

## Article

# Low-Power Long-Term Ambulatory Electrocardiography Monitor of Three Leads with Beat-to-Beat Heart Rate Measurement in Real Time

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**Abstract:** A low-power long-term ambulatory ECG monitor was developed for the acquisition, storage and processing of three simultaneous leads DL, aVF and V2 with a beat-to-beat heart rate measurement in real time. It provides long-term continuous ECG recordings until 84 h. The monitor uses a QRS complex detection algorithm based on the continuous wavelet transform with splines, which automatically selects the scale for the analysis of ECG records with different sampling frequencies. It includes a lead-off detection to continuously monitor the electrode connections and a real-time system of visual and acoustic alarms to alert users of abnormal conditions in its operation. The monitor presented is based in an ADS1294 analogue front-end with four channels, 24-bit analog-to-digital converters and programmable gain amplifiers, a low-power dual-core ESP32 microcontroller, a microSD memory for data storage in a range of 4 GB to 32 GB and a 1.4 in thin-film transistor liquid crystal display (LCD) variant with a resolution of 128 × 128 pixels. It has programmable sampling rates of 250, 500 and 1000 Hz; a bandwidth of 0 Hz to 50% of the selected sampling rate; a CMRR of −105 dB; an input margin of ±2.4 V; a resolution of 286 nV; and a current consumption of 50 mA for an average battery life of 84 h. The ambulatory ECG monitor was evaluated with the commercial data-acquisition system BIO-PAC MP36 and its module for ECG LABEL SS2LB, simultaneously comparing the morphologies of two ECG records and obtaining a correlation of 91.78%. For the QRS detection in real time, the implemented algorithm had an error less than 5%. The developed ambulatory ECG monitor can be used for the analysis of the dynamics of the heart rate variability in long-term ECG records and for the development of one's own databases of ECG recordings of normal subjects and patients with cardiovascular and noncardiovascular diseases.

**Keywords:** ambulatory ECG monitor; heart rate; real-time QRS detection; ESP32; ADS1294; long-term ECG recordings



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## 1. Introduction

Cardiovascular diseases are the leading cause of death worldwide [1]. Therefore, there is a need for ambulatory (Holter) electrocardiography (ECG) monitors that can supplement traditional medical and clinical care, allowing for the noninvasive evaluation of electrocardiographic abnormalities over long periods of time and permitting the patients to conduct their normal daily activities. In contrast to the standard 12-lead ECG recordings of brief duration used in clinical examinations, where these intermittent cardiac abnormalities during the day may be undetected, the Holter ECG monitor allows one to continuously examine a patient over an extended time of 24 to 48 h, providing a long-term continuous recording [2].

# Longterm Ambulatory Electrocardiography

**Sanjeev Saksena,A. John Camm**



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