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Design of an impedance matched near field passive antenna for medical microwave radiometry

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Abstract

The paper presents the numerical design and analysis of a compact microstrip patch antenna with superstrate for medical microwave radiometry at 1.3 GHz. The antenna design was optimized to obtain at least −10 dB power reflection coefficient, 100 MHz bandwidth centered at 1.3 GHz and localized power reception from deep seated tissue in homogeneous and layered tissue models mimicking the dielectric properties of the breast. Simulation results indicate that the optimized antenna with low loss superstrate meets the design criteria for passive deep tissue thermometry.

1. Introduction

Medical microwave radiometry (MMR) is used to obtain temperature of body tissues for diagnosis of different thermal anomalies such as cancer, inflammation, infection, etc. using a near field antenna. It is possible to passively measure the temperature of subcutaneous and deep body tissues as the penetration of the spectral radiance is relatively larger in microwave regime than the infrared regime. The downside is that the spectral intensity is about 10 million times smaller than in the infrared regime [1]. Thus, stable measurement of the ultra-low noise power is challenging.

Figure 1 shows a basic block diagram of the measurement setup in MMR. As illustrated in Figure. 1, the near-field resonant antenna in contact with the tissue receives the ultra-low power noise radiation from the body under consideration and transmit it to the radiometer for measurement [2]. Microstrip antennas have been widely reported for MMR [3-7] due to its low profile, ease of construction and low cost.

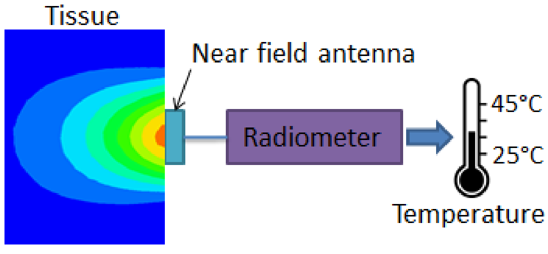


Figure 1. Basic block diagram of MMR setup.

The wide variations in the dielectric properties of biological tissues significantly affect the noise power received by the passive body contacting near field antenna [8, 9]. Impedance mismatch between the antenna and the body can shift the resonance and reduce the power coupled to the antenna which is not desirable as the spectral radiance from human body in the microwave regime is about −174 dBm/Hz. The active and reconfigurable techniques reported for compensating antenna resonance frequency shift are not suited for MMR as the insertion loss of the active elements will deteriorate the radiometer noise figure and measurement sensitivity. For accurate detection of thermal anomalies, the antenna performance should not be affected by variations in the tissue dielectric properties.

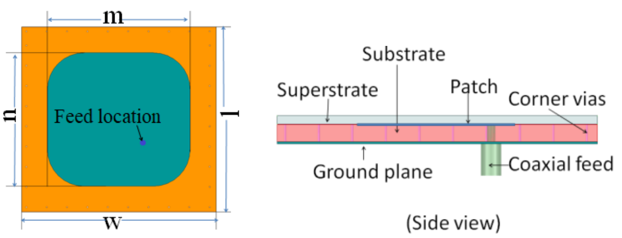
In this study, we present the numerical design and analysis of a compact microstrip patch antenna with stable resonance and good impedance matching for tissue models with homogeneous and layered dielectric profiles. Impedance stabilization was achieved for the near field antenna with the help of a low loss superstrate. Numerical simulations are presented for the microstrip patch antenna at 1.3 GHz for MMR application.

2. Near field antenna design

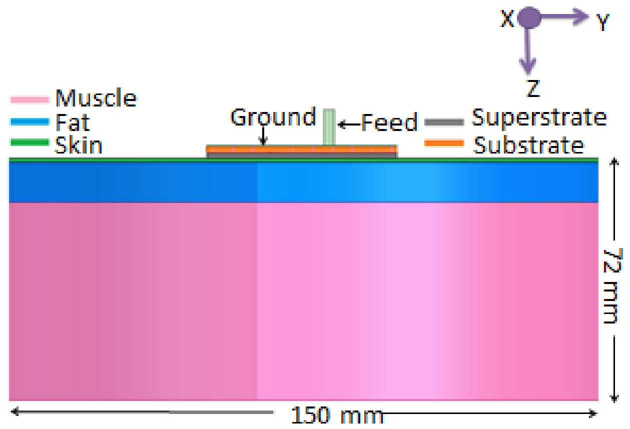
Figure 2(a) shows the top and side views of the microstrip patch antenna with the superstrate proposed for detection of breast cancer using MMR. The rectangular microstrip patch antenna with rounded edges was designed and optimized using EM simulation software HFSS (Ansys, Pittsburgh, USA). The antenna was excited by a coaxial center conductor passing through the substrate as shown in Figure 2(a). Plated via holes were distributed at the antenna periphery to suppress EMI pick up by the microstrip patch antenna. Figure 2(b) shows the near field antenna on a layered tissue block with dielectric property of human body tissue for each layer. The Cole-Cole model for the dielectric properties of tissues reported in literature was used in the simulations [8, 9]. Table 1 lists the tissue dielectric properties at the desired resonant frequency. The patch antenna was designed on 2.54 mm thick Rogers TMM10i substrate (Rogers Corp., USA). The antenna design parameters namely w, l, m, n and feed location (x, y) were optimized together with the superstrate. Microwave laminates from Rogers Corp, USA were used in the antenna simulations to select the

optimal antenna design parameters and the superstrate that satisfied the following criteria:
i. resonance at 1.3 GHz,
ii. −10 dB bandwidth of 100 MHz and
iii. −15 dB normalized power density at 40 mm depth.

The three-dimensional (3D) layered tissue model was surrounded by an airbox and the airbox was terminated with radiation boundary condition. Numerical simulations were carried out for swept frequency excitation of the probe fed antenna. Parametric sweeps of the design parameters and superstrate were used to arrive at the combination that satisfied the design criteria. The optimized parameters were used to assess the antenna performance for a homogenous tissue model of same dimensions as the layered tissue model and bulk dielectric property of the breast parenchyma reported in Table 1 [8].



(a)



(b)

Figure 2. 3D numerical model. (a) Top and side views of the microstrip patch antenna, (b) Near-field antenna on the layered tissue model.

Table 1. Dielectric properties of tissues [8, 9].

Tissue [‡]	Permittivity	Conductivity (S/m)
	Layered phantom	
Skin	39.92	1.00
Fat	24.94	0.14
Muscle	52.50	0.30
	Homogeneous phantom	
Bulk tissue	39.32	0.26

[‡]Values at 1.3 GHz

3. Numerical analysis

The optimized antenna design parameters are listed in Table 2. A 1.27 mm thick microwave laminate TMM6 (Rogers Corp., USA) was chosen as the optimal low loss superstrate for the patch antenna. Figure 3 shows the simulated power reflection coefficient of the optimized near-field antenna for the layered dielectric tissue model. The simulated return loss is less than −10 dB over 1.23-1.34 GHz and the −10 dB bandwidth is 110 MHz. The simulation results for the homogenous tissue model shown in Figure 3 also satisfied the resonance and bandwidth design criteria.

Table 2. Optimized antenna design parameters.

Design parameter	Optimized value
Antenna width (w)	47.78 mm
Antenna length (l)	45.78 mm
Patch width (m)	35 mm
Patch length (n)	33 mm
Substrate permittivity	9.8
Substrate thickness	2.54 mm
Superstrate permittivity	6.0
Superstrate thickness	1.27 mm
Feed location (x, y)	(9, 8) mm

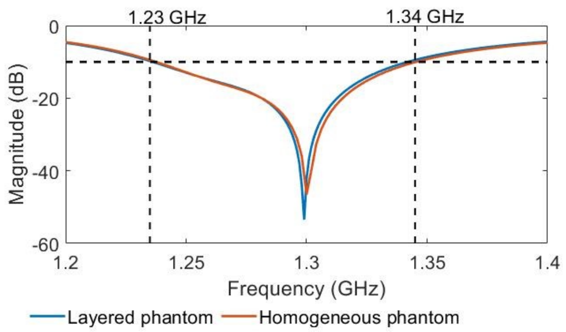
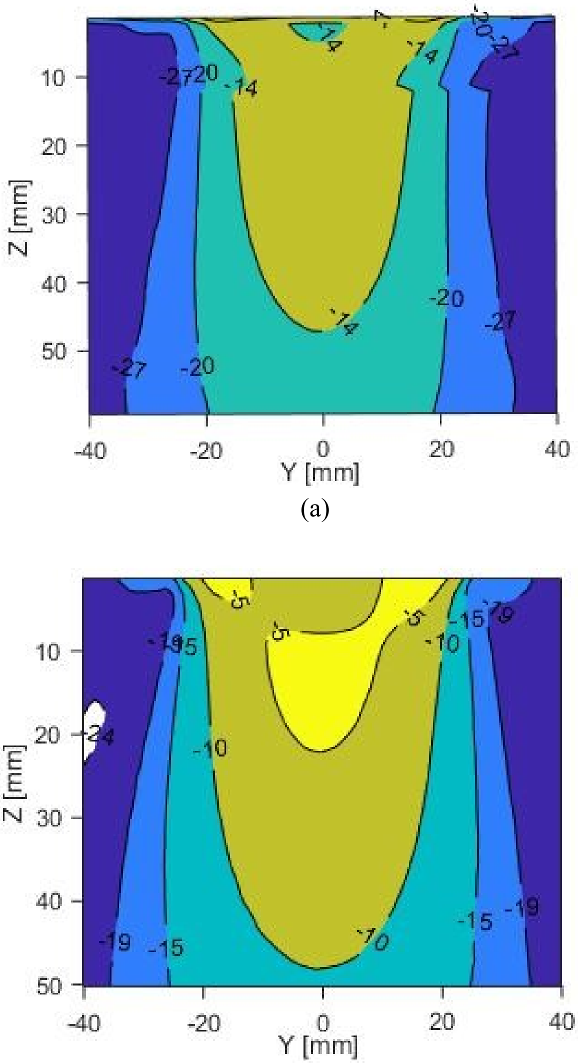


Figure 3. Simulated power reflection coefficient of the optimized near-field antenna for layered and homogeneous tissue models.

From reciprocity theorem, the power received by the antenna from the tissue was quantified using the volume power loss density (W/m^3) calculations in the transmit mode. Figure 4 shows the normalized volume power loss density in the tissue depth plane (YZ) at 1.3 GHz (center frequency). Figure 4(a) shows the antenna power reception profile in the layered tissue model and Figure 4(b) shows the power reception profile in the homogeneous tissue model. It can be seen that the power deposition pattern is directional with a maximum in the broadside of the near-field antenna. Furthermore, it can be observed that the antenna power reception decreases with the increase in depth in both tissue models. The −15 dB contour in the layered and homogeneous tissue models extends beyond 40 mm with a relatively deeper coverage for the homogeneous tissue model than the heterogeneous model. Despite the variation in the power depth profiles, simulation results of the optimized near-field antenna indicate directional power reception from deep tissues for the layered and homogeneous tissue models. The comparable antenna performance observed in the simulation results (Figure 3 and 4) is due to the stable impedance matching provided by the superstrate for the near field antenna irrespective of the variation in the dielectric properties of the tissue.



(a)

(b)

Figure 4. Normalized 2D power reception profile of the optimized near-field antenna at 1.3 GHz in the tissue depth plane for (a) layered and (b) homogeneous tissue models.

4. Conclusion

The design and simulations of a near-field impedance matched microstrip patch antenna was presented for MMR. The optimized near-field antenna with the impedance matched superstrate was observed to possess directional power deposition pattern with return loss greater than 10 dB over 1.23-1.34 GHz and bandwidth more than 100 MHz for the layered and homogeneous tissue models. The low loss superstrate also ensured power reception from deep tissue up to 40 mm depth irrespective of the variation in the tissue dielectric properties.

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