The unheralded side of medical ultrasound imaging: The high-voltage transmit path

Steve Taranovich - May 03, 2013

It seems that much of the focus in electronic solutions for medical ultrasound are the high resolution, high accuracy, multiple integrated components for the receive channels. Maxim Integrated has given the high-voltage transmit path arena an innovative analog switch that improves upon existing technology, especially by integrating the high voltage $V_{pp}$.

The MAX4968/MAX4968A are 16-channel, high-linearity, high-voltage, bidirectional SPST analog switches with 18Ω (typ) on-resistance. The devices are ideal for use in applications requiring high-voltage switching controlled by a low-voltage control signal, such as ultrasound imaging and printers. The MAX4968A provides integrated 40kΩ (typ) bleed resistors on each switch terminal to discharge capacitive loads. Using HVCMOS technology, these switches combine high-voltage bilateral MOS switches and low-power CMOS logic to provide efficient control of high-voltage analog signals.

Having multiple sources is really important to designers and procurement. The MAX4968 is pin-to-pin compatible with the MAX14802 and Supertex HV2601. The MAX4968A is pin-to-pin compatible with the MAX14803 and Supertex HV2701.

The only difference, which is a benefit that saves board space and cost, as well as simplifying the board design/layout, is the $V_{pp}$ positive supply voltage level. The MAX4968/MAX4968A require a low +10V (typ) voltage ($V_{pp}$), whereas the MAX14802/MAX14803 and HV2601/HV2701 require a high +100V supply voltage. The high voltage $V_{pp}$ is done internally in this IC!

In a typical ultrasound application, since these devices do not require a dedicated high-voltage supply, that implies a significant simplification of system requirement. The negative voltage supply can be shared with the transmitter, and the positive voltage supply is typically +10V.

**The MAX4968 functionality**

**Figure 1** shows the essential functional diagram of the MAX4968, which features 16 independent HV analog switches. Each switch's internal status can be programmed with an SPI™ interface. In most ultrasound applications, the HV analog switches are used to implement HV multiplexers.
Figure 1: The essential functional diagram of the MAX4968, features 16 independent HV analog switches

- SW1A, SW1B can swing from $V_{NN}$ to $V_{NN} + 200V$.
- Although most industrial ultrasound applications are unipolar, the HV analog switches can operate both in bipolar and unipolar applications. The input/output voltage range can be one of the following cases:
  - $(SW_{-})$ range = $[+100V, -100V]$ bipolar
  - $(SW_{-})$ range = $[0, -200V]$ unipolar negative
  - $(SW_{+})$ range = $[+200V, 0]$ unipolar positive
- $V_{NN}$ can vary from 0V to -200V, depending on the amplitude of the input signal and its polarity. $V_{NN}$ can be shared with the pulser (transmitter) negative supply.
- $V_{PP}$ is a low-voltage supply (10V only)
- Equivalent $R_{ON}$ is flat in the entire input range (approximately 20Ω) and on-capacitance is 16pF only.

The ultrasound system overview focusing on the transmit path
A typical block diagram of an ultrasound system shows the high-voltage transmit path in the lower middle section of the image (Courtesy of Maxim Integrated)

The transmit path

The transmit path

High-voltage multiplexing²

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 200VP-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.

High-voltage transmitters²

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 pulser{s 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 \( f_0 \) to energy at \( 2f_0 \). 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.

High voltage bleed resistors

The MAX4968A provides integrated 40kΩ (typ) bleed resistors on each switch terminal to discharge capacitive loads. Using HVCMOS technology, these switches combine high-voltage, bilateral MOS switches and low-power CMOS logic to provide efficient control of high-voltage analog signals.

**Applications**

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Medical Ultrasound with high voltage analog switches in the probe
Medical Ultrasound with high voltage analog switches in the mainframe
Multiple transmit and isolation per receiver channel is possible in a medical ultrasound application with the MAX4968.

The devices are available in the 48-pin LQFP package and are specified over the -40°C to +85°C extended temperature range. See Maxim’s [website](http://maxim-ic.com) for more details.

References

1 Maxim application note 5131
2 Maxim Medical Imaging. Ultrasound imaging systems