ANALOG DEVICES
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ADI's Medical Ultrasound Solutions

Medical Ultrasound System Theory and Typical Architecture

By transmitting acoustic energy into the body and receiving and processing the returning reflections, ultrasound systems can generate images of internal organs and structures, map blood flow and tissue motion, and provide highly accurate blood velocity information.

Ultrasound systems include transducers, high voltage multiplexing, high voltage transmitters, transmit/receive switches, receive-path analog front end (AFE), beamformers, beamformed digital signal processing, display processing, and peripherals. The AFE includes a low noise amplifier (LNA); a variable gain amplifier (VGA); an antialias filter (AAF); and an analog-to-digital converter (ADC). There are two kinds of beamformers: digital beamformers and analog beamformers for different applications.

Medical Ultrasound System Design Considerations and Major Challenges

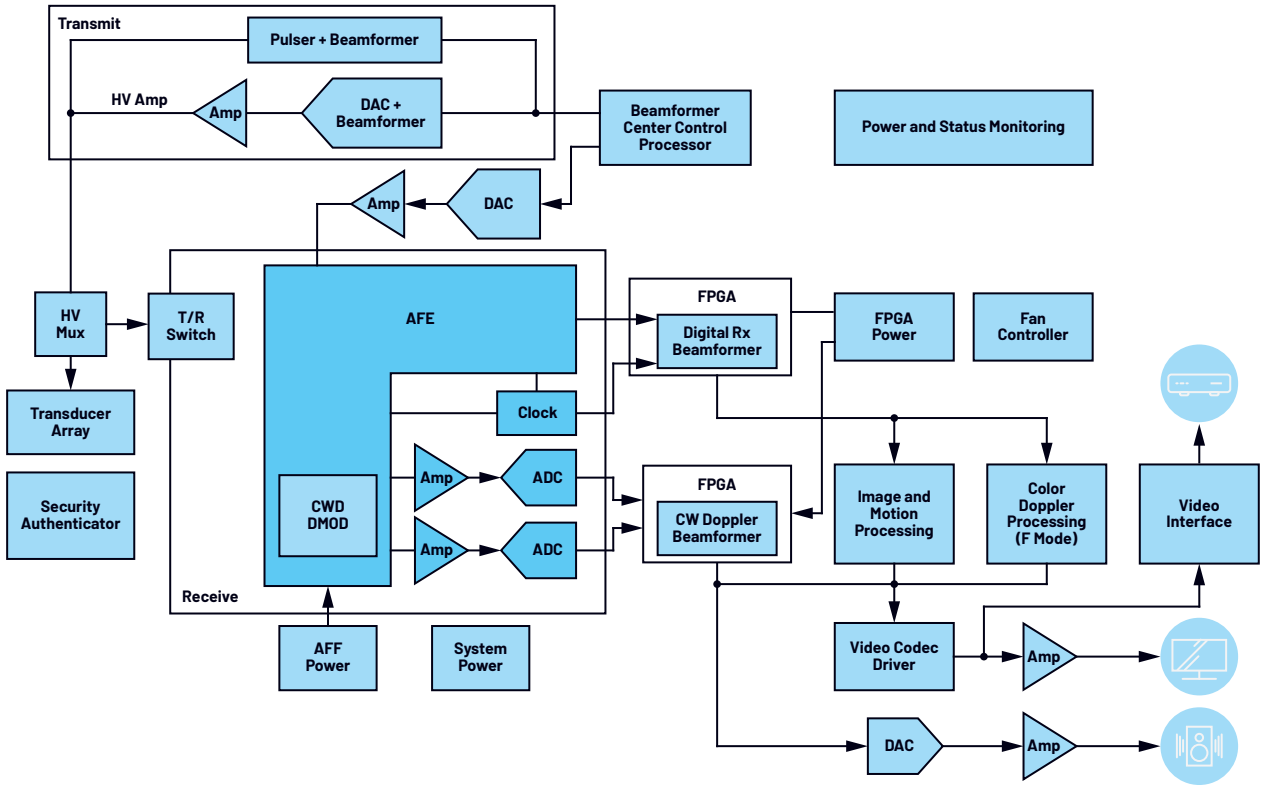
- Receiver AFE circuit performance such as noise performance, SNR (signal-to-noise ratio), and DR (dynamic range) are typically required for high end systems. The DR is 70 dB for B mode, 130 dB for PWD (pulse wave Doppler), and 160 dB for CWD (continuous wave Doppler).
- Beamformer complexity: high image quality requires a large number of beamforming channels. Increased complexity in turn leads to higher power dissipation and requires more imaging volume to implement.
- Transmit voltage: high transmit voltages are needed to improve signal penetration and also for harmonic imaging. Acoustic power grows as the transmit voltage is increased, but it is limited by safety requirements from agencies such as the FDA.
- Heat dissipation is an important issue for miniaturized devices, particularly when improved image quality is the goal.

Historically, the large number of high performance 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 cart-based systems. The challenge moving forward is to continue driving the integration of these solutions, while increasing their performance and diagnostic capabilities. As linear transmit can increase the SNR and improve the image quality significantly, linear transmit solutions are adopted more and more in premium and high end systems.

Total Solutions from ADI

ADI provides an extensive selection of transceiver, transmit, receiver, amplifier, data conversion, signal processing and power management solutions to maximize image quality and to reduce power consumption and cost in cart-based and portable ultrasound equipment. In addition, ADI provides evaluation boards, schematics, gerber files, simulation tools and applications expertise to support customer design and development efforts.

Main Signal Chain



Notes: The signal chain above is representative of medical ultrasound 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.

Market Category

Transceiver	Integrated Analog Front End	Transmit Pulser	HV Mux	Transmit/ Receive Switch	Cable Driver/ In Probe Amplifier	Transmit DAC
MAX2087J/ MAX2087/ MAX2086	AD9670/AD9671/ AD9674/AD9675/ AD9279/AD9278/ AD9273/ MAX2084/MAX2088	MAX14815/MAX14813/ MAX14987/MAX14988/ MAX14808	MAX14866/ MAX4968/ MAX4968B	MAX4936A/ MAX4936/ MAX4937	MAX14822/ MAX4805	AD9106/AD9709/ AD9763/AD9765/ AD9767

Transmit HV Amp	TGC control DAC	Clocking	Power Module	Silent Switcher® Device	LDO Regulator	Battery Charge	Voltage Reference
MAX14807	AD9709/AD9706/ AD9742/AD5424/ AD5433/AD5445	AD9528/AD9524/ AD9515/ADCLK9xx/ ADCLK8xx	LTM8060/ LTM4644/LTM8049/ LTM8074/LTM4625	LT8648S/ LT8625S	ADM7171/ ADM7170/LT3015/ LTC3070/LT3086	LTC4015/ LTC4162/ LTC4020	ADR45xx/ LT665x/ ADR35xx

I/Q Demodulator	ADC (CWD)	Amplifier (CWD)	Authentication	Video Processing	Audio Processing	Analog Switch	Sequencer/ Fan Controller
AD8333/ AD8339	AD4003/ AD4007/ AD7982	ADA4987/ ADA4896/ ADA4945-1	DS28E50/ DS2477/ DS28E39	ADV712x/ADV739x/ ADV202/ADV212/ ADV216/ADV7180/ ADV7441/ADA4420/ ADA4417	MAX98400A/ MAX98390/ MAX9809x/ ADAU1361/ ADAU1761	ADG714/ ADG619	ADM106x/ MAX31790/ MAX665x/ LTC2924

Introduction of Main Products for Medical Ultrasound

Part	Description	Benefits
Transceiver		
MAX2087J	8-channel transceiver with 5-level pulser, transmit/receive switch, integrated AFE, with 14-bit ADC and CWD mixers and JESD204B outputs; 0.8 nV/√Hz @ 24 dB Vn RTI LNA with a 27 dB VGA, an AAF, a 14-bit 65 MSPS ADC, phase noise: –141 dBc/Hz at 1 kHz; 200 V p-p with up to 2 A current capability and features an integrated 2 A active clamp together with transmit beamforming; The LVDS interface version is MAX2087	Fully integrated high performance ultrasound transceiver, small size, easy for design
MAX2086	8-channel transceiver with 3-level pulser, transmit/receive switch, integrated AFE, with 14-bit ADC and CWD mixers and LVDS outputs; 0.8 nV/√Hz @ 24 dB Vn RTI LNA with a 27 dB VGA, an AAF, a 14-bit 65 MSPS ADC, phase noise: –141 dBc/Hz at 1 kHz; 200 V p-p with up to 2 A current capability and features an integrated 2 A active clamp together with transmit beamforming	Fully integrated high performance ultrasound transceiver, small size, easy for design
Integrated Analog Front End (AFE)		
AD9670	8-channel AFE of a 0.78 nV/√Hz @ 21.6 dB Vn RTI LNA with a 45 dB VGA, an AAF with LPF 8 MHz to ~18 MHz or 13.5 MHz to ~30 MHz and HPF, a 14-bit, 10 MSPS to 125 MSPS ADC; 130 mW/ch @ 40 MSPS, and a digital demodulator and decimator for data processing and bandwidth reduction, also an I/Q demodulator with programmable phase rotation; AD9674 is the version without a digital demodulator	Low cost, low noise, high resolution, small size, reduces FPGA I/O and computational rate for beamformer and processors
AD9671	8-channel AFE of a 0.78 nV/√Hz @ 21.6 dB Vn RTI LNA with a 45 dB VGA, an AAF with LPF 8 MHz to ~18 MHz or 13.5 MHz to ~30 MHz and HPF, a 14-bit, 10 MSPS to 125 MSPS ADC; 130 mW/ch @ 40 MSPS, and a digital demodulator and decimator for data processing and bandwidth reduction, also an I/Q demodulator with programmable phase rotation; AD9675 is the version without digital demodulator	Four configurable 5 Gbps serial JESD204B CML data lanes provide an interface for further data processing; reduces the number of FPGA I/O and components
AD9273	8-channel AFE of a 1.26/√Hz @ 21.3 dB Vn RTI LNA with a 42 dB VGA, an AAF with LPF 8 MHz to ~18 MHz and HPF, and a 12-bit, 10 MSPS to 50 MSPS ADC; 104 mW/ch @ 40 MSPS, also an 8 differential × 8 differential crosspoint switch is included for CW Doppler	Low cost, low power, small size, and ease of use for medical ultrasound application
AD9278	8-channel AFE a 1.3 nV/√Hz @ 21.3 dB Vn RTI LNA with a 45 dB VGA, an AAF with LPF 8 MHz to ~18 MHz and HPF, and a 12-bit, 10 MSPS to 65 MSPS ADC; 88 mW/ch @ 40 MSPS, also an I/Q demodulator with programmable phase rotation for CW Doppler	Low cost, small size, lowest power and ease of use for medical ultrasound application
MAX2084	16-channel AFE of transmit/receive switch, integrated AFE, with 14-bit ADC and CWD mixers and LVDS outputs; 0.8 nV/√Hz @ 24 dB Vn RTI LNA with a 27 dB VGA, an AAF, a 14-bit 65 MSPS ADC, phase noise: -141 dBc/Hz at 1 KHz; MAX2088 is the version without a transmit/receive switch	High integration, low cost, small size, ultralow phase noise help for high image quality
Transmit Pulser		
MAX14815	8-channel 5-level pulser, integrated transmit/receive switch, and beamforming; 200 V p-p with up to 2 A current capability and features an integrated 2 A active clamp; –40 dBc @ 5 MHz THD2 and pulse inversion; low propagation delay: 12 ns (typ); MAX14813 is the 3-level version	12 × reduction of FPGA I/Os and interconnects, high density and high bandwidth saves PCB size
MAX14987	8-channel 5-level pulser, integrated transmit/receive switch; 210 V p-p with up to 2.5 A current capability and features an integrated 2.5 A active clamp; -40 dBc @ 5 MHz THD2 and pulse inversion; low propagation delay: 11 ns (typ); MAX14988 is the 3-level version	Direct coupling eliminates external caps, high integration power supplies save board space, no power sequencing simplifies design
HV MUX		
MAX14866	16-channel, high voltage linear SPST switches supporting all possible mux configurations; operates from 5 V supply only; low R_{ON} (7 Ω typ), low charge injection <100 pC	HV-less feature eases probe regulatory compliance and safety low R_{ON}; good linearity
T/R Switch		
MAX4936A	8-channel, high voltage transmit/receive switches; low 6 Ω (typ) on-impedance with 1.5 mA bias current only; low noise at low power consumption (< 0.5 nV/√Hz (typ) with 1.5 mA bias current); wide -3 dB lowercase 100 MHz (typ)	Standalone transmit/receive switch provides design flexibility; ultralow on impedance helps for better signal
In Probe Amp		
MAX14822	16-channel, high voltage protected, lower noise, operational amplifier; up to ±105 V high voltage protection, selectable voltage gain: 0 dB, 3.5 dB, 6 dB, 9.5 dB; 1.28 nV/√Hz Vn RTI (typ) (bias = 1, gain = 6 dB)	Improves system SNR for high frequency probes; no change required at system level
Transmit DAC + Beamformer		
AD9106	Quad, 12-bit, 175 MSPS DAC integrating 4096 × 12 on-chip pattern memory for complex waveform generation with one output direct digital synthesizer (DDS) and SPI interface to configure and load waveform data; phase noise @ 1 kHz output, 175 MSPS, 8 mA: –140 dBc/Hz	Suitable for ultrasound linear transmit signal waveform generation and transmit beamformer; small size and low power consumption
Transmit HV Amplifier		
MAX14807	Dual, high voltage 2.2 A analog pulser with HV amplifier up to 220 V p-p and low voltage for CWD signal or a trilevel HV pulse from low voltage digital inputs; -54 dB (typ) THD for second and third harmonic at 5 MHz (analog mode); low phase noise (-120 dBc/Hz in analog mode, 156 dBc/Hz in digital mode)	Linear transmit provides higher SNR and better image quality

Introduction of Main Products for Medical Ultrasound (Continued)

Part	Description	Benefits
ADC		
AD7982	18-bit, 1 MSPS, 7 mW, PulSAR differential ADC, 98 dB SNR; pin-pin compatible with: AD7984 (1.33 MSPS), AD7986 (2 MSPS)	High speed and accuracy; pin for pin compatible series can be flexibly selected for ultrasound CW path
AD4007	18-bit, 1 MSPS, 8 mW, PulSAR differential ADC, 100.5 dB SNR; pin for pin compatible with AD4003 (2 MSPS)	High SNR, pin for pin compatible series can be flexibly selected for ultrasound CW path
Amplifiers		
ADA4897/ ADA4896	Low wideband noise: 1 nV/√Hz and 2.8 pA/√Hz; Low 1/f noise: 2.4 nV/√Hz @ 10 Hz, 80 mA output current, rail-to-rail output	Suitable for ultrasound CW path I/V, summing and ADC driver application
ADA4945-1	Fully differential ADC driver, noise RTI: Vn 1.8 nV/√Hz and In 1.1 pA/√Hz; rail-to-rail output	Suitable for ADC driver, low noise for small signal conditioning
I/Q Demodulator		
AD8339	DC to 50 MHz, quad I/Q demodulator and phase shifter; 16 phases select on each output (22.5° per step); dual version: AD8333	The only standalone ultrasound CW I/Q demodulator in the market
DAC		
AD5424/ AD5433/ AD5445	AD5424/AD5433/AD5445 are CMOS 8-bit, 10-bit, and 12-bit current output DACs, respectively; update rate: 20.4 Msps	Suitable for ultrasound TGC gain control circuits
AD9706	12-bit current output DAC, update rate: 175 MSPS; pin-for-pin compatible with 8-/10-/14-bit version: AD9704/ AD9705/AD9707	Suitable for ultrasound TGC gain control high speed differential circuits
Analog Switch		
ADG714	Octal SPST (single-pole, single-throw) switch controlled via a 3-wire serial interface, 0.6 Ω on-resistance flatness; t_{ON} = 35 ns (typical) and t_{OFF} = 11 ns (typical)	Low on resistance and fast on/off time guarantees the signal integration
ADG619	Single-pole double-throw (SPDT) switches, 0.8 Ω (maximum) on-resistance flatness; t_{ON} = 80 ns (typical) and t_{OFF} = 45 ns (typical)	Low on resistance and fast on/off time guarantees the signal integration
Voltage Reference		
ADR45xx	Ultralow noise, voltage references with current sink and source; 0.04% accuracy and 4 ppm/°C for A grade, 0.02% accuracy and 2 ppm/°C for B grade	Low drift and high accuracy benefit ADC sampling performance
LTC6655	Ultralow noise, voltage references with current sink and source; 0.025% accuracy and 2 ppm/°C for B grade, 0.05% accuracy and 5 ppm/°C for B grade	Low drift and high accuracy benefit ADC sampling performance
Clocking		
ADCLK8xx/ ADCLK9xx	Multi-output fan-out buffer optimized for low jitter and low power operation; additive broadband jitter less than 500 fs	Well-suited for low jitter ultrasound clock distribution
AD9528	JESD204B clock generator with 14 LVDS/HSTL outputs; dual on-chip PLLs and VCO; absolute output jitter <160 fs @ 122.88 MHz	Well-suited for low jitter ultrasound clock generation and distribution
Audio Amplifiers		
SSM2356	2 W × 2 W into 4 Ω load and 2 W × 1.4 W into 8 Ω load at 5.0 V supply with <1% total harmonic distortion, 92% efficiency at 5.0 V, 1.4 W into 8 Ω speaker, 103 dB SNR	High efficiency, low distortion suited for ultrasound Doppler audio output
MAX98400A	Class D amplifiers, 2 W × 20 W into 8 Ω loads or 1 W × 40 W into a 4 Ω load	High performance provides high output capability for ultrasound audio
Audio DAC		
ADAU1361	Low power, stereo audio codec that supports stereo 48 kHz record and playback at 14 mW; 24-bit stereo audio ADC and DAC: >98 dB SNR	Suitable for ultrasound Doppler audio application
Video DAC		
ADV739x	ADV739x are a family of high speed, video encoders on single monolithic chips; three 2.7 V/3.3 V 10-bit video DACs provide support for composite (CVBS), S-Video (YC), or component (YPrPb/RGB) analog outputs in either standard-definition (SD) or high-definition (HD) video formats	Suitable for ultrasound image display and video application
ADV7125	Triple high speed, digital-to-analog converter on a single monolithic chip; It consists of three 8-bit video DACs with complementary outputs, a standard TTL input interface, and high impedance, analog output current source	Suitable for analog VGA output in ultrasound image display
Authentication		
DS28E50	DeepCover secure SHA-3 authenticator with ChipDNA PUF protection	Authentication of ultrasound probe
DS2477	DeepCover secure SHA-3 coprocessor with ChipDNA PUF protection	Authentication of ultrasound probe
DS28E39	DeepCover secure ECDSA bidirectional authenticator with ChipDNA PUF protection	Authentication of ultrasound probe

Introduction of Main Products for Medical Ultrasound (Continued)

Part	Description	Benefits
Power Module		
LTM8060	Quad 40 V_{IN}, V_{OUT}: 0.8 V to 8 V, 3 A step-down Silent Switcher module regulator, four outputs can be paralleled in an array for up to 12 A capability	Low noise, low EMI and synchronous function suited for ultrasound application
LTM4644	Quad step-down µModule® regulator with 4 A per output, V_{IN}: 2.375 V to 14 V, V_{OUT}: 0.6 V to 5.5 V, can be paralleled in an array for up to 16 A capability	Suitable for FPGA and digital circuits power supply
LTM8074	40 V_{IN}, 1.2 A Silent Switcher µModule regulator; V_{IN}: 3.2 V to 40 V, V_{OUT}: 0.8 V to 12 V external synchronization	Low noise, low EMI and synchronous function suited for ultrasound application
LTM8049	Dual SEPIC or inverting µModule DC-to-DC converter; V_{IN}: 2.6 V to 20 V, V_{OUT}: 2.5 V to 24 V or –2.5 V to –24 V, 1 A @ 5 V_{OUT} from 12 V_{IN}	Easy to use to generation negative power supply for transmit
LTM4625	20 V_{IN}, 5 A step-down DC-to-DC µModule regulator, 0.6 V to 5.5 V output voltage	Suitable for FPGA power supply
Switcher Device		
LT8648S	42 V_{IN}, 15 A synchronous step-down Silent Switcher 2, ultralow EMI emissions on any PCB; external synchronization	Low noise, low EMI helps for ultrasound image quality
LT8625S	18 V/8 A step-down Silent Switcher 3 with ultralow noise; ultralow rms noise (10 Hz to 100 kHz): 4 µV rms, ultralow spot noise: 4 nV/√Hz at 10 kHz, 2.7 V to 18 V_{IN}	Low noise, low EMI helps for ultrasound image quality
LDO Regulator		
ADM7171	6.5 V_{IN}, 1 A, 4 2 mV dropout LDO regulator, V_{OUT}: 1.2 V to V_{IN} – VDO; low output noise: 5 µV rms (10 Hz to 100 kHz), ADM7172 is 2 A version	Ultralow noise and high PSRR helps for the image quality
LTC3070	5 A, low noise, programmable output, 85 mV dropout LDO regulator, V_{OUT}: 0.8 V to 1.8 V, low output noise: 25 µV rms (10 Hz to 100 kHz)	Low dropout and big output current suited for ultrasound application
LT3086	40 V_{IN}, 2.1 A, 330 mV dropout LDO regulator, V_{OUT}: 0.4 V to 32 V; low output noise: 40 µV rms (10 Hz to 100 kHz)	Low dropout and big output current suited for ultrasound application
LT3015	1.5 A, low noise, 330 mV dropout negative LDO regulator, V_{IN}: –1.8 V to –30 V, V_{OUT}: –1.22 V to –29.3 V; low output noise: 60 µV rms (10 Hz to 100 kHz)	Suitable for the CWD negative power supply with low noise
Battery Charger		
LTC4162	35 V/3.2 A multicell lithium-Ion step-down battery charger with PowerPath and I²C telemetry	Suitable for the battery management in compact or handheld ultrasound
LTC4020	55 V buck-boost multichemistry battery charger; V_{IN}: 4.5 V to 55 V, V_{OUT}:Up to 55 V, Li-Ion and lead-acid charge algorithms	Suitable for the battery management in compact or handheld ultrasound
Sequencer		
ADM106x	Configurable supervisory/sequencing device that offers a single-chip solution for supply monitoring and sequencing in multiple (up to 10) supply systems	Suitable for ultrasound system power sequence control and monitor
LTC2924	Quad power supply sequencer	Suitable for ultrasound system power sequence control and monitor
Fan Controller		
MAX31790	6-channel PWM-output fan rpm controller, can be configured for closed-loop control for up to six fans or monitoring for up to 12 fans	Suitable for ultrasound system fans control and monitor
MAX665x	Fan-speed regulators and monitors with SMBus/I²C-compatible interface	Suitable for ultrasound system fans control and monitor

Design Tools

- Transceiver and receiver analog front end (Rx AFE)
  - AD967x and AD927x and MAX208x evaluation board with schematic and PCB layout Gerber file
  - High speed FPGA-based data capture board (HSC-ADC-EVALCZ)
  - VisualANALOG™ software
  - AFE SPI interface software (SPI Controller)
  - MAX208x evaluation software
- Transmit pulser, transmit/receive switch, linear transmit
  - MAX148xx, MAX1498x, MAX493x evaluation board with schematic and PCB layout Gerber file
  - AD9106, MAX14807 evaluation board with schematic and PCB la yout Gerber file
- ADIsimADC modeling tool
- Circuit Simulation: LTspice
- Clocking
  - ADIsimCLK modeling tool
  - AD9528/AD9524 evaluation software and board
  - Power management
  - LTpowerCAD
  - Evaluation board

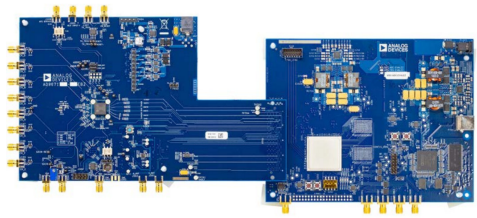


Figure 1. AD9671 evaluation kits

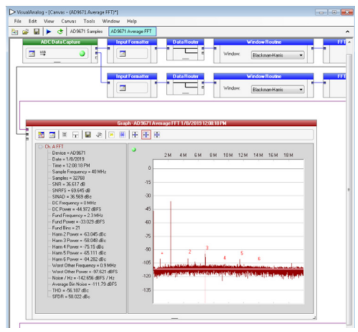


Figure 2. VisualAnalog for AFE data capture

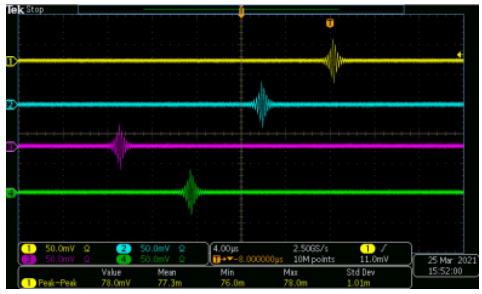


Figure 3. AD9106 evaluation software GUI

Design Resources

To view additional medical ultrasound resources, tools, and product information, please visit

- healthcare.analog.com/en/imaging/ultrasound/segment/health.html
- maximintegrated.com/en/applications/healthcare/imaging.html?diagram=ultrasound-imaging#2

To obtain a sample, please visit

- analog.com/en/content/samples_purchase/fca.html

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