High Performance GMI Sensor for Biomagnetic Field Measurement

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***Abstract*—In this paper, we present a high performance Giant Magneto-Impedance (GMI) sensor for biomagnetic field measurement. We used a first order gradiometer based on amorphous wire GMI sensor for measuring the cardiac magnetic field and the brain magnetic field. The measured results of a cardiac magnetic field perpendicular to the breast plane (cardio apex position) and simultaneously recorded Electrocardiography (ECG) are shown. The spontaneous brain activity (Alpha rhythm) measurements were carried out on a female subject by GMI sensor and simultaneously recorded Electroencephalography (EEG).**

Keywords-amorphou wire; GMI sensor; MCG; MEG.

I. INTRODUCTION

Superconducting interferential devices (SQUID) have been used as measuring tools for biomagnetic signals from human beings. Magnetocardiography (MCG) is a non-invasive and non-contact technique for the diagnosis of heart diseases. The existing experimental data and clinical data revealed the MCG is more sensitive (in comparison with the methods based on the measurement of electric potentials) to local currents that are generated at the interfaces of myocardium fragment with different electrophysiological properties. The technology for recording non-invasive cranial nerve activity that requires no liquid helium and high spatial resolution has been around for over 30 years. Recently, the use of different types of magnetic sensors, such as Tunnel Magneto-Resistance (TMR) sensor and atomic magnetometer are being studied for Magnetoencephalography (MEG).

In the present study, we report measurement results for MCG and MEG based on magnetoimpedance (MI) sensor that can be operating in an unshielded environment and at room temperature. This paper is organized as follows. Section II is dedicated to the description of the theoretical basis of GMI effect and the structures of complementary metal–oxide–semiconductor (CMOS) MI sensor. Section III presents the results of MCG measurements and spontaneous brain activity measurements via the new MI sensor system. Finally, a general conclusion is given in Section IV.

II. GMI SENSOR

We used the amorphous wire (manufactured by UNITIKA Ltd.) with composition of FeCoSiB. The wire was cold-drawn to around 30 um diameter from the as-quenched state of approximately 130 um diameter and then tension-annealed. The remarkable GMI effect occurs in the amorphous wire because the high frequency AC current passing through the amorphous wire leads to the skin effect. The impedance of the wire depends on the skin depth. In general, the skin depth is related to the permeability of soft magnetic materials. Therefore, the impedance has dependence on the magnetic field through change in permeability.

Using both pick-up coil and analogue switch for the signal processing, the temperature stability and linearly of the CMOS MI sensor was remarkably improved. The magnetic sensors using GMI element in combination with pick-up coil have been reported by several groups as Off-Diagonal GMI sensor [1][2]. More recently, we have successfully developed a high performance magnetic sensor having 2pT resolutions at 1Hz based on Off-Diagonal GMI sensor [3]. In order to cancel out the effect of environmental magnetic field noise, we have developed a first order gradiometer for biomagnetic field measurement. In the gradiometer, the amorphous wire has two coils: a sensing coil and a reference coil.

III. RESULTS

MCG measurements by MI gradiometer were carried out for a men subject (aged 54) in sitting position. We measured MCG at the point of the chest surface 25mm on the left hand side of subject from a pit of the stomach. Figure 1(a) illustrates the experimental set up in this study. The MI gradiometer is placed on the wooden table and we measure the perpendicular magnetic field component (Bz) to the chest surface. D is the distance from chest surface to the front edge of the MI gradiometer. Figure 1(b) represents simultaneous measurement of ECG and MCG signals, when the distance D is approximately 4 mm. In this case, we can identify sharp magnetic peak which corresponds to peak in R wave of ECG. Negative magnetic peak is observed following the T wave in ECG.

The spontaneous brain activity (Alpha rhythm) measurements were carried out on a female subject. The subject was with eyes open during the first 8 s of the recording. Then, the subject was instructed to close her eyes for the remaining 8 s of the recording. As expected, the alpha rhythm signals simultaneously measured by EEG and MI

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sensor were significantly attenuated when the subject opens her eyes, and intensified with eyes closed. The subject's α wave MEG signal has a main frequency component of 10-11 Hz and the maximum amplitude is about 25 pTrms. Significant susceptibility of MI sensor to spontaneous brain activity was confirmed by signal / noise of 8/1, as shown in Figure 2.

IV. CONCLUSION

The noise level of the developed GMI gradiometer, which can operate in an unshielded environment and at room temperature, was 30pT root-mean-square (rms) in a 40Hz bandwidth. In this study, measurement of MCG (by GMI sensor) and ECG was carried out simultaneously. We can identify sharp magnetic peak with strength of approximately 100pT, which was corresponded to peak in ECG R wave. We also tried to measure the brain magnetic field of female subject. The alpha rhythm signals simultaneously measured by EEG and MEG (by GMI sensor) were significantly attenuated when the subject opens eyes, and intensified with eyes close.

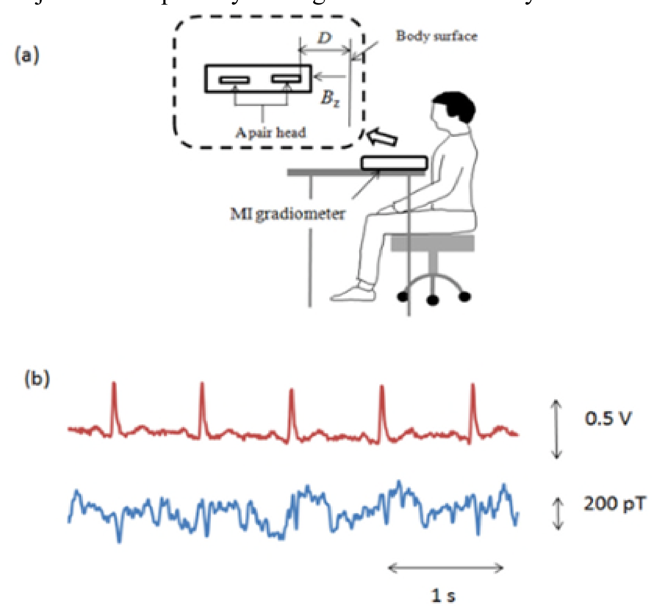

Figure 1. Set up for MCG measurement in (a). Simultaneous measurement of ECG and MCG in (b).

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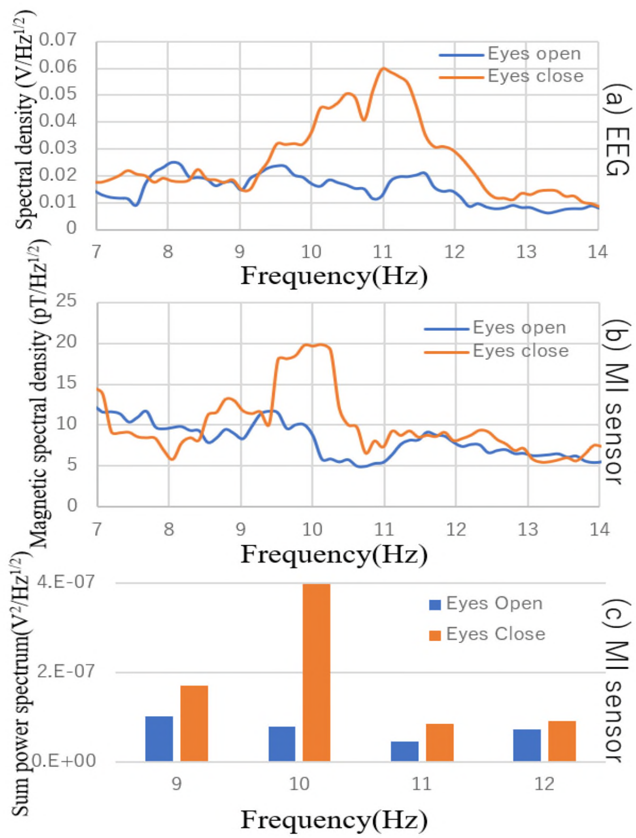

Figure 2. Comparison of the spectral density of alpha rhythm signals simultaneously measured by EEG and MI sensor between eyes opening and closing. (a) EEG. (b) measured by MI sensor. (c) the sum power spectrum level of MI sensor recording.