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DIELECTRIC LOADING FOR BANDWIDTH ENHANCEMENT OF ULTRA-WIDE BAND WIRE MONOPOLE ANTENNA

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Abstract—This work presents the results of numerical simulations and parametric studies of dielectric loaded wire monopole antenna, of which the main advantage is bandwidth enhancement. Introducing dielectric loading makes it possible to tune antenna to operate over a frequency range not covered with unloaded antenna, while maintaining an omnidirectional radiation pattern. The simulations are performed when loading is done with lossy as well as lossless dielectric and the results are compared. The observational frequency range is extended up to 40 GHz. In addition, the simulated results are compared with the measured S_{11} of four fabricated antennas loaded with lossy dielectric and a good agreement is obtained.

1. INTRODUCTION

Monopole antennas can be of various geometries [1] and are in use in many appliances, such as cellular telephones and car radios, and in broadcasting. One of the simplest is a wire monopole antenna over ground plane. In order to increase operational bandwidth, wire monopole antennas are loaded in different ways [2–4]. Dielectric loading [5–14] is one possibility for bandwidth enhancement. In some papers, dielectric loaded wire monopole antennas are called 'hybrid' antennas because they consist of two different radiators: a dielectric cylinder and a monopole. Thanks to dielectric loading, the bandwidth of the antenna can be changed without changing the existing device's profile (e.g., the height of antenna).

In our study, the loading of the antenna is done by placing the dielectric cylinders of various heights and radii around the wire which

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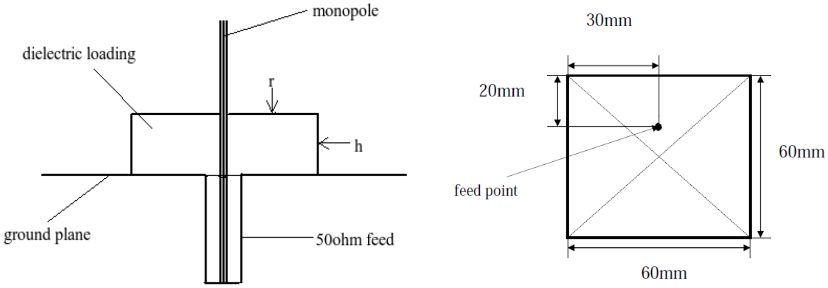
represents the monopole's radiator. The dielectric material used is the commercially available Stycast 2850 FT (s2850) epoxy. Using the numerical simulations and the dielectric cylinder height and radius as parameters, we investigated how a particular frequency range can be covered by tuning these parameters. We also investigated the radiation pattern of loaded antennas and compared this with the pattern from non loaded wire antenna. The observational frequency range of this type of antenna is extended up to 40 GHz which to our knowledge was not reported in published papers until now.

2. ANTENNA GEOMETRY, MODELING AND SIMULATION PARAMETERS

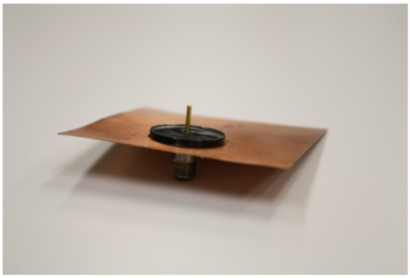
The monopole consists of a 9 mm long wire on the 60×60 mm ground plane and is the inner conductor of coaxial 3.5 mm 50 ohm SMA probe. The position of the monopole is not in the center of the ground plane but is a little offset (Figure 1(b)). The loading takes place using a dielectric cylinder wrapped around wire. The simulations are performed with CST Microwave Studio over the frequency range 0 to 40 GHz in the three following segments: 0 to 10 GHz, 10 to 30 GHz and 30 to 40 GHz, where the meshing of the structure is carried automatically. As previously stated the changing parameters in simulations are the height and the radius of the loading cylinder, and the simulations are performed both with lossless and lossy dielectric cylinder. Figure 2 displays the frequency dependent permittivity of the used s2850 epoxy dielectric which is extracted using the method described in [15] and is represented in CST Microwave Studio software using the appropriate Debye model. The lossless dielectric is represented as a material with a constant real permittivity value ($\varepsilon = 5$) over the frequency range, while imaginary permittivity equals 0.

3. FABRICATED ANTENNAS AND RELEVANT PARAMETERS

Four different loaded antennas are fabricated. The ground plane is made of copper and its dimensions are 60×60 mm. The hole in the ground plane (with diameter of 4.1 mm) is made in the offset position and the SMA connector with a 9 mm long inner conductor is attached from below. The loading cylinders are fabricated by pouring epoxy s2850 (100 g of s2850 resin is mixed with 4 g of C9 hardener) in the appropriate molds made from silicon that are placed around inner



(a) (b)



(c)

Figure 1. (a) Profile view of the geometry of proposed antenna, r is the radius of the dielectric cylinder and h is its height. (b) The position of the feed point is specified in drawing. (c) Fabricated antenna photograph. The dielectric loading is a black cylinder around the wire ($h = 2$ and $r = 10\,\mathrm{mm}$). The wire is the inner conductor of the coaxial probe and it is 9 mm long. The ground plane is made of copper.

conductor. 24 hours at room temperature is required for the epoxy to harden.

The fabricated antennas have the following loading dielectric cylinder dimensions (height (h) and radius (r)): antenna1 ($h = 2\,\mathrm{mm}$ and $r = 4\,\mathrm{mm}$), antenna2 ($h = 4\,\mathrm{mm}$ and $r = 6\,\mathrm{mm}$), antenna3 ($h = 2\,\mathrm{mm}$ and $r = 10\,\mathrm{mm}$) and antenna4 ($h = 4\,\mathrm{mm}$ and $r = 10\,\mathrm{mm}$). The photograph of the fabricated antenna3 is shown in Figure 1(c).

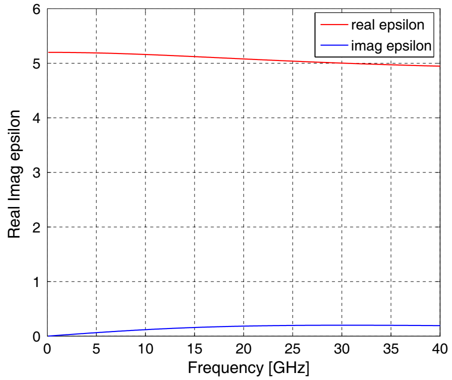


Figure 2. Real and imaginary part of permittivity of s2850 epoxy dielectric versus frequency.

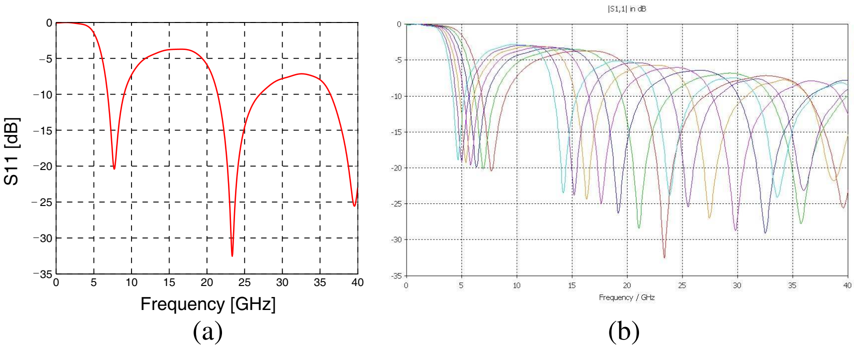


Figure 3. Simulated reflection coefficient of simple wire monopole antennas of different lengths: (a) S_{11} of 9 mm long monopole, (b) simulated S_{11} of monopoles which length varies from 9 mm to 15 mm.

4. SIMULATED AND MEASURED RESULTS AND DISCUSSION

4.1. Simulated Reflection Coefficients of Non Loaded Wire Monopole Antenna

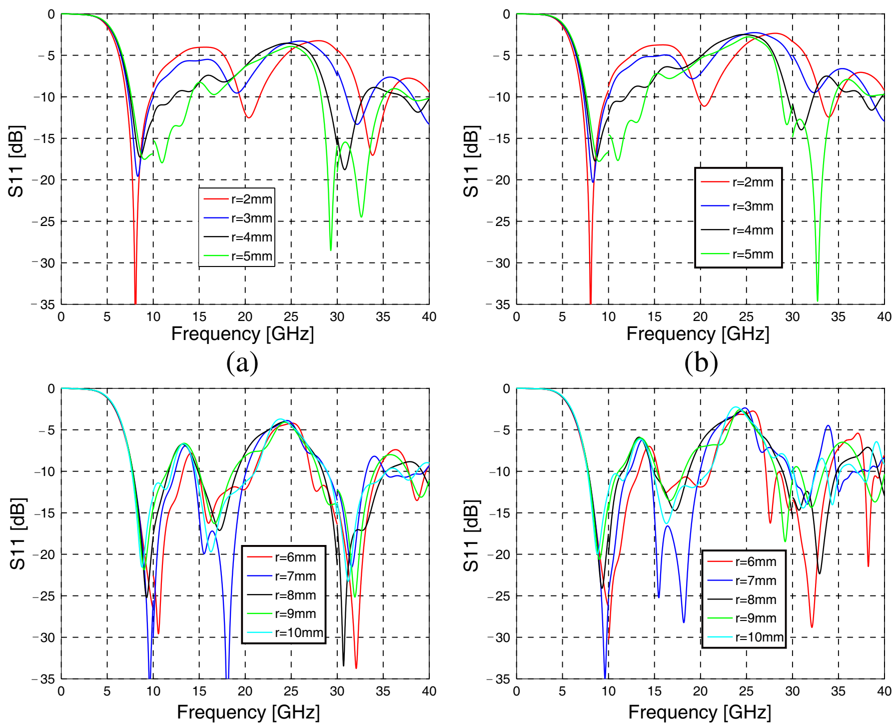
The simulated reflection coefficient of wire monopole antenna with a fixed length of 9 mm is presented in Figure 3(a), while the simulated reflection coefficients of wire monopole antennas where the length is varied from 9 mm to 15 mm are presented in Figure 3(b). We observe that by increasing of the length of wire, the resonances are shifted to the lower frequencies, whereas the bandwidth becomes slightly smaller. In our work, the wire length is fixed to 9 mm. Described geometry of monopole antenna with dielectric loading can be optimized for working at specific frequencies by simple frequency re-scaling of its dimensions.

From simulation presented in Figure 3(a) it is seen that for non loaded wire monopole antenna S_{11} is less then -10 dB from 6.8 to 9.04 GHz, 21.44 to 27.08 GHz and 36.3 to 40 GHz. These operational frequency bands will be later compared with the results obtained for loaded antennas.

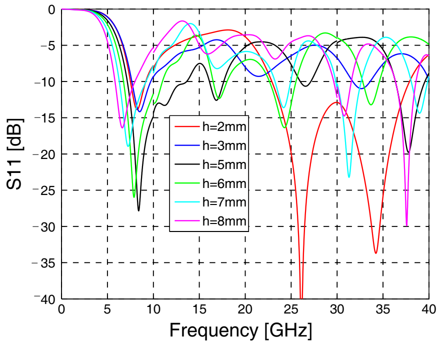
4.2. Simulated Reflection Coefficient of Loaded Antennas

First, we investigate influence on antenna's performances when loading cylinder is made of lossy and lossless dielectrics. Figure 4 displays the simulated reflection coefficients of loaded antennas in case of lossy and lossless dielectric.

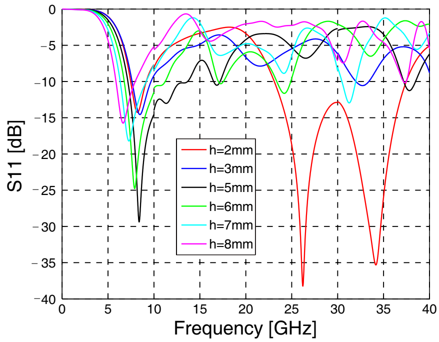
If the lossy material is used then the bandwidth is larger compared to the case of lossless material. The difference increases with icreases



(a) (b) (c) (d)



(e)



(f)

Figure 4. Simulated results of parametric computation of loaded monopoles when loading material is lossy and lossless. (a), (c) and (e) are simulations with lossy dielectric, while (b), (d) and (f) are simulations with lossless dielectric. In (a) and (b) the height of the loading cylinder is $h = 4\,\text{mm}$ and the radius r is changing from 2 to 5 mm. In (c) and (d), $h = 4\,\text{mm}$ and r is changing from 6 to 10 mm. (e) and (f) are simulations with $r = 4\,\text{mm}$ and h is changing from 2 to 8 mm.

Table 1. Lossy and lossless dielectric loading ($h = 4\,\text{mm}$, $r = 3\,\text{mm}$).

lossy, $S_{11} < -10\,\text{dB}$	7.48–10 [GHz]	30.98–33.72 [GHz]	38.17–40 [GHz]
lossless, $S_{11} < -10\,\text{dB}$	7.48–10 [GHz]	/	38.43–40 [GHz]

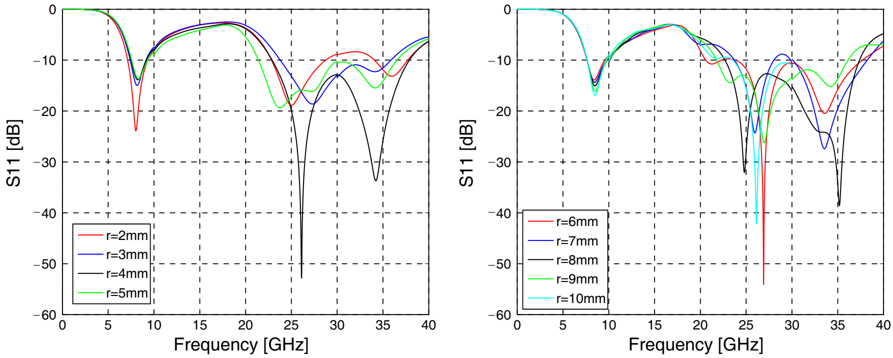
in frequency, especially in our case because the losses of lossy dielectric are lower at a lower frequency. This means that the permittivity has no imaginary part, only a real part. The important point is that losses of the lossy material that we used are not very big, which means that with bigger losses the bandwidth difference would be larger [5]. On the other hand, if we use very lossy materials for loading we must pay attention on efficiency of antenna [5].

Differences in antenna bandwidth behavior when loading cylinders are lossy and lossless dielectrics are summarized in Tables 1 and 2. In presented examples dimensions of loading cylinders are $h = 4\,\text{mm}$ and $r = 3\,\text{mm}$ (Table 1) and $h = 8\,\text{mm}$ and $r = 4\,\text{mm}$ (Table 2).

Figure 5 shows the simulations when $h = 2\,\text{mm}$ and radius is changed as parameter. This figure ilustrates that if h is low compared

Table 2. Lossy and lossless dielectric loading ($h = 8\,\text{mm}$, $r = 4\,\text{mm}$).

lossy, $S_{11} < -10\,\text{dB}$	5.8–8.05 [GHz]	29.56–31.58 [GHz]	36.3–40 [GHz]
lossless, $S_{11} < -10\,\text{dB}$	5.85–8 [GHz]	/	/



(a) (b)

Figure 5. Simulations of reflection coefficient of antenna when the height of loaded cylinder is $h = 2\,\text{mm}$ and (a) the radius is changing from 2 to 5 mm and (b) from 6 to 10 mm. The material that is used is a lossy dielectric.

to the monopole's height, the first resonance stays the same for all radius values, while the changes are visible at higher frequencies.

S_{11} of non loaded wire monopole antenna is higher than $-10\,\text{dB}$ at frequencies from $\sim$ 10 to 20 GHz and $\sim$ 27 to 37 GHz. The next two examples show how these frequency bands can have $S_{11} < -10\,\text{dB}$ with appropriate dielectric loading. According to the parametric study, if the wire antenna is loaded with dielectric cylinder with dimensions $h = 2\,\text{mm}$ and r is from 6 to 10 mm, S_{11} will be less than $-10\,\text{dB}$ at frequencies from $\sim$ 23 to $\sim$ 37 GHz. If dimensions of the loading cylinder are $h = 4\,\text{mm}$ and $r = 6\,\text{mm}$, S_{11} will be less than $-10\,\text{dB}$ at frequencies from $\sim$7 to 20 GHz.

What can be observed from simulations is when the height of loading cylinder is much shorter than wire length ($h = 2\,\text{mm}$), the first resonance is not influenced, but the second is. When the height is $h = 4\,\text{mm}$ and radius is changed, both first and second resonances can be enlarged. Finally, when radius is fixed to $r = 4\,\text{mm}$ and height is changed, both first and second resonances are enlarged and the first resonant frequency is lowered.

4.3. Measured and Simulated Reflection Coefficients of Fabricated Antennas

The simulated and measured S_{11} results of the four fabricated antennas are presented in Figure 6. We can observe the small differences between simulations and measurements which are more pronounced at higher frequencies. These differences can be caused by the imperfections in the fabrication process.

If we compare S_{11} of loaded and non loaded monopoles, the first resonant bandwidth of the wire antenna is enlarged for more than 10 GHz with dielectric loading as in antenna2 (Figure 6(b)). In Figure 6(c) (antenna3), the second resonance bandwidth of wire

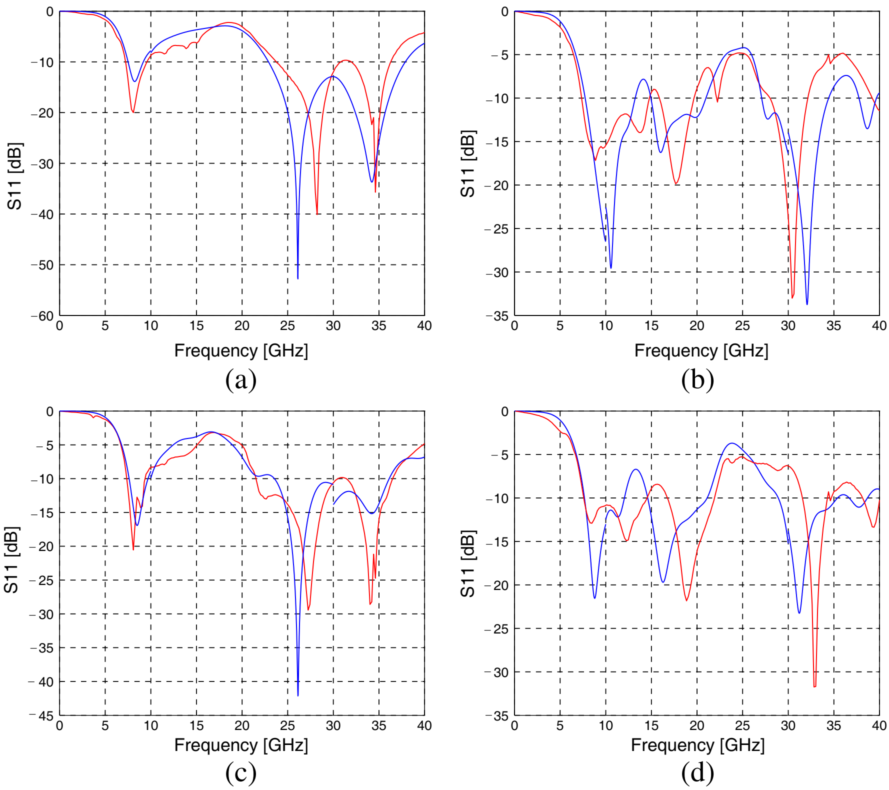


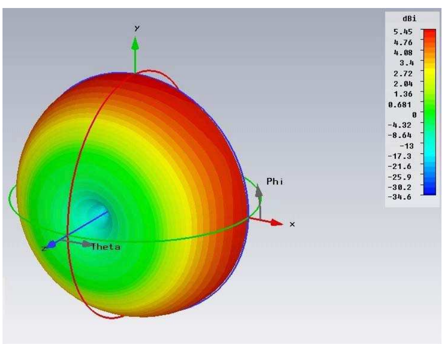
Figure 6. S_{11} of fabricated antennas, measured (red) and simulated (blue). Loading cylinder parameters (h and r) of fabricated antennas are: (a) $h = 2\,\text{mm}$, $r = 4\,\text{mm}$, (b) $h = 4\,\text{mm}$, $r = 6\,\text{mm}$, (c) $h = 2\,\text{mm}$, $r = 10\,\text{mm}$ and (d) $h = 4\,\text{mm}$, $r = 10\,\text{mm}$.

monopole antenna is also enlarged for $\sim$ 10 GHz. These examples show how with the appropriate loadings we can increase the first or the second resonance bandwidths of wire monopole antenna.

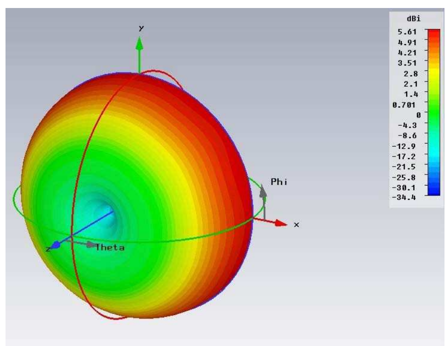
4.4. Simulated Radiation Pattern of Loaded and Non Loaded Antennas

The radiation pattern of wire monopole antenna depends on current distribution on the wire. It is omni directional in azimuthal direction and angle dependent on the elevation (at the zenith angle there is no radiation). Figure 7 shows the simulated radiation patterns for the wire monopole antenna and for the loaded monopole antenna with lossy dielectric.

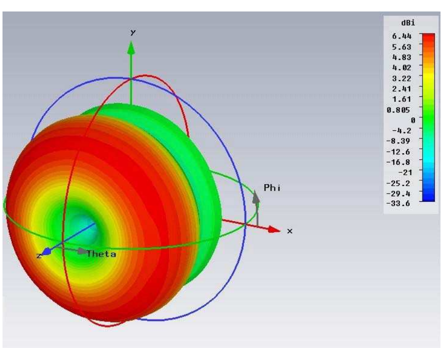
The radiation patterns are simulated at three frequencies that correspond to three frequency regions where antennas have $S_{11} <$ -10 dB. In Figures 7(a), (c) and (e), simulations of the radiation patterns of wire monopole antenna without loading are presented.



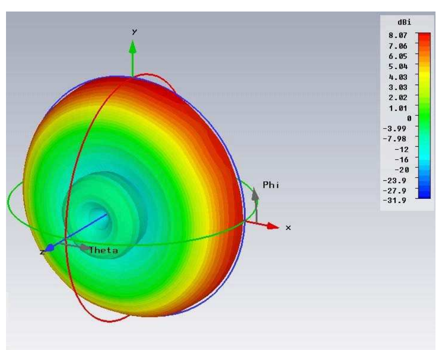
(a)



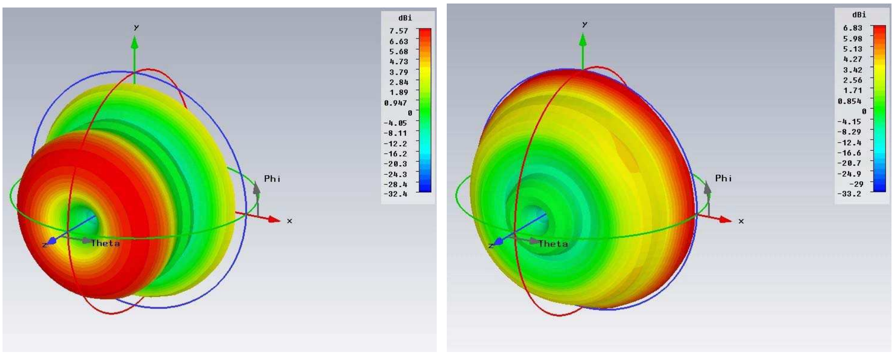
(b)



(c)



(d)



(e) (f)

Figure 7. Simulated radiation patterns of non loaded wire monopole antenna ((a), (c) and (e) wire length is 9 mm) and loaded monopole antenna with lossy dielectric ((b), (d) and (f) loading cylinder is $h = 4\,\text{mm}$, $r = 8\,\text{mm}$). Simulations are performed at the following resonant frequencies: (a) 7.5 GHz, (b) 10 GHz, (c) 23.5 GHz, (d) 17.5 GHz, (e) 39 GHz and (f) 31 GHz.

We can see that at higher frequencies, directivity increases but the maximum shifts to higher elevation angles (close to the zenith direction). In the case of the radiation patterns of loaded monopole antenna (Figures 7(b), (d) and (f)), by increasing the frequency, the directivity also increases (the gain is higher) but the half power beam width decreases. What is important to notice is that by loading of monopole antenna, the radiation pattern is not distorted and at higher frequencies it maintains omnidirectional characteristics at smaller elevation angles, which is not a case with not loaded antenna.

5. CONCLUSION

A FIT (Finite Integration Technique) with perfect boundary approximation has been applied to the analysis of dielectric loaded monopole antenna. Numerical simulations of S_{11} are performed in CST Microwave Studio software. We compared characteristics of antennas when loading material is lossy dielectric with frequency dependent permittivity as well as with lossless dielectric (which has constant and real permittivity over all frequency range). As a lossy dielectric we used s2850 epoxy material with which the real part of permittivity is much lower than the permittivity of dielectrics used in [7, 8]. The obtained result is that lossy dielectric has a bigger influence on the lowering of S_{11}. Also, the simulated radiation pattern of loaded antennas with lossy dielectric exhibits omnidirectional characteristics at low elevation angles in the observed frequency range, which is not the case with non-loaded monopole antenna. Depending on the application, this can be an advantage of loaded antenna over simple wire monopole.

Finally, the four loaded antennas are fabricated and the measured S_{11} is compared with the simulations. A good agreement is obtained. Slight disagreements are probably because of imperfections in the fabrication process.

The frequency range that is covered with the simulations and measurements is up to 40 GHz which is not found in literature so far. This parametric study also shows that without changing the existing profile of simple wire monopole antenna, by loading with lossy dielectric we can tune antenna to operate in the desired frequency range which is not covered by simple monopole.

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