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Calibration and Field Measurements of a Scalable Electromagnetic Induction System (SELMA-RB) for Agricultural Applications

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MOTIVATION AND AIMS

Application

- Non-invasive fast soil mapping with electromagnetic induction and high depth resolution
- Can be used as a handheld device, in a sled or on agricultural vehicles and drones

Special Features

- Modular system, flexibility in the selection of the coil spacings, spatial resolution of 0.3 m at 10 km/h

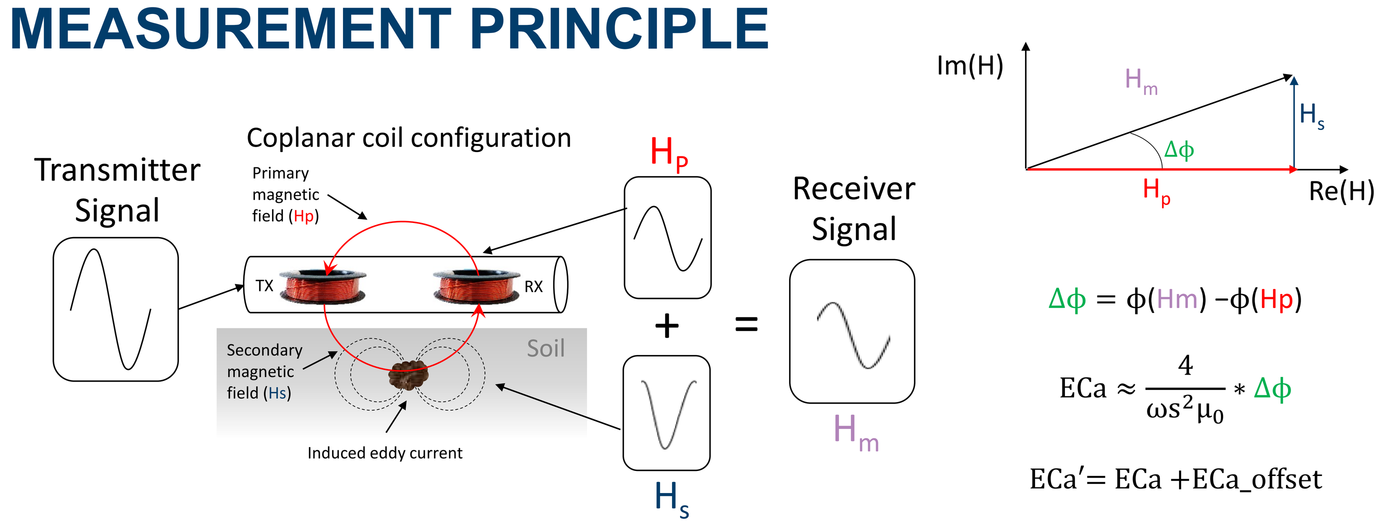
Aims of this study

- System offset calibration for absolute measurement values in mS/m
- Comparison of instrument measurements and the potential of the SELMA system for depth-resolved analysis

SPECIFICATIONS

- Scalable and modular concept with a high number of receiver coils
- Data acquisition rate: 10 Hz with 1 mS/m noise accuracy
- Measurement frequency/range: 20 kHz, 2 – 100 mS/m
- Coil spacing (s): 0.305 m * Coil_Number
- Temperature range: -10 – 60 °C

MEASUREMENT PRINCIPLE

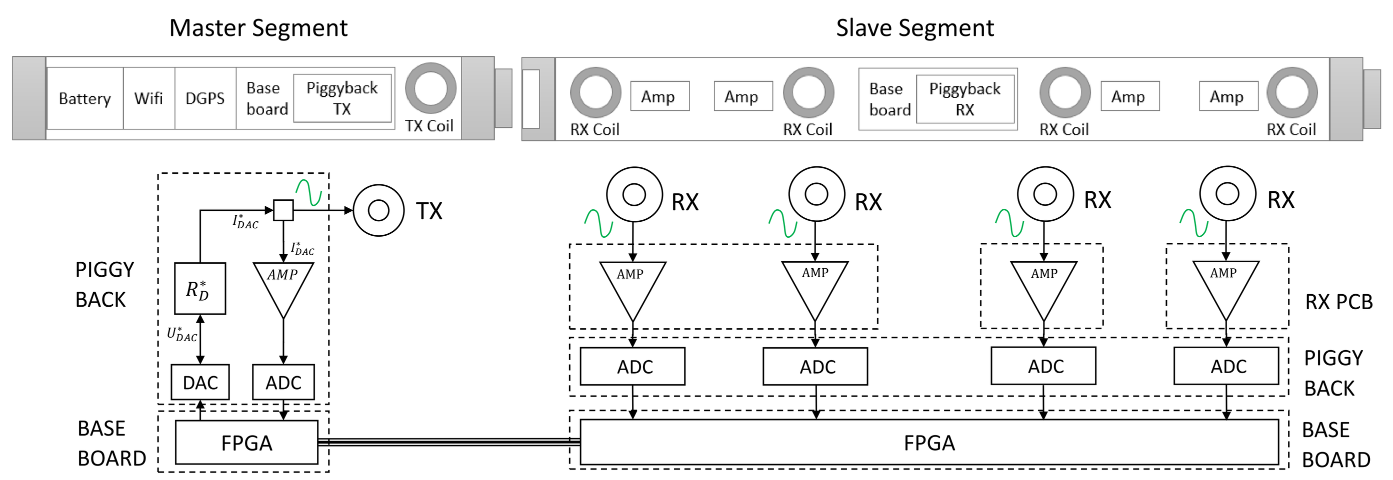


$$\Delta\phi = \phi(H_m) - \phi(H_p)$$

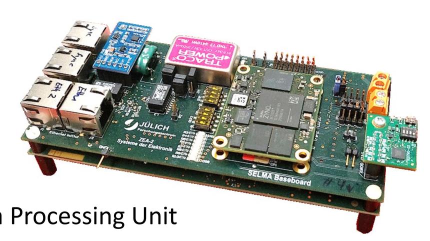
$$ECa \approx \frac{4}{\omega s^2 \mu_0} * \Delta\phi$$

$$ECa' = ECa + ECa\_offset$$

SYSTEM ARCHITECTURE



- Edge computing with FPGAs enable a scalable structure
- Architecture is also suitable for multi-transmitter systems
- Modules are synchronized via sync and clock lines
- In-house development from the coil to data evaluation



Data Processing Unit

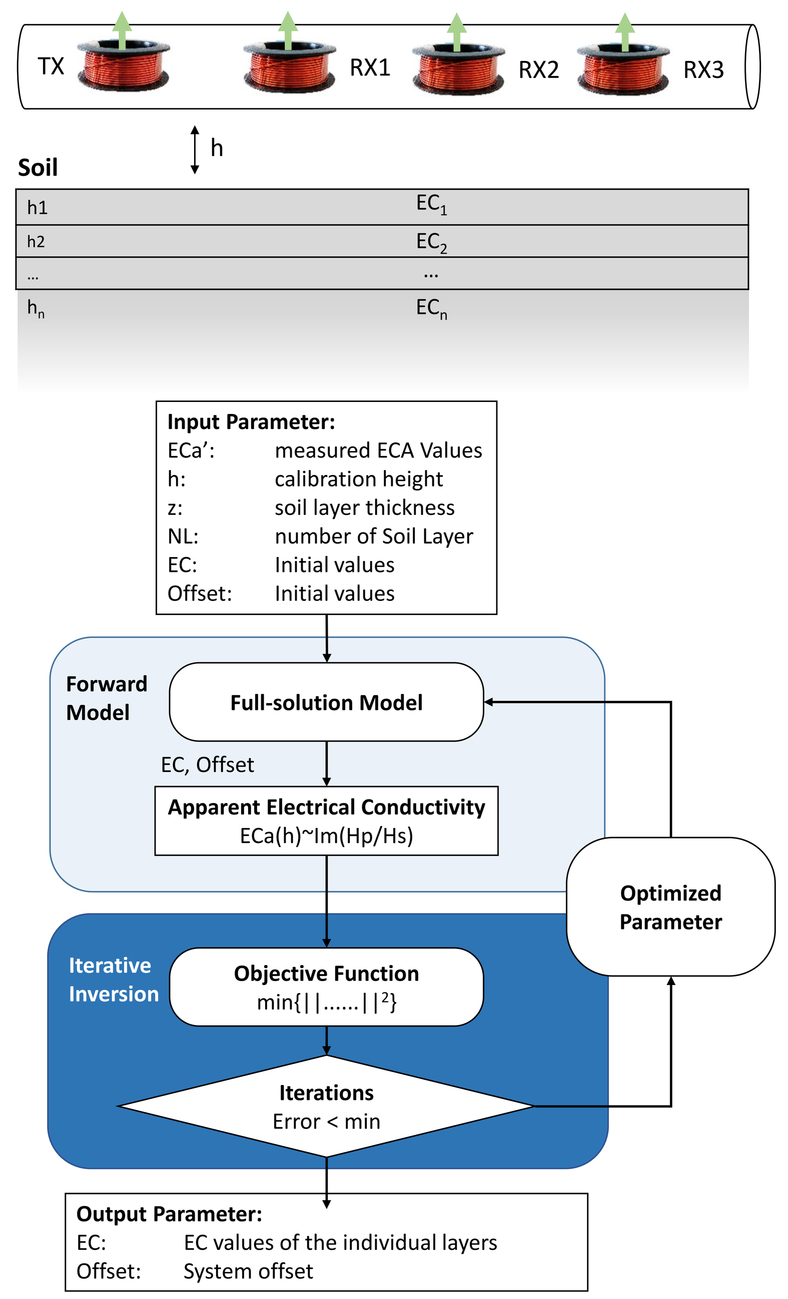
MULTI-ELEVATION CALIBRATION

General test cases and requirements:

- Varying the height of the instrument [1]
- Reduction of magnetic material in the environment
- Underground as homogenous as possible (water, air)
- As simple as possible for periodic tests
- Temperature correction method for ECa values [2, 4]

Model parameters

- Possible forward models
  - McNeill Equation (without frequency - McNeill, 1960)
  - Full-solution Equation (with frequency - Ward & Hoffmann, 1988)
- Objective function
  - $\min ||ECa_{mod}(EC,h,z,s,o) - ECa_{mea}(h,s)||_2$
  - Optimisation parameter: EC_n and h_n



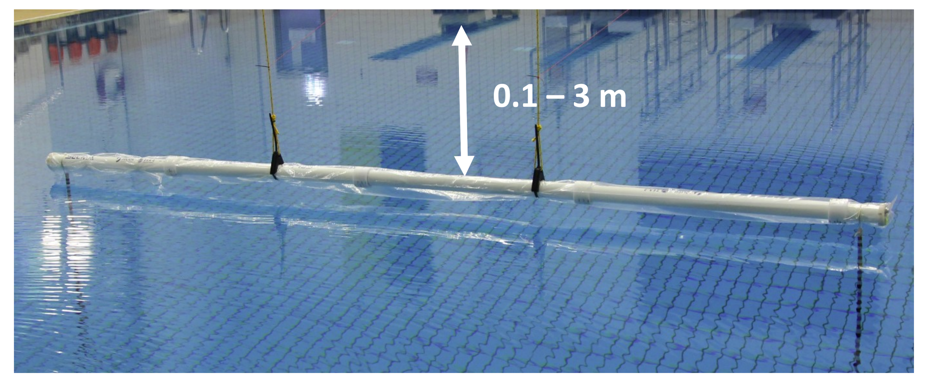
Scalable modular system with 1 transmitter and 12 receiver coils

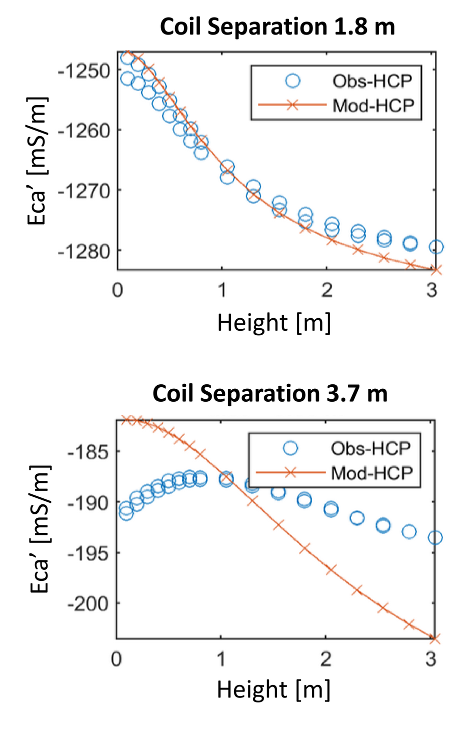
1D configuration of the SELMA system without housing

- Available segments
  - Master: TX, 1 x ADC (24 Bit), 2 x DAC (16 Bit)
  - Slave: RX, 4 x DAC (16 Bit)
- Wireless communication (Wlan)
- Processing with SoM Xilinx Zynq-7000 (TE0720) with Ethernet communication
- GPS interface (integrated, DGPS, 10 Hz)
- Housekeeping sensors e.g. temperature, gyroscope, acceleration, magnetometer
- LiPo battery for 12 hours operation
- Dimension: 10 x 437 cm with 16 kg
- Possible alignment: coplanar orientation

OFFSET CALIBRATION

Approach 1: Calibration in the swimming pool

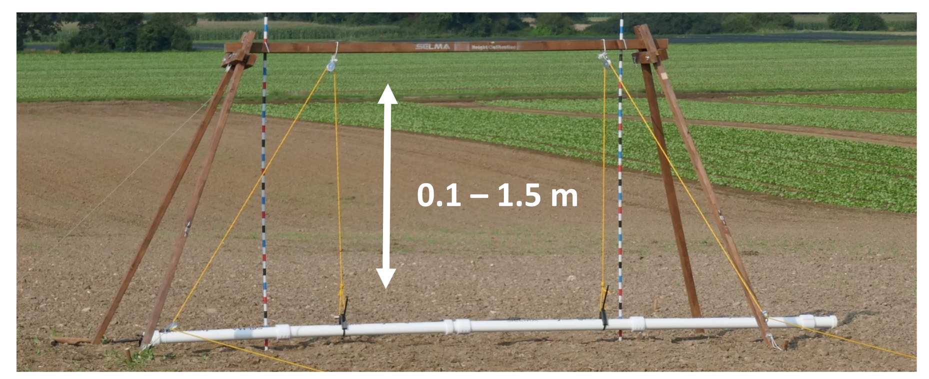


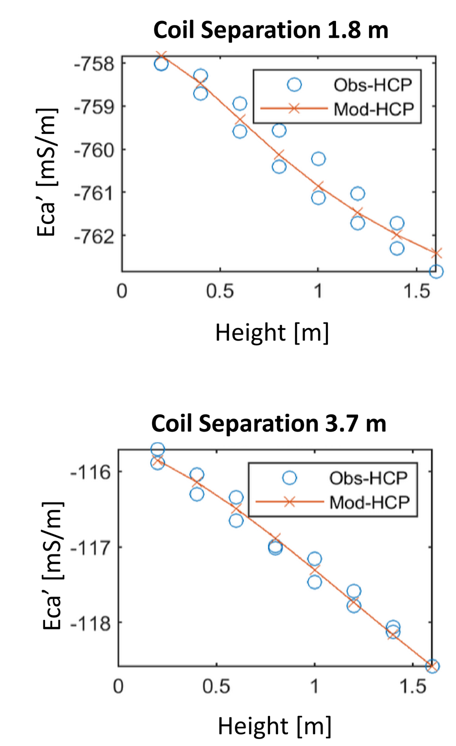


The Ulla-Klinger swimming pool in Aachen is 17 x 14 m with a depth of 4.5 m. The device was placed near the centre and two meters or more away from metallic objects. It was varied in height using ropes on the 10-meter tower. Note: Negative ECa' value includes the system offset.

Result: The coil pairs with large separations cannot be calibrated due to the pool edge effects.

Approach 2: Calibration in the field



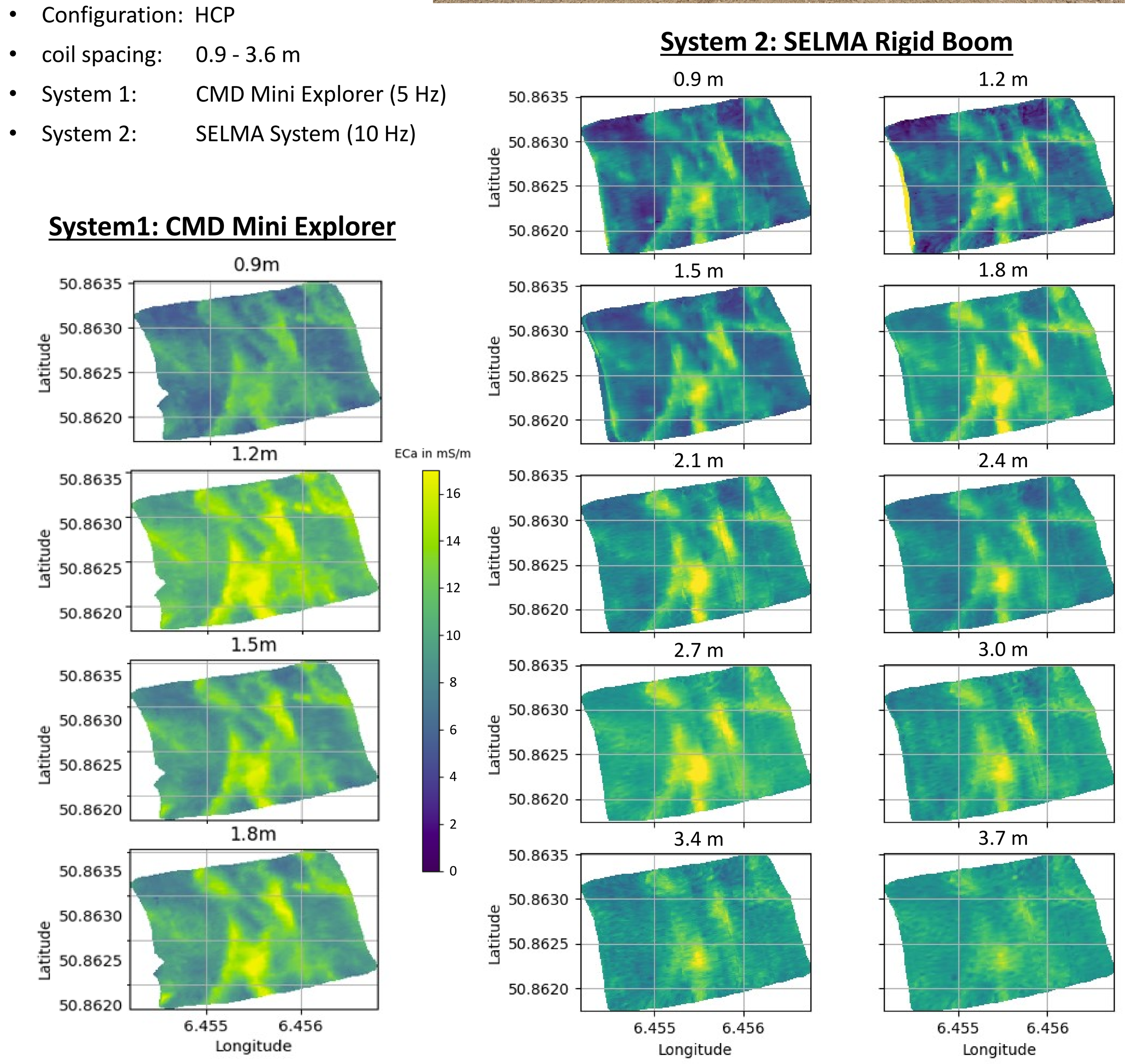


The height of the measuring device was varied using a portable wooden frame. The offset of each coil was determined using a 4-layer model of the subsoil.

Result: All measured ECa values could be modelled for all coil spacings > 0.9 m with a deviation of +/- 1 mS/m for the same subsurface. Possible sources of error are still the exact determination of the height between the device and the ground and the thermal drift. The influence of the sled was not calibrated.

FAST MAPPING

- Location: Selhausen near Jülich
- Platform: sled behind ATV
- Field size: 230 m x 160 m
- time: 90 minutes
- line spacing: 4 m
- driving speed: 8 km/h
- Configuration: HCP
- coil spacing: 0.9 - 3.6 m
- System 1: CMD Mini Explorer (5 Hz)
- System 2: SELMA System (10 Hz)



Result: Both systems show similar pattern in the ECa distribution for the same coil spacings. As expected, system 2 shows that the contrast decreases with increasing coil spacing. The different contrasts show the potential of the SELMA system for depth-resolved measurements using layer inversion [3, 4]. A problem that still exists is temperature drift, which was corrected in the images afterwards.

CONCLUSIONS

- Fast mapping with ten coil spacings was demonstrated with a field measurement.
- A practical method for offset calibration in the field was presented. However, the effect of heterogeneous ground in the field on the calibration still has to be tested.
- Calibration in the swimming pool is not suitable due to the large coil spacing. As an alternative to reference calibration over a defined homogeneous underground, measurement on a lake is intended.
- Further methods are being developed to correct temperature drift.

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