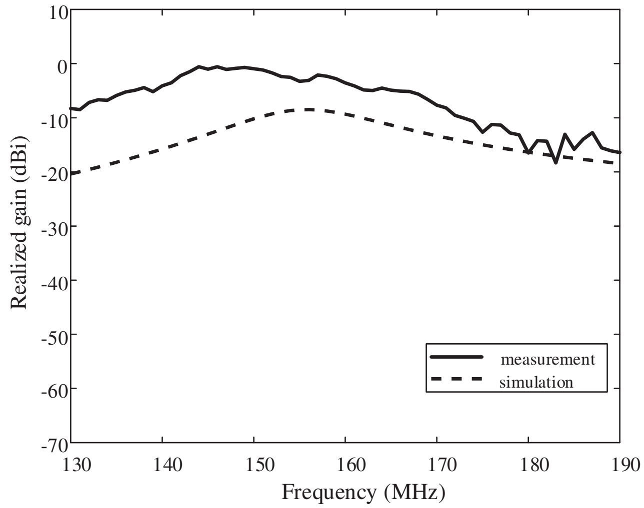

FIGURE 3 Simulated and measured boresight gains of the proposed antenna

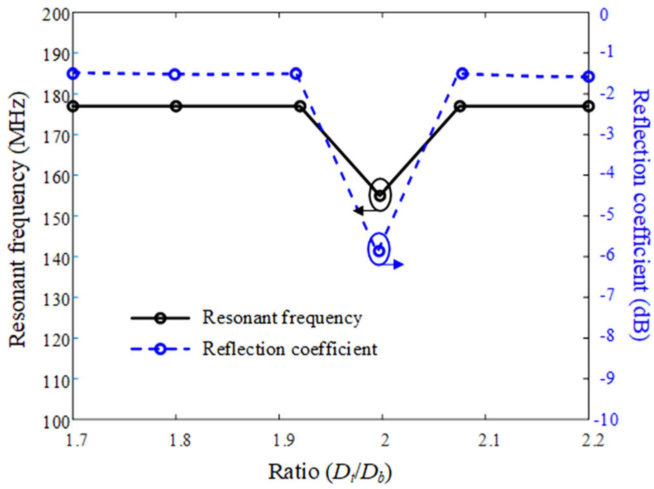

FIGURE 4 Simulated resonant frequencies and reflection coefficients as a function of the ratio of the top diameter (D_t) to the bottom diameter (D_b) of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

is obtained. However, the resonant frequency shift and the increase in reflection coefficient were observed as the stretched height of SICHA decreased from the 115 mm.

Figure 4 illustrates the resonant frequencies and their reflection coefficients when the ratio between the SICHA's top (D_t) and bottom (D_b) diameter varies. As previously mentioned, the SICHA can be mounted in a small MDWS module and exhibits high spatial efficiency as well as good radiation characteristics. In the limited space of the module, an optimum D_t:D_b ratio of 2 is obtained, that is D_t and D_b are 36 and 18 mm, respectively, when the sum of D_t and D_b is a constant of 54 mm. From this optimized ratio, the height (h) of the SICHA 115 m is obtained and is much shorter than a quarter-wavelength monopole at 156 MHz (~480 mm).

To compare the figures of merit for the conventional antenna as well as the proposed SICHA, the conventional antenna, where the top and bottom diameters are the same, is simulated. $D_t = D_b = 27$ mm, and the sum of D_t and D_b is restricted to 54 mm as examined in Figure 4. The reflection coefficients of the proposed SICHA ($D_t = 36$ mm and $D_b = 18$ mm) and the conventional helix at 156 MHz are −5.9 and −0.2 dB, respectively. Both antenna gains are −8.5 and −13.9 dBi, respectively. The figures of merit for both antennas are summarized in Table 1.

3 | PROPAGATION SIMULATION CONSIDERING MARITIME ENVIRONMENTS

Subsequently, we simulate and measure the outdoor propagation of electromagnetic waves taking into account the maritime environment on the surface of seawater. It would be best to measure the received power just above actual seawater; however, we performed our experiments on a rooftop with the SICHA slightly immersed in a basin of water. The received power intensities are measured at the receiving antenna as the distance between the transmitting and receiving antennas varies. This outdoor measurement environment can be easily described and simulated using the Wireless InSite electromagnetic propagation simulator.[12] The antenna performances obtained using the FEKO commercial software[11] can be imported into the Wireless InSite software as the input parameters.

Figure 5A shows the MDWS module in which the SICHA is mounted, and Figure 5B shows the module slightly immersed in water to imitate a marine environment and works as a transmitter. Important features of the module are as follows: (a) There is a function to detect water coming into the module. When water is detected, the SICHA is automatically stretched, assuming that the life jacket has fallen into the water. The circuit board, including the antenna feed, has a waterproof function so that degradation of the radiation characteristics is minimized; (b) Since the antenna is made of spring steel with a high tensile strength of about 2000 MPa, it can be packed into the module under normal circumstances by compressing it with a flat lid; (c) The lid of the module is connected to the upper part of the SICHA. In cases of emergency, the lid detaches from the module, and the compressed SICHA is automatically stretched to the required length.

Figure 6 presents the simulated and measured received power intensities based on the equipment in Figure 5 using Wireless InSite simulation software. A simple monopole antenna is used as the transmitting antenna; the proposed SICHA and a monopole antenna are used as receiving antennas in the different experiments. The solid lines in Figure 6 indicate the simulated received power levels for the monopole antenna (blue) and the SICHA (red). As the distance between the transmitting and

TABLE 1 Figures of merit for two helical antennas

Antenna type	D_t (mm)	D_b (mm)	Resonant frequency (MHz)	Reflection coefficient @ 156 MHz	Antenna gain @ 156 MHz
Conventional helix	27	27	176.5	−0.2 dB	−13.9 dBi
Proposed SICHA	36	18	156	−5.9 dB	−8.5 dBi

Abbreviation: SICHA, stretchable inverted conical helical antenna.

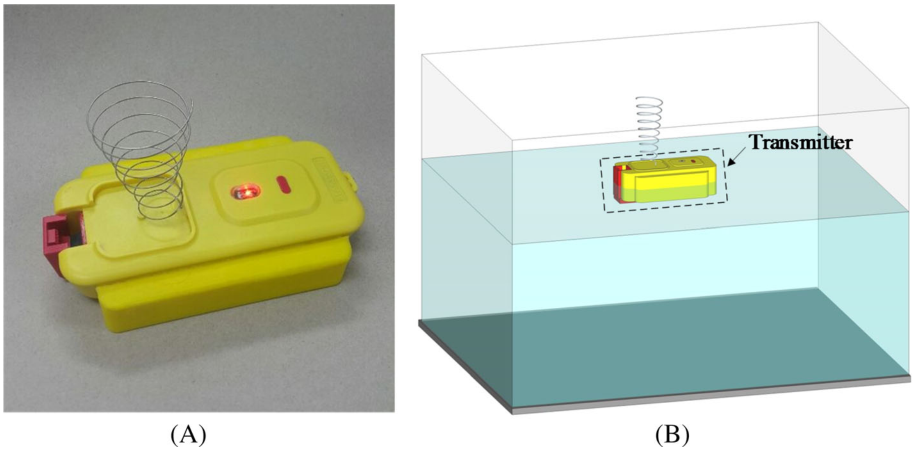

FIGURE 5 A, MDWS module with in-built SICHA. B, Illustration of measurement environment. MDWS, maritime distress warning system; SICHA, stretchable inverted conical helical antenna [Color figure can be viewed at wileyonlinelibrary.com]

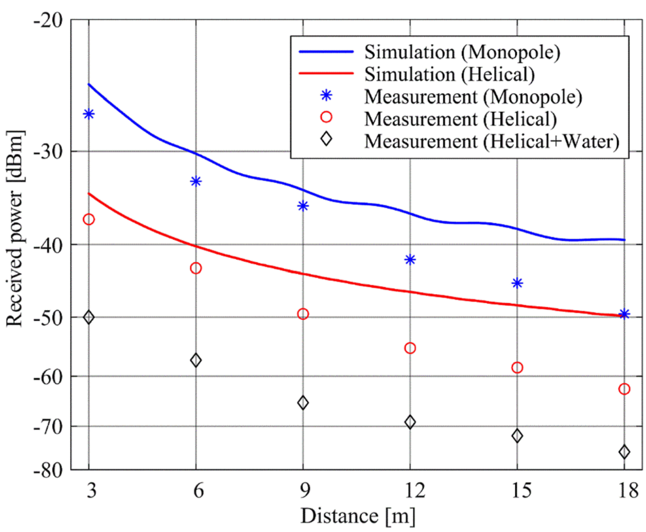

FIGURE 6 Simulated and measured received power, when the receiving antenna is a monopole or the proposed SICHA, vs the distance between the transmitting and receiving antennas. SICHA, stretchable inverted conical helical antenna [Color figure can be viewed at wileyonlinelibrary.com]

receiving antennas increases, the received power intensity decreases. Measured received power levels are also obtained for both the monopole antenna (blue asterisk) and the SICHA (red circle); these also decrease as the distance between the transmitting and receiving antennas increases. The power levels between the simulated and measured results are not exactly the same, but the overall trends are similar. When the receiving SICHA is slightly immersed in water, the received power intensity is reduced by approximately 10 dB compared to the free-space case due to the high attenuation of electromagnetic waves in the water. The measured received power intensities are similar to the simulated ones, with both seen to decrease as the distance between the two antennas increases.

4 | CONCLUSION

This article has proposed the design of a SICHA applicable to maritime search and rescue, and antenna performance was tested by varying the ratio between the top and bottom diameters of the helix. The gain and the reflection coefficient of the antenna were illustrated using commercial electromagnetic simulation software. The fabricated antenna resonated at around 156 MHz, and its performance was verified against the measured results. The optimized top and bottom diameters of the SICHA are 36 and 18 mm, respectively; its height of 115 mm is much shorter than a quarter-wavelength monopole at 156 MHz. Therefore, the proposed SICHA could be mounted in compressed form with good space efficiency for normal circumstances. Finally, we simulated the outdoor propagation of electromagnetic waves by the SICHA in a maritime-like environment; the simulated and measured power intensities similarly decreased as the distance between the two antennas was increased.

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