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An Improved RHCP Archimedean Spiral Antenna for Glacial Environmental Sensor Networks

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***Abstract*— An improved version of a printed RHCP Archimedean spiral antenna for glacial environmental sensor networks is presented. Two changes have been made to the previous design. Firstly, the microstrip connections between the balun and the antenna arms have been tapered. Secondly, the antenna arms have been rounded at the edges towards the antenna boundary. These measures have improved the antenna performance in the following ways. Firstly, the signal quality has been improved by minimizing reflections and signal distortion. Secondly, the microstrip tapering between the balun and the antenna arms has increased the radiating surface area in the region. Resultantly, significant improvements in the antenna's reflection coefficient, gain, total efficiency, and axial ratio have been observed.**

***Keywords*— Archimedean, printed spiral antenna, glacial, surface receiver, rounding edges, tapering, improvements**

I. Introduction

Increasing global warming and catastrophes like tsunamis and storms in the past few decades have attracted research on glaciers. Primarily, environmental sensor networks (ESNs) and radars have been used to monitor glaciers and develop predictive models. ESNs usually involve deploying sensor probes in boreholes, which periodically send sensor data wirelessly to surface receivers. The antennas used in englacial sensor probes and with surface receivers must fulfil the criteria for the respective project. Previously, a right hand circularly polarized (RHCP) Archimedean spiral antenna ver. 1 was developed for use with surface receivers to receive sensor data from englacial probes deployed up to a depth of 2300 m at the Thwaites glacier, Antarctica. Following are the novel contributions of this paper: (1) an improved printed RHCP Archimedean spiral antenna ver. 2 operating in the 433 MHz band for glacial ESNs with communication ranges up to 2300 m has been developed, (2) notable improvements in |S11|, gain, total efficiency, and axial ratio have been achieved. The related works [1], [2], and [3] used helical, Yagi, non-printed cross dipole, or log periodic dipole array antennas with surface receivers and did not assess printed spiral antennas for the application. Secondly, the previous works [1] - [3] achieved communication ranges up to only 86 m in the 433 MHz band, while longer ranges up to 2500 m were achieved at lower frequencies like 30 MHz, 151.6 MHz, and 173.25 MHz.

II. Antenna Design

The ver. 1 and 2 antennas are shown in Fig. 1. The two designs are the same except for the following two modifications: (1) the antenna arms have been tapered where they connect to the balun in the center in ver. 2. In ver. 1, a 143 µm wide 150 Ω line (calculated at 433 MHz) connects the antenna arms to the balun IC, (2) the antenna arms have been rounded at the edges towards the antenna boundary in ver. 2 compared to sharp edges in ver. 1. The modifications have firstly improved the signal quality by minimizing reflections and signal distortion caused by sharp edges. Secondly, tapering the arms near the center has increased the antenna's radiating surface area in the near-center region. This has increased the current density here and improved the associated antenna gain. The common features include the following: (1) this is an Archimedean antenna printed on FR-4 substrate ($\varepsilon_r = 4.3, tan\ \delta = 0.025$) with the arm width W and gap G equal which should ideally render a frequency independent input impedance of 188.5 Ω in line with Babinet's principle, (2) a 1:3 RF transformer NCS-72+ balun IC from Mini-circuits ® has been used to convert the unbalanced 50 Ω feed line to a 150 Ω balanced line and achieve an adequate impedance match with the antenna having a measured input impedance of 160 ± 10 Ω in the 250-760 MHz range, (3) a $\lambda/4$ reflector measuring $0.75\lambda\ x\ 0.75\lambda$ has been used to make the antenna radiation pattern unidirectional. The operating range of NCS-72+ is 250-760 MHz truncating the overall antenna response to this range. With an ideal balun, the antenna could work between the frequencies $f_{low} = 2\Pi r_{outer} c$ and $f_{high} = 2\Pi r_{inner} c$ where c is the speed of light and r_{outer} and r_{inner} are the outer and inner radii. The two arms radii can be represented by $r_{arm1i}(\varphi) = B\varphi + b_i$ and $r_{arm2i}(\varphi) = B(\varphi - \Pi) + b_i$ where $B = \frac{2W}{\Pi}$ is the growth rate, φ is the angle in radians, b_i is the initial distance of an arm from the center with the subscript i representing the two edge curves of an arm such that $W = |b_2 - b_1|$. The values of parameters shown in Fig. 1 are provided in Table I.

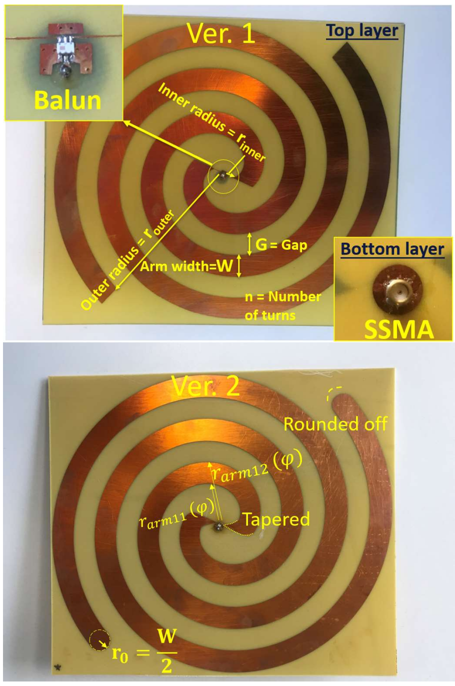


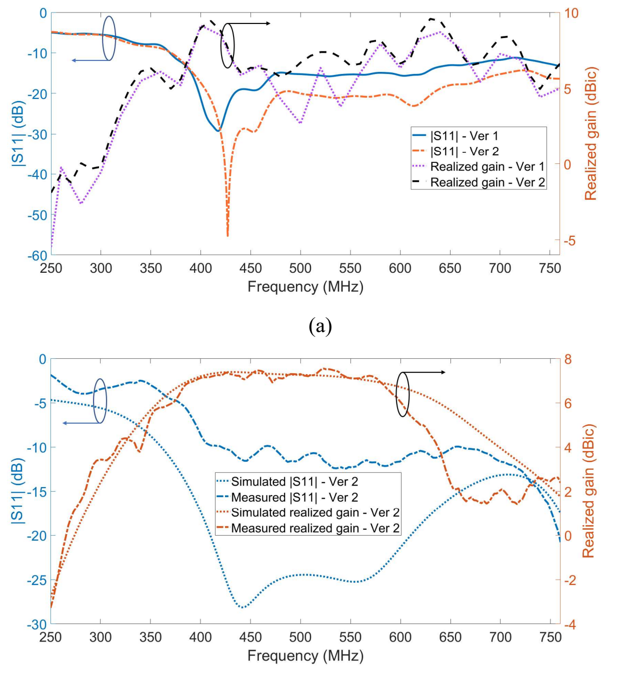
Fig. 1. Versions 1 and 2 of the developed printed spiral antenna.

TABLE I. PARAMETERS OF THE DEVELOPED SPIRAL ANTENNA VER. 2

Parameter	W	G	n	r_{inner}	r_{outer}
Value	1.6 cm	1.6 cm	1.7	0.8 cm	11.68 cm

III. RESULTS AND DISCUSSION

Testing of the spiral antennas ver. 1 and ver. 2 in snow medium was not possible due to limited lab resources, and an alternate test method was adopted. Simulations and experimental measurements were done in free space. A good agreement between free space simulations and experimental results would suggest expecting the antennas to perform in snow in line with the snow simulations. The ver. 2 antenna improved in the following figures of merit (FOM) compared to the ver. 1 antenna: (1) simulated mean |S11| in snow improved from -13.3 dB to -16.8 dB as shown in Fig. 2(a), (2) simulated realized gain of ver. 2 in snow remained > 5 dBic between 340-738 MHz range while ver. 1 gain remained > 5 dBic between 340-470 MHz and 550-738 MHz as can be seen from Fig 2(a), (3) mean simulated total efficiency in snow of ver. 2 antenna improved by 0.35 dB as shown in Fig. 4(a), (4) measured axial ratio of ver. 2 in free space remained below 1.3 dB while ver. 1 axial ratio remained below 1.8 dB also shown in Fig. 4(a). Other FOMs like -10 dB fractional bandwidth (FBW), 3 dB beamwidths from Fig. 3, and co and cross polarizations from Figs. 4(b), 4(c) and 4(d) remained similar for both the versions. A comparison of FOMs for the two antennas is shown in Table II. The FOMs in Table II are based on snow medium simulations except the axial ratio. The measured |S11| and gain of ver. 2 antenna are shown in Fig. 2(b). The measured |S11| though at higher values compared to the simulation has only 9 % less -10 dB FBW. Some differences between the measured and simulated gain between 600-720 MHz are attributed to the Balun IC performing poorly in that range. The free space far field measurements in xz ($\phi = 0^o$) and yz ($\phi = 90^o$) planes shown in Fig. 3 (b) as well as co and cross polarization measurements at 433 MHz in Figs. 4(c) and 4(d) are in good agreement.



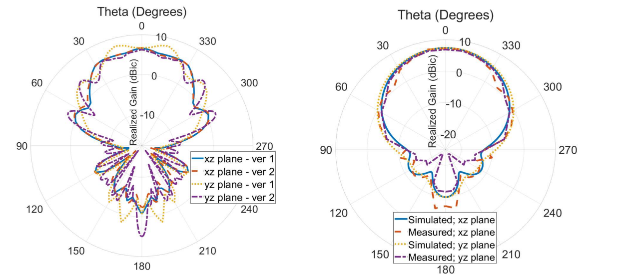
(a)

(b)

Fig. 2. |S11| and gain of ver. 1 and ver. 2 antennas, (a) shows simulated results in snow medium for ver. 1 and ver. 2 antennas, (b) shows the simulated and measured results of ver. 2 antenna in free space.

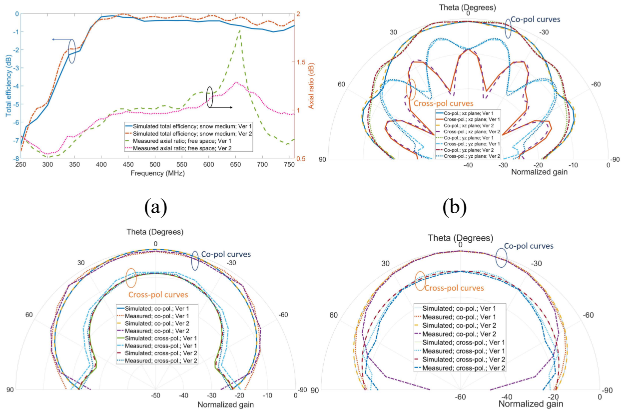
TABLE II. A COMPARISON OF VER. 1 AND VER. 2 ANTENNAS

Figure of Merit	Remarks
Mean |S11|	**Improved** from -13.3 dB to -16.8 dB
- 10 dB FBW	90% (ver. 1 and ver. 2)
> 5 dBic gain bandwidth	340-738 MHz (ver. 2) as opposed to 340-470 MHz, 550- 738 MHz (ver. 1) - **improvement**
3 dB beamwidth	xz plane: 72º (both ver. 2 and ver. 1), yz plane: 50º (ver. 2), 58º (ver. 1)
Mean efficiency	Mean total efficiency of ver. 2 **improved** by 0.35 dB
Axial ratio (free space)	< 1.3 dB (ver. 2), <1.8 dB (ver. 1) over 250-760 MHz range - **improvement**
Co and cross polarization	Co pol. stronger by at least 7.7 dB than cross pol. within a beamwidth of 60º in xz and yz planes (both ver. 1 and ver. 2)



(a) (b)

Fig. 3. (a) Simulated radiation patterns of ver. 1 and 2 antennas at 433 MHz in snow, (b) Simulated and measured radiation patterns of ver. 2 antenna at 433 MHz in free space.



(a) (b)

(c) (d)

Fig. 4. (a) Total efficiencies and axial ratios of ver. 1 and 2 antennas, (b) Simulated co and cross polarizations of ver. 1 and 2 antennas at 433 MHz in snow, (c) and (d) show free space simulated and measured co and cross polarizations of ver. 1 and 2 antennas at 433 MHz in xz and yz planes respectively.

IV. CONCLUSION

An improved RHCP Archimedean printed spiral antenna ver. 2 has been experimentally validated for use with glacier telemetry surface receivers. The newer version antenna offers improvements in |S11|, > 5 dBic gain bandwidth, total efficiency, and axial ratio. While the authors will utilize this antenna in the 433 MHz band, it can be used anywhere in the 340-738 MHz range.

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