# A Cavity Backed Slot Array with Gravity Controlled Radiation Pattern Using Conductive Liquid

Mehmet Emre Korkmaz and Sema Dumanli
Bogazici University, Istanbul, Türkiye, sema.dumanli@bogazici.edu.tr

***Abstract*—This paper introduces a cavity backed slot antenna array in a spherical distribution that has a constant maximum radiation direction opposing the earth as the spherical array rolls. Two nested conductive spheres constitute the inner and the outer wall of the cavities backing the slots. The side walls are created with shorting pins based on the substrate integrated wave-guide concept. The space between the outer wall and the inner wall is half filled with conductive liquid which is free to move with gravity. The conductive liquid deactivates the slots that face the earth with zero energy consumption. The proposed design operates at the 2.4 GHz ISM band, with a maximum gain of more than 6 dB as the sphere rolls around its local z axis when located horizontally according to the earth surface.**

## I. Introduction

In recent years, the utilization of reconfigurable antennas has been on the rise. Reconfigurable antennas enable coverage of different resonant frequencies or the steering of the main beam. They have the potential to offer improved performance, cost and space reduction. A crucial consideration for reconfigurable antennas is the mechanisms employed for reconfiguration. Typically, switching mechanisms introduce extra circuitry into the design, increasing costs and complexity, potentially impacting the performance [1]. While most common reconfiguration method is electrical, mechanical reconfiguration can be achieved passively which eliminates power loss [2]. In this paper, passive mechanical reconfiguration is aimed which entails no power consumption or external intervention.

Conductive liquids have been used for antenna reconfiguration in two different ways: altering the electrical connections of the antenna and modifying the radiating structure of the antenna [3]. Despite the viability of modifying the radiator structure for reconfiguration, the radiation performance often diminishes due to the limited metallic properties of the conductive liquids [4]. Here the conductive liquid is used for switching hence avoiding the deterioration of radiation performance.

This paper introduces a spherically constructed antenna array comprising two differently sized conductive nested spheres with conductive liquid between them. The concept is to activate the slots oriented against the gravitational force and deactivate the other slots to avoid the radiation towards earth. The shorting mechanism is facilitated by the conductive liquid between the spheres. Therefore, the proposed array undergoes mechanical reconfiguration without any power consumption, as gravity automatically performs the task. This can be useful for various wireless communication and wireless power transfer applications that involves rotation. Wireless sensors located in automobile tires can be given as an example. In order to achieve wireless communication or wireless power transfer for these sensors, a constant radiation pattern as the vehicle moves would be extremely beneficial.

In [5], polarization and frequency reconfiguration is realized for a single antenna using conductive liquid. In [6] beam steering is realized by utilizing the change in center of gravity of the antenna. While antenna rotating up to 360 degrees, changing center of gravity keeps the direction of the radiation pattern against the gravitational force. Here, these ideas are combined to realize pattern reconfiguration with conductive liquid. To the best of the author's knowledge, there is no other work in the literature performing gravity oriented pattern reconfiguration by utilizing conductive liquid.

The paper consists four section. The introduction is followed by Section II where the antenna design is detailed. The antenna performance is discussed in Section III. Lastly, the conclusion is given in Section IV.

## II. Antenna Design

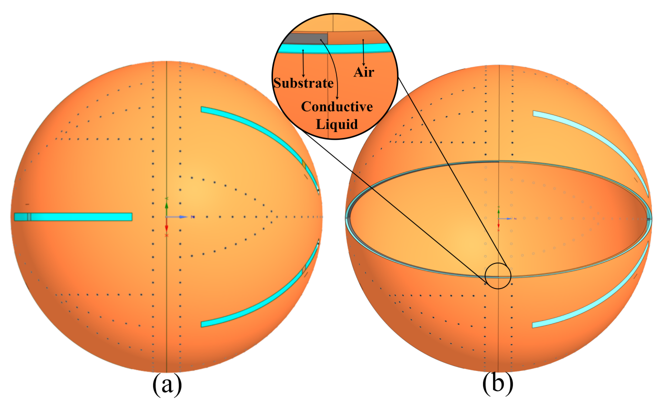


Fig. 1. Cavity backed slot antenna array with spherical distribution (a) Array model (b) A close look into the layers of the cavity.

Fig.1(a) illustrates the layout of the antenna array. The proposed design comprises two conductive nested spheres with 60 mm and 58 mm radii. The two spheres are shorted to each other by shorting pin walls to create eight cavities. A narrow slot of 64 mm length is located on the outer surface of each cavity. The slots are fed with offset striplines to create cavity backed slots [7]. The outer half of the cavities are filled with a substrate with a relative permittivity of 3 as depicted in Fig.

1(b). The inner half of the cavities are left vacant to be half filled with conductive liquid. The conductive liquid is free to flow between cavities hence it short circuits the stripline feeds to the inner walls of the cavities depending on their position against gravity. The short circuiting of the feed results in the corresponding slots being short circuited leaving the remaining slots radiating. By doing so, the passive reconfiguration of the radiation pattern is achieved. Since the conductive liquid is consistently positioned in the lower half of the sphere due to Earth's gravitational force, the resulting radiation pattern generated by the radiating slots consistently opposes the earth.

Note that the primary challenge with any array of antennas sharing the same surface is the undesirable coupling between the antennas. Here, the slots are located such that they do not share the same meridian and the cavity walls are created with double layer of shorting pins to tackle this well-known problem.

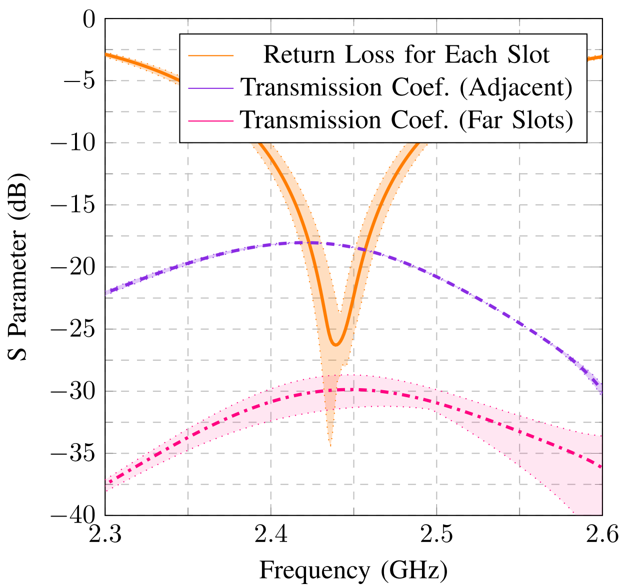


Fig. 2. Return loss of each slot, and transmission coefficients between the adjacent and non-adjacent array elements (dB) vs frequency (GHz). Note that the shaded area represents the variation among elements.

## III. Results

The return loss plots for the cavity backed slot antennas can be seen in Fig. 2. It can be observed that each antenna covers the 2.4 GHz ISM band. The transmission coefficients between the slots are presented under two categories. As expected, the adjacent slots have higher coupling than the non-adjacent ones. As seen in Fig. 2, the coupling is always lower than -17 dB for all cases which is a reasonable value.

In exploration of the reconfiguration, we emulate different rotations of the spherical antenna array. As the sphere rolls around its axis while located horizontally according to earth surface, the number of active slots is always three. The simulated gain pattern for one roll angle is presented in Fig.3. Note that the position of the liquid is demonstrated next to the pattern. The resulting radiation pattern is a directive pattern and it consistently avoids radiation towards earth.

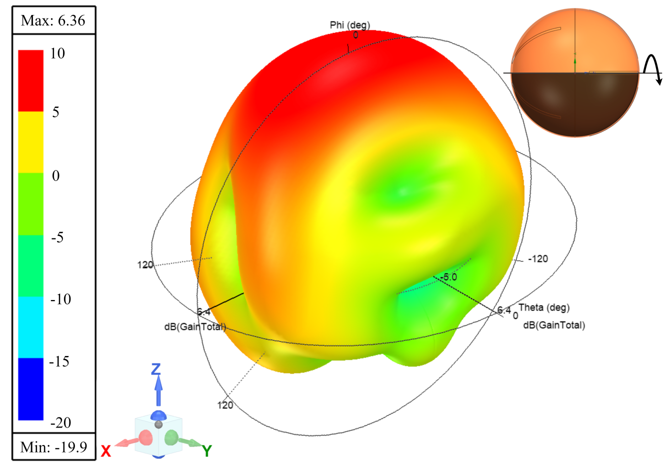


Fig. 3. Radiation pattern of the array while the slots in the lower half is deactivated with conductive liquid.

## IV. Conclusion

A passively reconfigurable spherical antenna array controlled by gravity is proposed, utilizing conductive liquid to realize switching between antenna elements. Through this passive antenna selection method, a consistent radiation pattern is created which avoids radiation towards earth. The resulting maximum gain values are greater than 6 dB for each roll angle. For future work, the antenna array is going to be realized using 3D printing technology with the transmitter located inside the inner sphere, and each slot fed by a separate RF chain.

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