Beam-steering Surface Wave Fluid Antennas

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***Abstract*—This paper proposed to use surface wave fluid antennas to realize beam-steering functionality and spatial diversity. By utilizing the advantage of the non-radiating feature of surface wave propagation, in contrast to the conventional multiple RF input ports approach reported, the proposed design only required one RF input to achieve the spatial diversity. The proposed surface wave fluid antenna is designed to work in the millimeter-wave frequency band from 20 to 26.5 GHz. The preliminary results show that the radiation direction of the antenna can be controlled by changing the position of the fluid metal radiator.**

Keywords — fluid antenna, surface wave, beam-steering

I. INTRODUCTION

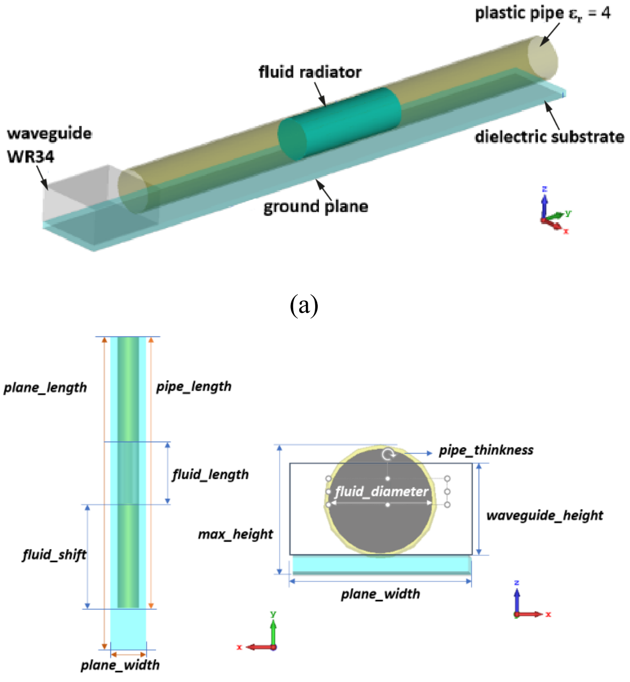
Multiple antenna systems, such as MIMO, have been used in wireless communications for decades [1], particularly in 4G and 5G mobile communications. They provide faster network speed and higher capacity and therefore better user experience [2]. However, it is challenging to integrate multiple antenna system inside mobile devices, such as mobile phones and tablet PCs, as the space available for multiple antennas is very limited [3].

Fluid antenna is an emerging technology for changing the antenna performance in a more flexible way, so that the antenna can be adaptive to the dynamic wireless communications environment [4]. Many works have been reported on frequency and radiation pattern reconfigurable fluid antennas [5]–[8]. The potential benefit of combining fluid antennas with MIMO system is huge. It has been theoretically demonstrated that a single-element fluid antenna system (FAS) with space, as small as half free space wavelength, can achieve the capacity that a multi-antenna maximum ratio combining (MRC) system can provide [9], [10]. However, multiple feeding ports are usually required to achieve the desired spatial diversity.

Surface wave antennas have been investigated extensively as it can be introduced into modern wireless communication device to improve the performance [11]. It can has a low profile and maintains the high performance [12] by increasing the effective area to reduce the beamwidth [13]. It can also been utilized as part of the antenna structure to improve the performance [14].

In this paper, we present our preliminary work in introducing the surface wave concept to simplify the feeding mechanism of FAS design. Therefore only one RF input port is required, without any complicated feeding network by the mean of RF switches or multiple radiating elements, to realize a beam-steering and spatial diversified antenna system.

II. ANTENNA GEOMETRY



(a)

(b)

Fig. 1. The geometry of the surface wave fluid antenna. Dimensions: plane_length = 75 mm; pipe_length = 65 mm; plane_width = 8.6 mm; fluid_diameter = 5 mm, fluid_length = 15 mm; fluid_shift = 25 mm; pipe_thickness = 0.2 mm; waveguide_height = 4.3 mm; max_height = 6.85 mm;

The geometry of the proposed surface wave fluid antenna is shown in Fig. 1. The antenna consists of a ground plane, a piece of dielectric substrate ($\varepsilon_r = 2.2$, thickness = 0.8 mm and $\tan\delta = 0.0009$ at 10 GHz), a circular pipe (epoxy resin, ε_r = 4, thickness = 0.2 mm), a fluidic metal 'Galinstan' radiator (electric conductivity = 3460000 S/m, thermal conductivity = 16.5 W/K/m, material density= 6440 kg/m^3, thermal diffusivity = 8.65578x10^{-6} m^2/s) and a surface wave launcher. The radius and length of the fluid radiator are 2.5 mm and 15 mm respectively. A conventional WR34 rectangular waveguide operates in the frequency band from 17.3 to 34.7 GHz is utilized as the surface wave launcher. The dimensions of the overall antenna structure is 75 × 8.6 × 6.85 mm^3. This is a reasonable size to start with and to show the potential applications of this antenna at the early development stage. CST 2019 was used in performing the simulations.

A micropump can be used to change the position of the Galinstan radiator (fluid_shift). Proof-of-concept experiments have been performed and reported in [4], [5]. Along with the advance of the nano pump technology [15], it is believed that precise and responsive position control of the Galinstan radiator is achievable.

III. OPERATING PRINCIPLE

In the leaky-wave and holographic antennas research area, it is well known that when a surface wave propagating along the dielectric medium is diffracted by metallic geometries, current will be induced on the geometry. The surface wave will then be scattered into the free space [14], [16], [17],. More importantly, the magnitudes and phases of these reflection coefficients could be evaluated mathematically, therefore it is possible to accurately control the main radiation [18]–[20]. To demonstrate the concept, the E-field distribution of the proposed surface wave fluid antenna is depicted in Fig. 2(a). It shows that the fluid radiator scatters the E-field and launches the field in to the free space at the direction θ = 65º (fluid_shift = 25 mm). The E-field distribution of the geometry without the fluid radiator has been provided in Fig. 2(b) for comparison.

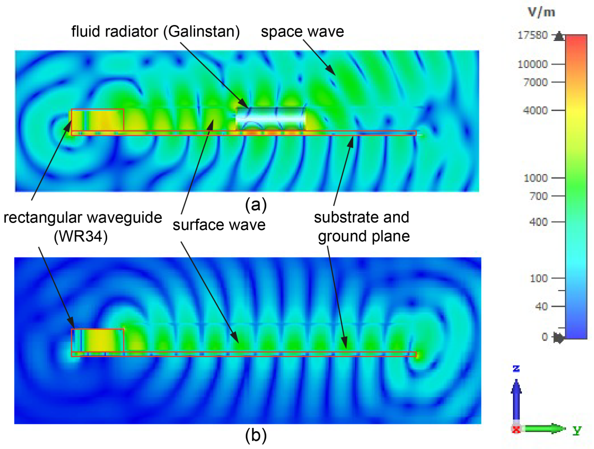


Fig. 2. Comparison of the E field distribution in the case (a) with, and (b) without, the fluid radiator.

IV. SIMULATED RESULTS

The S_{11} of the surface wave fluid antenna at different fluid radiator positions (fluid_shift) between 15 to 28 GHz is illustrated in Fig. 3. It can be observed that the antenna has a working frequency band from 19 to 26.5 GHz for $|S_{11}| < -10$ dB. As a standard rectangular waveguide was used in the model of the early stage, it is expected that the bandwidth of the antenna can be extended if a bespoke surface wave launcher similar to [21], [22] is used in the design.

The realized gains of the surface wave fluid antenna in the yz-plane are shown in Fig. 4(a). To clearly show the beam-steering feature of the surface wave fluid antenna, the radiation pattern of the antenna in the angular range from +30º to +100º was illustrated in Fig. 4(b). The main beam moves from +50º to +73º when the position of the fluid radiator, fluid_shift, varies from 10 mm to 40 mm and the realized gains in between are all above 8 dBi.

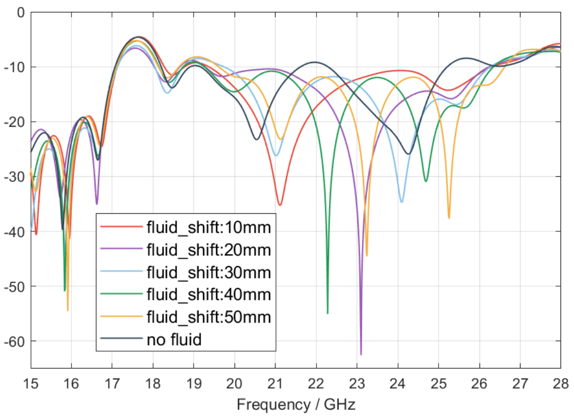
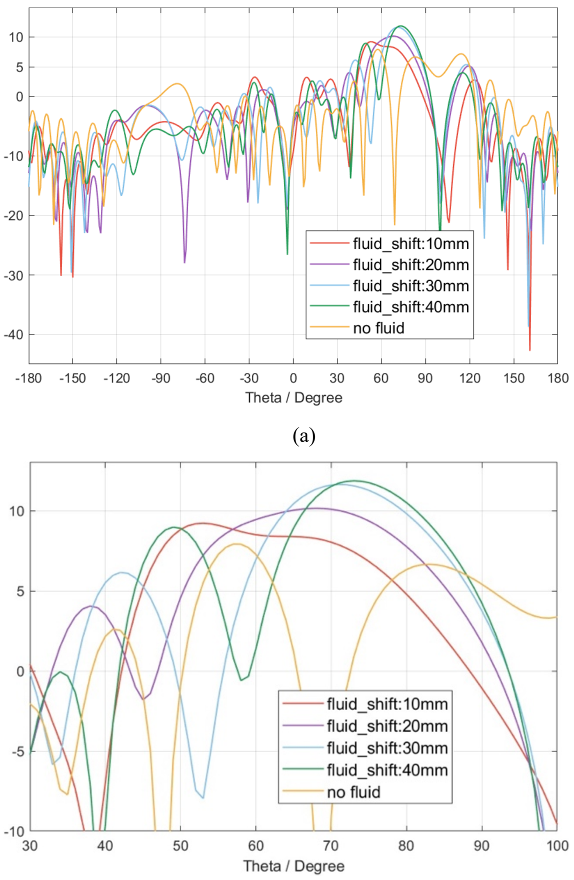


Fig. 3. S11 for the fluid shift from 10 to 50 mm



(a)

(b)

Fig. 4. Realized gains of the proposed surface wave fluid antenna in the yz-plane (a) from -180º to +180º, (b) from -30º to 120º

V. CONCLUSION

A simple beam-steering surface wave fluid antenna concept has been presented. The proposed design uses only one feeding point to achieve spatial diversity. The diversity gain will be evaluated and the results will be presented in the conference together with the experimental results of the fabricated prototypes.

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