Bradykinesia Detection in Parkinson’s Disease Using Smartwatches’ Inertial Sensors and Deep Learning Methods

Space-fed antenna based on dielectric-only transmitarray

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***Abstract*—In this work, preliminary results on the design of a dielectric transmitarray (TA) antenna are presented. The unit-cell consists in two circular cylinders located on the two sides of a thin square slab, with size 0.3λ at the central frequency, realized with the same dielectric material of the cylinders. The amplitude and phase of the transmission coefficient are controlled varying the diameter of the cylinders, while their height is kept constant. In order to minimize the unit-cell thickness, but at the same time assuming that 3D printing techniques will be used for the TA manufacturing, a dielectric material with $\varepsilon_r = 10$ is considered. The results obtained from the simulation of a transmitarray working in Ka-band with size 15$\lambda\times$15λ are presented and discussed.**

***Index Terms*—antennas, transmitarrays, 3D printing, additive manufacturing.**

I. Introduction

The continuous demand for satellite communication systems with improved performance also impacts on the requirement for antennas, either on board or for the ground segment; they must show not only good radiating features, but also have a low profile, be in many cases easily foldable and deployable and have reduced complexity and cost. The most conventional proposed solutions consist in using reflector antennas, that however are bulky, or phased arrays, that have generally a complex structure and not negligible losses. Further alternatives, aimed to overcome the drawbacks of these two solutions still keeping their good performance, are represented by the use of other types of space-fed antennas. They could be roughly be divided in three categories: (1) space-fed arrays [1] - [4], in which a patch or another small radiating element is used to excite an array of patches located at a distance multiple of λ/2. (2) Reflectarrays (see e.g. [5], [6] and references therein), presenting the disadvantage that the feed is located on the same side where the planar reflector radiates and therefore it is responsible for blocking. (3) Transmitarrays (TAs), characterized by a planar transmitting surface and a feeding system not located on the same side where the TA field is radiated and therefore it is not affected by blockage.

Several techniques have been developed for the realization of a transmitarray [7]. A first solution is to use a multi-layer Unit-Cell (UC), where resonant elements with same or different shapes are printed on different dielectric layers, in most of the cases separated by air gaps, with the aim of enhancing the antenna performance [8] - [11], even if this increases its complexity. More recently, the use of frequency selective surfaces has also been introduced [12], [13]. Another solution consists in using a transmitting and a receiving layer, connected each other through phase shift elements that could be transmission lines, slots in an intermediate ground plane or even active elements as pin diodes or varactors, adopted especially for the realization of reconfigurable configurations [14] - [19].

A further possibility consists in designing completely dielectric TAs, having the additional advantages that 3D printing techniques could be used for the fast and low cost manufacturing of prototypes, even though they impose limitations on the accuracy and the minimum feasible size of the elements constituting the unit-cell, and force the use of materials suitable for 3D printers. To control the amplitude and phase of the transmission coefficient (S_{21}) a perforated dielectric layer could be adopted, where the holes are characterized by varying size [20], [21], eventually not constant along the hole itself to enhance the bandwidth [22], [23]. Other researchers have introduced configurations where it is the height of the unit-cell that is used as the single parameter [24], [25] or one of the degrees of freedom [26] of the transmitarray.

Here, a different configuration is analyzed: the UC consists in two dielectric cylindrical elements, built on the two sides of a thin slab, made of the same material, and the S_{21} is controlled changing the diameter of the cylinders, while their height is kept constant. To reduce the total thickness of the TA, with a consequent reduction of its complexity, bulk and cost, still guaranteeing good performance, a 3D-printable dielectric material with high value of ε_r is chosen. The feasibility of the proposed solution is confirmed by preliminary simulation results of a Ka-band TA with size 15$\lambda\times$15λ.

II. Dielectric Unit-cell

The proposed TA unit-cell is a completely dielectric element composed of a thin slab and two identical cylinders built at the center of both the slab sides, as shown in Fig. 1. The diameter d of the cylinders is the geometrical parameter adopted for controlling the phase of the transmission coefficient. Its dielectric structure makes the cell suitable to be realized conveniently using Additive Manufacturing (AM) techniques, or most commonly 3D printing. In the hypothesis to chose the Fused Deposition Modeling (FDM) as the appropriate process for the TA manufacturing, it is possible to use for its realization an ABS-based filament material with high permittivity, as

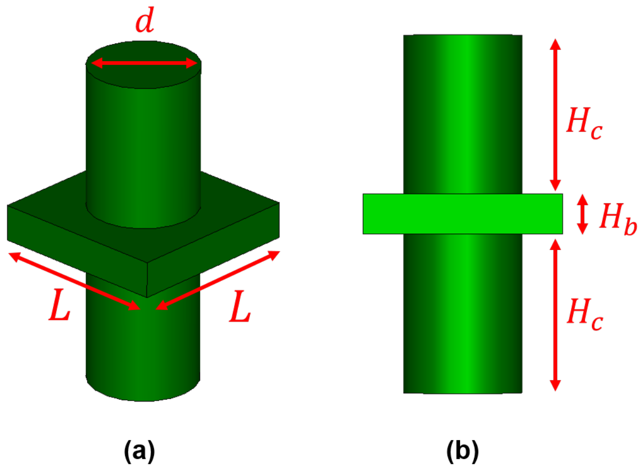

Fig. 1: TA dielectric unit-cell with cylindrical elements.: (a) 3D view; (b) Side view.

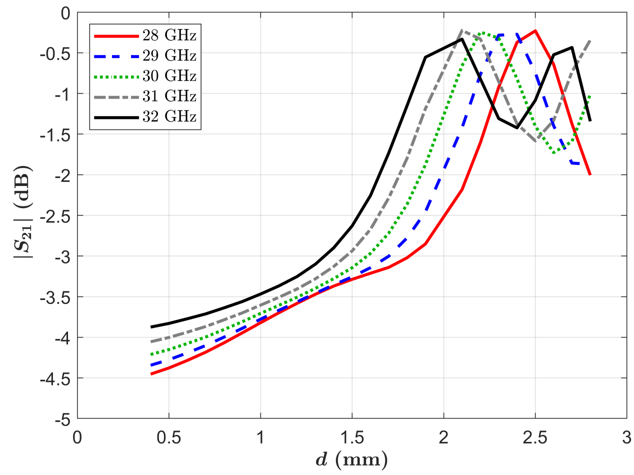

Fig. 2: Variation of the simulated reflection coefficient amplitude $|S_{21}|$ as a function of d for different frequencies.

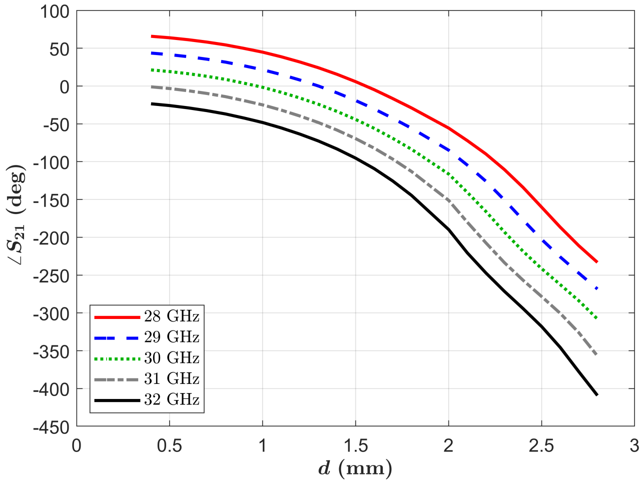

Fig. 3: Variation of the simulated reflection coefficient phase $\angle S_{21}$ with d for different frequencies.

for instance the PREPERM® ABS1000, characterized by a nominal dielectric constant of $\varepsilon_r = 10$ and tan$\delta = 0.004$. All the results discussed in the following refer to this material.

The UC has been designed at the operating frequency $f_0 =$ 30 GHz. The geometrical parameters have been optimized with the aim of maximizing the unit-cell performance, but also taking into account that the 3D printing process can introduce errors and therefore trying to minimize their risk. The resulting UC has a periodicity $L = 0.3\lambda_0 = 3$ mm, the heights of the base (H_b) and of the cylinders (H_c) have been chosen to $H_b = 1.0$ mm and $H_c = 3.2$ mm, so that the total thickness of the unit-cell is equal to $0.74\lambda_0$, while the diameter d of the cylinder can vary in the range from 0.4 mm to 2.8 mm to control the phase of S_{21}.

The variation of the transmission coefficient with d under normal incidence has been studied using the Floquet analysis in CST MW Studio®. The resulting amplitude ($|S_{21}|$) and phase ($\angle S_{21}$) for different frequencies are shown in Fig. 2 and Fig. 3, respectively: both the behaviors are on the whole satisfactory.

III. Transmitarray Design and Results

The unit-cell presented in the previous section has been used to design a square transmitarray operating in Ka-band and with size $D = 15\lambda_0 \times 15\lambda_0 = 150\text{mm}\times150\text{mm}$, where λ_0 is the wavelength at 30 GHz. The considered configuration is a center-fed TA composed of an array of 50×50 dielectric elements and designed to focus the beam in the broadside direction. The required phase shift and the resulting TA layout are shown in Fig. 4a and Fig. 4b, respectively. A 3D-printed conical horn optimized to work in in Ka-band [27] has been employed to illuminate the TA surface. The focal distance F from the phase center of the feed and the TA surface is set to 180mm. 3D-model of the entire antenna, including the 3D-printed conical horn and the dielectric TA can be seen in Fig. 4c.

The radiation performance of the dielectric transmitarray has been numerically analyzed using CST MW Studio®. The simulated co-polar components of the radiation pattern in E-plane and H-plane at f_0 are shown in Fig. 5. In both the planes it is characterized by very low SLL, approximately equal to -26 dB in E-plane and -24 dB in H-plane.

The TA achieves a maximum gain of 32 dBi at 32.5 GHz, while at 30 GHz it is equal to 31.6 dBi, corresponding to an aperture efficiency of 51.6%. The obtained high efficiency is essentially due to the low losses that characterizes the employed ABS material, and the reduced thickness of the TA. The evaluated 1-dB gain bandwidth is almost equal to 16%, while the 3-dB gain bandwidth is larger than 23%. These results confirms the good potentialities of the proposed unit-cell in comparison with similar ones [25], [26]: differently

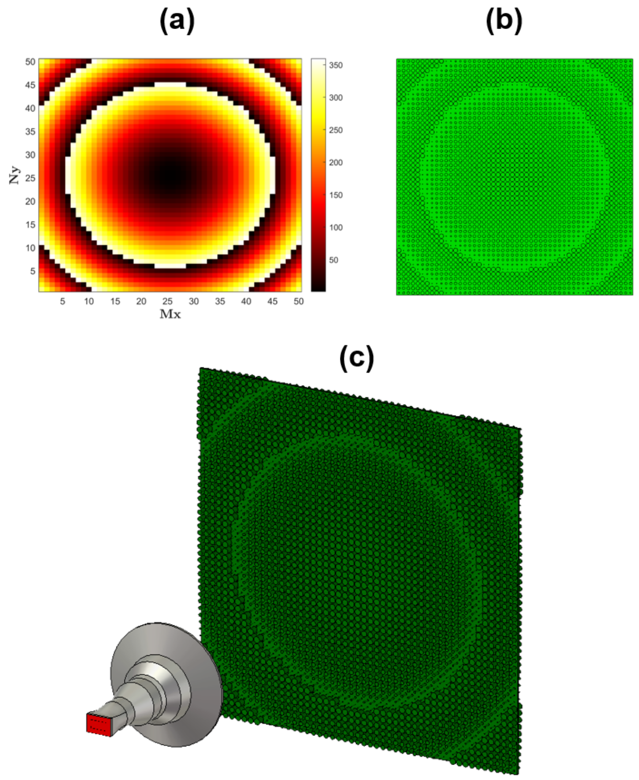

Fig. 4: Dielectric transmitarray with 50×50 elements: (a) Required phase shift; (b) Layout and cylinders distribution. (c) Complete structure (TA+feed).

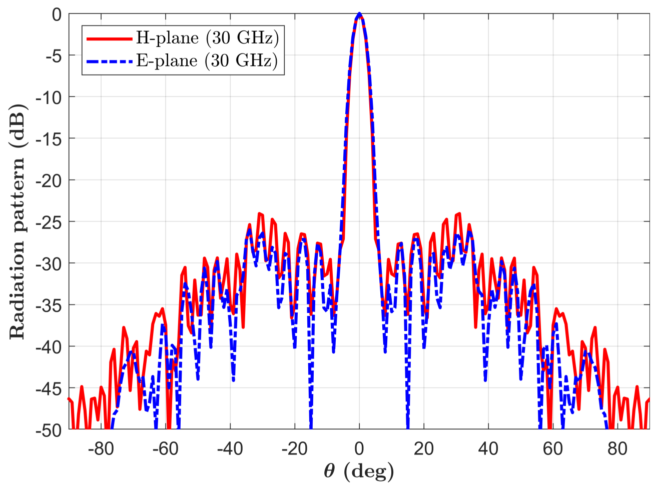

Fig. 5: Computed radiation patterns in the E-plane and H-plane at 30 GHz.

from the solution proposed in [25] it has a much smaller thickness, but in opposite to the unit-cell introduced in [26] it uses only one degree of freedom to control S_{21}, with the consequent simplification of the TA design procedure, not requiring the use of any particular optimization procedure. From the performance point of view, the here proposed antenna has little better efficiency and bandwidth than those of the configuration in [25], even if the TA considered there has a size of $8\lambda \times 8\lambda$, considerably smaller than the transmittarray here designed.

IV. Conclusion

In this work, a dielectric transmitarray unit-cell based on cylindrical elements has been used to design of a medium-sized and center-fed transmitarray that operates in Ka-band. Some preliminary results on the unit-cell analysis and the TA radiation performance have been presented. The antenna provided a gain of 31.6 dBi at 30 GHz and a 1-dB gain bandwidth of 16%. The major improvement of the proposed TA respect to other configurations proposed in literature is the aperture efficiency, achieving 51.6%. The future activity will focus on the aspects involving the manufacturing of a prototype using FDM techniques and its experimental characterization.

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