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Sensor Technologies for Brain Signal Registration and RF Emission Analysis

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Abstract. In recent years, new approaches to studying human brain activity have explored not only traditional electrophysiological methods but also the possibility of recording weak radio-frequency (RF) emissions. This paper presents the sensor technologies employed in our experimental setup for registering brain activity signals in the MHz range. We describe the design and characteristics of the sensors, including loop and dipole RF antennas, shielding systems, and auxiliary biomedical sensors, optimized to detect extremely weak electromagnetic emissions in controlled laboratory conditions. Experimental trials with volunteers inside a shielded area confirmed stable registration of brain RF signals, with repeatability across sessions. The described sensor configuration provides a reliable foundation for further research on brain RF signals and contributes to ongoing efforts in non-invasive neurophysiological monitoring.

Keywords: Brain radio signals, RF emissions, Applicator antenna, Coil antenna, Capacitive sensor, Inductive sensor, SWR measurement, Electromagnetic brain activity, Biomedical sensors, Signal registration

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1. Introduction

The study of human brain activity has traditionally relied on electroencephalography (EEG), magnetoencephalography (MEG), and related biomedical techniques. While these methods provide valuable information about neuronal processes, recent research has suggested that the brain may also emit weak electromagnetic signals in the radio-frequency (RF) domain, particularly in the megahertz range [1-2]. Detecting and analyzing such signals requires the development of highly sensitive designed sensors capable of operating under conditions of weak signals.

Two primary sensor types were used: applicator (capacitive) antennas and coil (inductive) antennas for registering brain RF activity. Each of these sensor families is based on distinct physical principles, offering complementary advantages for detecting weak brain emissions [3-4]. The applicator antenna is designed as a capacitive sensor, consisting of a central electrode, a dielectric layer, and a protective shielding electrode. When placed in contact with or in proximity to the scalp, the applicator antenna functions as a near-field capacitive coupler, primarily sensitive to local variations of the perpendicular component of the electric field generated by brain RF signals [3]. Owing to its geometry and layered structure, the applicator antenna provides stable coupling, reduced environmental interference, and effective suppression of external noise. These characteristics make it particularly suitable for long-duration recordings in shielded environments. The second class of sensors, the coil antenna, is based on inductive properties. Constructed as flat spiral coils or spherical coils of fine copper wire, these sensors are sensitive to the magnetic field components of the brain's RF emissions. Coil antennas have been widely used in biomedical and electromagnetic applications for their ability to register weak magnetic phenomena with high spatial resolution. In our setup, single-layer flat coils of various diameters were tested, optimized to balance sensitivity and resolution.

The coil configuration enables detection across a wide spectral range, making it possible to capture correlated spectral components that reflect subtle interactions in brain RF activity. It provides a complementary sensing modality to capacitive antennas, particularly in situations where electric-field coupling is less effective.By employing both applicator and coil antennas in a combined system, we achieve a more comprehensive and reliable registration of brain RF signals. This dual-sensor approach ensures sensitivity to both electric and magnetic field variations, enhancing the robustness of experimental observations. Furthermore, careful calibration, shielding, and impedance-matching techniques, such as standing wave ratio (SWR) characterization for applicator antennas were implemented to ensure consistent sensor performance.

The choice and design of these sensors represent a critical step in the experimental validation of brain RF emissions. Their ability to reliably capture ultra-weak signals in controlled laboratory conditions provides the foundation for subsequent statistical and bispectral analyses of brain activity.

2. Sensor Description

Accurate detection of weak brain radio-frequency (RF) signals requires sensors specifically designed to capture both the electric and magnetic field components of these emissions. In our experiments, we employed two complementary sensor types: applicator antennas serving as capacitive sensors and coil antennas serving as inductive sensors. The applicator antenna, shown in Figure 1, operates as a capacitive-type sensor optimized for near-field coupling with the scalp. It consists of a thin metallic electrode connected to the acquisition chain via a 50 Ω coaxial cable, a dielectric layer that ensures safe and stable insulation, and a protective shielding electrode that minimizes environmental interference.

When in contact with the scalp or in close proximity to the scalp, the electrode and tissue form a capacitive system in which weak electric field oscillations in the megahertz range induce electrical signals on the metal electrode of the applicator antenna. These signals are then transmitted to an amplifier stage and recorded for further processing.

This sensor type is highly sensitive to the electric field components of brain RF signals, relatively broadband in its response, and compact enough to allow multiple simultaneous placements on the scalp. The geometry of the applicator provides stable coupling, reduced motion artifacts, and effective suppression of external disturbances. To ensure proper operation and impedance matching with the acquisition system, the applicator antennas were characterized using a vector network analyzer.

Applicator antennas showed good matching at frequencies up to 50 MHz, with S11 equal to -10 dB to -15 dB see Figure 2.

Fig. 1. Applicator antenna used for registering brain-origin RF signals. The sensor consists of a metallic electrode connected via coaxial cable, a dielectric layer for safe contact, and a protective shielding electrode to minimize external interference.

Fig. 2. Standing wave ratio (SWR) / reflection coefficient (S11) measurement of the applicator antenna.

The main limitations of the applicator antenna are its sensitivity to motion artifacts and dependence on electrode–scalp coupling conditions, which require careful positioning during experiments.

The coil antenna, shown in Figure 3, operates on the principle of electromagnetic induction and is designed to detect variations in the magnetic field component of the brain's RF emissions.

These sensors are fabricated as flat, single-layer spiral windings of fine copper wire, with the diameter and number of turns selected to balance sensitivity and spatial resolution [4,5].

Magnetic field oscillations induce voltages across the coil turns, with the induced electromotive force proportional to the rate of change of magnetic flux. Larger diameter coils provide higher sensitivity by capturing more flux, while smaller coils improve spatial resolution and localization of the signal source [4, 6].

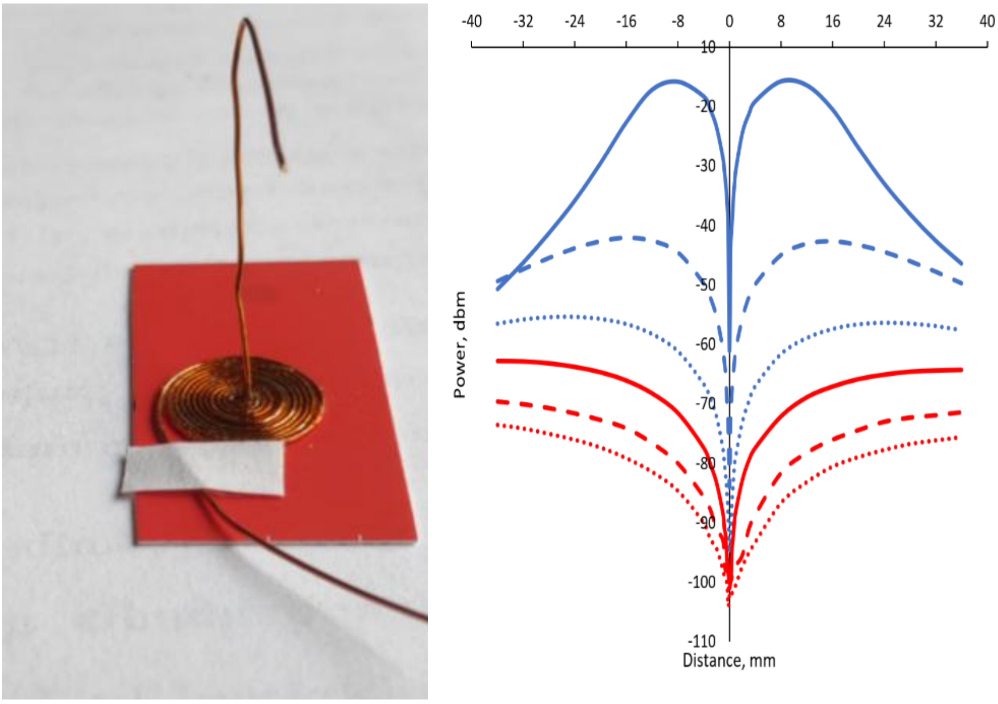

Fig. 3. Distribution of the tangential component of the field in the case of an 18 mm flat coil, depending on the distance between the coil and the magnetic probe (solid blue line – 0 cm, dashed blue line – 2 cm, blue dotted line – 4 cm, solid red line – 6 cm, dashed red line – 8 cm, red dotted line – 10 cm).

Due to their inductive nature, coil antennas are highly sensitive to time-varying magnetic fields and provide complementary information compared to applicator antennas, which primarily sense electric-field components. They are naturally less affected by capacitive interference; however, they generate very low output levels, requiring low-noise preamplification and careful orientation relative to the head for optimal performance [5]. This balance of sensitivity and resolution makes coil antennas suitable for distinguishing localized variations in brain electromagnetic activity.

By integrating both sensor types into a single system, the experimental setup benefits from dual-mode detection**:** applicator antennas ensure robust coupling to the electric field, while coil antennas capture subtle magnetic field variations. Together, they form a comprehensive platform for registering ultra-weak brain RF emissions in a shielded laboratory environment, providing reliable input for subsequent spectral and bispectral analyses [7].

3. Conclusions

In this work, we presented the sensor technologies employed for the registration of ultra-weak brain-origin radio-frequency signals. Two complementary types of sensors were investigated: applicator antennas functioning as capacitive sensors and coil antennas functioning as inductive sensors. The applicator antennas demonstrated high sensitivity to electric-field components of brain emissions, with compact geometry and stable scalp coupling. Their performance was verified through impedance characterization, with the best-performing unit exhibiting S11 around -15 dB at 10 MHz, confirming acceptable impedance matching.

Coil antennas, constructed as flat spiral windings, provided complementary sensitivity to magnetic-field components of the brain's RF emissions. Their performance was shown to depend strongly on diameter and number of turns, with larger coils enhancing sensitivity and smaller coils improving spatial resolution. While they generate weaker signals requiring low-noise preamplification, coil antennas contribute critical magnetic-field information that cannot be obtained with capacitive sensors alone.

The integration of both sensor types into a single experimental system ensures dual-mode detection, improving robustness against environmental interference and enabling cross-validation of recorded signals. This combined approach provides a reliable platform for capturing brain-origin RF emissions in controlled laboratory conditions and forms the foundation for subsequent higher-order statistical analyses, including bispectral methods. The results confirm that carefully engineered sensor configurations are key to advancing the registration and study of electromagnetic activity of the human brain in the MHz–GHz frequency range.

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