Application Report
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Highly Integrated Signal Chain Solutions TX7332 and AFE5832LP for Smart Ultrasound Probes

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ABSTRACT

Ultrasound imaging is widely used in both medical and industry applications. In the past decade, highly-integrated System-on-Chips have replaced many discrete circuits. Ultrasound analog front end and transmitter chips have achieved over 80% reductions in power and size. These advancements push ultrasound technology from niche radiology applications to broad point-of-care applications, such as the convenience of smart ultrasound probes connected with smartphones or pads. This application report discusses TI's latest 32-CH analog front end and transmitter, the AFE5832LP and TX7332, respectively. These parts enable integration for all electronics with a true 32 to 64-CH digital beamformer in a transducer while achieving very low power. The parts also enable system designers and doctors to deliver immediate, high-quality medical image care for patients who lack hospital access.

Key words: Wireless Ultrasound Probe, USB Ultrasound Probe, Smart Ultrasound Probe, NDT, Sonar

Topic **Page**

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2 Introduction

Over the past several years, more and more clinical applications demand cost-effective, smart ultrasound probes with performance comparable to existing portable or laptop-sized systems. One use case for these systems is to bring modern medical imaging technology to remote villages in developing countries for the first time. Smart ultrasound probes, or ultra-portable ultrasound systems, are the perfect fit for this task due to their cost-effectiveness. In 2017 and 2018, TI released a highly-integrated and low-power, analog front end solutions: the AFE5832 and AFE5832LP. In 2019, the TX7332, the industry's first 32-CH 200-V transmitter solution, completes the signal chain for smart, ultrasound probes. These AFE and TX solutions make it possible to deliver superior image quality with a handheld, smart ultrasound probe. This article discusses the principles of smart ultrasound probes and their design considerations.

3 System Analysis and Architectures

The performance of ultrasound systems is primarily determined by the system channel count of the transmitting and receiving signal chain, or ultimately the transmitting and receiving aperture size. More channels derive larger acoustic aperture, or better lateral resolution, and better signal-to-noise ratio. However, more channels also increase the system cost and power. Most systems used by medical professionals in hospitals include 64 to 256 channels of transmitter and receiver circuits.

Figure 1–Figure 3 show the clear image quality difference between a 16-CH system and a 64-CH system. It is clear that a 64-CH system demonstrates better resolution and deeper penetration.

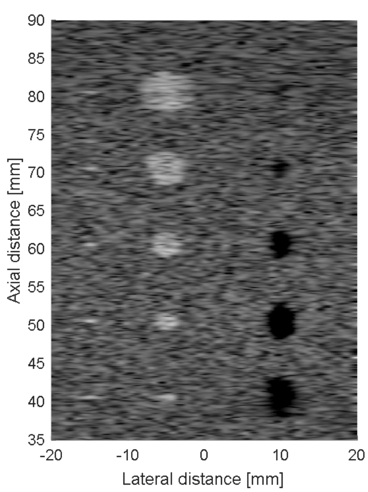

Figure 1. Image Simulation with Different System Channel Numbers. A 5-MHz Transducer Array and 40 MSPS Digitizer Were Selected in the Simulation: 64-CH

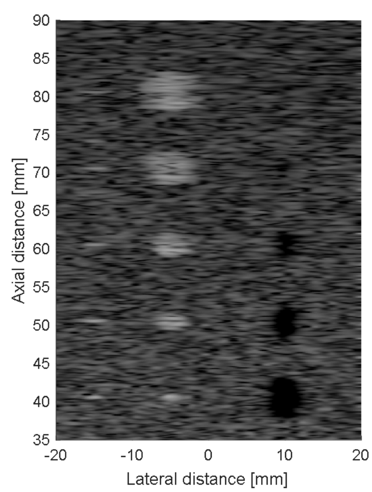

Figure 2. Image Simulation with Different System Channel Numbers. A 5-MHz Transducer Array and 40 MSPS Digitizer Were Selected in the Simulation: 32-CH

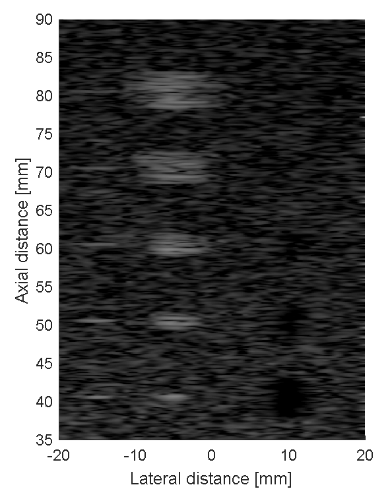

Figure 3. Image Simulation with Different System Channel Numbers. A 5-MHz Transducer Array and 40 MSPS Digitizer Were Selected in the Simulation: 16-CH

Early handheld systems were forced to choose trade-offs among power, size, and cost. Engineers came up with different architectures to achieve the necessary performance with 8 to 16-channel digitizers. Figure 4 shows high-voltage multiplexers used for expanding 16 AFE channels or, 16 TX channels, to all elements of a transducer array. Figure 5 shows a system with two-stage beamformers. The first stage is the low-power analog beamformer that reduces the channel count by the factor between four and eight. The second stage is the digital beamformer after an 8 to 16-channel digitizer or analog front end.

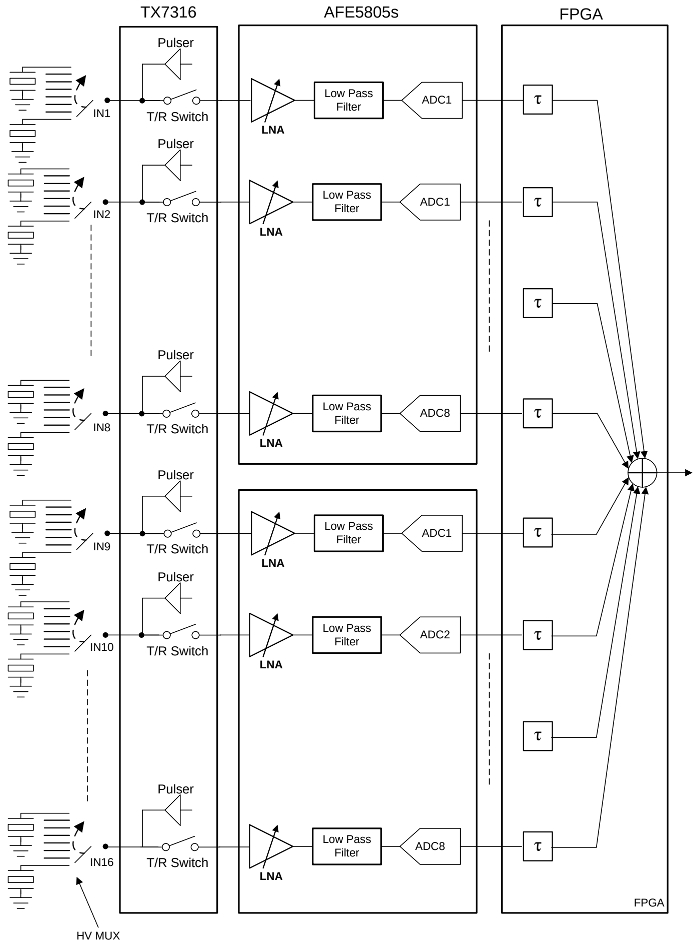

Figure 4. 16-CH System with HV MUXs

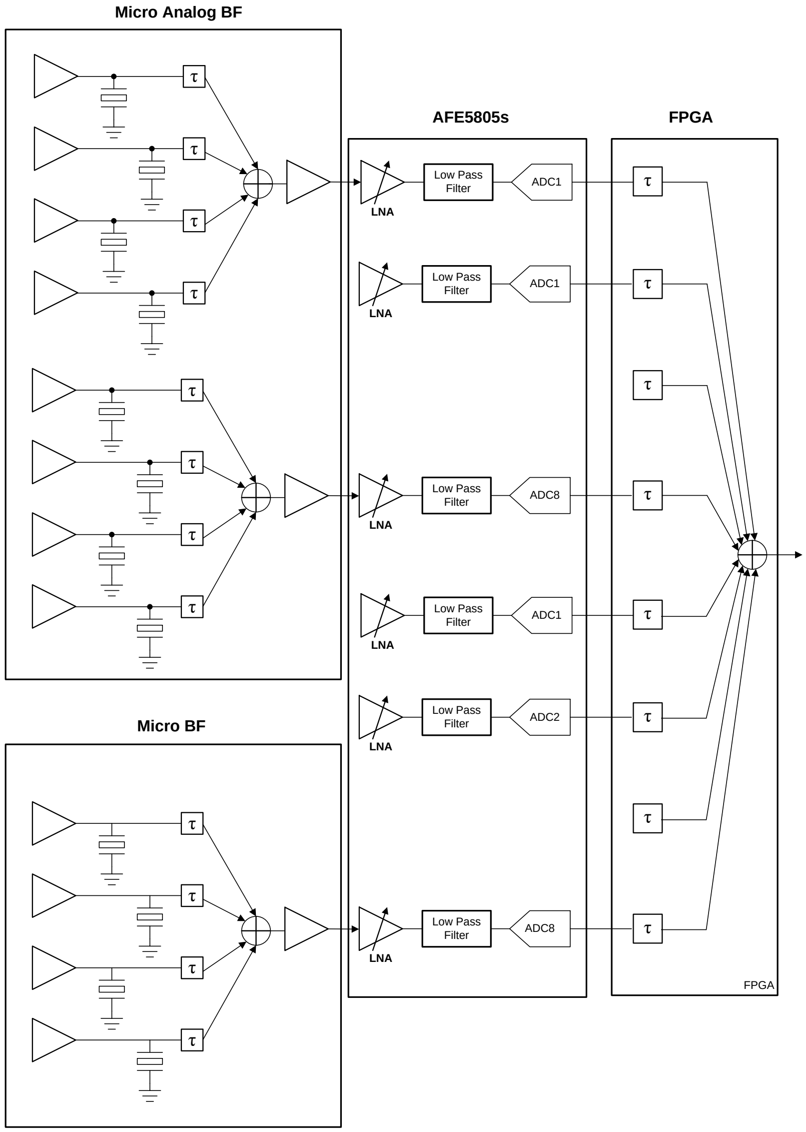

Figure 5. 16-CH System with Micro Beamformer

The HV multiplexer-based architecture is limited to 8–16 channel active AFE/TX each time. It is possible to transmit and receive multiple times to expand the 16 channels to 32, or more, channels. However, expanding the channels reduces the frame rate. This process imposes limitations on cardiovascular applications, which require high frame rates, to capture moving organs. Furthermore, the HV multiplexer has a Ron of 10 to 20 Ω. This introduces the insertion loss of the signal chain, or reduces the signal-to-noise ratio. As a result, the HV multiplexer, based on architecture, is only suitable for applications that do not require high performance.

The two-stage beamformer architecture benefits from the low-power analog beamformer by meeting the strict power budget for handheld applications. This was especially true in early days, when digitizer or AFE power consumption, and cost, were much higher. While the analog beamformer is less flexible and lower-performing than the mainstream digital beamformer, information lost at the analog beamformer stage cannot be recovered. In addition, it can be difficult to reuse most modern algorithms that are developed on premium systems to support full-digital beamformers. Therefore, significant system development and optimization are required to keep up with the fast-paced development of smart ultrasound probes.

Ideally, smart probe designers have a 64+ channel signal chain to support full-digital beamformers, similar to mainstream, high-end systems. This requires ultra-low power, and high channel-count analog front ends and transmitters. Figure 6 shows the following:

- Smart ultrasound probe electronics with a transmitter
- Receiver
- Digital beamformer
- Data communication
- Battery-power management

Figure 7 shows the architecture based on the AFE5832LP and TX7332. This configuration has 64-channel receivers and 128-channel transmitters. The transmitter channel count can be adjusted to support different 64 to 256 element transducers. In Figure 8 and Figure 9, each transducer element has a dedicated transmitter channel. Typically, there is a N:1 ratio between the AFE and TX channel for linear array transducers. This ratio is used with the unique multiplexing feature in the transmit and receive switches of the TX7332 (TRSW). The low-voltage TRSW outputs can be set as high impedance. Thus, multiple TRSW outputs can be shorted together to form an effective low-voltage mulitplexer.

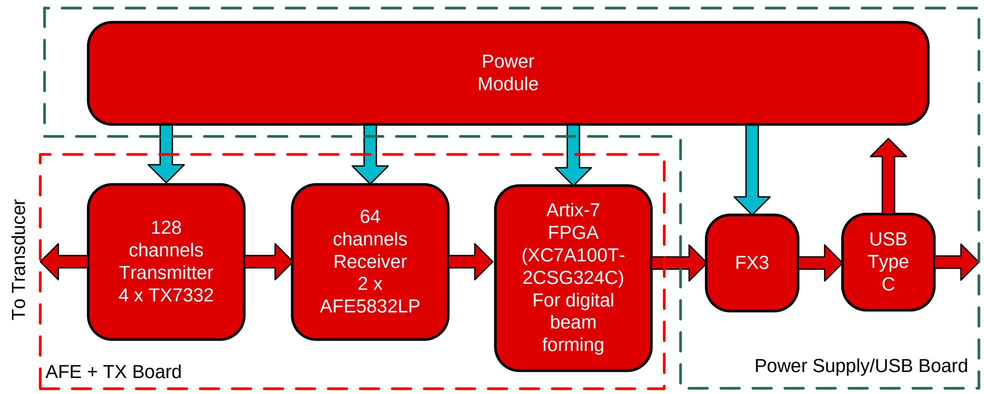

Figure 6. 64-CH System with Full-Digital Beamformer

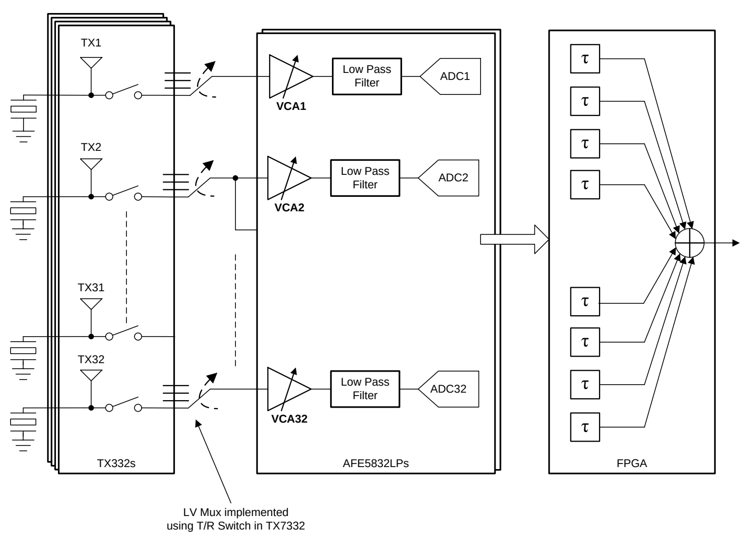

Figure 7. System Architecture with 128-CH TXs and 64-CH AFEs

4 System Power Analysis

The primary challenge in smart probe design is balancing power consumption and performance. The AFE5832LP achieves 18.5 mW/CH and 4 nV/rtHz at 20 MSPS, and the TX7332 achieves 16 mW/CH at ±70 V and 0.1% duty cycle. Both chips have flexible, and quick power-up and down management to reduce average power consumption and extend battery life.

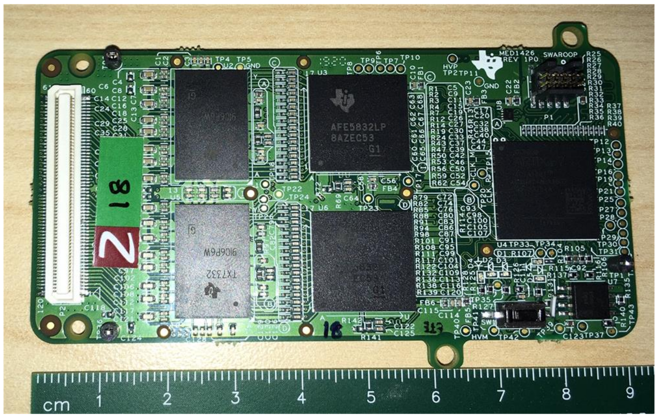

Figure 8. Transceiver Board Top View

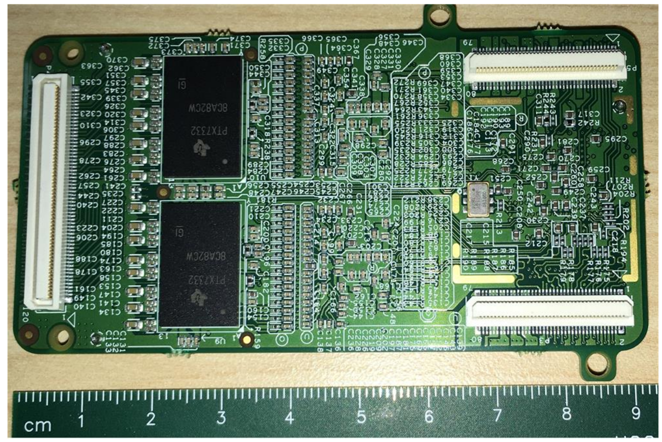

Figure 9. Transceiver Board Bottom View

Figure 8 and Figure 9 are based on the architecture of Figure 6. The <5×10 cm board consists of a complete transceiver path with a 128-CH transmitter, a 64-CH receiver, and the FPGA. A 12-layer PCB with blind vias was used to stack TX7332s on both the top and bottom layers. The performance of the FPGA clock distribution network was analyzed, and its sufficiency for 10 to 12-bit ADCs used in ultrasound applications was concluded. These steps minimized the power and size of the design. The transceiver board is also designed to mate with another power management board with USB type-C communication protocol. Table 1 shows the measured power numbers in both active mode and sleeping mode.

In clinical-use cases, the system duty cycle varies from 25% to 75%. It is feasible to adjust the overall operation duty cycle to achieve approximately 2 W of average power. As a result, the surface temperature of the transducer is controlled below 45°C. In some performance-driven, ultra-portable systems, an average power of 4 W to 5 W is acceptable when larger probe sizes or active cooling methods are implemented. In such cases, it is affordable for designers to implement a premium smart probe with 128-channel transmitters and receivers. When high-performance CW mode is needed, designers can add higher-quality clock distribution networks and low noise audio amplifiers.

Table 1. Alternative Device Recommendations

BLOCK	ACTIVE MODE (W)	SLEEPING MODE (mW)	FUNCTIONS
2xAFE5832LPs	1.64	64	Fs = 50 MHz, 10-bit
4xTX7332s	1.32	26	64 TX channels and 64 Rx channels
			±70 V, 5 MHz , 0.1% duty cycle with 2 K//110 pF load
CLK Crystal	0.05	50	
FPGA General	0.83	150	Rx de-serialization, clocking, static and switching power.
FPGA DBF	0.6	0	Reserved for digital beam forming implementation
USB	0.28	20	
Total power	**4.76 W**	**~410 mW**	

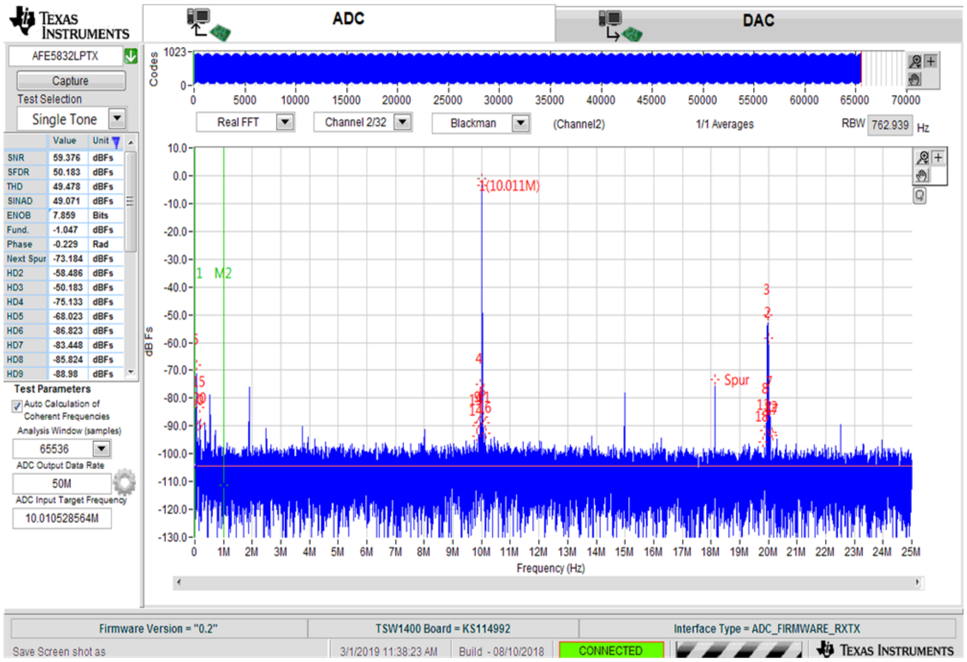

Figure 10. Measurement Results from the Transceiver Board: Measured SNR and AC Performance with 10-MHz Input

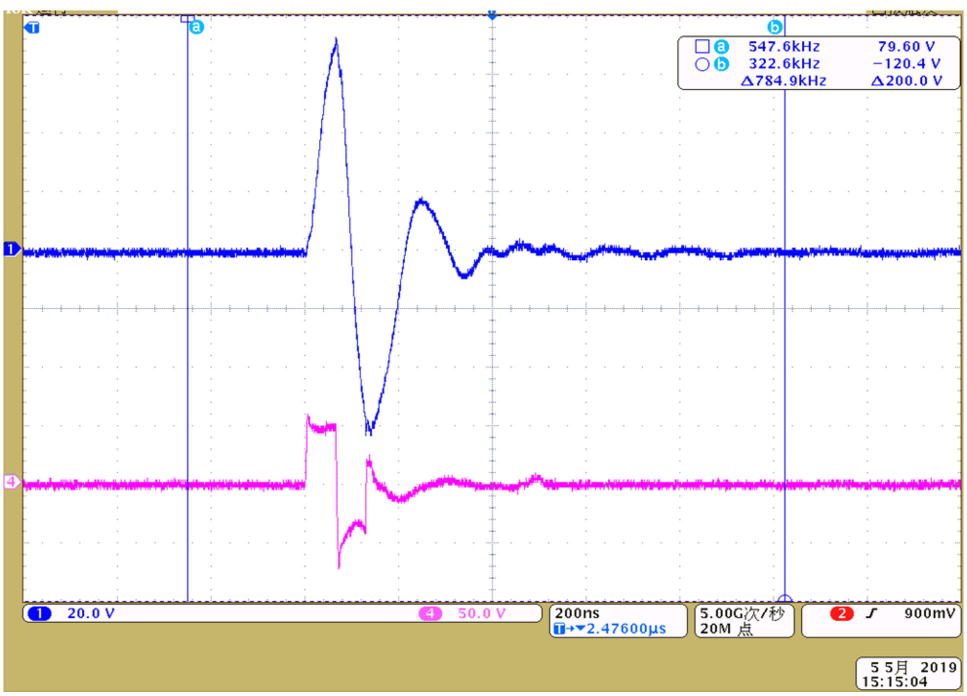

Figure 11. Measurement Results from the Transceiver Board: Transmitter Response with Transducer Connected (Pink: TX7332 Side Before the 3.3 µH tuning inductor; Blue: Transducer Side After the Inductor)

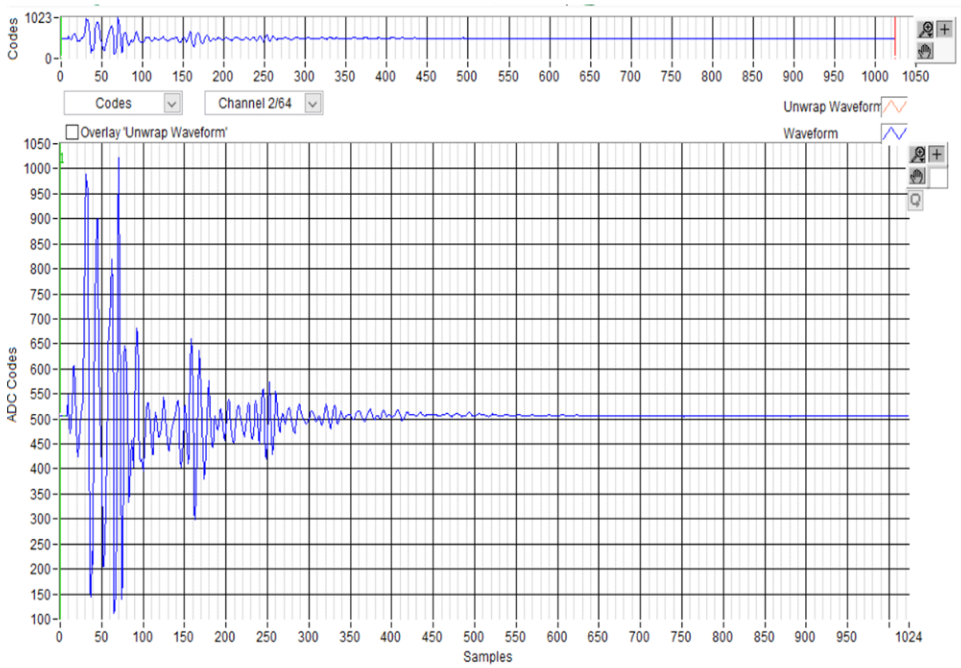

Figure 12. Measurement Results from the Transceiver Board: Captured Pulse Echo by the FPGA

5 Summary

TI's latest low-power AFEs and TXs have greatly simplified wireless, and digital, smart ultrasound probe design. These products achieved low power by optimizing features and simplifying external circuits. When compared to traditional systems, these AFEs and TXs make it possible to deliver ≥64-CH ultrasound systems to each physician or remote village at a fraction of cost. TI is motivated to see innovative products that enable quality, and immediate, health care service for those in need. In addition, TI is committed to delivering more low-power products to support smart probe applications.

6 References

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- AFE5832LP Product Page
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