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Design and Simulations of 2D Planar Antenna for Dielectric Characterization of Biological Samples †

Urvashi, Zeeshan, Mridul Kumar and K.S. Daya *

Dayalbagh Educational Institute; Agra, UttarPradesh, India
* Correspondence: sdayak@gmail.com
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Abstract: The dielectric parameters help in understanding the structural, compositional and functional analysis of biological samples. These parameters have also been widely adopted in biomedical and therapeutic fields. In the microwave region, these parameters carry much interest because the principal constituent of most biological cells is water. Therefore, it is difficult to isolate the dielectric response of water present in a biological-composite. So, the technique with enhanced sensitivity is essential for measuring the dielectric properties of biological samples. In this paper, we report the design and CST simulation of a 2D-planar patch type antenna with capacitive coupling introduced by dividing the patch through a gap. The aforementioned design further improves the antenna's sensitivity towards the dielectric properties of materials. Here, we simulated ten biological phantoms by measuring the shift in resonant frequency and return loss. Our results were identical when loading samples on either of the two introduced patches. These results suggest the repeatability and further improvements in a cavity-based technique where the sample localization is an important issue. Moreover, we analytically studied the dependency of gain and directivity of the antenna on the capacitive coupling, which plays a major role in the antenna's sensitivity towards dielectric characterization.

Keywords: dielectric; capacitive coupling; patch; sensitivity; directivity

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1. Introduction

The patch antennas are extensively used for implantable medical devices forvarious applications like microwave hyperthermia treatment, cancer tumor detection, tissue characterization,and imaging [1-5]. A patch antenna can be used as a dielectric-based biosensor which resonates depending upon the dielectric and other physical properties of the biological tissues. However, the patch antennas have a few disadvantages which include low gain and relatively large size [6-7]. Patch antennas generally use multiple array system to enhance their gain [8]. However, the use of multiple patches in multiple array system causes overall antenna size to increase which makes this technique not suitable for devices where size is the limitation. We in our simulations observed that the gain and sensitivity of patch antennas can be increased by introducing extra capacitance in the patch.We also observed that our technique enhances the sensitivity of patch towards dielectric properties of biological samples, which makes it an apt design for biological sample characterization.

2. Simulation Procedure

2.1. Design parameters forPatch antenna

The design parameters for the patch antenna were calculated using the equations reported for4 GHz resonant frequency (f_r) [9].We chose FR-4 as substrate(ϵ_r=4.3). The ground plane and patch weremade of copper. The resonant frequency of the antenna does not only depend uponthe width and length of the antenna but also on thecombination of inductance and capacitance introduced in the patch [10]. Here,we report that by introducing an additional capacitance the antenna gain, radiation field and sensitivity increases. We introduced the additional capacitance by cutting a small area surrounding the perimeter of a rectangle (Figure 1d (ii)), this rectangle is then further divided in two small patches separated by a small gap (Figure 1d (iii)).

2.2. CST Simulations

Initial design (D1) (Figure 1d (i)) wassimulated using CST Microwave Studio (version 2019) and the resonating frequency was found to be at 4.122 GHz. Further, D1 was modified (Figure 1d(ii), D2)and resonant frequency, S11 and electric field was found to be 4.2832 GHz, -17.14 dB and 17.8 dB V/m respectively. D2 was further modified (Figure 1d (iii), D3) in twopatches by introducing agap in the center. This final design has resonant frequency, S11 parameter and maximum electric field at 6.376 GHz, -14.8565 dB and 21.5 dB V/m respectively.This design has enhanced radiation field and can find applications in advanced biomedical, agriculture and wireless technology [11-13]. To check the sensitivity, ten biological phantoms were loaded on D2 and D3. We found that shift in resonant frequency and S11 response was maximum in the D3.

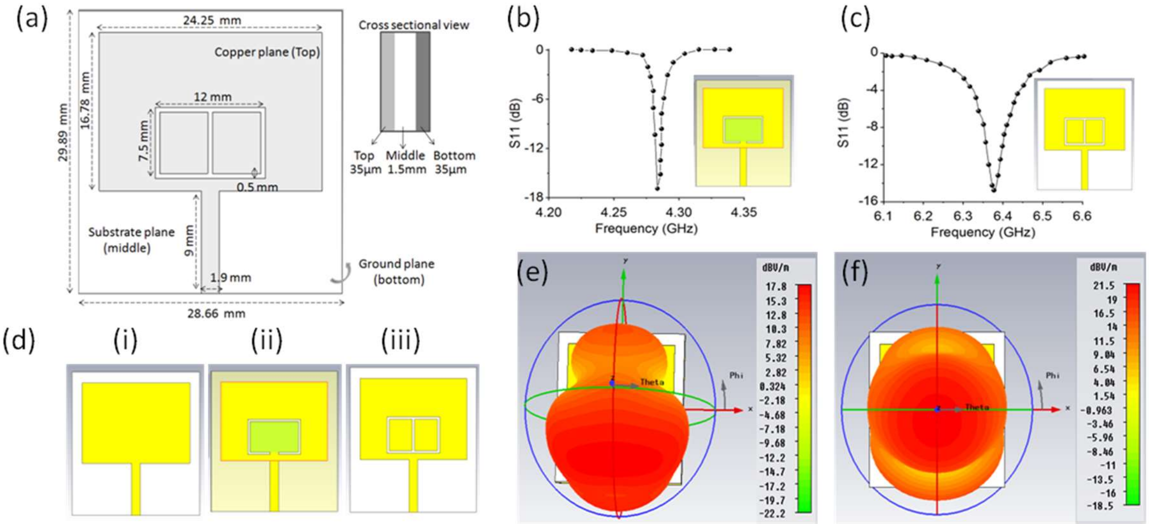

Figure 1. (a) Design paramters of patch antenna.(b-c) S11 response of patch shown in inset. d(i) initial design of patch. d(ii) improvement in the intial design. d(iii) final design. (e-f) electric field corresponding to patch d(ii) and d(iii) respectively.

3. Results

The resonant peak ofD1was broad and hada low quality factor, gain and directivity which show thelow radiation efficiency. However, in D2 peak became narrowas compared to D1. D2 had high quality factor, resonant frequency, gain and directivity. Furthermore, when D2 was modified to D3gain and directivity further increased. For checking the sensitivity of theD2 and D3, various biological phantoms (thickness 1mm) were loaded in simulation. The frequency shift of the antenna due to the presence of samples is shown in table 1. Here we have simulated 10 samples in which tooth phantomhas a low dielectric constant 9 and water has a high dielectric constant of 78. In the results, we found that tooth and fat have the difference of 1 unit of dielectric constant, the frequency shift measured in D3 was 9 MHzas compared to D2 which showed a shift of only 0.1 MHz frequency. Because of high electric field, D3 was sensitive to even half of the volume used in D1.In D3, we have left and right two small patches. To understand the symmetry of the left and right sections of patches in D3, samples (thickness 1mm) were loaded separately on these sections. We found that the frequency and S11 shift of the left and right sections were nearly the same as shown in the table1. Further, by varying the cut from 1 mm to 4 mm, resonant frequency and corresponding S11 response have changed as shown in the Figure2. As we increase the cut, resonant frequency, quality factor, gain and directivityalso increases.Therefore cut plays an important role in optimizing the performance of the patch.

Table 1. The Resonant Frequency (R.F.), Return Loss (R.L.) and Frequency Shift (F.S.) of D2 (See Figure 1d (ii)) and D3 (See Figure1d (iii)) by loading the various samples.

				Single Patch (Fig 1d(ii))			**Dual Patch (Fig 1d(iii))**					
				Sample Loading			**Left Side loading**			**Right Side Loading**		
No	**Samples**	**εr**	**σ**	**R.F.**	**R.L.**	**F.S**	**R.F.**	**R.L.**	**F.S**	**R.F.**	**R.L.**	**F.S.**
1	Empty	-	-	4.283	-17.145	0	6.376	-14.856	0	6.376	-14.856	0
2	Skin tissue	35	3.9	4.238	-8.860	44.3	6.321	-10.082	55	6.321	-10.085	55
3	Water	78	10^{-6}	4.225	-10.892	57.6	6.290	-12.473	86	6.290	-12.455	86
4	Tooth	9	1.2	4.246	-24.325	36.3	6.329	-13.740	47	6.329	-13.740	47
5	Tongue tissue	47	5.5	4.235	-14.681	48	6.311	-11.231	65	6.311	-11.230	65
6	Bile tissue	63	7.5	4.231	-10.733	52	6.304	-9.857	72	6.304	-9.857	72
7	Blood tissue	52	6.8	4.236	-11.128	46.4	6.310	-10.826	66	6.309	-10.836	67
8	Brain tissue	39	5.2	4.236	-11.128	46.4	6.314	-11.452	62	6.314	-11.452	62
9	Fat tissue	10	8.7	4.246	-27.325	36.4	6.320	-10.393	56	6.320	-10.385	56
10	Lung tissue	18	2.2	4.243	-23.588	40	6.323	-12.199	53	6.323	-12.200	53
11	Reproductive tissue	38	4.5	4.236	-19.820	46.4	6.314	-11.626	62	6.314	-11.626	62

4. Discussion

This paper presents a method of increasing the sensitivity of patch by artificially introducing capacitive effectsfor dielectric characterization of biological samples. This analysis is important for tuning the resonant frequency and optimizing the sensitive area on the patch without varying itssize. Even loading the sample separately on the two sections, the frequency shift and return loss appear symmetric, the proposed antennae can be used as an alternative to thebulky cavity perturbation technique in which device handling and the sample position are some limitations.Furthermore,validation of the results with fabricated antenna will play crucial role in biosensing.

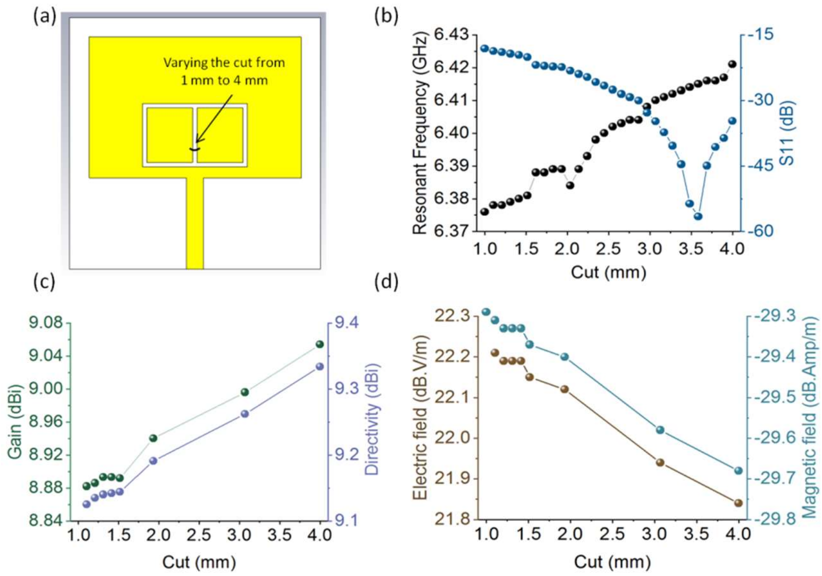

Figure 2. CST Simulations: (**a**) Front view of the design, (**b**)The change in resonant frequency and corresponding maximum S11 response, (**c**) Maximum Gain and Directivity, (**d**) Maximum electric field and magnetic field by varying the cut from 1 to 4 mm as shown the above patch shown in Figure 1d(iii))**.**

Conflicts of Interest: "The authors declare no conflict of interest."

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