

Fast-Recovery Capacitive ECG Front-End Based on Reverse-Connected Zener Diodes

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EXTENDED ABSTRACT

Capacitive electrocardiography (cECG) enables unobtrusive cardiac monitoring without direct galvanic skin contact and is therefore highly attractive for wearable and long-term biomedical sensing applications. Compared to conventional wet electrodes, capacitive electrodes improve user comfort and simplify integration into wearable and textile-based systems. However, the extremely high input impedance required for capacitive biosignal acquisition makes the analog frontend highly susceptible to motion artifacts, electrostatic interference, and common-mode transients. These disturbances may drive the amplifier into saturation, leading to prolonged recovery times and temporary loss of physiological signal acquisition [1].

One commonly used approach to achieve extremely high input impedance in capacitive ECG front-ends is the bootstrapping technique, where positive feedback from the analog front-end output is coupled to the shielding or biasing network of the capacitive electrode. By reducing the effective voltage difference across the input impedance network, bootstrapping minimizes leakage currents and increases the equivalent input impedance seen by the sensing electrode, thereby improving sensitivity for weak biopotential acquisition [2]. However, the large effective time constants associated with ultra-high input impedance front-ends and conventional gigaohm biasing networks can result in very slow discharge behavior after saturation events.

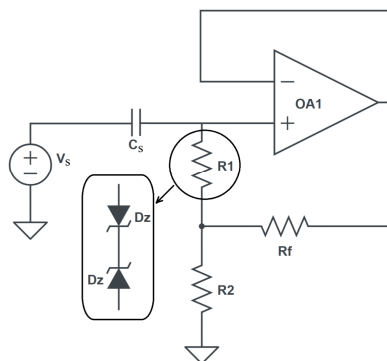


Fig. 1. Bootstrapped capacitive electrode using a reverse-biased Zener diode.

This work presents a fast-recovery capacitive ECG analog front-end employing a passive nonlinear recovery mechanism based on reverse-connected Zener diodes integrated into the bootstrapping network, as shown in Fig. 1. Instead of using conventionally bulky ultra-high-value bias resistors for charge dissipation [3], the proposed approach utilizes reverse-connected Zener diodes to achieve adaptive transient suppression while preserving the high effective input impedance required for weak ECG signal acquisition. During large transient disturbances, the nonlinear conduction characteristic of the Zener configuration provides a low dynamic resistance discharge path that accelerates removal of accumulated charge at the amplifier input stage, thereby significantly reducing saturation recovery time.

The proposed front-end was implemented using a high-input-impedance analog buffering stage optimized for capacitive sensing applications. The analog signal chain incorporates a 0.3 Hz high-pass filter and a second-order 45 Hz Butterworth low-pass filter suitable for ECG acquisition. The complete system was realized on a compact PCB electrode structure including shielding and guard-ring techniques to minimize leakage currents and electromagnetic interference.

Experimental measurements performed under representative wearable cECG operating conditions demonstrated substantially faster recovery behavior compared with conventional high-impedance front-end configurations employing only gigaohm bias resistors. Measurement results confirm recovery within less than one second following motion-induced disturbances while maintaining stable ECG acquisition during normal operation. The proposed passive recovery technique eliminates the need for active reset circuits or additional control logic, thereby reducing circuit complexity and power consumption while improving robustness against large transient events.

REFERENCES

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