Ultrasound imaging systems

Overview

By transmitting acoustic energy into the body and receiving and processing the returning reflections, phased-array ultrasound systems can generate images of internal organs and structures, map blood flow and tissue motion, and provide highly accurate blood velocity information. Historically, the large number of high-performance phased-array transmitters and receivers required to implement these imaging systems resulted in large and expensive cart-based implementations. Recently, advances in integration have allowed system designers to migrate to smaller, lower cost, and more portable imaging solutions with performance approaching these larger systems. The challenge moving forward is to continue to drive the integration of these solutions, while increasing their performance and diagnostic capabilities.

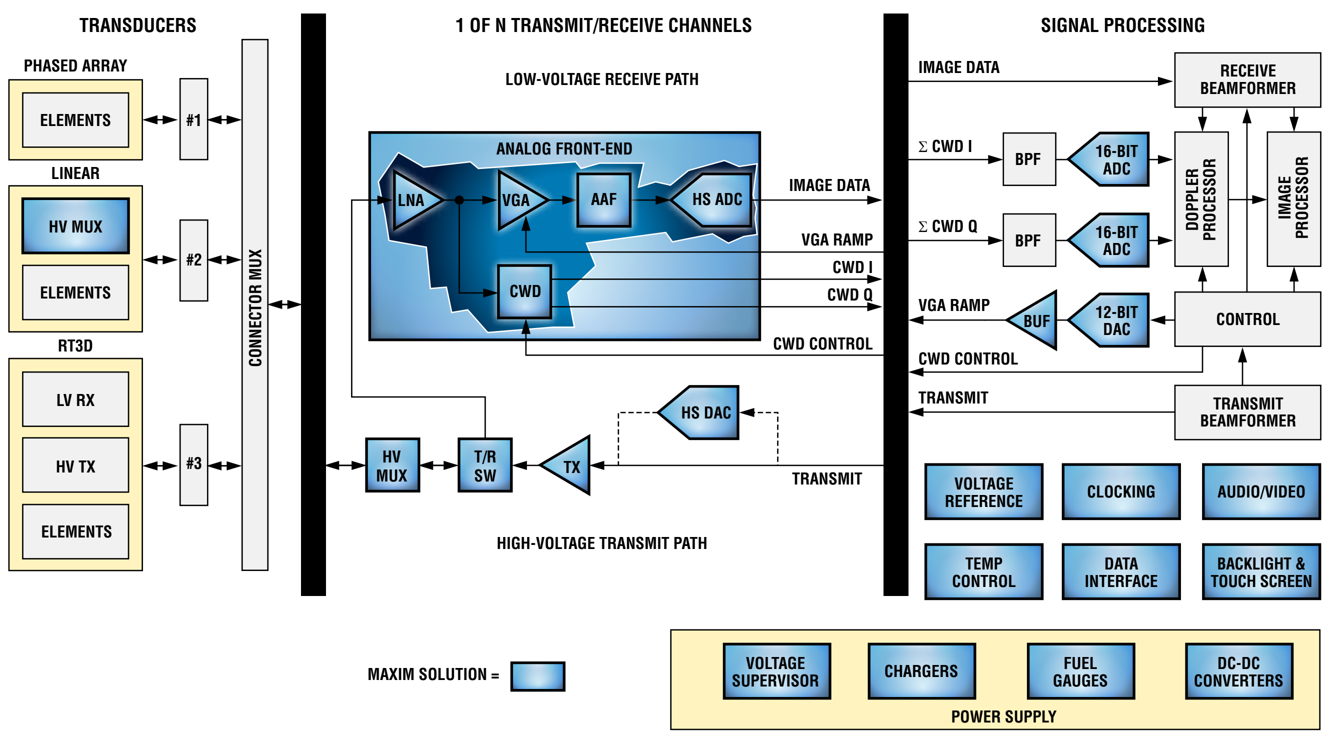
Transducers

A critical component of this system is the ultrasound transducer. A typical ultrasound imaging system uses a wide variety of transducers optimized for specific diagnostic applications. Each transducer is comprised of an array of piezoelectric transducer elements that transmit focused energy into the body and receive the resulting reflections. Each element is connected to the ultrasound system with fine coaxial cables. Typical transducers have 32 to as many as 512 elements and operate at frequencies from 1MHz to 15MHz. Most ultrasound systems provide two to as many as four switchable transducer connectors to allow the clinician to easily switch among the various transducers for each exam type.

High-voltage multiplexing

A typical phased-array ultrasound system will have from 32 to as many as 256 transmitters and receivers. In many cases, the system will have fewer transmitters and receivers than the number of available transducer elements. In these cases, high-voltage switches located in the transducer or system are used as multiplexers to connect a specific transducer element to a specific transmitter/receiver (Tx/Rx) pair. In this way, the system can dynamically change the active transducer aperture over the available transducer element array.

The requirements for these switches are severe. They must handle transmit pulses with voltage swings as large as $200V_{P-P}$ and with peak currents up to 2A. They must switch rapidly to quickly modify the configuration of the active aperture and maximize image frame rate. Finally, they must have minimal charge injection to avoid spurious transmissions and associated image artifacts.



Functional block diagram of an ultrasound imaging system. For a list of Maxim's recommended ultrasound solutions, please go to: www.maxim-ic.com/ultrasound.

High-voltage transmitters

A digital transmit beamformer typically generates the necessary digital transmit signals with the proper timing and phase to produce a focused transmit signal. High-performance ultrasound systems will generate complex transmit waveforms using an arbitrary waveform generator to optimize image quality. In these cases, the transmit beamformer generates digital 8-bit to 10-bit words at rates of approximately 40MHz to produce the required transmit waveform. Digital-to-analog converters (DACs) are used to translate the digital waveform to an analog signal, which is then amplified by a linear high-voltage amplifier to drive the transducer elements. This transmit technique is generally reserved for more expensive and less portable systems, as it can be very large, costly, and power hungry. As a result, the majority of ultrasound systems do not use this transmit-beamformer technique, but instead use multilevel high-voltage pulsers to generate the necessary transmit signals.

In this alternate implementation highly-integrated, high-voltage pulsers quickly switch the transducer element to the appropriate programmable high-voltage supplies to generate the transmit waveform. To generate a simple bipolar transmit waveform, a transmit pulser alternately connects the element to a positive and negative transmit supply voltage controlled by the digital beamformer. More complex realizations allow connections to multiple supplies and ground in order to generate more complex multilevel waveforms with better characteristics.

The slew rate and symmetry requirements for high-voltage pulsers have increased in recent years due to the popularity of second-harmonic imaging. Second-harmonic imaging takes advantage of the nonlinear acoustic properties of the human

body. These nonlinearities tend to translate acoustic energy at f_o to energy at $2f_o$. Reception of these second-harmonic signals has, for a variety of reasons, produced better image quality and is now widely used.

There are two basic methods used to implement second-harmonic imaging. In one method called standard-harmonic imaging, the second-harmonic of the transmit signal is suppressed as much as possible. As a result, the received second-harmonic derives solely from the nonlinear behavior of the body. This mode of operation requires that second-harmonic content of the transmit energy be at least 50dB below the fundamental. To achieve this, the duty cycle of the transmit pulse must be less than ±0.2% of a perfect 50% duty cycle. The other method, called pulse inversion, uses inverted transmit pulses to generate two phase-inverted receive signals along the same image line. Summation of these two phase-inverted receive signals in the receiver recovers harmonic signals generated by nonlinear processes in the body. In this pulse-inversion method, the summed phase-inverted transmit pulses must cancel as much as possible. To do this, the rise and fall times of the high-voltage pulsers must match very closely.

Image-path receivers

The ultrasound image-path receivers are used to detect 2D as well as pulsed-wave Doppler (PWD) signals necessary for color-flow imaging and spectral PWD. The receivers include a Tx/Rx switch; a low-noise amplifier (LNA); a variable-gain amplifier (VGA); an anti-alias filter (AAF); and an analog-to-digital converter (ADC).

Tx/Rx switch

A Tx/Rx switch protects the LNA from the high-voltage transmit pulse and isolates the LNA's input from the transmitter during the receive interval. The switch is usually implemented using an array of properly biased diodes which automatically turn on and off when presented with a high-voltage transmit pulse. The Tx/Rx switch must have fast recovery times to ensure that the receiver is on immediately after a transmit pulse. These fast recovery times are critical for imaging at shallow depths and for providing a low on-impedance to ensure that receiver noise sensitivity is maintained.

Low-noise amplifier (LNA)

The LNA in the receiver must have excellent noise performance and sufficient gain. In a properly designed receiver the LNA will generally determine the noise performance of the full receiver. The transducer element is connected to the LNA through a relatively long coaxial transducer cable terminated into relatively low impedance at the LNA's input. Without proper termination the cable capacitance, combined with the transducer element's source impedence, can significantly limit the bandwidth of the received signal from a broadband transducer. Termination of the transducer cable into a low impedance reduces this filtering effect and significantly improves image quality. Unfortunately, this termination also reduces the signal level at the input

to the LNA and, therefore, tends to reduce the receiver's sensitivity. Consequently, it is important for the LNA to have active-input-termination capability to provide the requisite low-input impedance termination and excellent noise performance required under these conditions.

Variable-gain amplifier (VGA)

The VGA, sometimes called a time gain control (TGC) amplifier, provides the receiver with sufficient dynamic range over the full receive cycle. Ultrasound signals propagate in the body at approximately 1540 meters per second and attenuate at a rate of about 1.4dB/cm-MHz round-trip. Immediately after an acoustic transmit pulse, the received "echo" signal at the LNA's input can be as large as $0.5V_{P-P}$. This signal quickly decays to the thermal noise floor of the transducer element. The dynamic range required to receive this signal is approximately 100dB to 110dB, and is well beyond the range of a realistic ADC. As a result, a VGA is used to map this signal into the ADC. A VGA with approximately 30dB to 40dB of gain is necessary to map the received signal into a typical 12-bit ADC used in this application. The gain is ramped as a function of time (i.e., "time gain control") to accomplish this dynamic range mapping.

The instantaneous dynamic range of an ultrasound receiver is also very important; it affects 2D image quality and the system's ability to detect Doppler shifts and thus blood or tissue motion. This is especially true in second-harmonic imaging where the second-harmonic signals of interest can be significantly less than signals at the transmit fundamental. It is also the case in Doppler modes where small Doppler signals can be located within 1kHz or less of very large signals from tissue or vessel walls. As a result, both the broadband and near-carrier SNR is of prime interest, and is often limited by this stage of the receiver.

Anti-alias filter (AAF) and ADC

The AAF in the receive chain keeps high-frequency noise and extraneous signals that are beyond the normal maximum imaging frequencies from being aliased back to baseband by the ADC. Many times an adjustable AAF is provided in the design. To avoid aliasing and to preserve the time-domain response of the signal, the filter itself needs to attenuate signals beyond the first Nyquist zone. For this reason Butterworth or higher-order Bessel filters are used.

The ADC used in this application is typically a 12-bit device running from 40Msps to 60Msps. This converter provides the necessary instantaneous dynamic range at acceptable cost and power levels. In a properly designed receiver, this ADC should limit the instantaneous SNR of the receiver. As previously mentioned, however, limitations in the poor-performing VGAs many times limit receiver SNR performance.

Digital beamformers

The ADC's output signals are typically routed to digital-receive beamformers through a high-speed LVDS serial interface. This approach reduces PC-board (PCB) complexity and the number of interface pins. The beamformer contains upconverting lowpass or bandpass digital filters which increase the effective sample rate by as much as 4x to improve the system's beamforming resolution. These upconverted signals are stored in memory and appropriately delayed, and then summed by a delay-coefficient calculator to yield the appropriate focus. The signals are also appropriately weighted, or "apodized," using an apodization calculator before summing. This step appropriately windows the receive aperture to lower the side-lobe interference of the receive beam and improve image quality.

Beamformed digital-signal processing

Received, beamformed, digital ultrasound signals are processed for visual and audio output using a wide variety of DSP and off-the-shelf PC-based computer solutions. This process can generally be separated into B-mode or 2D image processing, and Doppler processing associated with color-flow image generation and both PWD and continuous-wave Doppler (CWD) spectral processing.

B-mode processing

In B-mode processing, the RF beamformed digital signal is properly filtered and detected. The detected signal has an extremely wide dynamic range, which the B-mode processor must digitally compress into the visible dynamic range available for the display.

Color-flow processing

In color-flow processing, the RF digital beamformed data is digitally mixed by using quadrature local oscillators (LOs) at the transmit frequency to do the complex mixing into I and Q baseband signals. As a result, each sample of the acoustic receive line has associated magnitude and phase values assigned. In color-flow processing, 8 to 16 acoustic lines are typically collected along the same image path line in order to measure Doppler shifts. Reflections from moving blood flow or from moving tissue along that image path will create a

Doppler shift and, therefore, change the phase of the baseband I/Q samples where that shift occurred. The color processor determines the average phase shift versus time for each point along that image path over the 8 to 16 lines; the processor also assigns a color to represent that average velocity. In this way, a two-dimensional color representation of blood or tissue motion can be made.

Spectral Doppler

In spectral processing, the beam-formed digital signals are digitally filtered, mixed to baseband by using quadrature local oscillators (LOs) at the transmit frequency, and then sampled at the transmit pulse repetition frequency (PRF). A complex, fast Fourier transform (FFT) is used to generate an output spectrum representing the velocity content of the signal. The signal magnitude for each bin of the FFT output is calculated and compressed to optimize the available, visible display dynamic range. The signal magnitude is finally displayed versus time on the ultrasound display.

With CWD the signal is processed in much the same way. In addition to processing these signals for display, the spectral processor also generates left and right stereo audio signals that represent positive and negative velocities. A DAC converts these signals which are used to drive external speakers and headphones.

Display processing

The display processor performs the computations necessary to map the polar-coordinate, acoustic image data from the B-mode or color-flow processor into the rectangular-coordinate bitmap image to avoid image artifacts. This processing is generally referred to as R-θ conversion. The display processor also performs other spatial-image-enhancement filtering functions.

Continuous wave Doppler (CWD)

CWD is a modality available in most cardiac and general-purpose ultrasound imaging systems, and it is used to accurately measure the higher-velocity blood flows typically found in the heart. In CWD mode, the available ultrasound transducer elements are split into equal halves about the center of the transducer aperture. Half of the elements are used as transmitters to produce a focused acoustic CWD transmit beam; the other half of the elements serve as receivers to produce a focused receive beam. The signals applied to the transmit elements are square waves at the Doppler frequency of interest, typically 1MHz to 7.5MHz. Transmit jitter needs to be minimized to avoid phase-noise generation that can adversely affect Doppler phase-shift detection. The transmit beam is focused by properly phasing the signals applied to the transmit elements. In a similar way, the CWD received signals are focused by phasing and summing the signals from each receive element. Because the transmitters are on simultaneously with the receivers in this mode, the Doppler signals of interest are typically within a few kilohertz of a very large receive signal that is generated by reflections from stationary tissue at the transmit fundamental. The dynamic range necessary to handle this large signal is well beyond the range of the VGA, AAF, and 12-bit ADC in the image-receive path. As a result, an alternative high-dynamic receive solution for CWD is necessary.

CWD receivers are typically implemented in one of two ways. In one method high-performance ultrasound systems typically extract a received CWD signal at the LNA output. Complex mixers at an LO frequency equal to the transmit frequency are then used to beamform the signals and mix them to baseband for processing. The phase of the I/Q LOs can be adjusted on a channel-by-channel basis to shift the phase of the received CWD signal. The output of these mixers is summed, bandpass filtered, and converted by an ADC. The resulting baseband beamformed signal is in the audio range (100Hz to 50kHz). Audio-frequency ADCs are used to digitize the I and Q CWD signals. These ADCs need significant dynamic range to handle both the large low-frequency Doppler signals from moving tissue and the smaller signals from blood.

The other method to receive a CWD signal uses delay lines and is usually employed in low-cost systems. In this implementation signals are again extracted at the LNA's output and converted into current signals. A crosspoint switch sums channels with similar phases into 8 to 16 separate output signals, as determined by the receive beamformer. Delay lines are used to delay and sum these signals into a single beamformed signal at the RF frequency. This signal is then mixed to baseband using an I/Q mixer with an LO at the transmit frequency. The resulting baseband audio signal is filtered and converted to a digital representation.

www.maxim-ic.com/ultrasound

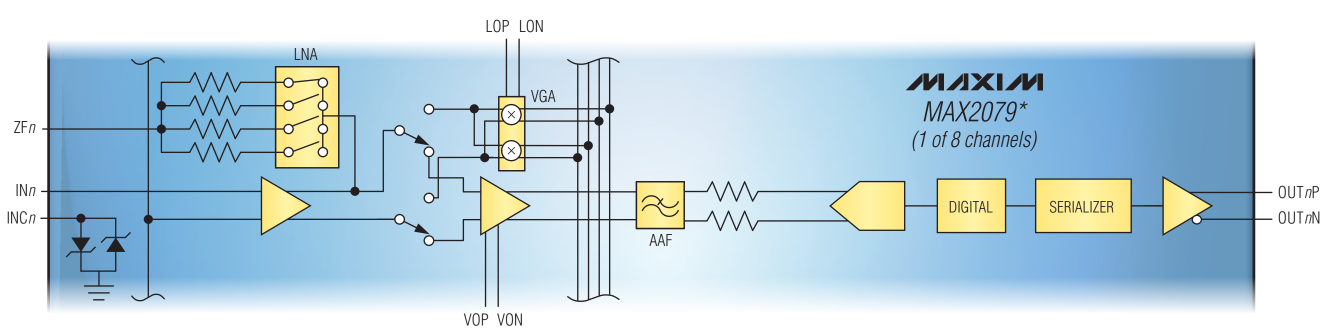
Fully integrated, ultra-low-power, 8-channel front-end provides superior image quality and sensitivity for difficult imaging

MAX2079*

Optimized for low-cost, high-channel-count, high-performance portable and cart-based ultrasound systems, the MAX2079 is a fully integrated, 8-channel ultrasound front-end with a 12-bit ADC. The highly compact and low-power imaging receiver lineup has the lowest noise and highest dynamic range of any competitive, fully integrated product. The receiver lineup achieves an ultra-low 2.4dB noise figure at $R_S = R_{IN} = 200\Omega$, and a full-scale output SNR of 67dBFS with a very low 115mW-per-channel power dissipation. A fully integrated, high-performance, mixer-based programmable CWD beamformer is also included. The MAX2079 gives superior image quality and sensitivity under the most difficult imaging conditions.

Benefits

- **High integration for high-channel-count, small portable or cart-based systems**
  - Octal BiCMOS LNA, VGA, AAF, mixer-based CWD beamformer, and 12-bit CMOS ADC
  - Small, 10mm x 10mm, 144-ball multichip module (MCM) BGA package (0.8 mm pitch)
- **Low power for longer battery life and reduced heat dissipation**
  - 115mW/channel in imaging modes
- **High performance**
  - 2.4dB receiver NF at $R_S = R_{IN} = 200\Omega$ for improved sensitivity and penetration
  - 67dB broadband SNR at gain = 30dB for improved second-harmonic imaging
  - 140dBc narrowband SNR at 1kHz offset from $V_{OUT} = 1\ V_{P-P}$, 5MHz carrier for superior PWD and color flow
  - 155dBc narrowband CWD path SNR at 1kHz offset from $V_{IN} = 200mV_{P-P}$, 1.25MHz carrier for improved CWD sensitivity to low-velocity flow
- **Unique features that reduce board space**
  - Programmable impedance, active-input-termination LNA (50, 100, 200, and 1kΩ)
  - Integrated input-protection diodes



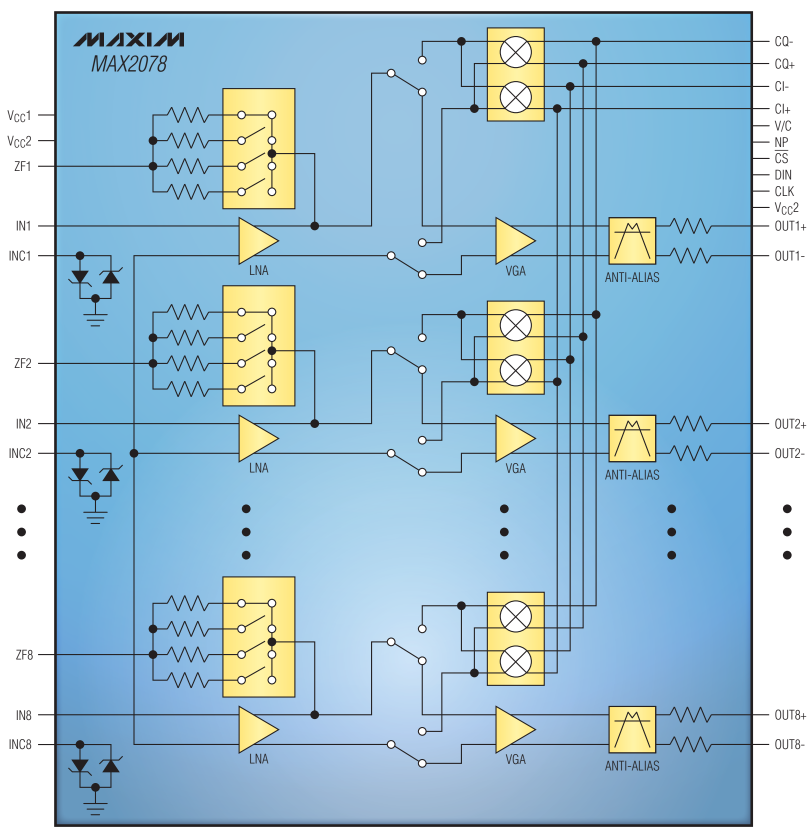
Simplified block diagram of internal schematics for the MAX2079.

*Future product—contact factory for availability.

Integrated 8-channel front-end provides unmatched performance with less space and power

MAX2078/MAX2077

The MAX2078/MAX2077 are 8-channel ultrasound front-ends optimized for high-channel-count, high-performance, cart-based ultrasound systems. The easy-to-use ICs deliver high-end, 2D PWD and CWD imaging capability using substantially less space and power. The highly compact imaging receiver lineup achieves an ultra-low 2.4dB NF at $R_S = R_{IN} = 200\Omega$ at a very low 64.8mW-per-channel power dissipation. When coupled with the MAX1437B octal ADC, the receiver lineup achieves 4dB greater SNR than its nearest competitor and yields superior second-harmonic imaging and color Doppler sensitivity. The MAX2078 also integrates a high-performance mixer-based, programmable CWD beamformer. The device can be combined with the MAX1437B/MAX1438B ADCs for ultra-high performance at only 161mW per channel, or with the MAX19527 for an excellent high-performance, low-power solution for only 123mW per channel.



Typical operating circuit for the MAX2078.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - Octal LNA, VGA, AAF, and mixer-based CWD beamformer
  - Small, 10mm x 10mm TQFN package
- **Low power for reduced heat dissipation and to facilitate designs with fewer PCBs**
  - 65mW/channel in imaging mode
- **High performance**
  - 2.4dB receiver NF at $R_S = R_{IN} = 200\Omega$ for improved sensitivity and penetration
  - $23nV/\sqrt{Hz}$ output referred noise (68dB SNR at gain = 30dB with the MAX1437B 12-bit ADC) for excellent second-harmonic imaging
  - 140dBc narrowband image path SNR at 1kHz offset from $V_{OUT} = 1\ V_{P-P}$, 5MHz carrier for superior PWD and color flow
  - 155dBc narrowband CWD path SNR at 1kHz offset from $V_{IN} = 200mV_{P-P}$, 1.25MHz carrier for improved CWD sensitivity to low-velocity flow
- **Unique features that reduce board space**
  - Programmable active-input-termination impedance LNA (50, 100, 200, and 1kΩ)
  - Integrated input-protection diodes

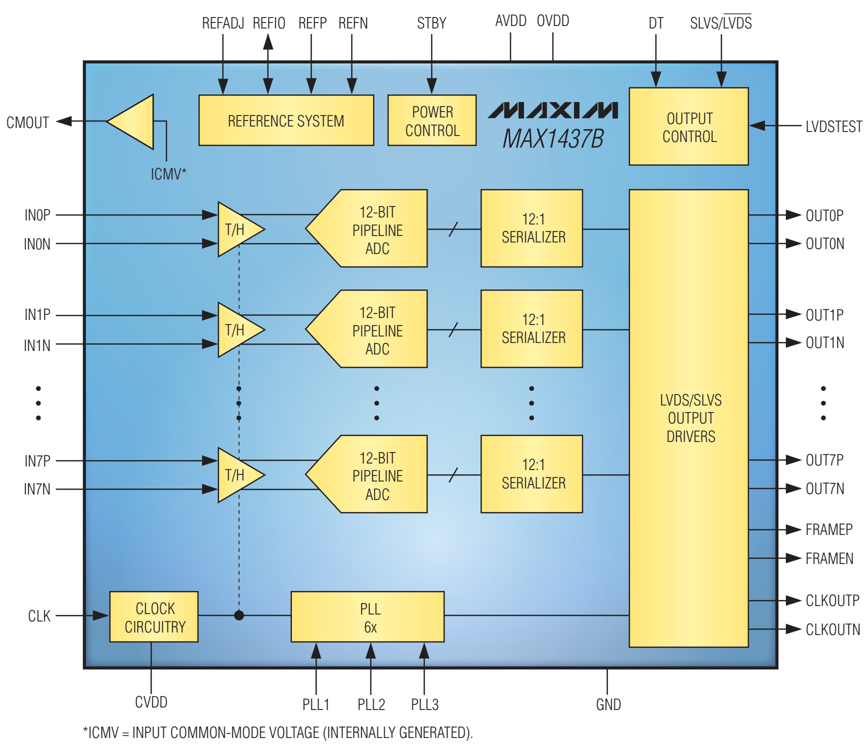
8-channel, 12-bit ADC for superior second-harmonic imaging and color flow

MAX1437B/MAX1438B

The MAX1437B/MAX1438B are high-performance 50Msps/64Msps (respectively) octal ADCs for high-performance ultrasound applications. Serial LVDS outputs reduce interface complexity and beamformer pin count. Optimized for rapid overload recovery, both devices will recover from a 6dB overload within 1 clock cycle. The MAX1437B provides an impressive broadband SNR performance of 70.7dBFS for superior second-harmonic imaging, and a narrowband SNR of 140dBc/Hz at 1kHz offset for superior color flow and PWD sensitivity.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - 8 channels per package
  - Serial LVDS outputs
  - Compact 68-pin, 10mm x 10mm TQFN package
- **Low power for reduced heat dissipation and to facilitate designs with fewer PCBs**
  - 96mW per channel at 50Msps
- **High performance**
  - 70.3dBc broadband SNR for excellent second-harmonic imaging
  - 140dBc/Hz narrowband SNR at 1kHz offset from 5MHz FS tone for PWD and color flow
- **Feature rich for debugging and ease of design**
  - Test mode for digital signal integrity



Typical operating circuit for the MAX1437B.

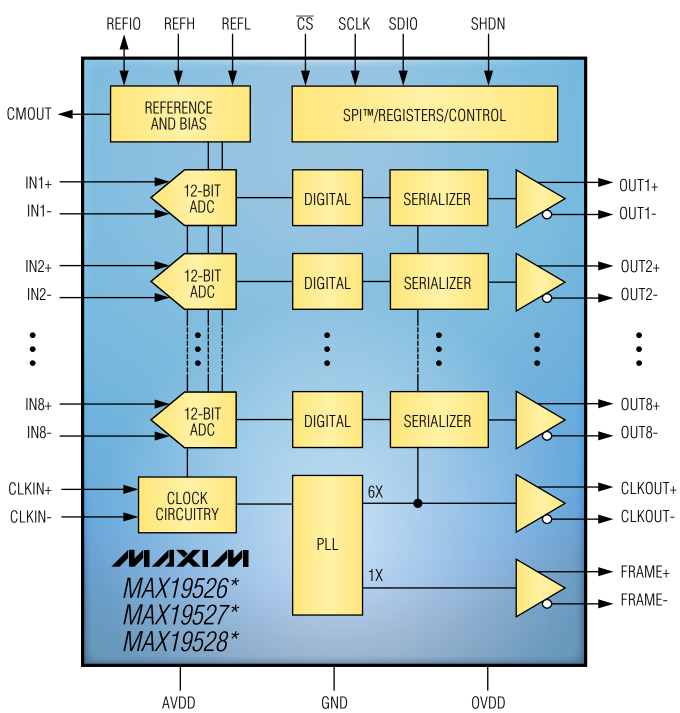
Ultra-low-power, 8-channel, 12-bit ADCs for portable and cart-based ultrasound imaging

MAX19526*/MAX19527/MAX19528*

The MAX19526/MAX19527/MAX19528 are ultra-low-power (52mW per channel at 40Msps), 40Msps to 64Msps, octal ADCs optimized for portable and price-sensitive, high-channel-count, cart-based ultrasound imaging applications. The ADCs achieve an impressive broadband SNR performance of 69dBFS for superior second-harmonic imaging, and a narrowband SNR of 140dBc/Hz at 1kHz offset. This performance provides superior color flow and PWD sensitivity. Further power savings can be achieved by proper utilization of the programmable LVDS output-current feature and the flexible nap and sleep modes. The devices also support differential clock inputs to reduce sensitivity to common-mode clock noise.

Benefits

- **High integration for high-channel-count, cart-based systems**
  - 8 channels per package
  - Serial LVDS outputs
  - Compact 68-pin, 10 mm x 10 mm BGA package
- **Ultra-low power improves reliability and reduces system costs**
  - 52mW per channel at 40Msps
- **High performance**
  - 69dBc broadband SNR for excellent second-harmonic imaging
  - 140dBc/Hz narrowband SNR at 1kHz offset from 5MHz FS tone for PWD and color flow
- **Flexible power-saving features**
  - Programmable LVDS output current
  - Sleep and fast-wake-up nap mode



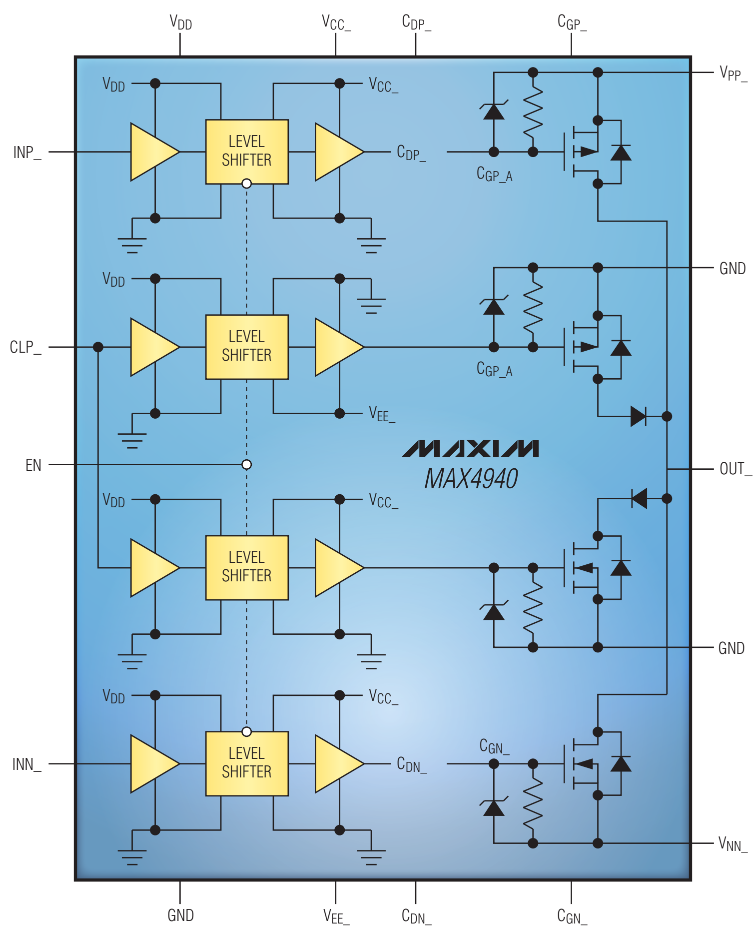
Typical operating circuit for the MAX19526/MAX19527/MAX19528.

*Future part—contact factory for availability.

Highly integrated digital pulsers use active clamping to enhance ultrasound imaging

MAX4940/MAX4940A

The MAX4940/MAX4940A dual/quad pulsers generate high-voltage, high-frequency, unipolar or bipolar (respectively) pulses from low-voltage logic inputs. The ICs feature independent logic inputs, independent high-voltage outputs with active clamps, and independent high-voltage supply inputs. These high-voltage pulsers provide 8.5Ω output impedance for the high-voltage outputs and a 21Ω impedance for the active clamp. The high-voltage outputs can provide 2.0A (typ) output current.



Typical operating circuit for the MAX4940.

Benefits

- **High density in smaller packages for high-channel-count, portable or cart-based systems**
  - Quad design (MAX4940A) with integrated active return to zero (RTZ)
  - TQFN (8mm x 8mm) package
- **High levels of integration**
  - Automatic, DC-coupled, 0.75A (typ) clamp feature improves 2D image quality
  - AC-coupled pulser (2A, typ) supports high-current output
- **Higher performance with lower power**
  - 15ns matched propagation delays for improved transmit focus
  - Matched rise/fall times and low second-harmonic distortion for improved second-harmonic imaging
  - -156dBc/$\sqrt{Hz}$ phase noise at 1kHz offset from a 1.25MHz transmit signal for improved low-velocity PWD and CWD sensitivity
  - Zero quiescent power consumption for longer battery life in portable imaging applications

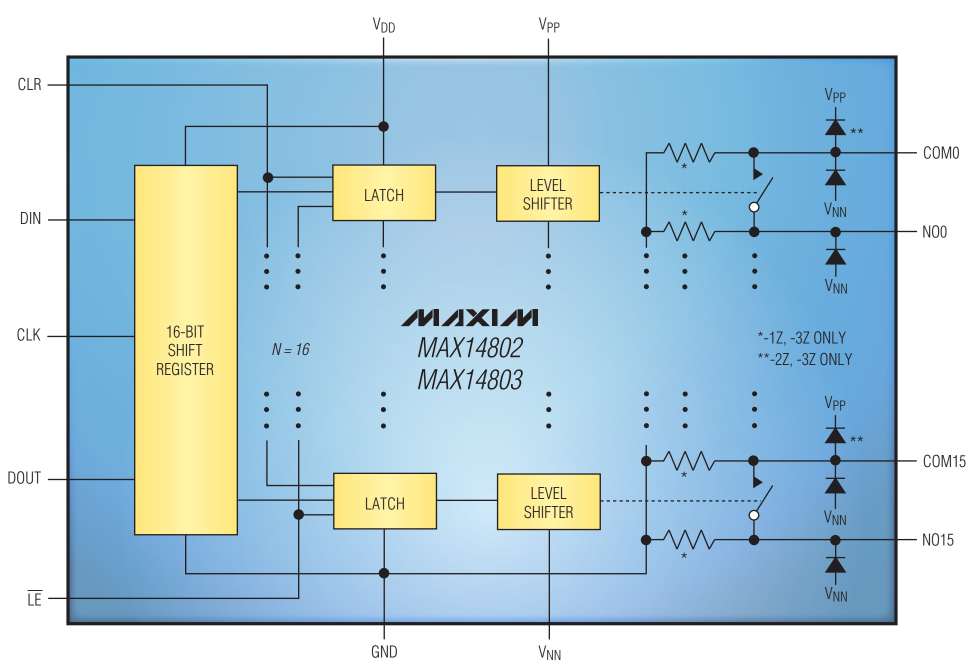
High-density, 16 channel, high-voltage switches allow design flexibility

MAX14802/MAX14803

The MAX14802/MAX14803 provide high-voltage switching on 16 channels for ultrasonic imaging. The devices utilize HVCMOS process technology to provide 16 high-voltage, low-charge-injection SPST switches, controlled by a digital interface. Data is clocked into an internal 16-bit shift register and retained by a programmable latch with enable and clear inputs. A power-on reset ensures that all switches are open on power-up

Benefits

- **High density in smaller packages facilitates smaller transducers**
  - 16 individually programmable high-voltage analog switches
  - 7mm x 7mm TQFP package; CSBGA available
- **Higher performance with lower power**
  - 20MHz serial interface (5V) facilitates higher frame rates
  - 0µA (typ) quiescent current for reduced power dissipation and heat
- **Integrated flexibility and system protection**
  - Integrated overvoltage protection (OVP) for improved reliability
  - Low-charge-injection, low-capacitance RL switches for reduced image artifacts
  - Daisy-chainable serial interface for efficient PCB layout
  - Flexible high-voltage supplies (V_{P-P}- V_{NN} = 250V) accommodate higher supply voltages

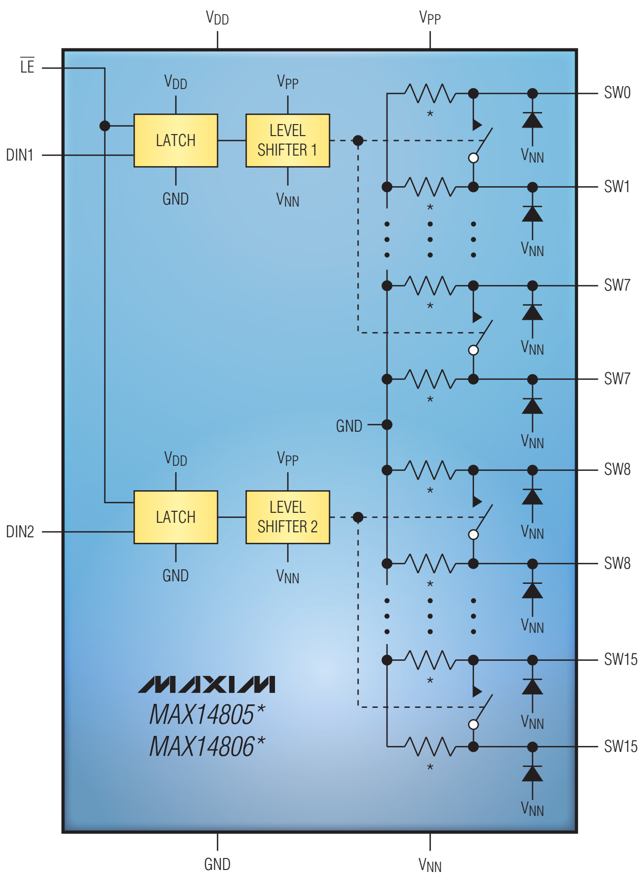


Typical operating circuit for the MAX14802/MAX14803.

Dual, 8-channel, high-voltage switches need no programming

MAX14805*/MAX14806*

The MAX14805/MAX14806 use 250V process technology to provide high-voltage switching on 16 channels configured as two sets of eight SPST switches for ultrasonic imaging. All switches are controlled by a digital interface. This design is optimized for banks selection in biplane or triplane ultrasound probes and relays replacement in medical ultrasound systems.



* BLEED RESISTORS AVAILABLE ON THE MAX14806 ONLY.

Typical operating circuit for the MAX14805/MAX14806.

Benefits

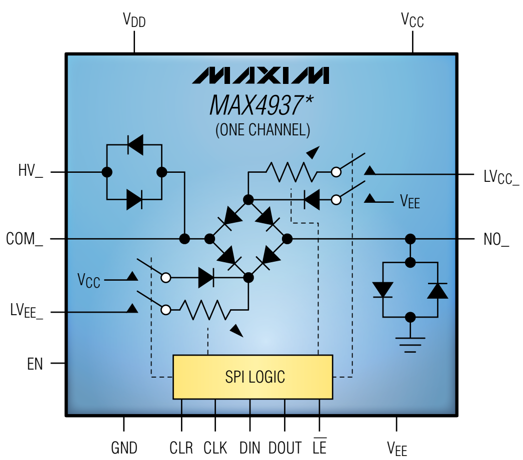
- **High density in smaller packages facilitates smaller transducers**
  - Two sets of eight high-voltage SPST analog switches
- **Higher performance with lower power**
  - DC to 20MHz low-voltage, analog signal-frequency range facilitates higher-frequency imaging
  - Very low quiescent current for reduced power dissipation and heat
  - -77dB (typ) off-isolation at 5MHz (50Ω) for improved 2D image quality
- **Integrated application flexibility**
  - Flexible high-voltage supplies accommodate higher supply voltages
  - 2.7V to 5.5V logic supply voltage for improved ease of use
  - Low-capacitance 20Ω switches for reduced image artifacts
  - Version with bleed resistor available

*Future part—contact factory for availability.

Octal, high-voltage Tx/Rx switches replace discrete components and reduce board space by half

MAX4936*–MAX4939*

The MAX4936–MAX4939 are highly integrated octal, high-voltage Tx/Rx switches. A latch-clear input asynchronously turns off all Tx/Rx switches and puts the devices into a low-power shutdown mode. Each Tx/Rx switch is based on a diode-bridge topology. The amount of current in all the bridges can be programmed with the SPI interface. The switches can be individually turned on and off with SPI for receiver-path multiplexing applications.



Typical operating circuit for the MAX4937.

Benefits

- **High density in smaller packages for high-channel-count, portable or cart-based systems**
  - Octal Tx/Rx switches
  - SPI-programmable switches for reduced pin count and smaller size
  - Low-voltage receive path with high-voltage protection (±110V)
  - Versions available with high-voltage transmit path and low-voltage isolation (grass-clipping diodes)
- **Higher performance with lower power**
  - Individually programmable, 4-bit binary bias resistors (from 187Ω to 2800Ω) for optimized power and performance
  - Low output noise for improved sensitivity
  - Wide -3dB bandwidth at 80MHz facilitates wideband, high-frequency imaging
  - Low 8Ω at 10mA on-impedance for reduced noise and improved sensitivity
  - Dedicated voltage supply allows use of external inductors for better SNR, crosstalk, and power-supply rejection ratio (PSRR)
- **Feature rich for design flexibility**
  - Flexible power supplies (V_{CC}, V_{EE} = +2.7V to +5.5V, V_{DD} = +1.8V to +5.5V) for ease of design

*Future part—contact factory for availability.

Recommended solutions

Part	Description	Features	Benefits
AFEs			
MAX2034	Quad ultrasound LNA	Ultra-low noise; programmable active-input termination; integrated input-protection diodes	Quad ultrasound-specific LNA allows flexible partitioning
MAX2035	Octal ultrasound VGA	High dynamic range; compatible with 10-bit ADCs	Performance optimized for economical 10-bit ADC imaging architectures
MAX2036	Octal ultrasound VGA with CW octal mixers	Compatible with 10-bit ADCs; low noise; high dynamic range; fully integrated mixer-based CWD beamformer	Performance optimized for economical 10-bit ADC imaging architectures; integrated CWD beamformer
MAX2037	Octal ultrasound VGA	Low noise; high dynamic range; compatible with 12-bit ADCs	Best performance for 12-bit ADC imaging architectures
MAX2038	Octal ultrasound VGA with integrated CW octal mixers	High dynamic range; compatible with 12-bit ADCs; fully integrated mixer-based CWD beamformer	Best performance for 12-bit ADC imaging architectures; integrated CWD beamformer
MAX2077	Octal ultrasound front-end with LNA, VGA, and lowpass AAF	Programmable active-input termination LNA; low noise; high dynamic range; 65mW per channel	High integration and high-sensitivity 2D and PWD for high-channel-count, cart-based systems
MAX2078	Octal ultrasound front-end with LNA, VGA, lowpass AAF, and CWD mixers	Programmable active-input termination LNA; low noise; high dynamic range; 65mW per channel; fully integrated mixer-based CWD beamformer	Saves space and power in high-channel-count systems; high-sensitivity 2D, PWD, and CWD for high-channel-count, cart-based systems
MAX2079*	Octal, ultrasound front-end with LNA, VGA, lowpass AAF, CWD mixers, 12-bit, 50Msps ADC	Programmable active-input termination LNA; low noise; high dynamic range; 12-bit ADC; 115mW per channel; fully integrated mixer-based CWD beamformer	Saves space and power in portable imaging applications, high-sensitivity 2D, PWD, and CWD, improved image quality
High-speed ADCs			
MAX1193	Dual, 8-bit, 45Msps ADC	Ultra-low power	Extends battery life for portable ultrasound
MAX1434	Octal, 10-bit, 50Msps ADC	Space-saving serial LVDS interface; compact TQFP package	Ideal for low-cost systems
MAX1436/37/38	Octal, 12-bit, 40/50/65Msps ADCs	High-broadband and narrowband SNR; low-power; space-saving serial LVDS interface	High-performance 2D and PWD image quality
MAX1437B/38B	Octal, 12-bit, 50/64Msps ADCs, 10mm x 10mm package	High density, high-broadband and narrowband SNR; low power; serial LVDS interface	High-integration and compact design for high-channel-count, cart-based systems
MAX19526*/ 27*/28*	Octal, 12-bit, 40/50/64Msps ADCs, 10mm x 10mm package	High density, high-broadband and narrowband SNR; ultra-low power, serial LVDS interface; 53mW per channel at 40Msps	Uncompromised 2D and Doppler sensitivity; ultra-low power; ultra-small package
High-speed DACs			
MAX5180	Dual, 10-bit, 40MHz, current-output simultaneous-update DAC, 6mm x 10mm package	Fully differential output; interleaved data bus; 11mW per channel at 40Msps	Space-saving solution for generating high-performance transmit arbitrary waveforms
MAX5183	Dual, 10-bit, 40MHz, voltage-output simultaneous-update DAC	Dual channels; interleaved data bus; 11mW per channel at 40Msps; 6mm x10mm package	Ultra-low power; compact solution for generating high-performance transmit arbitrary waveforms
MAX5853	Dual, 10-bit, 80Msps, current-output DAC	Interleaved data bus option; 29mW per channel at 80Msps; 6mm x 6mm package	Space-saving solution for generating high-performance transmit arbitrary waveforms
High-voltage muxes			
MAX4800/02	8-channel, high-voltage analog switches	Low charge injection; low capacitance; low R_{ON}	Reduce associated image artifacts
MAX4800A/02A	8-channel, high-voltage analog switches with 20MHz serial interface	Low charge injection; low capacitance; low R_{ON}; fast SPI interface	Low charge injection reduces image artifacts; fast SPI interface improves frame rate
MAX14802/03	16-channel, high-voltage analog switches with SPI interface	Low charge injection; integrated OVP; low capacitance; fast turn-on/off times	Reduce system and/or transducer size; ideal for space-constrained solution

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
High-voltage muxes (continued)			
MAX14805*/06*	Dual, 8-channel, high-voltage analog switches with low charge injection	Integrated OVP; low capacitance; switchable banks; fast turn-on/off times	Faster frame rates; low spurious transmissions; fewer associated artifacts
High-voltage pulsers			
MAX4806/07	Dual, 2A (min), unipolar/bipolar, high-voltage digital pulsers	Active-clamp circuitry for reduced second-harmonic output; low jitter; low power; 7mm x 7mm TQFN package	Improve Doppler sensitivity to low-velocity flow; improve second-harmonic imaging
MAX4810/11	Dual, 1.3A (min), unipolar/bipolar, high-voltage digital pulsers	Reduced second-harmonic output; low jitter; low power; 7mm x 7mm TQFN package	Improve second-harmonic imaging; improve Doppler sensitivity to low-velocity flow
MAX4940/ MAX4940A	Quad, 2.1A (typ), unipolar/bipolar, high-voltage digital pulsers	Active-clamp circuitry for reduced second-harmonic output; low jitter; matched rise/fall times; matched propagation delays	Improve second-harmonic distortion; enhance image quality
High-voltage Tx/Rx switches			
MAX4936*–MAX4939*	Octal, integrated, high-voltage Tx/Rx switches, 5mm x 11mm package	SPI-programmable bias resistors; low on-impedance; versions with high-voltage transmit-path protection and low-voltage isolation	Save space and power in high-channel-count and portable ultrasound systems
Audio headphone drivers			
MAX4230–MAX4234	Single/dual/quad, 10MHz, low-noise op amps	$10nV/\sqrt{Hz}$, excellent RF immunity; shutdown; small SC70 package	Smallest footprint for portable systems
MAX9724	60mW, fixed-gain, DirectDrive®, stereo headphone amplifier with low RF susceptibility and shutdown	Click-pop suppression; small package; low 0.003% THD+N; excellent RF immunity	Eliminates need for DC-blocking capacitors; reduces size and cost
MAX9705	2.3W, ultra-low-EMI, filterless, Class D audio amplifier	Class D efficiency and 0.02% THD+N	Efficient solution and ultra-low EMI; speeds time to market
MAX9718/19	Low-cost, mono/stereo, 1.4W differential, audio power amplifiers	Class AB with superior THD+N down to 0.002%	Simple, high-fidelity solution
Fan controller			
MAX6639	2-channel temperature monitor and PWM fan controller	Internal and external temperature measurement; closed-loop RPM control	Closed-loop control over fan speed minimizes noise and power
Fuel gauges			
DS2782	I^2C fuel gauge	FuelPack™ algorithm with precision voltage, current, temperature monitor; EEPROM	Improves battery-status reporting
DS2776/78	1-Wire®/I^2C, 2-cell stand-alone fuel gauges with Li+ protector and SHA-1 authentication	FuelPack algorithm with precision voltage, current, and temperature monitor; programmable protector; SHA-1 authentication	Save space and simplify design
DS2788	Stand-alone fuel gauge with LED drivers for multiple cells	FuelPack algorithm with precision voltage, current, and temperature monitor; programmable resistive-divider switch; LED drivers	Simplifies high-cell-count designs
MAX1789	2-/3-/4-cell battery fuel gauge and protector	Accurate fuel gauge; 8-bit RISC microcontroller core; integrated primary-protection IC	High accuracy; maximizes battery utilization
LED drivers			
MAX7313	16-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V; global and individual PWM intensity control with blinking	Tolerates lower supply voltage; simplifies driving LED indicators and backlights
MAX7315	8-port I/O expander with LED intensity control, interrupt, and hot-insertion protection	2.0V to 3.6V; 50mA output drive; global and individual PWM intensity control with blinking	Tolerates lower supply voltage; drives heavier loads; simplifies driving LED indicators and backlights

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
LED drivers (continued)			
MAX7323	I²C port expander with four push-pull outputs and four open-drain I/Os	1.71V to 5.5V; I²C; 20mA	Operates from low supply voltage while I/O operates at 6V, thus simplifying power design
Low-speed ADCs			
MAX1162	SAR ADC, serial	16-bit; 200ksps; 10µA shutdown; low 12.5mW power dissipation; 10-pin µMAX® package	Preserves battery life; saves space for portable systems
MAX1132	SAR ADC, serial	16-bit with no missing codes; 200ksps; single channel; 0 to 12V or ±12V input, integrated reference	High precision for wide input-voltage ranges; integration saves space and cost
Low-speed DACs			
MAX5580	Buffered, fast-settling, 12-bit DAC	3µs (max) settling time to 0.5 LSB; internal buffer; glitch-free buffered output	Saves board space with no need for an external buffer
MAX5661	Single-channel, 16-bit DAC with serial interface	Current- or voltage-buffered output	Saves space
Op amps			
MAX4475–MAX4478 MAX4488/89	Low-noise, low-distortion, CMOS-input op amps in a SOT23 package	4.5nV/$\sqrt{Hz}$ input noise; excellent distortion characteristics; 750µV (max) V_{OS}; tiny package	Save board space; excellent SNR for improved CWD sensitivity; RF immunity makes them ideal for use in sensitive environments
MAX410/12/14	Single/dual/quad, 28MHz, low-noise, low-voltage, precision op amps	1.5nV/$\sqrt{Hz}$ low-input noise, precision 250µV (max) V_{OS} and large 28MHz bandwidth; single 5V and dual ±5V rails; small TDFN package	Save board space; excellent SNR for improved CWD sensitivity
MAX9632*	36V precision, low-noise, wideband op amp	1.1nV/$\sqrt{Hz}$; 55MHz; 30V/µs; 125µV (max) V_{OS}; rail-to-rail output; fast 700ns settling to 16-bit accuracy; 3mm x 3mm small TDFN package	High-performance ADC driver for 24-bit delta-sigma converter-based systems; improves system resolution and performance
MAX9633*	36V dual op amp for 16-bit SAR ADC front-ends	2.8nV/$\sqrt{Hz}$; 36MHz; 18V/µs; 100µV (max) V_{OS}; fast 600ns settling to 16-bit accuracy; 3mm x 3mm small TDFN package	High-performance ADC driver for 16-bit SAR ADC converters improves CWD system resolution and performance
Power			
MAX5072	Dual-output buck or boost converter	2.2 MHz; dual outputs with POR and PFO	High frequency and internal FETs reduce total solution size
MAX1951	1MHz, all-ceramic, 2.6V to 5.5V input, DC-DC regulator	2.6V to 5.5V input; 2A; internal FET	Internal FET reduces complexity
MAX8556	Ultra-low-input-voltage LDO regulator	1.425V to 3.6V input voltage range; 4A output current	High current; fully protected from an output short circuit; provides robust design
References			
MAX6034_25	Precision, micropower, low-dropout, series voltage reference in SC70 package	25ppm/°C (max) temperature coefficient (-40°C to +85°C); ±0.2% (max) initial accuracy	More stability versus ambient temperature variations improves measurement repeatability
MAX6033	Ultra-high-precision, series voltage reference in SOT23 package	Ultra-low 7ppm/°C (max) temperature drift; low 16µV_{P-P} noise (0.1Hz to 10Hz) (2.5V output)	Reduces integrated systems noise
MAX6029	Ultra-low-power, precision series voltage reference	Ultra-low 5.25µA (max) supply current; 30ppm/°C (max) temperature coefficient	Saves power in handheld applications; increases stability over temperature
MAX6173	High-precision voltage reference with temperature sensor	Wide (V_{OUT} + 2V) to +40V supply voltage range; excellent 3ppm/°C (max) temperature stability; low 3.8µV_{P-P} noise	Wide operating voltage levels; improved performance over temperature; better systems-noise budget

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*Future part—contact factory for availability.

Recommended solutions *(continued)*

Part	Description	Features	Benefits
RF ICs			
MAX2830	2.4GHz to 2.5GHz RF transceiver with power amplifier	ISM band operation; integrates all circuitry required to implement the RF transceiver function	Saves space by eliminating the need for an external SAW filter
MAX2900–MAX2904	200mW single-chip transmitters for 868MHz/915MHz ISM bands	Comply with the FCC CFR47 part 15.247 902MHz to 928MHz ISM band specifications	High integration with minimal external components
MAX7030	Low-cost, factory-programmed ASK/OOK transceiver	Low current; compact package; no programming interface required	Long battery life; smaller size; faster and simpler product design
MAX7031	Low-cost, factory-programmed FSK transceiver	Low current; compact package; no programming interface required	Smaller size; faster and simpler product design
Supervisors			
MAX6720	Triple-voltage supervisor	Two fixed, one adjustable thresholds	Versatile for easy design reuse; saves space in small modules
MAX6746	Capacitor-adjustable watchdog and reset IC	Capacitor-adjustable timing; low power	Complete system management in easy-to-use, integrated solution
MAX16033	Battery-backup switchover	Battery backup; reset, chip-enable gating; PFI/PFO	Versatile for easy design reuse; saves space in small modules
MAX16054	Pushbutton on/off controller	±15kV ESD protection	Saves space and increases reliability by combining multiple functions in one IC
MAX6495	72V overvoltage protector	Easy to use; highly integrated	Increases system reliability by preventing component damage from high-voltage transients; saves space; easy to use
Temperature sensors			
DS600	Precision, analog-output temperature sensor	Industry's highest accuracy: ±0.5°C from -20°C to +100°C	Improved system temperature-monitoring accuracy
DS7505	Low-voltage, precision 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 upgrade
DS75LV	Low-voltage 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 allows easy conversion from LM75 to lower supply voltage
Video filters			
MAX9502G/M	2.5V video amplifiers with reconstruction filter	6-pin µDFN and 5-pin SC70 packages; low cost; DC-coupled input and output; low-current shutdown; fixed 6dB/12dB gain	Small size for portable applications; reduce component count, low-power shutdown mode
MAX9652/53/54	3.3V, HD/SD triple-channel filter amplifiers with shutdown	2V/V gain; 42MHz passband for high definition (HD) with 50dB attenuation at 109MHz	Selectable lowpass filter (MAX9654) allows for HD/SD switchable operation
MAX9586–MAX9589	Single/dual/triple/quad, standard-definition (SD) video filter amplifiers with AC-coupled input buffers	Low power; small size; 8.5MHz passband; 55dB attenuation at 27MHz	Multiple video input streams with combination of sync-tip clamp or bias clamp provide flexibility
MAX9507	1.8V DirectDrive video filter amplifier with load detection	Dual SPST analog switches controlled through I^2C; internal gain of 8V/V	DirectDrive sets black-level output to ground, reduces number of passive components required
MAX7450/51/52	Video signal conditioners with AGC and back-porch clamp	Back-porch clamp-to-GND (adj); fault detection with loss-of-signal (LOS) output; settable 0dB/6dB gain	Automatic gain control (AGC) and output clamp control improve signal quality

For a list of Maxim's recommended ultrasound solutions, please go to: www.maxim-ic.com/ultrasound.