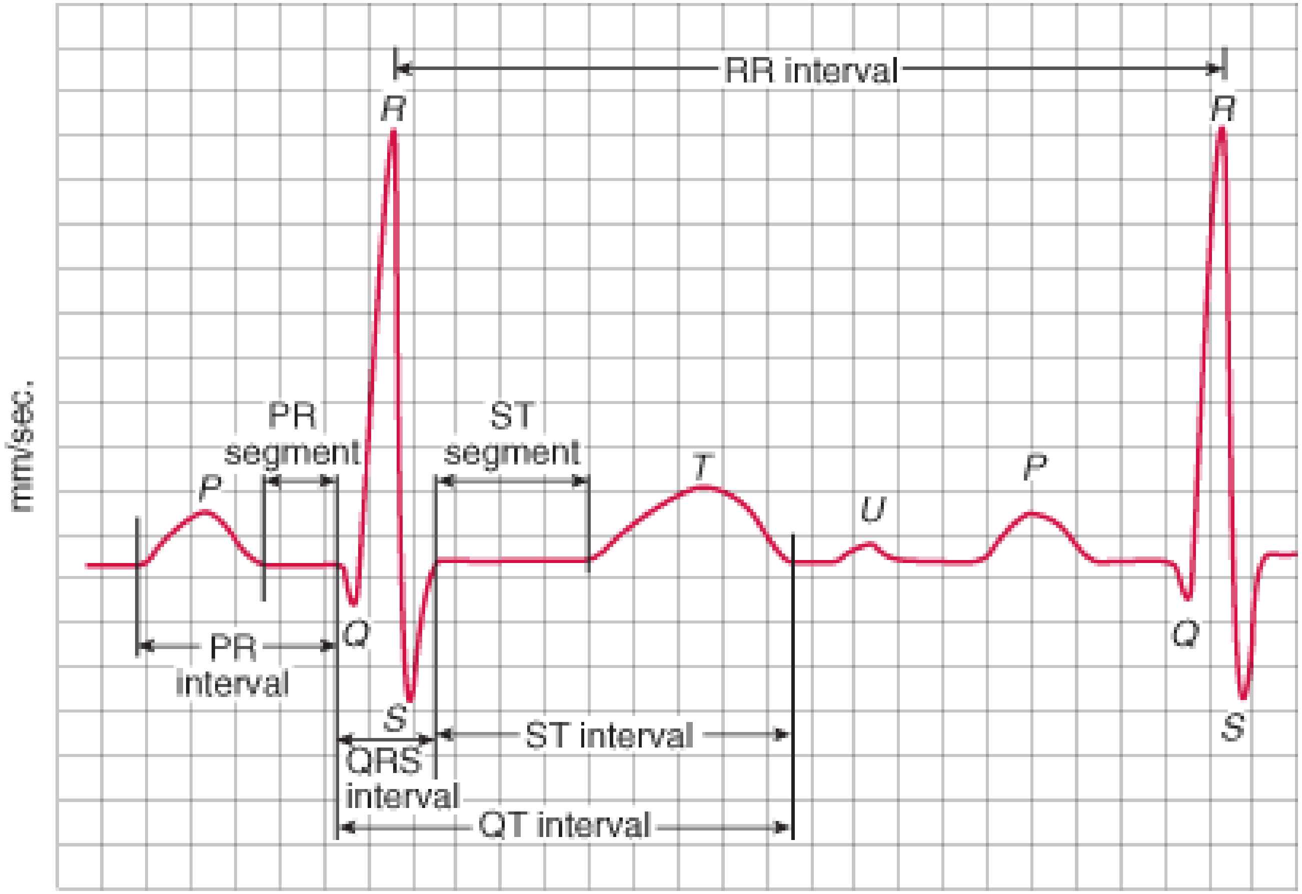
ECG Monitor

Single Lead Analog Heart Rate Monitor

ECG Waveform

ECG Monitor

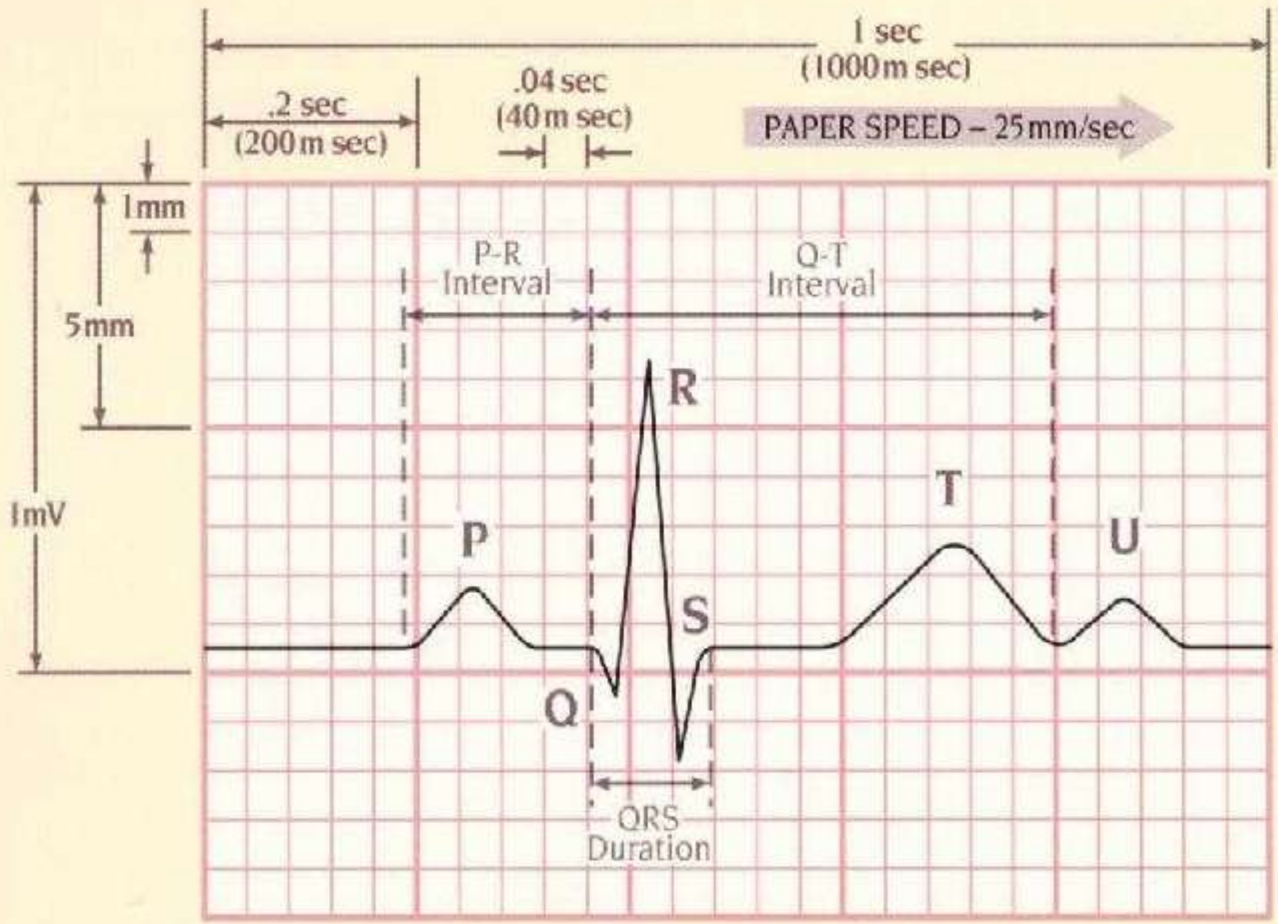
ECG Waveform



Wave	Amplitude (mV)	Duration (sec)
P	0.25	0.12 – 0.22 (P – R interval)
R	1.06	0.07 – 0.1
T	0.1 – 0.5	0.05 – 0.15 (S – T segment)
QRS Complex	-	0.09

ECG Monitor

ECG Waveform



VERTICAL AXIS	
	1 Small Square = 1mm (0.1mV)
	1 Large Square = 5mm (0.5mV)
	2 Large Squares = 1mV

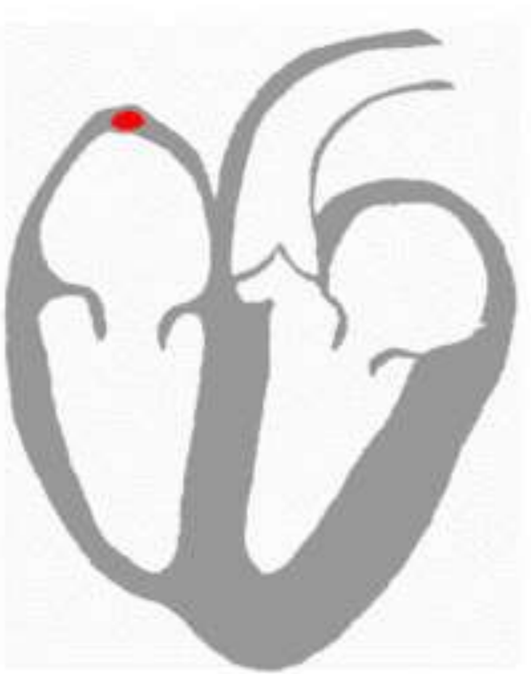
HORIZONTAL AXIS	
	1 Small Square = .04 sec (40 m sec)
	1 Large Square = .2 sec (200 m sec)
	5 Large Squares = 1 sec (1000 m sec)

ECG Monitor

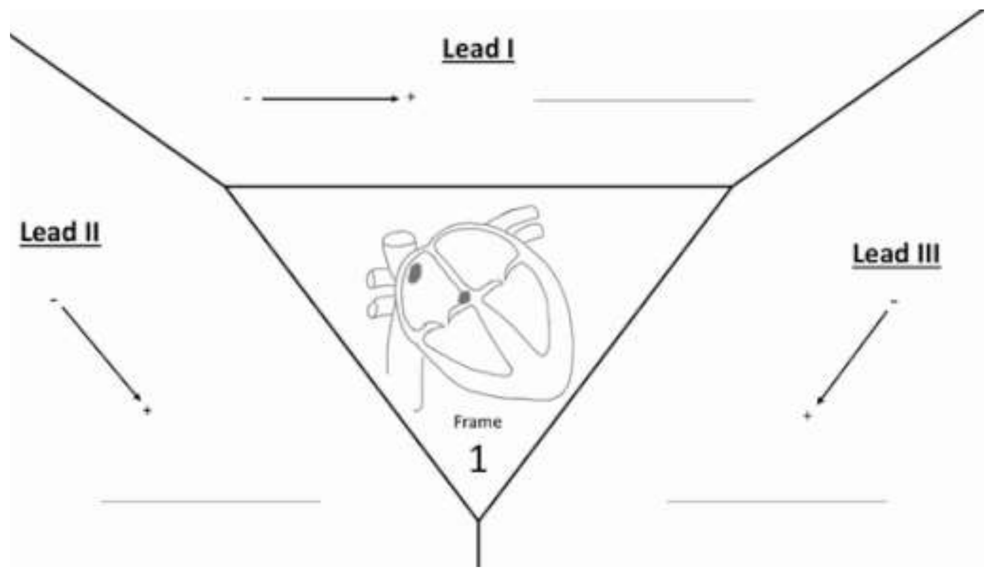
ECG Waveform

[Electrocardiography - Wikipedia]

Animation of a normal ECG wave



Formation of limb waveforms during a pulse

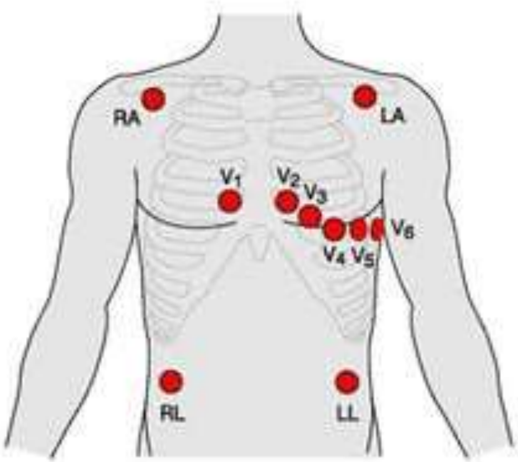


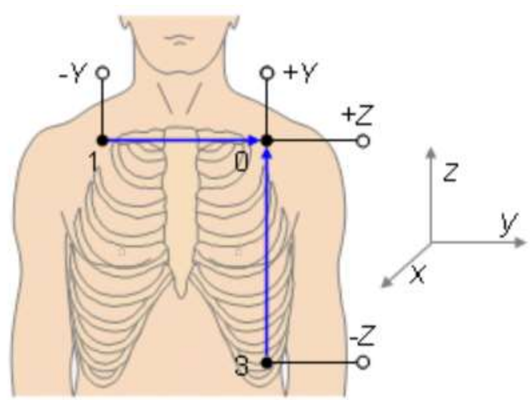
ECG Monitor

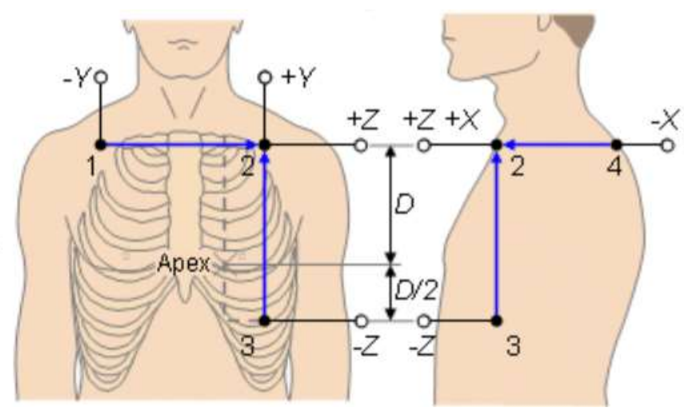
ECG Leads

Table 2. Definition of ECG Leads

Lead type	Electrodes used	Definition
Bipolar or limb leads (Einthoven)	LA, RA, LL, RL	$I = LA - RA$ $II = LL - RA$ $III = LL - LA$
Augmented (Goldberger)	LA, RA, LL, RL	$aV_R = RA - 0.5(LA + LL)$ $aV_L = LA - 0.5(LL + RA)$ $aV_F = LL - 0.5(LA + RA)$
Unipolar chest leads (Wilson)	$V_1, V_2, V_3, V_4, V_5, V_6$	$V_1 = v_1 - (LA + RA + LL)/3$ $V_2 = v_2 - (LA + RA + LL)/3$ $V_3 = v_3 - (LA + RA + LL)/3$ $V_4 = v_4 - (LA + RA + LL)/3$ $V_5 = v_5 - (LA + RA + LL)/3$ $V_6 = v_6 - (LA + RA + LL)/3$
Orthogonal vector leads (Frank)	I, E, C, A, M, H, F	$X = 0.610A + 0.171C - 0.781I$ $Y = 0.655F + 0.345M - 1.000H$ $Z = 0.133A + 0.736M - 0.264I - 0.374E - 0.231C$





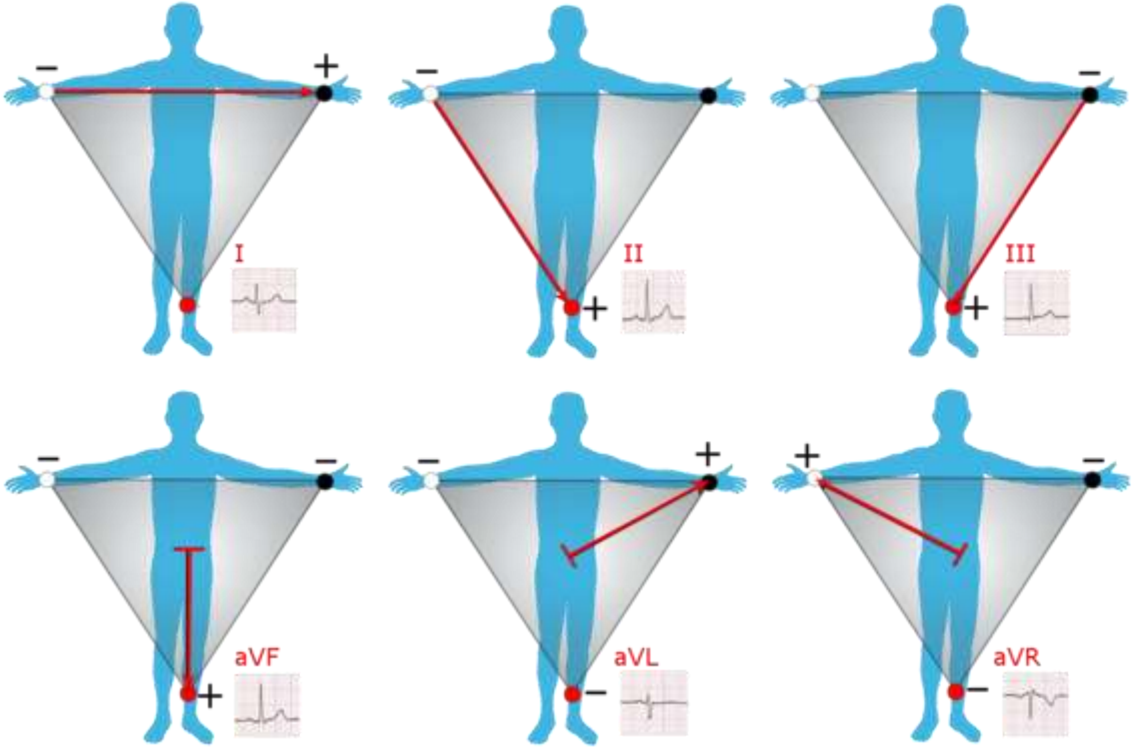


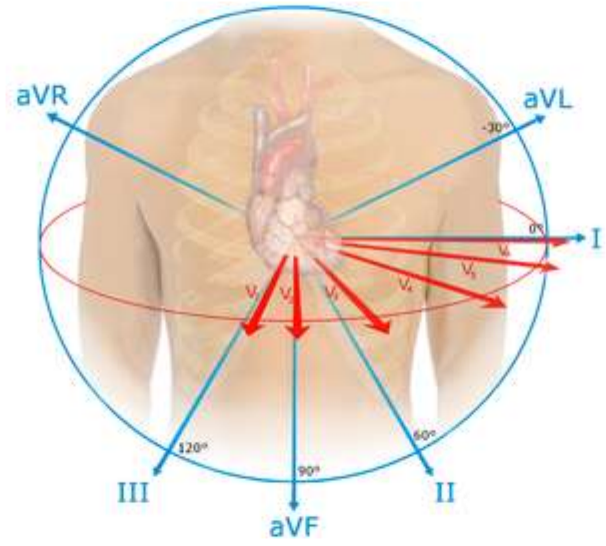
ECG Monitor

ECG Leads

[Electrocardiography - Wikipedia](#)

The limb leads and augmented limb leads (Wilson's central terminal is used as the negative pole for the latter in this representation)



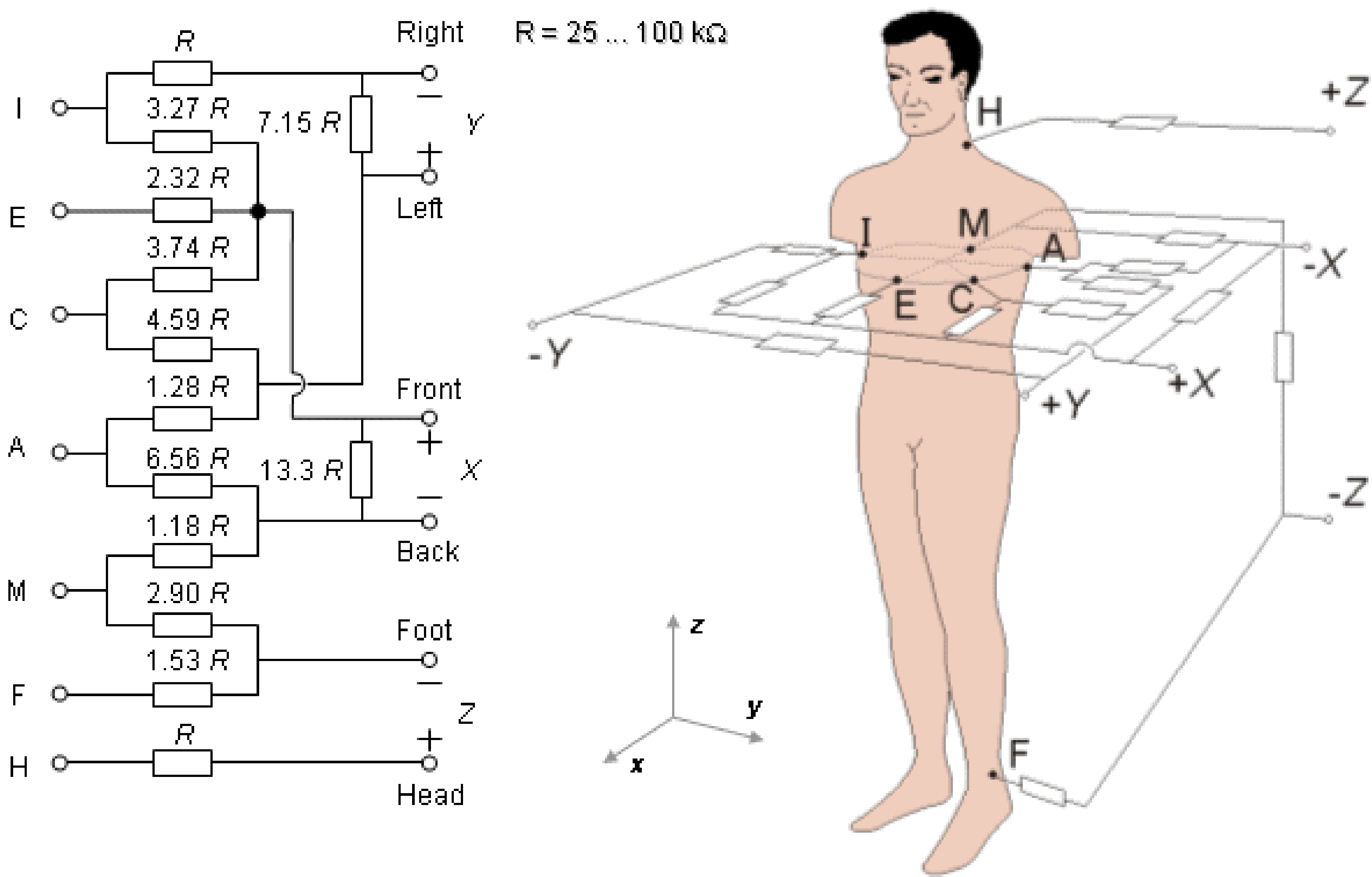


ECG Monitor

ECG Leads

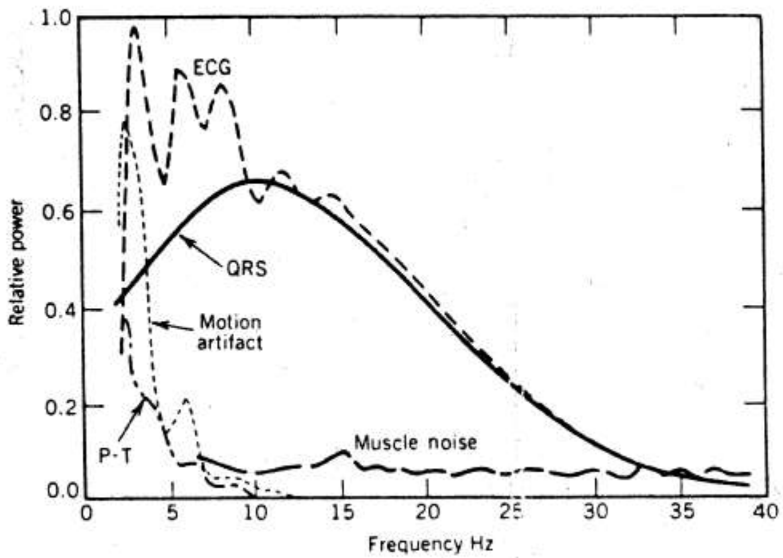
[16. Vectorcardiographic Lead Systems (bem.fi)]

The lead matrix of the Frank VCG-system. The electrodes are marked I, E, C, A, M, F, and H, and their anatomical positions are shown. The resistor matrix results in the establishment of normalized *x-, y-,* and *z*-component lead vectors, as described in the text.

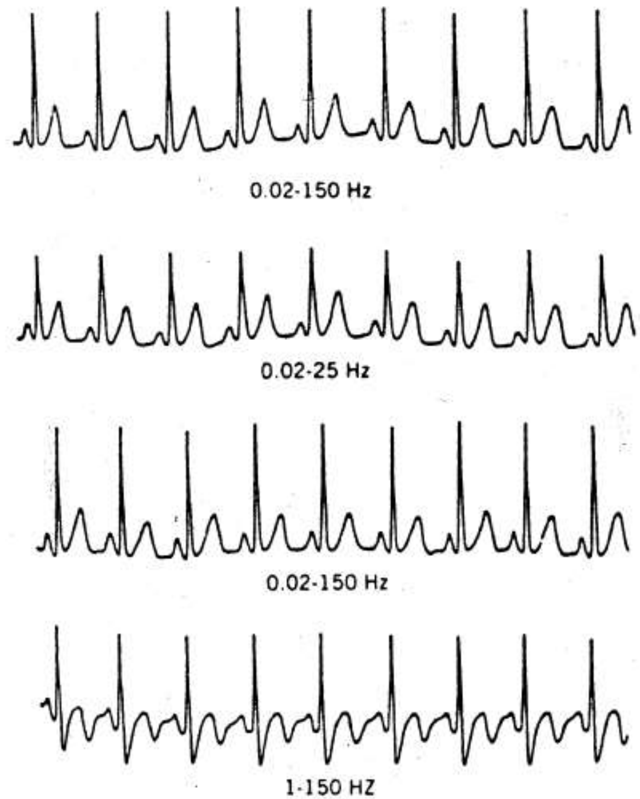


ECG Monitor

ECG Espectra



(a)



(b)

ECG Monitor

Introduction to Electrocardiograph, Maxim AN4693

https://www.maximintegrated.com/en/app-notes/index.mvp/id/4693

Overview

An electrocardiogram (ECG or EKG) is the measurement and graphic representation, with respect to time, of the electrical signals associated with the heart muscles. Applications of an ECG range from monitoring heart rate to the diagnosis of specific heart conditions. The basics of ECG measurement are the same for all applications, but the details and requirements for electrical components vary greatly. Electrocardiographs, or ECG devices, range from portable handheld units costing less than $200, to units that cost over $5,000 and are the size of facsimile machines. An ECG may even be embedded in a separate piece of equipment, such as a patient monitor or an automatic external defibrillator (AED).

All ECGs pick up heart signals through electrodes connected externally to specific locations on the body. The heart signals are generated by the body and have amplitudes of a few millivolts. The specific locations of the electrodes allow the heart's electrical activity to be viewed from different angles, each of which is displayed as a channel on the ECG printout. Each channel represents the differential voltage between two of the electrodes, or the differential voltage between one electrode and the average voltage from several electrodes. The different combinations of electrodes allow more channels to be displayed than there are electrodes. The channels are commonly referred to as "leads," so a 12-lead ECG device has 12 separate channels displayed graphically. The number of leads varies from 1 to 12 depending on the application. Unfortunately, the wires running to the electrodes are occasionally referred to as leads as well. This can create confusion, as a 12-lead (12-channel) ECG device only requires 10 electrodes (10 wires), so be careful of the context in which "lead" is used.

In addition to the biological signals, most ECGs also detect two manmade signals. The most important of these signals comes from implanted pacemakers and is referred to simply as "pace." The pace signal is relatively short, tens of microseconds to a couple of milliseconds, with an amplitude ranging from a few millivolts to nearly a volt. Often, the ECG must detect the presence of a pace signal while simultaneously preventing it from distorting the signals from the heart.

The second manmade signal is for detecting "lead-off," which is when an electrode is making poor electrical contact. Many ECG devices must provide an alert when this poor contact occurs. Therefore, the ECG device generates a signal to measure the impedance between the electrode and the body for detecting a lead-off occurrence. The measurement may be AC, DC, or both. In some ECG devices, respiration rate is also detected by analyzing the impedance from the lead-off measurement. Lead-off detection is continuous and should not interfere with accurate measurement of the heart signals.

ECG Monitor

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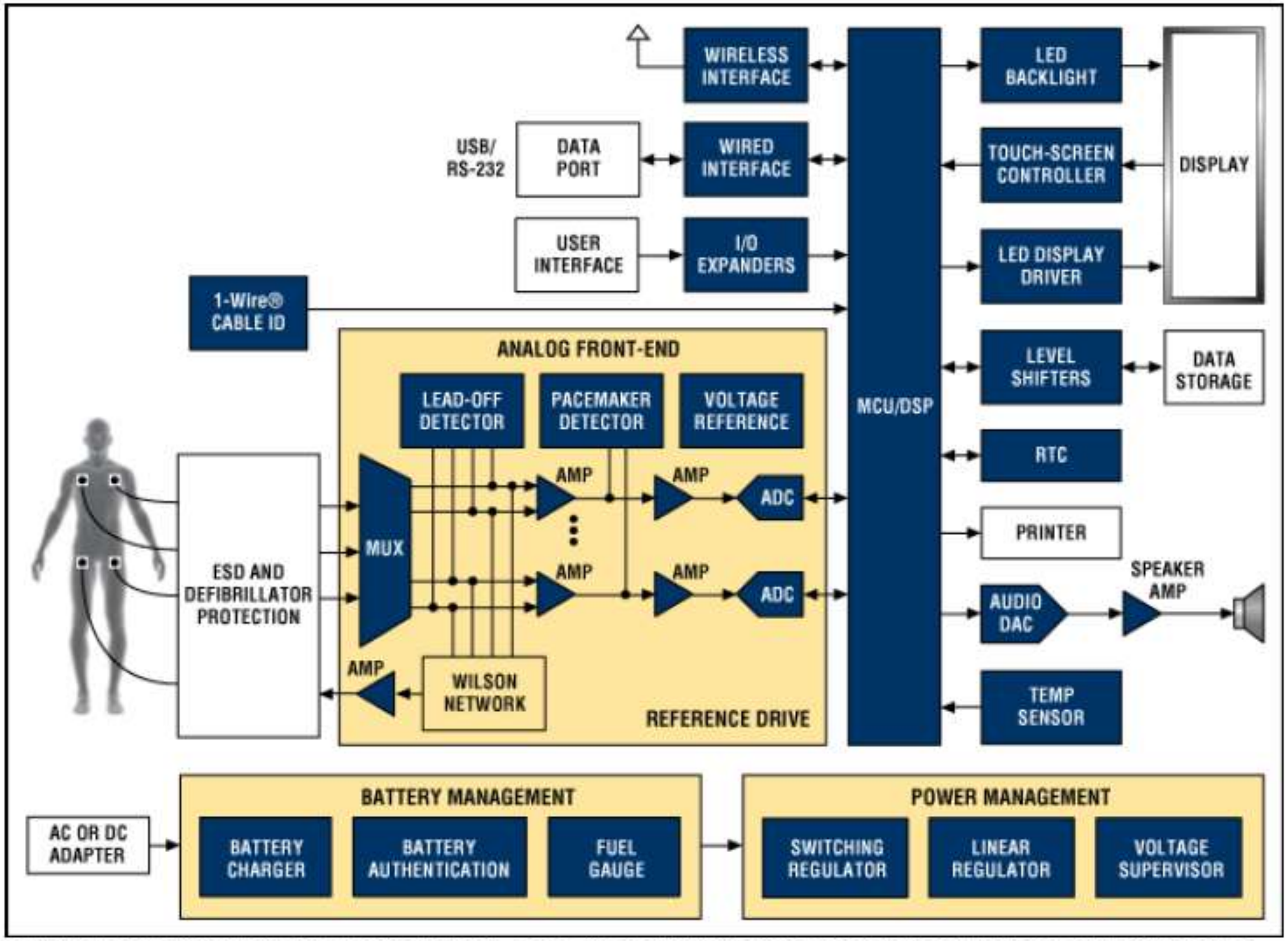
Funtional Block Diagram 2010



Full-featured ECG functional block diagram. For a list of Maxim's recommended solutions for an ECG design, please go to: www.maximintegrated.com/ECG.

ECG Monitor

Introduction to Electrocardiograph, Maxim AN4693

https://www.maximintegrated.com/en/app-notes/index.mvp/id/4693

Features

Understanding the required electronic components for an ECG is easier if it is separated into the analog front-end (AFE), which digitizes these signals, and "the rest of the system," which analyzes, displays, stores and transmits the data. AFEs share the same basic requirements, but differ in the number of leads, fidelity of signal, interference that must be rejected, and so on. The rest of the system differs more radically according to whether features are or are not present. Typical features include a built-in display, the ability to print a hard copy, a radio-frequency (RF) link, and rechargeable batteries.

Number of Leads

One of the most obvious features is the number of leads. Some ECGs have only one lead; the maximum number of leads is usually 12. The most common 12-lead ECGs require 10 electrodes. Nine of the electrodes pick up electrical signals and the tenth electrode, on the right leg (RL), is electrically driven by the ECG circuit to reduce the common-mode voltage. The nine input electrodes are: left arm (LA), right arm (RA), left leg (LL), and six precordial (chest) electrodes (V1 through V6). Each lead, or view of the heart, is the differential voltage between one electrode and another electrode or group of electrodes. When electrodes are grouped, their voltage is averaged. RA, LA, and LL are averaged for six of the leads (views) and become one side of the differential pair, while V1 to V6 are individually used for the other side of the differential pair. Three of the leads measure RA, LA, and LL against the average of the other two electrodes. The remaining three leads come from RA, LA, and LL measured as individual pairs. The six leads based on RA, LA, and LL contain duplicate information, but display it in different ways. Because the information is redundant, it is not necessary to measure all six leads. Some of the channels can be calculated by a DSP as it analyzes data from the measured channels.

While the 12-lead system described here is the most common, it is not the only one. In addition, 12-lead ECGs are capable of operating as a 5-, 3-, or 1-lead systems. The key point here is the need for a switch matrix and averaging circuits when more than one lead is required.

ECG Monitor

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Analog Front-End (AFE)

The primary function of the AFE is to digitize the heart signals. This process is complicated by the need to reject interference from strong RF sources, pace signals, lead-off signals, common-mode line frequency, signals from other muscles, and electrical noise. In addition, the millivolt-level ECG signal can be sitting atop a DC offset that is hundreds of millivolts, with channel-to-channel common-mode voltages differing by over a volt. The electrical connections to the patient must not create a shock hazard or interfere with other medical equipment that may be connected to the patient. The frequency range of interest for the ECG varies somewhat with the application, but is usually around 0.05Hz to 100Hz.

Secondary functions of the AFE are the detection of pace signals, lead-off detections, respiration rate, and patient impedance. All of this is done on several channels simultaneously or near simultaneously. In addition, most ECG devices are required to recover quickly from a defibrillation event, which can saturate the front-end and charge capacitors. This creates a long recovery time for capacitively coupled circuits.

AFE Architectures

The AFE architecture has a large impact on the features. The brute force architecture described below provides high fidelity over a wide frequency range due to its high-resolution, high-conversion-rate ADC. The lack of capacitive coupling and use of a DAC for RL drive enables it to recover very quickly from a defibrillation or RF event. Digitizing the pace signal allows pace analysis that reduces the number of false pace indications and may even detect faults in the pacemaker or its connections. On the down side, the brute force system requires expensive components and uses a great deal of power. In contrast, the minimal AFE features low cost and long battery life, but little else.

ECG Monitor

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AFE Capabilities of Various ECG Applications

Capabilities	Patient Monitor	Diagnostic	Telemetry	Holter	AED	Consumer
High RF immunity	U	U	S	S	S	N
Minimum frequency (Hz)	0.05	0.05	0.1	0.1	0.5	0.5
Maximum frequency (Hz)	500	500	50	150	40	40
ADC sample rate (sps)	1k to 100k	1k to 100k	1024	1024	250+	250+
ADC resolution (bits)	12 to 20	12 to 20	12 to 20	12 to 20	12	10 to 12
Right leg drive	A	A	S	S	N	S
Pace	A	A	U	U	U	S
Lead-off detection	A	A	U	U	A	S
Respiration	U	S	S	S	S	N
Impedance	S	S	S	S	U	N
Defibrillation compatible	A	U	A	U	A	S

A = always, U = usually, S = sometimes, N = never

ECG Monitor

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Brute force and DSP AFEs. The measurement requirements of an ECG can be met by using the brute force of powerful ADCs to simultaneously digitize the signals on all nine electrodes to a noise-free resolution of about 20 bits at a rate of 200ksps. A digital signal processor (DSP) can then be used to calculate the signal for each lead, isolate the pace signal, isolate the lead-off/respiration signals, and filter out unwanted frequencies. The DSP also calculates values for a digital-to-analog converter (DAC) driving the RL electrode. This AFE method requires the analog-to-digital (ADC) channels to be tightly matched and may require buffering to isolate the ADC sampling capacitance from the relatively high-impedance electrodes. While this approach may meet the measurement requirement, it will not meet the cost or power consumption requirements of most applications.

Minimal AFEs. At the other end of the AFE features spectrum is the 1-lead, consumer-grade ECG. The AFE circuit of this device capacitively couples the input signals to a lowpass differential amplifier that is followed by a 10-bit, 120sps ADC. Capacitively coupling the inputs eliminates DC-offset issues, and lowpass filtering removes the pace signal. There is no common-mode voltage, because the device is battery powered and has only one channel.

Typical ECG AFEs. The circuits in most ECG devices lie between the above two extremes. Instrumentation amplifiers (IAs) are used to reduce the common-mode voltage, eliminate common-mode noise such as line frequency, and provide a buffer for the ADC's sampling capacitance. Filters after the IA remove the pace and lead-off signals before the heart signals are digitized by the ADC. In some cases, the heart signal and its DC offset are directly digitized by a high-resolution ADC. In other cases, highpass filtering or DACs are used to remove the DC offset so that the heart signal can be amplified and digitized by a lower resolution ADC, typically 12 bits. A separate ADC can be used for each lead, or one ADC can be multiplexed to digitize multiple leads. Multiplexing the ADC can cause a slight time skew between channels. How objectionable this skew is depends on the application. If pace detection is needed, the pace signal is picked off by a highpass filter, amplified, and detected by a comparator circuit.

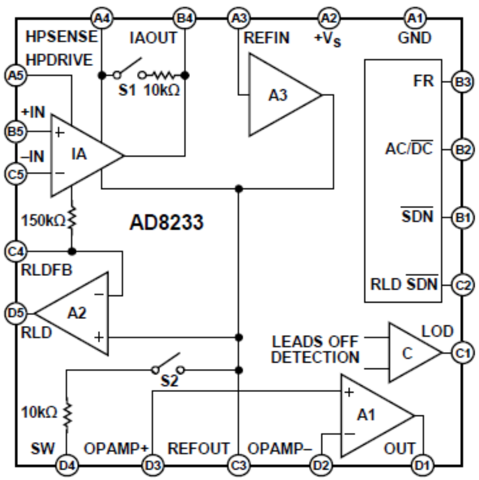
ECG Monitor

Analog Front End (AFE)

https://www.analog.com/media/en/technical-documentation/data-sheets/AD8233.pdf

ANALOG DEVICES **AD8233**

FUNCTIONAL BLOCK DIAGRAM



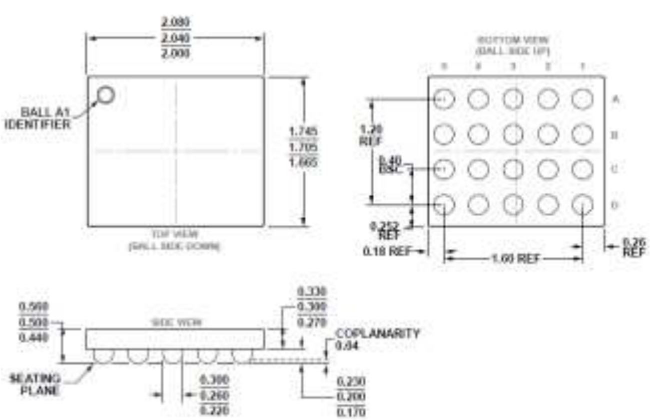
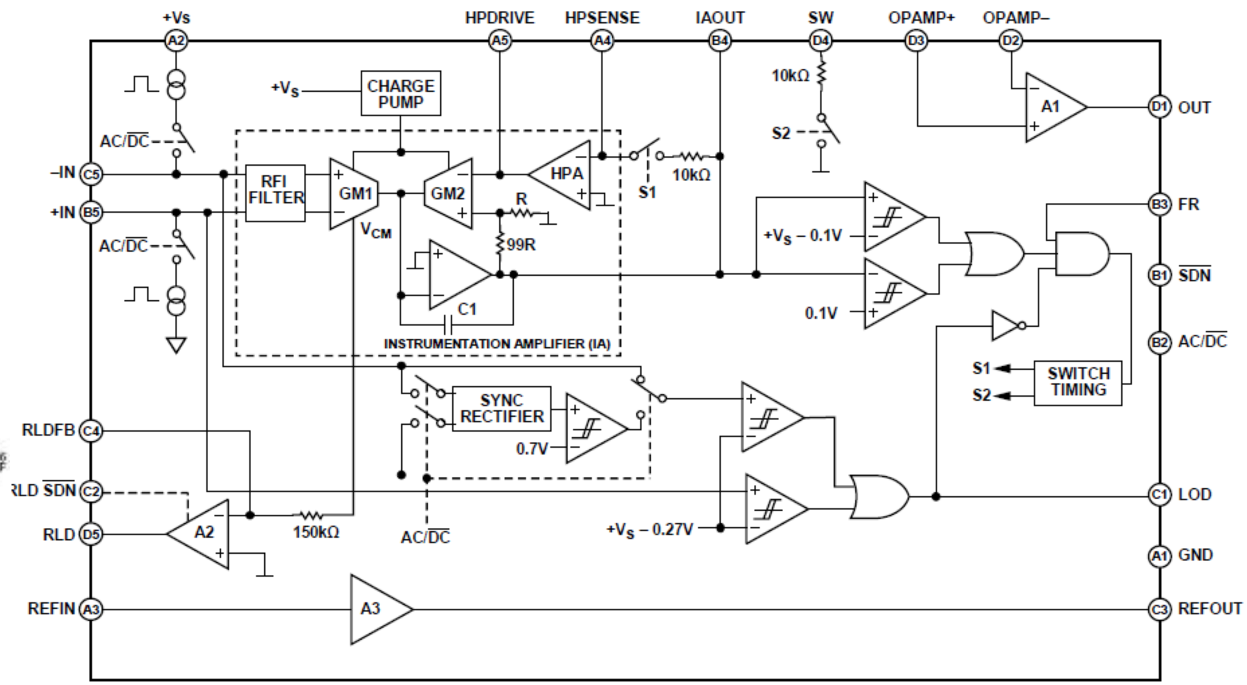


Figure 78. 20-Ball, Backside-Coated, Wafer Level Chip Scale Package [WLCSP] (CB-20-13) Dimensions shown in millimeters

50 μA, 2 mm × 1.7 mm WLCSP, Low Noise, Heart Rate Monitor for Wearable Products

The AD8233 is an integrated signal conditioning block for ECG and other biopotential measurement applications. It is designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement. This design allows an ultralow power analog-to-digital converter (ADC) or an embedded microcontroller to easily acquire the output signal.



*ALL SWITCHES SHOWN IN DC LEADS OFF DETECTION POSITION AND FAST RESTORE DISABLED

⊥ = REFOUT

Figure 50. Simplified Schematic Diagram

ECG Monitor

Analog Front End (AFE)

ANALOG DEVICES

AD8233

FEATURES

Fully integrated, single-lead electrocardiogram (ECG) front end
Low quiescent supply current: 50 µA (typical)
Leads on/off detection while in shutdown (<1 µA)
Common-mode rejection ratio: 80 dB (dc to 60 Hz)
2 or 3 electrode configurations
High signal gain (G = 100) with dc blocking capabilities
2-pole adjustable high-pass filter
Accepts up to ±300 mV of half cell potential
Fast restore feature improves filter settling
Uncommitted op amp
3-pole adjustable low-pass filter with adjustable gain
Integrated right leg drive (RLD) amplifier with shutdown
Single-supply operation: 1.7 V to 3.5 V
Integrated reference buffer generates virtual ground
Rail-to-rail output
Internal RFI filter
8 kV human body model (HBM) ESD rating
Shutdown pin
2 mm × 1.7 mm WLCSP

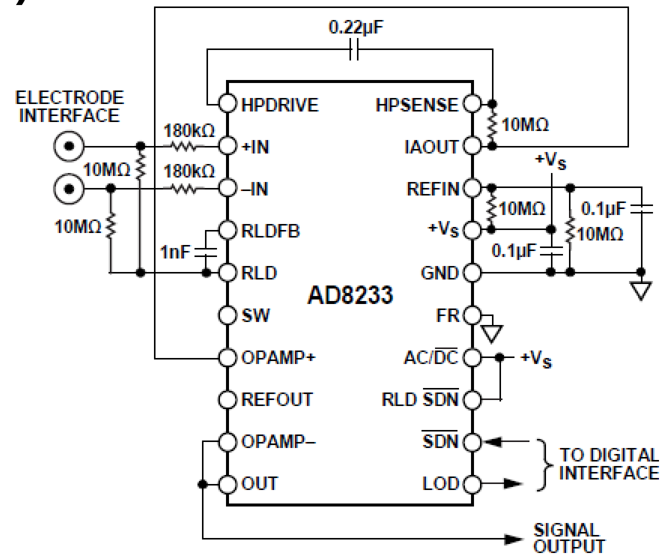


Figure 70. Circuit for HRM Next to the Heart

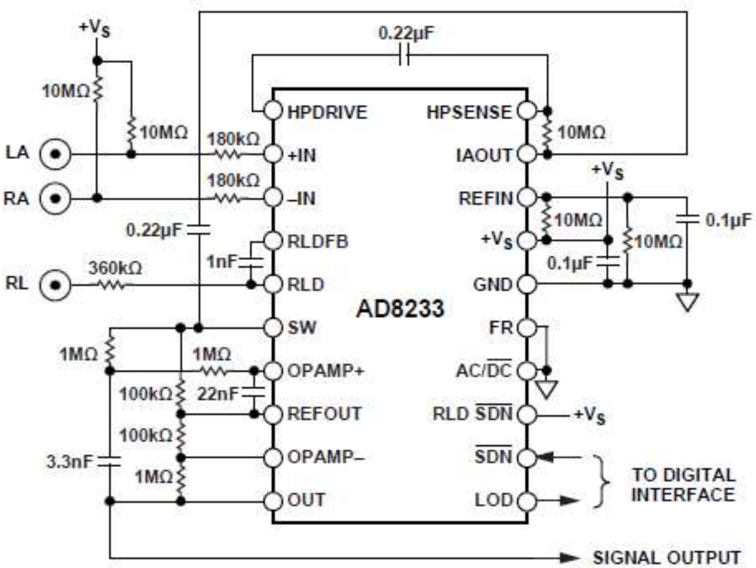


Figure 72. Circuit for HRM at Hands

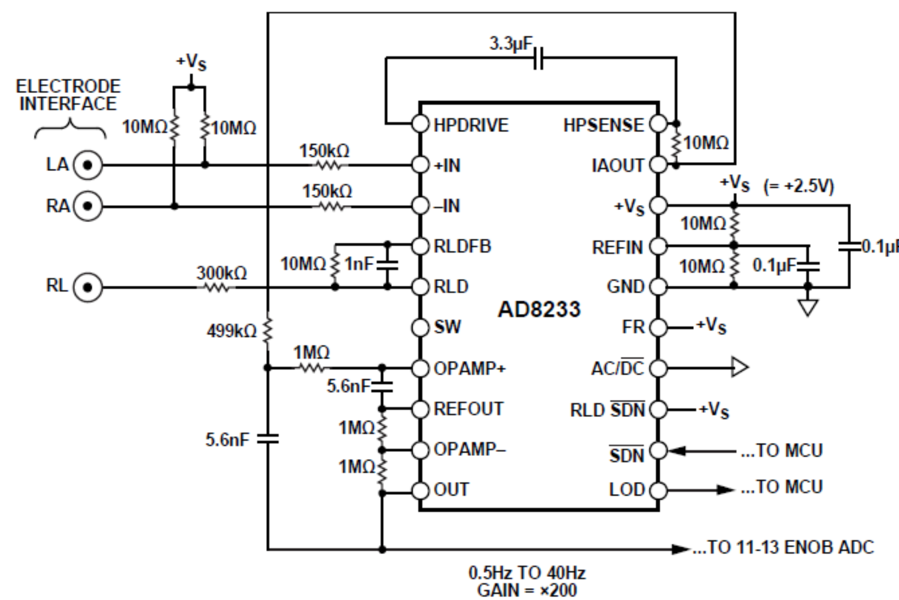


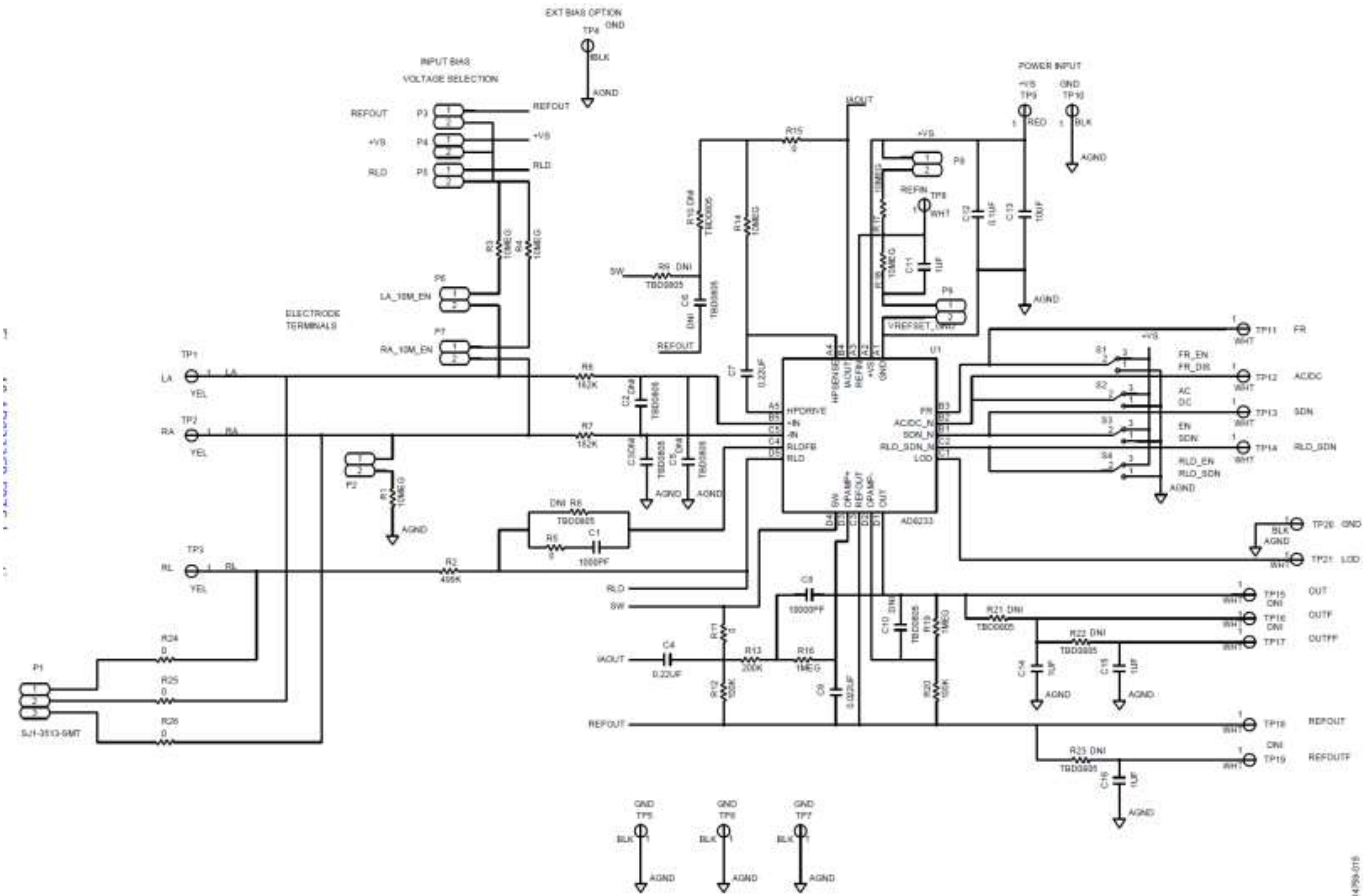
Figure 75. Holter Monitor Circuit

ECG Monitor

Analog Front End (AFE)

AD8233

Example Schematic



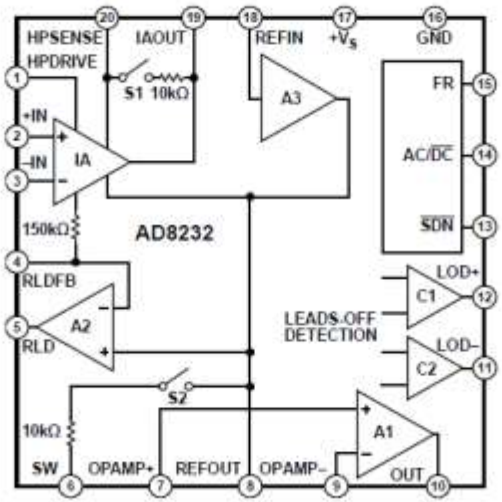
ECG Monitor

Analog Front End (AFE)

https://www.analog.com/media/en/technical-documentation/data-sheets/AD8233.pdf

AD8232 Single-Lead, Heart Rate Monitor Front End

FUNCTIONAL BLOCK DIAGRAM

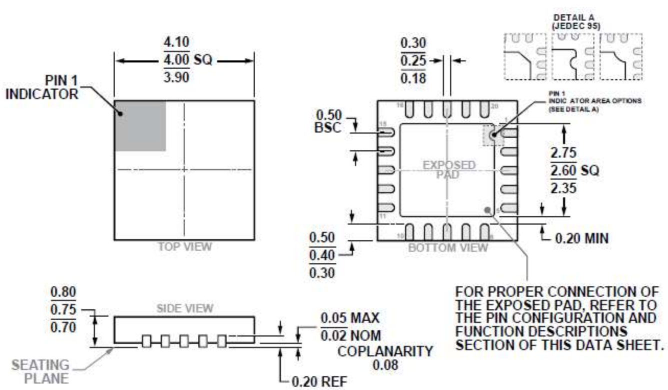


GENERAL DESCRIPTION

The AD8232 is an integrated signal conditioning block for ECG and other biopotential measurement applications. It is designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement. This design allows for an ultralow power analog-to-digital converter (ADC) or an embedded microcontroller to acquire the output signal easily.

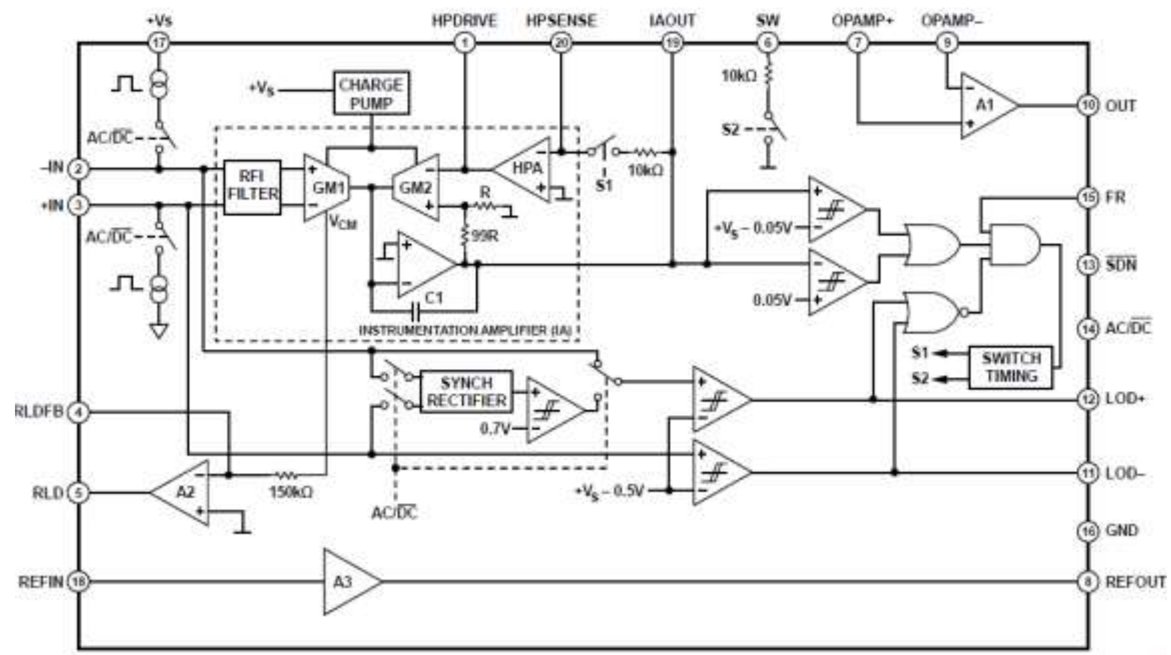
The AD8232 can implement a two-pole high-pass filter for eliminating motion artifacts and the electrode half-cell potential. This filter is tightly coupled with the instrumentation architecture of the amplifier to allow both large gain and high-pass filtering in a single stage, thereby saving space and cost.

An uncommitted operational amplifier enables the AD8232 to create a three-pole low-pass filter to remove additional noise. The user can select the frequency cutoff of all filters to suit different types of applications.



COMPLIANT TO JEDEC STANDARDS MO-220-WGGD-11.

Figure 69. 20-Lead Lead Frame Chip Scale Package [LFCSP] 4 mm × 4 mm Body and 0.75 mm Package Height (CP-20-8) Dimensions shown in millimeters



ALL SWITCHES SHOWN IN DC LEADS-OFF DETECTION POSITION AND FAST RESTORE DISABLED

⊥ = REFOUT

Figure 45. Simplified Schematic Diagram

ECG Monitor

Analog Front End (AFE)

ANALOG DEVICES **AD8232**

HIGH-PASS FILTERING

The AD8232 can implement higher order high-pass filters. A higher filter order yields better artifact rejection but at a cost of increased signal distortion and more passive components on the printed circuit board (PCB).

Two-Pole High-Pass Filter

A two-pole architecture can be implemented by adding a simple ac coupling RC at the output of the instrumentation amplifier, as shown in Figure 55.

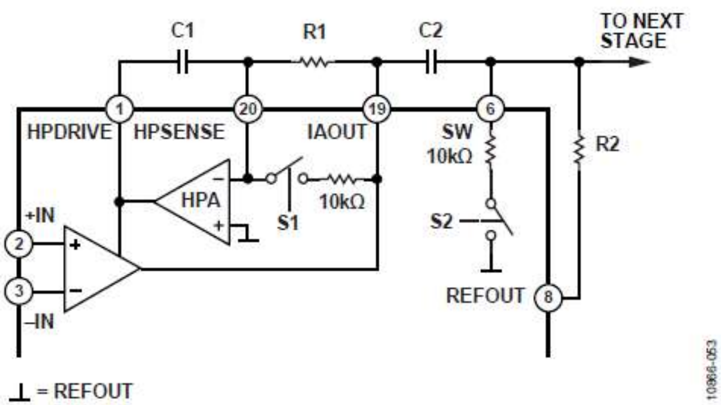


Figure 55. Schematic for a Two-Pole High-Pass Filter

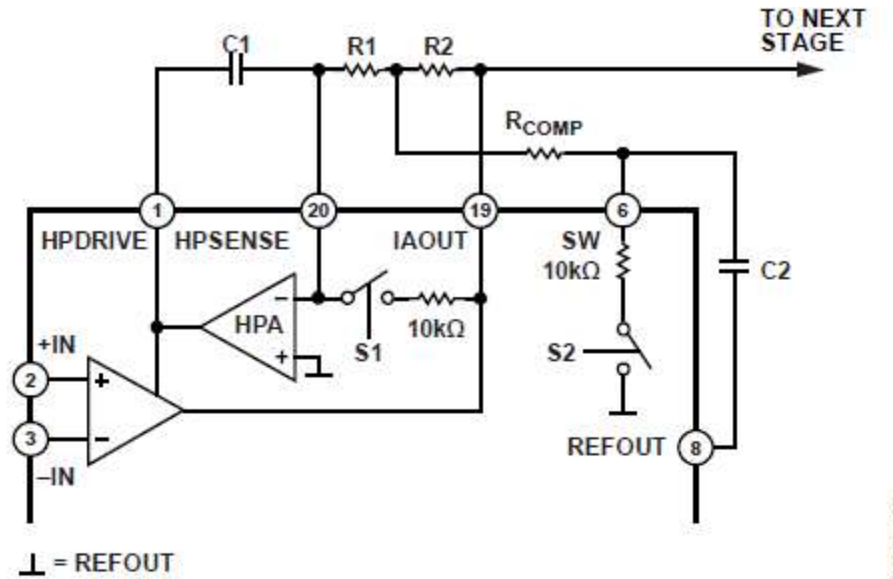


Figure 56. Schematic for an Alternative Two-Pole High-Pass Filter

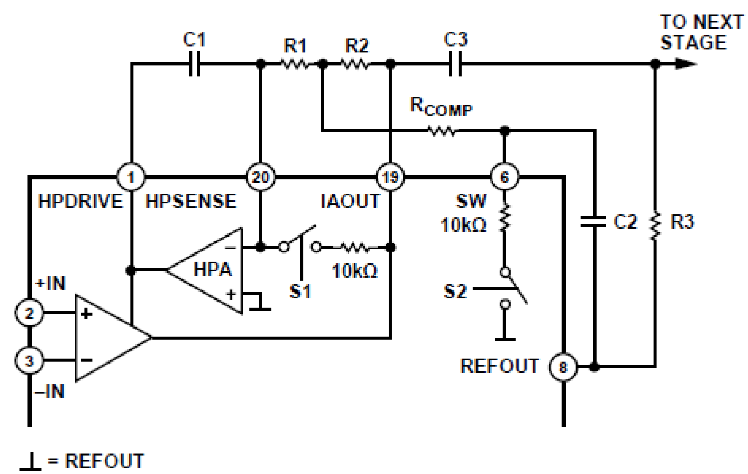


Figure 57. Schematic for a Three-Pole High-Pass Filter

ECG Monitor

Analog Front End (AFE)

ANALOG DEVICES **AD8232**

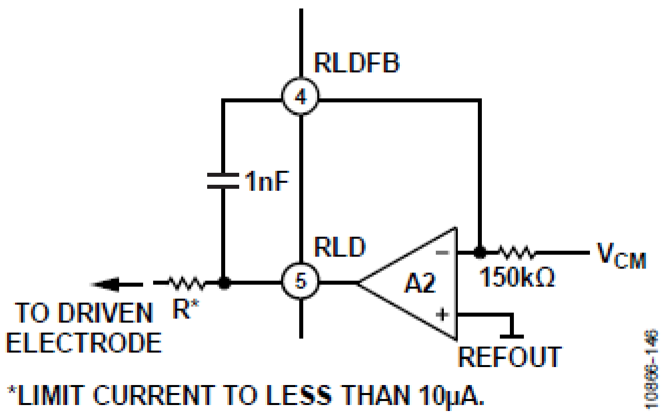


Figure 46. Typical Configuration of Right-Leg Drive Circuit

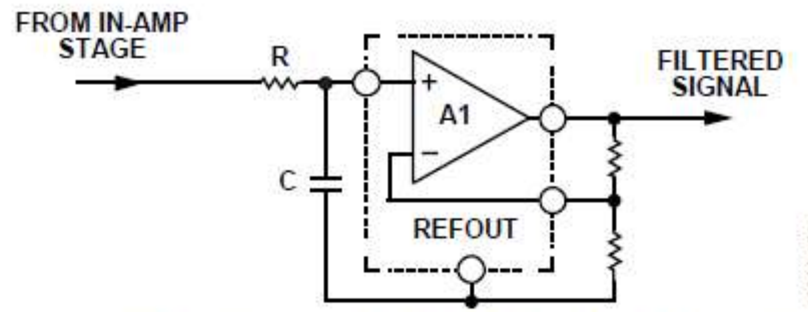


Figure 59. Schematic for a Single-Pole Low-Pass Filter and Additional Gain

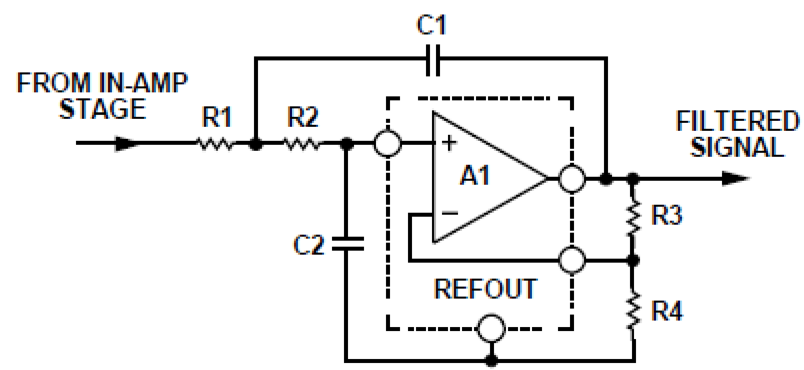


Figure 60. Schematic for a Two-Pole Low-Pass Filter

ECG Monitor

Analog Front End (AFE)

ANALOG DEVICES **AD8232**

HEART RATE MEASUREMENT NEXT TO THE HEART

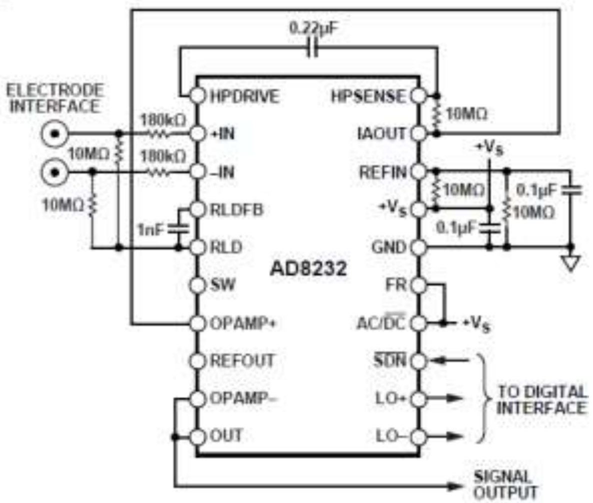


Figure 62. Circuit for Heart Rate Measurement Next to Heart

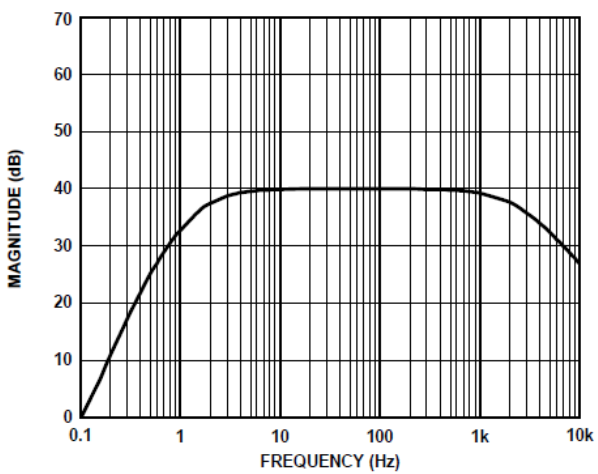


Figure 63. Frequency Response for HRM Next to Heart Circuit

EXERCISE APPLICATION: HEART RATE MEASURED AT THE HANDS

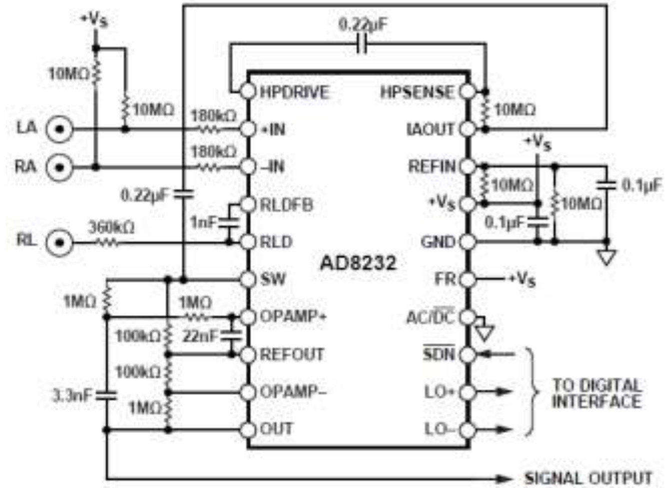


Figure 64. Circuit for Heart Rate Measurement at Hands

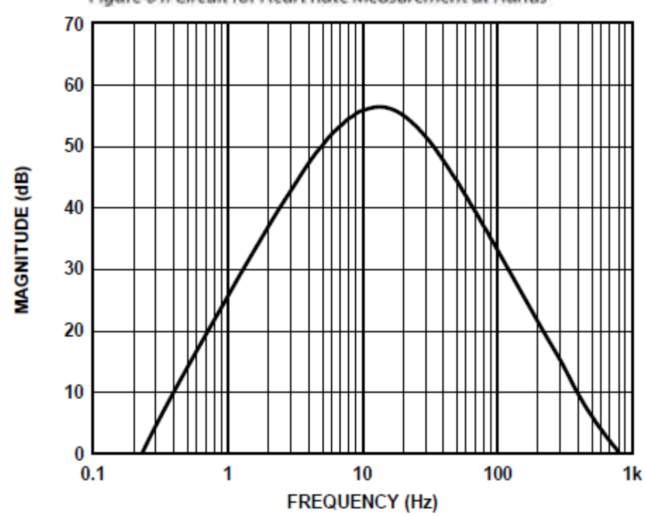


Figure 65. Frequency Response for HRM Circuit Taken at the Hands

ECG Monitor

Analog Front End (AFE)

ANALOG DEVICES **AD8232**

CARDIAC MONITOR CONFIGURATION

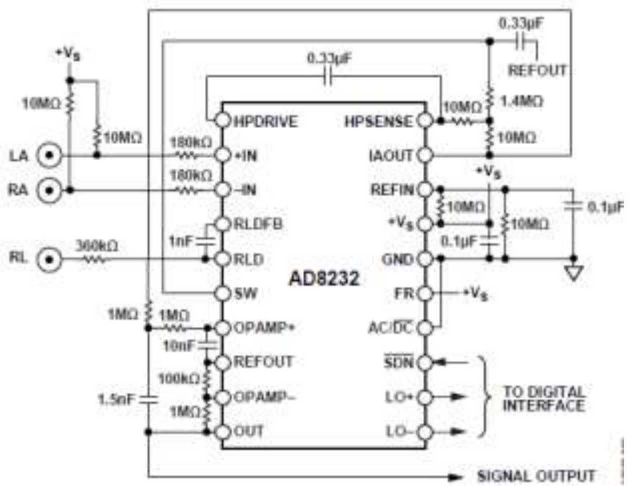


Figure 66. Circuit for ECG Waveform Monitoring

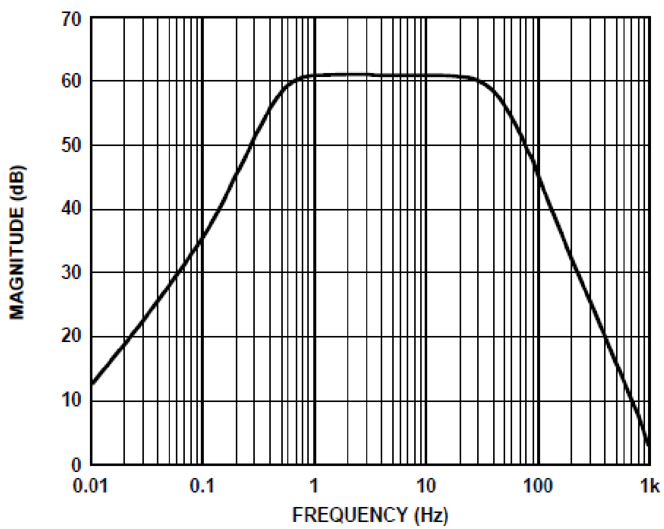
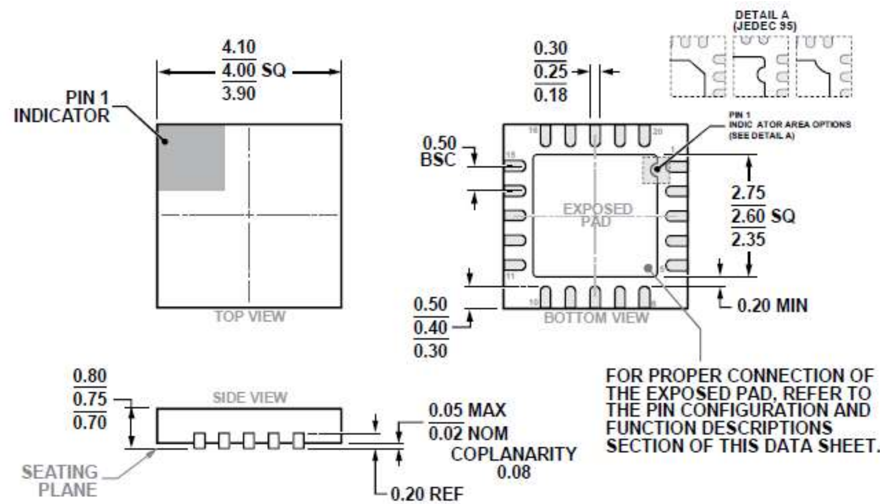


Figure 67. Frequency Response of Cardiac Monitor Circuit



COMPLIANT TO JEDEC STANDARDS MO-220-WGGD-11.

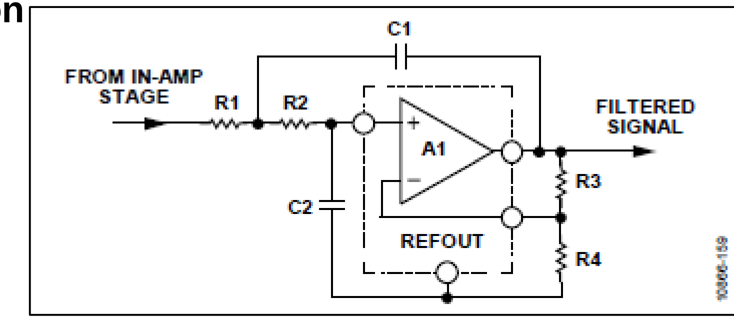
Figure 69. 20-Lead Lead Frame Chip Scale Package [LFCSP]
4 mm × 4 mm Body and 0.75 mm Package Height
(CP-20-8)
Dimensions shown in millimeters

ECG Monitor

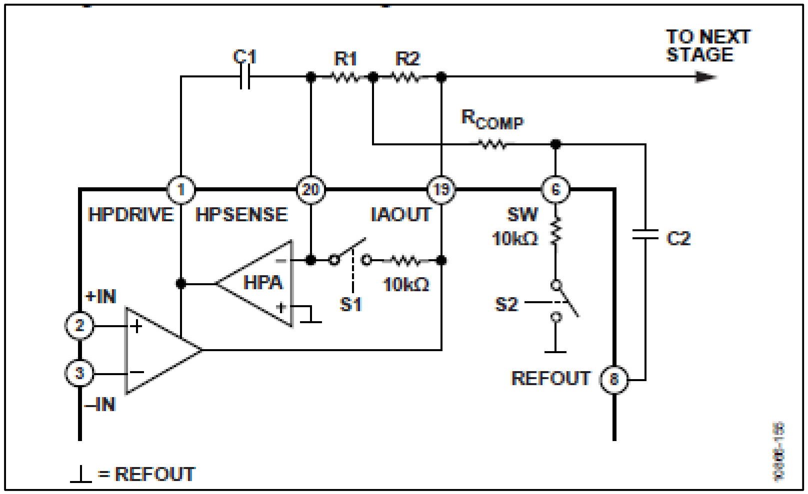
Analog Front End (AFE)

ANALOG DEVICES **AD8232**

Cardiac monitor Configuration
MIKROE ECG 5
SparkFun AD8232



Filtro pasa bajo de dos polos para el AD8232



Filtro pasa alto de dos polos para el AD8232

$$f_C = 1/(2\pi\sqrt{(R1\ C1\ R2\ C2)})$$

$$Gain = 1 + R3/R4$$

$$Q = \frac{\sqrt{R1 \times C1 \times R2 \times C2}}{R1 \times C2 + R2 \times C2 + R1 \times C1(1 - Gain)}$$

Formulas del filtro pasa bajo

Tanto Sparkfun como MIKROE emplean:
R1 = R2 = R3 = 1 MΩ
R4 = 100 kΩ
C1 = 1,5 nF
C2 = 10 nF
fc = 41 Hz
$Gain_{LP}$ = 11
Q = 0,77

$$R1 = R2 \geq 100\ k\Omega$$

$$C1 = C2$$

$$R_{COMP} = 0.14 \times R1$$

The cutoff frequency is located at

$$f_C = \frac{10}{2\pi\sqrt{R1\ C1\ R2\ C2}}$$

Formulas del filtro pasa alto

Tanto Sparkfun como MIKROE emplean:
R1 = R2 = 10 MΩ
C1 = C2 = 0.33 µF
Rcomp = 1,4 MΩ
fc = 0,48 Hz

INA DC Gain = $Gain_{INA}$ = 100

Total Gain = $Gain_{INA}$ x $Gain_{LP}$
= 100 x 11 = 1100
= 60.83 dB

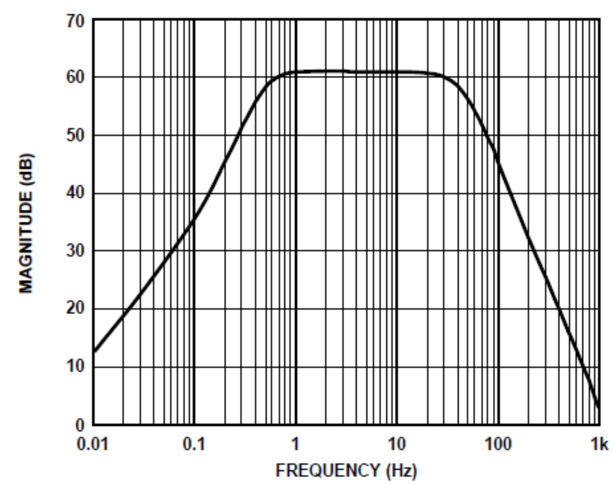


Figure 67. Frequency Response of Cardiac Monitor Circuit

ECG Monitor

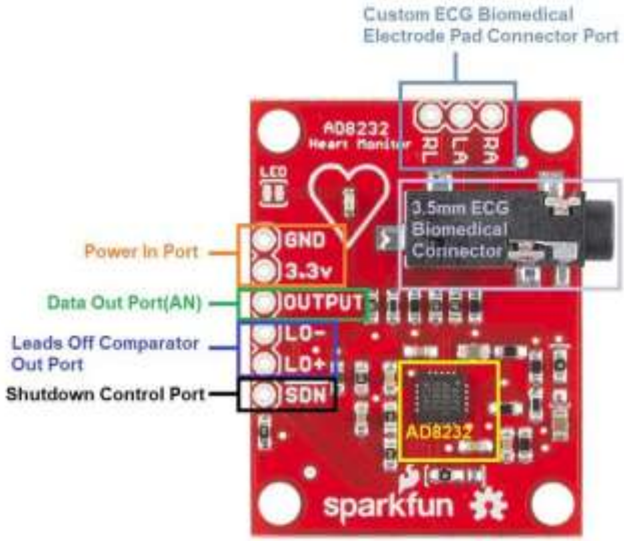
Analog Front End (AFE)

OEM example with AD8232

https://www.sparkfun.com/products/12650

https://github.com/sparkfun/AD8232_Heart_Rate_Monitor

SparkFun AD8232 Single Lead Heart Rate Monitor



Pin Description of the AD8232 ECG Module

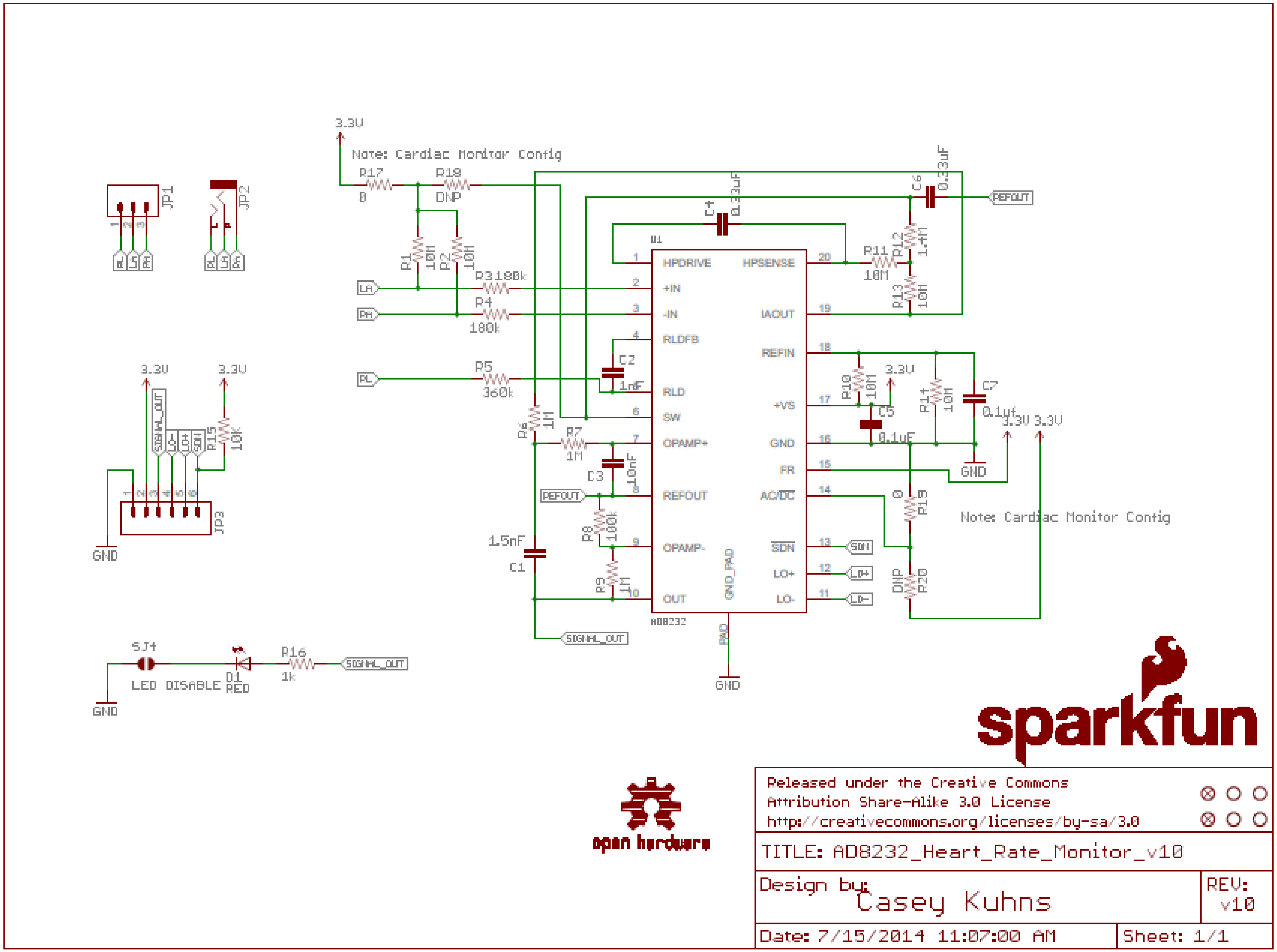
Pin Name	Description
GND	Power Supply Ground
3.3v	Power Supply 3.3v
Output (ADC)	Operational Amplifier Output. The fully conditioned heart rate signal is present at this output. OUT can be connected to the input of an ADC.
LO-	Leads Off Comparator Output. In dc leads off detection mode, LO– is high when the electrode to –IN is disconnected, and it is low when connected
LO+	Leads Off Comparator Output. In dc leads off detection mode, LOD+ is high when the +IN electrode is disconnected, and it is low when connected
$\overline{SDN}$	Shutdown Control Input. Drive SDN low to enter the low power shutdown mode.
RA (Right Arm)	**RED Biomedical electrode pad RA(input).** Instrumentation Amplifier Negative Input. –IN is typically connected to the right arm (RA) electrode
LA (Left Arm)	**YELLOW Biomedical electrode pad LA(input).** Instrumentation Amplifier Positive Input. +IN is typically connected to the left arm (LA) electrode
RL(Right Leg)	**GREEN Biomedical electrode pad RL(input).** Right Leg Drive Output. Connect the driven electrode (typically, right leg) to the RLD pin.

ECG Monitor

Analog Front End (AFE)

OEM example with AD8232

SparkFun AD8232 Single Lead Heart Rate Monitor Schematic



ECG Monitor

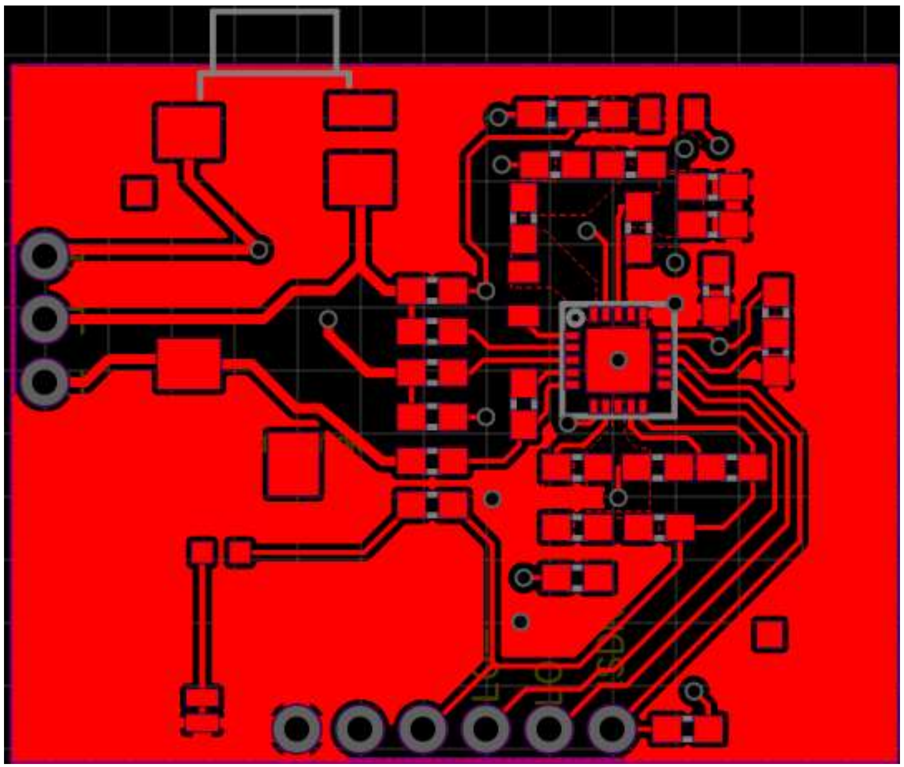
Analog Front End (AFE)

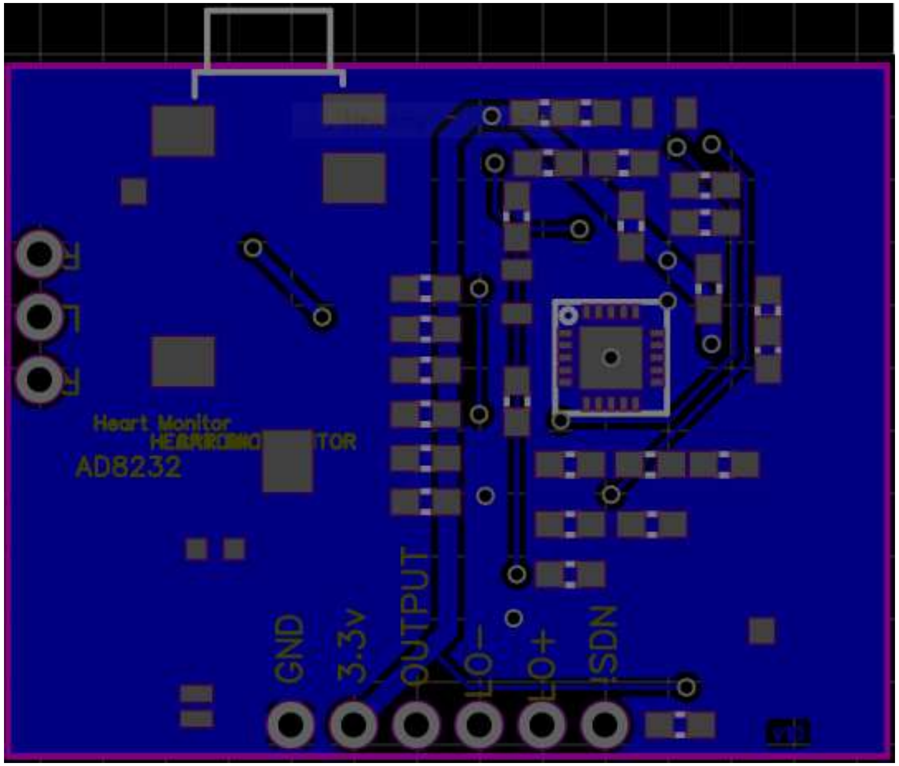
OEM example with AD8232

SparkFun AD8232 Single Lead Heart Rate Monitor PCB

EasyEDA (Open hardware_Org)

https://easyeda.com/Sungchankim/Single_Lead_Heart_Rate_Monitor_AD8232_Open_hardware-2c0cavtPN_copy





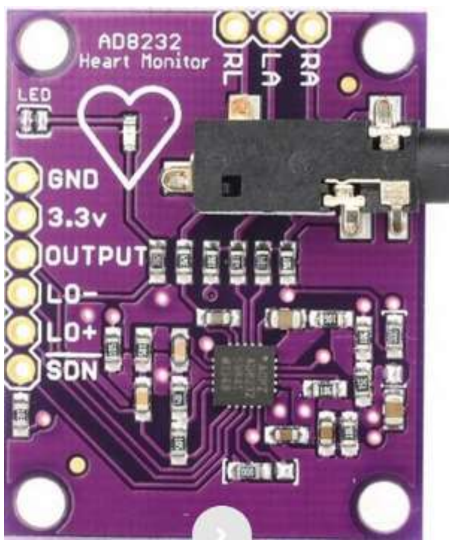
ECG Monitor

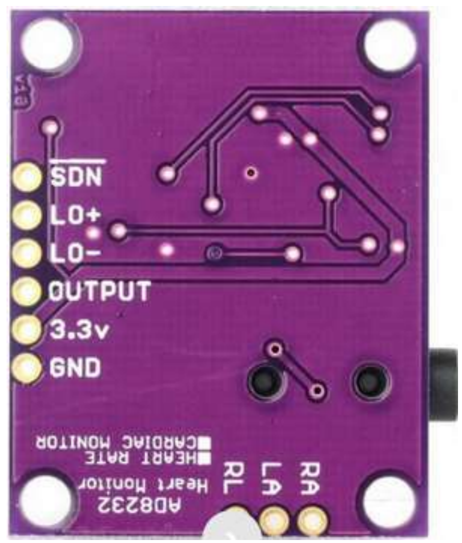
Analog Front End (AFE)

OEM example with AD8232

SparkFun AD8232 Single Lead Heart Rate Monitor

Different Options





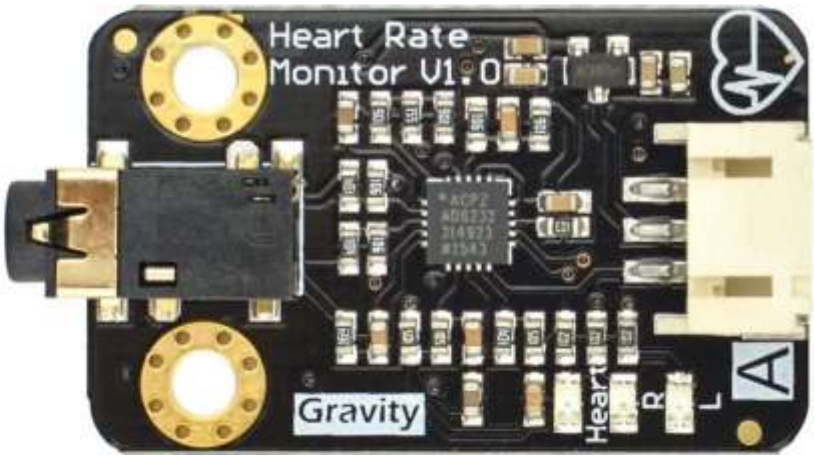
ECG Monitor

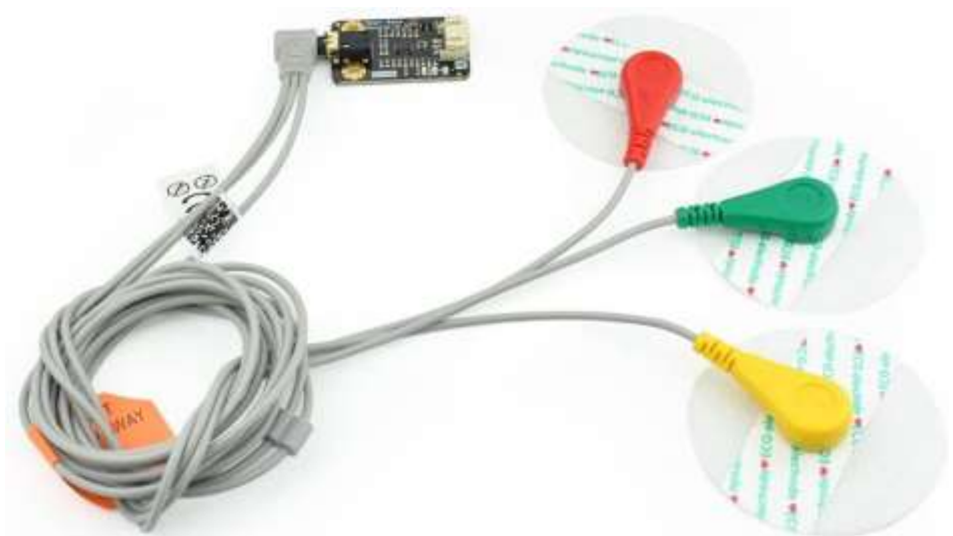
Analog Front End (AFE)

OEM example with AD8232

DFROBOT Gravity: Analog Heart Rate Monitor Sensor (ECG) For Arduino SKU:SEN0213

https://wiki.dfrobot.com/Heart_Rate_Monitor_Sensor_SKU__SEN0213 https://www.dfrobot.com/product-1510.html





ECG Monitor

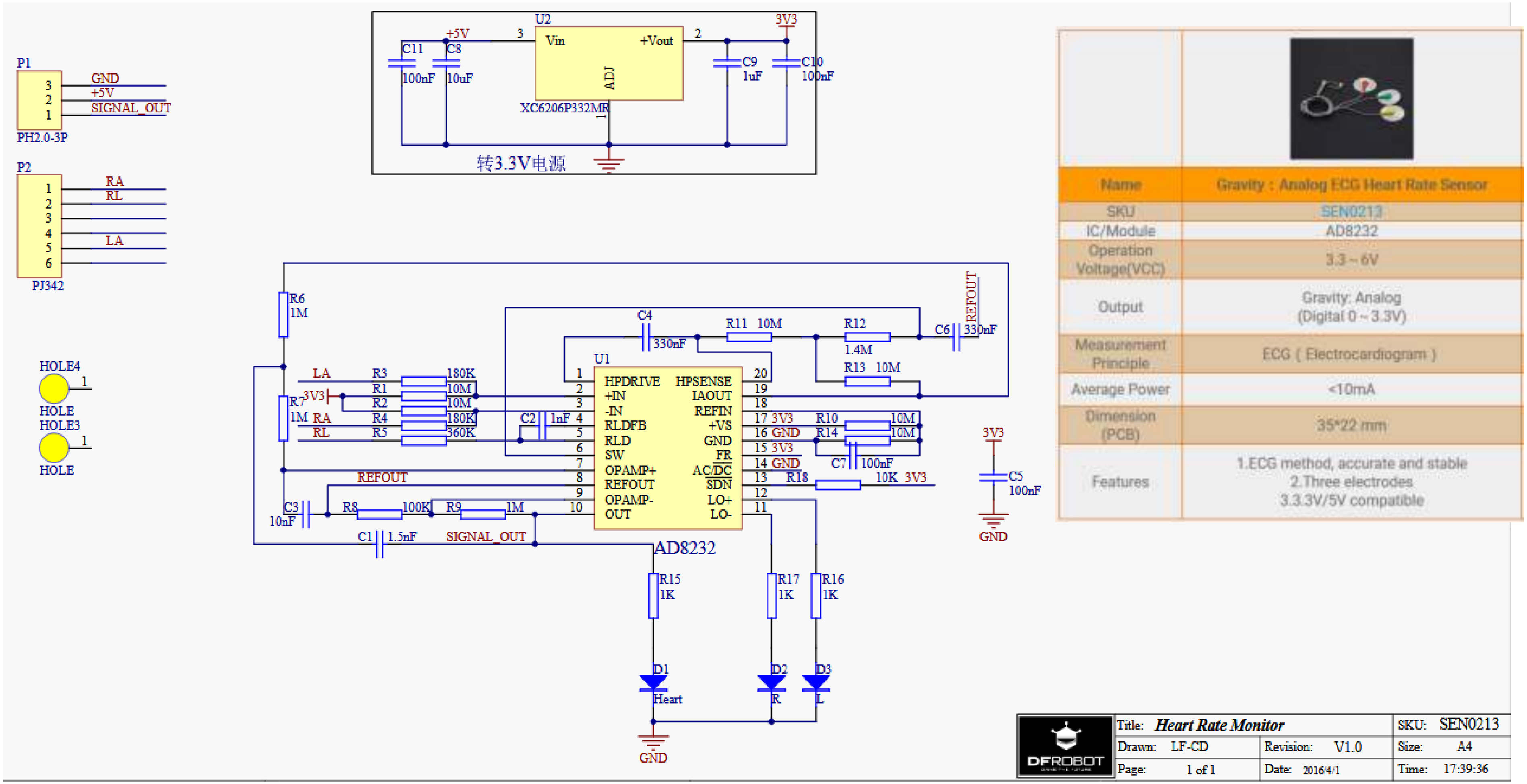
Analog Front End (AFE)

OEM example with AD8232

DFROBOT Gravity: Analog Heart Rate Monitor Sensor (ECG) For Arduino SKU:SEN0213

https://wiki.dfrobot.com/Heart_Rate_Monitor_Sensor_SKU__SEN0213

https://www.dfrobot.com/product-1510.html



Name	Gravity : Analog ECG Heart Rate Sensor
SKU	SEN0213
IC/Module	AD8232
Operation Voltage(VCC)	3.3～6V
Output	Gravity: Analog (Digital 0～3.3V)
Measurement Principle	ECG (Electrocardiogram)
Average Power	<10mA
Dimension (PCB)	35*22 mm
Features	1.ECG method, accurate and stable 2.Three electrodes 3.3.3V/5V compatible

ECG Monitor

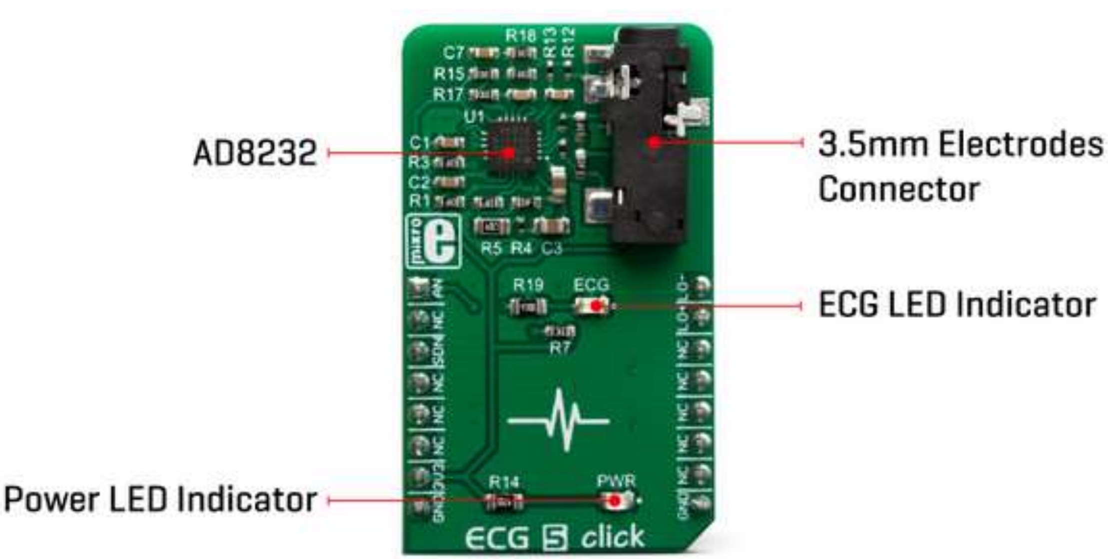
Analog Front End (AFE)

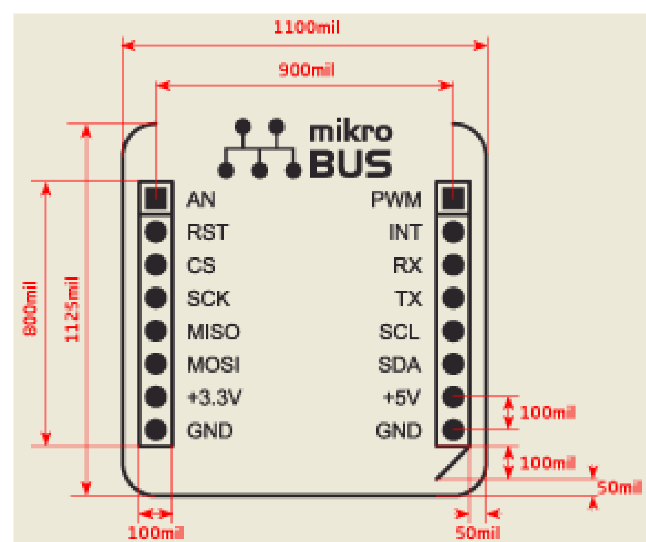
OEM example with AD8232: MIKROE ECG 5 Click

https://www.mikroe.com/ecg-5-click

ECG 5 click can be used for the development of ECG and Heart-Rate (HR) applications. The Click board™ features the AD8232, an integrated bio-signal front end. This IC has many features necessary for providing accurate ECG measurements, including very high common-mode rejection ratio, high gain with DC blocking capability, adjustable high-pass and low-pass filters, integrated right leg drive (RLD), etc. Electrodes presence detection pin helps to reduce the overall power consumption, as it can be used to set the standby mode of the host MCU. The fully conditioned bio-signal is available at the analog output to be sampled by an external A/D converter.

Notes	Pin	mikroBUS				Pin	Notes
Analog ECG signal OUT	**AN**	1	AN	PWM	16	**LO-**	Lead-off detection for IN-
	NC	2	RST	INT	15	**LO+**	Lead-off detection for IN+
Chip Enable	**SDN**	3	CS	RX	14	NC	
	NC	4	SCK	TX	13	NC	
	NC	5	MISO	SCL	12	NC	
	NC	6	MOSI	SDA	11	NC	
Power Supply	**3.3V**	7	3.3V	5V	10	NC	
Ground	**GND**	8	GND	GND	9	**GND**	Ground



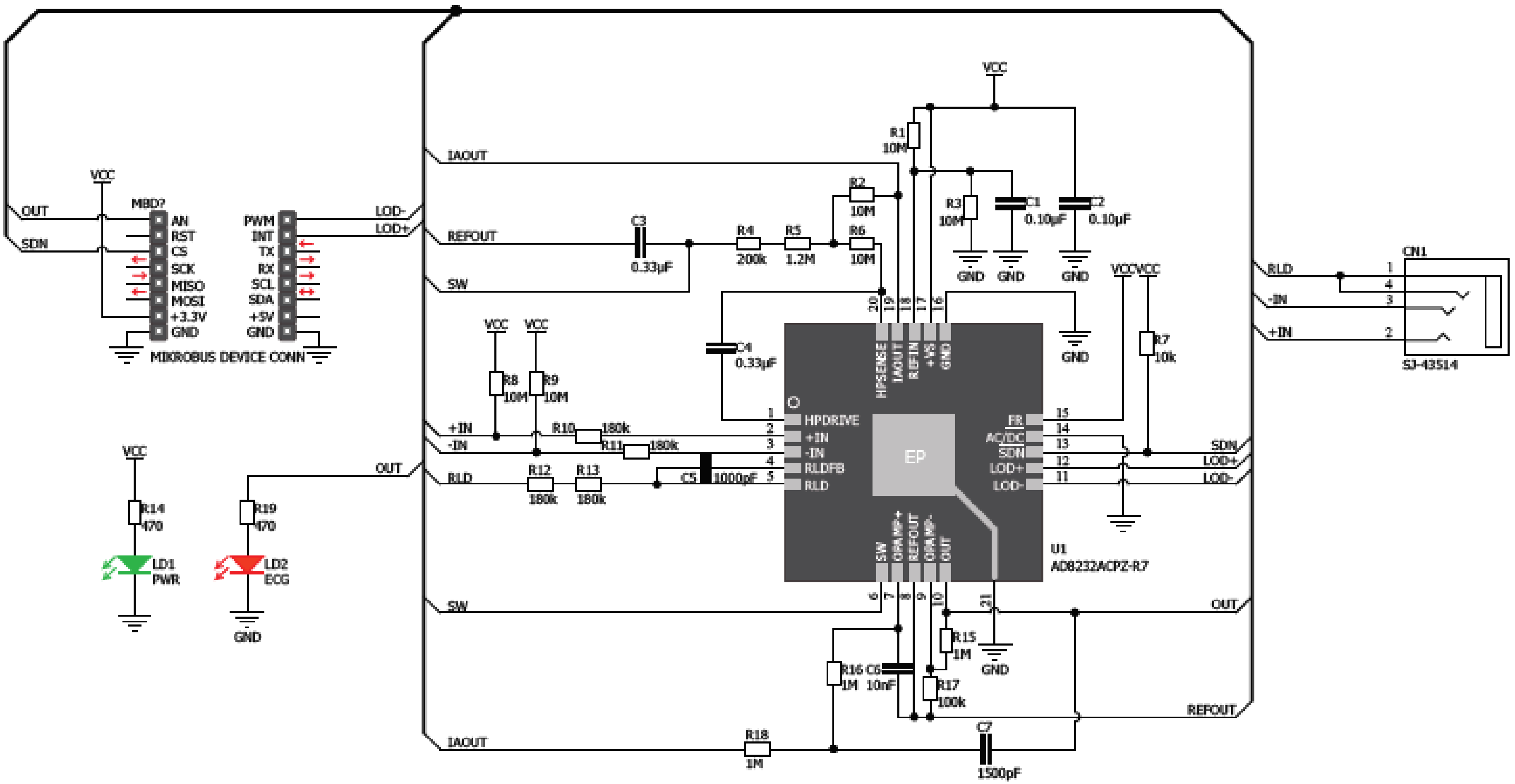


ECG Monitor

Analog Front End (AFE)

OEM example with AD8232

MIKROE ECG 5 Click Schematic



ECG Monitor

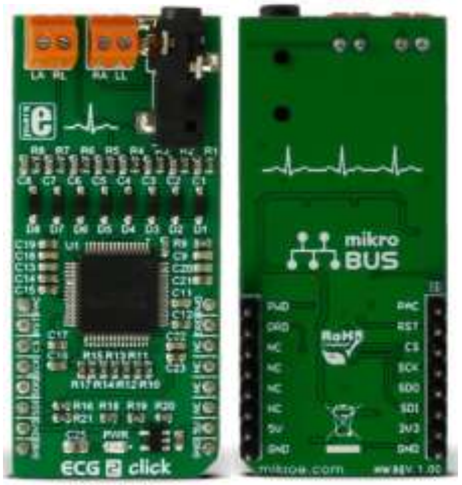
Analog Front End (AFE)

OEM example with ADS1194

https://www.mikroe.com/ecg-2-click

MIKROE ECG 2 click

ECG 2 click contains [ADS1194](ADS1194) 16-bit delta-sigma analog-to-digital converters from Texas Instruments, a built-in programmable gain amplifier (PGA), an internal reference, and an onboard oscillator.
The click communicates with the target MCU over SPI and the following mikroBUS pins: PWM, AN and INT.
ECG 2 click runs on 3.3V and 5V power supply.

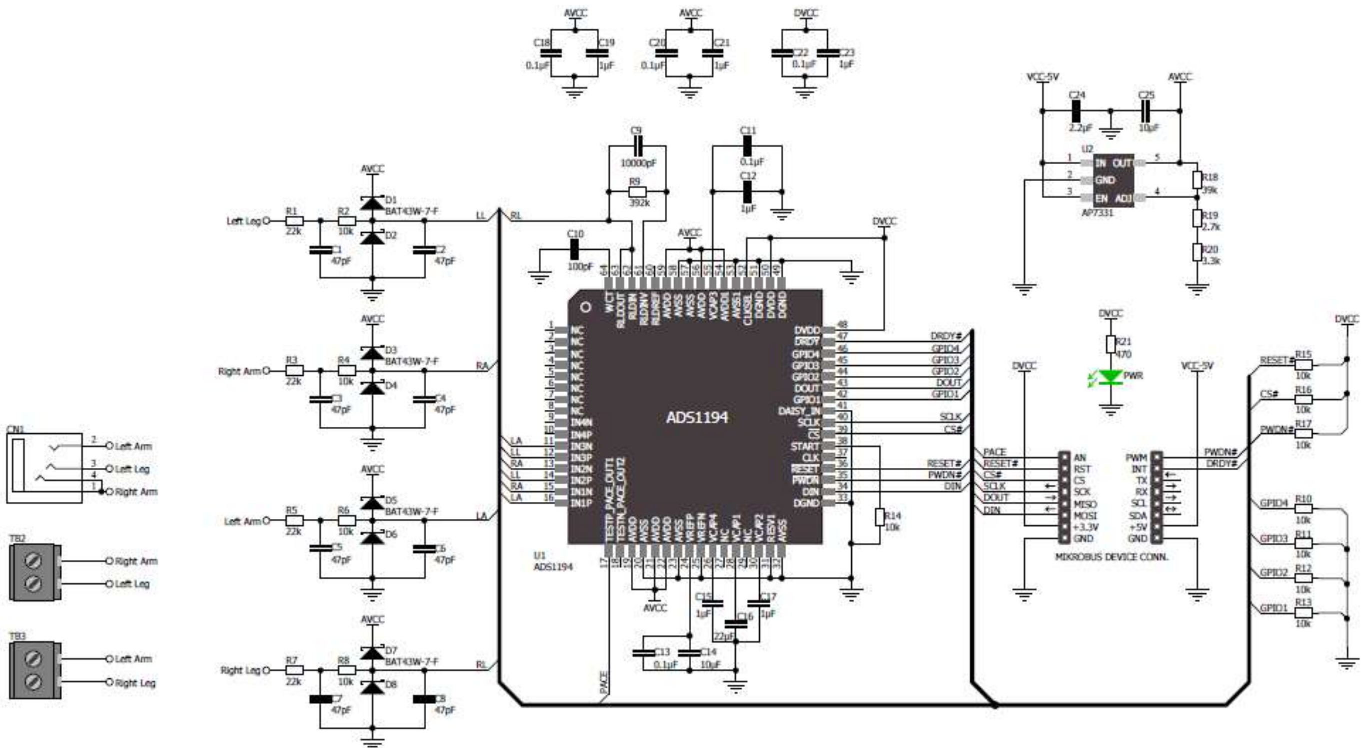


ECG Monitor

Analog Front End (AFE)

OEM example with ADS1294

MIKROE ECG 2 Click Schematic

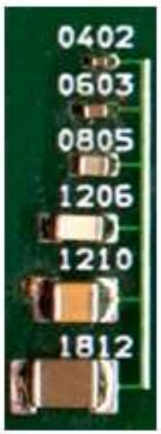


ECG Monitor

SMD Passive Components

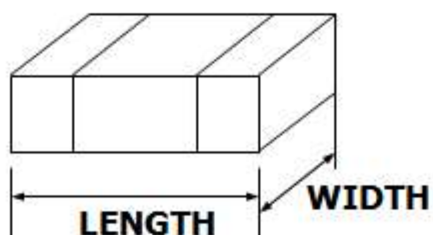
Surface-mount technology (**SMT**) is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit board (PCBs).
An electronic device so made is called a **surface-mount device** (**SMD**)

Dimensions (Surface Mount)



English	Metric	Length	Width
0402	1005	1.0mm (0.04”)	0.5mm (0.02”)
0603	1608	1.6mm (0.06”)	0.8mm (0.03”)
0805	2012	2.0mm (0.08”)	1.2mm (0.05”)
1206	3216	3.2mm (0.12”)	1.6mm (0.06”)
1210	3225	3.2mm (0.12”)	2.5mm (0.10”)
1812	4532	4.5mm (0.18”)	3.2mm (0.12”)
2225	5764	5.7mm (0.22”)	6.4mm (0.25”)

No Component Marking



NIC COMPONENTS CORP.

ECG Monitor
Protection

Transient Protection

- Other equipment attached to the patient can present a risk to the machine.
- For example, in the operating suite, patients undergoing surgery usually have their ECGs continuously monitored during the procedure.
- If the surgical procedure involves the use of an electrosurgical unit, it can introduce onto the patient relatively high voltages that can enter the electrocardiograph or cardiac monitor through the patient's electrodes.
- If the ground connection to the electrosurgical unit is faulty or if higher-than-normal resistance is present, the patient's voltage with respect to ground can become quite high during coagulation or cutting.
- These high potentials enter the electrocardiograph or cardiac monitor and can be large enough to damage the electronic circuitry.

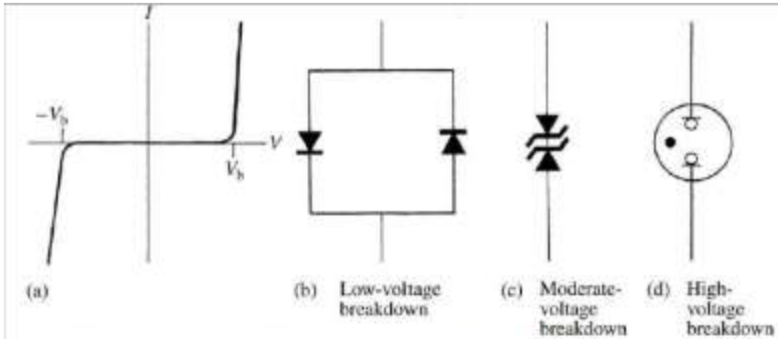


Figure 6.14 Voltage-limiting devices (a) Current–voltage characteristics of a voltage-limiting device, (b) Parallel silicon-diode voltage-limiting circuit, (c) Back-to-back silicon Zener-diode voltage-limiting circuit, (d) Gas-discharge tube (neon light) voltage-limiting circuit element.

•At voltages less than *Vb, the breakdown voltage*, the device allows very little current to flow and ideally appears as an open circuit.
•Once the voltage across the device attempts to exceed *Vb, the characteristics of the device sharply* change, and current passes through the device to such an extent that the voltage cannot exceed *Vb*
•Under these conditions, the device appears to behave as a short circuit in series with a constant-voltage source of magnitude Vb.

•Figure shows the basic arrangement of such protective circuits. Two-terminal voltage-limiting devices are connected between each patient electrode and electric ground.
•After a certain voltage level these devices become short circuit and prevents high current flowing through ECG.

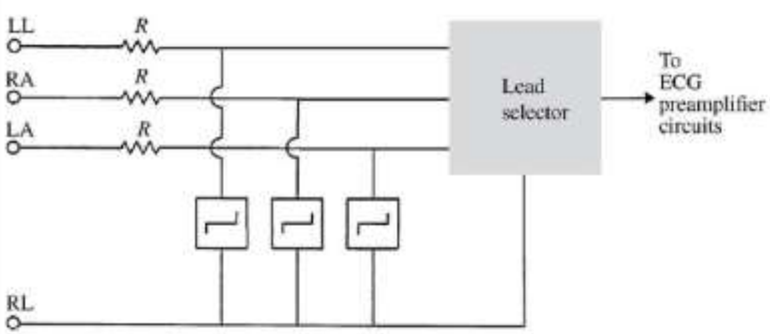
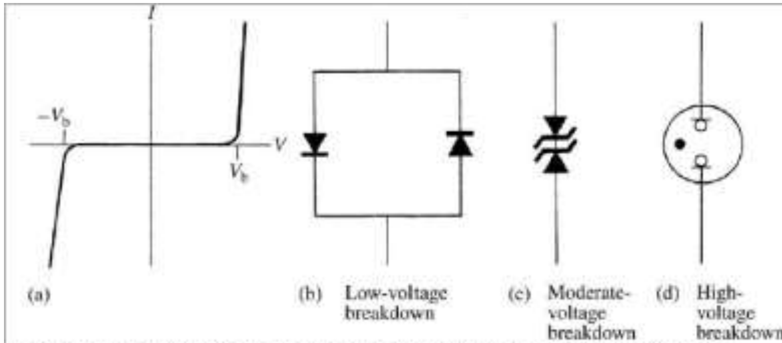


Figure 6.13 A voltage-protection scheme at the input of an electrocardiograph to protect the machine from high-voltage transients. Circuit elements connected across limb leads on left-hand side are voltage-limiting devices.



•**Parallel silicon diodes**, as shown in Figure 6.14(b), give a characteristic with a breakdown voltage of approximately 600 mV. the ECG itself does not approach such a voltage, it is possible under extreme conditions for dc-offset potentials.
•**Zener diodes**, connected back to back. When a voltage is connected across this circuit, one of the diodes is biased in the forward direction and the other in the reverse direction. The breakdown voltage in the forward direction is approximately 600 mV, but that in the reverse direction is in the range of 2 to 20 V.
•**Gas-discharge tube** appears as an open circuit until it reaches its breakdown voltage. It then switches to the conducting state and maintains a voltage that is usually several volts less than the breakdown voltage. Breakdown voltages ranging from 50 to 90 V are typical for this device.

ECG Monitor
Protection

https://www.microsemi.com/existing-parts/parts/137888

Features
- Protects Electrocardiographic (ECG) Monitoring Equipment (ME) Against Effects of Defibrillation
- Very Small Size and Very Low Leakage
- Integrates Zener Diodes and SCRs into a Single IC
- Easily Expandable to M×5 Channels
- Facilitates Compliance with IEC 60601-2-25 and IEC 60601-2-27
- Extremely Fast Turn-On
- Five Terminals Plus Substrates
- 28-Pin QFN Package
- Medical-Level Traceability

ZL70590
EKG/ECG
Surge Protection Device

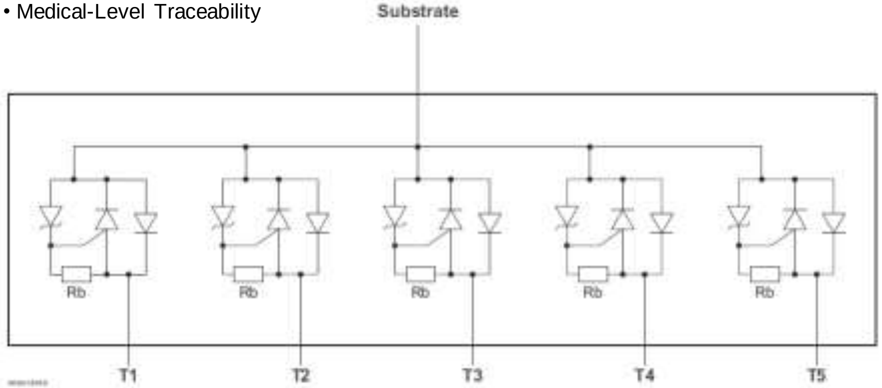


Figure 1 • ZL70590 Schematic Diagram

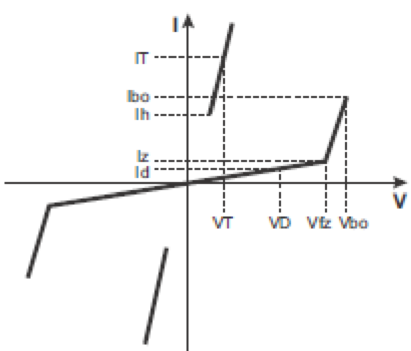


Figure 2-2 • **Terminal-to-Terminal Characteristic**

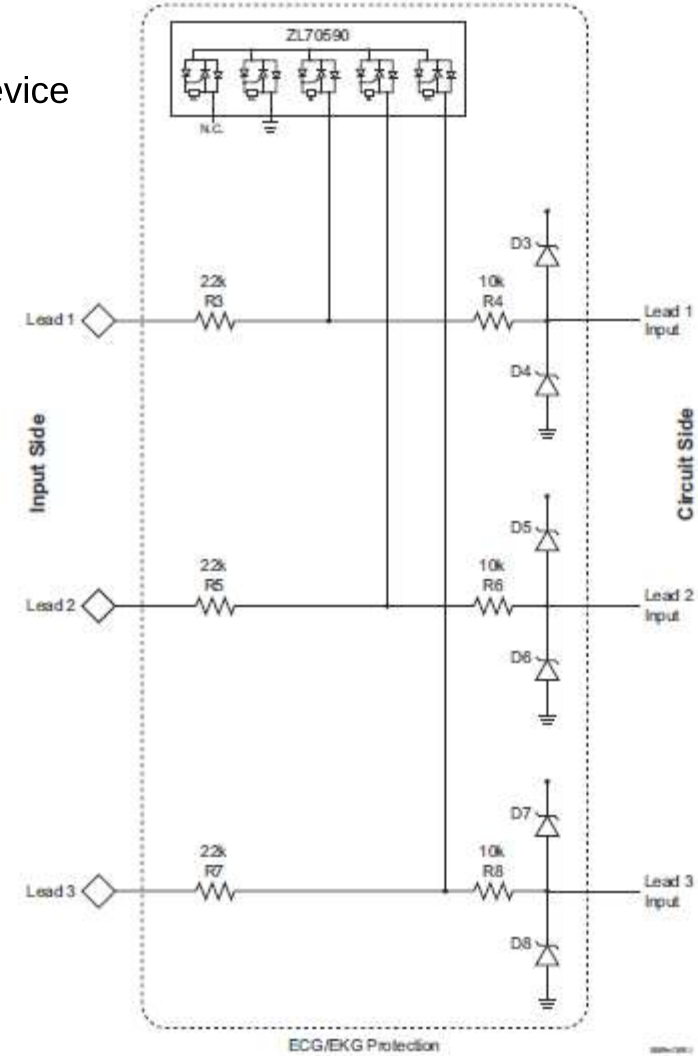
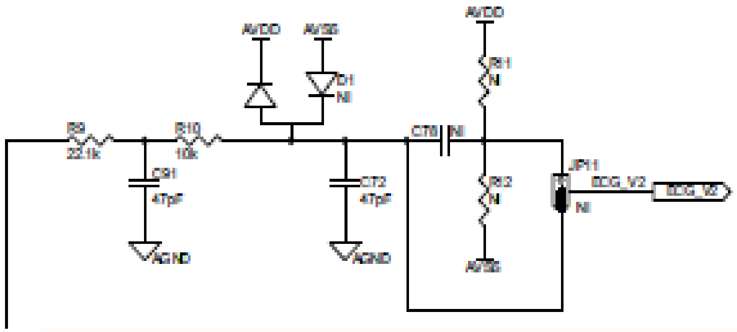
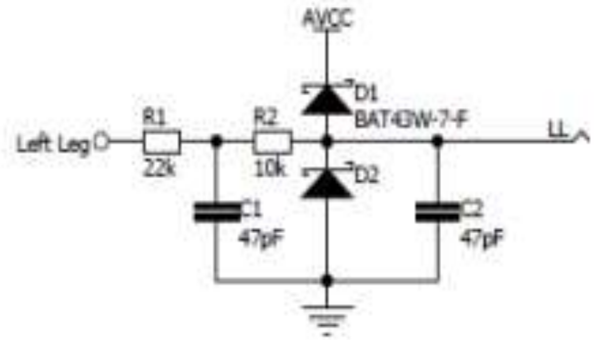


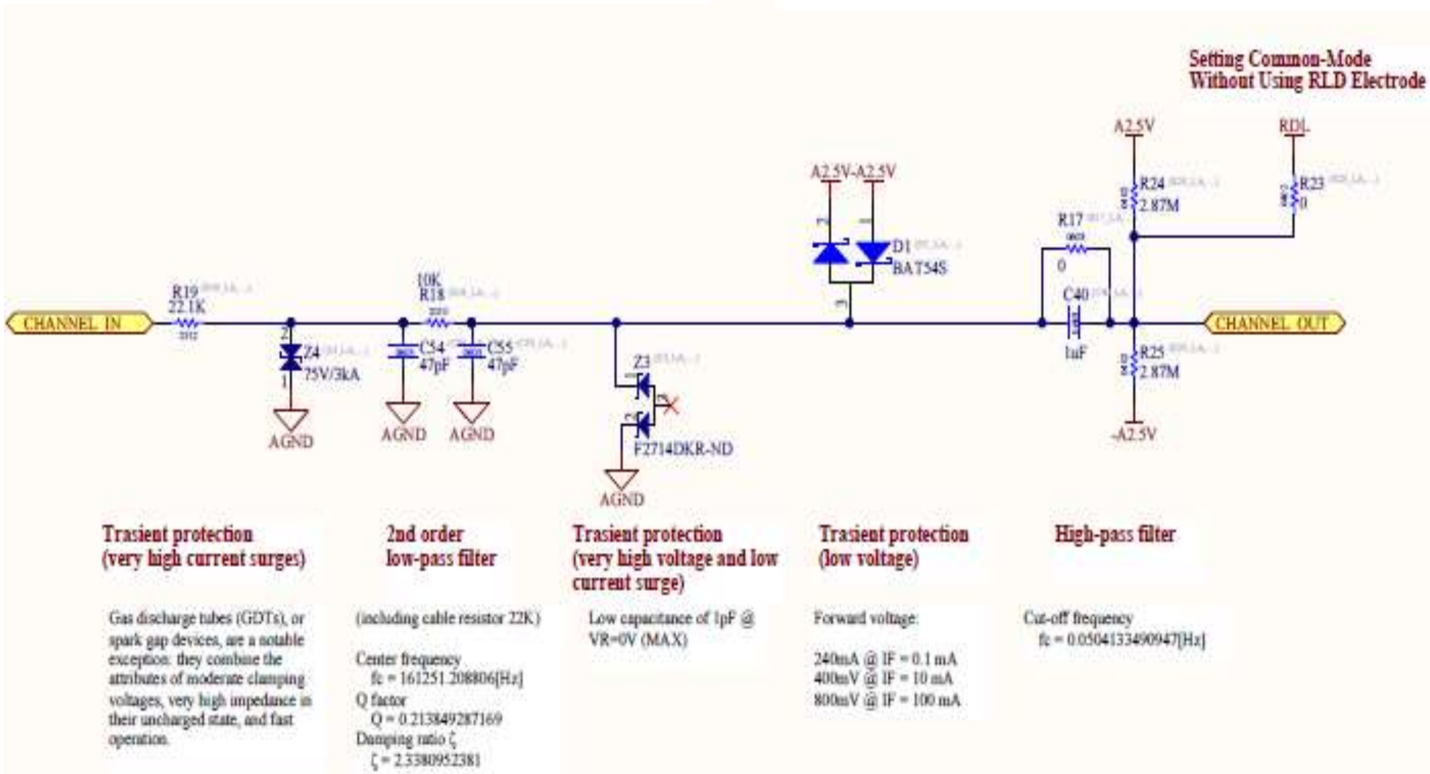
Figure 4-1 • **Example Protection Scheme (Three-Lead EKG Example Shown)**

ECG Monitor
Protection

Input Protection Examples

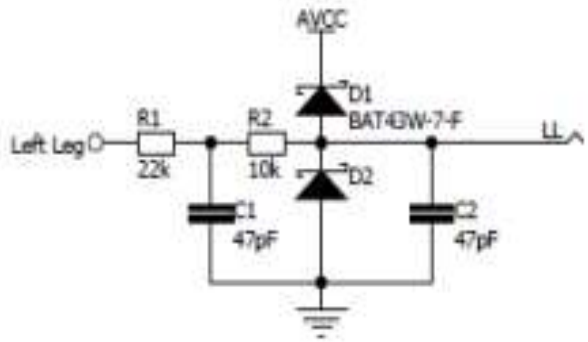




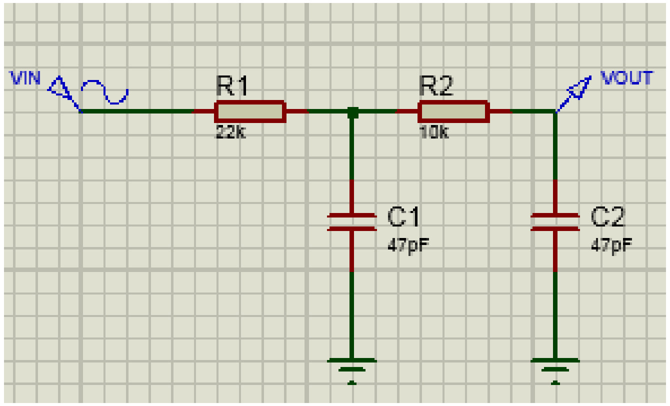


ECG Monitor
Protection

Consider Input Protection



Respuesta en frecuencia del circuito de protección (pasa bajo)



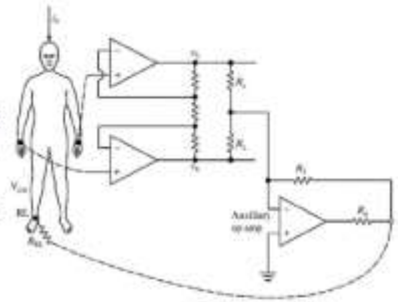
Bode de amplitud del circuito de protección. f3dB = 67.8 KHz

ECG Monitor
Protection

Driven-right-leg system

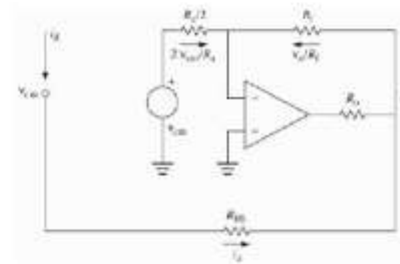
- The common-mode voltage on the body is sensed by the two averaging resistors R_a, inverted, amplified, and fed back to the right leg.

- This negative feedback drives the common-mode voltage to a low value.
- The body's displacement current flows not to ground but rather to the op-amp output circuit.
- This reduces the interference as far as the ECG amplifier is concerned and effectively grounds the patient



Driven-right-leg system

- When the amplifier saturates, as would occur during a large transient Vcm, its output appears as the saturation voltage Vs. The right leg is now connected to ground through this source and the parallel resistances Rf and Ro.
- To limit the current, Rf and Ro should be large. Values as high as 5 MΩ are used.

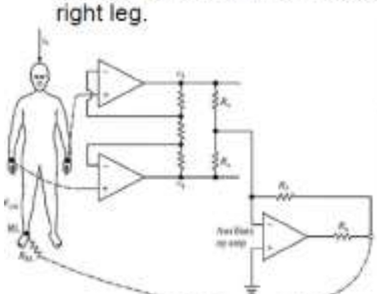


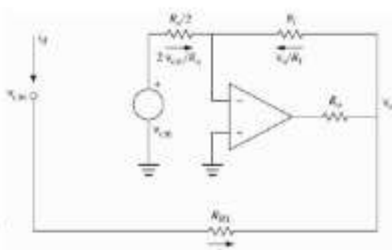
$$\frac{2v_{cm}}{R_a} + \frac{v_o}{R_f} = 0 \qquad v_o = -\frac{2R_f}{R_a} v_{cm}$$

$$v_{cm} = R_{RL} i_d + v_o \quad v_{cm} = \frac{R_{RL} i_d}{1 + 2R_f/R_a}$$

Driven-right-leg system

- The common-mode voltage on the body is sensed by the two averaging resistors R_a, inverted, amplified, and fed back to the right leg.



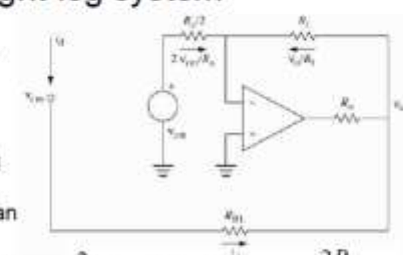


$$\frac{2v_{cm}}{R_a} + \frac{v_o}{R_f} = 0 \qquad v_o = -\frac{2R_f}{R_a} v_{cm}$$

$$v_{cm} = R_{RL} i_d + v_o \quad v_{cm} = \frac{R_{RL} i_d}{1 + 2R_f/R_a}$$

Driven-right-leg system

- When the amplifier is not saturated, we would like Vcm to be as small as possible or, in other words, to be an effective low-resistance path to ground.
- This can be achieved by making Rf large and Ra relatively small. Rf can be equal to Ro, but Ra can be much smaller.
- A typical value of Ra would be 25 kΩ.
- A worst-case electrode resistance R_{RL} would be 100 kΩ. The effective resistance between the right leg and ground would then be
- For the 0.2 mA displacement current, the common-mode voltage is



$$\frac{2v_{cm}}{R_a} + \frac{v_o}{R_f} = 0 \qquad v_o = -\frac{2R_f}{R_a} v_{cm}$$

$$v_{cm} = R_{RL} i_d + v_o \quad v_{cm} = \frac{R_{RL} i_d}{1 + 2R_f/R_a}$$

$$\frac{100\ \text{k}\Omega}{1 + \frac{2 \times 5\ \text{M}\Omega}{25\ \text{k}\Omega}} = 249\ \Omega$$

$$v_{cm} = 249\ \Omega \times 0.2\ \mu\text{A} = 50\ \mu\text{V}$$

ECG Monitor

Discrete ECG Amplifier with INA

Right Leg

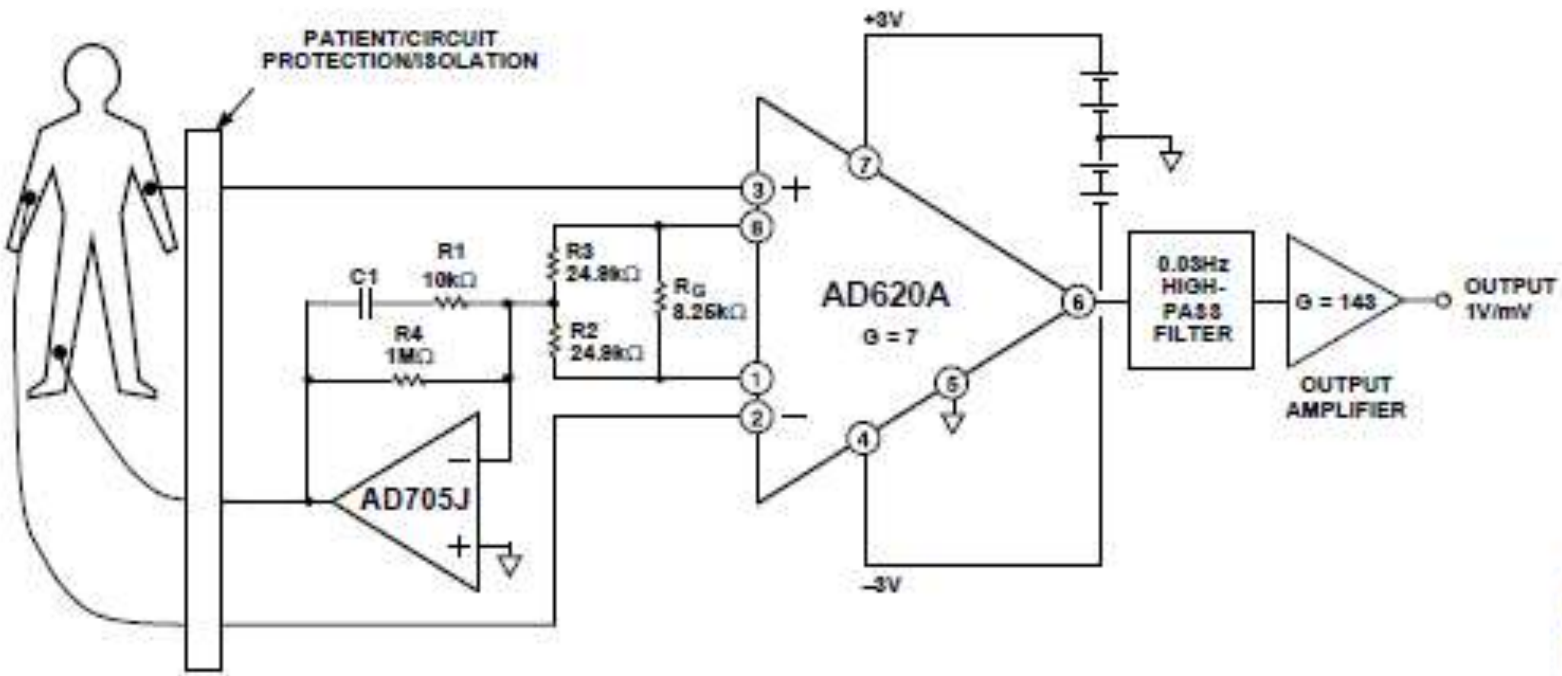
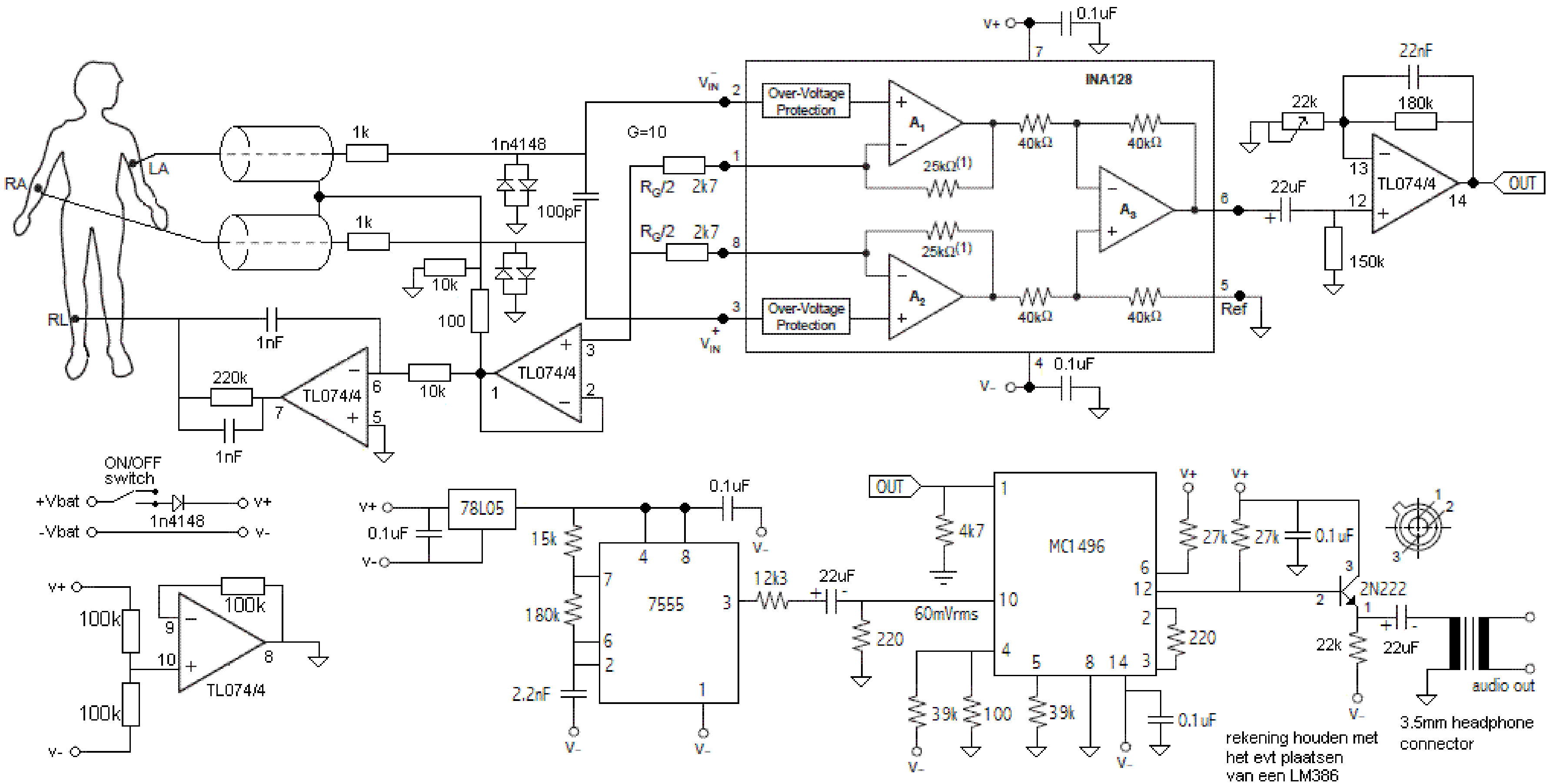


Figure 39. A Medical ECG Monitor Circuit

ECG Monitor

Discrete ECG Amplifier with INA

Right Leg and Protection



ECG Monitor
EMI Supression

Inductors, ferrite beads

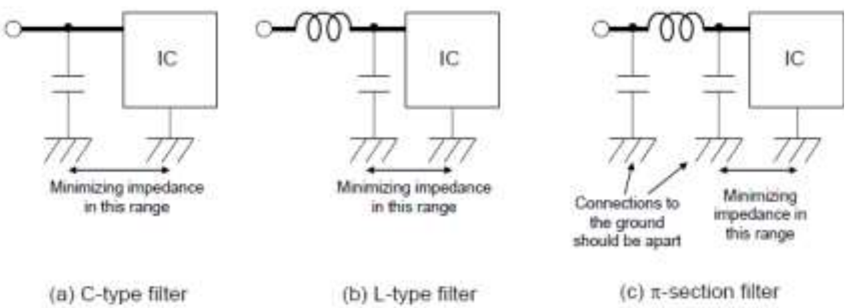


Figure 2-9 Filter configurations used for IC power supplies (C-type, L-type and π-section)

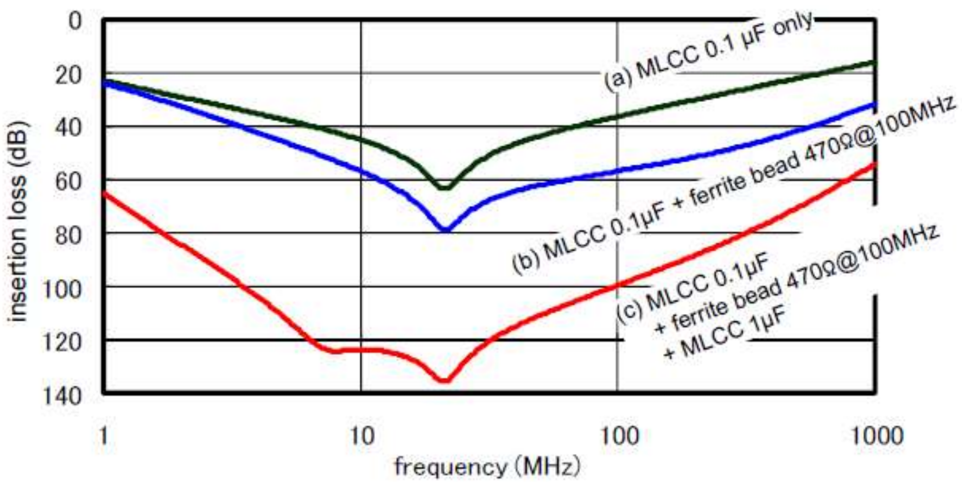


Figure 2-10 An example of insertion loss fluctuation when an inductor is combined (calculated values)

ECG Monitor
EMI Supression

Parallel connection of capacitors and antiresonance

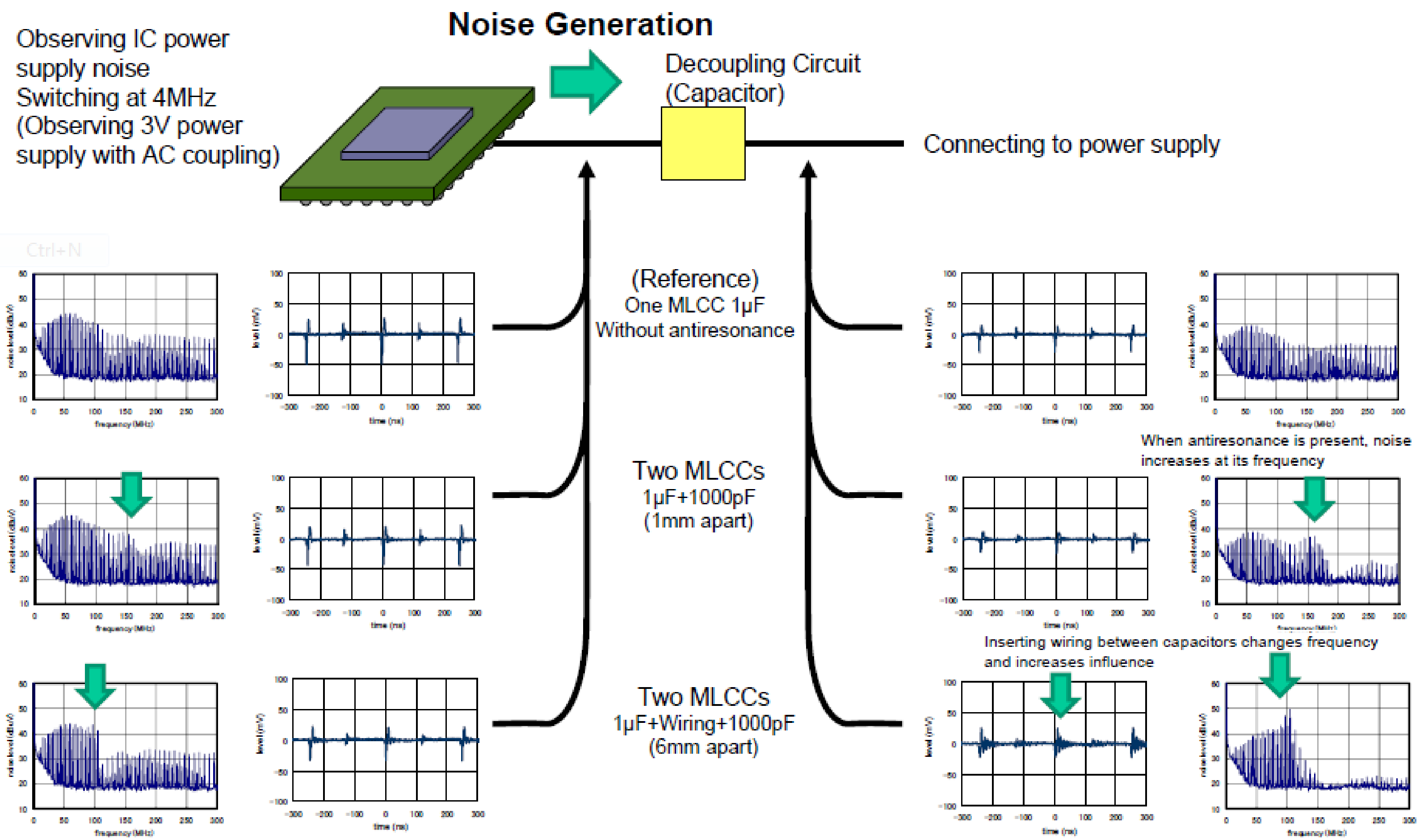
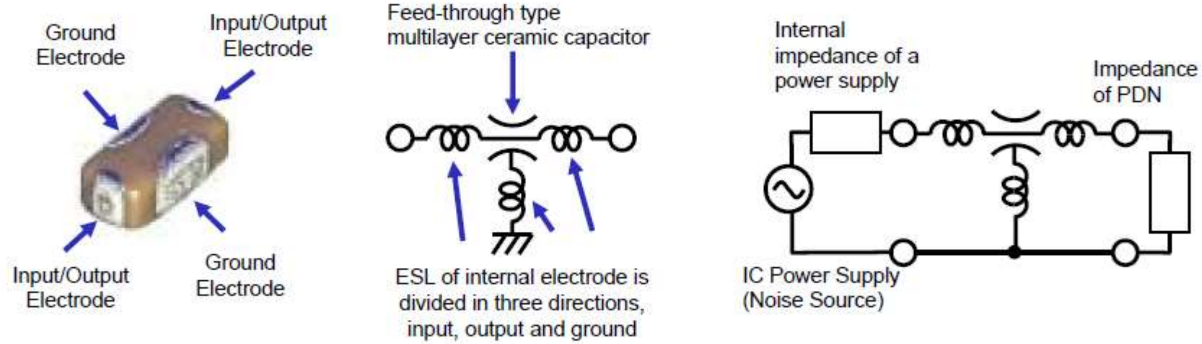


Figure 3-15 Examples of noise observation when antiresonance is present

ECG Monitor
EMI Supression

3-terminal capacitor



External Configuration for

Equivalent Circuit

Connecting to the circuit

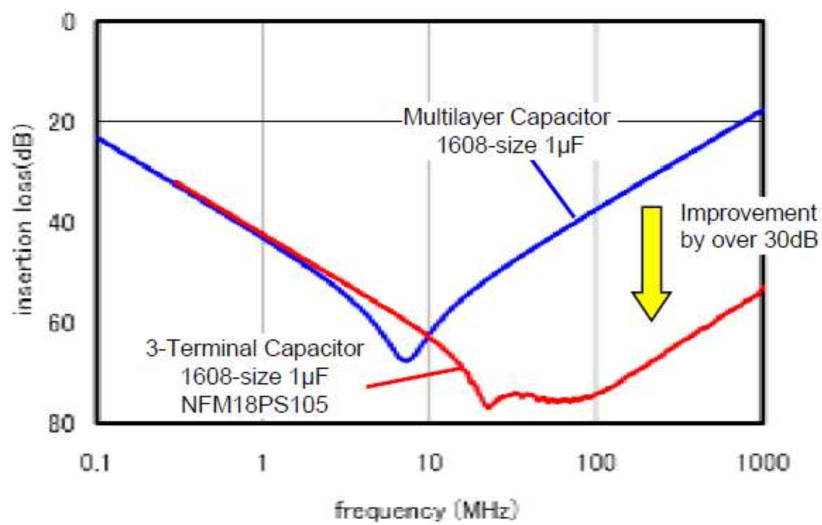


Figure 4-9 Insertion loss characteristics of a 3-terminal capacitor

ECG Monitor
EMI Supression

Low-ESL capacitor 3-terminal capacitor

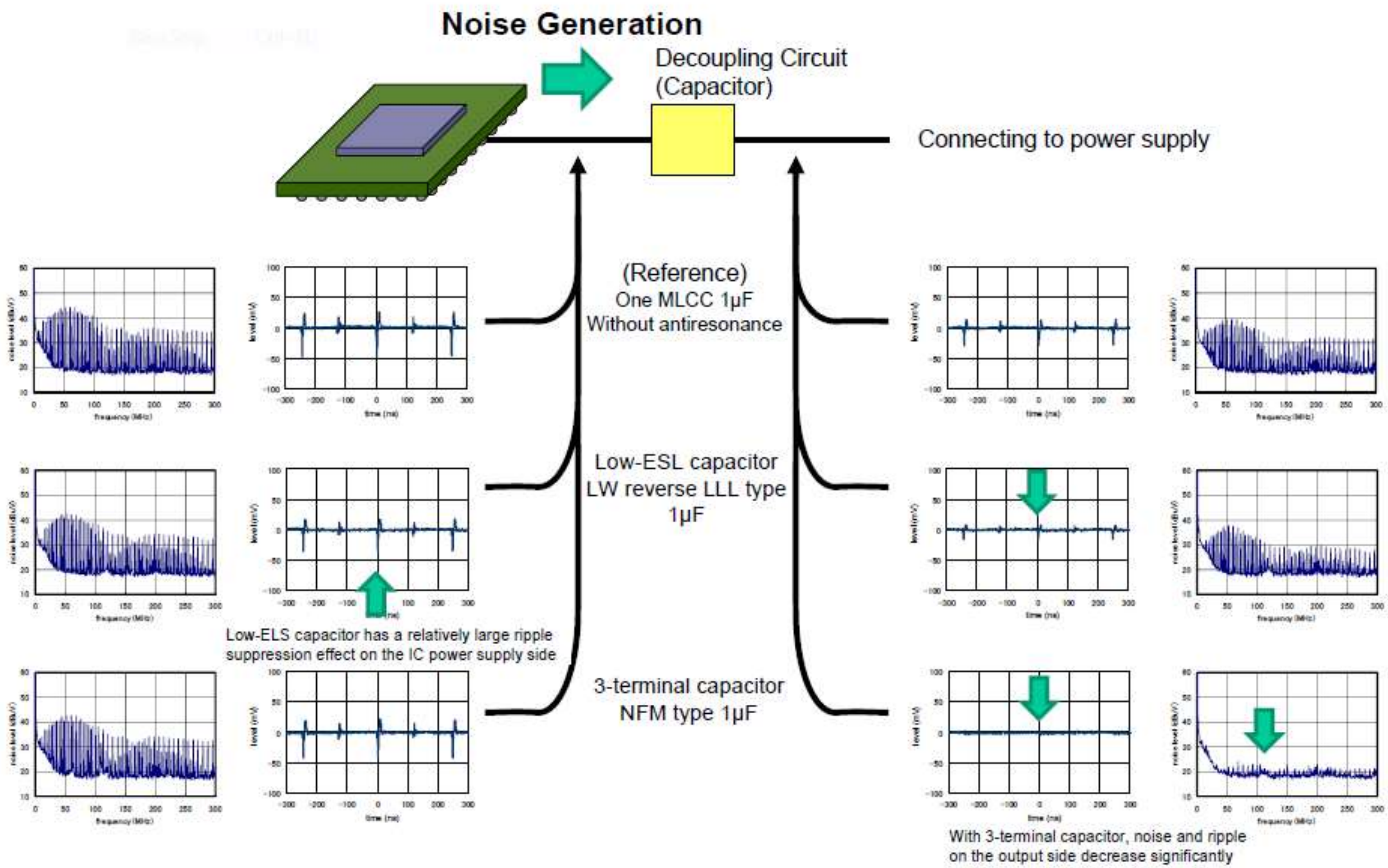


Figure 3-17 Measurement results when using low-ESL capacitors

ECG Monitor
EMI Supression

Characteristics for a combination of capacitors and inductors

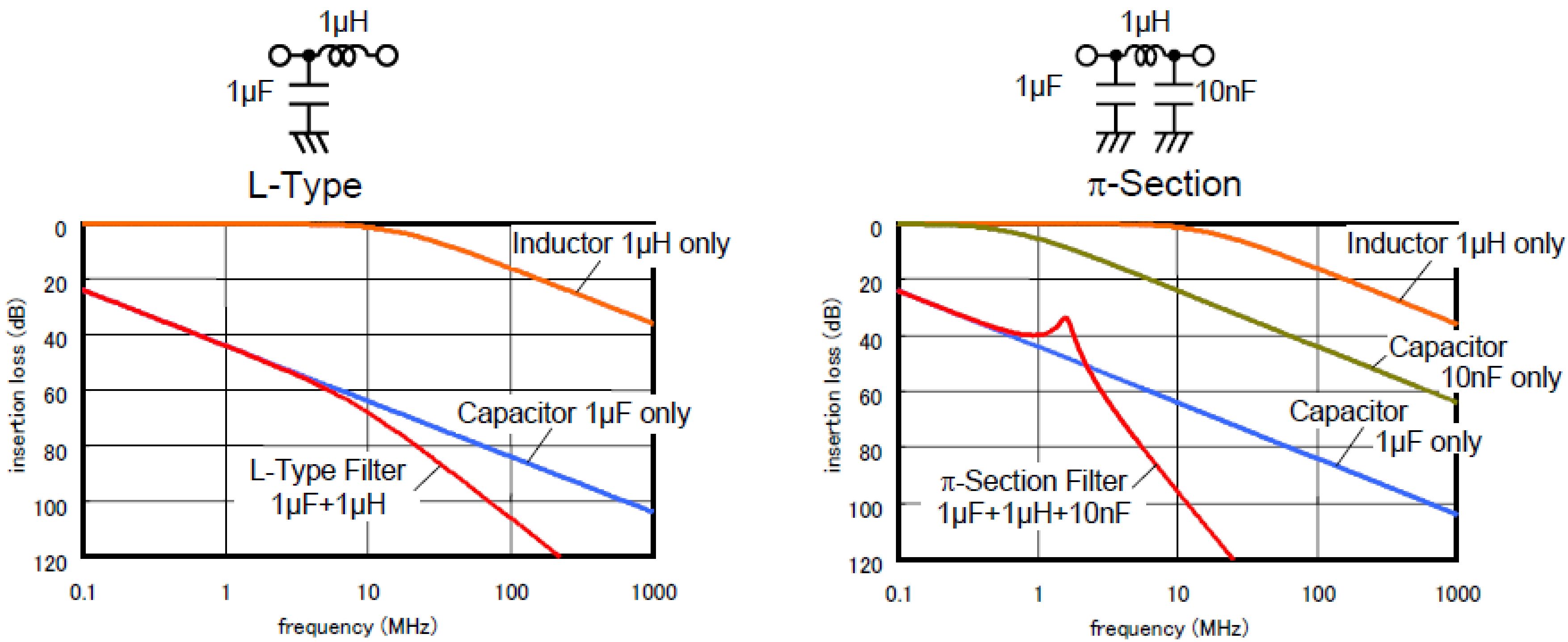


Figure 5-12 Examples of insertion loss characteristics of L-type and π-section filters (calculated values)

ECG Monitor
EMI Supression

Characteristics for a combination of capacitors and inductors

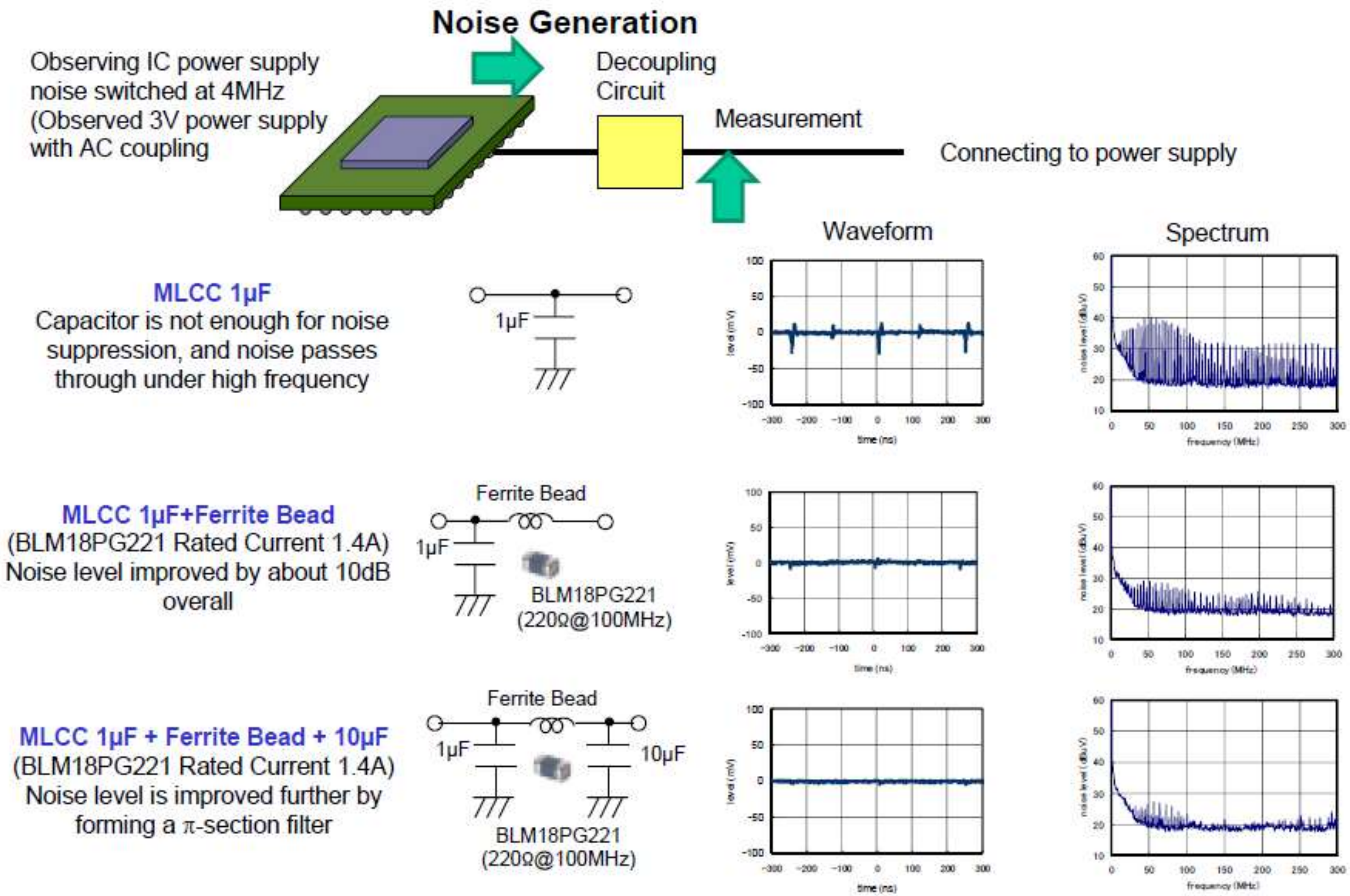


Figure 5-14 An example of noise suppression and improvement by ferrite beads

ECG Monitor
EMI Supression

LC filter

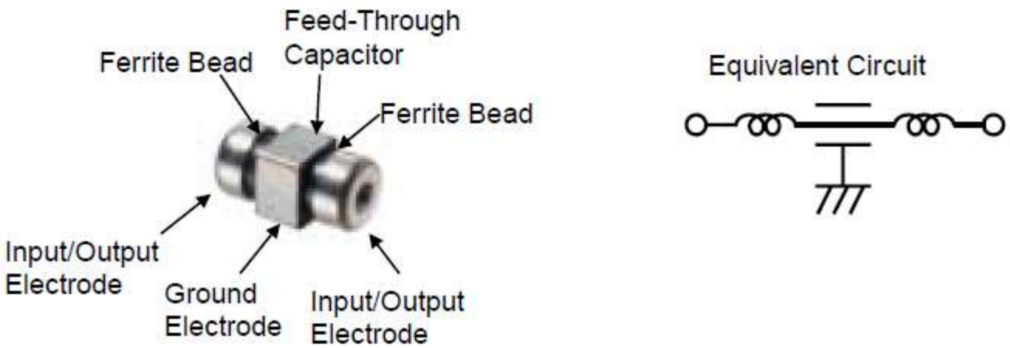
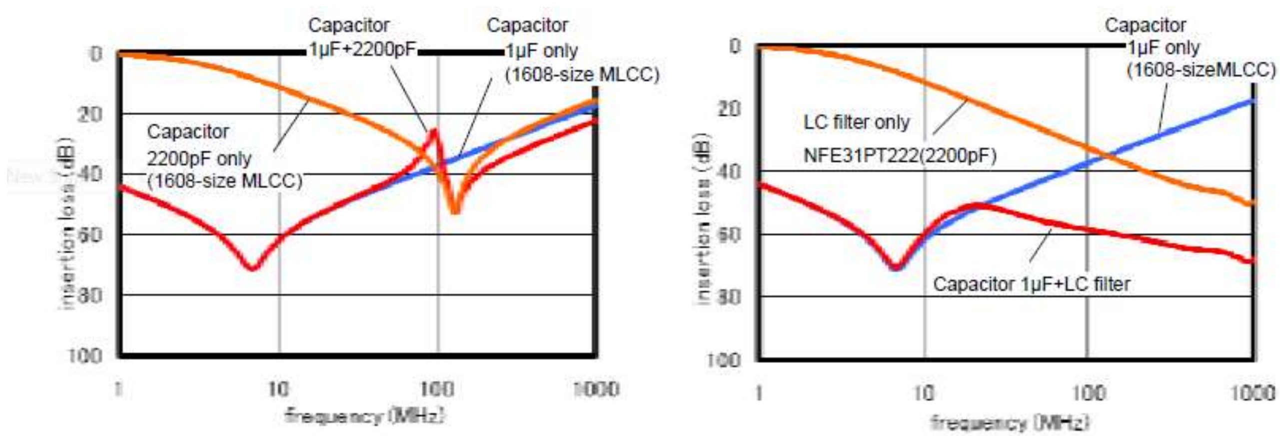


Figure 5-15 LC filter NFE31 for power supplies



(a) When combining two capacitors

(b) When combining a capacitor and a LC filter

Figure 5-16 Frequency characteristics of a power supply filter (calculated values)

ECG Monitor
EMI Supression

LC filter

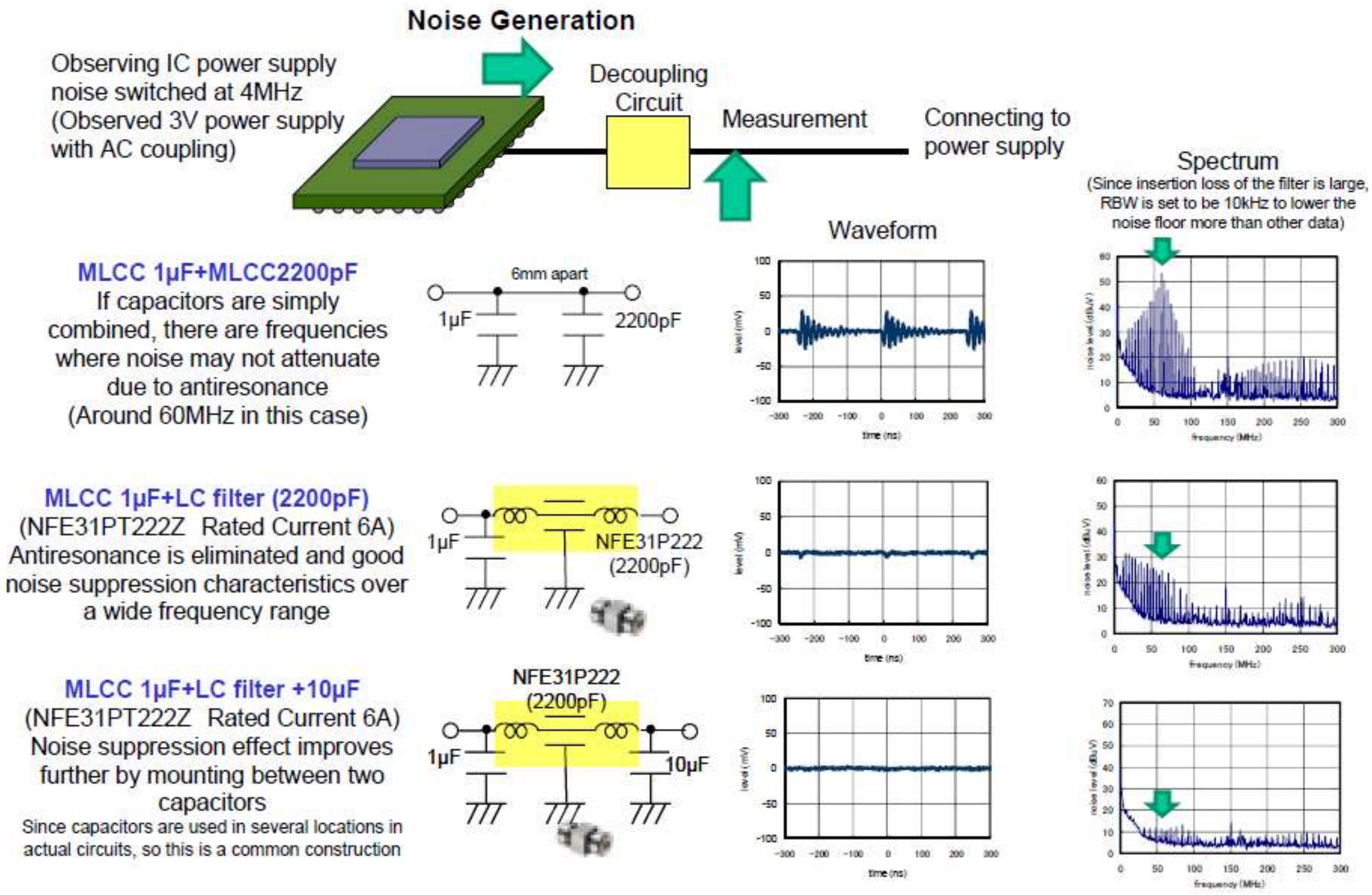


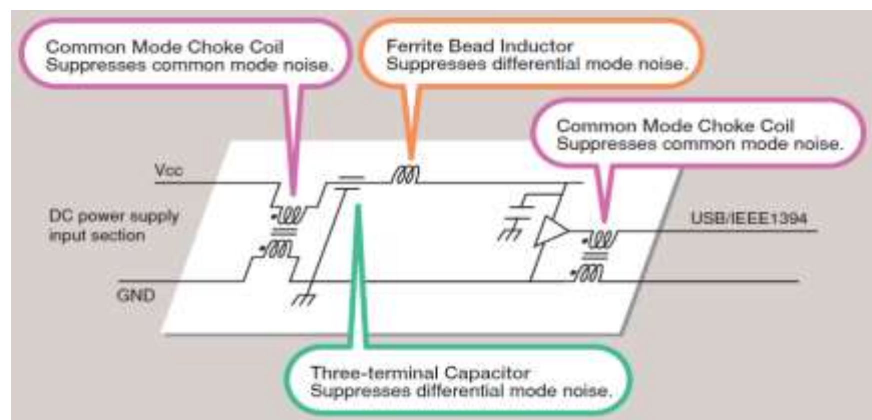
Figure 5-17 An example of improving noise suppression using an LC filter

ECG Monitor
EMI Supression

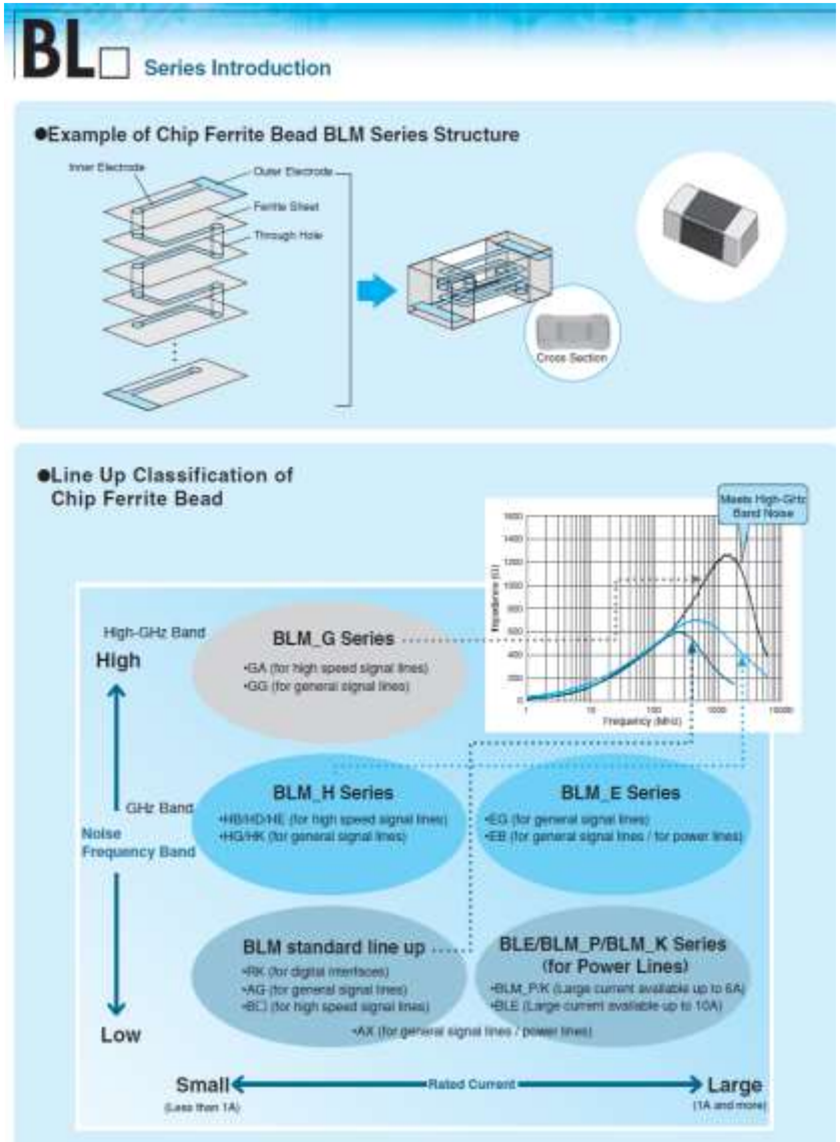
EMI suppression

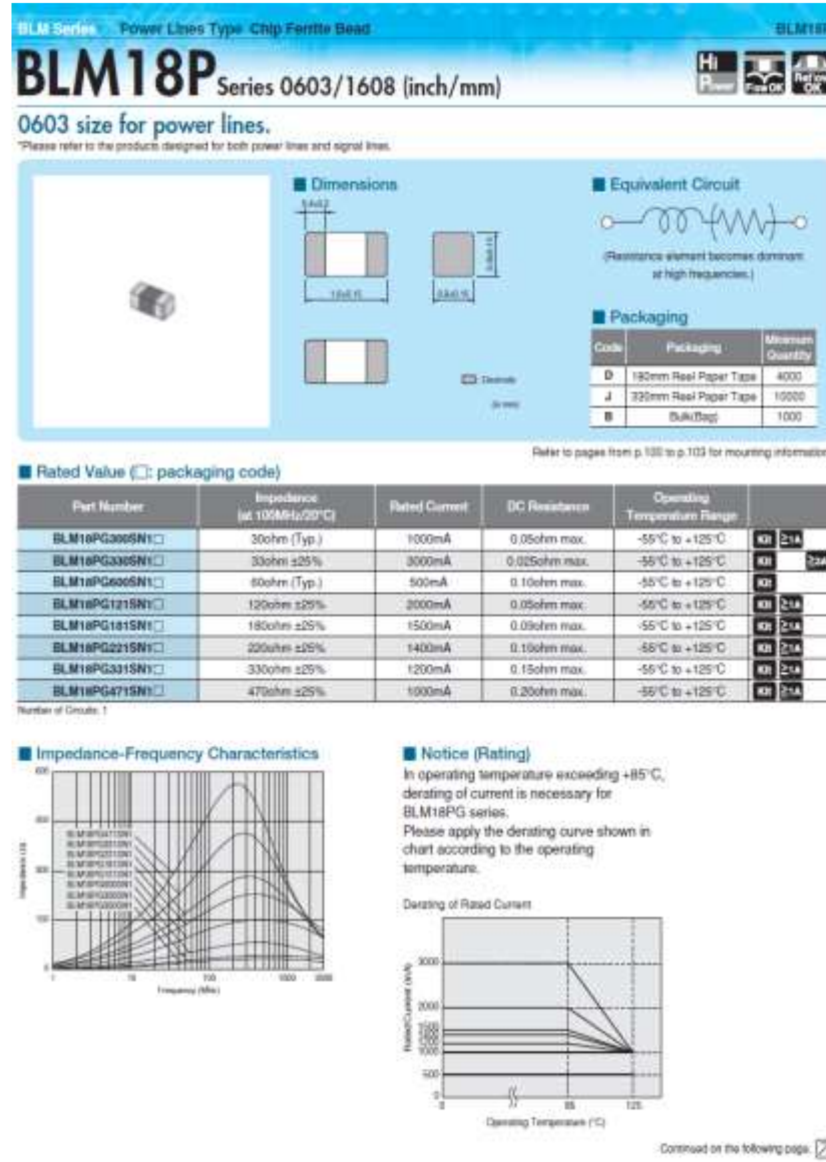
http://www.ti.com/lit/an/szza009/szza009.pdf
https://www.murata.com/products/emc/emifil/knowhow/basic
https://resources.altium.com/presentations/pcb-design-techniques-to-reduce-emi
https://resources.altium.com/ebooks/pcb-design-techniques-to-reduce-emi-ebook
https://resources.orcad.com/blog/techniques-to-reduce-emi-in-your-pcb-designs
https://www.eetimes.com/author.asp?section_id=36&doc_id=1327269#
Considerar las opciones Murata (Murata_EMILFIL_c31e-794748.pdf):
Ferrite Bead: BLM18PG121SN1
Capacitor Type: NFM18PS105D0J3
Common Mode Choque Coil: No

Type	Features	Suitable Circuits
Ferrite Bead BLM/BLA Series	· Miniaturized · GND connection unnecessary · Effective at low impedance line	· Application set with less noise radiation · Low impedance line
Capacitor Type NFM/NFA/NFE/NFR/ NFL/NFW Series	· Great noise suppression effect · With effect as By-Pass capacitor (Lineup for Power) · Good noise separation from signal (LC filter for Signal) · Effective at high impedance line	· Application set with higher noise radiation · High impedance line · Circuit with By-Pass capacitor · Circuit driven by high frequency
Common Mode Choke Coil	· Possible to suppress noise with less affect of ultra high speed signal · Great effect for common mode noise · Less magnetic saturation by current	· High speed differential signal line · I/F cable driver · Power line



ECG Monitor
EMI Supression




BLM Series Power Lines Type Chip Ferrite Bead BLM18P

BLM18P Series 0603/1608 (inch/mm)

0603 size for power lines.

*Please refer to the products designed for both power lines and signal lines.

■ Dimensions

■ Equivalent Circuit

(Resistance element becomes dominant at high frequencies.)

■ Packaging

Code	Packaging	Minimum Quantity
D	180mm Reel Paper Tape	4000
J	330mm Reel Paper Tape	10000
B	Bulk(Bag)	1000

Refer to pages from p.100 to p.103 for mounting information.

■ Rated Value (□: packaging code)

Part Number	Impedance (at 100MHz/20°C)	Rated Current	DC Resistance	Operating Temperature Range
BLM18PG300SN1□	30ohm (Typ.)	1000mA	0.05ohm max.	-55°C to +125°C
BLM18PG330SN1□	33ohm ±25%	3000mA	0.025ohm max.	-55°C to +125°C
BLM18PG600SN1□	60ohm (Typ.)	500mA	0.10ohm max.	-55°C to +125°C
BLM18PG121SN1□	120ohm ±25%	2000mA	0.05ohm max.	-55°C to +125°C
BLM18PG181SN1□	180ohm ±25%	1500mA	0.09ohm max.	-55°C to +125°C
BLM18PG221SN1□	220ohm ±25%	1400mA	0.10ohm max.	-55°C to +125°C
BLM18PG331SN1□	330ohm ±25%	1200mA	0.15ohm max.	-55°C to +125°C
BLM18PG471SN1□	470ohm ±25%	1000mA	0.20ohm max.	-55°C to +125°C

Number of Circuits: 1

■ Impedance-Frequency Characteristics

■ Notice (Rating)

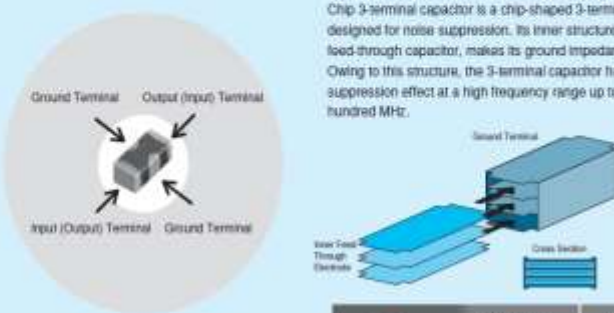
In operating temperature exceeding +85°C, derating of current is necessary for BLM18PG series.
Please apply the derating curve shown in chart according to the operating temperature.

Derating of Rated Current

Operating Temperature (°C)

Continued on the following page.

ECG Monitor
EMI Supression

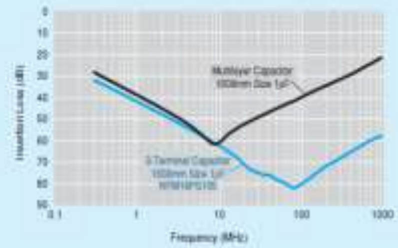


NF□ Series Introduction

Example of 3-Terminal Capacitor Structure

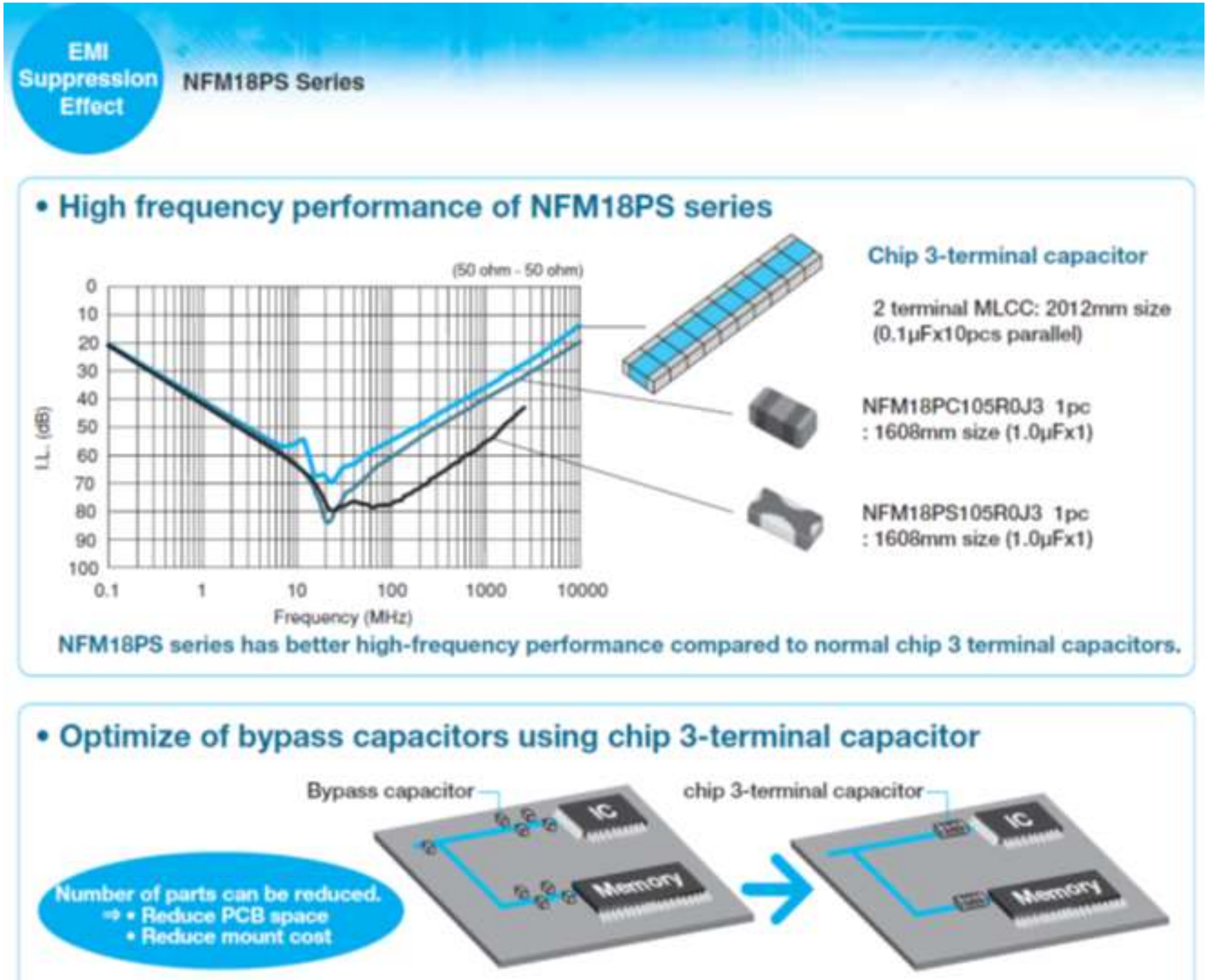
Chip 3-terminal capacitor is a chip-shaped 3-terminal capacitor designed for noise suppression. Its inner structure, like a feed-through capacitor, makes its ground impedance quite low. Owing to this structure, the 3-terminal capacitor has a good noise suppression effect at a high frequency range up to several hundred MHz.

Series	Equivalent Circuit	Part Number
NFM Series (3-terminal capacitor)		NFM18CC NFM21CC NFM18PC NFM18PS NFM21PC
NFL / NFW Series (LC filter)		NFL15ST NFL18ST
		NFL18SP NFL21SP NFW31SP
		NFA21SL NFA18SL NFA18SD
NFR Series (RC filter)		NFR21GD NFA31GD
NFE Series (Feed through capacitor with ferrite core)		NFE31PT NFE61PT

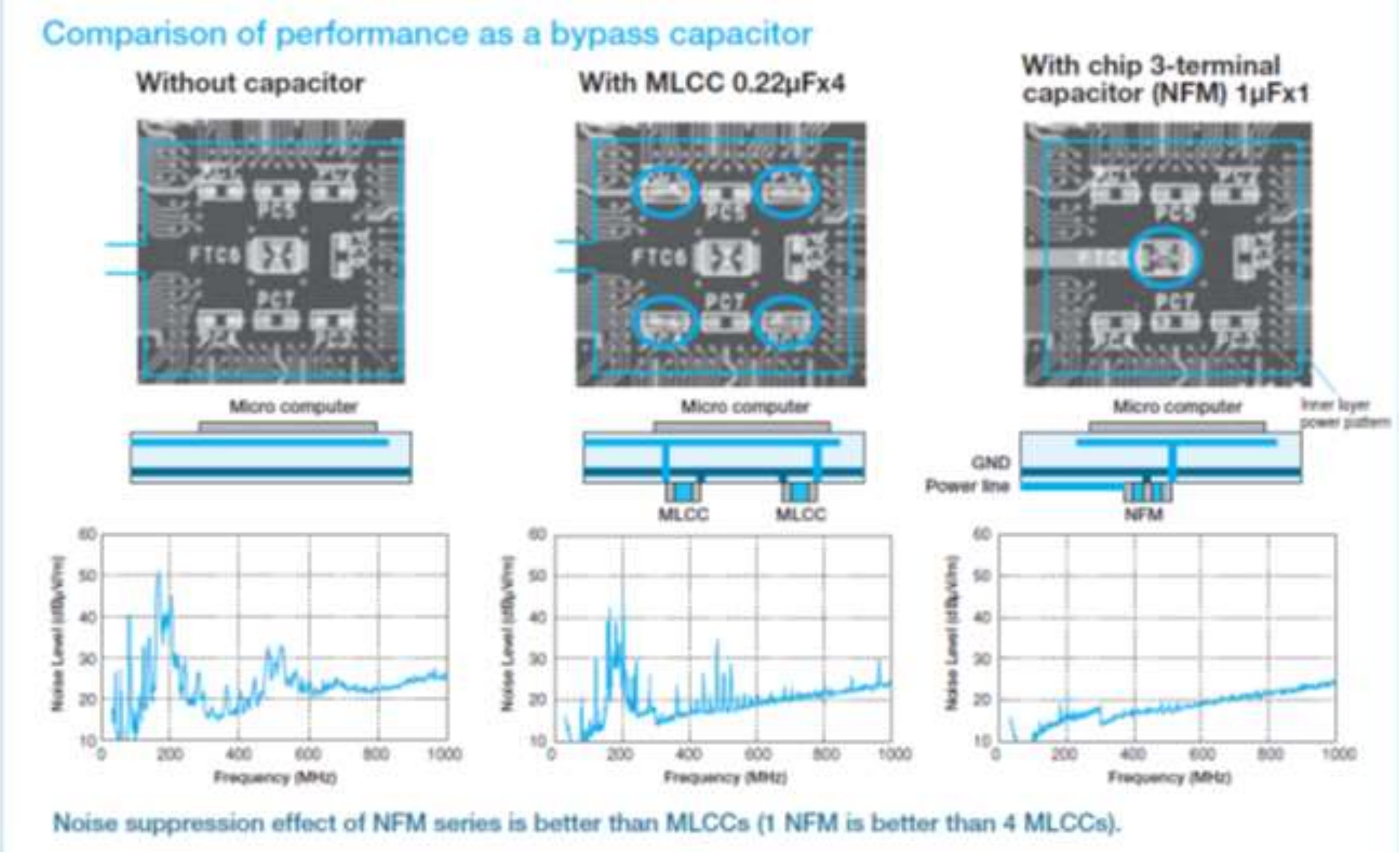


Insertion Loss Sample	Features	Classification		Applications	Example
	Standard of 3-terminal capacitor	NFM_CC	Standard type with varied capacitance	Noise suppression in low speed signal lines	·Low speed interface lines ·Sensor
		NFM_PC	Meet large current, high capacitance available, for power lines	Noise suppression in power lines	·Individual IC power lines
	Sharp insertion loss curve enables low damage to signal waveform	NFL_ST	T-type filter, effective in low impedance circuits	Noise suppression in high speed signal lines	·High speed interface lines ·Bus lines LCD lines Camera I/Fs ·High speed analog lines RGB / D terminal
		NFL_SP	π-type filter, effective in high impedance circuits		
		NFW_SP	π-type filter, designed for low impedance circuits		
		NFA_SL	4-line array, suitable for bus lines or flat cables		
	Limit noise using resistor, also loss back to ground			Noise suppression in signal line with unstable ground	·Interface lines ·Clock lines
	Meets large current, good high frequency performance because of its feed through structure			Noise suppression in power lines / low impedance lines	·Various power lines ·Sensor

ECG Monitor
EMI Supression



ECG Monitor
EMI Supression



ECG Monitor
EMI Supression

NFM Series Power Lines Type Chip EMIFIL® NFM18PS

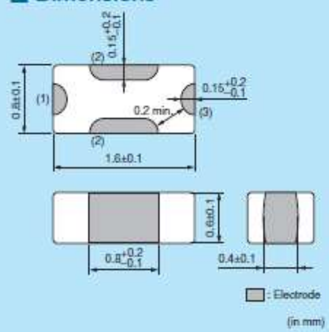
NFM18PS Series 0603/1608 (inch/mm)

Hi Power · Reflow OK

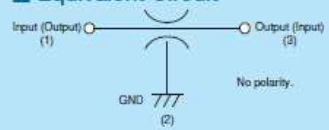
3-terminal capacitor for power lines whose ground impedance has reduced.

*Please refer to the products designed for both power lines and signal lines.

Dimensions



Equivalent Circuit



Packaging

Code	Packaging	Minimum Quantity
D	180mm Reel Paper Tape	4000
B	Bulk(Bag)	500

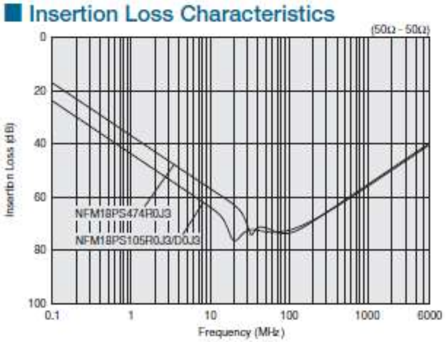
Refer to pages from p.156 to p.162 for mounting information.

Rated Value (□: packaging code)

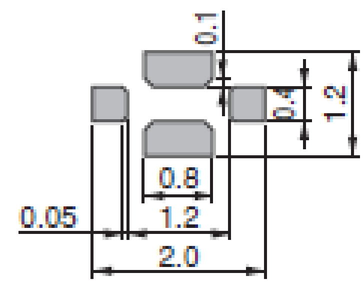
Part Number	Capacitance	Rated Current	Rated Voltage	Insulation Resistance (min.)	Operating Temperature Range	
NFM18PS474R0J3□	0.47µF ±20%	2A	6.3Vdc	1000M ohm	-55°C to +125°C	Kit ≥1A
NFM18PS105D0J3□	1.0µF ±20%	2A	6.3Vdc	500M ohm	-55°C to +125°C	New Kit ≥1A
NFM18PS105R0J3□	1.0µF ±20%	2A	6.3Vdc	500M ohm	-55°C to +105°C	Kit ≥1A

Number of Circuit: 1

Insertion Loss Characteristics



NFM18PS

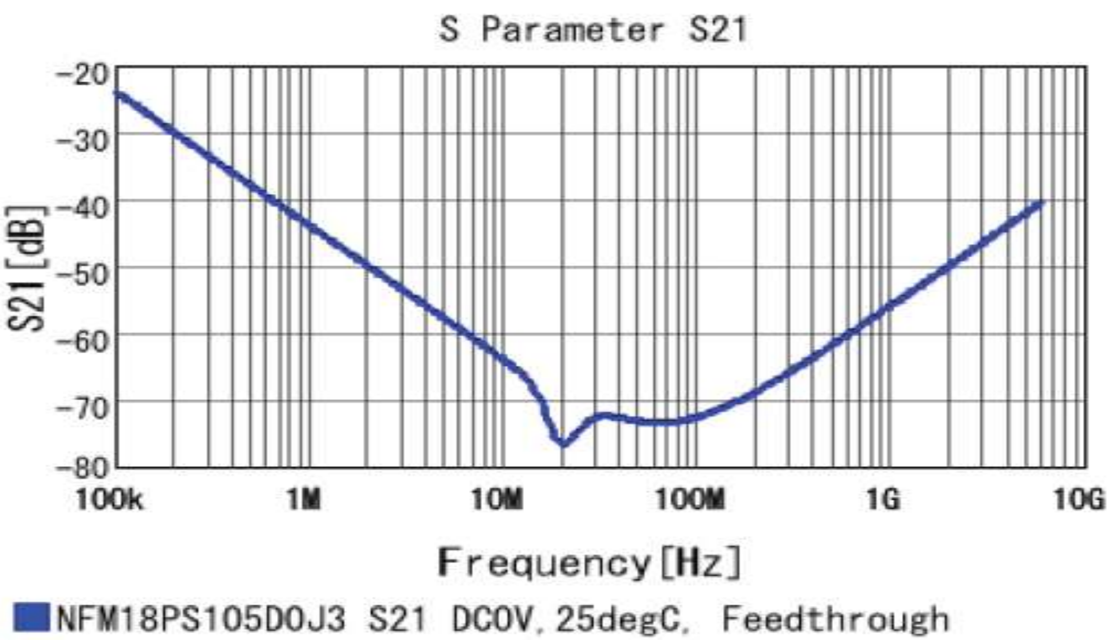


ECG Monitor
EMI Supression

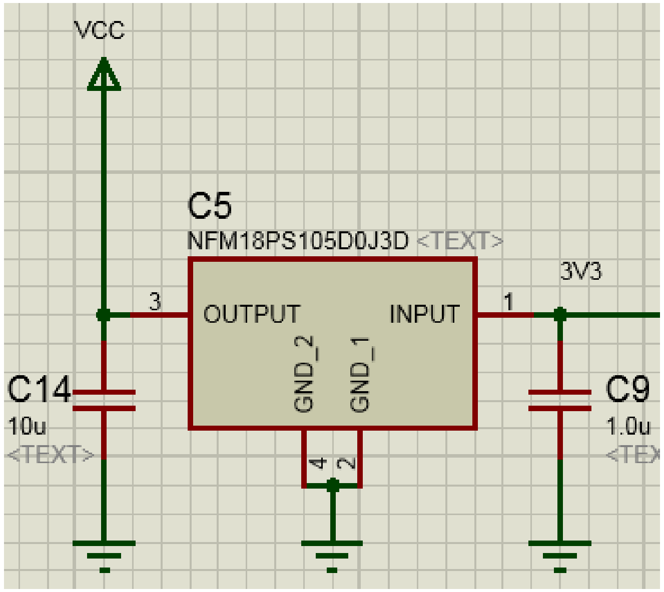
Consider 3 terminal capacitor for power supply

La inclusión de 3-terminal capacitor + capacitor (configuración π) para 3.3 V del conector mikroBus logra atenuar el ruido en frecuencias mayores a 100 KHz que incluye las frecuencias del microcontrolador de la aplicación. Además, protege del ruido de módulos de comunicaciones tipo WiFi y Bluetooth.

Respuesta del NFM18PS105D0J3D sin los condensadores



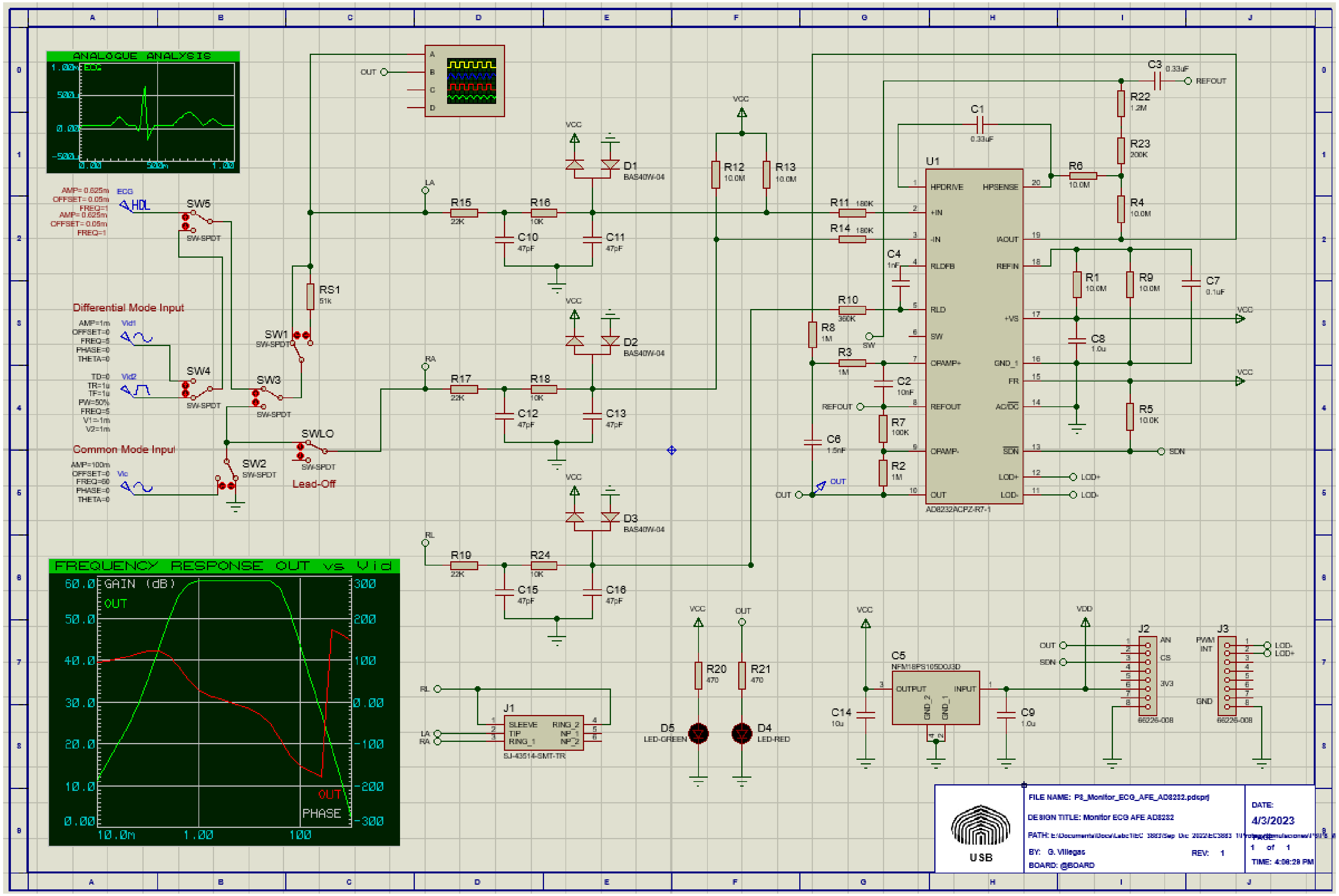
Configuración tipo π *con condensdadores*



ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)



ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

Simulaciones:

Caso AD8232:

El modelo Spice no simula completamente el AD8232.
El modelo Spice fue modificado y se consiguió que:
Se produce una salida OUT con ganancia 900 @ 5 Hz y Voffset = 1.64 V.
Los pines del AD8232 que el modelo Spice no soporta correctamente son:
SW, AD_DC, SDN, LOD+, LOD-
Eliminar solo el cable conectado al pin SW:

- Para que la simulación con osciloscopio digital funcione.
- El modelo también funciona para el Bode de amplitud y fase de la ganancia modo diferencial.
- Pero no funciona para el Bode de amplitud y fase de la ganancia modo común.

Exclude form Simulation para osciloscopio digital:
66226-008
BAS40W-04 (produce atenuación)

Exclude form Simulation para GRAPH de frecuencia (Bode de amplitud y fase de la ganancia modo diferencial):
Generador de ECG HDL
BAS40W-04
LED-RED
LED-GREEN
66226-008 (conector *header* macho)

ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

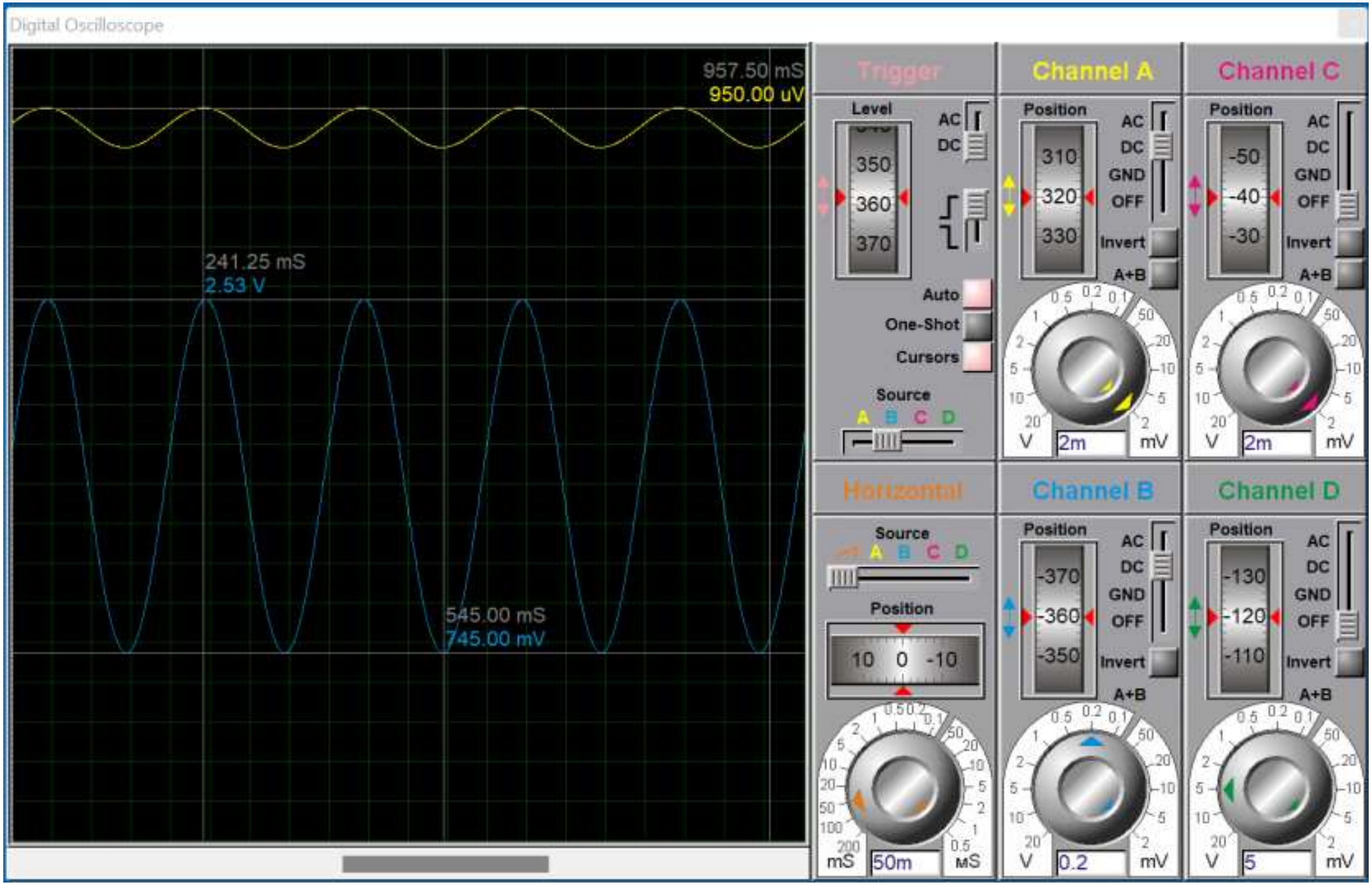
Bode de amplitud y fase de la ganancia modo diferencial Avd = Vo / Vid
Caso pasa bajo: fc = 43.6 Hz
Caso pasa alto: fc = 0.445 Hz.
Avd = 59,1 dB frecuencias medias

ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

Vid (onda senoidal 1 mVp @ 5 Hz) y Vo (OUT)

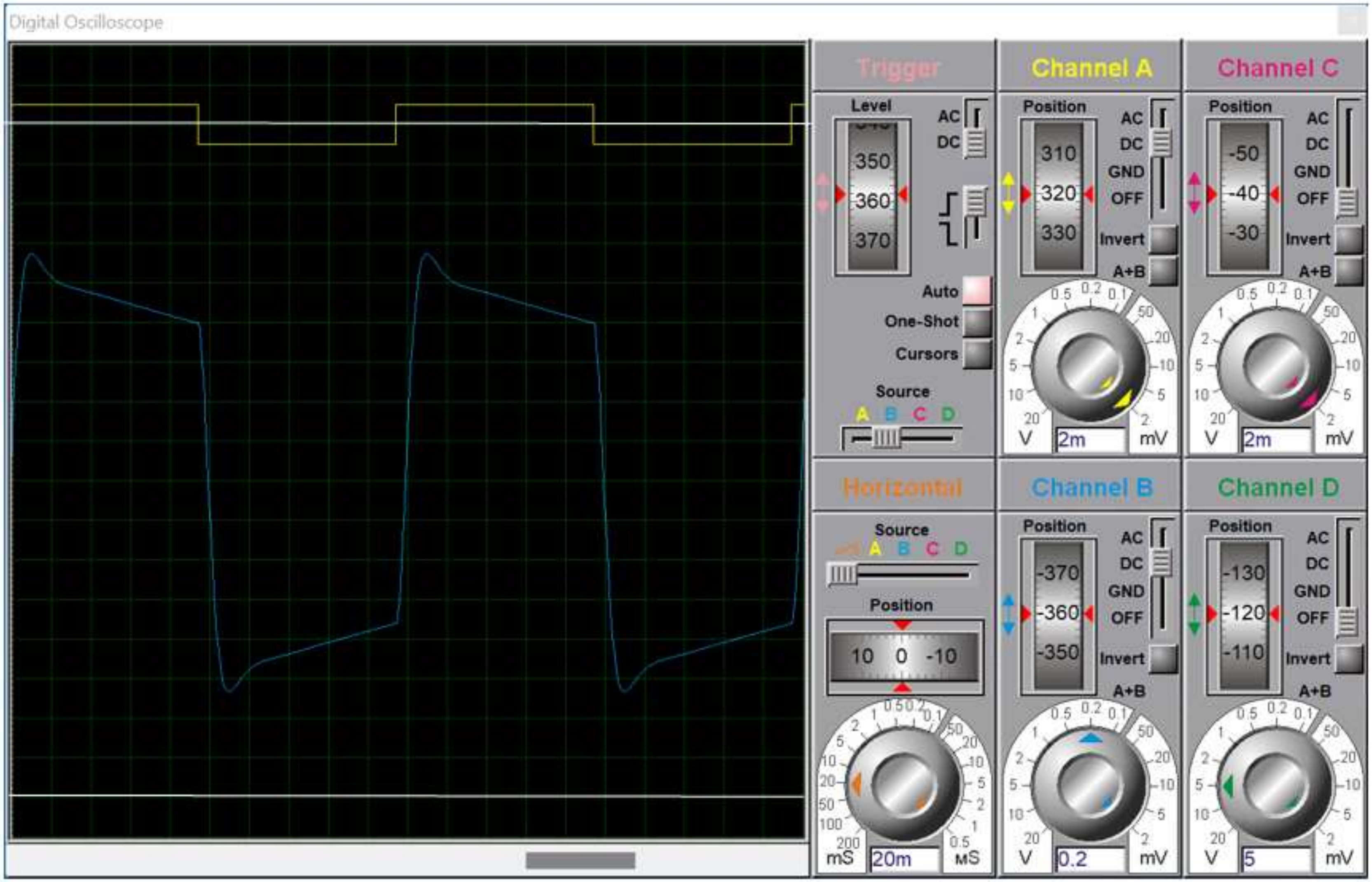


ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

. Vid (onda cuadrada 1 mVp @5 Hz) y Vo (OUT)

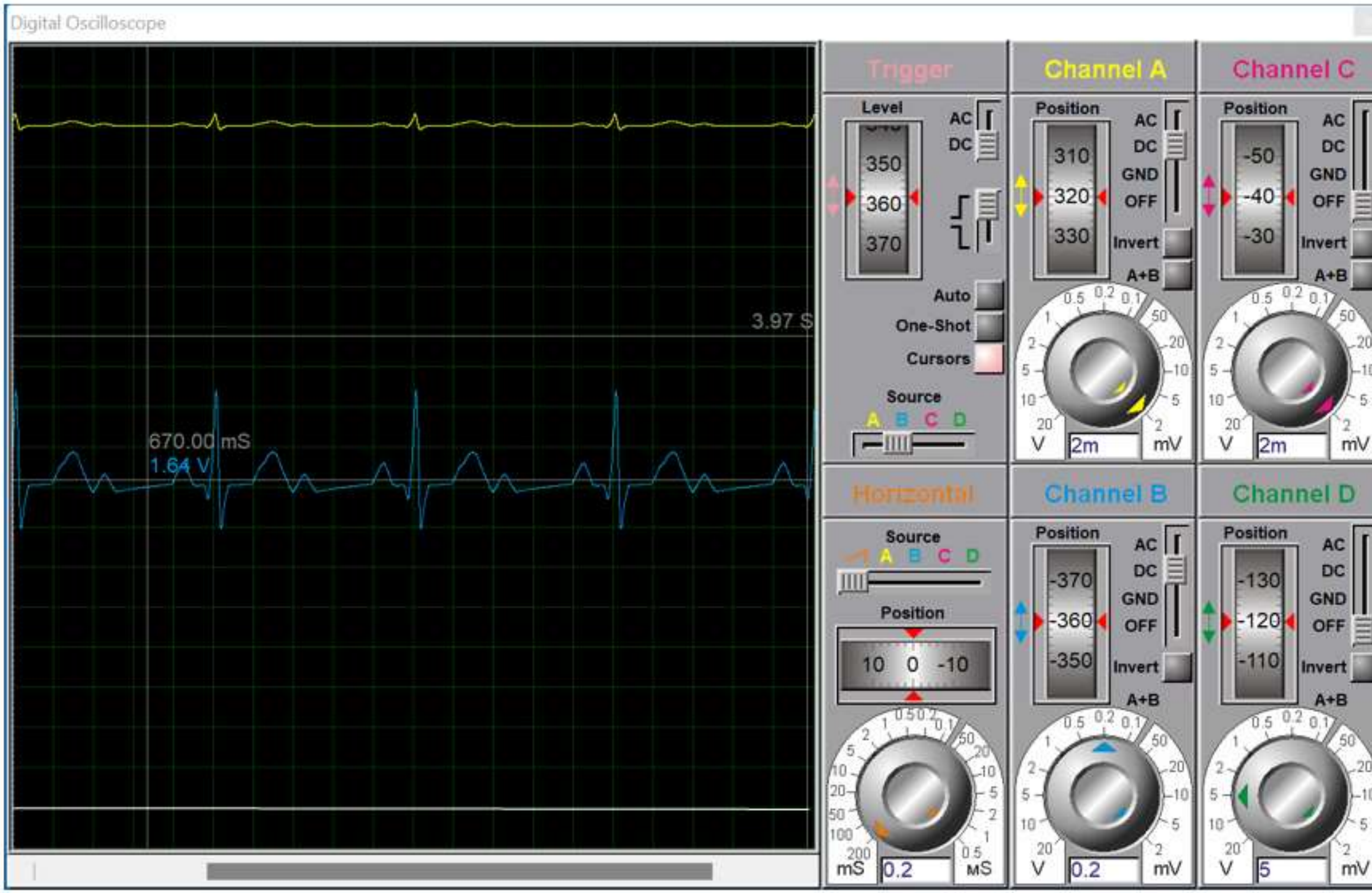


ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

Vid (ECG simulado 0.625 mVp) y Vo (OUT)



ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8)

BOM

Bill Of Materials for Monitor ECG AFE AD8232

Design Title	Monitor ECG AFE AD8232
Author	G. Villegas
Document Number	0
Revision	1
Design Created	Monday, April 3, 2023
Design Last Modified	Monday, April 3, 2023
Total Parts In Design	56

Category	Quanti	References	Value	Stock Code	Unit C	Manufacturer	Manufacture Part Number	Description	PCB Package
Capacitors	2	C1,C3	0.33uF	Digikey 399-4918-2-ND	$0.46	Kemet	C0603C334K9RACTU	CAP CERM .33uF 6.3V X7R 0603	CAPC1608X87
Capacitors	1	C2	10nF	Digikey 311-1085-2-ND	$0.10	Yageo	CC0603KRX7R9BB103	CAP 10000pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C4	1nF	Digikey 311-1080-1-ND	$0.10	Yageo	CC0603KRX7R9BB102	CAP 1000pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C5	NFM18PS105D0J3D	Digikey 490-13394-2-ND	$0.10	Murata Electronics	NFM18PS105D0J3D	1µF Feed Through Capacitor 6.3V 2A 30mOhm 0603 (1608 Metric), 3 PC Pad	NFM18CC101R1C3D
Capacitors	1	C6	1.5nF	Digikey 311-1184-6-ND	$0.10	Yageo	CC0603KRX7R9BB152	CAP 1500pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C7	0.1uF	Digikey 478-1239-1-ND	$0.12	AVX	0603YC104KAT2A	CAP CERM .1uF 10% 16V X7R 0603	CAPC1608X87
Capacitors	2	C8-C9	1.0u	Digikey 399-3217-1-ND	$0.12	Kemet	C0603C105Z9VACTU	CAP 1uF 6.3V CER Y5V SMD 0603	CAPC1608X87
Capacitors	6	C10-C13,C15-C16	47pF	Digikey 311-1065-1-ND	$0.10	Yageo	CC0603JRNPO9BN470	CAP CERAMIC 47pF 50V NP0 0603	CAPC1608X87
Capacitors	1	C14	10u	Digikey 399-3138-1-ND	$0.14	Kemet	C0805C106K9PACTU	CAP CERAMIC 10uF 6.3V X5R 0805	CAPC2012X100
Resistors	6	R1,R4,R6,R9,R12-F	10.0M	Digikey 311-10.0MCDKR-ND		Yageo	9C08052A1005FKHFT	RES 10.0M OHM 1/8W 1% 0805 (2012 metric) SMD	RESC2012X50
Resistors	3	R2-R3,R8	1M	Digikey P1.0MGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ105V	RES 1.0M OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R5	10.0K	Digikey P10.0KHTR-ND	$0.10	Panasonic - ECG	ERJ-3EKF1002V	RES 10.0K OHM 1/10W 1% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R7	100K	Digikey P100KHTR-ND	$0.10	Panasonic - ECG	ERJ-3EKF1003V	RES 100K OHM 1/10W 1% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R10	360K	Digikey 311-360KHTR-ND		Yageo	9C06031A3603FKHFT	RES 360K OHM 1/10W 1% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	2	R11,R14	180K	Digikey 311-180KGTR-ND		Yageo	9C06031A1803JLHFT	RES 180K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	3	R15,R17,R19	22K	Digikey 311-22KGTR-ND		Yageo	9C06031A2202JLHFT	RES 22K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	3	R16,R18,R24	10K	Digikey P10KGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ103V	RES 10K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	2	R20-R21	470	Digikey 311-470GCT-ND		Yageo	9C06031A4700JLHFT	RES 470 OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R22	1.2M	Digikey P1.2MGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ125V	RES 1.2M OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R23	200K	Digikey 311-200KGCT-ND		Yageo	ERJ-3GEYJ125V	RES 200K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Integrated Circuits	1	U1	AD8232ACPZ-R7-1	Digikey 505-AD8232ACPZ-R7CT-ND	$5.17	Analog Devices	AD8232ACPZ-R7	ANALOG DEVICES - AD8232ACPZ-R7-1 - SIGNAL CONDITIONING	QFN50P400X400X80-21
Diodes	3	D1-D3	BAS40W-04	Digikey BAS40W-04FDICT-ND	$0.34	Diodes Inc.	BAS40W-04-7-F	Schottky - 40.0V 0.200A 5.00ns	SOT23-D9
Diodes	1	D4	LED-RED					Animated LED model (Red)	
Diodes	1	D5	LED-GREEN					Animated LED model (Green)	
Miscellaneous	1	J1	SJ-43514-SMT-TR	Digikey CP-43514SJCT-ND	$1.06	CUI Devices	SJ-43514-SMT-TR	Phone Connectors Audio Jacks	SJ-43514-SMT-TR
Miscellaneous	2	J2-J3	66226-008	Digikey 66226-008-ND		FCI		8 Positions Single row Vertical Pin Connector	CON8_1X8_U_FCI
Miscellaneous	1	RS1	5k					Generic resistor symbol	NULL
Miscellaneous	6	SW1-SW5,SWLC	SW-SPDT					Interactive SPDT Switch (Latched Action)	NULL

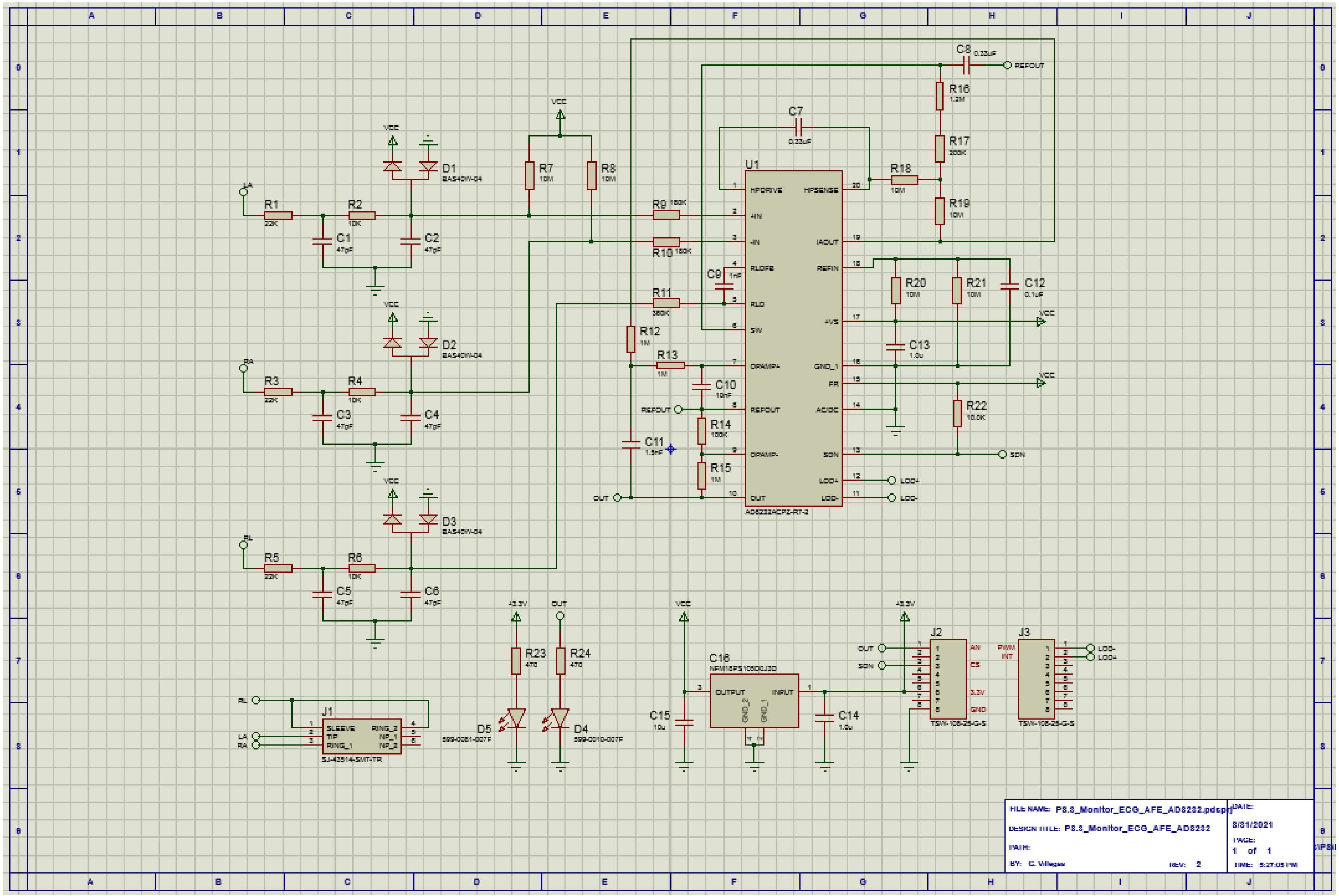
Totals

Category	Quantity	Unit Cost
Modules	0	$0.00
Capacitors	16	$2.42
Resistors	24	$0.90
Integrated Circuits	1	$5.17
Transistors	0	$0.00
Diodes	5	$1.02
Miscellaneous	10	$1.06
Total	**56**	**$10.57**

ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor (based on AFE TI AD8232) Schematic (P8.3)



ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor basado en AFE TI AD8232 BOM (P8.3)

Bill Of Materials for P8_Monitor_ECG_AFE_AD8232

Design Title	P8_Monitor_ECG_AFE_AD8232
Author	G. Villegas
Document Number	2
Revision	2
Design Created	Tuesday, August 31, 2021
Design Last Modified	Tuesday, August 31, 2021
Total Parts In Design	49

Category	Quantity	References	Value	Stock Code	Unit Cost	Manufacturer	Manufacture Part Number	Description	PCB Package
Capacitors	6	C1-C6	47pF	Digikey 311-1065-1-ND	$0.10	Yageo	CC0603JRNPO9BN470	CAP CERAMIC 47pF 50V NP0 0603	CAPC1608X87
Capacitors	2	C7-C8	0.33uF	Digikey 399-4918-2-ND	$0.46	Kemet	C0603C334K9RACTU	CAP CERM .33uF 6.3V X7R 0603	CAPC1608X87
Capacitors	1	C9	1nF	Digikey 311-1080-1-ND	$0.10	Yageo	CC0603KRX7R9BB102	CAP 1000pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C10	10nF	Digikey 311-1085-2-ND	$0.10	Yageo	CC0603KRX7R9BB103	CAP 10000pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C11	1.5nF	Digikey 311-1184-6-ND	$0.10	Yageo	CC0603KRX7R9BB152	CAP 1500pF 50V CERAMIC X7R 0603	CAPC1608X87
Capacitors	1	C12	0.1uF	Digikey 478-1239-1-ND	$0.12	AVX	0603YC104KAT2A	CAP CERM .1uF 10% 16V X7R 0603	CAPC1608X87
Capacitors	2	C13-C14	1.0u	Digikey 399-3217-1-ND	$0.12	Kemet	C0603C105Z9VACTU	CAP 1uF 6.3V CER Y5V SMD 0603	CAPC1608X87
Capacitors	1	C15	10u	Digikey 399-5504-1-ND	$0.32	KEMET	C0603C106M9PACTU	CAPACITOR, 0603 10uF +/-20% 6.3V	CAPC1608X87
Capacitors	1	C16	NFM18PS105D0J3D	Digikey 490-13394-2-ND	$0.10	Murata Electronics	NFM18PS105D0J3D	1µF Feed Through Capacitor 6.3V 2A 30mOhm 0603	NFM18CC101R1C3D
Resistors	3	R1,R3,R5	22K	Digikey 311-22KGRCT-ND	$0.10	Yageo	RC0603JR-0722KL	RES 22K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	3	R2,R4,R6	10K	Digikey P10KGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ103V	RES 10K OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	6	R7-R8,R18-R21	10M	Digikey P10MGCT-ND	$0.10	Yageo	ERJ-3GEYJ106V	RESISTOR, 0603 10M Ohms +/-5% 1/10 W	RESC1608X50A
Resistors	2	R9-R10	180K	Digikey 311-180KGRCT-ND	$0.10	Yageo	RC0603JR-07180KL	RESISTOR, 0603 180K Ohms +/-5% 1/10 W	RESC1608X50A
Resistors	1	R11	360K	Digikey 311-360KHRCT-ND	$0.10	Yageo	RC0603FR-07360KL	RESISTOR, 0603 360K Ohms +/-5% 1/10 W	RESC1608X50A
Resistors	3	R12-R13,R15	1M	Digikey P1.0MGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ105V	RES 1.0M OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R14	100K	Digikey P100KHTR-ND	$0.10	Panasonic - ECG	ERJ-3EKF1003V	RES 100K OHM 1/10W 1% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R16	1.2M	Digikey P1.2MGCT-ND	$0.10	Panasonic - ECG	ERJ-3GEYJ125V	RES 1.2M OHM 1/10W 5% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	1	R17	200K	Digikey 311-200KGRCT-ND	$0.10	Yageo	RC0603JR-07200KL	RESISTOR, 0603 200K Ohms +/-5% 1/10 W	RESC1608X50A
Resistors	1	R22	10.0K	Digikey P10.0KHTR-ND	$0.10	Panasonic - ECG	ERJ-3EKF1002V	RES 10.0K OHM 1/10W 1% 0603 (1608 metric) SMD	RESC1608X50A
Resistors	2	R23-R24	470	Digikey 311-470GRCT-ND	$0.10	Yageo	RC0603JR-07470RL	RESISTOR, 0603 470 Ohms +/-5% 1/10 W	RESC1608X50A
Integrated Circuits	1	U1	AD8232ACPZ-R7-2	AD8232ACPZ-R7TR-ND	$3.82	Analog Devices	AD8232ACPZ-R7	ANALOG DEVICES - ADACPZ-R7 - SIGNAL CONDITIO	QFN50P400X400X80-21
Diodes	3	D1-D3	BAS40W-04	Digikey BAS40W-04FDICT-ND	$0.34	Diodes Inc.	BAS40W-04-7-F	Schottky - 40.0V 0.200A 5.00ns	SOT23-D9
Diodes	1	D4	599-0010-007F	Digikey 350-4346-1-ND	$0.37	Dialight	5990010007F	Standard LEDs - SMD SMD 0603 RED	LEDC1608X90N
Diodes	1	D5	599-0081-007F	Digikey 350-4351-1-ND	$0.61	Dialight	5990081007F	Standard LEDs - SMD SMD 0603 GREEN	LEDC1608X90N
Miscellaneous	1	J1	SJ-43514-SMT-TR	Digikey CP-43514SJCT-ND	$1.06	CUI Devices	SJ-43514-SMT-TR	Phone Connectors Audio Jacks	SJ43514SMTTR
Miscellaneous	2	J2-J3	TSW-108-25-G-S	Digikey TSW-108-25-G-S-ND	$1.40	Samtec Inc.	TSW-108-25-G-S	8 Position, Single Row, Classic PCB Header Strips, 0.1 in pitch	TSW-108-XX-YY-S

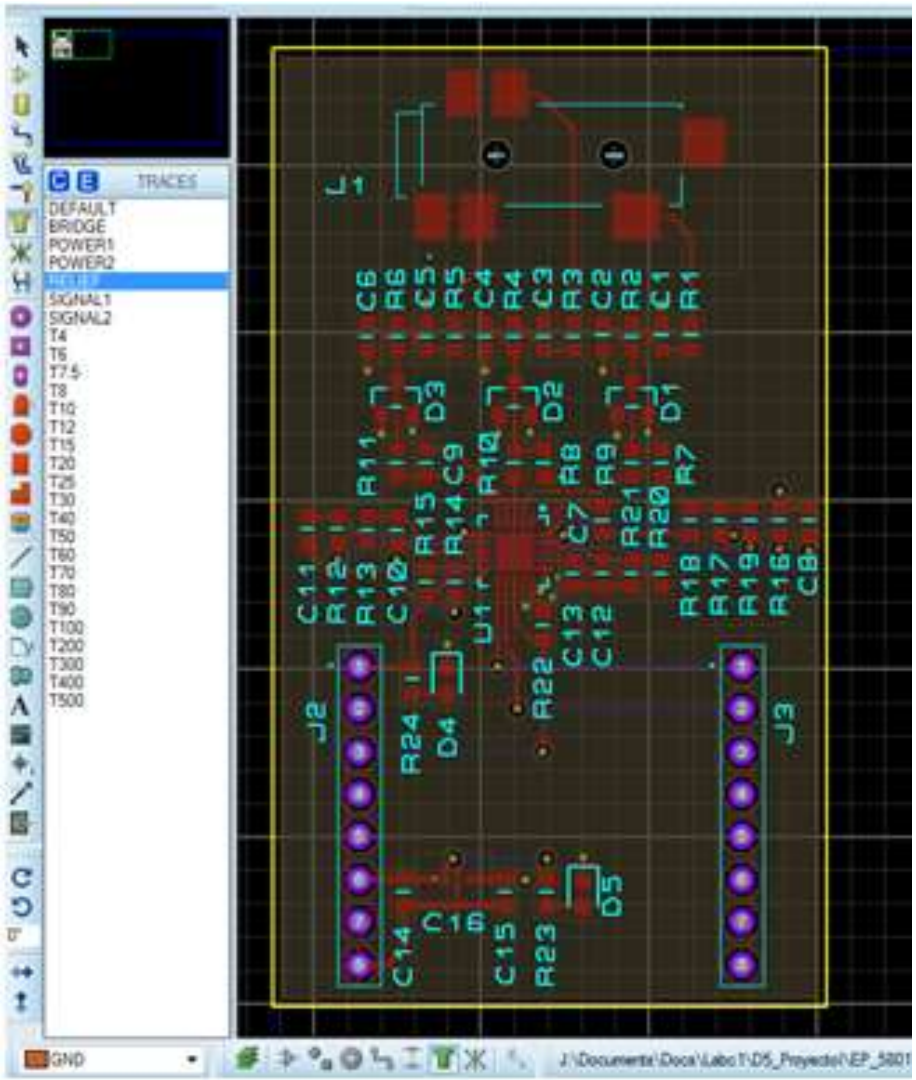
Totals

Category	Quantity	Unit Cost
Modules	0	$0.00
Capacitors	16	$2.60
Resistors	24	$2.40
Integrated Circuits	1	$3.82
Transistors	0	$0.00
Diodes	5	$2.00
Miscellaneous	3	$3.86
Total	**49**	**$14.68**

ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor basado en AFE TI AD8232 PCB Layout



ECG Monitor

Proyecto IIa con Proteus

Single Lead Heart Rate Monitor basado en AFE TI AD8232 3D Model