

Designing, Measuring and Modelling a Small-Scale Coil and Stimulation Circuit for Transcranial Magnetic Stimulation

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Introduction

Transcranial Magnetic Stimulation (TMS) is well-used, but the experimental science behind it is inconsistent. There is a need to carry out invasive measurements on mice to gain deep understanding about the underlying principles of TMS because they allow for more direct measure of TMS-induced synaptic and non-synaptic plasticity (Wilson *et al.*, 2018, Tang *et al.*, 2015).

Based on the physics of TMS, we intend to focus on the following main objectives;

- To design, build and demonstrate a good mouse coil and stimulating circuit
- To measure and maximize electric field intensity of the designed mouse-specific TMS coil.
- To perform measure of evoked potentials and seizure—like events on brain slices subjected to stimulation with the designed coil.

Results

Impedance:

The resistance of the coil is constant at about 162 m Ω and inductance is constant at about 37.5 μ H for frequencies less than around 10 kHz.

Measurements of Magnetic Field Strength and Electric Field Strength :

With an applied voltage of 45 V, we measured the magnetic flux density (B-field) as 338 mT and induced electric field (E-field) as 10–15 V/m.

Temperature measurement :

The temperature (T) increased by 31°C after 1200 pulses at 5 Hz frequency.

Current measurement:

The current (I) in the 50-turn coil reached up to 340 A at 45 V power supply.

Modelling

We modelled the coil using MATLAB which gave similar B-field and E-field results of around 500 mT and 8 V/m respectively.

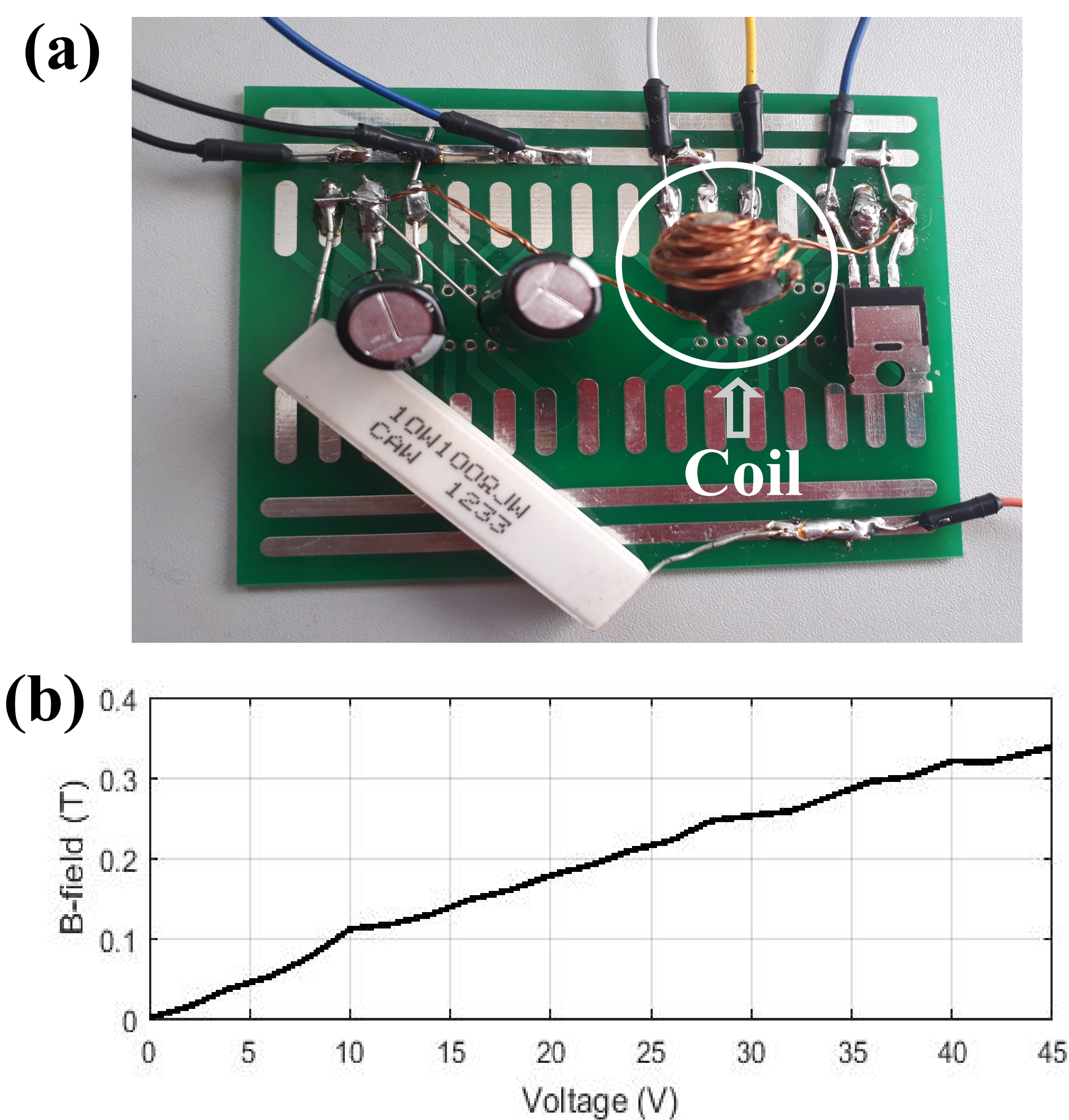


Figure 1. (a) A photograph of the stimulation circuit and the coil marked with a white circle (b) The magnetic flux density against different voltages for the coil .

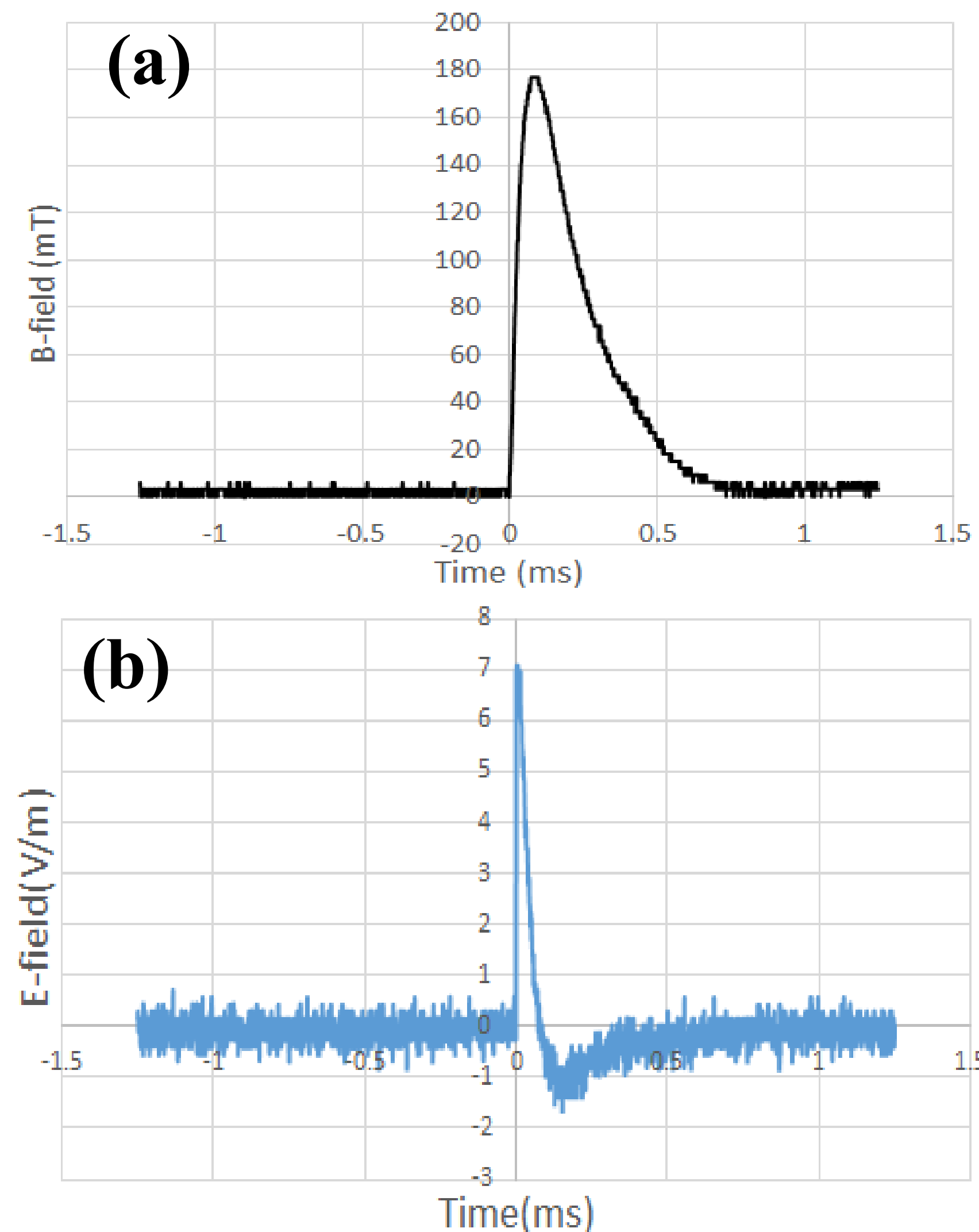


Figure 2. (a) The magnetic flux density against time for a typical pulse at 26 V (b) The electric field against time for a typical pulse at 26 V.

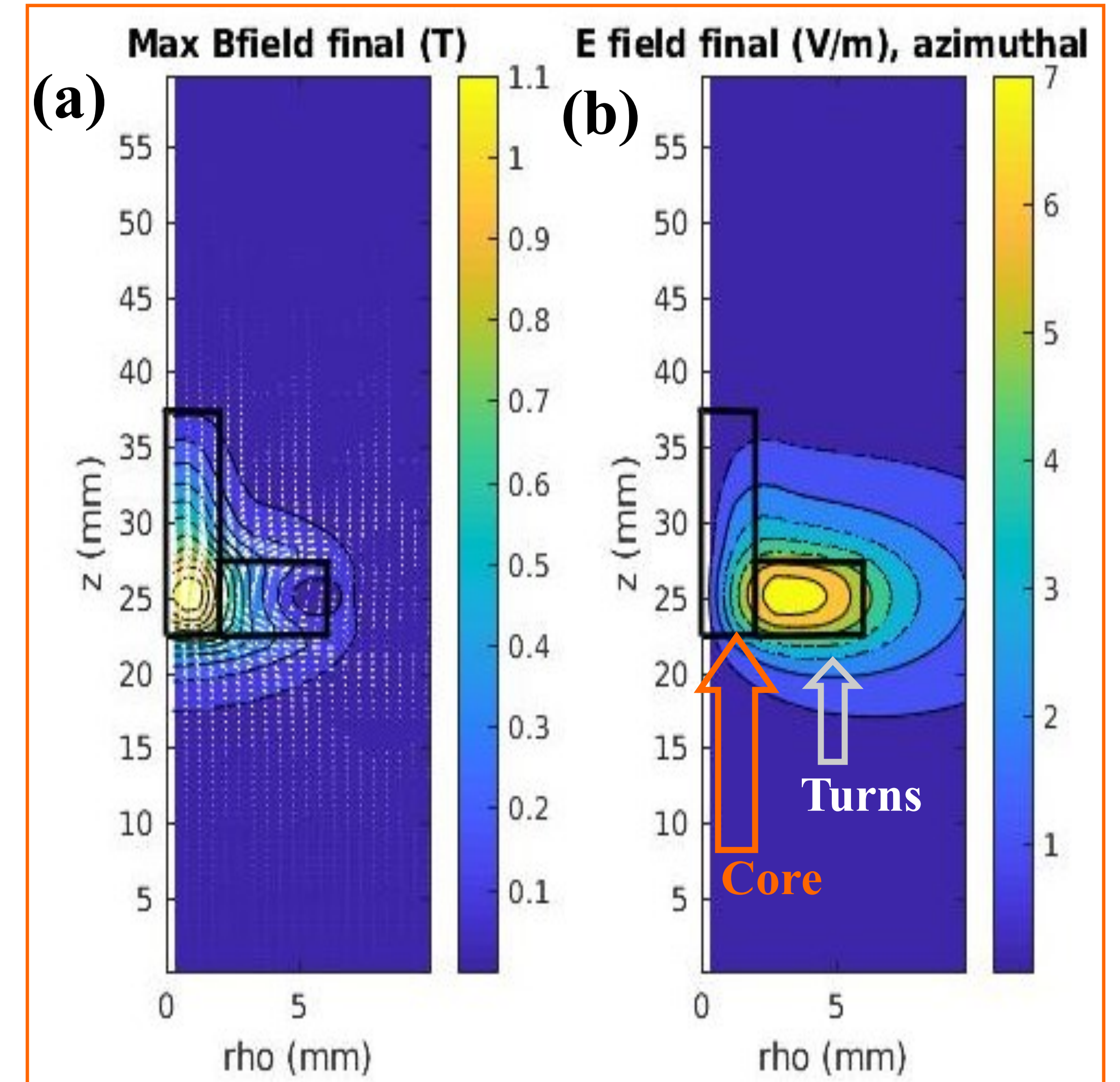


Figure 3. (a) The modelling of the magnetic flux density (b) The modelling of the electric field of the 50-turn ferrite core coil using a custom made MATLAB code. The red arrow and the white arrow in (b) represent the ferrite core and 50 turns respectively.

Method

- Based on established physics principles (Wilson *et al.*, 2018), we designed and built a cylindrical coil consisting of 50 turns of 0.4 mm diameter copper wire around a 4 mm diameter soft ferrite core.
- We built a simple electronic circuit to discharge a 300 μ F capacitor through the coil. The circuit is closed by gating a AU1RL3705N Metal-Oxide Semiconductor Field Effect Transistor (MOSFET). We have measured the magnetic flux density (B-field) with a AI302KUA Hall effect probe and electric field (E-field) with a wire loop.
- The heating of the coil is measured with a temperature probe.
- The current in the coil is evaluated by measuring the voltage between the source and drain of the MOSFET and dividing by the "ON" resistance (0.01 ohm) of the MOSFET.

Conclusion

- Although the designed cylindrical coil performs better than previously constructed mouse coils, the electromagnetic fields are still considerably lower than those of typical human coil of 2 T and 250 V/m (Nieminen *et al.*, 2015).
- The maximum B-field reached was 338 mT which compares well with the saturation flux density of ferrite core of 0.4–0.5 T (www.ferroxcube.com), so we are unlikely to get much improvement out of the ferrites.
- To achieve more better results relating B-field and E-field, we will now try powdered iron cores that have saturation flux densities of 1.5–1.9 T (www.micrometals.com).
- We will now apply the designed TMS coil to mouse brain slices and will measure the effects before and after TMS stimulation.

References

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