

A 64-channel SQUID Planar Gradiometer System for Magnetocardiogram

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We developed a 64-channel SQUID planar gradiometer system for measuring magnetocardiogram (MCG) signals. The SQUIDs are double relaxation oscillation SQUIDs (DROSSs) with high flux-to-voltage transfers and large modulation voltages, which enable direct readout of the SQUID output voltages by room-temperature dc preamplifiers and compact readout electronics. The SQUID sensors were fabricated from Nb/AlO_x/Nb junctions, Pd resistors, SiO₂ insulation layers, using a simple 4-level process. The planar pickup coils were fabricated on separate 4 or 6-inch Si wafers to increase the productivity. The sensors and pickup coils were connected superconductively using ultrasonic bonding of Nb wires. The planar gradiometer is first-order series pickup coil with a baseline of 40 mm, and feedback coil is formed in the flux transformer circuit as the external feedback to eliminate magnetic cross talk with the adjacent gradiometers. The readout electronics have dc bias current, dc preamplifier, and integrator, and the optimum control of the SQUID operation was done using digital signals through fiber-optic cables. The liquid helium dewar has a liquid capacity of 40 L, and the average boil-off rate with the 64-channel insert is 3.8 L/d. The 64 planar gradiometers were arranged to measure filed components tangential to the chest surface. By measuring the two tangential components, dB_x/dz and dB_y/dz , the sensor covering area could be made smaller than the conventional vertical component measurement. The sensor covering area of the 64 channel system is 162 mm x 162 mm, which was proved to be large enough to measure the essential MCG field distribution in a single-position measurement. The magnetic field average noise of the system is about $5 \text{ fT}/\sqrt{\text{Hz}}$ at 100 Hz, operated inside a magnetically shielded room. The dewar gantry and patient bed were made of nonmagnetic materials. The bed allows 3-dimensional movements, and nonmagnetic cycle is mounted for exercise MCG measurements. The software has the functions of automatic control of the SQUIDs, acquisition, signal processing and analysis. The analysis program allows field mapping and myocardial current mapping. By analyzing the field map and myocardial current information during the repolarization period of the heart cycle, the degree of myocardial ischemia can be calculated. 3 64-channel MCG systems were fabricated, and two of them were installed in hospitals for the diagnosis of heart diseases, especially, myocardial ischemia.

keywords : SQUID, readout electronics, low-noise field measurement, magnetocardiogram