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# Impedance Spectroscopy and Multi-Frequency Electrical Impedance Tomography

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## Abstract

*Validation and interpretation of reconstructed images using a multi-frequency electrical impedance tomography (MFEIT) require conductivity phantoms including imaging objects with known complex conductivity spectra. We describe imaging experiments using a lately developed MFEIT system called the KHU Mark1 with the frequency range of 10 Hz to 500 kHz. Using a bio-impedance spectroscopy system (BIS), we first measured complex conductivity spectra of different imaging objects. Imaging experiments were followed to produce time-difference images of the objects using a complex version of a difference image reconstruction algorithm. Compared with measured complex conductivity spectra, reconstructed images show changes of complex conductivity with respect to frequency.*

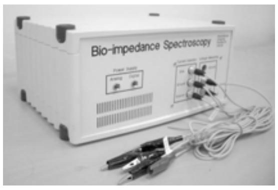
## 1. Introduction

Multi-frequency electrical impedance tomography (MFEIT) requires imaging objects with known complex conductivity spectra for its validation and performance evaluation [1]. Using a lately developed MFEIT system called the KHU Mark1 [2], we performed imaging experiments of conductivity phantoms containing different objects whose complex conductivity spectra were measured beforehand.

## 2. Methods

### 2.1. Impedance Spectroscopy

Fig. 1(a) shows a bio-impedance spectroscopy system (BIS) with a frequency range of 10 Hz to 500 kHz. We chose seven different materials including saline, agar, polyacrylamide (PAA), animal hide gelatin (AHG), TX151, cucumber and banana as imaging objects. Denoting the conductivity and permittivity of a chosen material as $\sigma$ and $\varepsilon$, respectively, we measured a complex conductivity ($\sigma+i\omega\varepsilon$) spectrum of each material using the four-electrode impedance measurement method.




(a) (b)

Fig. 1 (a) BIS and (b) 16-channel MFEIT system.

### 2.2. MFEIT System

Fig. 1(b) shows a 16-channel MFEIT system called the KHU Mark1 [2]. It has one balanced current source with a minimal output impedance of 1 MΩ in the frequency range of 10 Hz to 500 kHz. Injecting sinusoidal current with a chosen frequency, we can measure induced voltages between pairs of surface electrodes using 16 digital voltmeters. From a compete set of measured boundary current-voltage data, we reconstruct images of complex conductivity distribution using a difference image reconstruction algorithm.

### 2.3. Imaging Experiment

We constructed a two-dimensional saline phantom with 200 mm diameter, 100 mm height and 0.137 S/m background conductivity. It was equipped with 16 electrodes equally spaced around the circular phantom. Placing imaging objects inside the phantom, we injected current between a chosen neighboring pair of electrodes. Voltage data were collected between pairs of other neighboring electrodes.

## 3. Results

Fig. 2 shows $\sigma$ spectra of seven different materials. Fig. 3(a) shows the spectra of $\omega\varepsilon$ for seven different materials. Since the non-biological materials have significantly different ranges, we plotted $\omega\varepsilon$ spectra of those separately in Fig. 3(b). Fig. 4 and 5 are time-difference images of the banana and TX-151 object, respectively, at multiple frequencies.

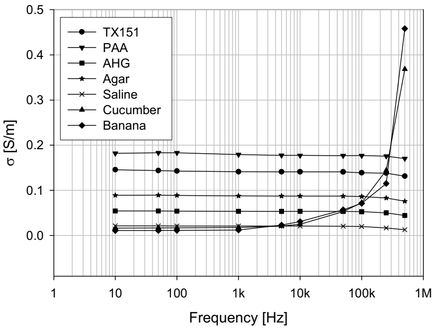
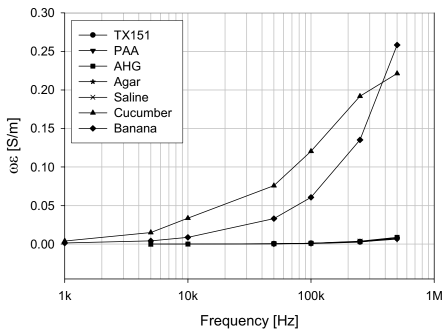



Fig. 2 $\sigma$ spectra of seven different materials.

(a)




(b)

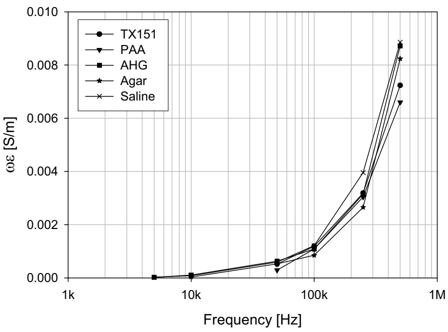



Fig. 3(a) $\omega\varepsilon$ spectra of seven different materials and (b) those of non-biological materials with a different scale.

## 4. Discussion and Conclusion

Reconstructed images in Fig. 4 and 5 show changes of conductivity and permittivity with respect to frequency. The changes are well correlated with the complex conductivity spectra in Fig. 2 and 3. Based on these preliminary results, we suggest further theoretical and experimental MFEIT so that we can use the technique to visualize frequency-dependent changes of complex conductivity distributions inside the human body. Frequency-difference imaging as well as time-difference imaging should be studied especially for the case where reference state is not defined or available.

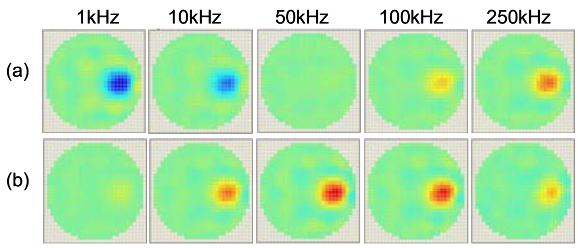



Fig. 4 Time-difference images of the banana object. (a) Real- and (b) imaginary-part images.

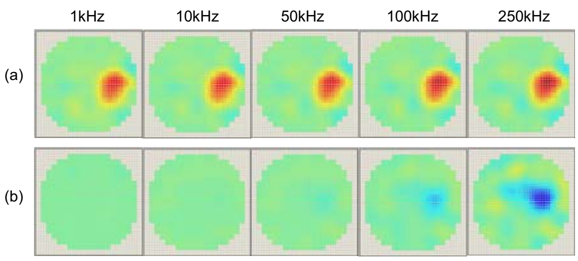



Fig. 5Time-difference images of the TX151 object. (a) Real- and (b) imaginary-part images.

## 5. Acknowledgement

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## 6. References

[1] D. Holder, *Electrical Impedance Tomography: Methods, History and Applications*, IOP Publishing, Bristol, UK, 2005.
[2] T. I. Oh, E. J. Woo and D. Holder, Multi-frequency EIT system with radially symmetric architecture: KHU Mark1, *Physiol. Meas.*, vol. 28, in press, 2007.