ADI's Automatic External Defibrillator (AED) Solutions

AED System Theory and Typical Architecture

An automated external defibrillator (AED) is a portable electronic device that automatically diagnoses the potential life threatening cardiac arrhythmias of ventricular fibrillation and ventricular tachycardia in a patient. Automatic refers to the unit's ability to autonomously analyze the patient's condition; to assist this, the vast majority of units have spoken prompts, while some may also have visual displays to instruct the user. With simple audio and visual commands, AEDs are designed to be simple to use for the layman.

Defibrillators can be external, transvenous, or implanted, depending on the type of device used or needed. The external defibrillator could be manual or automatic by operation method, and monophasic or biphasic waveform by energy delivery method.

Defibrillation consists of delivering a therapeutic dose of electrical energy to the affected heart with a device called a defibrillator. This depolarizes a critical mass of the heart muscle, terminates the dysrhythmia, and allows normal sinus rhythm to be reestablished by the body's natural pacemaker in the sinoatrial node of the heart. The energy selection is decided by the AED device automatically according to the electrocardiogram (ECG) and impedance gotten from both of the defibrillator electrodes, then the safety processor controls the power circuit to charge the high voltage capacitor with selected energy. After the capacitor charging is complete, the device should prompt the user to do a shock operation, which is a high risk operation, and a double confirmation is always needed to make sure both the operator and the patient are safe. Before and after defibrillation, the optional multi-lead ECG monitor (3/5/10 leads) may be used to evaluate the treatment. The ECG in the defibrillator electrode is a simple single-lead ECG for basic ECG measurement like R wavelet recognition, but the optional multi-lead ECG is a diagnostic monitor level, which can detect complex issues.

AED Design Considerations and Major Challenges

Safety is the first priority in AED design. Any operation must ensure the safety of both operator and patient, so some redundant designs are necessary.

- Both the safety and the operation processor need to check each other to ensure the right decision.
- Discharge the charged capacitor if it times out.
- Double confirmation is required for energy delivery.
- An audio prompt is helpful.
- Disable the energy delivery if the target impedance is not in range of the human body.

Isolation is critical for matters internal and external.

- The device must ensure enough insulation between the internal high voltage and the device surface/port.
- The device must provide an insulation mechanism between the internal high voltage and low voltage part. As you know, the defibrillation works in high voltage mode while the signal processor works in low voltage mode. Therefore, a path switch based on the relay can be used.

Fast response is critical. The AED is a device for life saving, so the faster the response of the device, the greater possibility of life saving.

- Fast boot-up for operation.
- Fast response to an external signal like the external patient monitor trigger out.
- Real-time R wavelet recognition for exact time to delivery energy.
- Real-time energy control for the shock procedure; it is IP related to a different energy delivery waveform.
- Fast charge and energy delivery to save time.

Reliability is critical. The AED can be used in many fields: in the hospital and out of the hospital, in high vibration conditions like ambulances and helicopters, and in outdoor applications like in sunshine and rainy weather. So the AED may need antivibration, waterproofing, and so on for complex conditions.

- Wide operation temperature range.
- Lower performance drift over temperature range, like bias current and noise.
- The power circuit should work well for large current surges.

Interaction is helpful to operate the AED easily.

- An audio prompt can be used to indicate how to do the next step.
- An audio recorder can be used to record the rescue procedure for evidence.

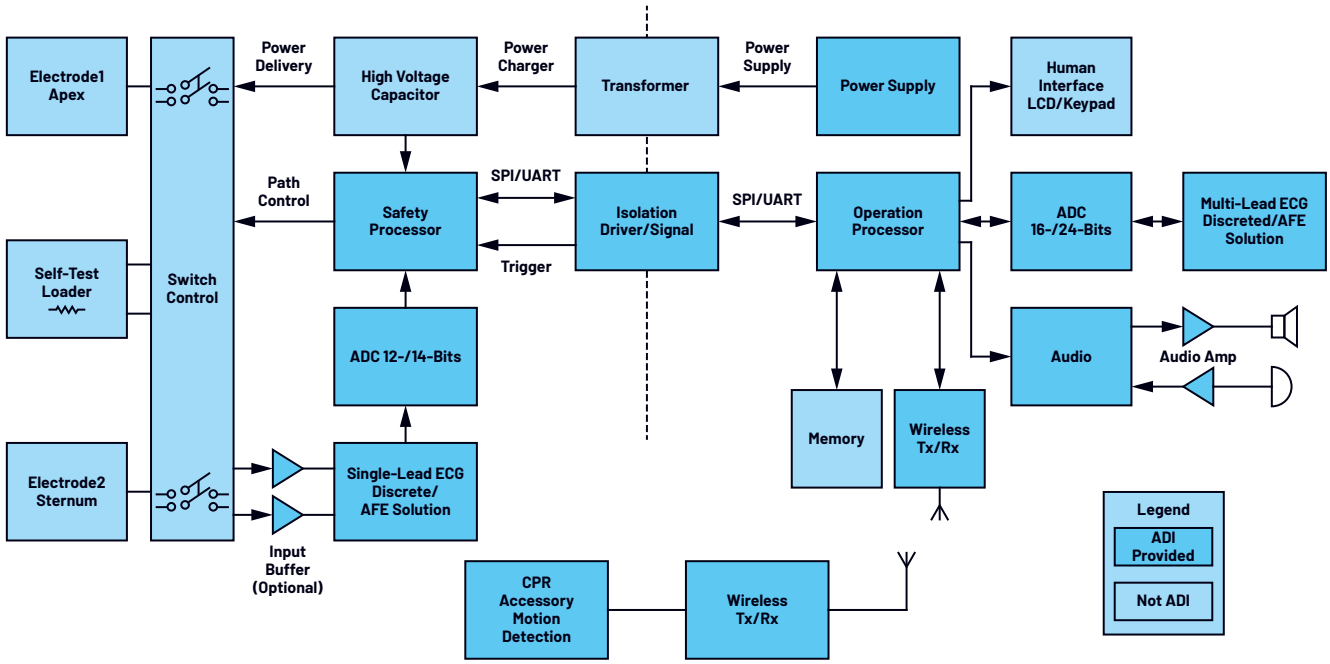
Connectivity is necessary for the modern AED.

- Wireless connectivity like ISM and Wi-Fi is helpful for the device in the hospital; GPRS/3G is helpful for the device out of the hospital.
- Some peripherals like LAN, UART, and a memory card are used for the electrical medical system.

Total Solutions from ADI

ADI provides an extensive selection of amplifier, data conversion, signal processing, audio processing, isolation, and power management solutions to maximize product quality and reliability for AED applications. In addition, ADI provides evaluation boards, simulation tools, and applications expertise to support customer design and development efforts.

Main Signal Chain



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

Table 1. AED Solution Main Products Model Selection List

Safety Processor	Input Buffer	Input Buffer	ECG AFE	Isolation Driver/Signal
ADuC7021/ADuC7022/ ADuC7023/ADuC7024/ ADuC7126	AD8625/AD8626/AD8542/ AD8544/AD8505/AD8506/ AD8613/AD8617/AD8619/ ADA4505-1/ADA4505-2/ ADA4505-4	AD8220/AD8221/ AD8226/AD8236/ AD8237	AD8232/ AD8233/ ADAS1000	ADuM4400/ADuM4401/ADuM4402/ ADuM4070/ADuM4470/ADuM4471/ ADuM4472/ADuM4473/ADuM4474/ ADuM6000/ADuM6200/ADuM6201/ ADuM6402/ADuM6400/ADuM6401/ ADuM6402/ADuM6403/ADuM6404/ ADuM4160/ADM2491E

ADC	Operation Processor	Power Supply	CPR Accessory Motion Detection	Wireless	Audio
AD7091R/AD7656-1/AD7684/ AD7687/AD7176-2	ADSP-BF524C/ ADSP-BF527C	ADP1621/ADP1821/ADP1822/ ADP1823/ADP1828/ADP1829/ ADP7102/ADP150	ADXL345/ ADXL362	ADF7020/ ADF7023	ADAU1701/ ADAU1702

Table 2. Main Products

Part Number	Description	Benefits
Safety Processors		
ADuC7021	ADuC7019/ADuC7020/ADuC7021/ADuC7022/ADuC7024/ADuC7025/ADuC7026/ADuC7027/ADuC7028 are fully integrated, 1 MSPS, 12-bit data acquisition systems incorporating high performance multichannel analog-to-digital converters (ADCs), 16-/32-bit MCUs, and flash®/EE memory on a single chip. The four DAC outputs are only available on certain models (ADuC7020 and ADuC7026). Features 62 kB flash/EE memory, 8 kB SRAM.	Precision analog MCU, low cost single-chip MCU with rich peripherals like ADC, DAC, and so on
Input Buffers		
AD8625	The AD862x is a precision JFET input amplifier. It features true single-supply operation, low power consumption, and rail-to-rail output. The outputs remain stable with capacitive loads of over 500 pF; the supply current is less than 630 µA/amp. Applications for the AD862x include photodiode transimpedance amplification, ATE reference level drivers, battery management, both line powered and portable instrumentation, and remote sensor signal conditioning including automotive sensors.	Precision, low power, single-supply, JFET amplifier
AD8505	The AD8505/AD8506/AD8508 are single, dual, and quad micropower amplifiers featuring rail-to-rail input/output swings while operating from a single 1.8 V to 5 V power supply or from dual ±0.9 V to ±2.5 V power supplies. Using a new circuit technology, these amplifiers offer zero input crossover distortion (excellent PSRR and CMRR performance) and low bias current while operating with a supply current of less than 20 µA per amplifier. This amplifier family offers the lowest noise in its power class.	20 µA maximum, RRIO, zero input crossover distortion single op amp
AD8613	The AD8613/AD8617/AD8619 are single, dual, and quad micropower rail-to-rail input and output amplifiers that feature low offset voltage as well as low input voltage and current noise. The AD8613 is fully specified to operate from 1.8 V to 5.0 V single supply (or ±0.9 V and ±2.5 V dual supply). The combination of low offsets, low noise, very low input bias currents, and low power consumption make the AD8613 especially useful in portable and loop-powered instrumentation.	Micropower, low noise, low cost CMOS RRIO single op amp
ADA4505-1	The ADA4505-1/ADA4505-2/ADA4505-4 are single, dual, and quad micropower amplifiers featuring rail-to-rail input and output swings while operating from a single 1.8 V to 5 V power supply or from dual ±0.9 V to ±2.5 V power supplies.	10 µA, RRIO, zero input crossover distortion single op amp
In-Amps		
AD8220	The AD8220 is a single-supply, JFET input instrumentation amplifier available in an MSOP package. Designed to meet the needs of high performance, portable instrumentation, the AD8220 has a minimum common-mode rejection ratio (CMRR) of 86 dB at DC and a minimum CMRR of 80 dB at 5 kHz for G = 1. Maximum input bias current is 10 pA and typically remains below 300 pA over the entire industrial temperature range. Despite the JFET inputs, the AD8220 typically has a noise corner of only 10 Hz.	JFET input instrumentation amplifier with rail-to-rail output
AD8221	The AD8221 is a gain programmable, high performance instrumentation amplifier that delivers the industry's highest CMRR over frequency in its class. The CMRR of instrumentation amplifiers on the market today falls off at 200 Hz. In contrast, the AD8221 maintains a minimum CMRR of 80 dB to 10 kHz for all grades at G = 1. High CMRR over frequency allows the AD8221 to reject wideband interference and line harmonics, greatly simplifying filter requirements. Possible applications include precision data acquisition, biomedical analysis, and aerospace instrumentation.	Precision instrumentation amplifier
AD8226	The AD8226 is a low cost, wide supply range instrumentation amplifier that requires only one external resistor to set any gain between 1 and 1000. The AD8226 is designed to work with a variety of signal voltages. A wide input range and rail-to-rail output allow the signal to make full use of the supply rails. Because the input range also includes the ability to go below the negative supply, small signals near ground can be amplified without requiring dual supplies. The AD8226 operates on supplies ranging from ±1.35 V to ±18 V for dual supplies and 2.2 V to 36 V for single supply.	Wide supply range, rail-to-rail output instrumentation amplifier
AD8236	The AD8236 is the lowest power instrumentation amplifier in the industry. It has rail-to-rail outputs and can operate on voltages as low as 1.8 V. Its 40 µA maximum supply current makes it an excellent choice in battery-powered applications.	40 µA micropower instrumentation amplifier
AD8237	The AD8237 is a micropower, zero drift, rail-to-rail input and output instrumentation amplifier. The relative match of two resistors sets any gain from 1 to 1000. The AD8237 has excellent gain accuracy performance that can be preserved at any gain with two ratio matched resistors.	Micropower, zero drift, true rail-to-rail instrumentation amplifier
ECG AFEs		
AD8232/ AD8233	The AD8232/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 for an ultra low power ADC or an embedded microcontroller to acquire the output signal easily.	Single-lead heart rate monitor analog front end
ADAS1000	The ADAS1000 measures electrocardiac signals, thoracic impedance, pacing artifacts, and lead on/off status and outputs this information in the form of a data frame supplying either lead/vector or electrode data at programmable data rates. Its low power and small size make it suitable for portable, battery-powered applications. The high performance also makes it suitable for higher end diagnostic machines.	Low power, 5-electrode ECG analog front end with respiration measurement and pace detection

Table 3. Main Products (Continued)

Part Number	Description	Benefits
Isolation Driver/Signal/Power		
ADuM4400	The ADuM440x are 4-channel digital isolators based on the Analog Devices, Inc. *i*Coupler® technology. Combining high speed CMOS and monolithic air core transformer technology, these isolation components provide outstanding performance characteristics that are superior to the alternatives, such as optocoupler devices and other integrated couplers.	5 kV rms quad-channel digital isolators
ADuM4070	The ADuM4070 is a regulated DC-to-DC isolated power supply controller with an internal MOSFET driver. The DC-to-DC controller has an internal isolated PWM feedback from the secondary side based on the *i*Coupler chip scale transformer technology and complete loop compensation. This eliminates the need to use an optocoupler for feedback and compensates the loop for stability.	Isolated switch regulator with integrated feedback
ADuM6000	The ADuM6000 is an isolated DC-to-DC converter based on the Analog Devices, Inc. *i*Coupler technology. The DC-to-DC converter in this device provides regulated, isolated power in several combinations of input and output voltages. The Analog Devices chip scale transformer *i*Coupler technology transfers isolated power in this DC-to-DC converter with up to 31% efficiency.	Isolated, 5 kV, DC-to-DC converter
ADuM4160	The ADuM4160 is a USB port isolator, based on Analog Devices' *i*Coupler technology. Combining high speed CMOS and monolithic air core transformer technology, these isolation components provide outstanding performance characteristics and are easily integrated with low and full speed USB-compatible peripheral devices.	Full/low speed USB digital isolator
ADM2491E	The AD8613/AD8617/AD8619 are single, dual, and quad micropower rail-to-rail input and output amplifiers that feature low offset voltage as well as low input voltage and current noise. The AD8613 is fully specified to operate from 1.8 V to 5.0 V single supply (or ±0.9 V and ±2.5 V dual supply). The combination of low offsets, low noise, very low input bias currents, and low power consumption make the AD8613 especially useful in portable and loop-powered instrumentation.	5 kV signal isolated, high speed (16 Mbps), ESD protected, half- or full-duplex RS-485 transceiver
ADCs		
AD7091R	The AD7091R is a 12-bit successive approximation ADC that offers ultra low power consumption (typically 349 µA at 3 V and 1 MSPS) while achieving fast throughput rates (1 MSPS with a 50 MHz SCLK). The AD7091R uses advanced design and process techniques to achieve this very low power dissipation at high throughput rates. The part also features an on-chip, accurate 2.5 V reference.	1 MSPS, ultra low power, 12-bit ADC with on-chip reference in 10-lead LFCSP and MSOP
AD7656-1	The AD7656-1/AD7657-1/AD7658-1 feature throughput rates of up to 250 kSPS. The parts contain low noise, wide bandwidth track-and-hold amplifiers that can handle input frequencies up to 4.5 MHz.	250 kSPS, 6-channel, simultaneous sampling, bipolar 14-bit ADC
AD7684	The AD7684 is a 16-bit, charge redistribution, successive approximation, PulSAR® ADC that operates from a single power supply, VDD, between 2.7 V to 5.5 V. It contains a low power, high speed, 16-bit sampling ADC with no missing codes, an internal conversion clock, and a serial, SPI-compatible interface port. The part also contains a low noise, wide bandwidth, short aperture delay, track-and-hold circuit. On the CS falling edge, it samples the voltage difference between +IN and –IN pins. The reference voltage, REF, is applied externally and can be set up to the supply voltage. Its power scales linearly with throughput.	16-bit, 100 kSPS PulSAR, differential ADC in MSOP
AD7687	The AD7687 is a 16-bit, charge redistribution, successive approximation ADC that operates from a single power supply, VDD, between 2.3 V to 5.5 V. It contains a low power, high speed, 16-bit sampling ADC with no missing codes, an internal conversion clock, and a versatile serial interface port. The part also contains a low noise, wide bandwidth, short aperture delay track-and-hold circuit. On the CNV rising edge, it samples the voltage difference between IN+ and IN– pins. The voltages on these pins usually swing in opposite phase between 0 V to REF. The reference voltage, REF, is applied externally and can be set up to the supply voltage.	16-bit, 1.5 LSB INL, 250 kSPS PulSAR differential ADC in MSOP/QFN
AD7176-2	The AD7176-2 is a fast settling, highly accurate, high resolution, multiplexed, 24-bit, Σ-Δ ADC for low bandwidth input signals with a fully flexible ODR (output data rate) between 5 SPS and 250 kSPS.	24-bit, 250 kSPS Σ-Δ ADC with 20 µs settling time
Operation Processors		
ADSP-BF524C	The ADSP-BF524C offers up to 400 MHz performance and up to 800 MMACs. This processor core is supported by an advanced DMA controller supporting one-and two-dimensional DMA transfers between on-chip memory, off-chip memory, and system peripherals. The combination of the processor core speed and the DMA controller allows for efficient processing of audio, voice, video, and image data.	Low power Blackfin processor with advanced peripherals and embedded stereo audio codec
ADSP-BF527C	The high performance 16-/32-bit Blackfin embedded processor core, the flexible cache architecture, the enhanced DMA subsystem, and the dynamic power management (DPM) functionality allow system designers a flexible platform to address a wide range of portable applications, including consumer, communications, and industrial/instrumentation.	Low power Blackfin processor with advanced peripherals and embedded stereo audio codec

Table 4. Main Products (Continued)

Part Number	Description	Benefits
Power Supply		
ADP1621	The ADP1621 is a fixed frequency, pulse-width modulation (PWM), current-mode, step-up converter controller. It drives an external N-channel MOSFET to convert the input voltage to a higher output voltage. The ADP1621 can also be used to drive flyback, SEPIC, and forward converter topologies, either isolated or nonisolated. The ADP1621 eliminates the use of a current sense power resistor.	5 kV rms quad-channel digital isolators
ADP1821	The ADP1821 is a versatile and inexpensive, synchronous, pulse-width modulation (PWM), voltage mode, step-down controller. It drives an all N-channel power stage to regulate an output voltage as low as 0.6 V. The ADP1821 can be configured to provide output voltages from 0.6 V to 85% of the input voltage and is sized to handle large MOSFETs for point-of-load regulators.	Step-down DC-to-DC controller
ADP7102	3.3 V to 20 V input, 300 mA output current, 200 mV low dropout voltage LDO with low noise performance, 15 µV rms for fixed voltage output, high PSRR 60 dB at 10 kHz, reverse current protection; pin-to-pin compatible with 500 mA version: ADP7104	Improves performance of noise sensitive loads and low dropout
ADP150	2.2 V to 5.5 V input, 150 mA output current, 105 mV low dropout voltage LDO with low noise performance, 9 µV rms independent voltage output, high PSRR 70 dB at 10 kHz; pin-to-pin compatible with 200 mA version: ADP151	Improves performance of noise sensitive loads and low dropout
CPR Accessory Motion Detection		
ADXL345	The ADXL345 is a small, thin, low power, 3-axis accelerometer with high resolution (13-bit) measurement at up to ±16 *g*. Digital output data is formatted as 16-bit twos complement and is accessible through either an SPI (3-wire or 4-wire) or I^2C digital interface.	3-axis, ±2 *g* /±4 *g* /±8 *g* /±16 *g* digital accelerometer
ADXL362	The ADXL362 is an ultra low power, 3-axis MEMS accelerometer that consumes less than 2 µA at a 100 Hz output data rate and 270 nA when in motion triggered wake-up mode. Unlike accelerometers that use power duty cycling to achieve low power consumption, the ADXL362 does not alias input signals by undersampling. it samples the full bandwidth of the sensor at all data rates.	Micropower, 3-axis, ±2 *g* /±4 *g* /±8 *g* digital output MEMS accelerometer
Wireless		
ADF7023	The ADF7023 is a very low power, high performance, highly integrated FSK/GFSK/OOK/MSK/GMSK transceiver designed for operation in the 862 MHz to 928 MHz and 431 MHz to 464 MHz frequency bands, which cover the worldwide license free ISM bands at 433 MHz, 868 MHz, and 915 MHz. It is suitable for circuit applications that operate under the European ETSI EN 300-220, the North American FCC (part 15), the Chinese short range wireless regulatory standards, or other similar regional standards. Data rates from 1 kbps to 300 kbps are supported.	High performance, low power, ISM band FSK/GFSK/OOK/MSK/GMSK transceiver IC
ADF7020	The ADF7020 is a low power, low IF transceiver designed for operation in the license free ISM bands at 433 MHz, 868 MHz, and 915 MHz. It is suitable for circuit applications that meet either the European ETSI EN 300-220 or the North American FCC (part 15.247 and 15.249) regulatory standards. It operates from a 2.3 V to 3.6 V power supply with programmable output power from −16 dBm to +13 dBm in 0.3 dBm steps. Its receiver sensitivity is −117.5 dBm at 1k bits/second in FSK mode or −110.5 dBm at 9.6k bits/second. Power consumption is 20 mA in receive mode and 30 mA in transmit mode (+10 dBm output).	ISM band transceiver IC
Audio		
ADAU1701/ ADAU1702	The ADAU1701/ADAU1702 is a 28-/56-bit digital audio processor with two ADCs and four DACs. The stereo audio ADCs and DACs could support sampling rates up to 192 kHz.	SigmaDSP® 28-/56-bit audio processor, 192 kHz, on-chip voltage regulator

Design Resources

Circuits from the Lab®

- Powering an ECG Front End in Battery-Powered Patient Monitoring Applications (CN-0308)
- Robust Completely Isolated Current Sense Circuit with Isolated Power Supply for Solar Photovoltaic Converters (CN-0280)
- Universal Serial Bus (USB) Peripheral Isolator Circuit (CN-0160)
- 16-Bit, 100 kSPS Low Power Data Acquisition System Optimized for Sub-Nyquist Input Signals up to 1 kHz (CN-0306)
- Precision 24-Bit, 250 kSPS Single-Supply Σ-Δ Data Acquisition System for Industrial Signal Levels (CN-0310)
- Sensing Low-*g* Acceleration Using the ADXL345 Digital Accelerometer Connected to the ADuC7024 Precision Analog Microcontroller (CN-0133)

Application Notes and Articles

- How ADIsimADC™ Models an ADC (AN-737)
- Designing an Inverting Power Supply Using the ADP2384/ADP2386 Synchronous Step-Down DC-to-DC Regulators (AN-1168)
- Multiphysiological Parameter Patient Monitoring (MS-2126)
- Mitigation Strategies for ECG Design Challenges (MS-2160)
- Designing Power Supplies for High Speed ADC (MS-2210)

Design Tools and Forums

- ADC
  - VisualAnalog™ software
    analog.com/VisualANALOG
  - ADC SPI interface software (SPIController)
    analog.com/SPIController
  - ADIsimADC modeling tool
    analog.com/ADIsimADC
- DSP
  - VisualDSP++® downloads and updates
    analog.com/VisualDSPupdates
  - Software Development Kit (SDK)
    analog.com/SDK
- Clocking and PLL
  - ADIsimCLK modeling tool
    analog.com/ADIsimCLK
  - ADIsimPLL™: PLL design and simulation
    analog.com/ADIsimPLL
  - AD951x/AD952x evaluation software and board
- Amplifier
  - ADIsimOpAmp: Amplifier Parametric Evaluation Tool
    analog.com/ADIsimOpAmp
  - DiffAmpCalc™: ADI's Differential Amplifier Calculator
    analog.com/diffampcalc

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