

Low-Power, Low-Voltage IC Choices for ECG System Requirements

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ECG Measurement from a Historical Perspective:

Electrophysical measurements have been made on humans and animals since Luigi Galvani first reported on his frog experiments in 1786. Electrocardiographic (ECG) measurements were first performed by a Dutch physician, William Einthoven, early in the 20th century. Electrocardiography refers to a commonly used noninvasive electrophysical measurement procedure for measuring, recording, and subsequently interpreting the electrical potentials that traverse the heart.

Electrodes are placed on the skin to obtain the signals of interest. Early researchers chose the hands and feet as sites for electrodes, simply immersing these extremities in buckets of salt water, from which wires were connected to a galvanometer. Subsequent research showed that metal electrodes attached to the wrists and ankles using conductive pastes obtained similar signals somewhat more conveniently.

But the equipment used at first was extremely crude, provided only basic information, with little or no storage capability and no internal diagnostic capability. Yet to come into use were the oscillograph, the vacuum-tube (and subsequently transistor- and integrated-circuit) amplifier, and the microprocessor.

The ECG Market: Today, ECG measurements are just a piece of the complete patient-monitoring system. Other *in vivo* bioelectric measurements include body temperature, blood pressure, blood glucose and blood oxygen levels, etc., as well as a host of off-line measurements on laboratory samples.

Today's equipment is safer and more accurate, with more internal diagnostic capability and able to operate at low voltage with battery

power—hence safe and portable.

Low-power/Low-voltage signal-processing ICs in ECG Systems: The first ambulatory monitoring system introduced in the U.S. over 50 years ago weighed about 50 lbs. Today's ECG systems pose but a small fraction of that weight, operate from lower voltages, and consume much less power.

Many factors drive the use of low voltage and low power for patient monitoring equipment—and consequently for low-power high-precision IC components. One of these factors is the continuing use of batteries, which have been used for decades in Holter, portable or ambulatory ECG systems. The use of low-voltage batteries as the only power source ensures that the patient (as well as the equipment) isn't exposed to "hot" line voltages under fault conditions. In addition, ambulatory ECG monitoring specifications call for 24-hour continuous recording capability; so low-power ICs are essential to maintain extended battery life.

Another driving force of increasing importance impacting on ICs for health care is the market's demand for additional functionality without increasing space, power, or cost.

Portable Computer and Communications Markets: Significant developments in other markets have helped provide the kinds of ICs that the medical market needs but could not support by itself. First, the explosive growth within the computer and communications markets has resulted in increased integration and decreased power consumption of semiconductors for signal processing (analog, digital, and mixed-signal). Second, similar growth within the portable consumer equipment markets has inspired a huge demand for ICs to work on single-supply voltages as low as 3.0 V, and for power-management ICs (i.e., highly efficient dc-to-dc converters and supervisory products for microprocessors). Third, long-life rechargeable batteries are now readily available. These changes have driven manufacturing volume of ICs up—and cost and power requirements down, with the benefits now enjoyed by designers for all low-power, low-voltage markets, including patient monitoring/ECG.

ECG Equipment Architectures: In multichannel measurement application, such as ambulatory, Holter or ECG, two basic front end architectures are in use: multiplexing analog signals into a single converter (Figure 1), and converter-per-channel (Figure 2).

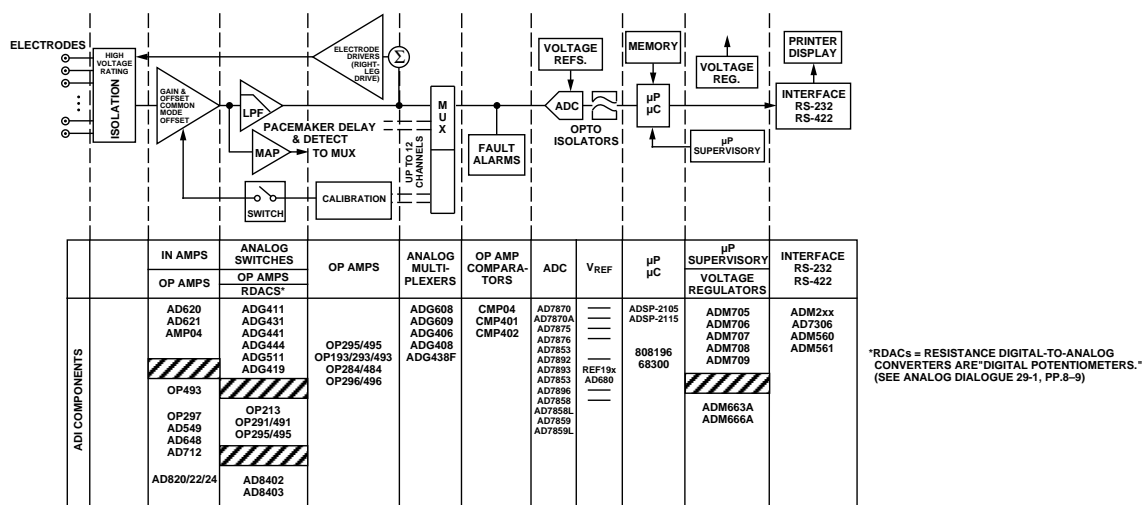


Figure 1. Typical ECG signal chain—multiplexed single-converter architecture.†

†For data sheets, use ADI's web site: <http://www.analog.com>. For immediate data on products mentioned here, find their corresponding Faxcodes on page 24, call ADI's AnalogFax™ line, 1 (800) 446-6212, and enter the appropriate Faxcodes.

The multiplexed architecture, based on an old assumption that the converter is by far the most-expensive front-end component, is prevalent in today's electrophysiological measurement systems. However, with the proliferation of sigma-delta converter architectures, converter-per-channel is now a power- and cost-competitive alternative, for rapid acquisition of high—or intelligently selected—volumes of data. Designers must now take into account all factors affecting the complete system, including power/cost trade-offs.

Let's review some important system performance requirements and their implications for the measurement electronics. The illustrations show the typical signal chains and available Analog Devices ICs that may fit requirements of the various architectures. Note that the front end amplifiers and filters of Figure 1 are repeated for each channel.

Wide Dynamic Range

The small ac signal voltage (5 to 10 mV) detected by the sensor on the electrodes will be accompanied by a large ac common-mode component (up to 1.5 V) and a large variable dc component (300 mV). The common-mode rejection specified by the AAMI (Association for the Advancement of Medical Instrumentation) is 89 dB minimum for standard ECG and 60 dB minimum for ambulatory recorders. In low-supply-voltage systems with wide dynamic range requirements, it's important to choose low-headroom amplifiers having output voltage range approaching rail-to-rail. Examples of low-power, dual/single supply op amps and instrumentation amps ideally suited for interfacing to electrodes include:

Product	Minimum Operating Voltage Range	Quiescent Supply Current (max)	Amplifiers On Chip
Operational Amplifiers			
AD820/822/824*	±1.5 V, +3 V	800/800/600 μA/amplifier	1/2/4
OP295/495*	+3 V	150 μA/amplifier	2/4
OP291/491†	+2.7 V	350 μA/amplifier	2/4
OP193/293/493	+1.7 V	22 μA/amplifier	1/2/4
OP196/296/496	+3 V	60 μA/amplifier	1/2/4
AD549 electrometer	±5 V	700 μA	1
AD648	±4.5 V	400 μA	2
Instrumentation Amplifiers			
AD620/AD621	±2/±2.3 V	1.6 mA	1/1

*Rail-to-rail output †Rail-to rail output and input

Besides single-supply and low-power operation, key features of A/D converters for electrophysiological systems include serial interface (ideally compatible with standard microprocessors and

microcomputers), on-chip voltage reference, sleep (power-down) mode and on-chip multiplexer. Available types include:

Product	Minimum Operating Voltage Range	Power Requirement
AD7853/53L	+3 V	20/6.9 mW, sleep: <60 μW
AD7858/58L (8-ch. multiplex)	+3 V	20/6.9 mW, sleep: <60 μW
AD7896	+3 V	10 mW
AD7892	+5 V	60 mW
AD7893	+5 V	25 mW
AD7716 (4-A/D channels)	±5 V	50 mW max
AD7714/AD7715	+3 V	105 mW max

Figure 2 shows the converter-per-channel architecture using the AD7716 (quad, 22-bit, sigma delta ADC). The AD7716 eliminates the need for IAs and active low pass filtering. It also eliminates additional external digital control circuitry needed for multiplexed systems. In prospect are additional Σ-Δ devices with wider dynamic ranges, such as AD1550/51, to support converter-per-channel ECGs.

Signal Bandwidth

The signal bandwidth will depend on whether a pacemaker pulse is being detected and whether the system is used for diagnostic (wveshape details important) vs. monitoring. In general, components of the signal of interest will reside in the 0.67 to 40-Hz bandwidth for standard ECGs and up to 300 Hz to 1 kHz for pacemaker detection.

Right Leg Drive

Depending upon the system architecture, the electrode located on the right leg is either driven in opposition to minimize the ac common-mode voltage swings (above), or it can be used as a reference node to measure common-mode voltage for removal digitally after conversion. A suitable amplifier would be the OP97, operating on ≥2.5 V and drawing ≤600 μA quiescent.

Low-power digital signal processors: Today's DSPs can now provide an attractive price/performance alternative to microcontroller/μP-based embedded systems. The ADSP-2173 is an example of a +3.3-V fixed-point device with on-chip memory (8 K of 24-bit program ROM, 2 K of 24-bit program RAM, and 2 K of 16-bit data RAM), suitable for low-power ECG systems.

We've described above a plethora of low-power, low-voltage ICs to fill designers' needs for most ECG applications, including patient and vital-sign monitors, diagnostic ECG, Holter (ambulatory ECG), defibrillators, and stress testers. As future systems continue to demand increased functionality and less power, new ADI ICs will exist to meet developing needs. ▀

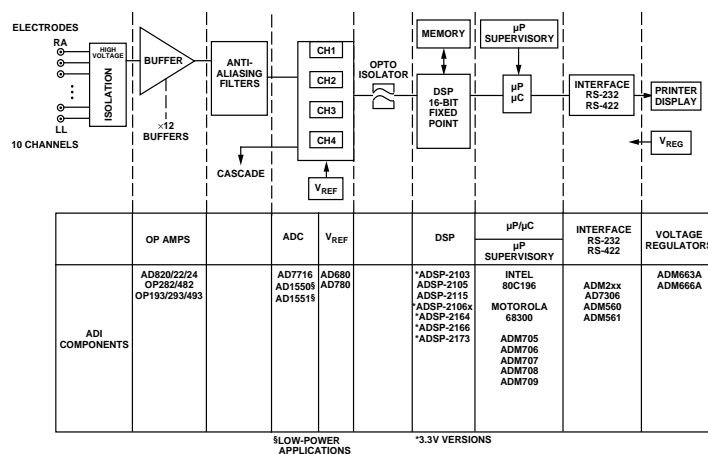


Figure 2. Typical ECG signal chain—converter-per-channel. †

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