Introduction to Ultrasound

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Medical and industrial ultrasound systems use focal imaging techniques to achieve imaging performance far beyond a single-channel approach. Ultrasound images are created by sending high voltage pulses into human tissue. The sound generated by these pulses echoes off of the tissues at varying amplitudes depending on factors such as depth within the body and type of tissue. Ultrasound technology is manufactured to measure the voltage magnitude of these echoes as they are collected at the receiver. These voltages are ultimately recorded and displayed in an image that tells what kinds of surfaces the pulses are passing through.

Ultrasound technology does not involve as much ionizing radiation exposure as other imaging methods such as X-ray. However, the acoustic waves used to generate the pulses are low energy, and there are some difficulties when the waves need to penetrate through thick layers of human tissue. The waves also need amplification depending on their location within the body. Texas Instruments has analog products to facilitate advanced ultrasound system designs with low power consumption, high performance and small size, yielding portability with high-quality images. By using an array of receivers, TI's latest products for ultrasound enable high definition images through time shifting, scaling and intelligently summing echo energy. This makes it possible to focus on a single point in the scan region.

Texas Instruments' AFE58xx family contains highly-integrated analog front-end (AFE) solutions specifically designed for ultrasound systems. The devices integrate a complete time-gain-control (TGC) path and a continuous wave Doppler (CWD) path to assess how close the body structures are to the probe and to increase the signal intensity accordingly. Various power and noise combinations can be selected to optimize system performance. TI's leading devices for these applications include the AFE5816, AFE5818, AFE5828, and AFE5832. Each of these devices is an analog front-end, integrating a low-power passive mixer to create the on-chip CWD beamformer within the machine. The AFE5816, AFE5818, and AFE5828 are all 16-channel devices while the AFE5832 is a 32-channel device. The AFE58JDxx devices come with the added features of an optional digital demodulator and JESD204B data packing blocks following the ADC.

When initiating a scan using an ultrasound machine, a pulse is generated and transmitted from each of the eight to 512 transducer elements. These pulses are timed and scaled to illuminate a specific region of the body. After transmitting, the transducer element immediately switches into receive mode. The pulse, now in the form of mechanical energy, propagates through the body as high frequency sound waves, typically in the range of 1 to 15MHz. At focal points close to the surface (the near field), the receive echoes are strong, requiring little if any amplification. At focal points deep in the body (the far field), the receive echoes will be extremely weak and must be amplified by a factor of 100 or more. As the signal travels, portions of the wavefront energy are reflected back to the transducer/receiver.

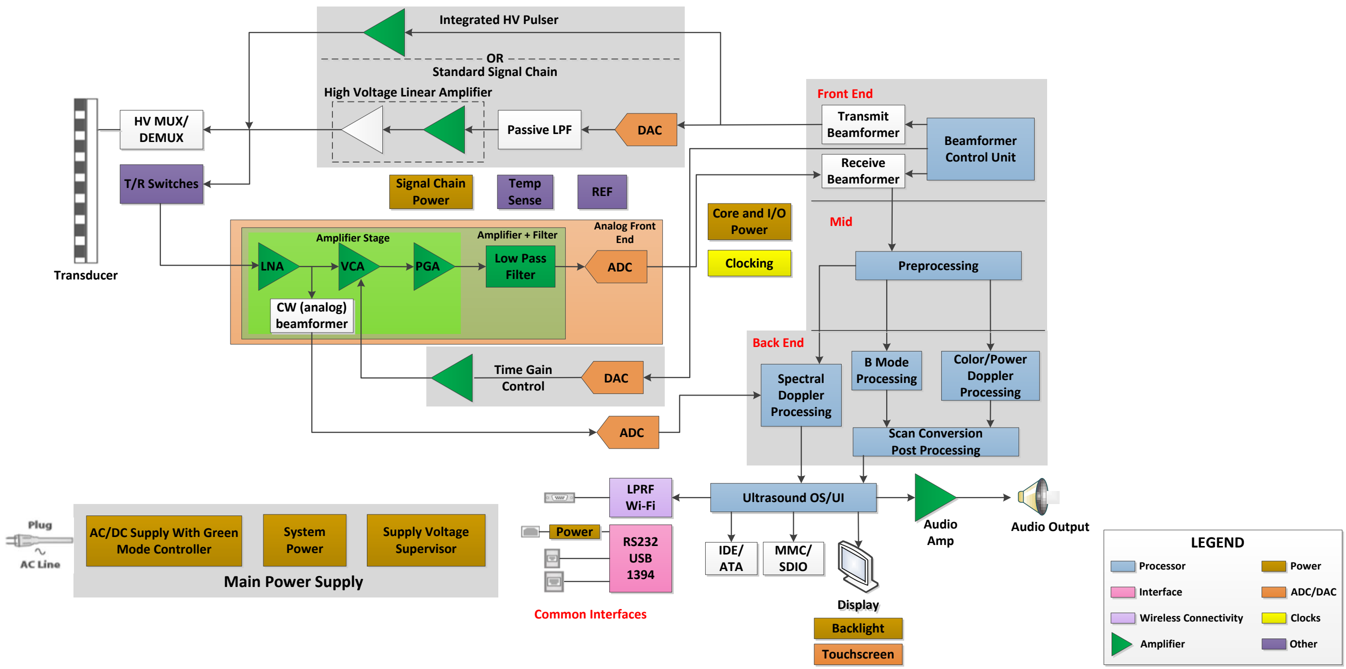
The two largest contributors of receive noise in the configuration are the transducer/cable assembly and the receive low-noise amplifier (LNA). In the low-gain mode (near field), the performance limit is defined by the magnitude of the input signal. Within the receive chains in TI's AFEs, the LNA is integrated with a voltage-controlled attenuator (VCA) and a programmable gain amplifier (PGA). Low-pass filtering is typically used between the VCA/PGA and ADC as an anti-aliasing filter and to limit the noise bandwidth.

For analog-to-digital converters (ADCs), channel integration and SNR are two of the most important issues. Each channel of the ADC_CONV die in the AFE58xx series has a high-performance ADC with programmable resolution of 10-, 12- or 14- bits. The ADC provides excellent signal-to-noise ratio (SNR) at low-channel gain by achieving an SNR of 75-dBFS in 14-bit mode, and 72-dBFS in 12-bit mode. The output interface of the ADC is also a low-voltage differential signaling (LVDS) or JESD204B interface that can easily connect with low-cost field-programmable gate arrays (FPGAs).

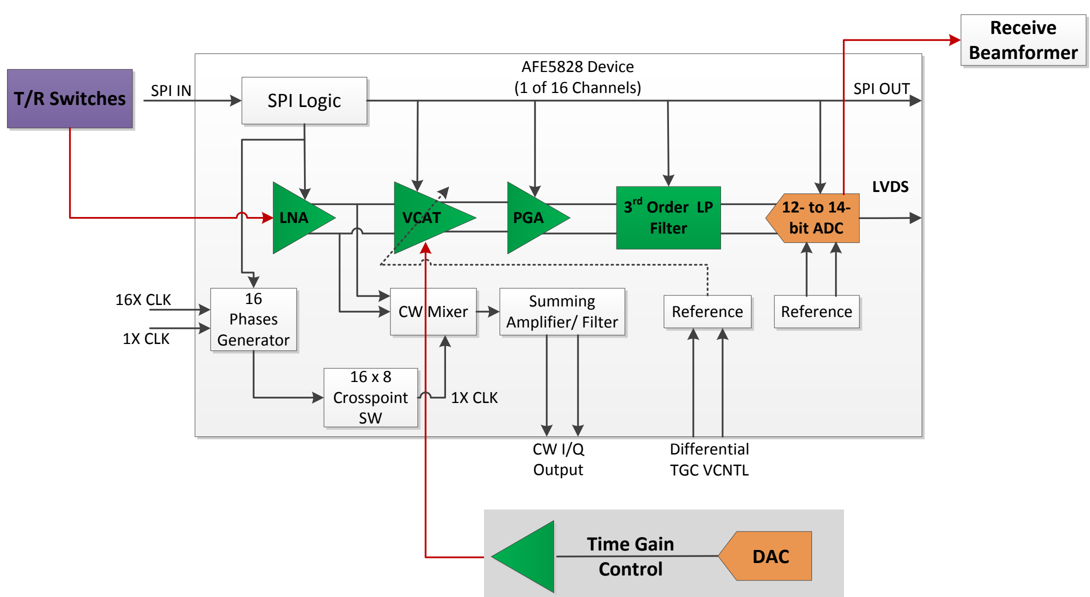
The digital front-end part of the system takes in data from a number of ADCs. The channel count can vary from eight for ultra-portable systems to 512 for high-end devices. The main function of the digital front-end is to perform focusing at a given depth and direction. This beamforming is performed by resampling the ADC output at a higher rate, properly delaying the resampled data, multiplying by a weight (apodization factor), and then summing all the weighted and delayed outputs.

The beamformed data is then passed through a mid-processing block where various filtering is performed to reduce noise and properly extract the ultrasound RF data. This is followed by demodulation to create complex baseband data. Adaptive processing based on the depth and angle of measurements can be used to get an optimized ultrasound image. The output from the mid-processing stage is handled in the back-end in various ways. For 2D mode imaging, the envelope data is compressed to bring it to the dynamic range of the human eye. The data is then scan converted to the final output display form and size. For doppler processing, velocity and turbulence are estimated in the color flow mode, and power is estimated in the power doppler mode. All of these estimates are scan converted to the final output display form and size.

The following system block diagram shows module interaction in the ultrasound end equipment.



The following image shows TI's AFE5818 signal chain and how it connects to the rest of the ultrasound topology (denoted by the red arrows).



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