Electrocardiographs

Overview

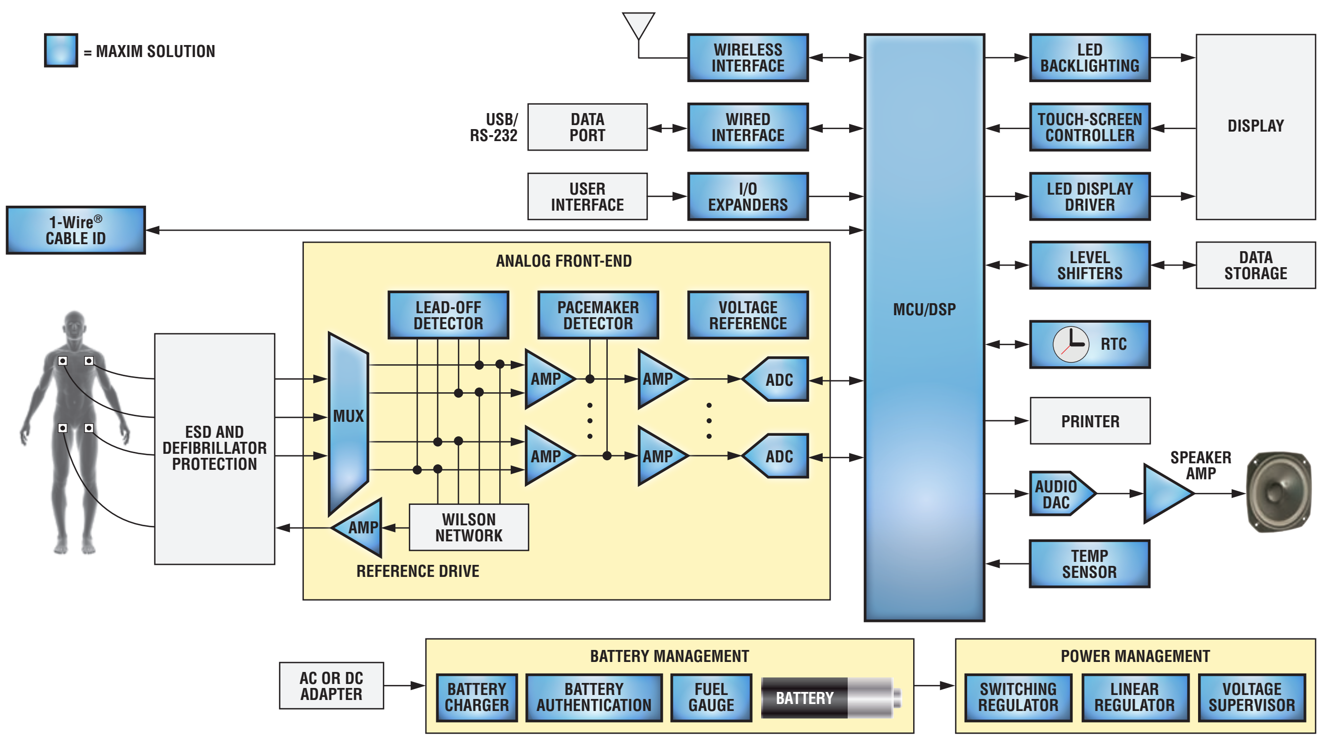
An electrocardiogram (ECG or EKG) is the measurement and graphic representation, with respect to time, of the electrical signals associated with the heart muscles. Applications of an ECG range from monitoring heart rate to the diagnosis of specific heart conditions. The basics of ECG measurement are 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-

Patient monitor showing ECG and pulse oximetry readings.

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



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

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.

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.

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.

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	A	U	A	U	A	S

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

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.

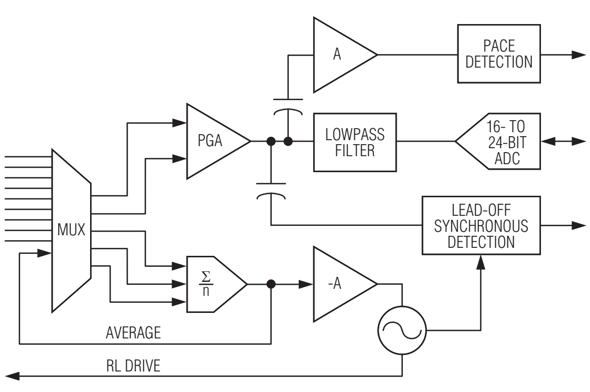
AFE architectures

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.

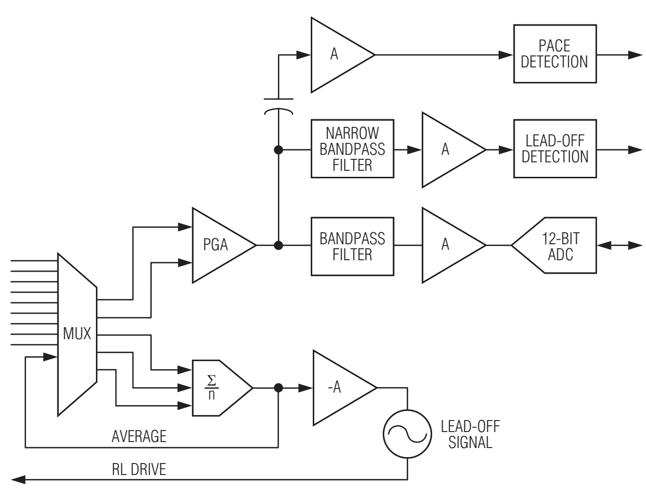
Brute force and DSP AFEs. The measurement requirements of an ECG can be met by using the brute force of powerful ADCs to simultaneously digitize the signals on all nine electrodes to a noise-free resolution of about 20 bits at a rate of 200ksps. A digital signal processor (DSP) can then be used to calculate 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.



DC-coupled, high-resolution ADC



AC-coupled ADC

Types of ECG equipment

Telemetry devices

ECG telemetry systems are used to continuously monitor ambulatory patients in a clinical setting. They consist of an RF-equipped ECG measurement unit worn by the patient and a central RF receiving station that collects and analyzes the data from many patients. Some telemetry systems provide additional data such as blood-oxygen levels. The data is used to verify or alter the effectiveness of treatments and to warn of impending problems.

Many telemetry systems are limited to 5 leads, as full 12-lead ECGs make it difficult for patients to be ambulatory. Patients typically use the device continually for a couple of days. Disposable batteries are frequently used in these devices. Other ECGs are also capable of telemetry, but the term "ECG telemetry" refers specifically to the mobile units worn in a hospital that transmit data to a local receiving station. Key considerations for telemetry system designs are low power, low noise, and small size.

Holter monitors

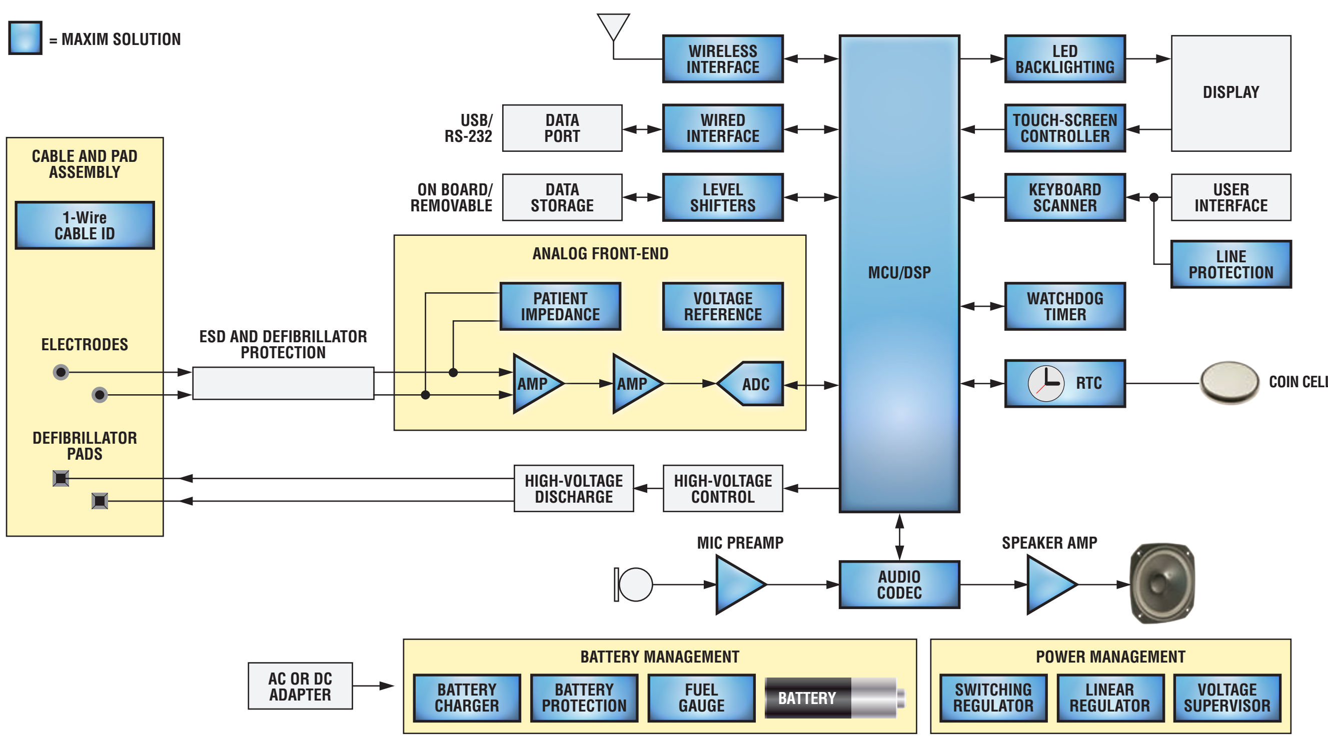
The name Holter comes from Dr. Norman Holter who invented mobile monitors for collecting data that is later uploaded to another system for analysis. Unlike a telemetry unit, these monitors do not require a central receiving station and can be used at home, outdoors, or just about anywhere. Five leads are frequently the maximum for a Holter ECG monitor, since being ambulatory is difficult with a full 12-lead ECG. Data is most commonly retrieved from the monitor by removing the memory card; however, USB and other methods are also used. Most patients need only to be monitored for a day or two. Special long-term monitors are used for patients involved in drug studies—they are used by a single patient for a year or more. Principal concerns for Holter ECG monitor designs are low power, low noise, and small size.

Consumer ECGs

These low-end ECGs easily fit in a hand and are used by people to take their own ECG test at home. The device stores the data, and also displays it on a built-in screen. This data can be transferred to a computer or sent through phone lines to a healthcare provider. Some units have multiple electrodes on wires, while others have two electrodes built into the case. Electrodes in the case can be pressed against the chest, or one hand can be placed on each electrode. The resulting ECG may not be the best quality, but it is a way for people to monitor themselves and to capture data about their heart while they are experiencing an abnormal event. Focal issues for consumer ECG designs are low cost and small size.

Automatic external defibrillators (AEDs)

Intended for emergency use by the untrained public, these devices are frequently seen in public places such as shopping malls, gyms, and offices.



Functional block diagram for an AED device. For a list of Maxim's recommended solutions for an AED design, please go to: www.maxim-ic.com/ECG.

They are used immediately after, or during, a heart attack to jump-start the heart and restore its natural rhythm by delivering a high-energy electric pulse to the chest. This pulse can also kill if delivered at the wrong time; ECG functionality is needed to ensure that this does not happen. AEDs typically have one lead and pick up the heart signal through the same pair of electrodes that deliver the high-energy pulse to the chest.

An AED could sit for months or years without use, and then be used by untrained personnel who are not likely to recognize a problem if one existed. When the system is needed, it must turn on, do a thorough self-check to verify that everything is working perfectly, and then operate for a relatively short period of time. All of the ECG data, as well as the defibrillation information, must be recorded for later analysis. Using a defective AED could do more harm than good. Therefore, reliability and self-diagnostics are essential considerations for AED designs.

Diagnostic ECGs

These machines are used in hospitals and doctors' offices to perform high-quality ECG tests. They are capable of performing a full 12-lead ECG test and creating a hard-copy printout. These units use a high-performance AFE that typically has options for gain adjustment and selection of various filters to improve the quality of the ECG measurements. Being larger and less portable, these machines have room for more features, such as built-in printers, multiple communication ports, and large display screens. These devices are line powered, but usually include a rechargeable backup battery. Key considerations for diagnostic ECG designers are low noise, interference rejection, and flexibility.

Patient monitors

These machines monitor vital signs (pulse rate, respiration rate, blood pressure, and temperature). In addition, they may include ECG functionality, as well as monitor blood oxygen and carbon dioxide levels. Integrating all of these functions into one unit helps unclutter the operating room and simplifies the process of moving the patient from room to room without disconnecting the monitoring equipment.

The AFE used for patient monitors is similar to the AFE used in a diagnostic ECG, but must meet RF-rejection requirements—these machines are used during surgery and can receive strong RF signals from electrocautery knives and argon plasma coagulation (APC) equipment. Rapid recovery from a defibrillation event is also essential.

Patient monitors are line powered but have battery backup, which makes power consumption an important issue. The cases must be splash proof and easily cleanable. This precludes cooling vents, thereby making power dissipation a consideration. Along with power consumption and dissipation, key considerations for patient monitor designs are RF immunity and low noise.

Common features of various ECG applications

Features	Telemetry	Holter	Consumer	AED	Diagnostic	Patient Monitor
Power						
Line	N	N	N	N	A	A
Rechargeable	S	S	S	S	U	A
Disposable	U	U	U	U	S	S
Communication						
RF	A	S	S	S	S	S
RS-232/RS-485	N	S	S	S	S	S
Ethernet	S	S	S	S	S	S
USB	N	S	S	S	S	S
Modem	N	S	S	S	S	S
Data card	N	U	S	S	S	S
Graphic display	S	U	A	S	S	A
Printer	N	N	N	N	A	S

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

www.maxim-ic.com/ECG

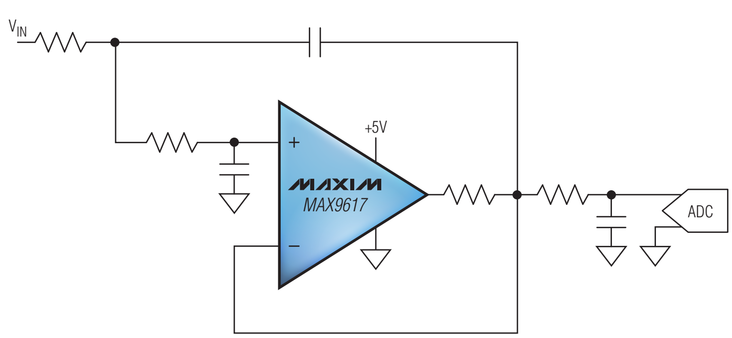
Accurate op amps in SC70 packages save space to accommodate more channels in compact ECG equipment

MAX9617–MAX9620

The MAX9617–MAX9620 are precision op amps with rail-to-rail inputs and outputs. These devices have a low 10µV (max) input offset voltage that hardly drifts over temperature and time due to the self-correcting nature of the on-chip, input offset-voltage-correcting autozero circuitry. The MAX9617–MAX9620 have a large 1.5MHz gain bandwidth (GBW) for good stopband attenuation, while consuming just 59µA of supply current. They operate over a wide 1.6V to 5.5V operating voltage and are available in tiny 2mm x 2.1mm, 6-pin and 8-pin SC70 packages. All devices are specified over the -40°C to +125°C operating temperature range.

Benefits

- **Precision signal processing for high performance**
  - Ultra-low, 10µV (max) input offset voltage
  - Autozero circuitry reduces 1/f noise and temperature drift
  - Low, 10pA input bias current due to CMOS input
  - Large 1.5MHz bandwidth provides good stopband attenuation
- **Extends battery life by reducing power consumption**
  - Consumes just 59µA of supply current
  - Shutdown pin available
  - Able to operate from a low 1.6V voltage rail
- **Saves space in multichannel designs**
  - Single- and dual-channel versions available in 2mm x 2.1mm SC70



Typical application circuit: Sallen-Key active lowpass filter

Zero-drift, low input offset-voltage instrumentation amplifiers save space and cost

MAX4208/MAX4209

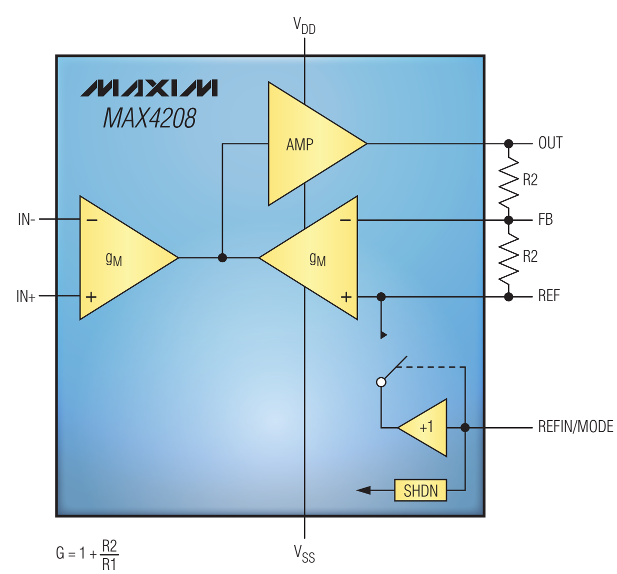
The MAX4208/MAX4209 are precision, CMOS-input instrumentation amplifiers that combine a patented spread-spectrum chopping technique* with a novel, also patented, indirect current-feedback architecture.** This continuous, self-correcting, autozeroing and chopping technique reduces input offset voltage to just 20µV (max), while minimizing drift over temperature and time.

The indirect current-feedback architecture extends the input common-mode voltage range of these amplifiers to below ground, unlike amplifiers using the three-op-amp type of architecture. This feature allows the instrumentation amplifiers to operate from a single-supply voltage rail, eliminating the need for a negative voltage rail, thus reducing space, power, and cost. Also unlike three-op-amp instrumentation amplifiers, an internal REF buffer allows the use of simple resistor-dividers to drive the reference pin. The MAX4208/MAX4209 are available in a small, 3mm x 5mm, 8-pin µMAX® package and are specified over the -40°C to +125°C temperature range.

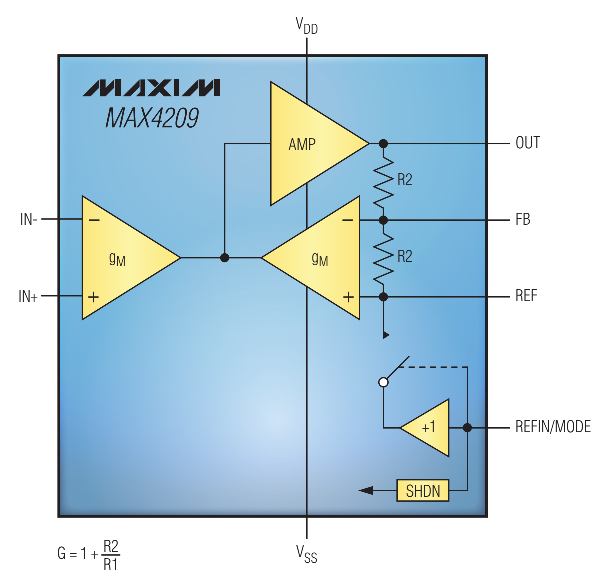
Awarded Product of the Year: Most Innovative Instrumentation Amplifiers by EN-Genius Network in 2008

Benefits

- **Precision signal processing for excellent performance**
  - Ultra-low 20µV (max) input offset voltage
  - Autozeroing circuitry eliminates 1/f noise and temperature drift
  - Low input bias currents due to CMOS inputs
- **Reduces cost and saves space when compared to three-op-amp implementations**
  - Operate from a single-supply voltage rail, thereby needing no negative voltage rail
  - Uses only simple external resistor-dividers to drive reference pin due to internal REF buffer (MAX4208)
  - Internal matched resistors eliminate need for precision resistor packs (MAX4209)
  - Combines the equivalent of four precision op amps in a single 3mm x 5mm µMAX package



MAX4208 functional diagram



MAX4209 functional diagram

*U.S. Patent #6,847,257.
**U.S. Patent #6,559,720.

Recommended solutions

Part	Description	Features	Benefits
1-Wire memory ICs			
DS2502	1-Wire, 1024-bit, one-time-programmable (OTP) EPROM	Single dedicated contact operation; programmable data protection; ±8kV Human Body Model (HBM) ESD protection	Simplifies design by requiring only minimal contact to add nonvolatile memory for ID, calibration, or authentication
DS28E01-100/ E02*	1-Wire, 1024-bit EEPROM with SHA-1 authentication	Single dedicated contact operation; SHA-1 secure authentication and data protection; 1.8V operation (DS28E02); ±8kV (Contact Discharge)/±15kV (Air-Gap Discharge) IEC 1000-4-2 Level 4 ESD protection	Ensures that consumables are OEM with crypto-strong SHA-1 authentication increases reliability
DS2431	1-Wire, 1024-bit EEPROM	Single dedicated contact operation; programmable data protection; ±8kV (Contact Discharge)/±15kV (Air-Gap Discharge) IEC 1000-4-2 Level 4 ESD protection	High-ESD protection typically eliminates need to add protection to sensor, thus saving cost and space
Amplifiers			
MAX9617–20	High-efficiency, 1.5MHz op amps with rail-to-rail inputs and outputs	10µV (max) V_{OS} with near zero (5nV°/C, typ) drift; 0.42µV_{P-P} noise; 59µA quiescent current; tiny, 2mm x 2mm SC70	Low drift improves measurement accuracy and reduces calibration requirements
MAX4238	Single, 2µV (max), low-drift, 1MHz op amp in SOT23	Low 10nV/°C (typ) V_{OS} drift; low-charge-injection, self-correcting V_{OS} circuitry	Ultra-low V_{OS} and V_{OS} drift amplify small signals precisely, improving quality of signal capture
MAX4208/09	Ultra-low-offset/drift, precision instrumentation amplifiers with REF buffer	±20µV (max) input V_{OS}; ultra-low 0.2µV/°C drift; 1pA input bias current; 1.4µA shutdown current; fixed and programmable gain versions available; ground-sensing input	Near-ground sensing simplifies design; ultra-low offset/drift ensures accuracy
MAX4194–97	Micropower, three-op-amp instrumentation amplifiers	450µV (max) V_{OS}; 93µA quiescent current; adjustable and fixed (1, 10, 100V/V) gain versions; shutdown mode	Shutdown function and low-current operation save power, thereby extending battery life
Audio ICs			
Audio codecs			
MAX9851/53	Stereo audio codecs with flexible input selection and multiple audio outputs	1.7V to 3.3V digital supply voltage; 2.6V to 3.3V analog supply voltage; 26mW playback power; accepts up to two inputs at different sample rates; microphone, DirectDrive® headphones, speaker amplifiers, and/or stereo line outputs	Flexible solution simplifies audio design
MAX9867	Ultra-low-power, stereo audio codec	1.65V to 1.95V supply voltage; 1.65V to 3.6V digital I/O supply voltage; 6.7mW playback power consumption; battery measurement auxiliary ADC; < 6mm^2 footprint	6.7mW playback extends battery life; super-small footprint enables smallest design
Audio DACs			
MAX9850	Stereo audio DAC with DirectDrive headphone amplifier	Integrated volume control; 1.8V to 3.6V supply voltage; clickless/popless operation	DirectDrive architecture allows elimination of DC-blocking capacitors, which saves board space
Microphone preamplifiers			
MAX4060–62	Differential microphone preamplifiers with internal bias and complete shutdown	2.4V to 5.5V supply voltage; adjustable or fixed-gain options; low input noise; 300nA shutdown; 0.04% THD+N; 3mm x 3mm TQFN	Shutdown and low supply voltage operation extend battery life
Speaker amplifiers			
MAX9700	Mono, 1.2W, Class D audio amplifier	Up to 94% efficiency, filterless operation; 1.5mm x 2mm UCSP™	High efficiency extends battery life; small package minimizes solution size and saves space

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Battery-management ICs			
Fuel gauges			
MAX17043*	Low-cost, I²C fuel-gauge IC	ModelGauge™ algorithm for calculating battery capacity relative state of charge (RSOC) in quick-start mode; small, 2mm x 3mm footprint; low-battery alert	Allows system µC to remain in sleep mode for a longer period of time, thus saving power; quick-start mode decreases cost (needs no current-sense resistor), reduces supply-chain constraints on battery
DS2782	Stand-alone fuel-gauge IC	1-cell Li+ battery fuel gauge; FuelPack™ algorithm with precision voltage, current, and temperature monitoring; I²C interface; EEPROM storage	Stand-alone solution needs no host-side fuel-gauging algorithms, thus simplifying software development
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel-gauge IC; 8-bit RISC microcontroller (µC) core; integrated primary-protection features	High integration reduces development time and design complexity for highly accurate sophisticated designs
Comparators			
MAX9060–64	Ultra-low-power (sub-1µA) single comparators in space-saving UCSP package	50nA/400nA supply current; internal 0.2V reference (MAX9062–MAX9064)	Saves space and power in lead-off detection, pace-maker detection, and voltage-rail-monitoring applications
Analog-to-digital converters			
MAX1162	16-bit, 200ksps SAR ADC with serial interface and 10µA shutdown	16-bit resolution; 1 channel; 10µA shutdown; 3mm x 5mm, 10-pin µMAX	Low 12.5mW power dissipation preserves battery life; tiny µMAX package saves space
MAX1167/68	Multichannel, 16-bit, 200ksps SAR ADCs with serial interface	16-bit resolution, no missing codes; 4-/8-channel input mux; 4.096 reference	Integrated mux saves board space and reduces cost; internal reference saves board space
MAX1300*/01	16-bit, 115ksps SAR ADCs with serial interface	16-bit resolution; 8/4 single-ended or 4/2 differential software-programmable analog inputs	Software-programmable input ranges reduce design time; ±16.5V analog input overvoltage protection (OVP) allows elimination of external circuitry to save space
MAX1132	16-bit, 200ksps SAR ADC with serial interface and reference	1 channel; 0 to 12V or ±12V input; 4.096V reference	16-bit resolution with no missing codes allows high precision for wide input-voltage ranges; internal reference saves space and reduces cost
Display ICs			
LED backlight drivers			
MAX1574	180mA, 1x/2x, white-LED (WLED) charge pump in 3mm x 3mm TDFN	Up to 3 LEDs, up to 60mA/LED; 5% to 100% dimming through a single wire; 100nA shutdown current; soft-start limits inrush current	Integrated dimming saves space by eliminating the need for external/additional components
MAX1984–86	Ultra-efficient WLED drivers	1 to 8 LEDs; selectively enable LEDs; switching topology; open-LED detection; up to 95% efficiency	Open-LED detection increases reliability
MAX8630	125mA, 1x/1.5x charge pumps for 5 WLEDs in 3mm x 3mm TDFN	Up to 93% efficiency; PWM dimming; factory-trimmed, full-scale LED current options	Integrated derating function protects LEDs from overheating, thus increasing reliability
LED display drivers			
MAX6950/51	Serially interfaced, +2.7V to +5.5V, 5-/8-digit LED display drivers	Slew-rate-limited drivers for low EMI; blinking control; PWM dimming; small, 16-pin QSOP	Reduces system cost by offloading display control from host to allow a simpler MCU
MAX6978/79	8-/16-port LED drivers with fault detection and watchdog	8/16 constant-current LED outputs, up to 55mA per output; ±3% current matching between outputs; serial interface; reports open-circuit LED faults	Meets self-test requirements for displays in medical devices, thus speeding design approval

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
Touch-screen controllers			
MAX11800–03	Low-power, ultra-small resistive touch-screen controllers with I^2C/SPI™ interface	4-wire touch-screen interface; 12-bit SAR ADC; 5:1 multiplexer; 1.7V to 3.6V supply voltage; direct and autonomous modes; 1.6mm x 2.1mm WLP; digital preprocessing; data tagging and filtering	Small, highly integrated solution reduces design size and cost; digital processing reduces bus loading of applications processor
MAX11811	4-wire touch-screen controller with integrated haptic motor driver	12-bit ADC; I^2C interface; proximity driver; automatic power-down; direct or autonomous mode	Autonomous mode reduces processor burden; automatic power-down extends battery life
MAX1233/34	±15kV ESD-protected touch-screen controllers include DAC and keypad controller	4-wire touch-screen interface; 12-bit SAR ADC; 10MHz SPI interface; keypad controller; low power (6μA at 1ksps, 0.3μA shutdown current)	Combines touch-screen and keypad controllers to simplify design and save board space; low power consumption extends battery life
Interface ICs			
I/O expanders			
MAX7318	2-wire, 16-bit, I/O port expander with interrupt and hot-insertion protection	Bus timeout; 2.0V to 5.5V	Lock-up free operation improves reliability; lower supply voltage simplifies design
MAX7328/29	I^2C port expanders with 8 I/O ports	2.5V to 5.5V operation; address up to 16 devices with 100kHz I^2C interface; 10μA quiescent current	Increases number of available port pins without needing a more costly μC
Logic-level translators			
MAX13030E	6-channel, high-speed logic-level translator	100Mbps (max) data rate; bidirectional; ±15kV HBM ESD protection on I/O V_{CC} lines; 2mm x 2mm UCSP	ESD-protected level shifting enables high-speed data rates
MAX13101E	16-channel logic-level translator	20Mbps (max) data rate; bidirectional; ±15kV HBM ESD protection on I/O V_{CC} lines; 3mm x 3mm WLP	Integrates level translation with ESD protection in a space-saving package
USB transceivers			
MAX3349E	USB transceiver with UART multiplexer	USB compliant, operates at 12Mbps; integrated ESD on D+/D- lines	ESD protection increases reliability; USB and UART share a connector to save space
MAX13481E–83E	±15kV ESD-protected USB transceivers with external/internal pullup resistors	USB compliant, operates at 12Mbps; integrated ESD on D+ and D- lines; 1.6V to 3.6V logic supply voltage	Needs no interface chip (compatible with low-voltage ASICs and ASSPs), thereby saving space and reducing cost
RS-232 drivers/receivers			
MAX3221E/23E/43E	±15kV ESD-protected, RS-232 transceivers with AutoShutdown™	1/1, 2/2, and 3/5 driver/receiver options	AutoShutdown functionality extends battery life without changes to existing basic input/output system (BIOS) or operating system (OS)
MAX3224E–27E/44E/45E	±15kV ESD-protected, 1μA, RS-232 transceivers with AutoShutdown Plus™	1/1, 2/2, and 3/5 driver/receiver options; 3.3V or 5V supply voltage options; 1Mbps (MAX3225E/27E/45E)	ESD protection increases reliability; small solution can be located on main board or in cable; saves power without changes to existing BIOS or OS
ESD/line protection			
MAX3202E/03E/04E/06E	Low-capacitance, 2-/3-/4-/6-channel, ±15kV ESD-protection arrays	5pF input capacitance; 1nA input leakage current; 1nA supply current; footprint as small as 1mm x 1mm	Easily add (and comply with) IEC 61000-4-2 ESD protection to any design
MAX3205E/07E/08E	Low-capacitance, 2-/4-/6-channel, ±15kV ESD-protection arrays with TVS	2pF input capacitance; transient voltage suppressor (TVS)	Increase reliability by protecting high-data-rate interfaces
MAX9940	2.2V to 5.5V, signal-line overvoltage protector	Small, 5.3mm² SC70; low, 13μA supply current; ±4kV (Contact Discharge) IEC 61000-4 ESD protection	Protects low-voltage circuitry from high-voltage faults, thereby improving reliability

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Keyboard scanners			
MAX7359	2-wire, low-EMI key-switch controller/ general-purpose output (GPO)	1.62V to 3.6V operation; monitors up to 64 keys; key debounce; key-release detection; 6 key-switch outputs + 1 INT pin can be used as GPOs	GPOs free up µC I/O; key monitoring reduces software complexity to minimize total system cost
Microcontrollers			
MAXQ2010	16-bit mixed-signal µC with LCD interface	8-channel, 12-bit SAR ADC; 64KB of flash memory; supply-voltage monitor; hardware multiplier; 160-segment LCD controller; 370nA stop-mode current; DC to 10MHz operation, approaching 1MIPS/MHz	Powerful, highly integrated µC saves space in battery-powered applications
MAXQ8913	16-bit, mixed-signal µC	7-channel, 12-bit SAR ADC; 64KB of flash memory; two 10-bit DACs; two 8-bit DACs; four op amps; temp sensor; two current sinks	Integrates multiple functions to minimize solution size
MAXQ612/22	16-bit µCs with infrared (IR) module and optional USB	1.7V to 3.6V supply range; 128KB of flash memory; USB transceiver (MAXQ622); 1 I^2C, 2 SPI, and 2 USART ports; up to 52 GPIOs; low power in stop mode (0.3µA, typ) and at 12MHz (4.8mA, typ)	Low power consumption provides extended battery life; USB port provides easy data transfer from portable device
Power-management ICs			
Linear regulators			
MAX8556	Ultra-low-input-voltage LDO regulator	1.425V to 3.6V input voltage; 4A output current; short-circuit current foldback protection	High-current regulator with short-circuit protection provides robust design
Switching regulators			
MAX5072	Dual-output buck or boost converter	2.2MHz; power-on reset (POR); power-fail output (PFO)	High frequency, 180° out-of-phase outputs, and internal FETs eliminate external components to reduce total solution size
MAX1951	1MHz, all-ceramic, 2.6V to 5.5V input, step-down DC-to-DC regulator	Up to 2A output; internal FET	Internal switch minimizes EMI, reduces board space, and provides higher reliability by minimizing external components
Voltage references			
MAX6034	Precision, micropower, series voltage reference in small SC70	±0.2% accuracy; 30ppm/°C; 90µA quiescent current; 2.048V to 4.096V V_{OUT}	Small SC70 package eases layout and saves board space
MAX6029	Ultra-low-power, precision series voltage reference	Ultra-low 5.25µA supply current; 30ppm/°C tempco; internal compensation capacitor for stability with capacitive loads up to 10µF	Ultra-low operating current saves power to extend battery life; stability over temperature increases reliability and eliminates the need for an external capacitor
MAX6173	Wide supply-voltage range, high-precision voltage reference with temperature sensor	(V_{OUT} + 2V) to +40V supply voltage; excellent temperature stability: 3ppm/°C (max) with capacitive loads up to 100µF; low noise: 3.8µV_{P-P}; ±0.06% initial accuracy	Low noise helps meet system noise budget; stability eliminates need for output bypass capacitor, thus saving board space
Voltage supervisors			
MAX6443–52	Single/dual microprocessor (µP) reset circuits with manual-reset inputs	Two manual-reset inputs with extended setup period (6.72s) can be connected to front-panel switches; precision voltage monitoring down to 0.63V	Precision voltage monitoring prevents short switch closures (nuisance resets); front-panel switch connection eliminates the need for a pinhole in the equipment case
MAX6746–53	µP-reset circuits with capacitor-adjustable reset/watchdog timeout delay	Capacitor-adjustable timing; 3.7µA quiescent current	Integrated, easy-to-use solution saves space and simplifies design

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Recommended solutions *(continued)*

Part	Description	Features	Benefits
Voltage supervisors (continued)			
MAX16056–59	Ultra-low-power supervisory ICs with watchdog timer	125nA supply current; capacitor-adjustable timing	Save power and battery life—use one IC across multiple applications due to adjustable timeouts
MAX16060–62	Quad/hex/octal-voltage µP supervisors	Fixed and adjustable thresholds and timeouts; margin-enable and tolerance-select inputs; watchdog timer	Breadth of features and options provides flexibility to meet many design needs
MAX16072–74	µP supervisory circuits in chip-scale package	1mm x 1mm UCSP; ultra-low, 0.7µA supply current	Small package saves space; low-power operation extends battery life
Temperature sensors			
DS75LV	Low-voltage, ±2.0°C accurate digital thermometer and thermostat	±2°C accuracy from -25°C to +100°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout simplifies migration from LM75 to lower supply voltage
DS7505	Low-voltage, ±0.5°C accurate digital thermometer and thermostat	±0.5°C accuracy from 0°C to +70°C; 1.7V to 3.7V operation; industry-standard pinout and registers	Industry-standard pinout allows easy accuracy upgrade and supply-voltage reduction from LM75
MAX6612	Small, low-power, analog temperature sensor	19.5mV/°C slope; ±3°C accuracy from 0°C to +70°C; SC70 package; 35µA (max) quiescent current	Small, low-power solution saves board space and extends battery life
Watchdog timers			
MAX6814	5-pin watchdog timer circuit	4µA operating current; 1.6s timeout; 140ms watchdog output (WDO) pulse period; push-pull active-low output	Increases safety and reliability by monitoring for and alerting the system of software code execution errors
MAX6369–74	Pin-selectable watchdog timers	Pin-selectable timeout periods and startup delays; disable feature; open-drain or push-pull active-low options	Increases safety and reliability by monitoring for and alerting the system of software code execution errors
Wireless transceivers			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier	ISM band operation; integrates all RF transceiver circuitry; on-chip monolithic filters (Rx and Tx)	Saves space by eliminating the need for an external SAW filter
MAX2831	2.4GHz to 2.5GHz, 802.11g RF transceiver with integrated PA	IEEE® 802.11g/b compatible; complete RF transceiver, PA, PLL, and crystal oscillator	High level of integration reduces BOM cost and eases implementation
MAX2829	Dual-band, 802.11a/b/g RF transceiver	Designed specifically for OFDM 802.11a/b/g WLAN; supports 2.4GHz and 5GHz bands; integrates all RF transceiver circuitry	High level of integration reduces BOM cost and eases implementation

For a list of Maxim's recommended solutions for an ECG design, please go to www.maxim-ic.com/ECG.