Planar Conformal Radio-frequency Sensors for Detection of Tissue Abnormity

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Introduction: A planar conformal radio-frequency sensor is developed to detect permittivities inside tissues. The near-field sensor with localized field distributions can noninvasively distinguish permittivity variations within tissues. The principle is based on electromagnetic-wave interaction in materials where permittivity variations affect the wave reflection. The permittivity variations may occur due to malignant tumors among normal tissues. Conventional antennas or resonators on printed circuit boards are rigid. It is difficult to obtain reliable measurements when the device needs to be pushed firmly onto skins. The measured reflection coefficients often depend on the applied pressures. The deformation of tissues further alters the field distributions inside the tissues. The planar and conformal features of the proposed sensors provide compliance and a firm contact on the tissue surface. Conventional loop or patch antennas and resonators, although having a benefit of a small footprint, do not provide sufficient spatial and spectral resolutions due to their field scattering. The tissue permittivity differences among individuals make impedance tuning difficult. Thus, performance suffers from low sensitivity. In this work, we propose a planar tuned ring resonator on a thin, flexible polymer substrate for sensing tissue permittivity.

Materials and Methods: A planar ring resonator on a flexible polymer substrate is designed. Thin-film copper with a thickness of 70 µm forms a loop resonator with a tuning concentric pad. The loop radius is 13.8 mm. The tuning gap provides distributed capacitance and reduces mutual inductance for impedance matching at the desired resonant frequency of 900 MHz. A significantly improved quality factor of 37.5 from 4 at the resonance is reached with a reflection coefficient of −52 dB when the sensor is placed on human tissues. Experiments conducted on human forearms have validated our finite-element simulation models. The tissue conductivities and permittivities are extracted from the measurements to compose tissue models. The models are then used to investigate different scenarios with various sizes of tumors and locations.

Results and Discussion: The near-field resonator has a localized field distribution, as shown in Fig. 1. The field strength drops 20 dB at a depth of about 25 mm and at a radial distance of 27.6 mm outside the loop. The effective permittivity is thus influenced by a confined area, and the resonant frequency provides a good spatial resolution for sensing. When a circular tumor phantom with a radius of 15 mm is placed at a depth of 18 mm in the tissue, directly below the sensor, the resonant frequency changes from 900 to 882 MHz, and returns to 900 MHz at a depth of 25 mm. When the sensor moves 30 mm from the center, the frequency shift becomes zero. To increase the depth resolution, four tuned loops are placed in a mirrored configuration with a spacing of 34.5 mm between centers. The electromagnetic fields combine and penetrate deeper into the tissues. The resonance is measured at the port of each loop. When the same circular tumor phantom is placed at a depth of 18 mm, the resonant frequencies change from 948 to 936 MHz, as shown in Fig. 2. They return back to 948 MHz at a depth of 30 mm. With a smaller tumor of a radius of 7 mm, there is a 6-MHz shift up to a depth of 25 mm. With the phantom off-center, the respective port individually indicates the location with its frequency shift.

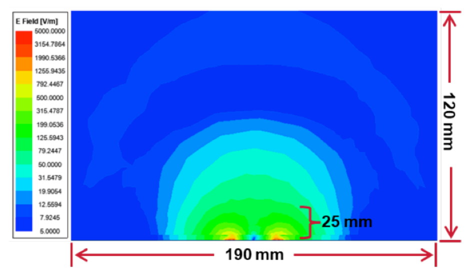

Figure 1. Electric field distribution inside the tissues.

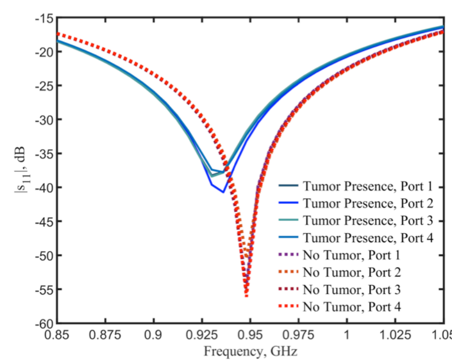

Figure 2. Comparison of reflection coefficients ($|s_{11}|$) at the ports of four loop resonators in a spatially-mirrored configuretion, with or without the tumor phantom at a depth of 18 mm.

Conclusions: We investigated the ability of a resonant loop that conforms to the skin to detect tissue effective permittivity variations. It is shown that electromagnetic fields are altered in the presence of a tumor phantom, and the high-quality factor resonance can sense the abnormity with a sufficient spatial resolution. The high-quality resonance also allows fast detection of peak frequency, making it possible to use the sensors for raster scanning in spatial imaging. The demonstration shows the feasibility of a wearable imaging system to diagnose abnormities in tissues for muscle fatigue, and for skin or breast cancers.

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