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Opportunities in Antenna Development by Using Distilled Water

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ABSTRACT: This paper presents some opportunities in the development of antennas when using Distilled Water (DW) as a dielectric with high relative electrical permittivity ($\varepsilon_{r(DW)} = 80$). By embedding an antenna in DW, the electrical growth of the antenna is achieved without significantly increasing its physical size. In other words, the antenna will resonate at frequencies lower than those to whom it originally resonated. It was also found that the antennas developed through this technique are usually multiband antennas, offering various resonance frequencies at frequencies lower than the original ones. Finally, the change in radiation patterns was also verified through the use of this technique that allows beamforming to be carried out by varying the size and shape of the DW block. The development of more efficient antennas has a direct impact on the energy consumption of wireless systems, which represents an effective contribution to climate change mitigation, the reason that the improvement of antennas is a very important research area.

1. INTRODUCTION

Antenna design as part of communication systems is an area in constant evolution. This work presents the experience of the authors with the embedding of antennas in high permittivity dielectrics. The structure of conventional antennas can be modified applying several techniques to accomplish different purposes, for example, for reducing its size, for changing its radiation pattern, and for adapting their resonant bands to multiband. Such embedded antennas are an important part of wireless systems or radio links, and their design is not easy. Optimizing the performance of antennas is an important way of significantly reducing the energy consumption of wireless systems, which is a good way of collaborating with the climate change mitigation objectives. Diminishing the energy consumption of telecommunication systems is a goal with a long history[1].

Performance evaluation by means of simulations is required before fabrication and characterization. This paper describes results for different antennas embedded in DW and provides insights on their development. The equations for the design of embedded antennas are not tractable analytically, and for this reason the simulation becomes extremely important. In this work, simulations of antennas embedded in DW for achieving new features as: improved performance, size reduction, new bands of work, etc. are discussed. Simulations are performed by using the CST Studio Suite® Electromagnetic field simulation software [1]. It is a high-performance 3D EM analysis software package for designing, analyzing, and optimizing electromagnetic components and systems.

With previous experiences it can be mentioned that DW as high permittivity dielectric has been used in different ways for the antenna design, such as the selected substrate of resonators for reconfiguring the resonant frequency as a function of the amount of water [2, 3], also, as part of the antenna radiant elements for reducing the size of the resonant patch [4] and for improving the circular polarization [5]. This is a cutting-edge topic as discussed in [6].

SPIDA[2] antenna is an option widely studied as an alternative for wireless sensor networks [7–11]. The authors have also explored this antenna performance when it is embedded in DW [12]. The results observed for this antenna are consistent with the ones that we have obtained for our Hemisphere Distilled Water Patch (HDWP) antenna.

This paper is going to put the focus on the results obtained for a patch antenna (originally designed to resonate at 2.4 GHz) when it is embedded in an hemisphere of DW. Let's call this antenna HDWP antenna. Also we will provide results for a SPIDA antenna embedded in DW [12], which are consistent with the results that we obtained for the HDWP antenna.

The sections in this manuscript are organized as follows. Section 2 explains the use of a high permittivity dielectric for embedding antennas and the size reduction effect. Section 3 explains the results of our experience with the simulations and use of DW as a high permittivity dielectric for the development of antennas with new properties. Finally, Section 4 offers conclusions and final remarks.

2. USE OF HIGH PERMITTIVITY DIELECTRIC FOR EMBEDDING ANTENNAS

When an antenna is embedded in a high permittivity dielectric material, the reduction in size is proportional to the square root of the material's relative electrical permittivity [13]. Then, the first step was to look for a material with high relative permittivity (ε_r). DW is an excellent candidate for its high relative

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[1] https://www.bell-labs.com/greentouch/index-page=about-us.html

[2] Whose name comes from Swedish Institute of Computer Science Parasitic Interference Directional Antenna.

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FIGURE 1. Photo of the patch antenna embedded in a DW hemisphere with a 25 mm radius.

permittivity $\varepsilon_{r(DW)} = 80$ and for its easy accessibility. Considering this data and by using DW as a material to embed our antennas, we can achieve a size reduction factor (SRF) of approximately 9, as shown in (1).

$$SRF = \sqrt{\varepsilon_{r(WD)}} = \sqrt{80} = 8.94 \quad (1)$$

The following section presents the results for two types of antennas whose performance was tested once they were embedded in DW. First, we will talk about a patch type antenna and then about a SPIDA type antenna [9]. In the first step, we will share the results of our simulations that show the interest and feasibility of using this technique for changing the performance of the antenna, finding in this way new scenarios of applicability for the antenna. In the second case, we will present results obtained for a SPIDA antenna embedded in DW that are consistent with our result for the HDWP antenna. This contributes to confirming the interest and feasibility of using this technique to obtain improved antennas.

The process followed in the design of this antenna is a standard process. It began with the design equations for a patch antenna, using [14] as a reference, and then using the CST simulation tool, the modified antenna (including the DW hemisphere) was optimized.

3. RESULTS

This section presents results of the use of DW as a high permittivity dielectric for the development of antennas with new properties.

As mentioned before, by embedding an antenna in a high permittivity dielectric, several things happen: on the one hand, the electrical size of the antenna increases (which makes it possible to obtain smaller antennas capable of working at lower frequencies); on the other hand, the radiation characteristics of the antenna change. Additionally, new working bands tend to appear, in which the original antenna was not capable of working.

3.1. Hemisphere Distilled Water Patch Antenna

In this case, we started with a patch antenna made on FR4, with a rectangular patch, to which we placed an SMA connector. This antenna was originally dimensioned and optimized to work at 2.4 GHz. This antenna is the one that can be seen in Fig. 1, through the DW and fiberglass container (epoxy + roving fabric), which gives it the shape of a hemisphere of 25 mm in diameter. Then, to that simple patch antenna, prepared to work in 2.4 GHz, the DW + the fiberglass casing is added to turn it into our DW embedded patch antenna.

The patch antenna in Fig. 1, without the DW hemisphere, has a module of S_{11} as shown in Fig. 2 in the blue dotted curve. As this antenna is embedded in the DW hemisphere of Fig. 1, the curve of the module of S_{11} becomes the entire red curve of Fig. 2. This shows a very significant change in the behavior of the antenna. It shows the possibility of working at lower frequencies for the antenna embedded in DW and represents a significant opportunity to develop smaller antennas capable of working at lower frequencies. You can also see the appearance of several working bands at a lower frequencies, with which the new antenna (embedded in DW) can also behave as a multiband antenna.

On the other hand, in Fig. 3 and Fig. 4 you can see changes in the radiation patterns of the embedded antenna. These changes are observed by varying the working frequency, and it was also verified (through simulations) that these changes are related to the lens effect that the DW hemisphere produces on electromagnetic radiation. This is an important aspect, and the shape of the dielectric in which the antenna is embedded has a direct influence on the shape of the radiation pattern. It is also a variable in which we can work to develop an optimized radiation pattern [15].

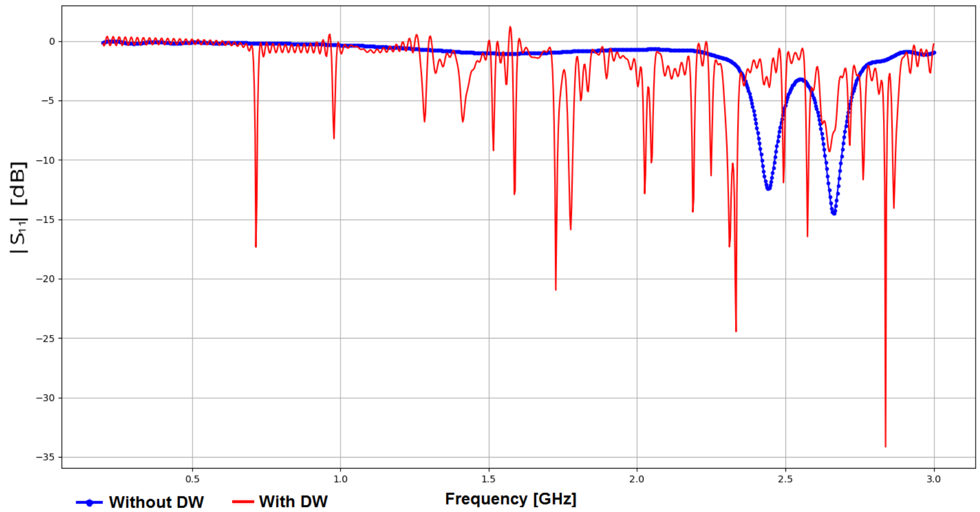

FIGURE 2. Simulations of $|S_{11}|$ for the Patch antenna embedded in a DW hemisphere with a radius of 25 m.

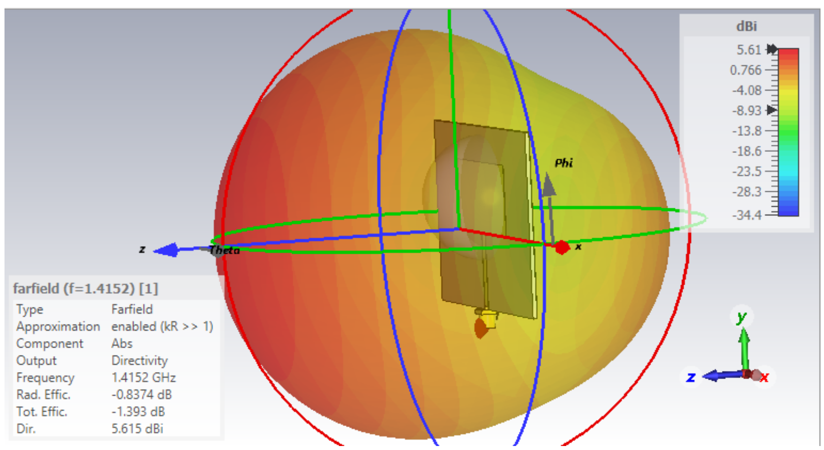

FIGURE 3. Radiation pattern of the Patch antenna embedded in a DW hemisphere with a radius of 25 mm for $f = 1.4152$ GHz.

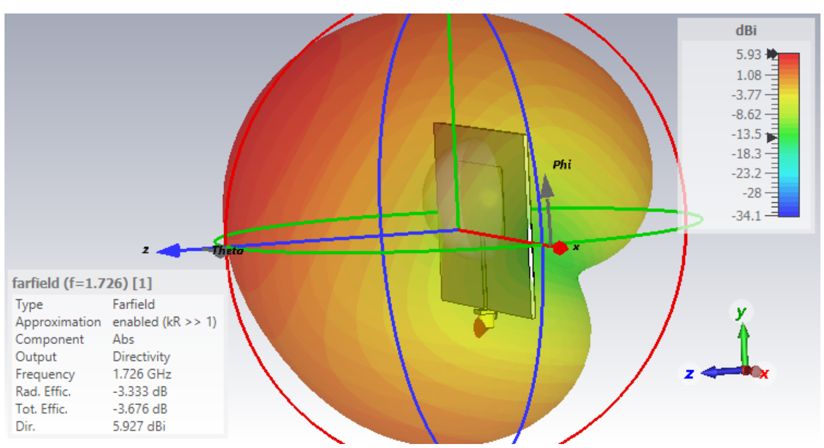

FIGURE 4. Radiation pattern of the Patch antenna embedded in a DW hemisphere with a radius of 25 mm for $f = 1.7260$ GHz.

Additionally in Fig. 5 and Fig. 6, the main plane (co-polarization radiation patterns) and the cross-polarization radiation patterns are shown for these two frequencies.

So with these simulations we find three important effects that appear when embedding an antenna in DW. The first is the ap-

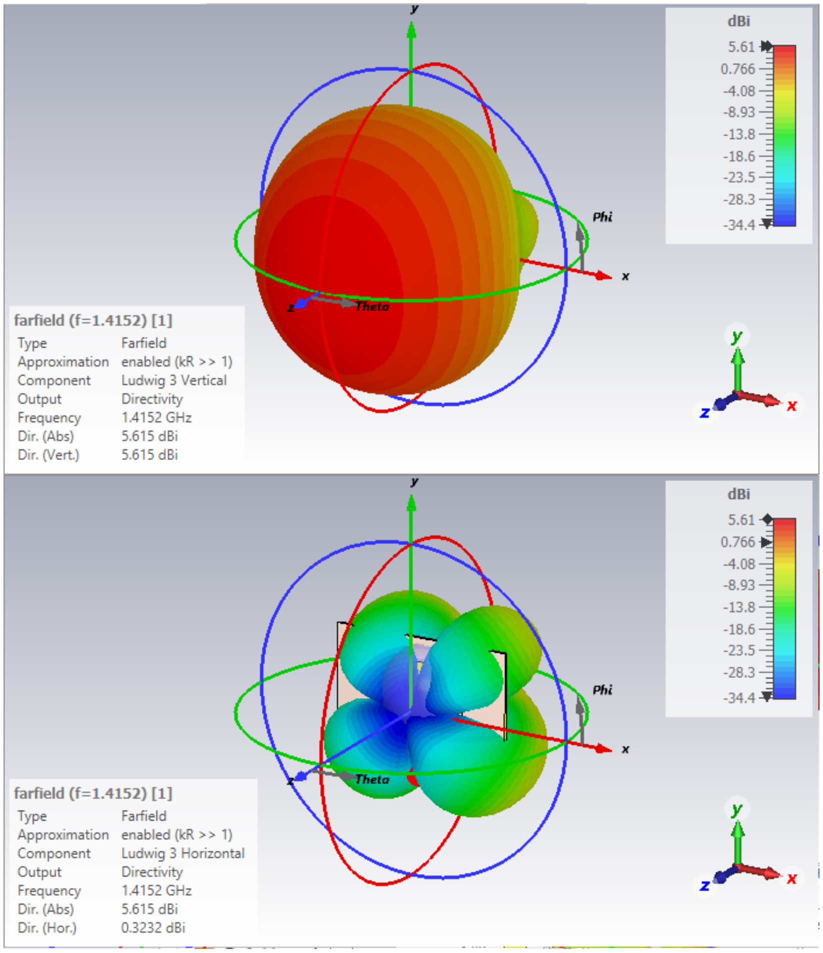

FIGURE 5. Radiation pattern of the patch antenna embedded in a DW hemisphere with a radius of 25 mm for $f = 1.4152$ GHz in co-polarization and cross-polarization.

TABLE 1. Simulation results for the HDWP antenna.

	Frequency	Maximum Gain	$\lvert S_{11}\rvert$
1	1.4152 GHz	4.8 dBi	-7 dB
2	1.7260 GHz	2.6 dBi	-21 dB

pearance of resonance bands at lower frequencies for which the antenna has a good impedance match (low modulus value of S_{11}). The second is that it is not usually a single resonant band, but several, with which the antenna becomes a multiband antenna. The third is the change in the shape of the radiation pattern due to the presence of the new dielectric. The dielectric size, shape, and properties cause lens effects modifying the antenna radiation pattern.

Finally, Fig. 7 shows the construction process of this patch antenna embedded in a DW hemisphere of 25 mm radius. In a), it is shown how the container of epoxy resin and roving fabric was developed, molding it on a mold with release agent. In b) and c), the two sides of the resin container are shown already dry and ready to be trimmed and fixed on the patch antenna. In d), the resin containers and patch antennas are shown, and the first ones already have their SMA connectors in place. In e), the finished antennas are shown. After the resin container has been glued onto the patch antenna with epoxy resin, a small hole is drilled in the upper part of the hemisphere (see blue dot). Then, the DW container is filled through this hole with a syringe, and then this hole is sealed with epoxy resin. In this way, the antennas used in this work were manufactured.

Evaluating the values of the real and imaginary parts of the relative electrical permittivity of the DW in the frequency and temperature range in which we use our antenna [16], it was concluded that the DW should not cause any appreciable attenuation of the electromagnetic signal, which is consistent with the good values obtained in the simulations.

In Table 1, the results for HDWP antenna are summarized. Table 1 reports two of the frequencies in which the HDWP antenna performs well. While those frequencies (1.4152 GHz and 1.7260 GHz) are not nine times less than the resonant frequency

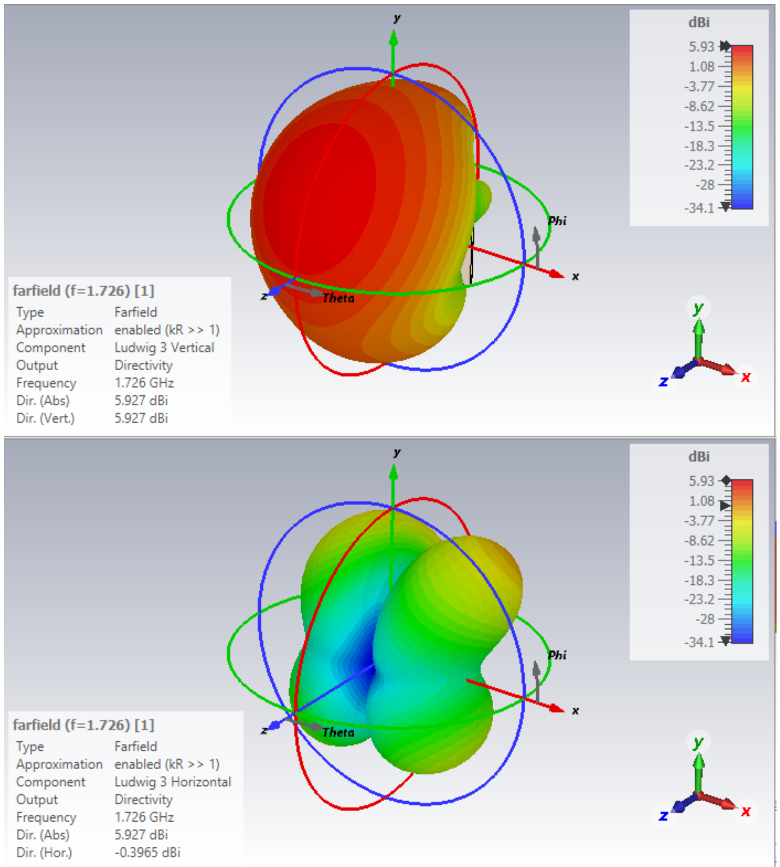

FIGURE 6. Radiation pattern of the patch antenna embedded in a DW hemisphere with a radius of 25 mm for $f = 1.7260$ GHz in co-polarization and cross-polarization.

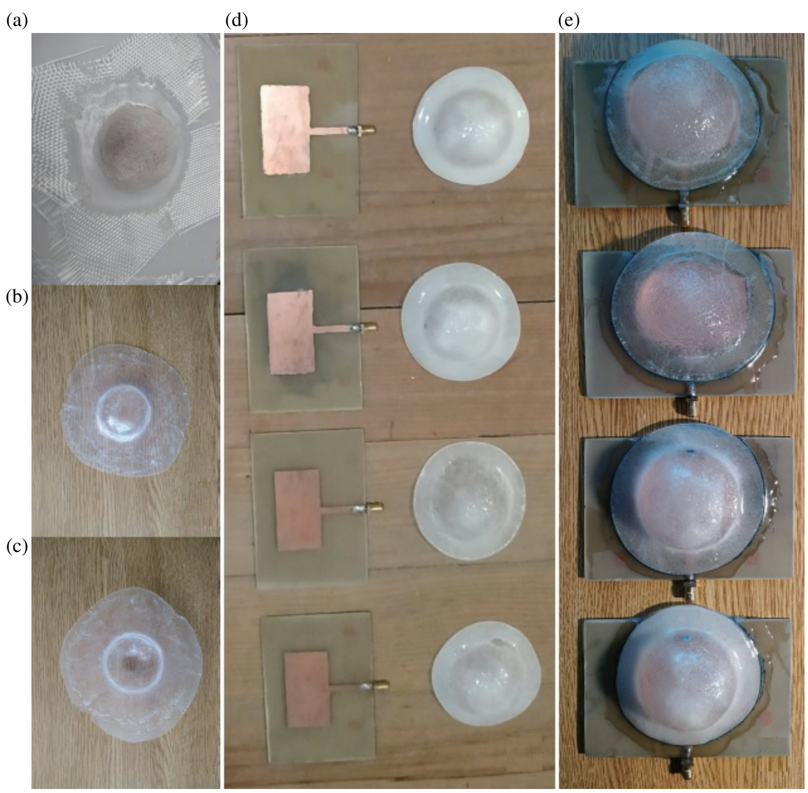

FIGURE 7. Constructive process for a patch antenna embedded in a DW hemisphere with a radius of 25 mm (HDWP antenna).

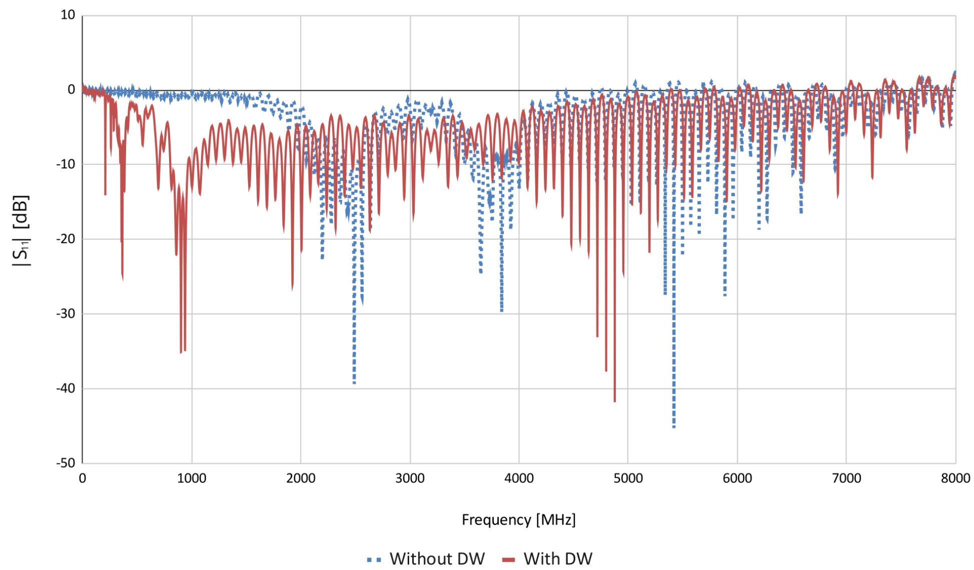

FIGURE 8. Measures of $|S_{11}|$ for the SPIDA antenna with and without DW (source [12]).

of the original patch antenna (2.4525 GHz), they are two frequencies lower than this one where the HDWP antenna works efficiently. In Fig. 2, several frequencies below 2.4525 GHz are shown where the HDWP antenna resonates, but not for all these frequencies where the antenna has an adequate gain and radiation pattern (which is observed in the specific simulations for these frequencies). For all the above we can say that the HDWP antenna is at least a dual-band antenna, in which all the aforementioned factors are observed.

As it was already said, the results for SPIDA antenna embedded in DW that the authors found previously are consistent with the results that we found now for the HDWP antenna. The modification in $|S_{11}|$ parameter shown in Fig. 2 for the HDWP antenna is consistent with the modification for $|S_{11}|$ measured for SPIDA antenna. In Fig. 8 the $|S_{11}|$ modification produced by embedding the SPIDA antenna in DW can be observed. In this case, these curves of $|S_{11}|$ parameter were measured over the SPIDA antenna embedded in DW with a Rohde & Schwarz ZVB 8 Vector Network Analyzer. Observing similar behavior for both antennas allows to think that this kind of effect can also be exploited for other kinds of antennas.

4. CONCLUSIONS

In this work, the potential of embedding a known antenna in a dielectric with high electrical permittivity is thoroughly analyzed. In particular, the results are shared for the case in which the dielectric is distilled water, a dielectric that is easy to obtain and cheap, which has the difficulty of being a liquid, solved by using epoxy resin or plastic containers. This technique makes it possible to obtain smaller antennas (up to nine times smaller) to work at lower bands, allows to obtain multiband antennas, and also offers the possibility of formatting the beam in different ways, taking advantage of the physical conditions of the dielectric and the lens effect that it produces on the electromagnetic radiation. All these effects, easy to achieve with the proposed technique, have enormous potential for improving antennas, making it possible, among other things, to reduce their sizes. The scenarios where antennas of reduced dimensions are widely desired are numerous, and some of them are listed below: when the antenna is installed on a tower (reducing wind resistance and allowing a greater density of antennas on the tower), when the antenna is part of a small wireless device (allowing its portability to be maintained), when the antenna is integrated into a small device, etc. The application significance of having small antennas with good performance is critical in most mobile and portable devices. That is why the study of techniques like these to reduce the size of antennas while maintaining and/or improving their performance has great value. This paper evaluates particularly the value that the use of a dielectric with high electrical permittivity can have as a design tool, especially if it is shaped in a way that also exploit the lens effect. With this, a reduction in antenna size, multiband operation, and an improvement in gain due to the lens effect can be obtained. These three effects, to the best of the authors' knowledge, have not been reported jointly through the use of this type of dielectrics and even less so for this type of antennas. In that sense, the paper is novel and shows the great potential that this technique can have. Of course, the other papers on water antennas report benefits and other ingenious ways of using water (in some cases offering dynamic variations of the antenna parameters), whether using water as a conductor or dielectric. The body of existing publications in the area of water-based antennas shows an enormous potential and field of application for this type of antennas. Simulation tools such as CST allow exploring the potential of this technique and finding novel antennas with improved performance. Obtaining improved antennas is a great way of collaborating with the mitigation of climate change. Just think that an antenna with an improved gain of 3 dB allows the transmitter to work with half of the power. If this improved version of the antenna would be used in both sides of the link, then the needed power in the transmitter could be reduced by a factor of four. This important save in power would be for sure a great achievement for climate change mitigation.

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