Full Signal Path Solution for Portable Ultrasound Systems

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There is a rising demand for accessible medical care. The world population is rapidly growing and aging, increasing the cost of healthcare. Medical practitioners need small energy efficient and cost effective diagnostic devices. Portable diagnostic equipment that improve quality of healthcare in a cost effective manner are highly desirable.

In addition to addressing traditional imaging applications in Obstetrics, Gynecology, Radiology, Cardiology and Vascular, portable ultrasound imaging allows for deployment at the point-of-care. System designers are finding that simply shrinking a console into a portable or hand held unit does not guarantee adequate battery life or diagnostic image quality.

Beamforming Technique

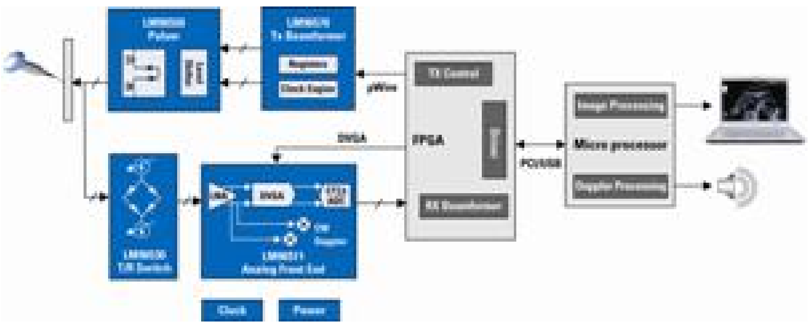

Figure 1. Phased array ultrasound system.

Innovations in system architecture, coupled with analog and mixed signal electronics, FPGA-based algorithms and control, CPU or GPU-based image processing enable compact systems with high diagnostic relevance. Ultrasound Systems use focal imaging techniques to achieve performance far beyond what can be achieved through a single-channel approach. Using an array of transmitters and receivers, a high-definition image can be built by time shifting, phasing, scaling, and coherently summing echo energy. The concept of shifting, phasing and scaling of transmit and receive signals, generally from the same reciprocal transducer array, is known as beamforming. It provides the ability to form an image by dynamically focusing and concentrating energy sequentially in points of the scan region.

A Gate Array based solution like National‘s ultrasound chipset, in comparison with a DSP based solution, has many advantages. The most important ones are higher flexibility; lower cost and significantly less power consumption. National’s eight-channel ultrasound transmit/receive chipset (see Figure 1) shows a phased array ultrasound system. The transmit beamformer provides the delay patterns and profiles to set the desired focal point of the transducer.

The LM96570 [1] Configurable transmit beamformer provides a seamless interface between the master control engine and the pulser, allowing programmable pulse pattern profiles with fine delay resolution. Delay resolution of 1 µs /1280µs provides an order-of-magnitude better jitter performance over traditional FPGA beamforming.

The pulser needs to deliver high voltage pulses to the transducer. Ringing during positive and negative signal transitions affects image quality. Symmetrical square wave pulses improve second harmonic imaging. Often times, it may not suffice to simply visualize abnormal tissue. Harmonic imaging improves spatial resolution and the resultant diagnosis of the abnormality.

The LM96550’s [2] symmetric pulses can be used in either B-mode or the CW Doppler mode. An on-chip active damper minimizes ringing. A transmit receive (T/R) switch is required to protect the receive path amplifier from the high voltage transmit pulses. The LM96530 [3] T/R Switch allows independent control of each channel through a daisy-chained SPI interface. Only three pins are required from the FPGA to control any channel in the system. This simplifies the system design significantly where otherwise dedicated pins are required for each chip. Bias current adjustment allows either high performance or low power mode.

Time Gain Control

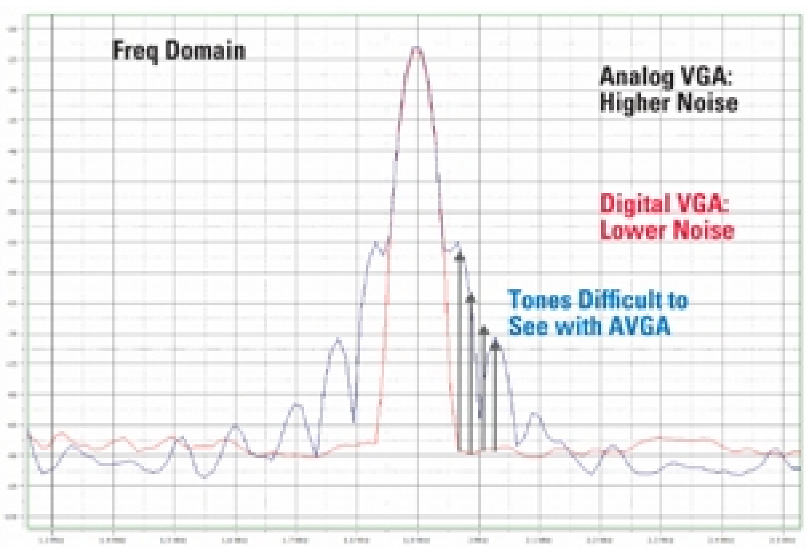

Figure 2. Close-in noise performance.

Low receiver noise floor is desired for deep penetration with high spatial resolution. In a well designed system, the low noise amplifier (LNA) sets each channel’s performance. The purpose of the variable gain amplifier (VGA) is to map the LNA output signal to the full scale range of the analog to digital converter (ADC) as return signals from the body become weaker with depth and time. This process is called Time Gain Control (TGC) or Depth Gain Control (DGC). High resolution digital variable gain amplifiers (DVGAs) offer better gain matching, gain flatness, and close-in phase noise than log amps or piecewise-linear analog VGAs. In addition, gain errors of DVGAs are relatively low and consistent throughout the entire variable gain range. Analog VGAs often have gross errors at the lower and higher gain extremes, reducing the amount of usable range.

As shown in Figure 2, the DVGA’s improved close-in noise performance facilitates visualization of low velocity blood flow deep in an organ like the liver. Small signals are readily discerned when they aren’t buried in the high close-in noise floor of a traditional analog VGA.

The analog-to-digital converter (ADC) digitizes the signals for further processing. The CT?? is a highly oversampled system. The high rate of oversampling spreads the quantization noise. The on-board modulator shapes noise and moves it out of band. The on-chip brick wall digital filter then creates an alias free Nyquist sample range. (See Figure 3 for illustration.) The elimination of anti-aliasing filters, and power hungry sample-and-hold amplifiers, inclusion of an on-chip clock and low jitter PLL simplifies the receive path front end design.

Dynamic Range Requirements

In Continuous Wave (CW) Doppler systems used to measure blood flow velocity, a continuous sine wave is broadcast into the body and the phase shift of the returning signals is measured. Dynamic range (DNR) requirements of the CW Doppler analog signal path are very high, since small signal reflections from deep in the body are summed with large close-in signals. Any nonlinearity creates cross-products that are difficult if not impossible to remove.

Multiple channel I and Q components are summed and High Pass filtered to minimize stationary clutter, vessel wall returns and slow sonographer hand movement. High Pass filter outputs are presented in both audible and visual formats.

The LM96511 [4] Receive Analog Front End (AFE) combines the benefits of a DVGA and CT?? ADC with CW Doppler to provide a total input-referred noise of 0.9 nV/rtHz across a gain range of 58 dB, a DVGA step resolution of 0.05 dB, 110 mV/channel B-mode power consumption, a CW Doppler phase rotation resolution of 22.5°, -144 dBc/Hz phase noise at 5 kHz offset, a -161 dB/Hz dynamic range and 208 mW/channel CW Doppler power consumption in a small footprint package.

Summary

In summary, medical ultrasound is a sophisticated signal processing system. It is the least invasive diagnostic tool, finding widespread use in many applications. The portable system designer is challenged with numerous tradeoffs to achieve optimal balance between power consumption, performance and size. National's 8-channel Transmit & Receive chipset comprising the Programmable Transmit Beamformer, Pulser, T/R Switch and Receive AFE provides a comprehensive subsystem solution designed with system level features to pack console performance within a small form factor portable or handheld system.

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References: [1] LM96570, Programmable Transmit Beamformer data sheet www.national.com/ultrasound [1] [2] LM96550, Pulser data sheet www.national.com/ultrasound [1] [3] LM9530, T/R Switch data sheet www.national.com/ultrasound [1]
[4] LM96511, Receive Ultrasound Analog Front End datasheet www.national.com/ultrasound [1]
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