

# Magnetocardiography Measurements via Peak to Peak Voltage Detector Type MI Gradiometer

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In the previous study, we had reported a high-performance MI magnetometer [1]. However, for detecting extremely weak magnetic field such as a bio-magnetic field, we have to cancel the background uniform noises such as geomagnetic field. In this study, we have proposed a peak to peak voltage detector type MI gradiometer (shortened: Pk-pk VD-type MI gradiometer), which is aimed to measure an extremely weak magnetic field. Meanwhile, we have demonstrated Pk-pk VD-type MI gradiometer for detecting magnetic cardiogram signals, with simultaneous measurement of cardiac electric activity. The new MI gradiometer is composed of a pair of MI elements: a sensing element and a reference element. The distance between the coils is set to be 3cm. The figure 1 illustrates the block diagram of new MI gradiometer. The pulse generator produces a rectangular voltage wave to differential circuit. Then, the rectangular waves are transferred into three different positive pulses. We detect both the positive peak and negative peak of induced waves in each pick-up coil excited by rising edge and drop edge of the excitation pulse, by using the staggered pulses and analog switches. Finally, the Pk-pk VD-type MI gradiometer outputs the difference between the sensing element and reference element for canceling out uniform magnetic field noise. Therefore, we can achieve a highly sensitive, low noise level, and stable MI sensor system for bio-magnetic field measurement in unshielded environment, at room temperature. Both of sensing and reference MI elements illustrate good linearity. The difference in the sensitivity of sensing and reference elements is within 1%. The noise floor of the Pk-pk VD-type MI gradiometer is lower than  $2 \text{ pT/Hz}^{1/2}$  in the frequency range from 1 Hz to 100 Hz. It is 1/5 of noise level of previous MI gradiometer in a 1-100 Hz frequency range.

MCG measurement by using the Pk-pk VD-type MI gradiometer is carried out on a male subject (aged 26) in sitting position, without any magnetic shielding equipment. We set up the MI gradiometer on a wooden table, and the sensor head is perpendicularly placed to the chest surface, with a distance of 10 mm between the chest surface and sensor head. The measurement point is set at the chest surface, 25 mm to the left of the pit of stomach. The output superposing noise of new MI gradiometer is lower than previous MI gradiometer. Meanwhile, we have successfully measured the MCG signals in averaging over only 6 cycles. Comparing with the previous MCG measurements [2], we have markedly reduced the cycles for arithmetic average processing. The Fig.2 illustrates the simultaneously measured ECG and MCG signals in averaging over only 6 cycles. As illustrated in Fig.2, we can obviously identify a sharp magnetic peak, corresponding to the QRS complex of ECG. The amplitude of this magnetic peak related to the R peak is approximately 100 pT, which coincides well with the reported MCG value.

## Reference

- 1) J. Ma, and T. Uchiyama, IEEE Trans. Magn., VOL. 53, NO. 11, (2017).
- 2) T. Uchiyama and T. Takiya, AIP Adv., vol. 7, no. 5, 2017

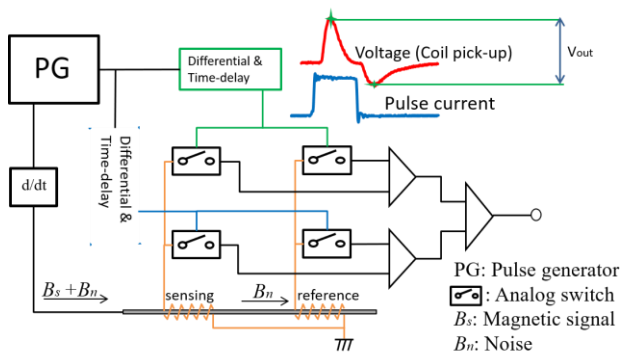


Fig. 1. The block diagram of Pk-pk VD-type MI gradiometer.

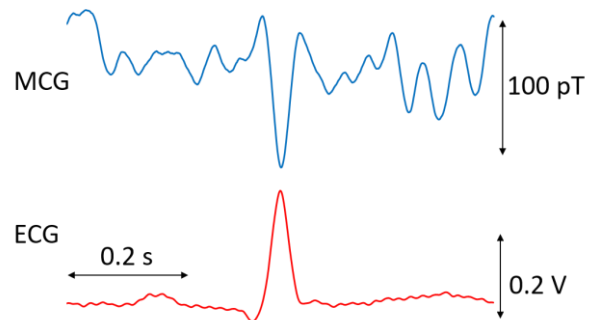


Fig. 2. Simultaneously measured ECG and MCG signals in averaging over 6 cycles.