

Enhancing and Localizing Surface Wave Propagation with Reconfigurable Surfaces

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Abstract—As an attempt to develop a reconfigurable surface architecture that can use liquid metal such as Galinstan to shape surface channels on demand, this paper considers a punctured surface where cavities are evenly distributed and can be filled with liquid metal potentially via digitally controlled pumps. In this paper, we look at the benefits of such architecture in terms of surface-wave signal enhancement and isolation, and examine how various system parameters impact the performance using full wave 3-dimensional electromagnetic simulations. It is shown that extraordinary signal shaping can be obtained.

Keywords—Interference control, Liquid metal, Propagation, Reconfigurable surfaces, Surface waves.

I. INTRODUCTION

Intelligent surfaces are anticipated by many to provide the next leap in 6G mobile communications [1], [2]. While most focused on utilizing surfaces as intelligent passive reflectors, the authors in [3] presented a vision of benefiting from the desirable propagation characteristics of surface waves [4] and creating a smart radio environment. The vision is attractive but only if adaptable surface waves are realizable.

Of particular relevance is the work in [5] where mechanically controlled metal bars were made to appear or disappear to create changeable surface wave pathways. The practicality of the approach in [5] is nonetheless questionable. To address this, [6] proposed to use liquid metal bars to form specific pathways to shape surface waves. Unfortunately, the setup in [6] did not consider the materials for containing the liquid metal or they were assumed to be infinitesimally thin, which was unrealistic or practically unachievable.

In this paper, we propose a punctured surface model, as shown in Fig. 1, where cavities are evenly distributed and can be filled with liquid metal on demand to form specific pathways for surface wave propagation. Surface wave signal localization and enhancement will be investigated.

II. THE PUNCTURED SURFACE MODEL

It was illustrated in [6] that liquid metal structures can be used to form isolated pathways for surface wave propagation but their platform does not readily facilitate implementation since it would be difficult to make the tiny tubes with sub-millimeter thickness. The proposed model in this paper thus opts for a punctured surface where cavities are formed to be filled with liquid metal such as Galinstan to reproduce the ability to shape the transmitted surface waves.

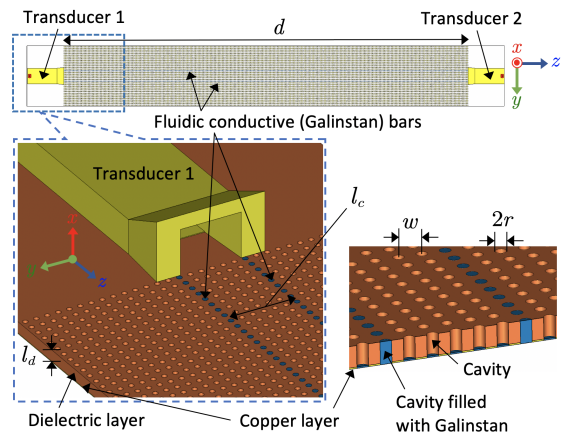


Fig. 1. The punctured surface model with cavities potentially filled with liquid metal, e.g., Galinstan, on demand via digitally controlled pumps.

Specifically, we have the parameters of the model defined in Fig. 1 and their numerical values presented in TABLE I. With a porosity ϕ , the effective relative dielectric constant of the surface can be found as [7]

$$\epsilon_r^{\text{eff}} = \frac{\epsilon_r [1 + 3\epsilon_r + 3\phi(1 - \epsilon_r)]}{1 + 3\epsilon_r + \phi(\epsilon_r - 1)}, \quad (1)$$

where ϵ_r denotes the original relative dielectric constant. In what follows, the surface impedance can be obtained by

$$X_s = 2\pi f \mu_0 \left(\frac{\epsilon_r^{\text{eff}} - 1}{\epsilon_r^{\text{eff}}} l_d + \frac{\Delta}{2} \right), \quad (2)$$

where Δ is the skin depth of the metal sheet, f is the operating frequency, and μ_0 is the permeability of the free space. In our model, we have 4 cavities for every $4\text{mm} \times 4\text{mm}$ space, which gives $\phi = \frac{4\pi(0.5)^2}{4^2} = 19.63\%$. Also, a fixed transducer with height of 2.8mm and width of 9.6mm is used as this paper's focus is on the design of the reconfigurable surface. That said, as in [8], it is possible to choose the dimensions of the transducer more carefully to have the optimal surface impedance with maximum excitation efficiency.

III. SIMULATION RESULTS

Simulations were conducted by CST Studio Suite 2020 and Taconic TLY-5 ($\epsilon_r = 2.2$, $\tan \delta = 0.0009@10\text{GHz}$) was chosen as the dielectric layer and copper (annealed) as the



Fig. 2. The E-field distribution in dB over the surface with $l_c = 12\text{mm}$ and $f = 30\text{GHz}$ when shaping the path with (a) one layer, (b) two layers or (c) three layers of cavities filled with Galinstan.

Parameter	Value
radius of the bar, r	0.5mm
center-to-center separation between bars, w	2mm
thickness of the dielectric layer, l_d	1.6mm
channel propagation distance, d	600mm
channel width, l_c	12, 16, 20mm
operating frequency, f	30, 40GHz
inductive surface impedance, X_s	$j190\Omega$ at 30GHz $j245\Omega$ at 40GHz
dielectric porosity, ϕ	19.63%
dielectric effective relative permittivity, ϵ_r^{eff}	1.94
conductivity for Galinstan, σ_g	$3.46 \times 10^6 \text{ Sm}^{-1}$
conductivity for copper, σ_c	$59.6 \times 10^6 \text{ Sm}^{-1}$

TABLE I
THE PARAMETERS USED IN THE SIMULATIONS.

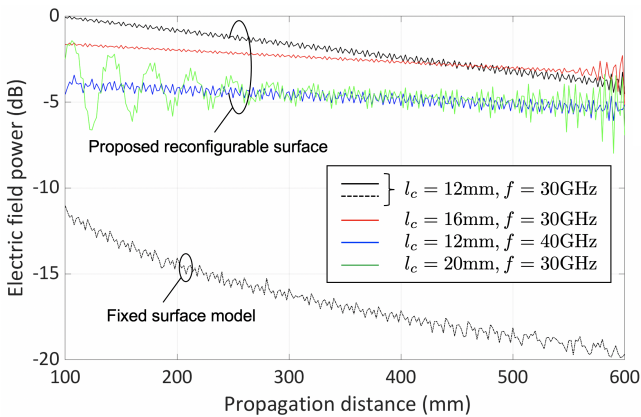


Fig. 3. The E-field in dB over propagation distance.

metal layer. Galinstan with conductivity σ_g was employed as the liquid metal alloy to fill the cavities when needed. Results in Fig. 2 demonstrate the E-field distribution over the surface when a direct path is formed by layers of cavities filled with Galinstan. We can see that the Galinstan layers are able to concentrate the field inside the path and have little leakage outside the path. In particular, there is some 25dB difference of the field strength between inside and outside the path. Additionally, adding more layers of Galinstan filled cavities

can result in better signal localization, suggesting that the proposed reconfigurable surface could be instrumental to the realization of controllable surface waves.

Fig. 3 provides the results of the power over propagation distance. First, we see that the power loss for the proposed surface is much less than the surface with no cavities filled with Galinstan. At a distance of 600mm, a 15dB gain can be obtained using the proposed surface. Results also show that different channel widths and frequencies lead to different performance but the Galinstan filled cavities appear to keep the loss mild. Note that the curves look bumpy as numerous reflections occur when the waves interact with the cavities.

IV. CONCLUSION

This paper proposed a reconfigurable surface platform in which cavities can be filled to form controllable surface wave pathways. The results have demonstrated great promises for enhancement and localization of surface waves.

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