Publication [P4]

O. Lehmus, J. Ollikainen, and P. Vainikainen, ”Characteristics of half-volume DRAs with different permittivities,” *IEEE Antennas and Propagation International Symposium Digest (AP-S 1999)*, vol. 1, Orlando, FL, July 11-16, 1999, pp. 22-25. © 1999 IEEE. Reprinted with permission.

Characteristics of half-volume DRAs with different permittivities

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1. Introduction

Development of small antennas for mobile phone handsets has been extensive during the last few years due to miniaturization of the handsets, employment of multisystem phones, and the requirements to reduce the RF power absorbed to the user. Traditionally monopole and helix antennas have been used in the handsets [1] and lately planar antennas like patches or PIFAs have gained increasing interest [2]. The basic problem in the development of handset antennas is to obtain fairly large impedance bandwidth (8 - 15 %) combined with small size and possibly also with directivity. In some proposals this has been solved trivially at the expense of radiation efficiency by adding resistive loading to the antenna. The decrease of efficiency mainly due to conduction losses is also a general problem in the miniaturization of RF resonators used in filters and small antennas. Furthermore, it is known that waveguide resonators like dielectric resonators have typically relatively low conduction losses. Thus the half-volume dielectric resonator antenna (DRA) presented in [3] is an interesting candidate for a small antenna of mobile handsets. In this paper the properties of half-volume DRAs are studied as a function of permittivity ($\varepsilon_r' = 2...70$). In addition to the normal characterization of impedance and radiation properties special emphasis is put also on the behavior of radiation efficiency of the antenna.

2. Tested antennas

In this work rectangular half-volume DRAs have been constructed from five kinds of dielectric materials. The antenna dimensions were approximately scaled according to the relative permittivity value in order to keep a fixed geometrical shape. The material parameters and the dimensions are listed in Table 1. The antenna configuration is shown in Figure 1. The resonator element was placed symmetrically and glued to a 150 mm by 150 mm ground plane. Short circuit plate perpendicular to the ground plane was glued to the edge of the element and soldered to the ground plane. The antenna was excited by an extended inner conductor of a SMA connector inserted from beneath the ground plane into the dielectric. The feed position was selected in the middle of the resonator.

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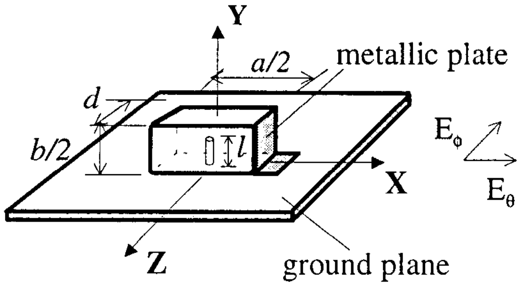

Figure 1. *Antenna structure.*

Table 1. *Parameters of the antennas.*

ε_r'	**2.1**	**6.15**	**16**	**38**	**70**
tanδ	$3.0 \cdot 10^{-4}$	$2.5 \cdot 10^{-3}$	$7.0 \cdot 10^{-4}$	$2.6 \cdot 10^{-4}$	$6.9 \cdot 10^{-4}$
***a*/2 [mm]**	49.5	28.6	17.5	11.4	8.4
***b*/2 [mm]**	45.0	26.0	15.9	10.3	7.6
***d* [mm]**	22.0	12.6	8.0	5.2	3.8
***l* [mm]**	24.9	14.4	8.8	5.7	3.3

3. Measurements

The reflection coefficients of the antennas were measured with a vector network analyzer. The unloaded quality factor Q_0 was calculated from the measured reflection coefficient ρ_r at the resonant frequency f_r and the measured half power bandwidth B_{HP} [4]:

$$Q_0 = \frac{2f_r}{(1 \pm |\rho_r|)B_{HP}}. \tag{1}$$

Here, the plus sign was used in the undercoupled and the minus sign in the overcoupled cases. It should be noted that Q_0-values for the $\varepsilon_r' = 2$ and $\varepsilon_r' = 6$ antennas were roughly approximated due to unclear resonance characteristics.

Radiation efficiencies η_r were measured with the Wheeler cap method [5]. The procedure was to measure the antenna reflection coefficients at resonance with and without the cap. The measured results were used to calculate the respective input resistances based on which the radiation efficiency could be obtained. The measurements were repeated with several caps of different size and shape. The results obtained with different caps agreed very well.

The radiation efficiency may be written as

$$\eta_r = \frac{Q_0}{Q_r} = \frac{Q_r^{-1}}{Q_r^{-1} + Q_c^{-1} + Q_d^{-1}}. \tag{2}$$

The radiation quality factor Q_r was determined from Eq. (2). Since the power loss occurs both in the dielectric and the conductors, the contributions of dielectric and conduction quality factors Q_d and Q_c were estimated. The estimation was based on an approximation that the fields were totally inside the resonator. Therefore the calculation of Q_d was made according to $Q_d = 1 / \tan\delta$. The rest of the losses were assumed to be due to imperfect conductor material.

Table 2. *Experimental results for the resonant frequencies, radiation efficiencies, and quality factors.*

ε_r'	**2.1**	**6.15**	**16**	**38**	**70**
f_r **[MHz]**	2075	2566	2172	2642	3005
η_r [%]	99	95	93	89	86
Q_0	2.0	2.7	12.4	28.2	51.5
Q_r	2.0	2.8	13.3	31.7	59.9
Q_d	3333	400	1429	3846	1449
Q_c	213	93	202	274	492

The results in Table 2 show that the radiation quality factor for $\varepsilon_r' \geq 16$ is approximately inversely proportional to the volume of the resonator in wavelengths as could be expected [6]. The conduction quality factor of resonators of similar shape and resonant mode should typically behave as $Q_c \propto (f_r/\varepsilon_r')^{1/2}$ [4], however, this is not the case with the results in Table 2 as Q_c increases when ε_r' increases. The reason for this is probably that for lower values of ε_r' the monopole-type resonant currents in the vertical metallic short circuit plate and/or the feed probe are high as can be seen also from the radiation pattern results presented below. Generally, it is seen that the efficiency stays high also for high values of ε_r', which gives good basis for miniaturization of half-volume DRAs.

The radiation patterns were measured for all the studied antennas. The normalized radiation patterns for the $\varepsilon_r' = 6$ and $\varepsilon_r' = 38$ antennas are given here as examples (Fig. 2). It is seen that the radiation pattern of the $\varepsilon_r' = 6$ antenna resembles that of an (y-directed) electric dipole because of a high cross-polarization level in the yz-plane. The radiation characteristics change gradually from that of an electric dipole to a (z-directed) magnetic dipole when increasing the permittivity value. The radiation pattern of the $\varepsilon_r' = 38$ antenna resembles that of a magnetic dipole, as was expected [6]. Some asymmetry of the radiation pattern due to the short circuit plate can also be noticed.

The antenna gains were measured using gain comparison method (Table 3). The values were obtained in the direction of the maximum power gain. The gain decrease with increased ε_r' is mainly supposed to be due to the less directive pattern, and the effect of a reduced η_r on gain is supposed to be small.

Table 3. *Measured antenna gains.*

ε_r'	**2.1**	**6.15**	**16**	**38**	**70**
G **[dB]**	6.4±1.1	6.2±1.1	5.5±1.1	5.6±1.1	5.2±1.5

4. Conclusions

In this paper properties of half-volume DRAs were studied as a function of permittivity. For $\varepsilon_r' = 2$ and $\varepsilon_r' = 6$ the bandwidth was wide (resonant properties actually unclear) but the antenna size was large. For smaller DRAs with ε_r' = 16...70 the bandwidth was approximately proportional to the size of the DRA in wavelengths, which sets the limits to the miniaturization of the antenna. However, the bandwidth-to-volume-ratio is somewhat larger than e.g. with typical low-profile single-resonant patch antennas on a large ground plane. Also the radiation efficiency of the DRAs is high and thus they are a good candidate for mobile handset antennas. Future work is still required to develop multiresonant and multifrequency versions of half-volume DRAs.

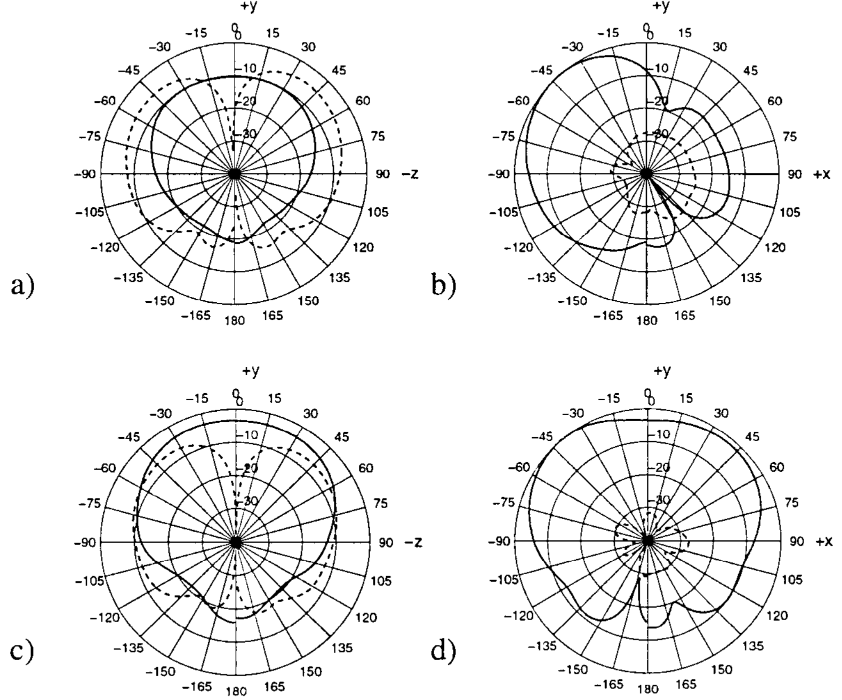

Figure 2. *Measured radiation patterns a) ε_r' = 6, yz-plane b) ε_r' = 6, xy-plane c) ε_r' = 38, yz-plane d) ε_r' = 38, xy-plane. Solid line represents the E_θ- component and dashed line the E_ϕ-component.*

5. References

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