Simulation Verification on OTA Characteristics of Surface Wave Propagation System

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***Abstract*—A simulation of the OTA (Over The Air) characteristics of the proposed surface wave propagation system is verified in this paper. The system is designed on a reconfigurable porous surface where cavities are evenly distributed and can be filled with metal posts on demand. To guide the wave to the desired positions, a transmission channel employing two rows of metallic posts is created. While at the desirable position, a specially designed surface wave launcher can launch the wave into free space from the surface to the users. As shown in the simulated results, the attenuation of waves propagating on the surface is much lower than that in the free space, the proposed system can be utilized as a position-flexible radiator as described in fluid antenna systems (FAS). The simulated OTA performance of the system shows excellent characteristics of low propagation loss and high propagation efficiency, making it a good candidate for sixth generation (6G) mobile communications.**

Keywords—High propagation efficiency, Intelligent surface, Low loss, Reconfigurable surface, Surface wave.

I. INTRODUCTION

Many researchers anticipate that the intelligent surfaces will bring a further leap for the sixth generation (6G) mobile communications due to its advantage of low cost and excellent transmission performance [1]. However, the propagation loss in multiple reflections in the free space must be carefully considered in the implementation. Different from the free-space propagation, the E-field strength of surface wave is proportional to the inverse of propagation distance (d), i.e. $|\mathbf{E}(d)| \propto d$, rather than the inverse of square of propagation distance (d^2) [2]. It reveals that employing surface wave technology can enhance the quality of signal propagation [3-5].

Recently, several applications based on the surface wave technology have been proposed, including the network-on-chip (NoC) for core systems [6], wearable devices for on-body networks [5], and costs reduction in industrial environment [7]. The proposal of these intelligent reflecting surfaces has further

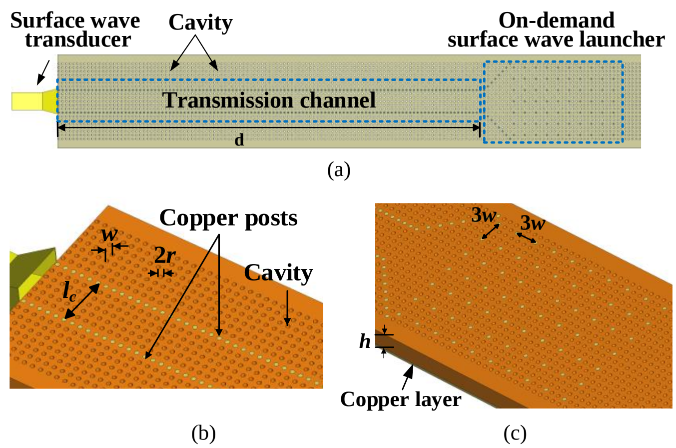


Fig. 1. The proposed porosity-based reconfigurable surface. (a) Top view. (b) Transmission channel, and (c) on-demand surface wave launcher. d = 600, w = 1.2, r = 0.3, h = 3.4, l_c = 7.2 (unit: mm)

promoted the trend of using reconfigurable surface technology for smart wireless communication [8], therefore, the research development of the physical surface which can enable these applications is critical. In [9 - 11], a reconfigurable surface platform is proposed, where the air cavity can be filled with fluid metal or solid metallic conducting posts on demand, allowing the surface wave to propagate along the desired path with a low loss feature. Nevertheless, the surface wave is guided on the reconfigurable platform and not launched to the free space for wireless applications.

Motivated by this demand, a surface wave propagation system with an on-demand surface wave launcher is proposed in this paper. Firstly, by filling two rows of copper posts into the hollow cavities, a low loss and high propagation efficiency surface wave transmission channel is realized. Then, an on-demand surface wave launcher, which is composed of two ±45 degrees lines of 1×8 copper posts and a rectangular grid of 7×10 copper posts, is designed to launch the surface wave to space as described in [12]. Finally, a simulation of OTA (Over The Air) characteristics of surface wave propagation system is set up to compare the performance with free space propagation. The low loss and high propagation efficiency characteristics of the proposed system are then verified.

II. Reconfigurable Surface

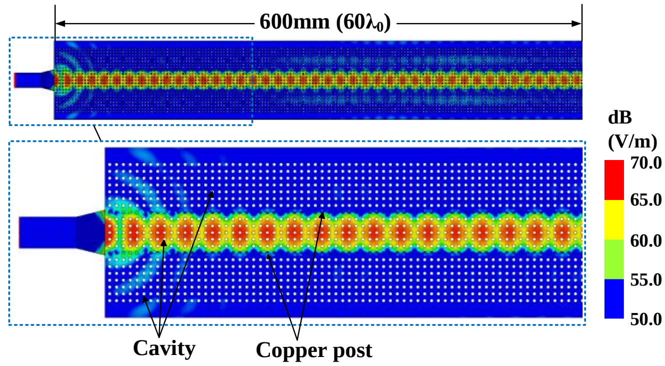
Fig. 1 depicts the structure of the proposed reconfigurable surface, which is formed by a porous dielectric layer (TLY-5, ε_r = 2.2, and tan δ = 0.0009) and a metal ground layer. The dielectric layer is evenly distributed with hollow cylindrical cavities of center-to-center spaced 1.2 mm where metallic posts of 0.3mm radius can be inserted on demand. Therefore, a surface wave transmission channel and an on-demand surface wave launcher can be specifically designed on the reconfigurable surface based on the required operating frequency, radiation directions and gain, as shown in Fig. 1(a). As observed in Fig. 1 (b), the surface wave transmission channel is composed of two rows of copper posts, which concentrates the surface wave within a specific path to realize isolated propagation. In Fig. 1 (c), An on-demand surface wave launcher, which is achieved by the applying of two ±45 degrees lines of 1×8 copper posts and a rectangular grid of 7×10 copper posts, is employed to launch the energy from the dielectric to the free space.

By using these novel structures, a new form of fluid antenna system (FAS) with on-demand surface wave launcher for demonstrating the position-flexible radiation surface technique is designed as an example. The design parameters are provided under the caption of Fig. 1.

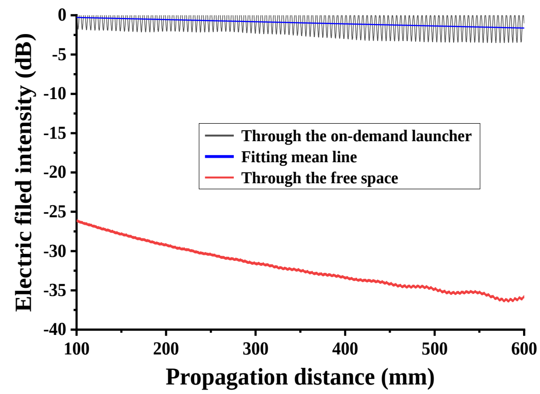
III. Simulated Results

As a complementary technology to traditional space wave propagation, more attention is paid to the propagation characteristics of the surface wave than to the optimization of interface matching in the following discussion. Two conventional rectangular waveguides were used as the transducer to evaluate the performance of the surface wave transmission channel and the on-demand surface wave launcher.

Fig. 2 shows the E-field intensity of the surface wave transmission channel. As observed in Fig. 2 (a), the surface wave is guided inside the channel formed by two rows of copper posts at 30 GHz, while is very weak outside the channel. In Fig. 2(b), the electric field strength over the propagation distance is provided, where the fluctuation is caused by the standing wave reflection and diffraction from the cavities. The fitting mean line reveals that the energy has only dropped 1.6dB at the distance of 60λ_0 through the surface wave transmission channel and surface wave, while the loss through free space is up to 36.4 dB. Obviously, the proposed channel enables the surface wave to arrive at destination in a more concentrated way, achieving a high propagation efficiency and low loss transmission. Fig. 3 provides the simulation results of the on-demand surface wave launcher. reconfigurable surface to free space. It is noticed that the angle of the maximum radiation

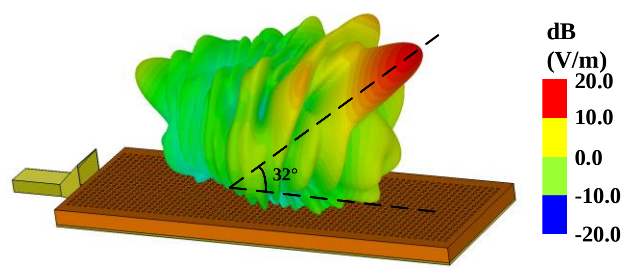


(a)

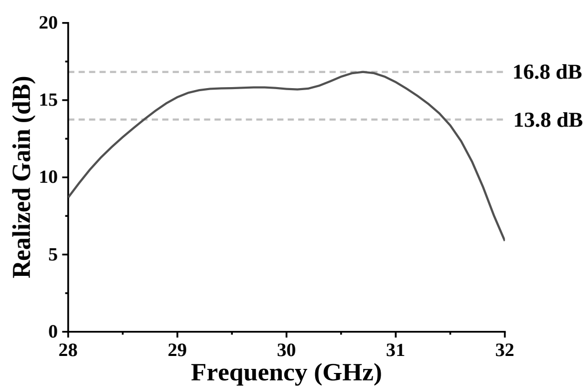


(b)

Fig. 2. The simulation results of the surface wave transmission channel at 30GHz. (a) the electric field distribution, (b) the E-field in dB over propagation distance.



(a)



(b)

Fig. 3. The simulation results of the on-demand surface wave launcher. (a) the radiation pattern at 30GHz, (b) the realized gain.

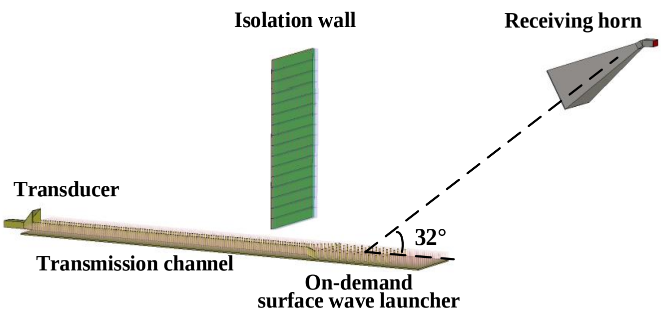
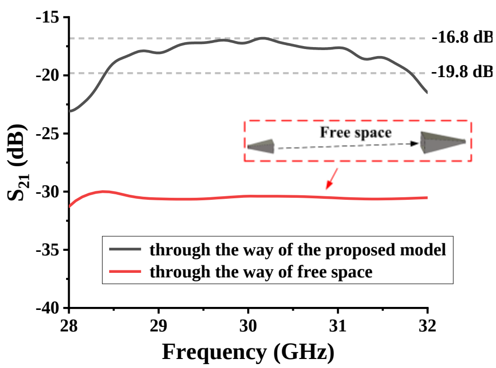


Fig. 4. Simulation setups for the proposed model.

(a)



(b)

Fig. 5. The simulation results. (a) the electric field distribution of the proposed model at 30GHz, (b) the S_{21} with different propagation way.

to the horizontal plane is 32°. This angle can be adjusted by applying different posts configuration to achieve the reconfigurability of beam direction. The peak realized gain of the on-demand surface wave launcher 16.8 dBi and a 3dB gain bandwidth of 9.3% (28.7-31.5GHz) is achieved. These promising features show the potential of the proposed technology and motivate us to further developments in surface wave technology.

As shown in Fig. 4, the surface wave structure and receiving horn are modelled to evaluate overall performance of the system in practical applications. An isolation wall is used to prevent the horn from receiving the direct space wave that is not propagated through the surface, ensuring the accuracy of the evaluation. As depicted in Fig.5 (a), the proposed model maintains the prominent performance of the surface wave transmission channel and the on-demand surface wave launcher. Fig. 5 (b) demonstrates that the proposed model achieves a 3-dB bandwidth of 11.3% (28.4-31.8GHz). Moreover, when compared to the transmission through the free-space way with the same propagation distance and a transmitting horn of similar realized gain as the on-demand surface launcher is used, the proposed model exhibits the advantage of low propagation loss and high propagation efficiency. It is worth mentioning that the proposed system is reciprocal therefore any signal coming from the free space can be received by the on-demand launcher and propagated on the surface. The signal received by the on-demand launcher can be guided to an alternative position for re-radiation which can be used for minimum interference between users making the technology a strong candidate for the next generation mobile communications.

IV. Conclusion

This paper presented a position-flexible radiation surface with a performance of high propagation efficiency and low propagation loss. Due to the attendance of the surface wave transmission channel, the propagation of surface wave is concentrated along the pathway. Meanwhile, to launch the wave out of the surface, an on-demand surface wave launcher is designed. A 3D full simulation model is established to assess the OTA properties of the proposed system, confirming that its characteristics of low propagation loss and high propagation efficiency. Such system can be utilized in the future mobile communications.

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