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MAGNETOCARDIOGRAMS TAKEN INSIDE A SHIELDED ROOM WITH A SUPERCONDUCTING POINT-CONTACT MAGNETOMETER

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A point-contact (SQUID) magnetometer was used inside a shielded room to record the magnetic field of the human heart, without noise-averaging. The resulting magnetocardiograms, with the peak signal at about 3×10^{-7} G had a noise level of about 1×10^{-9} G (rms, per root cycle). They approach good medical electrocardiograms in clarity, and are an order-of-magnitude improvement in sensitivity over previous magnetic detectors of the heart. These results suggest new medical uses for this magnetometer.

During the past decade the weak magnetic fields produced by natural ion currents in humans have been detected from outside the body. In particular, measurements have been made of magnetic fields which are produced by the human heart[1-4] and brain.[5] It was shown[4] that the magnetic field of the heart arises from the same ion currents which produce the electrocardiogram (ECG). The brain's alpha-rhythm magnetic field is much weaker,[5] and arises from the same currents seen on the electroencephalogram (EEG).

The magnetocardiogram (MCG), which is a record of one component of the heart's field versus time at any point around the torso, resembles the ECG in general form. The flux density at the most favorable location is typically 3 or 4×10^{-7} G at the time of the heart's peak electrical activity during the heartbeat cycle (peak of QRS), from a normal subject. Up to now the most sensitive magnetic detector for MCG's has been a compact copper coil feeding a parametric amplifier; subject and detector were housed in a magnetically shielded room to eliminate background. With this system the QRS peak was just visible over the intrinsic detector noise, and increased to about five times noise if a ferrite rod was inserted along the coil axis, although this distorted the field to be measured. Accurate MCG's were taken only by using noise-averaging, without using ferrite. Here, we present the first results of a new method for taking MCG's; this method consists of using a point-contact detector instead of a copper coil. The greater sensitivity allows accurate MCG's to be taken directly, without noise-averaging. In this letter it is our intention to describe only an initial trial of this technique; an evaluation with full calibrations will be made later.

The new method is a union, suggested by one of us (E. E.), of two recent developments; one is the completion at the FBNML of a heavily magnetically shielded room, the other is the development of the point-contact magnetometer. The great sensitivity of this instrument can only be exploited in a highly shielded enclosure and the FBNML room is the only enclosure known to us which is of walk-in size and which is magnetically quieter than the intrinsic detector noise.

Point-contact detectors are a family within the species which uses the Josephson effect and which are called SQUIDS (Superconducting Quantum Interference Devices). The detector used here was a single point-contact rf biased SQUID[6] in a recently developed symmetric configuration of a high mechanical stability.[7] It was coupled to the local magnetic field through a flux transformer with a sensing loop, about 2 cm^2 in area. The sensing elements were mounted at the lower end of a coaxial pipe; the upper (room temperature) end was connected to a compact electronic unit containing the rf bias oscillator, amplifier, and detector. Coupling parameters were such that an applied field of 2.5 μG produced one flux quantum. The sensitivity of this unit was considered adequate for this trial which, to our knowledge, is the first time a SQUID has recorded a living signal. The sensitivity or signal/noise of future units can readily be improved by increasing the area of the flux transformer and improving its coupling to the SQUID.

FIG. 1. The FBNML shielded room, roughly spherical in shape, with i. d. and o. d. of 100 and 148 in. Five layers of shielding are used: three high-μ layers (including Hipernom) and two aluminum layers. The room is designed to have an inside field of $<10^{-8}$ G ac (rms) and $<10^{-7}$ G dc.

The shielded room,[8] shown in Fig. 1, was planned, among other uses, for measurements of heart and brain fields, both ac and dc. The floor is independently suspended so that slight motions of, say, a human subject do not couple into the ferromagnetic walls and produce extraneous magnetic signals at any detector rigidly attached to the walls through a mounting network.

The sensing end of the coaxial pipe was placed in the thin tail of a He-N double Dewar system about 2 ft long; the system was cooled down, then mounted inside the room. The output signal was fed to various display devices outside the room. A subject sat with his chest an inch or two from the detector, and was oriented to maximize his heart signal.

Figure 2 shows a typical MCG taken during that trial. From previous studies[4] it was known that

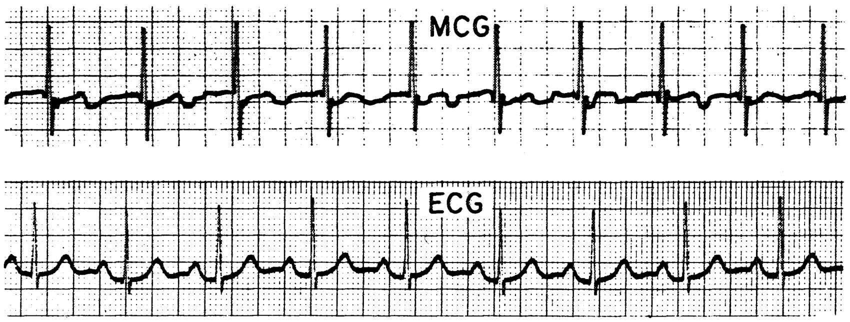

FIG. 2. Upper trace: an MCG taken inside the shielded room with the point-contact magnetometer; the *T* wave is visible but the *P* wave seems masked by detector noise. Lower trace: for comparison, a lead-II ECG of good medical quality taken the next day of the same subject. The chart speed for both traces was 25 mm/sec and bandwidth about 0.5 to about 40 Hz. Assuming 3×10^{-7} G at the peak of QRS, the magnetometer noise is estimated to be about 1×10^{-9} G (rms, per root cycle).

the subject orientation chosen here produces an MCG with a peak of about 3×10^{-7} G and which must superficially resemble the lead-II ECG, also shown in Fig. 2. This ECG may be considered as a standard for clarity and it is seen that the MCG is not far from this standard. About a factor of 3 in noise reduction in the MCG would clarify the *T* wave and bring out the *P* wave and baseline; the resulting MCG would then be of high medical quality. This noise reduction is being planned, and the improved point-contact magnetometer will also be useful in other studies, such as magnetoencephalography.

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