Tunable and flexible liquid spiral antennas

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A cylindrical spiral liquid antenna and a tapered helical water antenna are presented. Saline water with a concentration of 3.5% is injected into a flexible tube to form the radiation structure. Thresholds for changes of the radiation direction are calculated to be 0.1 and 0.4 for the ratio between the spiral diameter and the wavelength. Resonance frequency increases when the probe length or the radius of the vertical liquid decreases. The quantity of the water could be changed with the help of a syringe to enable the reconfigurability. Measurement results show fairly good agreements with that simulated.

Introduction: Liquid antennas have drawn lots of attentions due to its features of flexible, reconfigurable etc. [1, 2]. Monopole seawater antenna, half-loop water antenna with pump and water-loaded antenna were developed [3–5]. Though good performance has been obtained, variety of liquid antennas are limited. We design spiral water antennas in this Letter to make more use of its virtues.

Geometry and configurations: A spiral liquid antenna is fabricated by utilising a transparent plastic tube to fix a flexible one around it. Saline water with the concentration of 3.5% serves as the radiation liquid, as shown in Fig. 1*a*. Similarly, a tapered helix liquid antenna could be developed with help of a conical structure, and the liquid can be injected into or sucked out from the thin flexible tube by an injection syringe, as shown in Fig. 1*b*. When confecting solution, balance, thermometer and beaker are necessary, as shown in Fig. 1*c*.

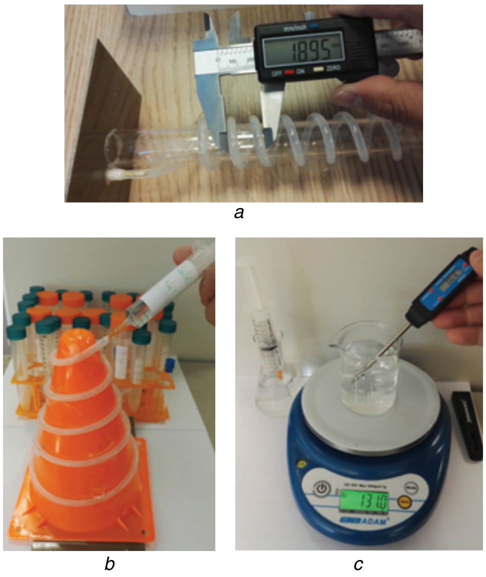

Fig. 1 *Photograph of spiral liquid antennas*
a Photograph of cylindrical spiral liquid antenna
b Photograph of taper spiral antenna
c Making saline water with help of balance and thermometer

Structure of the spiral liquid antenna is shown in Fig. 2*a*. A single-side microstrip substrate with metal layer on the bottom is used together with a coaxial connector to make feeding structure. Outer diameter of the hard transparent tube is 20 mm, and there are totally ten turns of soft tube around it. Distance between the adjacent turns is 18.95 mm. The structure of the taper spiral liquid antenna is shown in Fig. 2*b*. Height of the conical support is 180 mm, consisting of five turns of flexible tube. The inner diameter of the tube to contain the saline water is 3.0 mm for both antennas. Thickness of the substrate is 1.6 mm, and material is Rogers RO4003 with a dielectric permittivity of 3.55.

Results and discussions: The length of the excitation probe of the antenna has a significant impact on the matching performance, as shown in Fig. 3*a*. The reflection coefficients corresponding to the probe length of 2, 5, 8 and 12 mm are presented, respectively. It could be seen that the resonance frequency decreases when the length increases, and the central frequencies are 2.44, 2.12, 1.92 and 1.70 GHz, respectively.

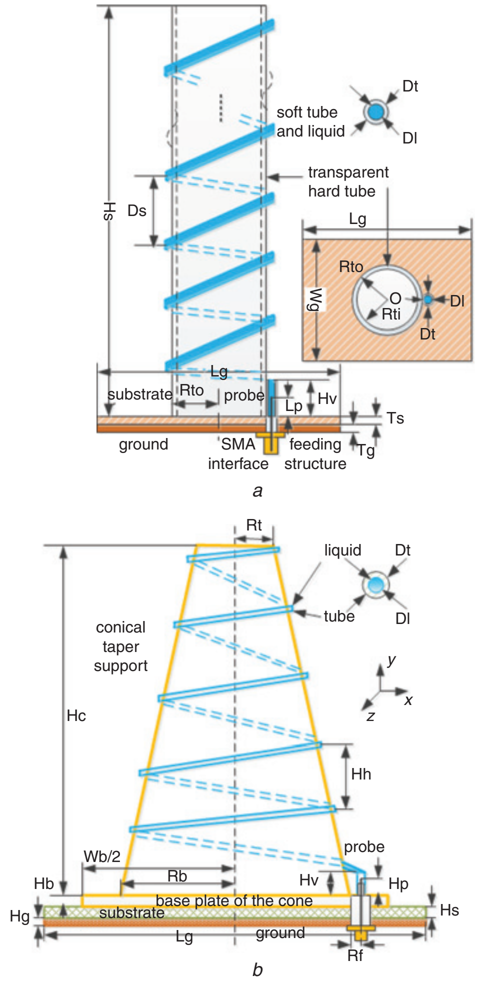

Fig. 2 *Geometry of the two spiral liquid antennas*
a Structure of the spiral liquid antenna
b Structure of the taper spiral liquid antenna

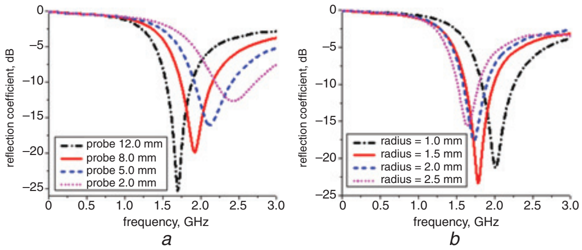

Fig. 3 *Reflection coefficients of the saline water antenna*
a Reflection coefficients (S11) against length of the feeding probe
b Reflection coefficients (S11) against radius of the vertical part

There are both a small vertical part in the two antennas between the feeding probe and the helix liquid turns, and the diameter of it will also influence the reflection coefficient, as shown in Fig. 3*b*. We simulated the S11 of the radius of 1.0, 1.5, 2.0 and 2.5 mm. It could be read from the curves that the frequency shift is to the upper direction when the radius becomes smaller.

It is natural to think about the features of spiral antenna since it is particular for the classical metal one. In addition, it is conclusively similar for the saline water liquid antennas, as shown in Fig. 4, which are the 3D radiation patterns of the non-taper spiral antenna. The main radiation direction varies from the horizontal to the right top and then to the upper front when the ratio between the diameter of the liquid turns and the wavelength rises.

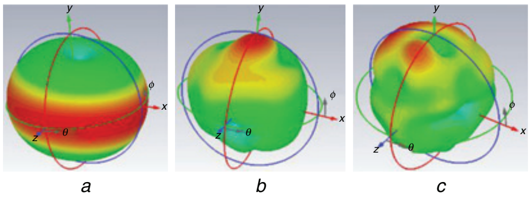

Fig. 4 *3D radiation pattern of different dimensions of the spiral antennas*

a Radiation pattern with small ratio between diameter and wavelength
b Radiation pattern of the antenna with a medium ratio
c Radiation pattern with a large ratio

Though similar in shape and tendency, the concrete values of the thresholds for the three states of the liquid antennas are different from that of the metal antenna, as shown in Table 1. The ratio is ∼0.1 and 0.4 for the saline water of 3.5% at 17.1°C.

Table 1: Radiation parameters of the liquid water spiral antenna versus the ratio of the diameter to the wavelength

Radiation situation	Horizontal omnidirectional	End fire	Sloping up
Diameter (mm)	25	25	25
Frequency range (GHz)	<1.2	1.2–4.8	>4.8
Wavelength range (mm)	>250	62.5–250	<62.5
Ratio (D/λ)	<0.1	0.1–0.4	>0.4
Ratio of metal antenna (D/λ)	<0.18	0.25–0.46	>0.5

The radiation pattern will change if we add or reduce the quantity of the water, as shown in Fig. 5, where the angles are 1440°, 1800°, 1260° and 2520°, respectively. It indicates a characteristic of reconfigurability.

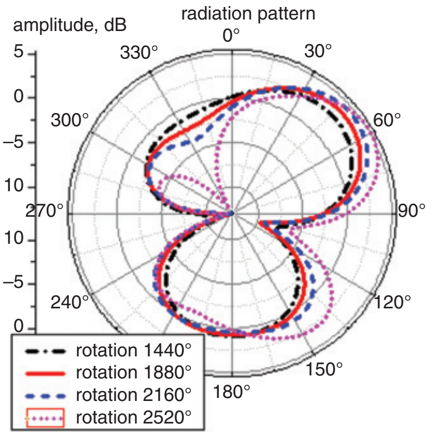

Fig. 5 *Radiation patterns of different rotation angles*

The two kinds of spiral antennas are fabricated and the matching and radiation performance are measured in the anechoic chamber with a vector network analyser, Anritsu 37369A, as shown in Fig. 6.

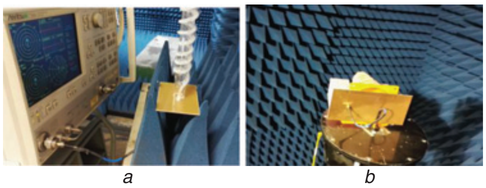

Fig. 6 *Measurement of liquid antennas in anechoic chamber*

a Measurement of reflection coefficients of spiral antenna
b Measurement of radiation patterns of taper spiral liquid antenna

Fig. 7*a* shows the measured reflection coefficients of the taper spiral liquid antenna, and Fig. 7*b* is one of the radiation patterns of it. The return losses of RO4003 with a thickness of 3.0 mm and that of a probe length of 6.5 mm are offered here. The presented radiation patterns are of $\theta = 90°$ and ϕ varies from 0° to 360° at 1.65 GHz, and conversely.

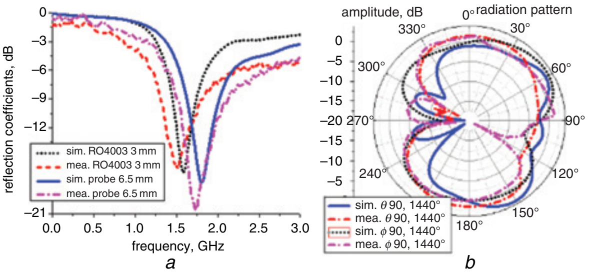

Fig. 7 *Measured and simulated results of taper spiral liquid antenna*

a Measured and simulated reflection coefficients (S11)
b Measured and simulated radiation patterns

Comparisons of the measured and simulated radiation patterns of horizontal and vertical polarisation of the cylindrical antenna at 1.90 GHz are shown in Fig. 8. The points of view are $\theta = 90°$ and ϕ varies from 0° to 360° in Fig. 8*a* and $\phi = 90°$ and θ varies from 0° to 360° in Fig. 8*b*. A reasonable agreement could be seen in each graph.

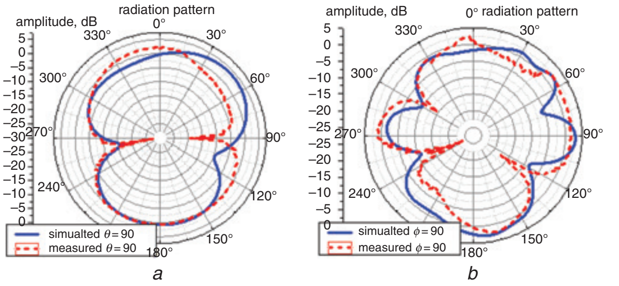

Fig. 8 *Measured and simulated radiation patterns of spiral antenna*

a Radiation pattern of horizontal polarisation
b Radiation pattern of vertical polarisation

Conclusion: Spiral saline water liquid antennas have quite a few design freedoms and could achieve fairly wide operation bandwidths with a potential of reconfigurability, which makes them good tools for various wireless systems.

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