

## 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

**Richard Millis**



## **Longterm Ambulatory Electrocardiography:**

**Long-Term Ambulatory Electrocardiography** J.R. Roelandt,P.G. Hugenholtz,2012-12-06 Recent technological developments have brought long term ambulatory electro cardiography to the front of clinical cardiology Its application for solving clinical problems potentially related to cardiac arrhythmias is rapidly increasing In the meantime the method has found widespread use in the identification of patients at risk for cardiac death as well as in the assessment of therapeutic interventions It was the purpose of this symposium to bring together an international group of authorities in order both to provide an overall view of the field and to discuss critically the value of clinical epidemiological and research applications of long term ambulatory electrocardiography in the light of new concepts and recent advances The first section of this volume discusses the methodology and the performance criteria of the equipment and analysis systems In the second section the potentials and problems encountered in the use of long term ambulatory electrocardiography for solving clinical questions and for predicting the occurrence of clinically important arrhythmias are extensively as continuous ST segment monitoring blood dealt with New applications such pressure measurement and other physiologic parameters are also included Prevalence variability and prognostic aspects of ventricular arrhythmias both in normals and in patients with cardiac disease are the subject of section 3 The last section provides a critical review of the use of the method for the evaluation of therapeutic interventions with drugs The editors feel that this volume represents the state of the art in this newly important area of clinical cardiology     Handbook of Cardiac Electrophysiology Andrea Natale,Oussama M. Wazni,Kalyanam Shivkumar,Francis E. Marchlinski,2020-03-23 The second edition of this bestseller provides a practical user friendly manual guiding the theory and practice of cardiac electrophysiology The handbook provides the specialist in training with a thorough grounding procedures and clinical findings for clinicians It provides a review of the main kinds of arrhythmia with illustrations of typical ECG findings supported where appropriate by correlative imaging It also details the principal diagnostic and therapeutic procedures include implantation of pacemakers resynchronization therapy and ablation techniques Key Features Provides concise user friendly guide to the equipment procedures and clinical findings with which EPs need to be familiar Delivers alternatives resource to the flagship titles available in this field idea for those beginning training or seeking an update Presents extensively updated material to enhance comprehension Includes new treatments and devices for electrophysiologists trained to perform interventional cardiac electrophysiology studies EPS as well as surgical device implantations     **Electrocardiography and Cardiac Drug Therapy** Vinzenz Hombach,H.H. Hilger,H. Kennedy,2012-12-06 This book is a comprehensive overview of electrocardiography and the major effects of current cardiac pharmacological therapy on electrocardiography The text is based on work presented at the International Symposium on Non invasive Cardiovascular Diagnosis and Therapy held in May 1987 at the University of Cologne The theme of the book is to review in broad clinical perspective the current state of the art of electrocardiography as it pertains to standard electrocar

diagrams exercise testing ambulatory electrocardiography electrocardiographic telemetry and high resolution electrocardiography Furthermore advance in cardiac drug therapy in relation to diuretics beta blocking drugs antiarrhythmic agents and thrombolytic agents are reviewed The emphasis of the conference and this book is to review the clinical state of the art information and applications in this regard In the initial section on electrocardiography Dr Spodick reviews our present day physiologic and pathophysiologic understanding of systolic time intervals and how they are affected by a variety of cardiac disease states and pharmacologic agents Dr Ellestad examines problems and provides pragmatic tips on exercise testing in the diagnosis of coronary artery disease and advances in exercise scores and computer analysis Dr Graboys reviews the value of exercise testing in the diagnosis and management of patients with serious ventricular arrhythmias Dr Kellermann presents the complimentary role that exercise testing plays in comprehensive follow up therapy of the cardiac patient and the use of exercise for work and physical training Detailed information concerning the interaction of cardiac rehabilitation and ventricular arrhythmias are examined

*Advances in Electrocardiograms* Richard Millis, 2012-01-25

Electrocardiograms are one of the most widely used methods for evaluating the structure function relationships of the heart in health and disease This book is the first of two volumes which reviews recent advancements in electrocardiography This volume lays the groundwork for understanding the technical aspects of these advancements The five sections of this volume Cardiac Anatomy ECG Technique ECG Features Heart Rate Variability and ECG Data Management provide comprehensive reviews of advancements in the technical and analytical methods for interpreting and evaluating electrocardiograms This volume is complemented with anatomical diagrams electrocardiogram recordings flow diagrams and algorithms which demonstrate the most modern principles of electrocardiography The chapters which form this volume describe how the technical impediments inherent to instrument patient interfacing recording and interpreting variations in electrocardiogram time intervals and morphologies as well as electrocardiogram data sharing have been effectively overcome The advent of novel detection filtering and testing devices are described Foremost among these devices are innovative algorithms for automating the evaluation of electrocardiograms

*Advances In Electrocardiology 2004 - Proceedings Of The 31th International Congress On Electrocardiology* Masayasu Hiraoka, Itsuo Kodama, Hiroshi Inoue, Hiroshi Kasanuki, Takao Katoh, Satoshi Ogawa, 2005-04-13

Electrocardiology has witnessed a century of development since the introduction of Einthoven's Galvanometer With rapid progress in the scientific technological and clinical aspects of the field of electrocardiology in recent years electrocardiology now covers a wide range of topics from molecules as the electrical origin of the heart to diagnostic and therapeutic applications for cardiovascular diseases This volume presents the latest information and developments in the field from basic science to clinical electrocardiology A wide range of topics are covered including molecular biology genetics channelopathy atrial fibrillation catheter ablation modeling of cardiac electrical activity cardiac mapping as well as diagnosis treatment and prevention of cardiac disease and arrhythmic disorders Contributors to

the volume include leading experts in the field such as PJ Schwartz C Antzelevitch Y Rudy HJGM Vrijin DG Escande AAM Wilde DA Kass J Jalife and A d Avila The book is an essential source of reference for cardiologists and electrocardiologists

**Biomedical Electronics, Noise Shaping ADCs, and Frequency References** Pieter Harpe,Andrea Baschiroto,Kofi A.A. Makinwa,2023-06-22 This book is based on the 18 tutorials presented during the 30th workshop on Advances in Analog Circuit Design Expert designers present readers with information about a variety of topics at the frontier of analog circuit design with specific contributions focusing on analog circuits for machine learning current voltage temperature sensors and high speed communication via wireless wireline or optical links This book serves as a valuable reference to the state of the art for anyone involved in analog circuit research and development Evidence-Based Cardiology Salim Yusuf,John A. Cairns,A. John Camm,Ernest L. Fallen,Bernard J. Gersh,2008-04-15 This second edition is a ground breaking clinical text with a strong emphasis on rigorous evidence Leaders in the field discuss best practice in the light of systematic reviews and randomised control trials and how best to treat where the information is less clear Case histories provide intriguing discussions on how to apply the evidence in real life situations Evidence based Cardiology also includes free access to the latest evidence which is automatically posted on a companion website **Acute Coronary Care** Robert M. Califf,G.S. Wagner,2012-12-06 When a patient develops symptoms suggestive of and infarction this section is emphasized There acute coronary insufficiency the health care sys are brief sections on prediction and prevention of tem is presented with a challenging diagnostic ischemic events methods of diagnosing and siz and management problem During the past 20 ing infarcts and methods of monitoring the pa years hospitals have been developing coronary tient with myocardial ischemia A major focus of care units as the specialized inhospital facilities for the text is on coronary care As indicated above such patients For the past 15 years many com during the past 20 years five distinct phases of munities have employed paramedical personnel coronary care have evolved a prehospital b to extend the principles of coronary care to the postadmission c coronary care unit d predis site of the patient who develops the problem charge and e convalescent Cardiac rehabilitation programs have also been The section on pathophysiology begins with a established to facilitate the return to function of chapter by Greenfield and Rembert discussing patients who have had acute coronary insuffi the factors that determine the transmural distri ciency More recently aggressive medical and bution of blood flow Reimer then shows the surgical techniques have been developed to either relationship between coronary blood flow and prevent or limit the extent of myocardial necrosis both reversible and irreversible damage to the that develops due to acute coronary insufficiency myocardium Cardiac Arrhythmias 7th Edition: Practical Notes on Interpretation and Treatment David H Bennett,2006-09-29 Cardiac Arrhythmias is a long established and widely respected guide to the interpretation and treatment of cardiac rhythm disorders Acting as a practical handbook to dip into when required and also as a comprehensive textbook it covers the basics and detail of cardiac arrhythmias at a realistic level without overwhelming the reader with

unnecessary technical details and references For this seventh edition the content has been brought up to date throughout incorporating results from recent major clinical trials developments in the treatment of atrial fibrillation greater sophistication in pacemaker technology and the increased availability of defibrillators The book will provide invaluable advice to junior hospital doctors coronary care nurses cardiac technicians higher level medical students and practising physicians requiring a ready reference to this important subject Highly Commended at the 2002 BMA Medical Book Competition Awards Sixth edition A thoroughly usable handbook to dip into and practical textbook covering the area of the basics and detail of cardiac arrhythmias for trainee cardiologists technicians GPSI cardiology and cardiologists but without unnecessary technical detail and references From the reviews of previous editions I enjoyed reading it and would recommend it unreservedly to anaesthetists who wish to improve their knowledge of cardiac arrhythmias My advice is to buy the book and read it British Journal of Anaesthesia a well conceived practical guide to the interpretation and treatment of the main cardiac rhythm disturbances Many a medical registrar will be grateful for this clear concise up to date manual Lancet This book presents a concise and simplified approach to the diagnosis and management of abnormalities in cardiac rhythm One of the books strengths is the number and quality of electrocardiographic tracings that are juxtaposed with the text to highlight important points New England Journal of Medicine This book about cardiac arrhythmias is of much educational value and is written and edited simply and clearly European Heart Journal My choice would be Bennetts Cardiac Arrhythmias which is rather more advanced and therefore suitable for junior hospital staff This includes a list of key learning points at the end of each section and ends with a challenging ECG quiz British Medical Journal Cumulated Index Medicus ,1994 **Health Technology Assessment Reports** ,1989 The ECG Manual Marc Gertsch,2008-10-16 For every physician that interprets ECGs there is great need to understand a vast amount of information regarding the technique That the basics of the technique have changed little over the last 100 years means that there is a huge amount of subtle detail that must be learnt to enable its effective use as a diagnostic test The ECG technique is critical for deciding upon further diagnostic procedures and therapeutic interventions notably coronary angiography PTCA stenting coronary artery bypass grafting pacemaker insertion ablation electroconversion etc Without attaining the skills to practice the ECG procedure and knowledge of its diagnostic value skills often overlooked during medical training physicians will be unlikely to use it to the benefit of their patients **Tresch and Aronow's Cardiovascular Disease in the Elderly** Wilbert S. Aronow,Jerome L. Fleg,Michael W. Rich,2019-02-06 With an exponential growth in the number of older adults understanding the common disorders of the elderly patient requiring cardiac care is becoming increasingly important Incorporating recent advances in the field Tresch and Aronow s Cardiovascular Disease in the Elderly 6th Edition has been completely revised and updated to provide cardiologists primary care physicians geriatricians and other clinicians caring for the elderly a comprehensive and accessible overview of the epidemiology pathophysiology and treatment of cardiovascular disorders in older patients **11th**

**Mediterranean Conference on Medical and Biological Engineering and Computing 2007** Tomaz Jarm, Peter Kramar, Anze Zupanic, 2007-10-24 Biomedical engineering today is a well recognized area of research It brings together bright minds from diverse disciplines ranging from engineering physics and computer sciences on one side to biology and medicine on the other side With valuable assistance of members of the International Advisory Committee and Scientific Program Committee the co organizing institutions and societies our sponsors and distinguished invited lecturers we will ensure that the research and development presented at MEDICON 2007 plenary meetings scientific sessions and workshops will truly be relevant and up to date The MEDICON conferences are international events of high scientific standards with long lasting tradition held every third year in one of the Mediterranean countries under the auspices of the International Federation for Medical and Biological Engineering

*Electrophysiological Disorders of the Heart E-Book* Sanjeev Saksena, A. John Camm, 2011-12-12 The new edition of *Electrophysiological Disorders of the Heart* helps you diagnose and treat a full range of heart rhythm disorders using today's latest technologies and therapies It provides practical hands on coverage of hot topics such as pediatric EP imaging echocardiography guided EP procedures regenerative therapies cardiac pacing and more Now available in a new full color format the title also includes easy online access at [www.expertconsult.com](http://www.expertconsult.com) Discover new ways to treat and manage the full range of heart rhythm disorders with content focused on common clinical features diagnosis and management Review expert management strategies to help you handle complex patient problems Stay current with the latest molecular and technical advances as well as new treatment options implemented over the last few years Use the latest technologies and devices to accurately diagnose and manage heart rhythm disorders Consult new and expanded coverage of regenerative therapies echo guided procedures cardiac pacing and CRT as well as a new section on pediatric electrophysiology and imaging Enjoy improved visual guidance with many new full color images Log on to [www.expertconsult.com](http://www.expertconsult.com) to easily search the complete contents online and access a downloadable image library

Ambulation Analysis in Wearable ECG Subhasis Chaudhuri, Tanmay D. Pawar, Siddhartha Duttagupta, 2009-07-21 *Ambulation Analysis in Wearable ECG* demonstrates why due to recent developments the wearable ECG recorder substantiates a significant innovation in the healthcare field About this book Examines the viability of wearable ECG in cardiac monitoring Includes chapters written by practitioners who have personally developed such hardware to write about the hardware details Bridges the gap between hardware and algorithmic developments with chapters that specifically discuss the hardware aspects and their corresponding calibration issues Presents a useful text for both practitioners and researchers in biomedical engineering and related interdisciplinary fields Assumes basic familiarity with digital signal processing and linear algebra

Comprehensive Electrocardiology Peter W. Macfarlane, Adriaan van Oosterom, Olle Pahlm, Paul Kligfield, Michiel Janse, John Camm, 2010-11-05 New edition of the classic complete reference book for cardiologists and trainee cardiologists on the theory and practice of electrocardiography one of the key modalities used for evaluating cardiology patients and

deciding on appropriate management strategies      Cardiac Arrhythmia Philip J. Podrid, Peter R. Kowey, 2001 The Second Edition of this clinically oriented textbook about cardiac arrhythmia management continues to be a must have volume for practicing cardiologists and internists who require up to date information for the daily management of their patients The material prepared by recognized experts in the field presents an in depth look at diagnostic and treatment protocols in a readable well organized format Unique chapters regarding pregnancy athletes and genetics also are included A Brandon Hill recommended title      **Feature Engineering and Computational Intelligence in ECG Monitoring** Chengyu Liu, Jianqing Li, 2020-06-24 This book discusses feature engineering and computational intelligence solutions for ECG monitoring with a particular focus on how these methods can be efficiently used to address the emerging challenges of dynamic continuous long term individual ECG monitoring and real time feedback By doing so it provides a snapshot of the current research at the interface between physiological signal analysis and machine learning It also helps clarify a number of dilemmas and encourages further investigations in this field to explore rational applications of feature engineering and computational intelligence in ECG monitoring The book is intended for researchers and graduate students in the field of biomedical engineering ECG signal processing and intelligent healthcare      **Handbook of Research Methods in Cardiovascular Behavioral Medicine** Neil Schneiderman, Stephen M. Weiss, Peter G. Kaufmann, 2013-11-21 Cardiovascular disease continues to be the number one cause of death in the United States Behavioral medicine was developed and shaped into the one source of morbidity and mortality in our country following definition by Deshpande Despite a 35% reduction since 1964 these Behavioral medicine is the interdisciplinary field concerned with the development and integration of behavioral and biomedical science knowledge and techniques the United States has lost nearly 1 000 000 lives each year in cardiovascular disease and behavioral medicine The Framingham study among others has identified the application of this knowledge and these techniques to prevention diagnosis treatment and rehabilitation identified three major risk factors implicated in the development of CHD smoking elevated serum cholesterol and high blood pressure de Schwartz Weiss 1978 development of CHD smoking elevated serum cholesterol and high blood pressure Castelli et al This concept of biobehavioral collaboration 1986 Given that these factors account for less than 50% of the variance associated with CHD scientists and clinicians of many disciplines have begun to consider how they might more effectively address these risk factors Jenkins 1976 it has become obvious that additional diagnostic treatment and prevention strategies must be identified if further progress is to be made in disease prevention and simultaneously among others behavioral psychology control

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