Capacitive coupling in spectral electrical impedance tomography (sEIT) measurements with a centralized multiplexer

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Abstract

We analysed capacitive coupling in sEIT measurements associated with different cable types (shielded and unshielded) and measurement approaches (active and passive electrodes) using circuit models and actual sEIT field measurements. The modelling results showed the intricate trade-offs between wire-wire, wire-shield, and shield-soil capacitive coupling for shielded and unshielded cables when using passive electrodes with a centralized multiplexer. The field measurements with a centralized multiplexer and a fan-shaped cable layout with elevated cables showed that unshielded cables showed lower capacitive coupling than shielded cables because of the dominance of wire-shield capacitive coupling. Analysis using the developed circuit models showed that this result is a consequence of the site conditions, and cannot be generalized.

Introduction

Electromagnetic (EM) coupling effects, including both inductive and capacitive coupling, have long been an essential problem in broadband sEIT measurements. While data correction and filtering methods exist for inductive coupling, addressing capacitive coupling remains complex. Capacitive coupling usually refers to the leakage of electric current through possible capacitances wherever a potential difference exists. Typically, three types of capacitive coupling are considered. The first type is wire-to-wire coupling, which occurs between non-shielded cables with small separation. This type of capacitive coupling can be eliminated by using coaxially shielded cables. The use of coaxial cables results in the second type of capacitive coupling between the inner wire and shield (i.e. wire-to-shield capacity). This type of capacitive coupling can be avoided by using distributed amplifiers at the electrodes for voltage measurements (i.e. active electrodes), but most commercially available systems have a centralized multiplexer with amplifiers at the measurement system (i.e. passive set-up). The third type of capacitive coupling occurs between cable shield and soil and can be reduced by elevating cables above the ground surface. Recently, a fan-shaped cable layout has been proposed for sEIT field measurements, which separates cables for easier survey design and enables model-based corrections for inductive coupling. In such a case, capacitive coupling is the main remaining sources of errors for sEIT measurements in the kHz frequency range. Therefore, the aim of this study is to analyse the three types of capacitive coupling in sEIT measurements for different cable types (shielded and unshielded) and measurement approaches (active and passive set-up) using circuit models and actual sEIT field measurements.

Methodology

Measurements were carried out at the campus of the Forschungszentrum Jülich using a customized sEIT measurement system. Eleven electrodes with 1 m electrode spacing were used, and the individual cables were arranged in a fan-shaped layout. Three different measurement setups were used for the field measurements. The first setup (active setup, reference measurement) used amplifiers at the electrodes, which ensures that the voltage at the electrodes is known. The second setup (non-shielded passive setup) has amplifiers close to the system using a custom-made switchbox (i.e. a centralized multiplexer). Unshielded wires are used to connect the electrodes and the switchbox using the same fan-shaped lay-out. The third setup (shielded passive setup) also employs the switchbox, but coaxially shielded cables were used for the connection. This introduces an additional wire-shield capacity, and the developed circuit models showed that the voltage at the electrode can be estimated using a simple voltage divider that requires an estimate of the contact impedance. sEIT measurements were made using a skip-6 circulating measurement scheme from 1 Hz to 10 kHz for all three setups. Since the customized measurement system measures voltages at all electrodes except the electrodes used for current excitation, the potential differences of 396 selected electrode configurations were calculated during post-processing.

Results

Fig. 1a-c shows the measured imaginary part of the complex impedance using the three measurement setups. Considering the measurements acquired with the active setup (Fig. 1a) as the reference here, it is clear from Fig. 1b that sEIT measurements using the passive setup with non-shielded cables in a fan-shaped layout resulted in accurate sEIT measurements. Based on the developed circuit models, the reasons for this can be analyzed. First of all, the unshielded wires have a large separation in the fan-shaped cable layout, which avoids significant leakage of current between wires. In this particular set of measurements, the cables were elevated about 5-10 cm above ground by the lush grass. This resulted in insignificant capacitive coupling between the shield and ground. Since there is no wire-shield capacitive coupling for unshielded cables, the effects of capacitive coupling were low. Measurements using the passive setup with shielded cables (Fig. 1c) showed larger variation at higher frequencies above 1 kHz. This is due to the high cable-shield capacity. After correction of the cable-shield capacity using the developed circuit model, the variation at 10 kHz has been largely reduced. Remaining errors are due to approximations in the correction approach.

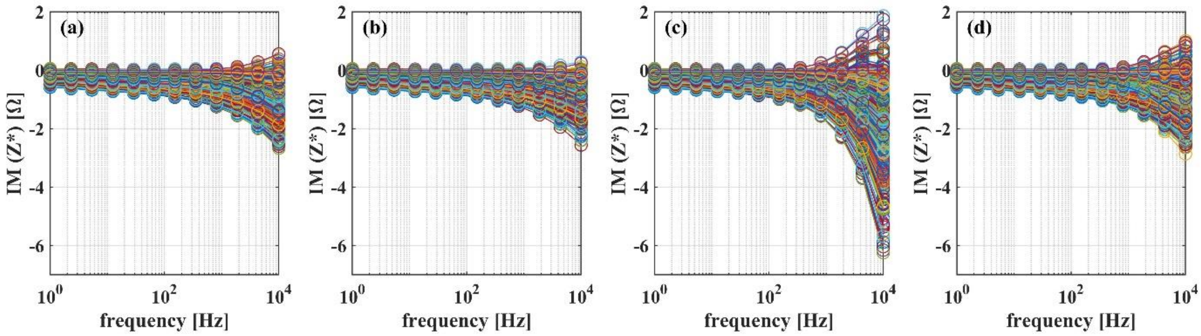

Fig.1 Measured imaginary part of complex impedances using: (a) active setup, (b) passive setup with unshielded cables, (c) passive setup with shielded cables before and (d) after correction.

Conclusions and outlook

The sEIT field measurements with a centralized multiplexer and a fan-shaped cable layout with elevated cables showed that unshielded cables showed lower capacitive coupling than shielded cables because of the dominance of wire-shield capacitive coupling. Analysis using the developed circuit models showed that this result is a consequence of the site conditions, and cannot be generalized. Overall, it was concluded that the combination of circuit models with sEIT measurements with different cable types and measurement approaches provided valuable insights in the intricate trade-offs between different types of capacitive coupling. Future research should focus on the quantitative evaluation of the correction approach for wire-shield capacity for shielded cables and 3D modelling of the passive set-up with unshielded cables to allow for sEIT measurements with this setup for larger layouts and in resistive soil environments.