

A PROBE FOR ELECTRIC PROPERTIES OF PHANTOM LIQUIDS

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Introduction:

In MRI, phantoms are often used for system tests or coil design. In many of these applications, the phantoms should interact with electromagnetic fields like a real patient. Therefore, the phantom's electric conductivity σ and permittivity ϵ are chosen to mimic typical values of human tissue [Gab96]. Standard methods for the determination of these tissue characteristics are of limited accuracy since they are based on absolute impedance or reflection measurements [Ala99, Ath82]. More accurate methods are using a setup of filling the phantom liquid into dedicated tanks and are therefore less convenient [Giv06, Chew91, Rob98, Sch80, Rus04]. In this study, a resonant probe was designed for a fixed frequency of 64 MHz (1.5T), showing a high accuracy, although it can be dipped into the phantom liquid.

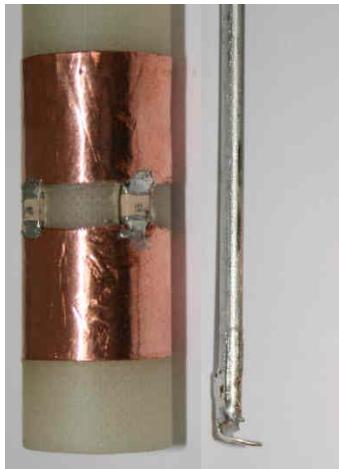


Fig. 2: Probe and pickup-coil

Methods:

The resonant probe (Figs.1,2) consists of two ring-shaped electrodes (diameter 14mm, distance 3.2mm) inside a test tube forming a capacitor, which couples electrically to the liquid located outside the test tube. The electrodes are connected by an inductivity (around 250nH) forming a resonant circuit. The capacity depends on the surrounding tissue, which influences resonance frequency f and quality factor Q . Additional capacitors (in total 22pF) were used in parallel to the electrodes to limit the impact of the surrounding tissue. This helps to reduce the frequency shift, but, on the other hand, reduces sensitivity and accuracy.

The design parameters of the probe were chosen according to simulations based on the Method of Moments [CON]. Here, the probe was embedded in a homogeneous material, and the shift in resonance frequency f and quality factor Q was investigated for typical electric properties of human tissue.

Finally, the probe was built up according to these simulations (Fig. 2) and the resonance parameters were extracted from a fit of the reflection of an inductively coupled pickup-coil with an accuracy of approximately $\Delta f=10\text{kHz}$ and $\Delta Q=1$.

The complex conductivity $\sigma_c := \sigma + j\omega\epsilon$ has to be calculated from the measured resonance parameters f and Q . To this goal, an equivalent circuit was derived as a simple model of the probe (Fig. 3).

Results:

Figure 4 depicts the resonance frequency and quality factor of the probe for $\text{H}_2\text{O}-\text{NaCl}$ solutions, showing a good agreement between simulated (magenta lines) and measured (green lines) resonances. For the measurements, the conductivity was evaluated at low frequency with a conductivity meter (HI93300, Hanna Instruments). The fitting result (Fig. 4, red curve) agrees very well with the corresponding measurement (green). Thus, after an appropriate calibration, the probe can be used for measuring unknown liquids. Figure 5 shows the contour plots of resonance frequency and quality factor in the typical range of σ_c of human tissue, based on the equivalent circuit

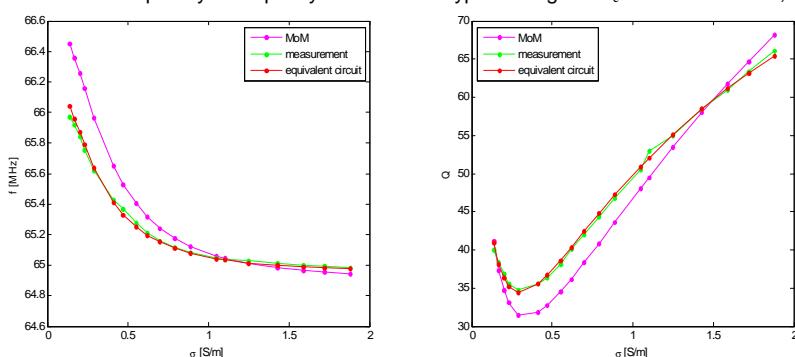


Fig. 4: Resonance frequency and quality factor: Simulation, measurement, and corresponding fit based on the equivalent circuit model of Fig. 3

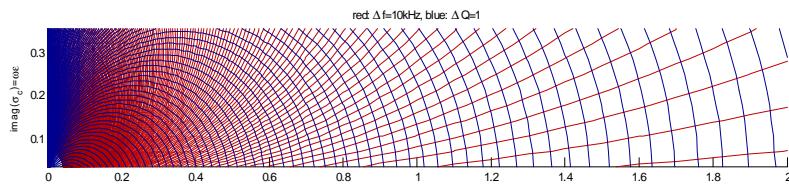


Fig. 5: Contour plots of resonance frequency (red) and quality factor (blue) showing the expected accuracy of the probe in the desired range

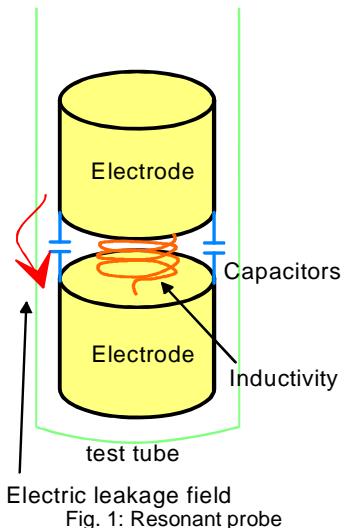


Fig. 1: Resonant probe

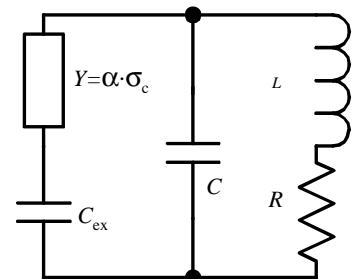


Fig. 3: Equivalent Circuit

model. The steps between the contour lines were chosen by the estimated measurement accuracy $\Delta f=10\text{kHz}$, $\Delta Q=1$. The size of the rectangles shows the accuracy for σ_c to be about 5%.

Conclusion:

A resonant probe for measuring the electric properties of MRI phantom liquids was designed and validated. It is able to measure the complex conductivity $\sigma_c := \sigma + j\omega\epsilon$ of phantom liquids with an accuracy of about 5%.

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