Design of the detecting resonator for in-vivo electron paramagnetic resonance spectrometer for tooth dosimetry for radiological accident

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1. Introduction

Under an unexpected emergency situation involving a large number of people who may have been exposed to radiation, a triage infrastructure should be established in the exposed area to assess whether exposure is above or below a treatment threshold for acute radiation syndrome [1]. The whole body dose at which 50% of the victims will die within 60 days or LD 50/60 without intensive medical management approximately 4 Gy [1]. Radiation disaster have occurred at nuclear power plants at Three Mile Island, Pennsylvania, USA, in 1979 [2], Chernobyl, Ukraine in 1982 [3], and Fukushima, Japan in 2011 [4]. Since the general population cannot be expected to be personal monitoring devices for measuring individual irradiated dose, it would not be easy to estimate absorbed doses in individuals.

A magnetic resonance-based technique called electron paramagnetic resonance (EPR) tooth dosimetry, was suggested for evaluating irradiated doses of individuals after exposure [5–6]. EPR tooth dosimetry is the only method to detect free radicals in the enamel of human teeth. After exposure to radiation, an impurity in hydroxyapatite (CO_3^{2-}) becomes CO^{2-}, which is very stable species. By detecting EPR signals from CO^{2-} radicals in enamel in vivo, absorbed dose can be estimated for individuals.

To achieve the goal of efficiently assessing people for potential exposure to radiation in the context of a large-scale disaster, it is important to develop a triage process that can be performed quickly and reliably by minimally trained volunteer or related personnel on site. As a part of a development of electron paramagnetic resonance spectrometer project, the resonator has a critical role of assessment for irradiated dose within the tooth after radiological accident.

2. Methods and Results

2.1 Configuration and Implementation of the Surface-Coil Resonator

Fig. 1 is a schematic diagram of the developed prototype of resonator. It consists of two 96-mm long transmission line, formed by two parallel 50 Ω coaxial lines and two 10 mm diameter single-turn coils made from 1.2 mm silver plated wire. Plate capacitor was 1.7 pF consists of CuFlon. One single-turn coil called the surface coil is used to deliver the RF magnetic field to the tooth, and the other coils called the matching coils are inductively coupled between coils to transmit the microwave power from the microwave bridge to the resonator. Microwave bridge circuit transmits the detected signal from sample to PC. The impedance matching between the resonator and the 50 Ω coaxial line is adjusted by changing the distance between coils as in a standard inductive coupling. The coupling coil is connected to the coaxial line by a twisted pair cable, and the length of this twisted pair cable is λ/4 of resonance frequency.

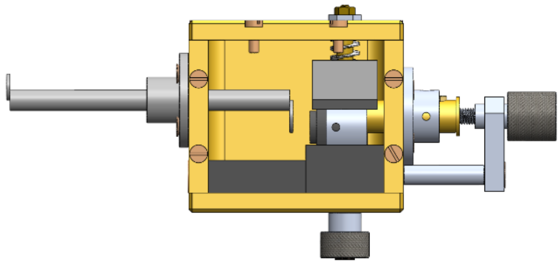

Fig. 1. The design of prototype resonator for electron paramagnetic resonance spectrometer. Two matching coils have role to couple the impedance by changing the distance of matching coils.

A silver-plated brass shielding case isolates the matching coils from the magnetic field modulation. The resonance frequencies and quality factors of the critically coupled resonator were measured with a Network analyzer (Keysight Technologies, USA). Measured results are shown in the figure 2.

2.2 Evaluation of the Characteristics of Resonators

Electromagnetic fields around the surface coil were calculated using ANSYS HFSS 3-D full-wave microwave field simulator (version 14.0.0). The space of 150 mm × 150 mm × 150 mm was modeled with a radiation boundary condition.

To maximize the EPR signal intensity, the quality factor of the resonator was computed using a numerical model of the resonator. EPR signal intensity is proportional to the product of the quality factor Q and the filling factor η of the resonator [7]. Filling factor is not factor for changing of relatively signal intensity. Calculated Q was 193.

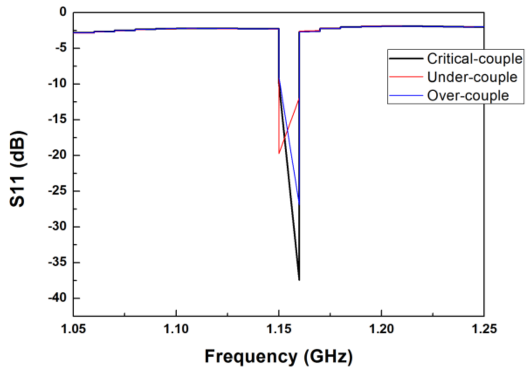

Fig. 2. Measured results of S_{11} parameters from developed resonator. Critical-couple means the perfect impedance matching between matching coils which can transmit signal with minimized loss. Under-couple and over-couple show the reduced characteristics within the sample.

S_{11} is the reflection index parameter that indicates the reflected signals from signal port. Minus sign of S_{11} describes the efficacy of store energy within the resonator. Measured S_{11} was approximately -40 dB when the circuit was critically coupled.

2.3 Evaluation with Tooth Model

For our analysis, tooth model was imported using HFSS software by taking online free open source (CadNav.com) as shown in figure 3. Resonator and tooth model were simulated to evaluate the efficiency of stored energy within the tooth model as shown figure 4.

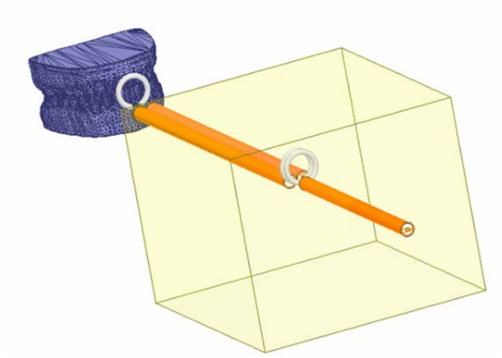

Fig. 3. Simulation setup of modeled resonator with imported tooth model

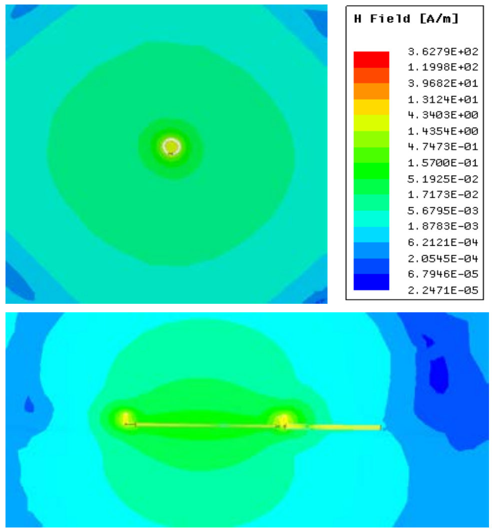

Fig. 4. Distribution of magnetic field strength which was described as log scale. Energies were focused within the coils.

3. Conclusions

Based on the simulation model of the resonator, we could maximize the signal intensity of EPR detection for an irradiated incisor tooth. The resonator was developed described in this paper will significantly enhance the capability of EPR-based dosimeters for use unwanted following events where large populations may have been unexpectedly exposed to significant amounts of ionizing radiation.

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