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A 3D directive microwave antenna for biomedical imaging application

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Abstract. A directive three dimensional antenna, using folded radiating structure has been presented for the application of microwave imaging in clinical diagnosis. Two reflector walls have been introduced to achieve higher gain and directive radiation pattern along with the folding technique. The shorting wall technique is utilized to reduce the overall antenna size and to get resonance at a lower frequency. The proposed antenna obtained operating band at 1.67 GHz to 1.74 GHz. The dimension of the 3D radiating structure is $40\times25\times10.5$ mm^3. The antenna has an average realized gain of 5.2 dBi. Owing to the unidirectional radiation pattern, high gain and operating bandwidth within lower microwave frequency, the proposed antenna has potential to be used in microwave imaging for biomedical diagnosis. Also, the antenna has been utilized to compute an imaging phenomenon to detect abnormality in human head and result is presented. The design and simulation process are performed in the CST Microwave Studio software. The antenna is fabricated from 0.2 mm thick copper sheets. The results of the fabricated antenna are measured using PNA Network Analyzer (N5227A) and Satimo Star Lab.

Key words: antenna, 3D antenna, microwave sensor, microwave imaging, unidirectional.

1. Introduction

Microwave imaging in the application of clinical diagnosis of human health is an emerging issue. By using electromagnetic waves, the approach to identify hidden or concealed phenomena in structures is microwave imaging. Microwave based health care diagnosis method is a reliable monitoring tool for different health disorder like congestive heart failure [1], stroke [2], breast cancer etc. A microwave imaging system usually consists of two sections; hardware and software. A transmitter and a receiver antenna are the major apparatus in the hardware part to obtain data from the sample under test condition.

In [3], an attempt to apply an experimental system to use microwave screening on realistically shaped breast phantom is presented. In [4], an early stage heart failure detection system has been reported based on a three dimensional antenna. An array of 16 antennas is used for microwave system in human head imaging application in [5]. The antenna should possess some basic properties for human head imaging, like unidirectional radiation pattern, high gain and operating band within 1–4 GHz [6]. The lower operating frequency band of the antenna, the better signal penetration and image resolution can be obtained [7]. When the operational frequency needs to be limited within lower microwave frequency bands, obtaining all the antenna requirements is a challenge.

The accuracy of the detection of traumatic tissue and the positioning of the imaging process becomes easier and simpler with highly directive antenna [8]. To achieve the operating frequency in required band and high directivity, several attempts have been reported for the application of human head imaging. In [7], an antenna with three dimensional structure has been proposed which possess a good impedance bandwidth. However, the antenna is not unidirectional, instead its radiation pattern is more like omnidirectional with peak gain nearly 4 dBi and the height of the antenna is 30 mm, which might not be considered as compact enough in question of portability.

A coplanar waveguide-fed three dimensional antenna for human head imaging application has been proposed in [9]. The antenna covers frequency bandwidth well. However, peak gain is still 4 dBi approximately.

Many other antenna designs have been proposed for biomedical diagnosis. A bowtie shaped antenna has been presented in [10]. The antenna is proposed for on-body application during medical diagnosis process. In [11], an approach to detect the early stage of congestive heart failure is presented, where a three dimensional antenna of overall size $160\times60\times50$ mm^3 has been used. Although the overall performance of the antenna is satisfactory, the total Dimension of the antenna is slightly large.

Researchers applied several methods to obtain directive radiation pattern. One of the most effective techniques to obtain a unidirectional radiation pattern is to locate a reflector from half wavelength far from the antenna. In [12], closely spaced loading technique is used to make a unidirectional antenna. In [4], folding technique is obtained to get directional radiation characteristics. In [13], meandering, dual monopole feeding, as well as folding techniques are used to get directivity for the antenna.

In this paper, a three dimensional design of an antenna is proposed, which is composed of traditional 3D design structures along with performance optimization methods. To design the main radiating element of the antenna, folding technique is ap-

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plied, which exhibits operating bandwidth at lower frequency. Two reflector walls are used on the ground plane placed on the left and right side of the whole radiating element to attain higher gain. Finally, the structure successfully achieved impedance bandwidth of 1.67 GHz to1.74 GHz, resulting in the resonant frequency at 1.71 GHz. The antenna has a highly directional radiation pattern along z axis with peak gain of 5.2 dBi.

2. Design of the antenna

The proposed antenna has been designed and simulated in CST Microwave Studio electromagnetic simulator. The design of the antenna is depicted in Fig. 1. The structure of the proposed antenna is developed using 0.2 mm copper sheets. The air gap between the ground plane and radiating element acts as a substrate. The coaxial probe and the small shorting wall left to the antenna are responsible for providing support to the radiating element. The antenna height is total H = 10.5 mm, from the ground plane to the upper radiating arms. The optimized design parameters of the proposed antenna are enlisted in Table 1.

Table 1
Design parameters of the proposed antenna

L	80	*b*	5	*e*	4.3	h	2
W	80	*c*	15	*f*	4	i	36
a	40	*d*	35	*g*	10		

There is a direct connection between the lower radiating element and the connecting probe. The extended parts of the reflector walls, lower radiating element and the shorting wall used to aid the fabrication process and provide stability to the structure. The two reflector walls on both sides enhance the directivity and gain. Current gets reflected from these walls and propagates towards upper radiating elements. The shorting wall plays a vital role in obtaining better reflection coefficient and get resonance at lower frequency.

Coaxial feeding is applied to the structure as it decreases spurious emission that happens in other feeding methods. The inductance associated with the line of the probe gets more efficient and exhibits a narrow bandwidth of reflection coefficient due to the increase in the length of the probe. To deal with this inductance, minimizing the probe length can be a solution. The total dimension of the radiating structure is responsible for achieving band in the lower microwave frequency range. Folding method is applied to obtain operating band at lower frequency.

To reduce the disruption of current concentration, a distance is maintained between feeding point and the bending points [4, 14]. The upper radiating elements look like two 5 mm wide small copper strip when seen from the top view.

The resonant frequency of the proposed antenna can be approximately obtained from the equation mentioned in [15],

$$f_r = \frac{c}{x\sqrt{2(\varepsilon_r + 1)}}. \tag{1}$$

Where c is the speed of light, x is the total length of the radiating element, ε_r is the relative permittivity of the material used and f_r is the resonant frequency of the operating band. In this proposed antenna the length x is 88.6 mm.

The antenna prototype has been built in three steps. The 5 mm wide upper radiating elements are cut from a 0.2 mm thick copper sheet and they are bent at their respective points according to design. The lower radiating element, reflector walls, and the shorting wall are cut and modified accordingly. Finally, they are soldered together at their respective position.

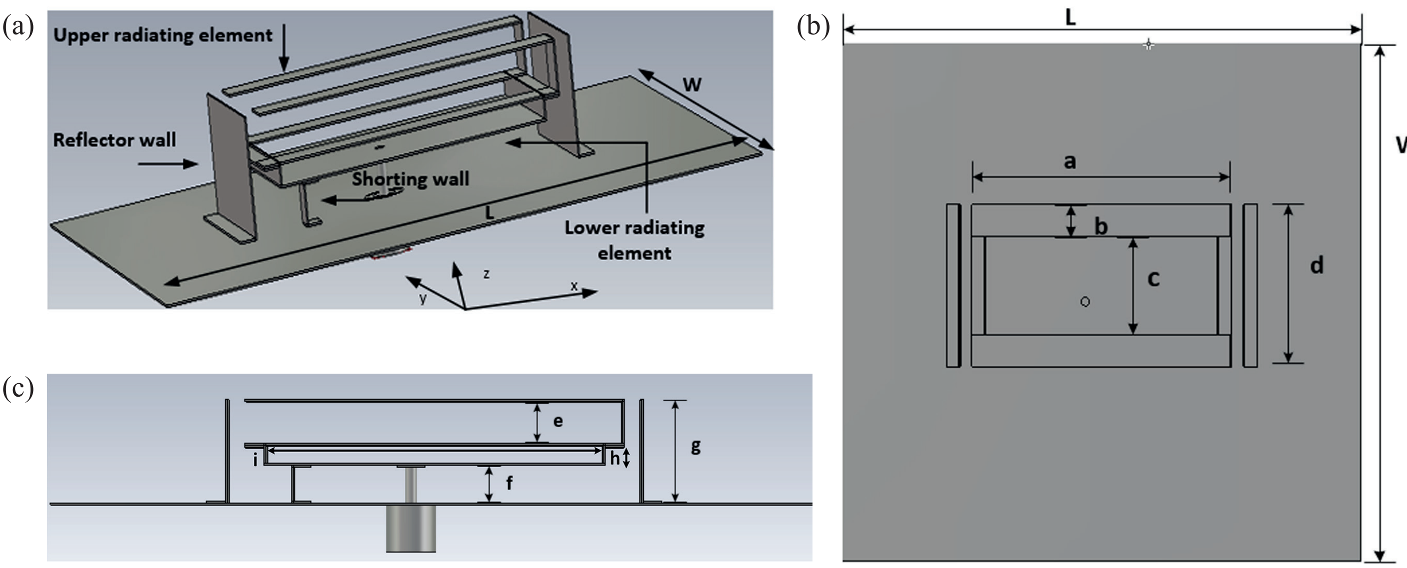

Fig. 1. (a) 3D view, (b) top view and (c) side view of the proposed antenna

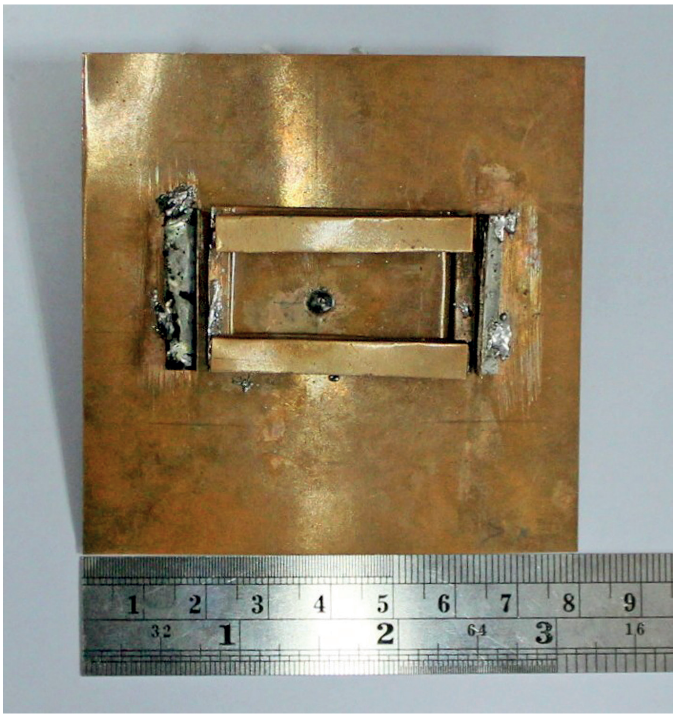

Fig. 2. Fabricated prototype of the proposed antenna

The fabricated prototype of the proposed antenna is shown in Fig. 2.

3. Results and discussion

The antenna prototype has been fabricated using the optimized design parameters enlisted in Table 1. The simulated and measured reflection coefficients are illustrated in Fig. 3. Although there has been 20 MHz shift in measured reflection coefficient, the measured and simulated results are in good agreement. Error

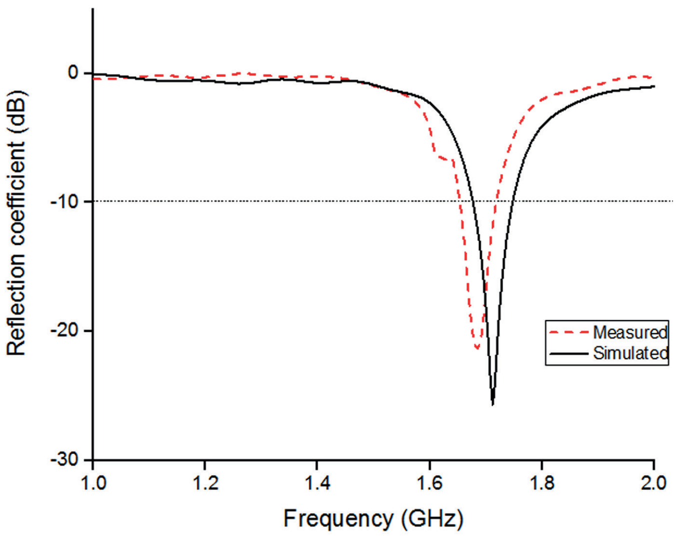

Fig. 3. Reflection coefficient of the proposed antenna

during manual fabrication might be responsible for a little mismatch.

The proposed antenna has measured reflection coefficient below –10 dB at 1.65–1.72 GHz, where it is at 1.67–1.74 GHz in the simulated result.

The antenna achieved an average realized gain of approximately more than 5dBi within the operating bandwidth shown in Fig. 4. In Fig. 5, measured and simulated efficiency plot is presented.

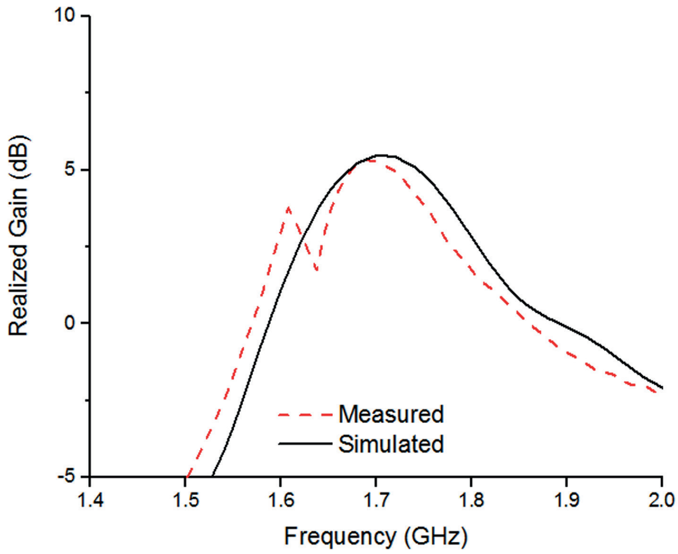

Fig. 4. Peak gain of the proposed antenna

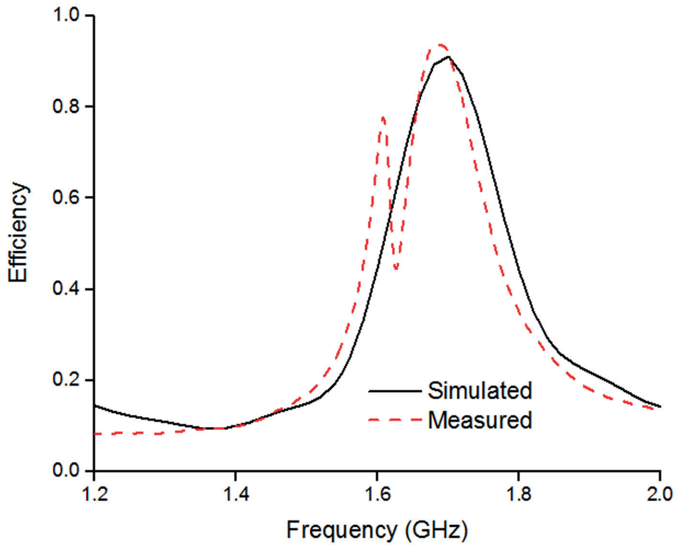

Fig. 5. Efficiency of the proposed antenna

Figure 6 represents the simulated result of the front to back ratio of the proposed antenna. The front to back ratio of the antenna is nearly 20 in the resonant frequency of the operating band, which proves the unidirectional feature.

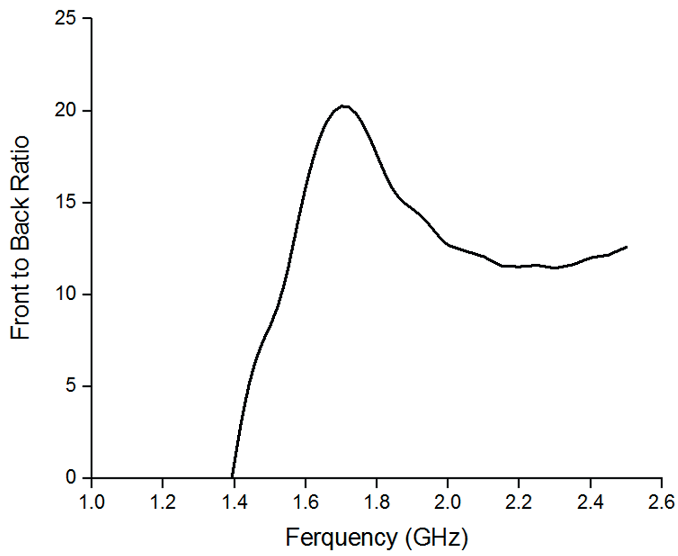

Fig. 6. Front to back ratio of the proposed antenna

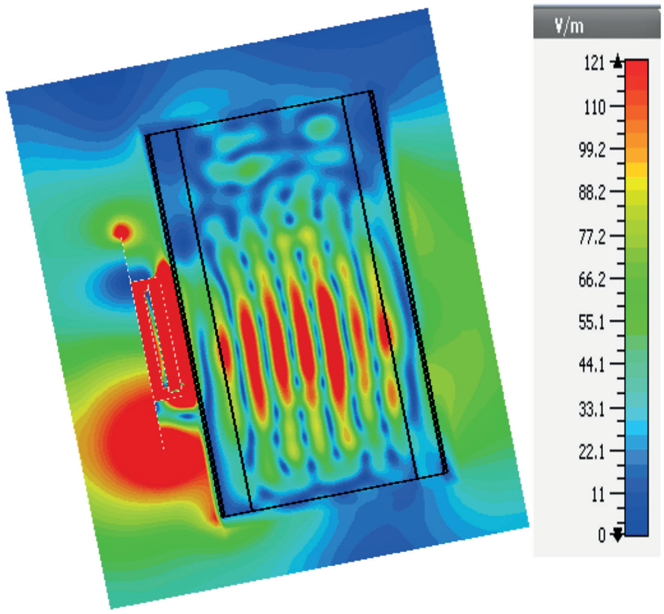

Fig. 9. E-field distribution of the proposed antenna at 1.7 GHz

Figure 7 illustrates the surface current distribution of the proposed antenna at 1.70 GHz. Presence of strong current can be observed on the upper radiating elements that has a total length of roughly 88.6 mm which is primarily responsible for resonance at 1.70 GHz. In addition, reflections from the ground plane right beneath the radiating elements and the reflector walls influence the antenna to achieve unidirectional performance.

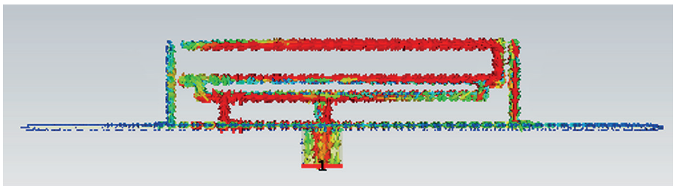

Fig. 7. Surface current distribution of the proposed antenna

Figure 8 presents the far-field radiation patterns of the proposed antenna at 1.7 GHz. It is clear that, the measured and simulated radiation patterns are both in good agreement. The radiation patterns of Fig. 8 validates the simulated result of front to back ratio of the proposed antenna shown in Fig. 7.

The overall performance of the fabricated antenna validates the results obtained from simulated design. Slight mismatch between simulated data and measured data might be due to imperfection of manual fabrication.

Figure 9 illustrates the EM propagation behavior of the proposed antenna with a computational model of human head phantom depicted in Fig. 11(a) at the resonant frequency. It seems that, the distribution of the electric field remains directive even through the phantom.

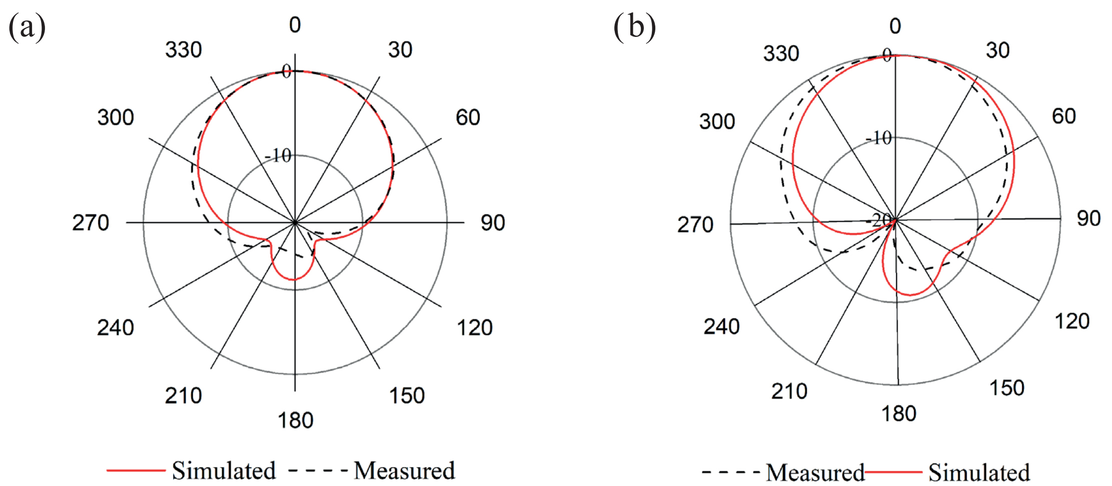

Fig. 8. Radiation pattern of the proposed antenna at 1.7 GHz. (a) xz measured and simulated, (b) yz measured and simulated

Computation of antenna near E-field distribution in the head model has been performed to investigate antenna nearfield performance, presented in Fig. 10. It is evident that, the near field of the antenna is fairly uniform at close proximity to the model. Also, the magnitude of the E-field decreases as the antenna is placed closer. This phenomenon is because of the increase in the losses of the coupling medium. It can be predicted that, the antenna performance will be fair enough in near field imaging too.

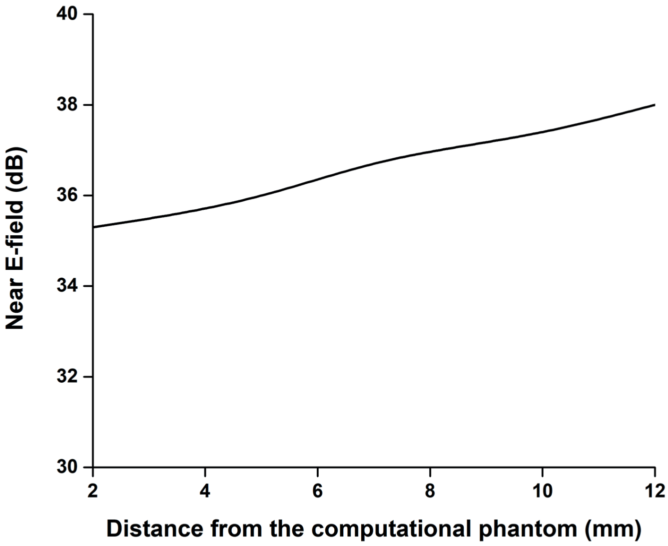

Fig. 10. Antenna near E-field in proximity of multilayer phantom model

Finally, the antenna has been utilized to compute an imaging phenomenon to detect abnormality in human head as shown in Fig. 11(a). A rectangular brick consisting three layers of different dielectric is used to mimic human head. Layer 1, layer 2 and layer 3 are considered skin, skull and gray matter of human head. Dielectric constants of layer 1, layer 2 and layer 3 are 38, 15 and 45. Inside the brick a rectangular object with high dielectric of 70 is placed to represent tumor. The data has been obtained using the raster scanning method [16]. Normalized scattered parameter data have been used to construct the image in Fig. 11(b). The existence of the tumor can easily be identified by the most red part of the image.

4. Conclusion

The proposed design of the folded 3D structure provides an antenna of considerably smaller dimensions. Shorting wall provides the structure stability and lower frequency operation. The antenna prototype's E-field pattern remain directive in both near-field and far-field condition. The proposed antenna obtained a peak realized gain of 5.2 dBi. Unidirectional radiation pattern, high gain and lower frequency operation make the proposed antenna a potential candidate for microwave imaging. Computation of microwave imaging phenomenon with the proposed antenna using raster scanning method has been performed. The abnormality is successfully detected in a computational model.

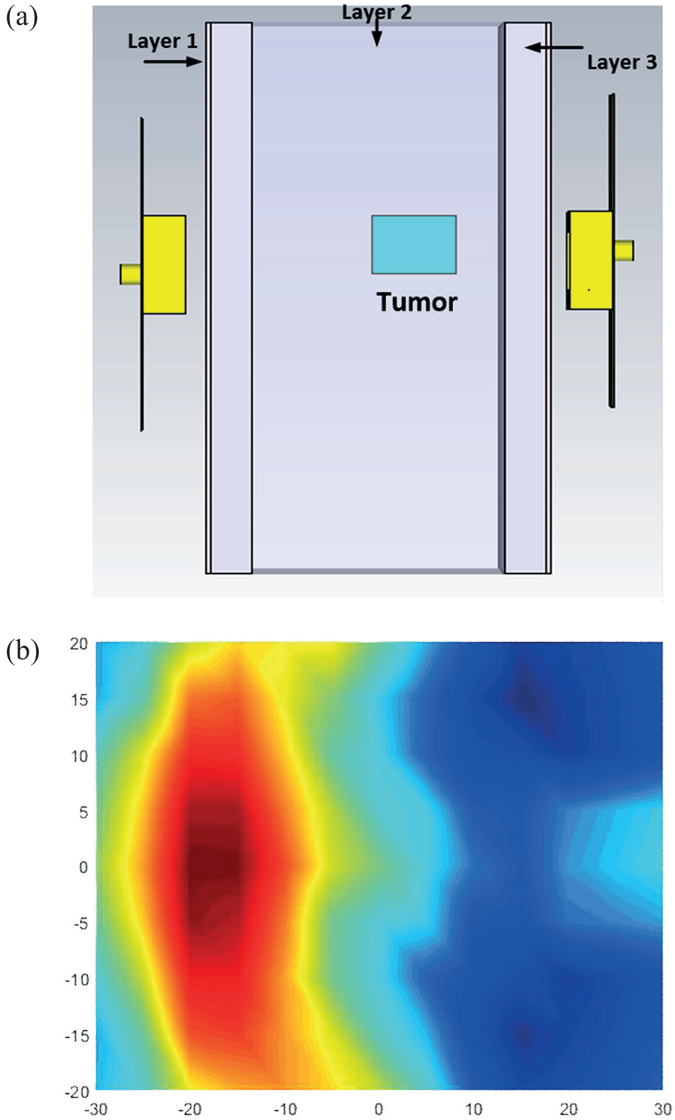

Fig. 11. (a) Computational imaging setup, (b) Normalized Imaging result with rectangular shaped tumor

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