EFFECTS OF LOSSY BACKGROUND AND REBARS ON ANTENNAS EMBEDDED IN CONCRETE STRUCTURES

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ABSTRACT: *In this letter the effects of a lossy background on an antenna developer for wireless embedded sensors network has been studied. The efficiency of the antenna versus the concrete structure size decreases from 72% down to ~ 20%. However, it is shown that the boresight gain is essentially unaffected by the block size. The proposed configuration is robust against concrete permittivity variations, change in block dimension and presence of rebars.*

Key words: *Concrete Structure Monitoring; Wide Permittivity Antennas; Patch Antennas; Left Hand Circular Polarization (LHCP).*

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1. INTRODUCTION

Health monitoring of concrete constructions such as home walls or bridge pillars is an important area both for structures and people safety in the future. An external reader antenna interrogates an embedded one, which backscatters the interrogatory signal in such a way to transmit information by embedded sensors about the health state of the concrete. In this application, a simple printed antenna can be used [2, 1], embedded inside concrete.

In this case, a circularly polarized antenna is proposed for two reasons: 1) reader match is achieved even if the reader apparatus is positioned without particular alignment and 2) the presence of double resonance, due to CP, has a positive effect that is enlarging the operating bandwidth and also obtain an antenna more robust against concrete parameters fluctuations.

2. ANTENNA DESIGN

The proposed circularly polarized patch antenna has been designed and optimized following the guidelines [1], on substrate Rogers RO3010, with relative permittivity $\varepsilon_r = 10.2$ and $\tan\delta = 0.0035$. The antenna operates embedded inside concrete blocks of various dimensions at a fixed distance of 3 cm from the concrete-air interface, assumed flat (without imperfections) for simplicity. In simulations, concrete blocks of specific dimensions have been positioned inside air background: in this way, real working conditions have been replicated.

Assuming concrete nominal permittivity of $\varepsilon_r = 6$ and tangent loss of $\tan\delta = 0.03$, two protective layers of Rogers RO4360G2 ($\varepsilon_r = 6.15$ and $\tan\delta = 0.003$) are added on the top and at the bottom of the antenna structure to preserve robustness in the transition with the concrete background.

The total size of the antenna results in 80 x 80 x 3.24 mm^3. Circular polarization can be achieved with several feeding methods [3]: in this paper, a standard off-diagonal feed-pin technique that

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works well at sub-GHz wavelength [1] and higher frequencies, has been adopted [4]. The antenna layout and geometric parameters are shown in Figure 1, Table 1.

The antenna feed is a 50Ω coaxial cable which is connected to the patch through the bottom substrate at the position (x_1, x_2). The patch and substrate dimensions have been optimized to achieve circular polarization for different surrounding environmental conditions of the concrete, such as permittivity variations, dimension of the embedded antenna's test blocks and implantment of reinforcement bars. At first, antenna has been optimized inside a concrete block of 15 x 15 x 15 cm^3, with $\varepsilon_r = 6$ and $\tan\delta = 0.03$: resulting $|S_{11}|$ is presented in Figure 2.

With this configuration, an Axial Ratio of 0.86 dB at 900 MHz has been achieved, as shown in Figure 3.

The LHCP Gain of the antenna inside a concrete block of 15 x 15 x 15 cm^3, with $\varepsilon_r = 6$ and $\tan\delta = 0.03$, is plotted in Figure 4.

3. PERFORMANCE

The antenna top and bottom coating, with $\varepsilon_r = 6.15$, have been introduced in order to: 1) allow smooth transition between antenna main substrate ($\varepsilon_r = 10.2$) and concrete ($\varepsilon_r = 6$) and 2) better protect the antenna structure, avoiding direct contact between metallization and concrete. Moreover, thanks to this safeguard region, an optimal performance for a wide range of concrete/permittivity configurations has been achieved [1]. In order to verify the immunity of the antenna to such variations, a specific series of simulations, using Ansys HFSS, has been performed and the relative results are reported in the following.

3a. Concrete permittivity variations

The reference concrete permittivity is $\varepsilon_r = 6$; however, due to various environmental conditions, such as wetness, it can fluctuate below and above this value [6].

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The proposed antenna is well matched within a concrete background permittivity interval of [3.5, 10]; this band is known as permittivity band [5], that is the band in which the antenna results matched, in the frequency band of interest, in terms of $|S_{11}|$ value. These fluctuations have been simulated inside a block of dimensions 15 x 15 x 15 cm^3 with $\tan\delta = 0.03$. Results in terms of $|S_{11}|$, axial ratio (AR) and efficiency (η), for $\varepsilon_r = 4, 6, 9$, are shown in Figure 5 and Table 2. LHCP Gain vs ε_r variation is also shown in Figure 6.

3b. Concrete block size

The effects on efficiency when the concrete block size increases, has been taken in account. In particular, η has been evaluated from a block edge of 15 cm and more, with steps of 15 cm. Due to the increasing block size, the simulations become more computational demanding. As a result, a hybrid simulation metod (Hybrid FEM-IE) has been used, in HFSS. With this method, one can solve electrically large objects coupling FEM and Integral Equation methods: the first is used in the near field zone of the antenna and the second, very less memory and time demanding, is used to simulate large surrounding environments, in this case the concrete blocks. Obtained results are summarized in Table 3.

In Table 4 the LHCP Gain in boresight direction ($\theta = 0$) vs block size, for FEM and Hybrid FEM-IE methods, is presented. Values of the total gain have been omitted because, in this case, $G_{tot} \sim G_{LHCP}$.

Figure 7 shows LHCP gain in boresight direction ($\theta = 0$) for block edge size of 15, 45, 75 and 105 cm respectively, obtained through FEM-IE method in HFSS.

Efficiency is defined as $\eta = P_{rad} \setminus P_{acc}$, where P_{rad} is the total radiated power and P_{acc} is the input power at the antenna terminals. From Tables 3, 4 and Figures 7, 8 one can see that, even if radiation

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efficiency η decreases with increasing block size, the total gain (G_{tot} ~ G_{LHCP}) still preserve its main lobe (i.e. its maximum) in boresight direction (θ = 0), the direction through which the antenna communicates with external devices.

Axial Ratio values are contained in the interval [0.93; 4.79] dB, for a block edge size interval of [15; 105] cm.

3c. Effects of rebars presence

Project constrains impose that the antenna is positioned 3 cm far from the concrete-air interface. However, the presence of rebars inside the concrete has been taken in account in simulations. To study their effect on the whole structure, a concrete block of 15 x 15 x 15 cm^3, with $\varepsilon_r = 6$ and $\tan\delta = 0.03$, has been used. Six iron rebars, 1 cm diameter each and positioned 5 cm one from each other, have been implanted inside the concrete block and arrayed to form a grid. Then, the rebars grid has been positioned at different distances from the antenna's back cover, in particular at 2 mm, 1 cm, 2 cm and 5 cm. Results in terms of $|S_{11}|$, AR and efficiency η are shown in Figure 8 and Table 5.

It can be seen that the presence of rebars is negligible, in terms of efficiency, if their distance from the antenna is greater than 1 cm. In particular, at 2 cm distance an efficiency value equal to that evaluated in a structure without rebars, is obtained.

4. CONCLUSIONS

In this article, a circularly polarized patch antenna has been proposed and optimized to work embedded in the concrete. The antenna achieves very good performances in terms of $|S_{11}|$ vs concrete block characteristics and the polarization is always preserved. Effects of concrete permittivity variations, block size and rebars presence have been also investigated to prove its robustness. In all the simulations, PEC metallizations have been assumed, so antenna efficiency

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results sightly overestimated (~ 3%). Neverthless, the antenna shows a very simple, compact and low-cost design.

5. AKNOWLEDGEMENTS

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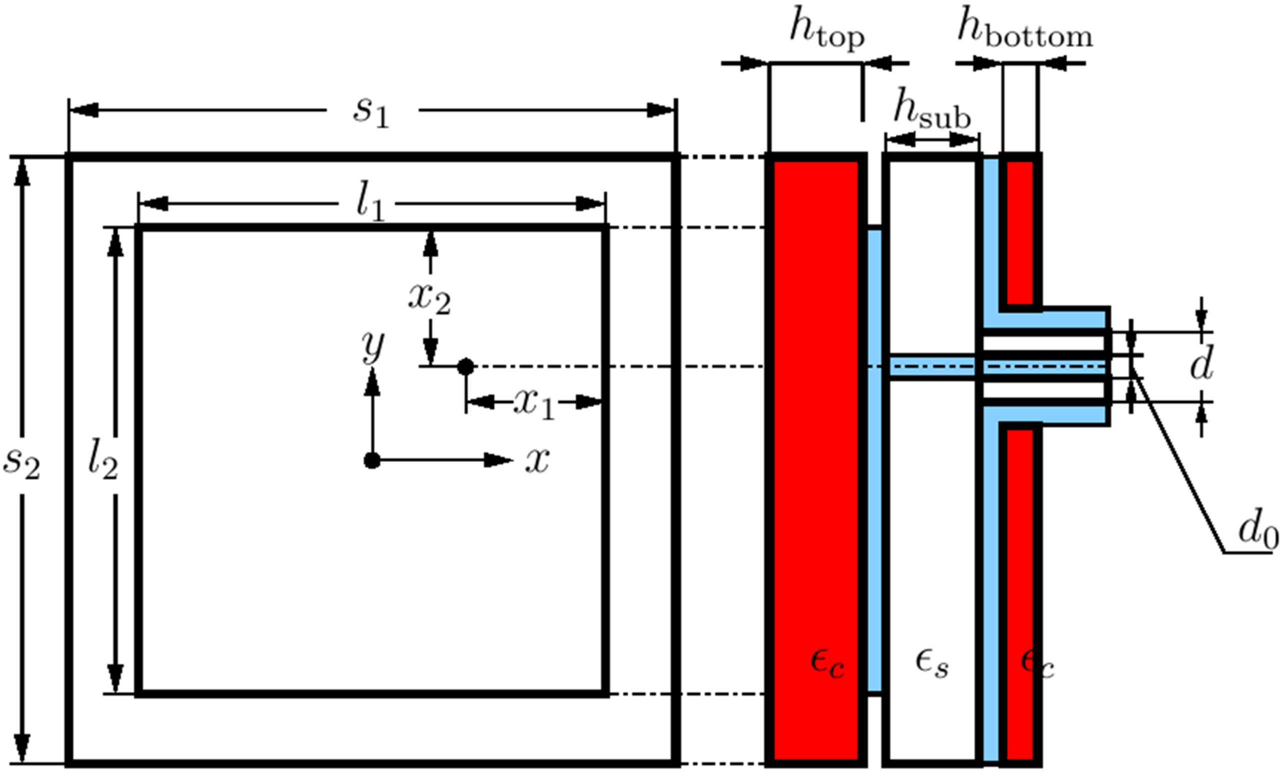

FIGURE 1 - Layout of the proposed antenna

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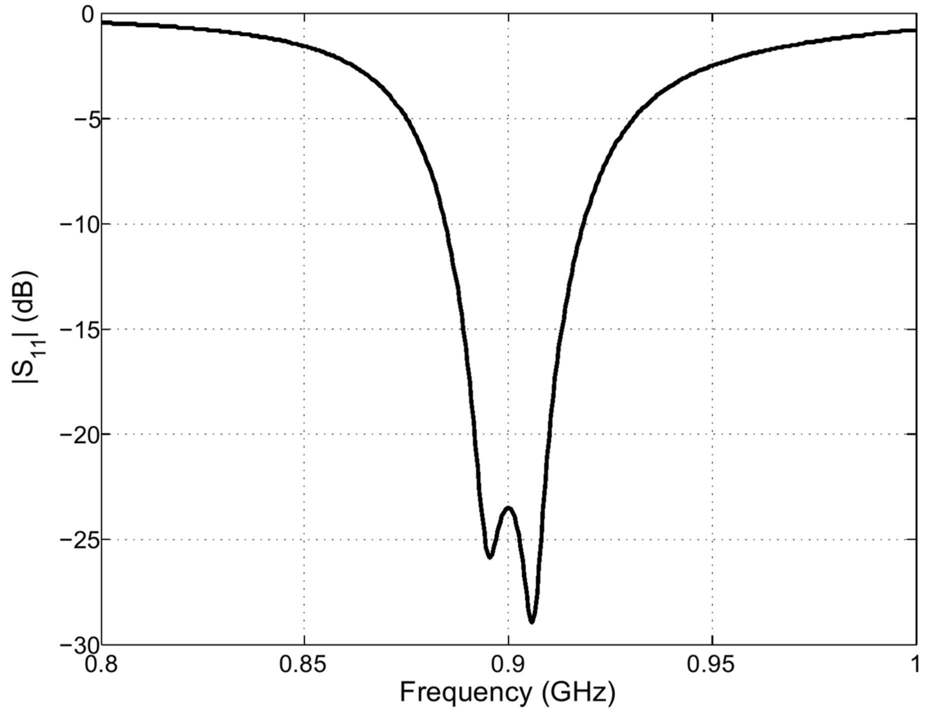

FIGURE 2 - Simulated $|S_{11}|$ of the antenna inside a concrete block of 15×15×15 cm^3, with nominal ε_r = 6 and tan δ = 0.03

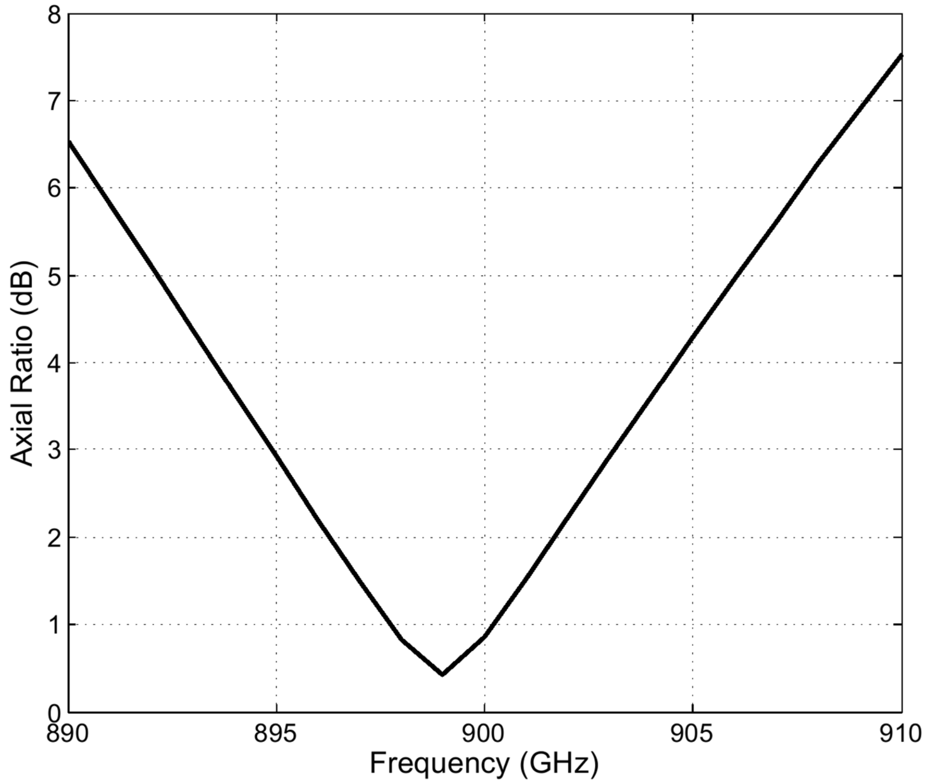

FIGURE 3 - Simulated Axial Ratio of the antenna inside a concrete block of 15×15×15 cm^3, with nominal ε_r = 6 and tan δ = 0.03

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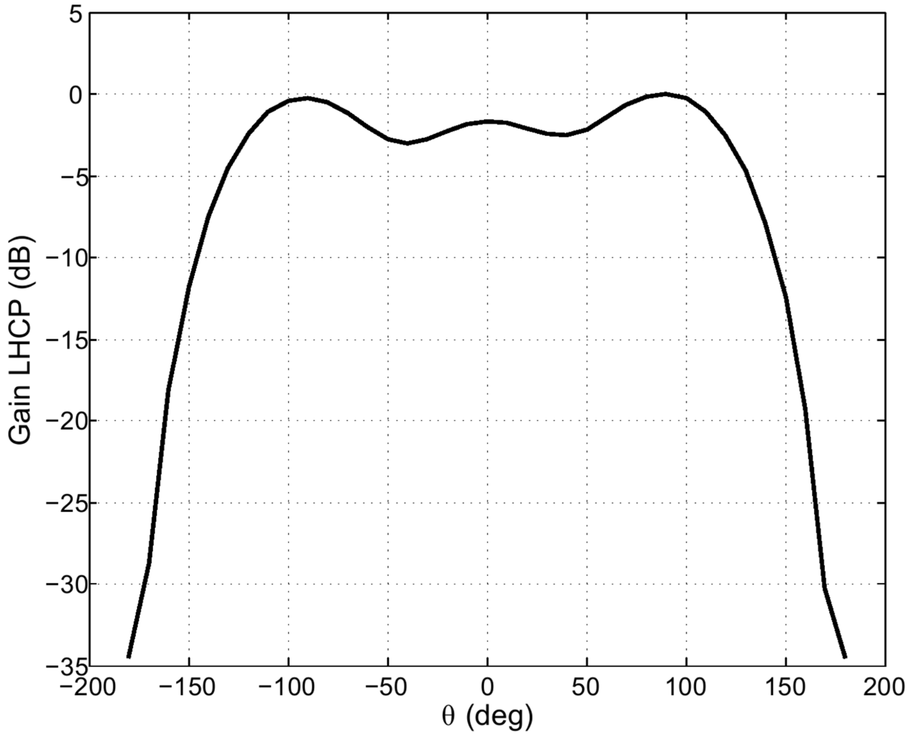

FIGURE 4 - LHCP gain of the antenna inside a concrete block of 15×15×15 cm^3, with nominal ε_r = 6 and tan δ = 0.03

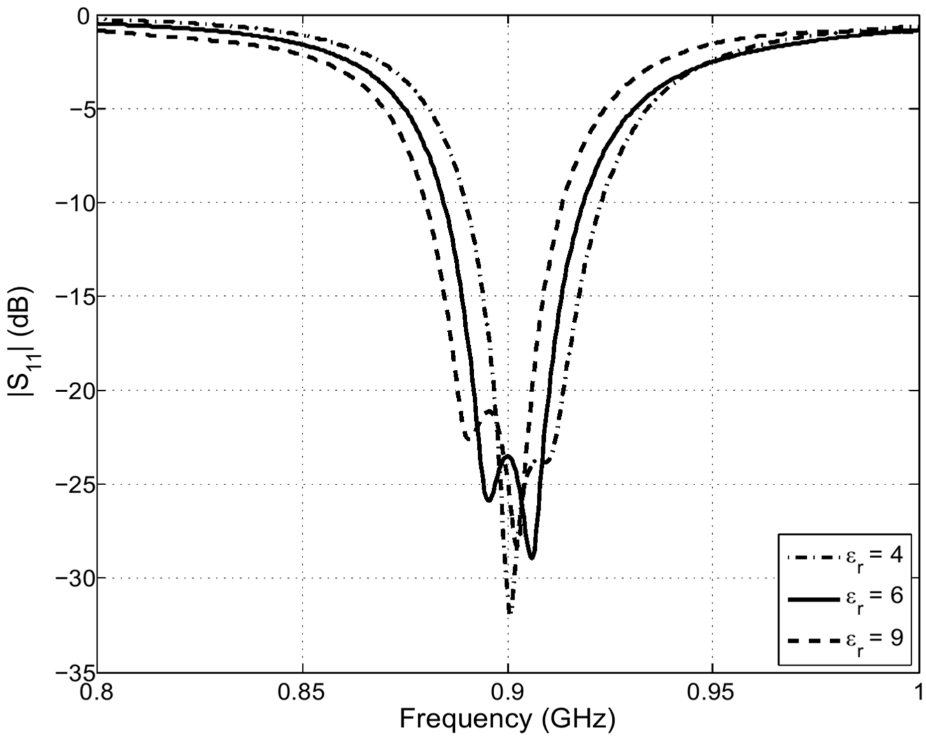

FIGURE 5 - Simulated $|S_{11}|$ of the antenna inside a concrete block of 15×15×15 cm^3, with ε_r = 4, 6, 9 and tan δ = 0.03

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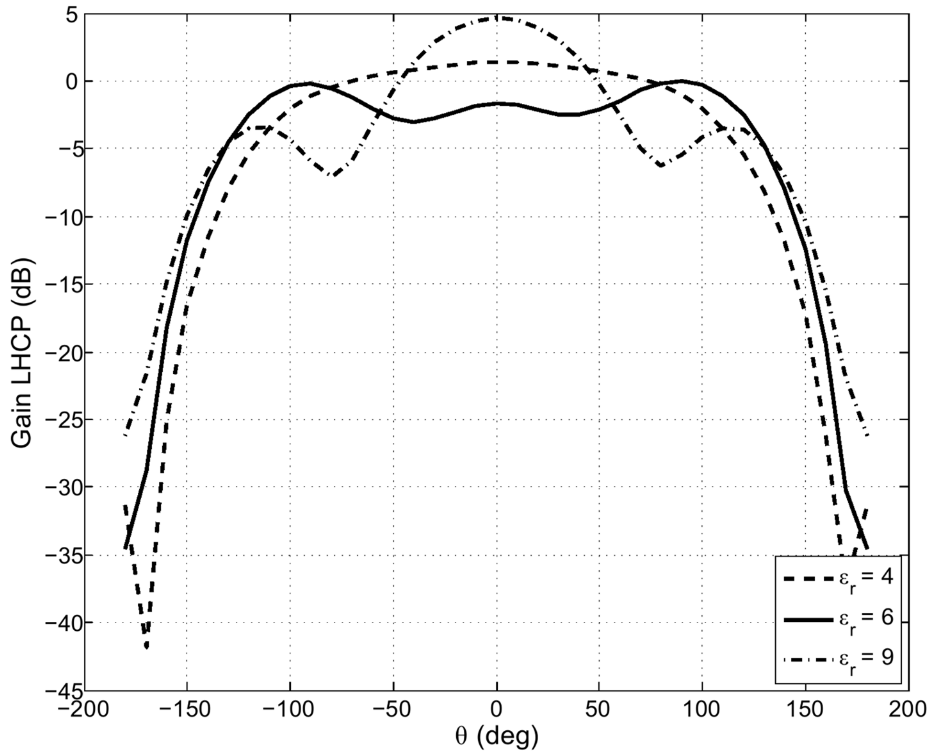

FIGURE 6 - LHCP gain of the antenna inside a concrete block of 15×15×15 cm^3, with ε_r = 4, 6, 9 and tan δ = 0.03

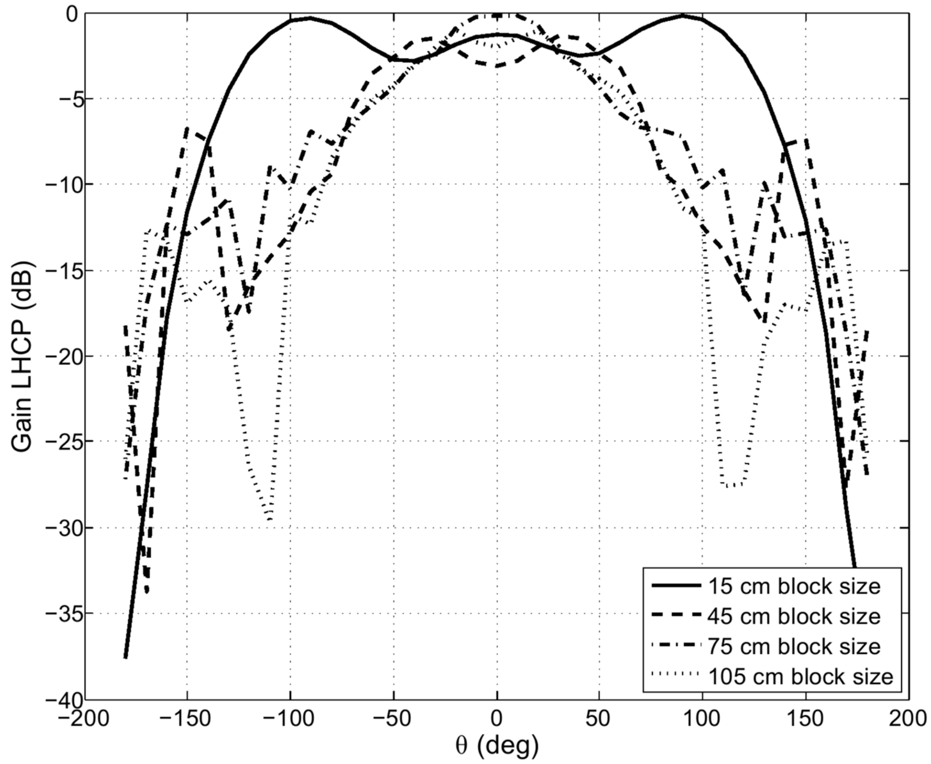

FIGURE 7 - LHCP gain of the antenna embedded inside concrete (ε_r = 6 and tan δ = 0.03), for block edge size of 15, 45, 75 and 105 cm

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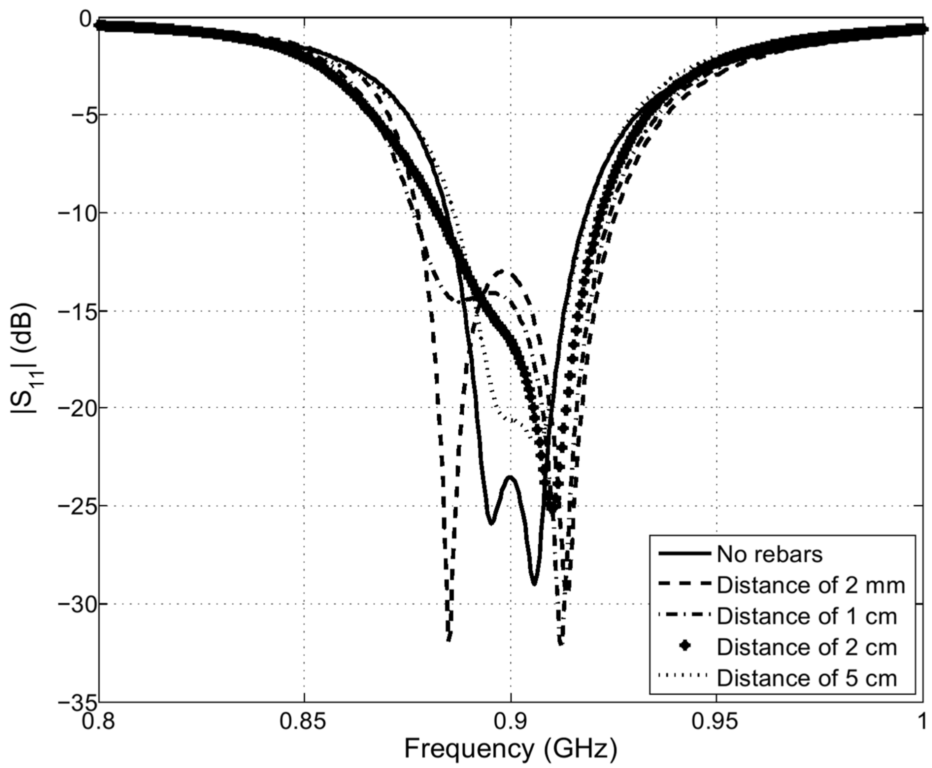

FIGURE 8 - Simulated $|S_{11}|$ of the antenna inside a concrete block of 15 × 15 × 15 cm^3, with $\varepsilon_r = 6$ and tan $\delta = 0.03$, for various rebars grid distances from antenna's back cover

TABLE 1 - Antenna parameters

Parameter	Description	(mm)
l_1	Patch width	50.4
l_2	Patch height	48.9
x_1	Feed *x* position	15
x_2	Feed *y* position	15
$S_{1,2}$	Substrate *x* and *y* dimensions	80
h_{sub}	Substrate height ($\varepsilon_r = 10.2$)	1.52
h_{top}	Top cover height ($\varepsilon_r = 6.15$)	1.52
h_{bottom}	Bottom cover height ($\varepsilon_r = 6.15$)	0.2
d_0	Coax feed inner diam.	0.9
d	Coax feed outer diam.	2.98

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TABLE 2 - Axial ratio and antenna efficiency, η, versus permittivity. Concrete block: 15 × 15 × 15 cm^3 and tan δ = 0.03

Permittivity	Axial Ratio (dB)	η
$\varepsilon_r = 4$	3.33	76%
$\varepsilon_r = 6$	0.86	72%
$\varepsilon_r = 9$	4.05	65%

TABLE 3 - Efficiency η of the antenna inside a concrete block of variable dimensions, with $\varepsilon_r = 6$ and tan δ = 0.03

Block edge size (mm)	η (FEM)	η (Hybrid FEM-IE)
15	72%	68%
30	49%	44%
45	32%	30%
60	28%	26%
75	25%	24%
90	22%	22%
105	21%	21%

TABLE 4 - Boresight LHCP Gain of the antenna inside a concrete block of variable dimensions, with $\varepsilon_r = 6$ and tan δ = 0.03

Bl. edge (cm)	Gain (dB) (FEM)	Gain (dB) (FEM-IE)
15	-1.69	-1.24
30	-1.27	-1.11
45	-3.58	-3.10
60	0.39	0.44
75	-0.20	-0.16
90	-0.47	-0.54
105	-2.87	-1.98

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TABLE 5 - Axial Ratio, Efficiency η and LHCP Boresight Gain of the antenna inside a concrete block of 15×15×15 cm^3, with $\varepsilon_r = 6$ and tan $\delta = 0.03$, at different distances of rebars grid from the antenna's back cover

Dist. rebar grid-antenna	AR (dB)	η	Gain (dB)
No rebars	0.86	72%	-1.69
2 mm	5.6	64%	1.53
1 cm	4.31	70%	1.78
2 cm	3.17	72%	1.73
5 cm	4.03	73%	1.74

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