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Embedded Microstrip Patch Antenna with Superstrate

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1. Introduction

Recently there has been an increase in demand for wireless sensors in civil engineering applications. The sensors are typically embedded in concrete at a depth greater than 100 mm. The wireless sensors consist of two elements, first is the sensor (passive device), and the second is the antenna element used for communication with an external data acquisition unit. The antenna element under investigation here, is a microstrip patch antenna embedded within concrete. The antenna operates at frequency of 2.44 GHz.

It is well known that placing a dielectric layer above a patch antenna will cause a shift in its resonant frequency [1]. Additionally, the gain and radiation pattern of the antenna are affected depending on the thickness and permittivity of the dielectric slab. Thick dielectric slabs with larger permittivity values lead to production of surface waves, which in turn lowers the antenna gain and distorts the radiation patterns. Unfortunately, in civil engineering applications, the concrete permittivity is variable. It can vary anywhere between a minimum of 6 to a maximum of 10 depending on the humidity, water content, and the material used in the production process. Keeping all these in mind, the antenna resonant frequency and gain, have to be independent of concrete properties, so that the system is operational under different humidity and water content of the concrete.

In this paper, properties of patch antennas with concrete as superstrate are investigated. Simulations for different cases (different concrete permittivity and thickness) are performed using Ansoft Designer which is based on the Method of Moments. A stacked antenna configuration with a foam superstrate is investigated, and the results show that the stacked antenna provides sufficient gain throughout the permittivity range with good impedance matching at a specific depth within the concrete.

2. Concrete Superstrate

The geometry of a microstrip antenna with concrete used as a cover layer is shown in Fig. 1a. The dielectric material used underneath the patch is (Arlon Diclad) with $\varepsilon_r = 2.5$ and $h = 1.59$ mm. Placing the patch antenna against concrete reduces the resonant frequency. This is illustrated in the return loss shown Fig. 1a. Return loss is shown for two extreme concrete permittivity (ε_{rc}) values of 6 and 10, and different concrete thickness t. Note that large concrete thickness and permittivity values create more significant shifts in the resonance. Next, the broadside gain vs. frequency of the embedded antenna is compared in Fig. 1b, with the reference antenna radiating in the air. Two different thicknesses of the slab, 10 mm, and 20 mm are also shown to indicate the surface wave effects. For concrete slab thicknesses larger than 10mm, the gain drops significantly, which is due to the excitation of surface waves within the concrete. For such cases, the peak of the radiation pattern is no longer in the broadside direction, and for certain cases it moves to the horizon.

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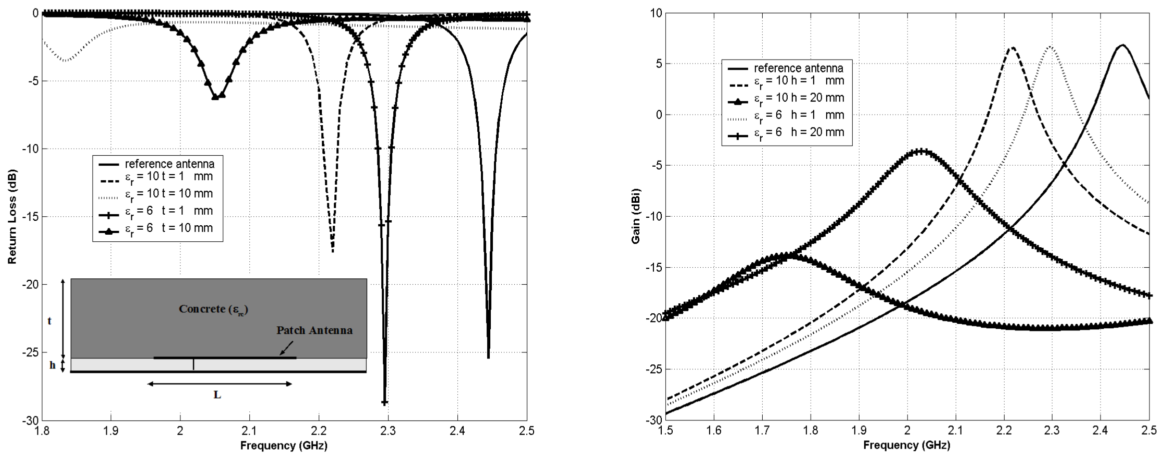
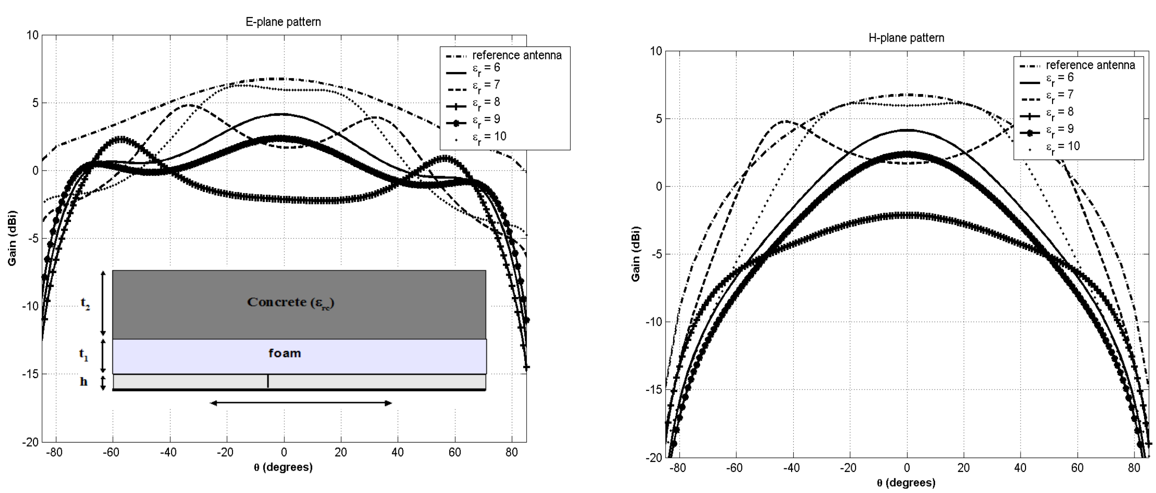


(a) (b)

Fig. 1 (a) Return loss of the embedded antenna (b) Gain vs. frequency plots of the embedded antenna

To correct the problem associated with the resonance shift, a layer of foam was inserted between the concrete and the surface of patch antenna (Fig. 2a). This creates a multiple superstrate structure with foam as the 1st layer, and concrete as the 2nd layer. For this structure to behave as a resonant superstrate [2,3], the foam thickness t_1 has to be approximately $\lambda_g/2$ while the concrete thickness t_2 has to be $\lambda_g/4$. However, in current application this is not possible, due to the depth at which the antennas are embedded. The concrete thickness is 100-150 mm, which is far greater than $\lambda_g/4$. The addition of foam causes the resonant frequency to be independent of the concrete thickness and permittivity. The resonant frequency remains practically unchanged at 2.44 GHz for all cases. Radiation patterns in both E and H planes for a foam thickness t_1 = 10 mm and different concrete permittivities are shown in Fig. 2a and Fig. 2b respectively. For all cases, t_2 is 100 mm. Note that, the simulation tool uses Green's function for an infinite dielectric layer and the fields at 90º are assumed to be zero, which for a finite structure is incorrect. Therefore, the simulated radiation pattern points at 90º are omitted from the plots.

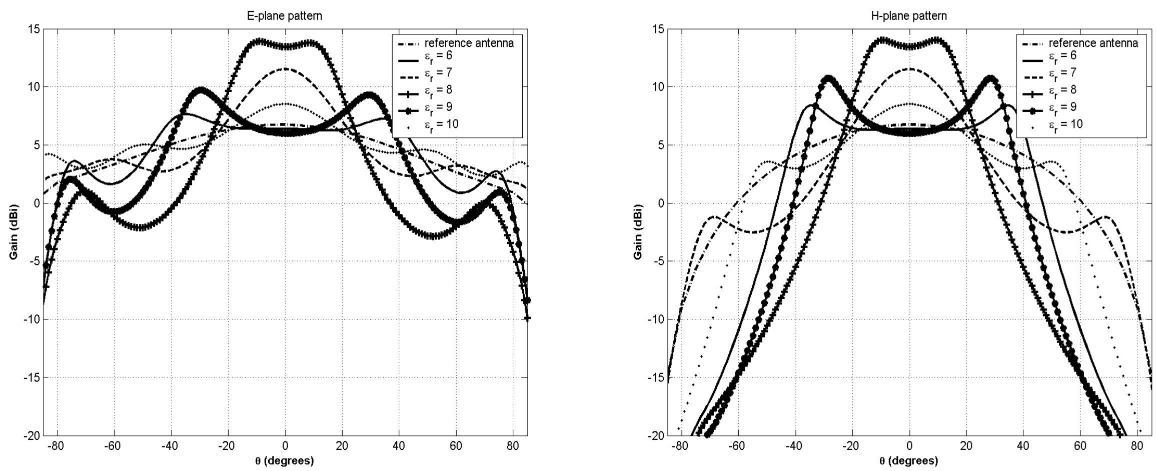


(a) (b)

Fig. 2 Patterns of the antenna with foam, t_1=10 mm, (a) E-plane (b) H-plane

Comparing the radiation patterns in Fig. 2, one can clearly see the drop in the antenna gain when the patch is placed adjacent to concrete. Beam splitting occurs for ε_r of 7 and 8 in the E-plane. The gain is particularly low (-2.13 dBi at broadside) for ε_r of 8, with maximum beam at $\theta = 57^{\circ}$. It is obvious that a foam thickness of 10 mm is not sufficient at a concrete depth of 100 mm.

Next, the same structure was simulated with a foam thickness of 60 mm ($\lambda_g/2$). The radiation patterns in the E and H planes are shown in Fig. 3a and 3b respectively. As expected, the gain levels are much higher, due to the superstrate effect of the foam layer. However, the beam splitting effect of the thick concrete slab is still evident. The radiation patterns shown in Fig 3. are considerably narrower than the ones shown in Fig 2. particularly for the H-plane. The lowest gain level in the broadside is 6 dBi for a concrete $\varepsilon_r = 9$. This is 0.7 dBi below that of the reference antenna. Overall, using the foam layer will provide sufficient gain of 6 dBi to 13.45 dBi, for the permittivity range of concrete, while keeping the resonant frequency unchanged.



(a) (b)

Fig. 3 Radiation patterns of the antenna with foam, t_l=60 mm, (a) E-plane (b) H-plane

3. Stacked Antenna with Concrete Superstrate

In this section, we introduce a new stacked antenna configuration that provides narrower overall beamwidth. Since the antennas will be placed periodically within the concrete, it is important to reduce their coupling effect with narrower radiation patterns. Its geometry is shown in Fig. 4. For this configuration, (Arlon Diclad) with ε_r = 2.5 and thickness h_2 = 1.6 mm, was used as the substrate between the top and bottom patch. The parasitic patch is slightly longer in length (L_2 = 36 mm) than the fed patch (L_1 = 35.5 mm). As before, the foam thickness t_2 = 60 mm with concrete thickness t_1 = 100 mm. The radiation patterns for this configuration in both E and H planes, are shown in Fig. 5a and 5b, respectively. The patterns in both planes are much narrower than those of the previous antenna for θ greater than 40º. Once again, beam splitting is seen due to the thickness of the concrete slab. The gain in the broadside varies between 6.7 dBi to 12.9 dBi. An additional advantage of this antenna is the stability of its resonant frequency, with respect to concrete permittivity and thickness. Even with no foam present, the resonant frequency is unaffected by the concrete slab. This is due to the fact that, the resonant frequency is controlled by the length of the fed patch, which is not in direct contact with concrete.

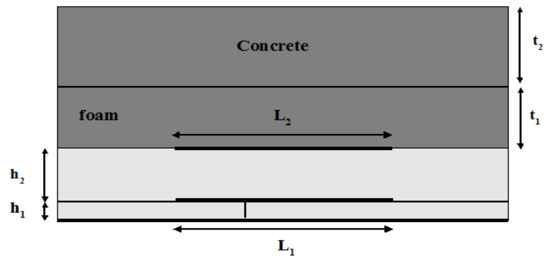
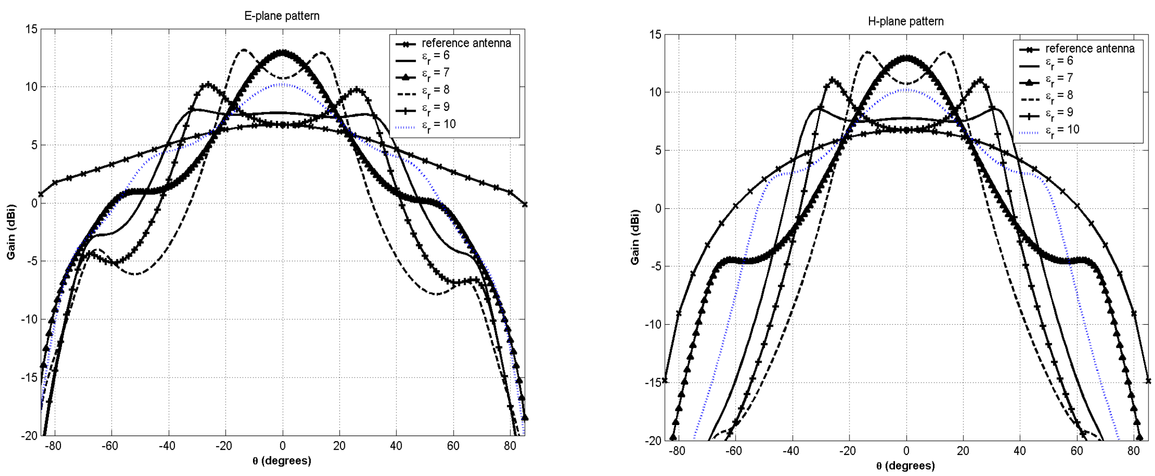


Fig. 4 Geometry of the stacked patch antenna



(a) (b)

Fig. 5 Patterns of the stacked patch antenna, t_1=60 mm, (a) E-plane (b) H-plane

4. Conclusion

Two new microstrip antennas with foam superstrates capable of operating within concrete were presented. The antennas operate with different concrete permittivites, and have resonant frequencies independent of the concrete thickness. The gain patterns however, were affected by the concrete thickness and beam splitting occurred for certain permittivities. Overall, the stacked configuration provided narrower beamwidths, suitable for the civil engineering application.

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