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A Magnetoencephalography System Having Superconductively Shielded SQUID Magnetometer

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Abstract*—We fabricated a whole-head SQUID magnetometer system having a superconductive shield to measure magnetoencephalography (MEG) signals inside a thin magnetic shielding for practical MEG measurements. For a robust magnetometer with a reduced flux trap, compact axial SQUID magnetometers were made using a wire-wound pickup coil with simple connection structure between the pickup coil and the input coil. The white noise of the SQUID system was about 2 fT/√Hz at 100 Hz. The magnetometers have a distance of 30 mm from the superconducting Pb surface, forming gradiometers with a baseline of 60 mm. The superconductive shielding structure showed shielding factors in the range of 20~500, depending on the positions of the magnetometers inside the helmet. Simulation showed that magnetic flux lines are concentrated at the inner corner of the helmet brim, and magnetometers at the brim picked up large environmental noise. To enhance the overall shielding performance, we improved the design by extending the shield plate brim toward the inner side of the helmet, and found that the shielding performance was improved much especially in the brim area. The MEG signals measured with a double-side brim showed much better signal quality than having single-side brim, showing that a thinner magnetically shielded room can be used.

***Keywords*—SQUID; magnetoencephalography; magnetic shielding; magnetometer**

I. INTRODUCTION

Measurements of weak magnetoencephalography (MEG) signals using superconducting quantum interference devices (SQUIDs) require adequate reduction of environmental magnetic noises. This has been done typically using a combination of SQUID gradiometers and moderate magnetically shielded room (MSR) or SQUID magnetometer and heavy MSR. Another type of shielding is a superconductive shielding, either cylinder [1] or helmet type [2]. The advantage of superconductive shielding (SS) is that its shielding performance is frequency-independent in the frequency range of interest for MEG measurements. A SQUID array inside a helmet-type SS was shown to have low-frequency shielding factor in the range of 10-1000 depending on the position of the SQUID magnetometers [3]. Reference magnetometers installed outer upper part of the helmet were used to measure environmental noises only, since the SS prevents the reference magnetometers from measuring the MEG signals. However, we found that some noises originated from inner lower part of the helmet, for example, noise of magnetic teeth and magnetocardiography (MCG) signals, are difficult to be removed using software gradiometers. In this paper, we propose a upgraded structure of the helmet-type SS having inward extension at the helmet brim.

II. SUPERCONDUCTIVE SHIELDING STRUCTURE

A. Helmet-type Superconductive Shield

We made a simulation of the shielding performance for two SS structures; helmet without an inward brim at the brim and with brim. Fig. 1 shows the structure of the helmets. The SS is made of a Pb plate of 1 mm thick. The outward brim is 5 cm long for both Fig. 1(a) and (b), and the inward brim in Fig. 1(b) is 3 cm long.

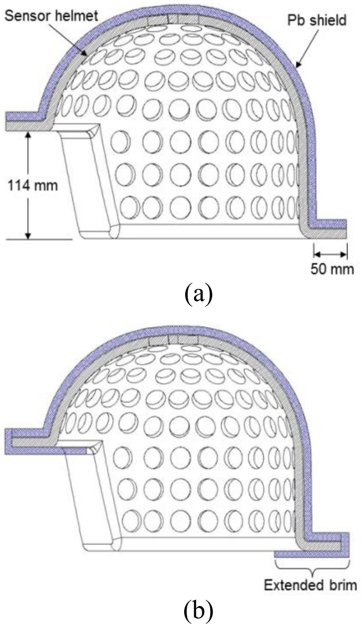
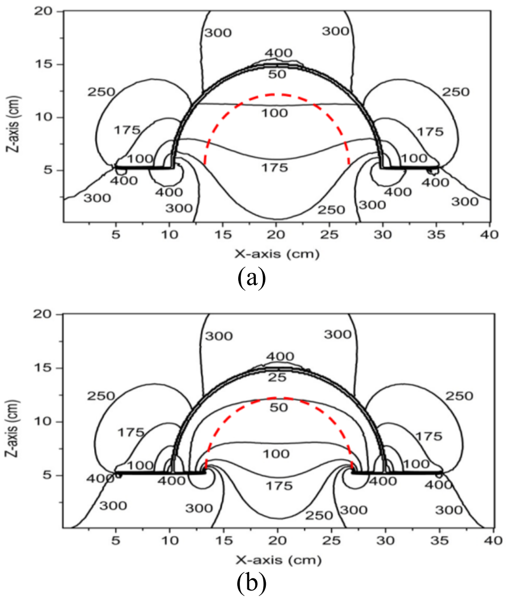


Fig. 1. Superconductive shield helmets. (a) Helmet without and (b) helmet with inward extension.

B. Simulation of Shielding Performance

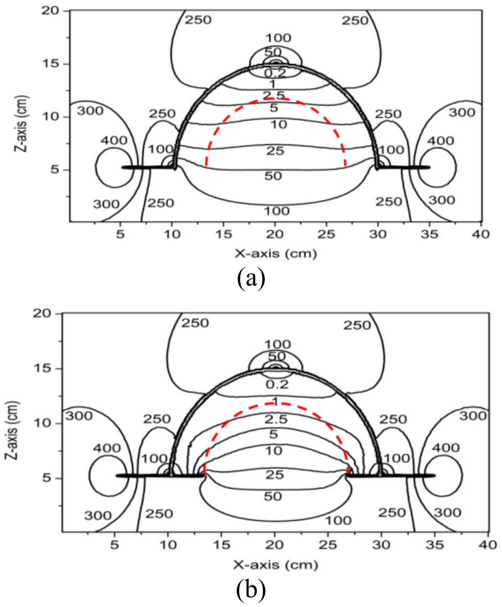
The magnetic field analysis was done using Maxwell 3D software, assuming the superconductor as a perfect conductor. A uniform magnetic field of 250 μT was applied to the helmets in the two directions; horizontal or vertical direction. Fig. 2 and 3 show the simulation results of the field distributions for horizontal and vertical direction, respectively. The red broken lines are the hypothetical magnetometer surfaces at which magnetometers are positioned. Compared with the helmet structure without inward brim (Fig. 2(a) and Fig. 3(a)), the helmet with inward brim has smaller field strength inside the helmet. Especially, the field direction at the magnetometer surfaces is more tangential to the magnetometer planes, that is, the normal component of the magnetic field at magnetometer surface is much weaker than those without inward brim.



(a)

(b)

Fig. 2. Simulation results of the field attenuation for horizontal field (along the left-right direction). (a) Isofield contour lines without internal brim and (b) with internal brim. Red broken line is the magnetometer surface.



(a)

(b)

Fig. 3. Simulation results of the field attenuation for vertical field (along the top-down direction). (a) Isofield contour lines without internal brim and (b) with internal brim.

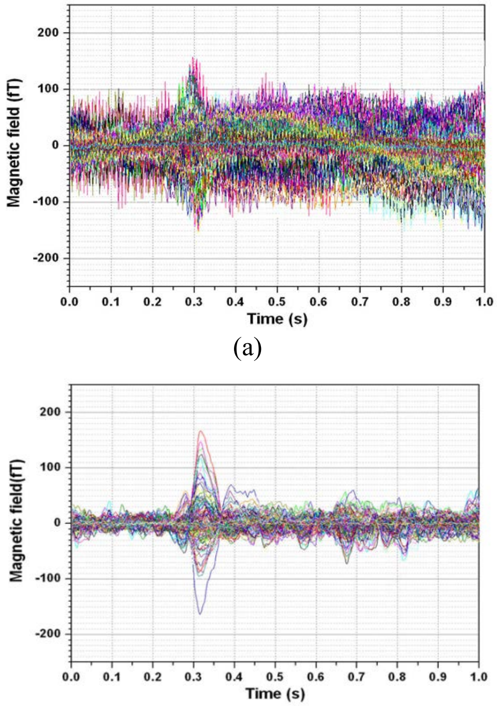
III. HELMET-TYPE MAGNETOMETER ARRAY

A. Helmet MEG System

When a SQUID magnetometer is separated by a distance d from the surface of a superconductive surface, a mirror image is formed in the SS surface and the SQUID output is like a first-order axial gradiometer having a baseline of $2d$. For the compact and reliable pickup coil, we made axial magnetometers made of NbTi wire as the pickup coil [4]. The distance d is 3 cm, thus forming a first-order gradiometer of baseline 6 cm. Direct bonding between the NbTi wires and input coil was made by ultrasonic boding of annealed Nb wire. Pb plate of 99.5% purity and 1 mm thick was used for the SS, and the number of magnetometers is 140.

B. Auditory-evoked Fields

Fig. 4 shows the auditory-evoked fields (AEFs) after sound stimuli of 500-Hz pure tone with 200-ms duration. The signals were averaged by 100 times. Compared with the results without inward brim, the introduction of inward brim greatly improves the quality of the signals.



(a)

(b)

Fig. 4. Auditory-evoked fields. (a) Measured without inward extension at the brim and (b) inward extension at the brim..

IV. CONCLUSION

By extending the brim inward, the shielding performance and the signal-to-noise ratio of AEF signals was improved much.

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