# Electrocardiogram (ECG) Solutions

## ECG Systems Theory and Typical Architecture

Electrocardiogram (ECG) systems record the electrical activity of the heart over time by measuring electric potentials on the surface of living tissue. A biopotential electrode is used to pick up heart signals from specific locations on the body. The differential voltage between two electrodes, or the differential voltage between one electrode and the average voltage of multiple electrodes, can be measured and displayed as one channel on the ECG printout.

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 frequency, signals from other muscles, and electrical noise. Typically, the AFE includes instrumentation amplifiers (INAs), filtering, and ADCs. There are two kinds of ECG architecture design approaches—ac coupling and dc coupling.

## ECG System Design Considerations and Major Challenges

When designing ECG systems, there are various challenges to overcome, such as safety, common-mode rejection, dc offset, RFI (radio frequency interference)/EMC (electromagnetic compatibility), input protection, and equivalent input noise floor.

- Patient and operator safety relating to isolation from ac mains and sourced or sink current relating to the patient electrode attachment is the first priority. Ensure no path exists for normal or single fault conditions that can create a current to flow in excess of 10 $\mu$A rms through the patient. Ensure dc and low frequency isolation of the patient circuitry through the 10th harmonic of ac mains and beyond. Insure isolation between the patient and earth ground for at least 5000 V.
- Standards require CMRR per specified tests of slightly less than 100 dB. Some clinical use scenarios require 120 dB. Techniques such as "right leg drive" can help reduce the CMRR requirements of the INA, but will not preclude the need for careful overall component and system design.
- The electrodes attached to the skin generate offset voltages that can be as high as ±300 mV. This offset voltage has a big impact on how to measure the signal of interest that is just a couple of mV in amplitude.
- The system must not be compromised by other medical equipment in the immediate vicinity that complies with AAMI, ISO, and IEC standards. The system must also not radiate or "conduct" through ac mains or other "external cables" with emissions that exceed IEC60601-1-2.
- It is necessary to protect the ECG front end system from damage from environmental and man-made transients, such as defibrillator protection and ESD.
- Limits on input noise floor as measured in $\mu$V peak-to-peak over a bandwidth of 0.05 Hz to 150 Hz for a period of 20 seconds or longer is  often a challenge. Various hardware and software techniques are utilized to achieve the required noise floor.

## ECG Functional Block Diagrams

ADI offers a comprehensive portfolio of high performance linear, mixed-signal, MEMS, and digital signal processing technologies for ECG designs. Our data converters, amplifiers, microcontrollers, digital signal processors, MEMS inertial sensors, isolators, and power management products are backed by leading design tools, applications support, and systems expertise.

## Ambulatory/Holter DC Coupled
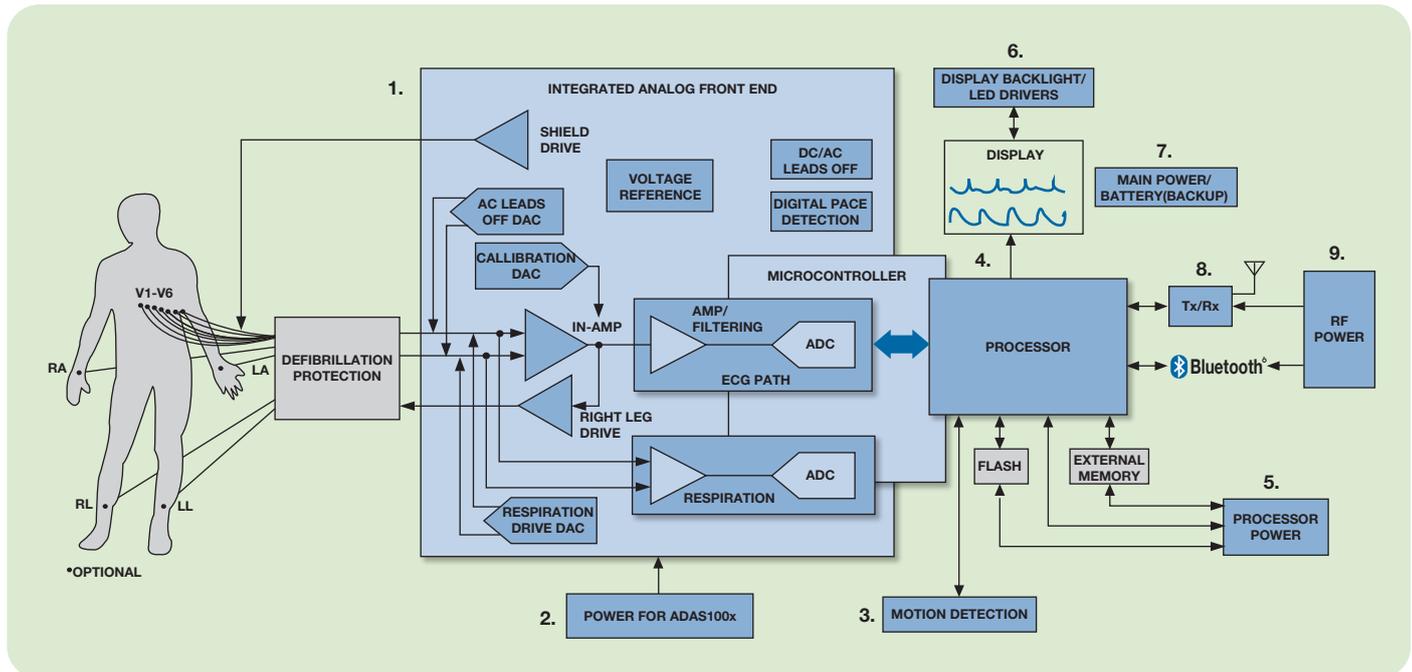


| 1. Integrated AFE | 2. Power for ADAS100x | 3. Motion Detection | 4. Processor | 5. Processor Power | 6. Display Backlight | 7. Main Power/ Battery(Backup) | 8. Tx/Rx | 9. RF Power |
|---|---|---|---|---|---|---|---|---|
| ADAS1000 | ADP121 ADP150 ADP160 | ADXL346 ADXL345 | ADSP-BF523 ADSP-BF524 ADSP-BF526 ADSP-BF527 | ADP2108 ADP2119 ADP12x ADP1707 | ADP5501 ADP5520 ADP8860 ADP8870 | ADP1612 ADP2503 ADP2121 ADP3050 | ADF702x | ADP121 ADP150 |

## Ambulatory/Holter Monitor AC-Coupled
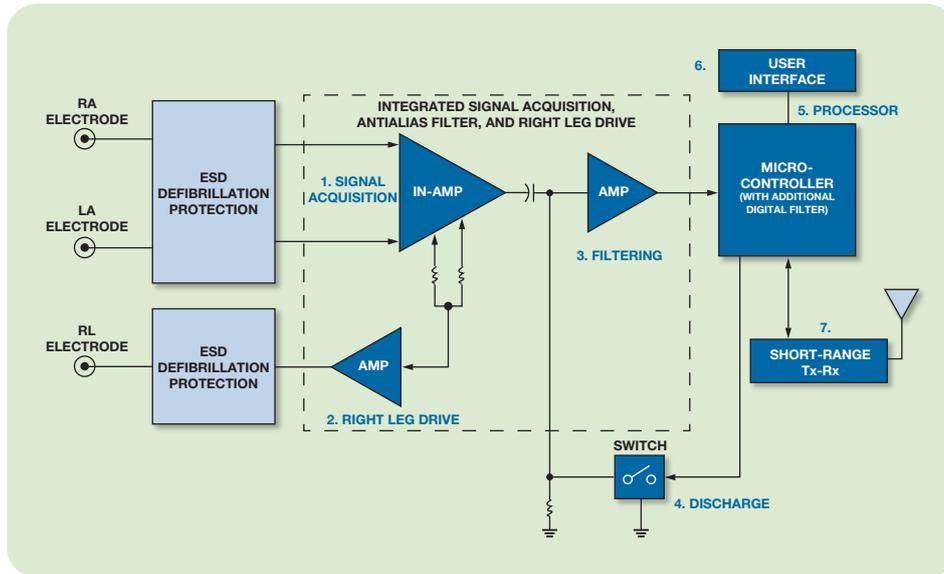


| 1. Signal Acquisition | 2. Right Leg Drive | 3. Filtering | 4. Discharge | 5. Processor | 6. User Interface | 7. Short-Range Tx-Rx |
|---|---|---|---|---|---|---|
| AD822x<br>AD8235<br>AD62x | AD8613<br>AD8538<br>AD8642<br>AD8607 | AD8613<br>AD8539<br>AD8642<br>AD8617 | ADG621<br>ADG721<br>ADG821 | ADUC702x | AD7147 | ADF7020<br>ADF7021<br>ADF7025 |

## Consumer Grade
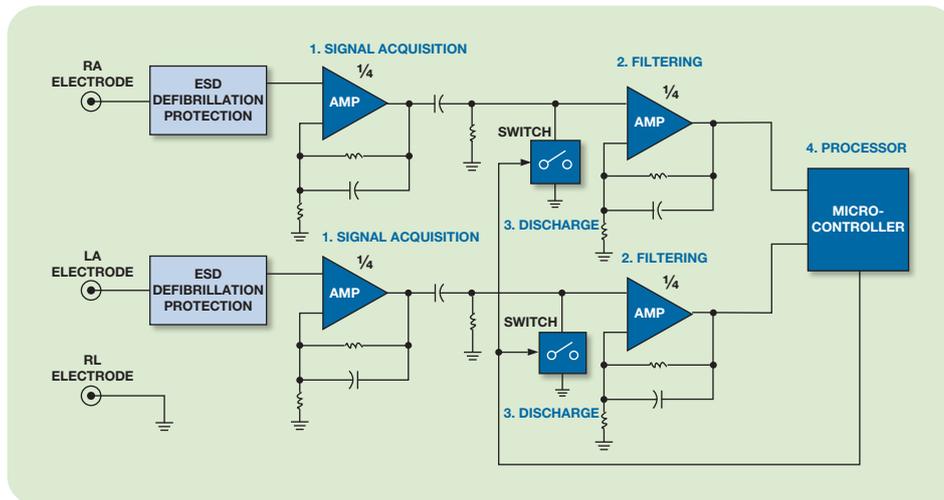


| 1. Signal Acquisition | 2. Filtering | 3. Discharge | 4. Processor |
|---|---|---|---|
| AD8609<br>AD8544<br>AD8508<br>ADA4505-4 | AD8609<br>AD8544<br>AD8508<br>ADA4505-4 | ADG621<br>ADG721<br>ADG821 | ADUC702x |

Notes: The signal chains above are representative of ECG design. The technical requirements of the blocks vary,
but the products listed in the table below are representative of ADI's solutions that meet some of those requirements

## Comparison for AC Coupling and DC Coupling

| Comparison | AC Coupling | DC Coupling |
|---|---|---|
| Signal Chain | INA + Filter + ADC (Low resolution ADC ~12-bit). | INA + ADC (24-bit or 18-bit). |
| Advantages | High gain; low ADC resolution (<16-bit); insensitive to electrode offsets; slow overload recovery. | Simple hardware; lower power consumption; fast overload recovery. |
| Disadvantages | Complex hardware; higher power consumption. | Low gain (only INA); higher ADC resolution (18-bit and higher); complex software (filtering). |

# Monitoring Level 12-Lead ECG Demo System Designed by ADI

## Discrete Components (Signal Chain)
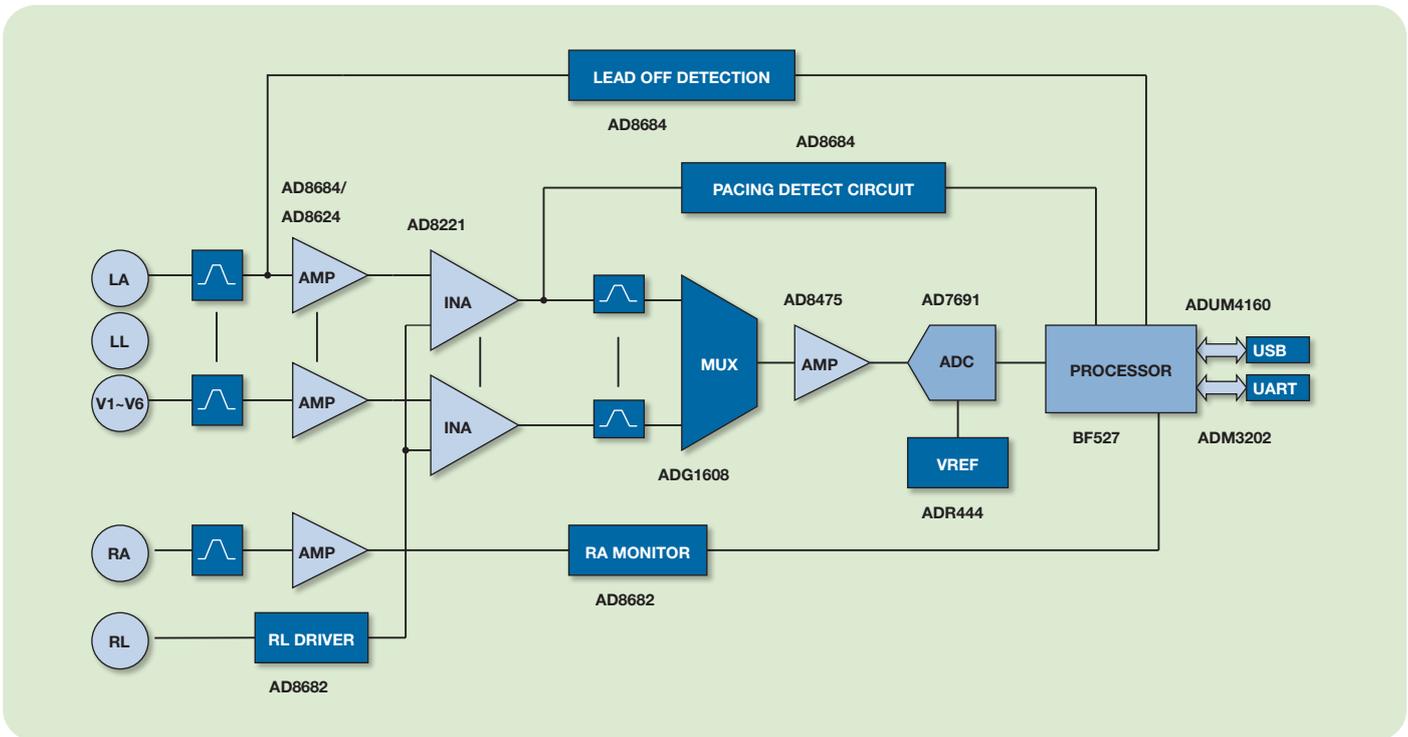


## Discrete Components (Power Supply Chain)
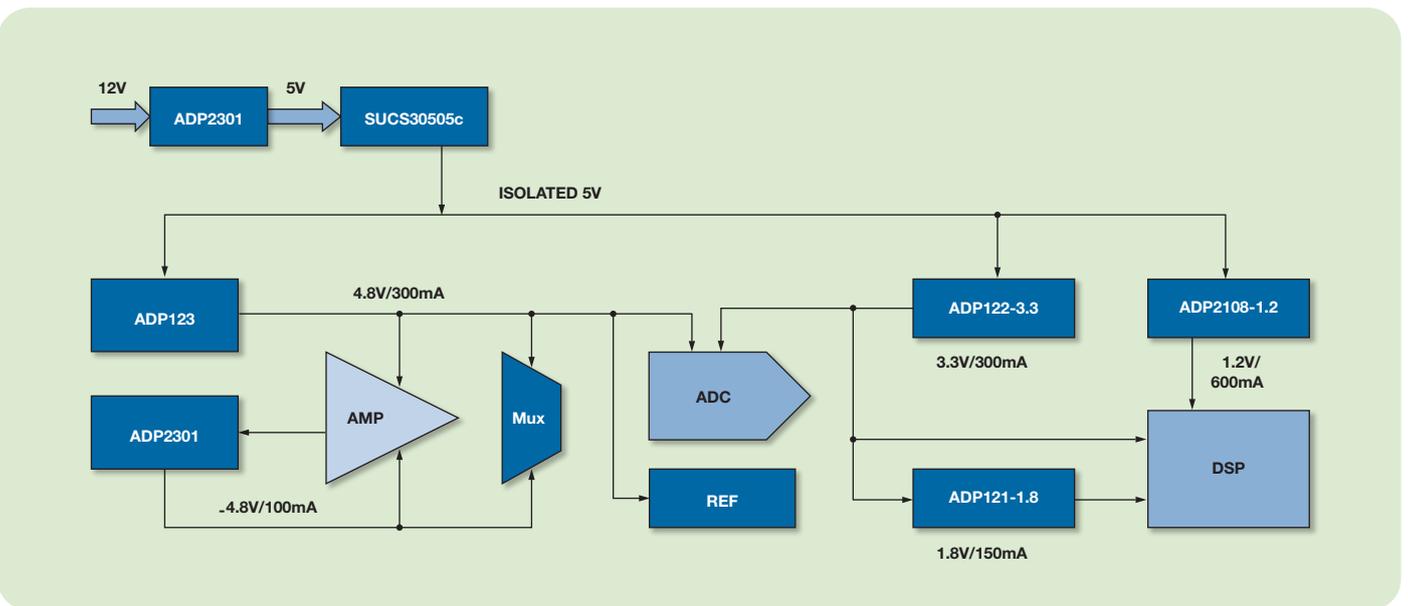


## Safety Considerations

Please do not hook up the circuit to a human being if the board and pc are powered up from the main. If you want to do a real ECG test on a human being, your circuit and PC should be battery operated and not be plugged into ac. The leakage current caused by 50 Hz or 60 Hz leaking to any human hooked to the circuit can kill the person. The current can be very small and still kill. The leakage at 60 Hz that is allowed by the safety standards is 10 μA. In addition, if you hook up your circuit to a human and it is battery operated and then you hook up an oscilloscope to your circuit you will have ac leakage current again to the human.

The recommendation is using a heart simulator instead. The danger of making any medical circuit available to customers is that even if it is battery operated they may hook up an oscilloscope to the circuit, thus grounding the circuit and creating an unsafe situation.

## Introduction of Main Products for ECG

| Part Number | Description | Benefit |
|---|---|---|
| *Analog Front End (AFE)* | | |
| ADAS1000 | Low power, 5-electrode AFE includes all circuitry for right leg drive amplifier, ac and dc leads off detection, and shield drive plus respiration measurement and pacemaker pulse detection on a single chip. Low noise performance of 10 μV peak-to-peak over 0.05 Hz to 150 Hz. Operating power as little as 19 mW. | The chip can be configured to optimize noise performance, power, or data rate—making it suitable for home, ambulatory, and clinical ECG systems. The ADAS1000 simplifies the design of a 5-electrode ECG by reducing active component count from more than 50 components to a single component. |
| *ADC* | | |
| AD7980 | 16-bit, 1 MSPS, 1.5 LSB (24 ppm); PulSAR differential ADC; pin-to-pin compatible with 18-bit version, AD7982. | High speed, high accuracy; pin-to-pin compatibility of series provides flexible selection. |
| AD7690/AD7691 | 18-bit; 1.5 LSB INL; 250 KSPS PulSAR differential ADC; pin-to-pin compatible with 400 KSPS version: AD7690. | Higher resolution, lower INL for high accuracy sampling system. |
| *Amplifiers* | | |
| AD8221/AD8226 | High performance instrumentation amplifier; gain = 1 to 1000, high dc and ac CMRR: 80 dB @ 10 KHz G = 1 (min),100 dB @ G = 10 | High CMMR, unity gain stability improves system performance. |
| ADA4505-4 | 10 μA, rail-to-rail I/O, zero input crossover distortion amplifiers; PSRR: 100 dB minimum; CMRR: 105 dB typical. | Lower power for portable ECG, higher PSRR, CMRR can guarantee the better system performance. |
| AD8235/AD8236 | 40 μA micropower instrumentation amplifier in WLCSP package; 110 dB CMRR; G = 100. | For portable and low power ECG applications, such as heart rate monitors, etc. |
| *Processor* | | |
| ADuC7xxx | Precision analog microcontroller; 12-bit analog I/O; ARM7TDMI MCU; ADUC7124/ADUC7126 (large flash/SRAM, 126 KB/32 KB). | SoC, higher integration with signal besides MCU benefits small size applications; larger memory for data storage. |
| ADSP-BF592 | The ADSP-BF592 is the low cost entry point into the blackfin portfolio of processors; with a 400 MHz core clock speed and a peripheral set. | High data processing capability, flexible peripheral interface, and low cost to reduce BOM cost. |
| ADSP-BF51x | The ADSP-BF51x products are highly integrated system-on-a-chip solutions for the next generation of embedded network connected applications; with a 400 MHz core clock speed and a peripheral set. | Low cost, low power, general-purpose parts with enhanced internet and consumer connectivity. |
| ADSP-BF52x | The ADSP-BF52x family provides good scalability 600 MHz odd numbered and 400 MHz even number product; with rich set of peripherals and connectivity options. | Low power processors that balance the combination of high performance, power efficiency, and system integration to enable highly optimized designs. |
| *Isolator* | | |
| ADuM4160 | Full/low speed 5 kV USB digital Isolator. USB 2.0 compatible; low and full speed: 1.5 Mbps and 12 Mbps IEC 60601-1 medical certification. | Simple USB isolation approach fully compatible with IEC 60601-1 certification. |
| ADuM220x/ ADuM240x | Dual/quad, high isolation voltage: 5000 Vrms; enhanced ESD per IEC 61000-4-x low power operation; 3 V/5 V; high rate: dc to 10 Mbps (NRZ). | Single chip ideally suited for medical applications that require IEC 60601-1-certified isolation to protect patients. |
| ADuM620x | Dual-channel, 5 kV isolators with integrated dc-to-dc converter; 5 V/3.3 V output; up to 400 mW output power; dc-to-25 Mbps (NRZ) speed. | High integration for ease of design and reduced PCB size with lower component count for low BOM cost. |
| *RF/IF ICs* | | |
| ADF702x | High performance ISM and licensed band transceivers. | Allows device to operate in the presence of strong interferers with high sensitivity; low power consumption. |
| *Capacitance to Digital Converter* | | |
| AD7147 | An integrated CDC with on-chip environmental calibration;13 inputs channeled through a switch matrix to a 16-bit, 250 kHz sigma-delta ADC. | High integration for implementing buttons, scroll bars, and wheels. sensor needs one PCB layer for ultrathin systems. |
| *MEMS accelerometer* | | |
| ADXL345/ ADXL346 | Small, thin, ultralow power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*; output is formatted as 16-bit. | Well suited for mobile device applications, such as consumer ECG; low power modes can reduce power consumption. |
| *Power Management* | | |
| ADP2302/ ADP2303 | 2 A/3 A, 700 KHz nonsynchronous step-down dc-to-dc switching regulator wide input voltage range: 3.0 V to 20 V. | Less external components for circuit design with integrated high-side MOSFET and integrated bootstrap diode. |
| ADP122/ADP123 | 5.5 V input, 300 mA, low quiescent current, CMOS LDO. | Low Iq for high accuracy; easy to use. |
| *Mux* | | |
| ADG14xx | Lowest on resistance switches & multiplexers, 4.7 Ω max @ 25°C. | Lowest on resistance guarantees the signal integration and quality. |
| *Voltage Reference* | | |
| ADR444 | Ultralow noise voltage references with current sink and source; 0.15% accuracy and 10 ppm/°c for a grade. | Current sink and source; simple driver circuits; low drift and high accuracy benefit ADC sampling performance. |

**To view additional ECG resources, tools, and product information, please visit:**
**www.analog.com/healthcare/ECG**

**To obtain a sample, please visit:**
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