Water-Based Microwave Antennas.

Jacobsen, Rasmus Elkjær; Vandborg, Mads H.; Laurynenka, Andrei; Arslanagic, Samel

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Abstract—The interesting properties of water make it an attractive material platform for many microwave applications including artificial material design, sensing, heating systems and dielectric resonator antennas. Presently, electrically small versions of the latter are considered. We present the numerical and experimental results for an antenna consisting of a short monopole fed against a large conducting ground plane and encapsulated by a water-filled cylindrical cavity. The resonant antenna is designed for 300 MHz operation and is successfully matched to a 50 Ohm transmission line and the surrounding air.

Index Terms—dielectric resonator antenna, water-based, Mie resonance.

I. INTRODUCTION

Development of electrically small antennas is important to satisfy the desire for smaller and compact technology designs as miniature versions of today’s conventional antennas are inefficient radiators with their highly reactive input impedances [1]. Matching of such a load to a realistic source using a matching network results in poor bandwidth, high fabrication requirements and modest efficiencies. A different approach is to shape the radiator and/or add elements such that the antenna utilizes its occupying volume more efficiently while being matched to its feed-line and resonant. Several solutions have been proposed such as folded spherical helix antennas [2], metamaterial-based [3] and -inspired antennas [4] and dielectric resonator antennas (DRAs) [5]–[7]. The latter usually consists of a dielectric structure placed on a ground conducting plane and with a metallic radiator for excitation like e.g. a monopole or patch antenna positioned inside or close to it. Using high-permittivity dielectrics, the antenna size can be a small fraction of the operating free-space wavelength \( \lambda_0 \). However, the high permittivity and compact size also decreases the bandwidth of the antenna. Therefore, the relative permittivity is normally in the range from 8 to 100. Typically, low-loss ceramics are used, but it has also been shown that simple and natural water can function as an alternative material [6]–[7]. Beside DRAs, several applications of water have been demonstrated such as in metamaterial and metasurface designs as well as in sensing and heating systems [8]–[11]. It has been shown that water adds flexibility as well as several tuning capabilities to such systems.

In this work, we present numerical and experimental results for water-based DRAs. The investigated DRA consists of a short monopole antenna fed against a large ground conducting plane and encapsulated by an electrically small cylindrical water-filled cavity. The antenna is designed for 300 MHz operation and has been matched to a 50 Ohm transmission line, as well as the surrounding air medium, providing a total efficiency of 33.4 % and a reflection coefficient of \(-28\) dB. In addition, the frequency-tuning by extraction of water from the cylindrical cavity is investigated. The presentation at the conference will also include results for some other water-based DRAs as well as their tuning abilities induced by temperature variations.

The paper is organized as follows. Section II introduces the water-based DRA. Section III presents the numerical and experimental results. Section IV includes a summary and conclusions of this work. Throughout the work, the time-factor \( \exp(\jmath \omega t) \), where \( \omega \) is the angular frequency, and \( t \) is the time, is assumed and suppressed.

II. CONFIGURATION

The DRA consists of a short monopole fed over a large conducting ground plane and encapsulated by a water cylinder. A sketch of the antenna is shown in Fig. 1(a) with a Cartesian coordinate system introduced. The cylinder has equal radius and height \( r_{3d} \), and the monopole has the wire diameter of 1.6 mm and the length \( l \); it is displaced a distance \( d \) from the cylinder center. The monopole is connected to a coaxial transmission line with inner (outer) diameter of 1.28 mm (4.1 mm). A model of the antenna is built in COMSOL Multiphysics 5.3 [12], which is used for the numerical calculations. The model consists of the antenna placed in a PML-supported hemisphere of free space and with a Perfect Electric Conductor (PEC) plane as the ground. On the bottom of the transmission line, a matched port is placed.

![Fig. 1. (a) Sketch of the antenna, and (b) photograph of the antenna prototype.](image-url)
The permittivity of water is described by the Debye model [13]. The antenna parameters used in the paper are calculated as defined in [1].

III. RESULTS AND DISCUSSION

First, the resonant size of the cylinder was determined through a scattering analysis of the cylinder without the monopole. At 300 MHz, the required radius and height of the water cylinder exhibiting a magnetic dipole resonance were found to be \( r_{\text{cyl}} = 49.4 \) mm. Second, \( l \) and \( d \) providing the largest total efficiency were determined with the result shown in Fig. 2(a). The optimal values are \( l = 37.05 \) mm and \( d = 9.88 \) mm, and the spectral response of the optimized antenna is shown in Fig. 2(b) with a water temperature of 24 °C. At 302 MHz, the reflection coefficient of the DRA are 3\( \times \)2\% (water scale) in the xy-plane and the measured reflection coefficient (S21) is 3\( \times \)8\% (not shown here) as well as reflection coefficient of the DRA are 3\( \times \)2\% (water scale) in the xy-plane together with numerical results showing good agreement. There are deviations at angles close to the ground plane, where the measured transmission coefficient start to decrease, which is expected with the truncated ground plane size.

Subsequently, water was extracted from the cavity to investigate the tunability of the antenna. The position of the antenna was fixed such that the water kept the cylindrical form. The resonance frequency is shown in Fig. 3(b) as a function of the reduction in the cylinder height of the water. From 0 mm to 10 mm, the monopole antenna is completely covered by water, where linear frequency blue-shift, as well as low reflection coefficient (not shown here), is achieved. Above 10 mm, the reflection coefficient greatly increases, and the tendency of the frequency shift changes.

Other types of water-based DRAs have been investigated with some based on the electric resonance and others based on both magnetic and electric resonances. We will show some of the representative results for these designs at the conference. We will also discuss the tunability by temperature as well as the effect from increasing water losseses at higher frequencies.

IV. SUMMARY AND CONCLUSIONS

In summary, an electrically small water-based cylindrical DRA designed for 300 MHz operation was investigated. We presented both numerical and experimental results exhibiting good agreement. The total efficiency and reflection coefficient of the DRA are 33.4 % and -28 dB, respectively. Additionally, we investigated the frequency-tuning of the proposed DRA by extraction of water.

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![Fig. 2](image1.png) (a) Total efficiency (colors) as a function of length and position of the monopole antenna used to find the optimum monopole design (water temperature: 24 °C). (b) Results for the optimized antenna with the spectrum of the total efficiency and reflection coefficient (water temperature: 24 °C). Measured reflection coefficient is included.

![Fig. 3](image2.png) (a) Simulated and measured radiation pattern (S21 in logarithmic scale) in the xy-plane. (b) Resonance frequency as a function of reduction of the cylinder height due to extraction of water.
REFERENCES


