Development of High Resolution Multi-input and Multi-output Transient Electromagnetic Instrument (MIMO-TEM) for Near-surface Application

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SUMMARY

The time-domain transient electromagnetic (TEM) method is a commonly used geophysical exploration technique for near-surface investigations, particularly effective in identifying low-resistivity structures. However, its limitations, such as near-surface blind zones and cumbersome coils, restrict its broader application in near-surface explorations. To address these challenges and meet the demands of near-surface exploration, we have designed a portable, high-resolution multi-transmitter and multi-receiver transient electromagnetic transceiver (MIMO-TEM).

This instrument is designed to meet the high-resolution requirements of near-surface detection through a multi-transmitter and multi-receiver circuit structure. The transmitter sequentially emits two levels of current, while the receiver simultaneously collects early and late-stage signals with different amplification factors. Signal fusion processing yields high-precision induced electromotive force data for the entire period of the induced field. For enhanced portability, the instrument is operated and controlled via a smartphone app, which displays data and communicates with the main instrument via Bluetooth and WiFi. Power is supplied by an external 12V DC battery, significantly reducing the instrument's size and weight to just 5 kg. The integrated transceiver coil of the instrument is compact, lightweight, and detachable. The integrated and layered design improves coil performance, with an equivalent resistance of 494 mΩ, an inductance of 1.03 mH, and a capacitance of 260 pF. These small resistance, capacitance, and inductance values minimize the coil's impact on secondary field data. The coil has an equivalent area of 24.96 m² and a resonance frequency of 316 kHz, making it suitable for near-surface exploration environments. The transmitter uses an H-bridge inverter circuit built with new silicon carbide MOSFETs, capable of emitting bipolar rectangular waves at 0.25-625 Hz. Leveraging the fast turn-off advantage of silicon carbide materials and passive constant voltage clamping technology, the transmitter achieves turn-off times of 5 μs and 38 μs for transmission currents of 1.2 A and 14 A, respectively, with good linearity and consistency in the waveform's falling edge. The transmission circuit includes a current self-collection circuit with an effective resolution of 20 bits and a maximum sampling rate of 1.8 Msps, using a segmented variable sampling rate collection scheme to fully record the waveform data. The receiver features dual acquisition channels for early and late stages, each fronted by a high-impedance buffer and equipped with an operational amplifier circuit set to achieve controllable gains from 1 to 625 times. The overall control functions are handled by a high-performance FPGA Kintex-7. The receiver provides a signal resolution of 24 bits, with a minimum detectable voltage of approximately 0.1 μV and a maximum sampling rate of up to 2.5 Msps, allowing for exploration depths of up to 200 meters.

To validate the instrument's performance, we conducted multiple indoor and field tests. The testing data demonstrate that our multi-transmitter and multi-receiver transient electromagnetic transceiver (MIMO-TEM) exhibits excellent performance, stable operation, good interactivity, and high portability, making it well-suited for near-surface exploration environments.

Keywords: Transient Electromagnetic Instrument, Silicon carbide MOSFET, MIMO-TEM