

Solving Engineering Challenges in Ultrasound Through Integration and Power Scaling

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IDEA IN BRIEF

Advances in integrated multichannel devices are reducing power, size, and cost in portable, low power ultrasound systems for healthcare and industrial applications.

In the early 1990s, “portable” phones (sometimes called “bag phones”) the size of modern laptop computers were widely used. Less than two decades later, pocket size cell phones can send email and text messages, take pictures, get stock quotes, make appointments, and of course, call anyone anywhere in the world. Likewise, in the medical field, early so-called “portable” ultrasound systems were

cart-based, high power, and extremely costly. Fortunately, ultrasound systems have also benefitted over the years from breakthroughs in silicon integration and power scaling.

These breakthroughs have yielded more portable and efficient ultrasound systems with improved image performance and increased functionality. Higher dynamic range, lower power, and more compact system-level ICs provide high quality images that allow for better diagnoses. Ultrasound systems of the future may well become handheld and become the physician’s second “stethoscope.”

The Ultrasound Signal Chain

Figure 1 shows a simplified diagram of an ultrasound system signal chain. All ultrasound systems use a transducer at the end of a relatively long cable, typically about two meters. This cable, which contains a minimum of eight—and as many as 256—micro-coaxial cables, is one of the most expensive parts of the system. In almost every system the transducer elements drive the cable directly. The cable capacitance loads the transducer elements and causes significant signal attenuation. This requires a highly sensitive receiver to preserve the dynamic range and yield the best system performance.

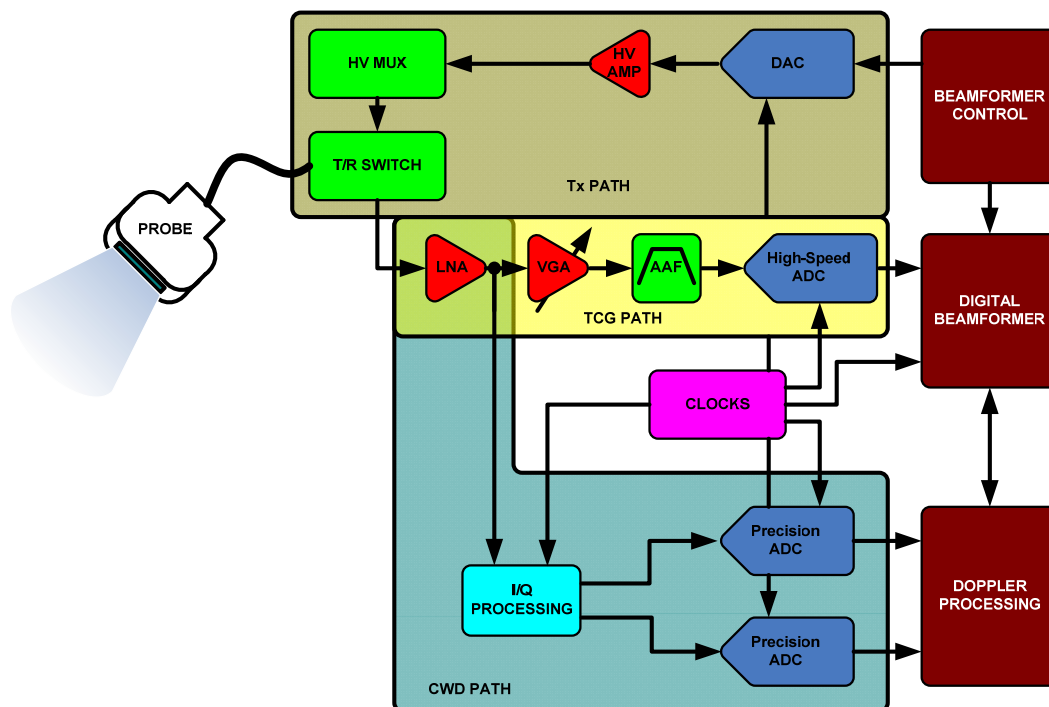


Figure 1. Typical Ultrasound Signal Chain

On the transmit side (Tx path) the beamformer determines the delay pattern of the pulse train that sets the desired focal point. The outputs of the beamformer are then amplified by high voltage transmit amplifiers that drive the transducers. These amplifiers can be controlled by digital-to-analog converters (DACs) or an array of high voltage FET switches to shape the transmit pulses for better energy delivery to the transducer elements. On the receive side, a transmit/receive (T/R) switch, generally a diode bridge, blocks the high voltage Tx pulses. A high voltage (HV) multiplexer/demultiplexer is used in some arrays to reduce the complexity of transmit and receive hardware at the expense of flexibility.

The time-gain control (TGC) receive path consists of a low-noise amplifier (LNA), variable gain amplifier (VGA), and an analog-to-digital converter (ADC). The VGA typically has a linear-in-dB gain control, which matches the attenuation of the reflected ultrasound signal. Under operator control, the TGC path is used to maintain image uniformity during the scan. A low noise LNA is critical in minimizing the noise contribution of the following VGA. Active impedance control optimizes noise performance for applications that benefit from input impedance matching.

The VGA compresses a wide dynamic range input signal to fit within the input span of the ADC. The input-referred noise of the LNA limits the minimum resolvable input signal, whereas the output-referred noise—which depends primarily on the VGA—limits the maximum instantaneous dynamic range that can be processed at a particular gain-control voltage. This limit is set in accordance with the quantization noise floor, which is determined by the ADC resolution. Early ultrasound systems were based on 10-bit ADCs, but most modern ones use 12- or 14-bit ADCs.

The antialiasing filter (AAF) limits the signal bandwidth and rejects unwanted noise in the TGC path prior to the ADC.

Beamforming, as applied to medical ultrasound, is defined as the phase alignment and summation of signals that are generated from a common source but received at different times by a multi-element ultrasound transducer. In the continuous wave doppler (CWD) path, receiver channels are phase-shifted and summed together to extract coherent information. Beamforming has two functions: it imparts directivity to the transducer—enhancing its gain—and it defines a focal point within the body, from which the location of the returning echo is derived.

There are two distinct approaches to beamforming: analog beamforming (ABF) and digital beamforming (DBF). The main difference between an ABF and DBF system is the way the beamforming is done; both require extremely good

channel-to-channel matching. In ABF, an analog delay line and summation are used. Only one precision high resolution, high speed ADC is needed. The DBF system, which is the most popular method used today, employs “many” high speed, high resolution ADCs. The signal in a DBF system is sampled as close to the transducer elements as possible; the signals are then delayed and summed digitally. A simplified diagram of a DBF architecture is shown in Figure 2.

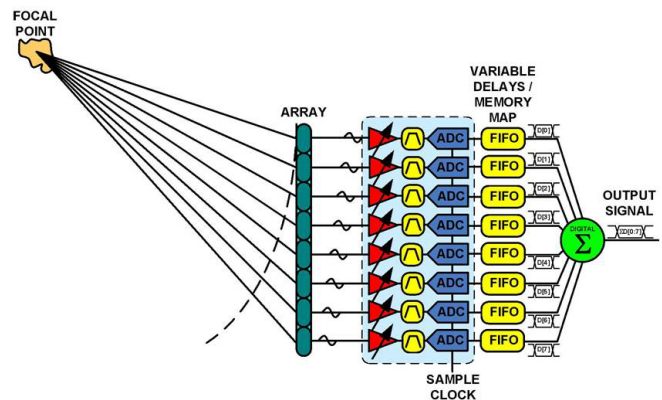


Figure 2. Simplified Diagram of a Digital Beamforming (DBF) System

Integration and Partitioning Strategies

With so many channels and components, ultrasound systems are some of the most complicated systems built today, even though great advancements in technology have been made. As with other complex systems, many approaches to system partitioning exist. In this section, several ultrasound partitioning strategies will be reviewed.

Early ultrasound systems utilized analog beamforming techniques, requiring a large number of analog components. Digital processing in the TGC and Rx/Tx paths was accomplished with custom ASICs. This approach was common before multichannel VGAs, ADCs, and DACs became widely available. ASICs have a large number of gates, and their digital technology is not optimized for analog functions, such as amplifiers and ADCs. Systems which use ASICs must depend heavily on the reliability of suppliers.

The use of ASICs, FPGAs, and DBF techniques, along with discrete IC ADCs and VGAs, was the first step toward portability, but it was the availability of multichannel quad and octal TGCs, ADCs, and DACs that made significant reductions in both the size and power possible. These multichannel components allow the designer to partition the sensitive analog circuits on separate boards from the digital circuitry. This allows for system scaling and good reuse of the electronic circuits over many platforms.

However, interconnecting quad and octal VGAs and ADCs with high pin counts can make PCB trace routing difficult, in some cases forcing the designer to use smaller channel count devices, such as a move from an octal ADC to a quad ADC. Placing a large number of these multichannel components in a small area can also present thermal problems. Determining the optimum partitioning can become a challenge.

Further integration of the full TGC path with multichannel, multi-component integration makes the design approach easier because the requirements on PCB size and power are further reduced. As higher level integration becomes more predominant, the advantages once again follow in cost, size, power reduction, and longer battery life in a portable unit.

An architecture of this kind can be built with an ultrasound subsystem such as the AD9271, which includes the LNA, VGA, programmable antialiasing filter, 12-bit ADC, and serial LVDS outputs for eight channels of TGC.

The ultimate ultrasound solution integrates more of the electronic functions in the probe, as close to the transducer elements as possible. Remember, the cable from the probe elements impedes the dynamic range and is costly. If the front-end electronics were closer to the probe, the effects of cable loss would be minimized, easing the requirements on

the LNA, therefore reducing power. One approach would be to move the LNA into the probe electronics. Another would be to split the VGA control between the probe and the PCB electronics. Ultimately, the system gets closer to fitting into an ultrasmall package. The disadvantage is that the designer has gone full circle and must now customize the probe. In other words, probe/electronic customization will lead the modern designer to the same problems as faced by earlier designers using digital ASICs.

Power/Performance Scaling Using Modern ICs

Ultrasound covers a wide range of varying applications, so the trade-offs a system designer must make have increased. Each diagnostic imaging modality has limitations that are defined generally by performance vs. power. Today these challenges have been met with components that allow the designer to scale the performance vs. power ratio within the IC, thus cutting down on time to market. Again, look for an ultrasound subsystem that offers a host of options within the IC to scale input range, bias current, sample rate, and gain. Depending on which imaging modality or probe type is required, the system designer can literally system-scale the design appropriately in real-time, offering the maximum performance at minimum power.

Medical Ultrasound Configuration Tool for an Integrated Rx Channel

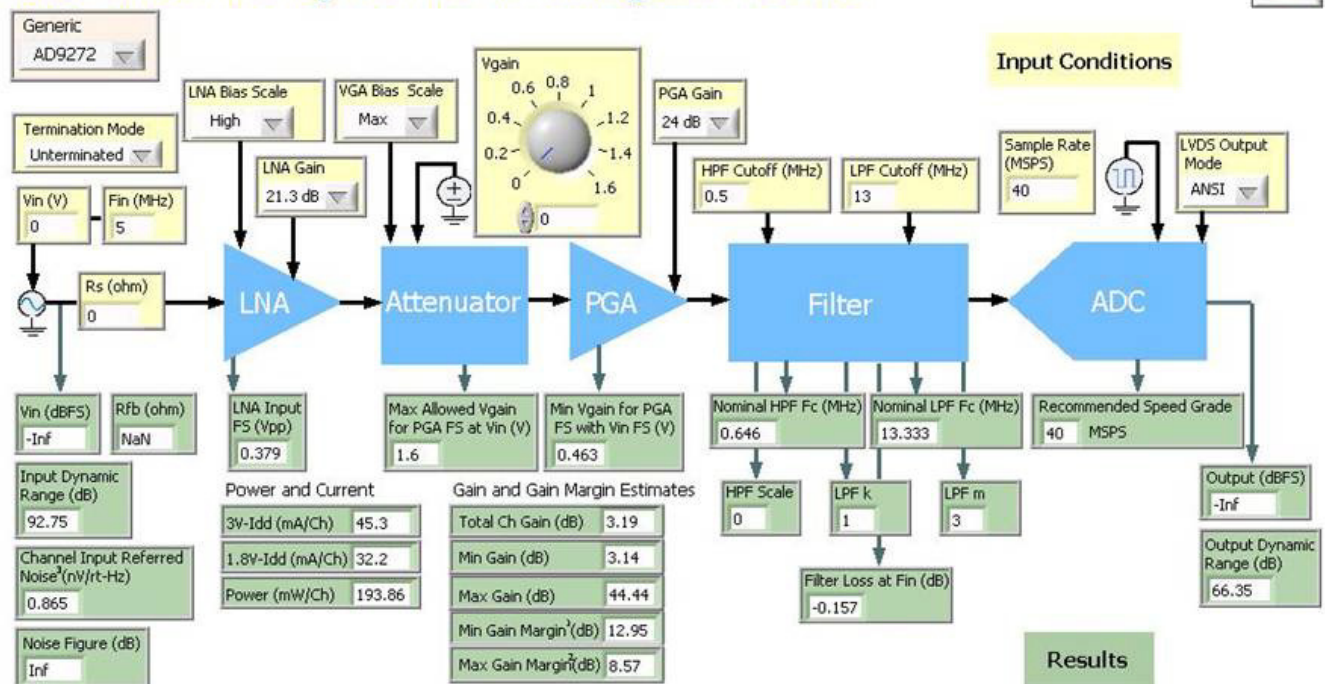


Figure 3. Ultrasound Subsystem Configuration Tool Graphical User Interface

Designers can also use a configuration design tool for these devices, thereby allowing evaluation of individual probe and modality performance as shown in Figure 3. The system designer can make these trade-offs quickly and scale the system design at the IC level directly. This eliminates the need for changing hardware and performing sophisticated image processing tests to validate these trade-offs. Furthermore, the configuration tool converts the optimized configuration parameters to digital settings and generates a file that can replicate the part final configuration setup for the system.

Conclusion

There is a growing trend toward portable and low power ultrasound systems in both medical and industrial applications. All such systems have similar requirements and have been implemented in recent years through integration and power scaling innovations.

Advances in integrated multichannel devices are reducing power, size, and cost even further today. New, innovative products and configuration tools make the system designer's life easier, without a doubt. This provides a means of developing diversified ultrasound products that have configurable and scalable performance vs. power, depending on the imaging modality.

The intellectual property (IP) of most ultrasound manufacturers lies within the probe and beamformer technology. Multichannel integration of commodity devices, including quad and octal ADCs, minimizes high cost analog components and reduces the need for time consuming calibrations in the TGC path. Other portions of the ultrasound system offer possibilities for further integration. Integration of more of the signal chain portion will lead to further reductions in power, size, and cost as well as increased processing capability.

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RESOURCES

For information on ultrasound and other healthcare applications, visit www.analog.com/healthcare.

Products Referenced in This Article

Product	Description
AD9271	Octal LNA/VGA/AAF/ADC and Crosspoint Switch