Stretchable Helical Antenna With an Inverted-F Feeding Structure for Man Overboard Devices

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***Abstract*—This letter proposes a design of a stretchable helical antenna with an inverted-F feeding structure to enhance the impedance matching characteristics and to reduce the size for maritime rescue man overboard (MOB) devices. The proposed antenna consists of a conical-shaped helical body, an inverted-F structure with metal posts and bolts, and a perforated printed circuit board (PCB). To enhance the durability, the metal posts and bolts are employed to tightly fix the helical radiator and the inverted-F feeding structure to the PCB. To verify the proposed antenna, an outdoor propagation test is performed on the MOB device. The results confirm that the proposed antenna with an inverted-F feeding structure is suitable for wireless communications in maritime rescue.**

***Index Terms*—Helical antenna, inverted-F structure, maritime rescue, man overboard (MOB) devices.**

I. Introduction

THE man overboard (MOB) device is a transmitter of the location of survivors in the event of a distress accident, and research is actively being conducted to increase the communication distance. In the event of a distress accident, the MOB devices collect the survivors' location information through a global positioning system and provides such information to the adjacent ships using maritime rescue wireless communications [1]–[3]. The antenna for the maritime rescue wireless communication network is internationally operated in the very high frequency (VHF) band, specifically channel 16 (156.8 MHz), and the VHF antenna with omnidirectional characteristics is requested to transmit signals in all directions around the survivor. Such VHF antenna needs to be installed in the MOB devices, and these devices are typically attached to commercial life jackets. However, the wavelength at 156.8 MHz is about 2 m, so a conventional quarter-wavelength monopole would be about 0.5 m, which is too large to be mounted on the MOB devices. In addition, as the VHF antenna needs to operate well even when the MOB devices are slightly submerged in seawater, both the feeding circuit board and the antenna must be waterproof from the outside. Therefore, the MOB devices and antenna should be designed to prevent corrosion from the seawater. To overcome these issues, extensive efforts have been made to reduce the antenna size and to make the antenna more durable. There have been previous studies on the VHF antenna for MOB devices such as, a printed helical antenna applying the meander line technique [4], [5], a hybrid-type antenna with a monopole and a helical body [6], a monopole antenna with a clear acrylic tube [7], and a conical helical antenna with optimized top and bottom diameters [8]. However, these approaches are weak in seawater as they require conducting radiators to be printed on dielectric substrates. In addition, the acrylic tube is too bulky for mounting on a life jacket.

In this letter, we propose a novel stretchable helical antenna with an inverted-F feeding structure for MOB devices operating on channel 16 (156.8 MHz). The stretchable helical radiator can be efficiently inserted in the device, and the inverted-F feeding structure is applied to the proposed antenna for improving the matching characteristics and reducing the antenna size. The inverted-F feeding structure is applied for the first time to the helical antenna with an electrically small 3-D structure. The proposed antenna operates in conjunction with a sensor, so when the MOB device is submerged in seawater, the sensor detects the water and activates the MOB module for communication via channel 16. In addition, the proposed antenna is made of a wire with elastic strength, which can be stretched to a certain height and maintains the antenna performance with a low tolerance. To enhance durability, metal bolts and posts are employed to tightly fix the helical radiator and the inverted-F feeding structure to the printed circuit board (PCB). These metal posts and bolts can be assembled with an external plastic case, making the MOB devices waterproof and corrosion resistant. At this time, one of the metal posts is connected to the feeding line and the other is electrically connected to the PCB ground. To prevent radiator corrosion, the helix wire is coated in a resin that is also water-proof material. Finally, the received powers according to the distance from the receiver near the coastal area are measured using the proposed antenna mounted on the MOB device, and these results are compared with those of a simulation.

II. Antenna Design and Measurement

Fig. 1 shows the geometry of the proposed helical antenna with an inverted-F structure to enhance the impedance matching

Manuscript received June 29, 2021; revised July 30, 2021; accepted August 3, 2021. Date of publication August 10, 2021; date of current version December 20, 2021. This work was supported in part by the Basic Science Research Program through a National Research Foundation of Korea (NRF) grant funded by the Ministry of Education under Grant NRF-2017R1A5A1015596 and in part by an NRF grant funded by the South Korean government under Grant 2015R1A6A1A03031833. *(Corresponding author: Hosung Choo.)*

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Digital Object Identifier 10.1109/LAWP.2021.3103529

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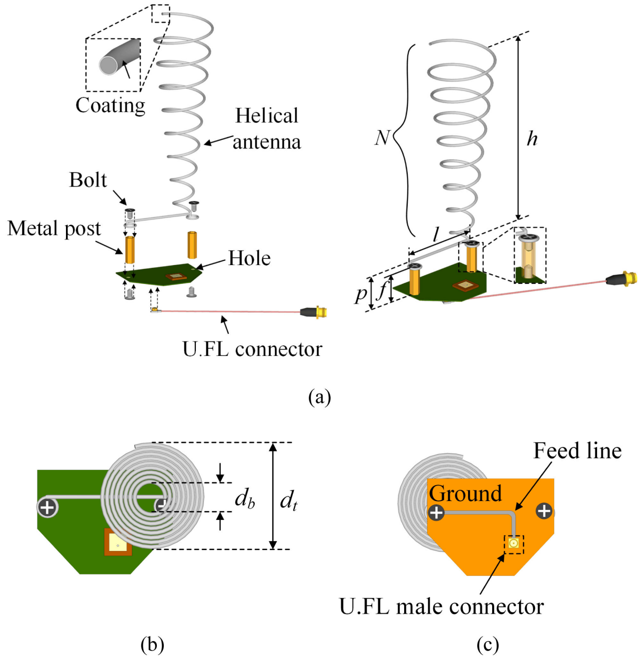

Fig. 1. Geometry of the proposed helical antenna. (a) Isometric view. (b) Top view. (c) Bottom view.

TABLE I
DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Values
h	120 mm
l	41 mm
p	15 mm
f	14 mm
d_b	17 mm
d_t	29 mm
N	9.4

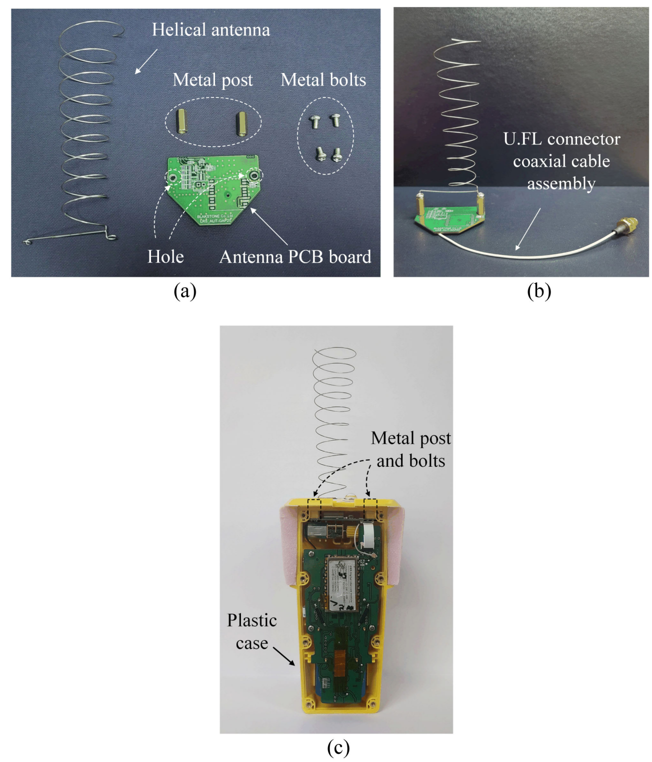

Fig. 2. Photographs of the fabricated antenna. (a) Antenna parts (helical radiator, PCB board, metal posts, and bolts). (b) Proposed antenna with an inverted-F feeding structure. (c) Cross-sectional view of the fully assembled MOB device.

and durability. The proposed antenna consists of a conical-shaped helical body, an inverted-F structure with metal posts and bolts, and a perforated PCB, as shown in Fig. 1(a). The conical-shaped helical antenna is designed to be stretchable so that it can be efficiently inserted into the MOB device. For durability, metal bolts and posts are employed to tightly fix the helical radiator and the inverted-F feeding structure to the PCB. In addition, metal posts and bolts can be assembled with an external plastic case, making the MOB waterproof and corrosion resistant. Fig. 1(b) presents a top view of the proposed antenna with the upper diameter (d_t), lower diameter (d_b), and height (h), which are minimized to be efficiently mounted on the MOB device. The steel wire of the helical antenna body with the turn number (N) is coated with resin to prevent corrosion and to have elasticity for maintaining a constant height. The inverted-F feeding structure has a length (l), which is assembled with two metal posts and four metal bolts. The antenna PCB has two holes, one for connecting the metal posts to the ground and the other for connecting to the feedline, as shown in Fig. 1(c). These metal posts are electrically connected to the PCB through the bolts assembly to increase the antenna's durability, and the inverted-F feeding structure can enhance the impedance matching to miniaturize the antenna. The ultra-small coaxial male-type connector, U.FL series connector (Hirose Electric Co. Ltd., Japan), is located at the feeding point, and the proposed antenna is fed by the U.FL female-type connector coaxial cable assembly. The optimized design parameters are obtained using the FEKO EM simulator [9], and the specific values are listed in Table I.

Fig. 2(a) presents photograph of the fabricated the VHF helical antenna, which consists of the helical antenna body, two metal posts, four metal bolts, an antenna PCB board, and a U.FL connector coaxial cable assembly. The fully assembled antenna is illustrated in Fig. 2(b). The helical antenna and metal posts are connected by metal bolts. These metal bolts are tightened with a screwdriver. The metal posts and bolts can be assembled with an external plastic case to make the MOB waterproof and corrosion resistant.

Fig. 3 shows the simulated and measured bore-sight gains in the VHF band. The measured and simulated gains are represented by the solid and dashed lines. The gain values are −3.2 and −3.6 dBi at 156.8 MHz, respectively. Fig. 4 presents comparisons of the simulated and measured reflection coefficients with similar values of around −12 dB at 156.8 MHz. The proposed antenna performances are compared with the previous study in [8], and a summary of this compassion is listed in Table II. The antenna performance is improved by the inverted-F feeding structure.

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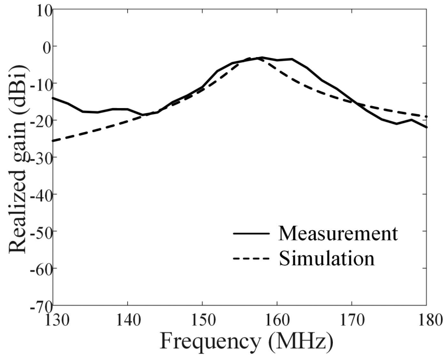

Fig. 3. Simulated and measured bore-sight gains of the proposed antenna.

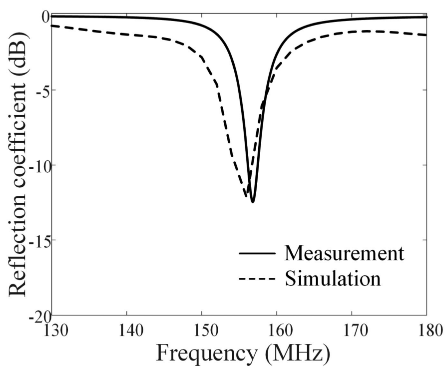

Fig. 4. Simulated and measured reflection coefficients of the proposed antenna.

TABLE II
COMPARISON WITH PREVIOUS RESEARCH

Parameters	[8]	This work
Top diameter (mm)	36	29
Bottom diameter (mm)	18	17
Height (mm)	115	120
Number of turns	8.3	9.4
Bore-sight gain (dBi)	−8.5	−3.2
Reflection coefficient (dB)	−5.9	−12
Resonant frequency (MHz)	156	156.8

III. ANTENNA ANALYSIS AND FIELD TEST

To verify the effect of the inverted-F feeding structure, the helical antenna is modeled as an equivalent lumped element circuit with and without an inverted-F feeding structure, as illustrated in Fig. 5(a) and (b). This equivalent circuit model is developed using a data fitting method by advanced design system [10]–[12]. The equivalent lumped element circuit without an inverted-F feeding structure is shown in Fig. 5(a). A 50 Ω impedance coaxial cable is directly connected to the helical radiator through L_f, which is the metal post (p). The helical radiator is composed of the lumped element series of R_h, L_h, and C_h. The detailed values of the lumped elements are $L_f = 11$ nH, $R_h = 7$ Ω, $L_h = 500$ nH, and $C_h = 2$ pF. On the other side, the

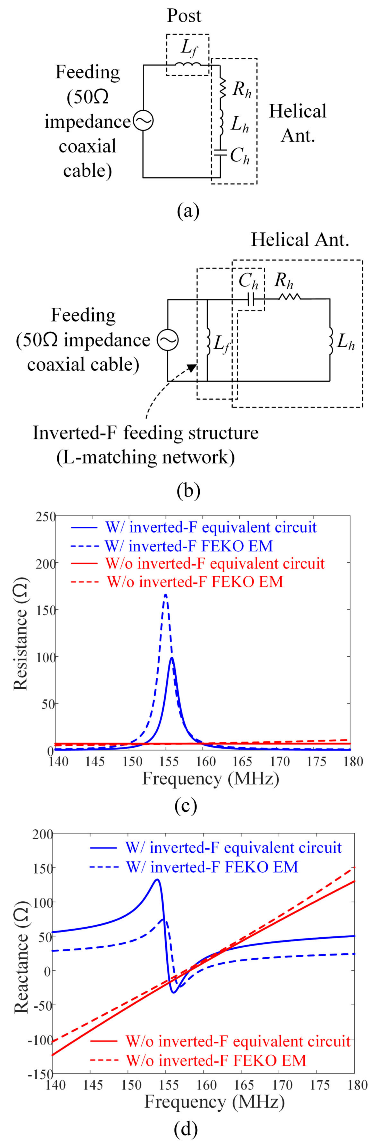

Fig. 5. Equivalent circuit analysis. (a) Equivalent circuit without an inverted-F feeding structure. (b) Equivalent circuit with an inverted-F feeding structure. (c) Comparison of the resistance values. (d) Comparison of the reactance values.

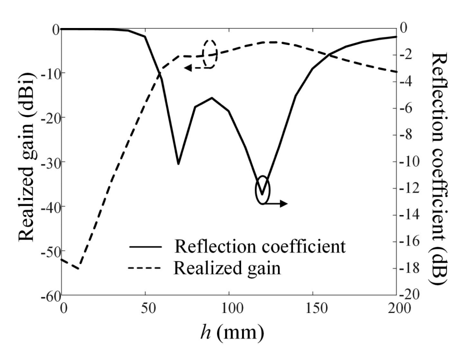

Fig. 6. Simulated realized gain and reflection coefficient according to h.

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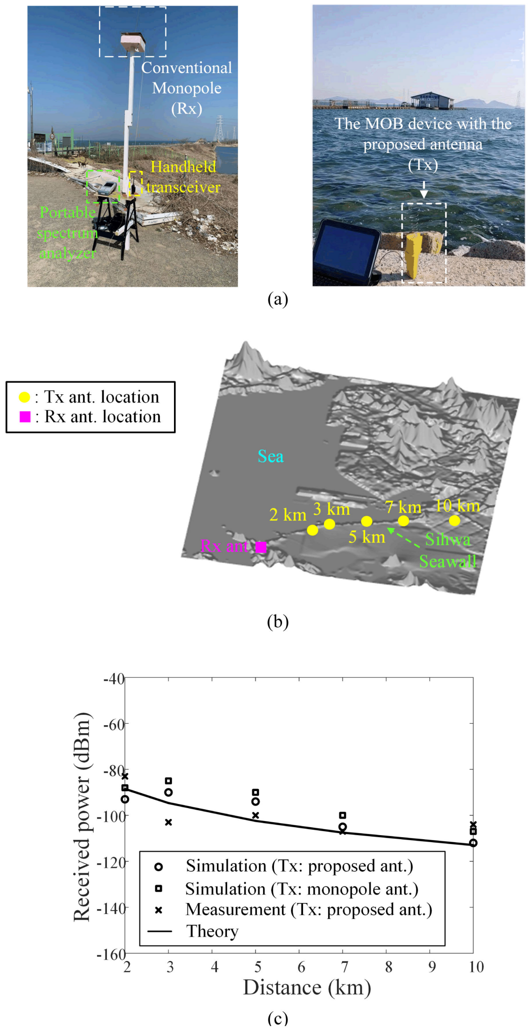

Fig. 7. Proposed antenna field test with MOB device. (a) Tx and Rx antenna set-up. (b) Specific coastal geometry. (c) Comparison data of simulation, measurement, and theory.

equivalent circuit with an inverted-F feeding structure is shown in Fig. 5(b), and the feeding structure can be represented by the additional shunt inductance of L_f (37 nH). This feeding structure operates similarly to a simple L-matching network, which can improve impedance matching characteristics. Fig. 5(c) and (d) presents a comparison of the impedance values, where the blue lines indicate the impedance characteristic of the antenna with an inverted-F feeding structure, and the red lines represents the impedance characteristic of the antenna without an inverted-F feeding structure. Each equivalent circuit is compared with the result of the simulation with the FEKO EM simulation software, and the results show similar tendencies.

Fig. 6 shows the simulated realized gain and reflection coefficient according to the radiator height (h). The optimum h is found at 120 mm, and we observe a drastic change in the antenna performance according to h.

Finally, an outdoor propagation test is performed with the proposed antenna and the MOB device [13]. To measure the received power, a conventional quarter-wavelength monopole antenna is used as the receiving antenna (Rx), and the proposed antenna is applied to the transmitting antenna (Tx) with the MOB device, as shown in Fig. 7(a). The Rx is located 3 m above the ground, and the ROHDE & SCHWARZ FSH4 spectrum analyzer is connected for measuring the received power. Also, the HT644 marine handheld transceiver (Entel, U.K.), operating on the VHF marine band, is utilized to double-check the communication link between the Rx and Tx.

Fig. 7(b) shows the digital elevation data for the measurement site near Sihwa Seawall in Ansan, South Korea, where the Tx and Rx are represented by the circle and rectangle markers, respectively. We measure the received power at 2, 3, 5, 7, and 10 km from the Rx. Fig. 7(c) presents the simulated and measured received power results. The Wireless InSite software [14] is used for the simulation. The digital elevation data is included as the input of Wireless InSite (with the radiation patterns of the proposed antenna and the monopole). The measured and simulated data of the proposed antenna are represented by the "○" and "×" markers, respectively. Also, the solid line indicates the theoretical values from free-space propagation using the ground reflection theory [15]. The average received powers are −99.8, −99.4, and −98.7 dBm. In addition, a simulated data of the conventional monopole antenna are presented by the "□" marker. The average received power is −94 dBm. The results of the proposed antenna show good agreement with the simulated values in terms of received power. The average received power difference between the proposed antenna and the conventional monopole is around 5 dB. However, the proposed antenna is miniaturized a quarter height of the conventional quarter-wavelength monopole. These results verify that the proposed antenna is miniaturized and suitable for MOB devices in maritime rescue wireless communications.

IV. Conclusion

We have investigated the design of a novel stretchable helical antenna with an inverted-F feeding structure to improve the impedance matching characteristics and reduce the size. The proposed antenna consisted of a conical-shaped helical body, an inverted-F structure with metal posts and bolts, and a perforated PCB. The helical body was designed to be stretchable for efficient insertion in the MOB device. For durability, metal bolts and posts were employed to tightly fix the helical radiator and the inverted-F feeding structure to the PCB. The measured and simulated bore-sight gains were −3.2 and −3.6 dBi at 156.8 MHz, respectively. The measured and simulated reflection coefficients were similar values of around −12 dB at 156.8 MHz. We also analyzed the antenna performance to achieve the optimum height. Finally, we compared the received power of the simulation, measurement, and theoretical data near the sea circumstance for the MOB device with the proposed antenna. These results verify that the proposed antenna was suitable for MOB devices in maritime rescue wireless communications.

Acknowledgment

The authors would like to thank the scientists of Blakstone Company Ltd. for providing invaluable measurement guidance as well as the device.

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