Application Note

Improve Portability of Ultrasound Scanners with TI High-Voltage Switches

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ABSTRACT

In ultrasound systems, the piezoelectric transducer (or PZT) elements used for imaging can number in the dozens to hundreds, depending on the type of the machine and number of supported channels. These piezo electric elements are driven with high-voltage (HV) (typically up to ±100V) pulses to produce enough ultrasonic energy for imaging. The elements are arranged in arrays, which allows directional tuning of ultrasonic signals (for example, beamforming). To achieve the high channel count demands of modern ultrasound systems, while balancing size and power constraints, the front-end transmit-and-receive architecture of the machine plays a key role. This application brief discusses and compares two architectures for creating an example 64-channel ultrasound system using TI's latest 32-channel analog high voltage multiplexer TMUX9832 and 16-channel transmitter device TX7516. This document also showcases the implementation of a 128-channel system with two transmitter and four multiplexer devices, demonstrating that the same architectures can extend to higher channel count systems.

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Trademarks

1 Introduction

Modern ultrasound systems employ as many as 256 transducer elements in a probe. Increasingly, there is growing demand to add more transducer elements to a traditional corded ultrasound probes while keeping their size the same. Additionally, there is growing demand develop portable ultrasound smart probes where more analog circuitry is added into the probe (so it can be portable) while keeping the probe form factor the same size (or making the probe even smaller). These portable ultrasound smart probes have smaller effective space for designing in all needed circuitry and need to consume less power to enable battery powered portability (cordless ultrasound smart probes). One way to design a high channel count system is to drive each transducer element with one transmitter channel. However, ultrasound transmitters consume more power than multiplexers which impedes portability; a device which consumes more power will naturally require a larger battery for the same run time. Furthermore, the number of transmitters needed in a high channel count system take up more PCB area than using a combination of transmitters and multiplexers.

Taking a closer look at how high voltage multiplexers fit into an ultrasound system are shown in Figure 1-1. In this context, the multiplexer is responsible for connecting the transmit and receive circuitry to the transducers. The channels of the multiplexer are activated in turn to drive sequential sections of the probe elements. Each multiplexer channel passes the transmitter's ±100V pulses to each piezoelectric element. When an element subsequently receives the return signal from the subject of imaging, the multiplexer also passes this signal back to the receiver circuitry for amplification, digital conversion, processing, and display.

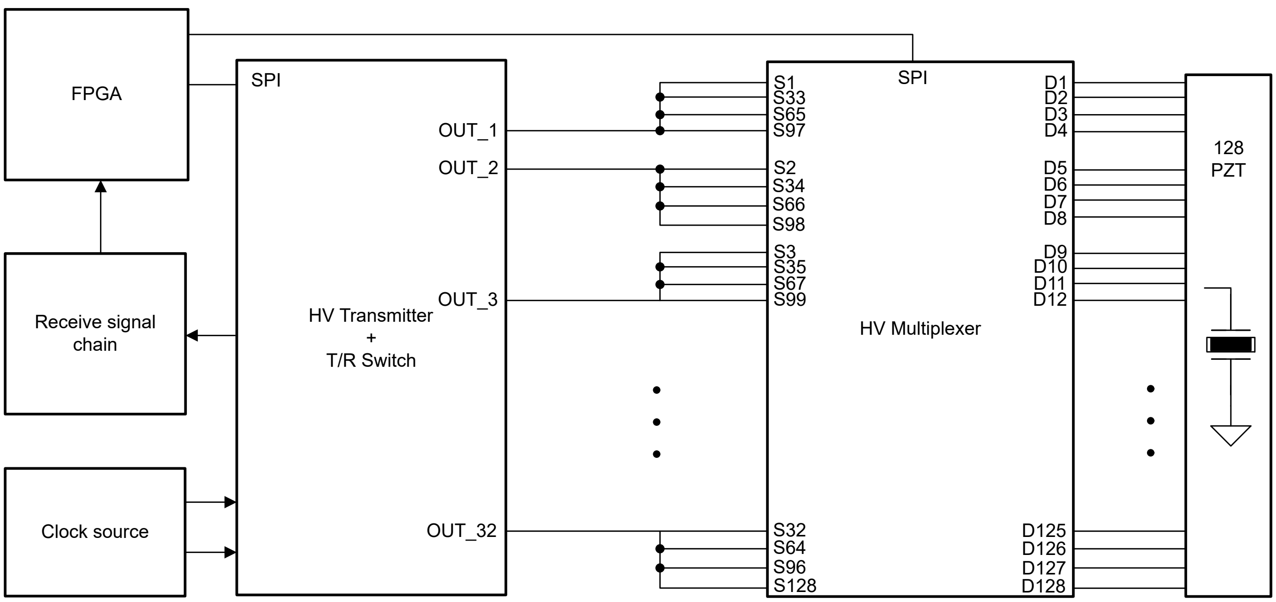

Figure 1-1. High Level Block Diagram of an Ultrasound System Showing Transmitter, Switches, and Probe Elements

The need for multiplexers is present in traditional ultrasound devices in addition to newer, portable ultrasound devices. Consider cart-based ultrasound systems, where power and board area are not as constrained as in smart hand-held ultrasound devices. For such systems, a limiting factor for designing a high channel count system is cable and probe design. Broadly speaking, each ultrasound probe element needs a corresponding driver signal source. For example, to maintain good signal integrity, a 256-channel system with only transmitters requires that each of probe element has a corresponding signal and ground wire in the connecting cable. The size of the cable is reduced in a probe design containing high voltage multiplexers. The multiplexers in the probe body route a reduced number of transmitter signal lines in the cable to the original quantity of transducer elements; the signal source for each element is shared between the wires of the cable, creating a lighter and more material efficient design. Figure 1-2 illustrates a 1:2 configuration, where one transmitter and receiver channel are connected to two transducer elements.

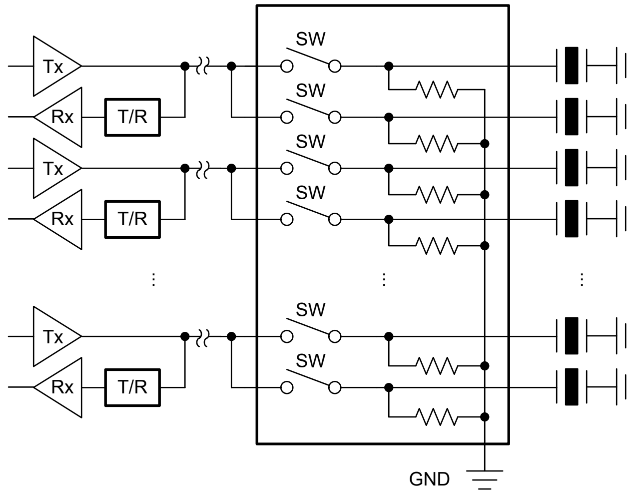

Figure 1-2. Switch IC Internals Shown With Transceivers and Probe Elements

Depending on the design of the multiplexer IC, the IC is powered in one of two ways: either with high voltage supplies, or a low voltage supply. TI's latest multiplexer, TMUX9832, is a 32 channel 1:1 device operating on a nominal 5V single ended supply. This eliminates the need for HV isolation within the probe, compared to probes with a dedicated HV supply. It also reduces heat and power dissipation because of the lower supply voltage involved.

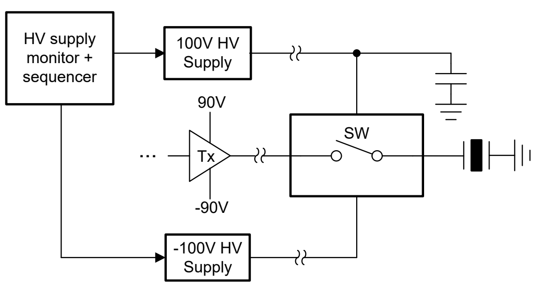

Figure 1-3. TMUX96xx Family (Single Channel Shown)

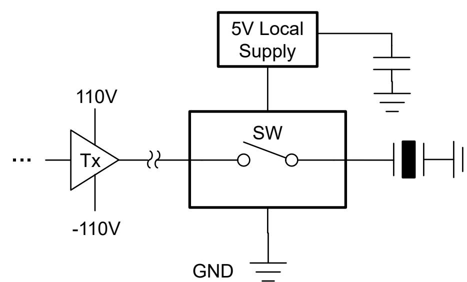

Figure 1-4. TMUX98xx Family (Single Channel Shown)

2 Front-End Architecture Comparison

This section looks at two different ultrasound transmitter front-end architectures for creating a 64-CH system (Figure 2-1). Both of the architectures employ the TX7516 (±100V, five-level, 16-channel transmitter with transmit/receive switch and on-chip beamformer). The latter employs the TMUX9832, which is a 5V Supply, 220V High Voltage 1:1, 32-Channel Switch with Latch-Up Immunity.

The first architecture is composed of four TX7516 transmitters in parallel. In this configuration all 64 channels can be driven simultaneously. Each TX7516 dissipates 77mW/channel in transmit receive mode and up to 197mW/channel in continuous wave (CW) mode. For four transmitters this equates to a power range of 4.93W to 12.6W. Each transmitter IC is 100mm^2 for a total IC area of 400mm^2.

The second architecture consists of two TX7516 transmitters connected to two TMUX9832 multiplexers. In this configuration, only 32 of the channels are driven at a time from both transmitters. The switches route the signals to the appropriate transducer elements, alternating between each set of 32 to make up the whole 64 channels. TMUX9832 has a typical dynamic power consumption of 9.5mW when switching all 32 channels at 50kHz. Altogether, the two transmitters and two switches can take anywhere from 2.47W to 6.31W. This corresponds to a power reduction of nearly 50% compared to the design with all transmitters. Each multiplexer IC (in BGA package) is 56.25mm^2 for a total IC area of 312.5mm^2, corresponding to a 22% size reduction.

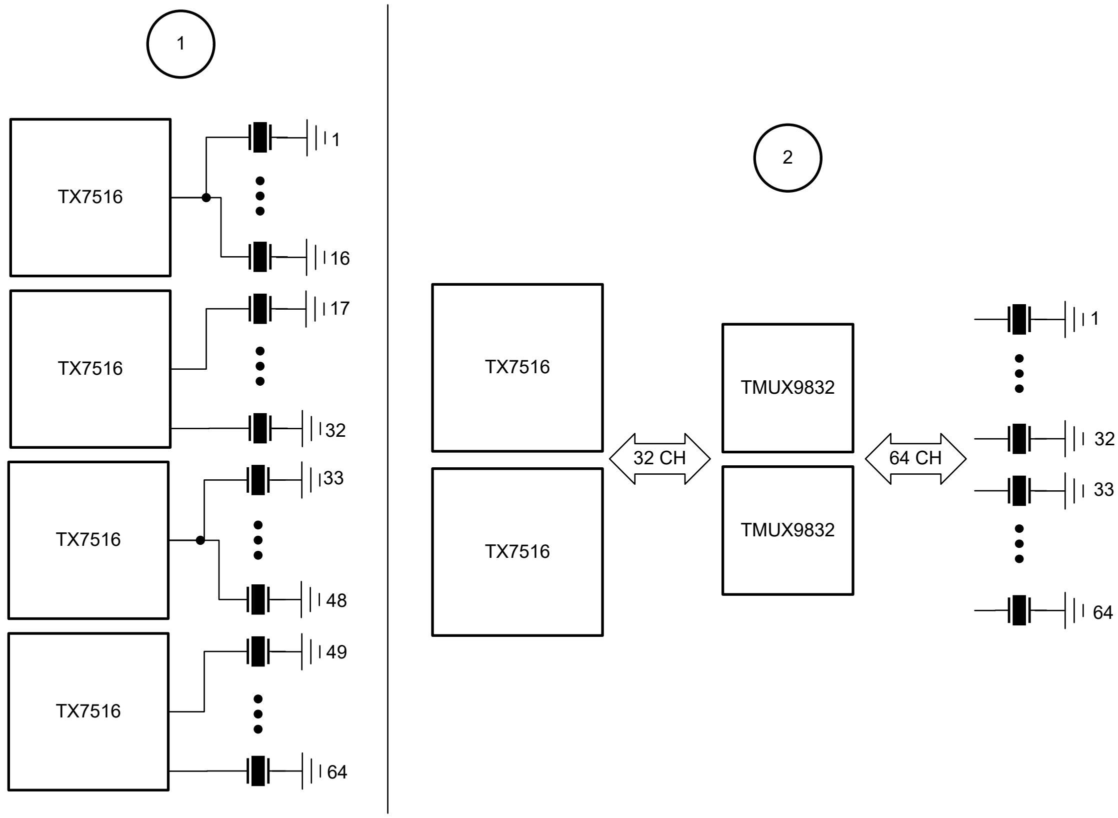

Figure 2-1. Example Front-End Architectures for 64-CH Ultrasound Systems

Table 2-1 summarizes the power and size comparison between the two architectures outlined previously.

Table 2-1. Power and Size Comparison Of Ultrasound Front-End Architectures

	Four 16-CH transmitters	Two 16-CH transmitters, Two 32-CH switches	% Reduction with multiplexers
Power - B mode (W)	4.93	2.47	49.7%
Power - CW mode (W)	12.6	6.31	49.8%
IC area (mm^2)	400	312.5	21.9%

Another potential option is to use four TX7516 devices (and no multiplexers), but only operate two of the TX7516 ICs for a total of 32CH transmitting at a time. In this case for B Mode, the total power for this design can be 2.496W, with the transmitting channels having 77mW/CH ×32, and the two TX7516 ICs not transmitting can consume 16mW/IC ×2. For this configuration, the two 16CH TX7516 transmitters plus two 32CH TMUX9832 switch architecture power improvement is only 1% better. However, if four transmitters are still on the board, the IC Area can still be larger by the same amount, and the customer can also need to consider the price difference of having four TX7516 ICs versus two TX7516 ICs and two TMUX9832 ICs.

3 Routing Topologies for Transmitters With Multiplexer Switches

Broadly, there are two ways to organize the connections between the transmitters and the mux switches. This section shows an example system with two 16CH transmitters and two 32CH multiplexers, but the concepts and routing topologies outlined here can be extended and applied more broadly.

The first is an *interwoven input* style (Figure 3-1), referring to how the multiplexer switch inputs are routed. Each adjacent switch input connects to sequential transmitter outputs. The transmitter outputs repeated to connect the additional multiplexer IC and hence *interweaving* with connections to the previous. The advantage is that on the output side, the routing from the multiplexer to the transducer is optimized for orderly connections. Additionally, only one clock cycle is required to update the state of all switch channels during scan, resulting in a faster system switching time.

The second is an *interwoven output* style (Figure 3-2) referring to how the multiplexer switch outputs are routed. Each adjacent switch output connects to disparate transducer elements and *interweave* as a result. The advantage is that on the input side, the routing from the transmitter to the multiplexer is optimized for short connections between switches. Additionally, because only half of the channels on each multiplexer can be active at a time, power dissipation is divided evenly between each IC.

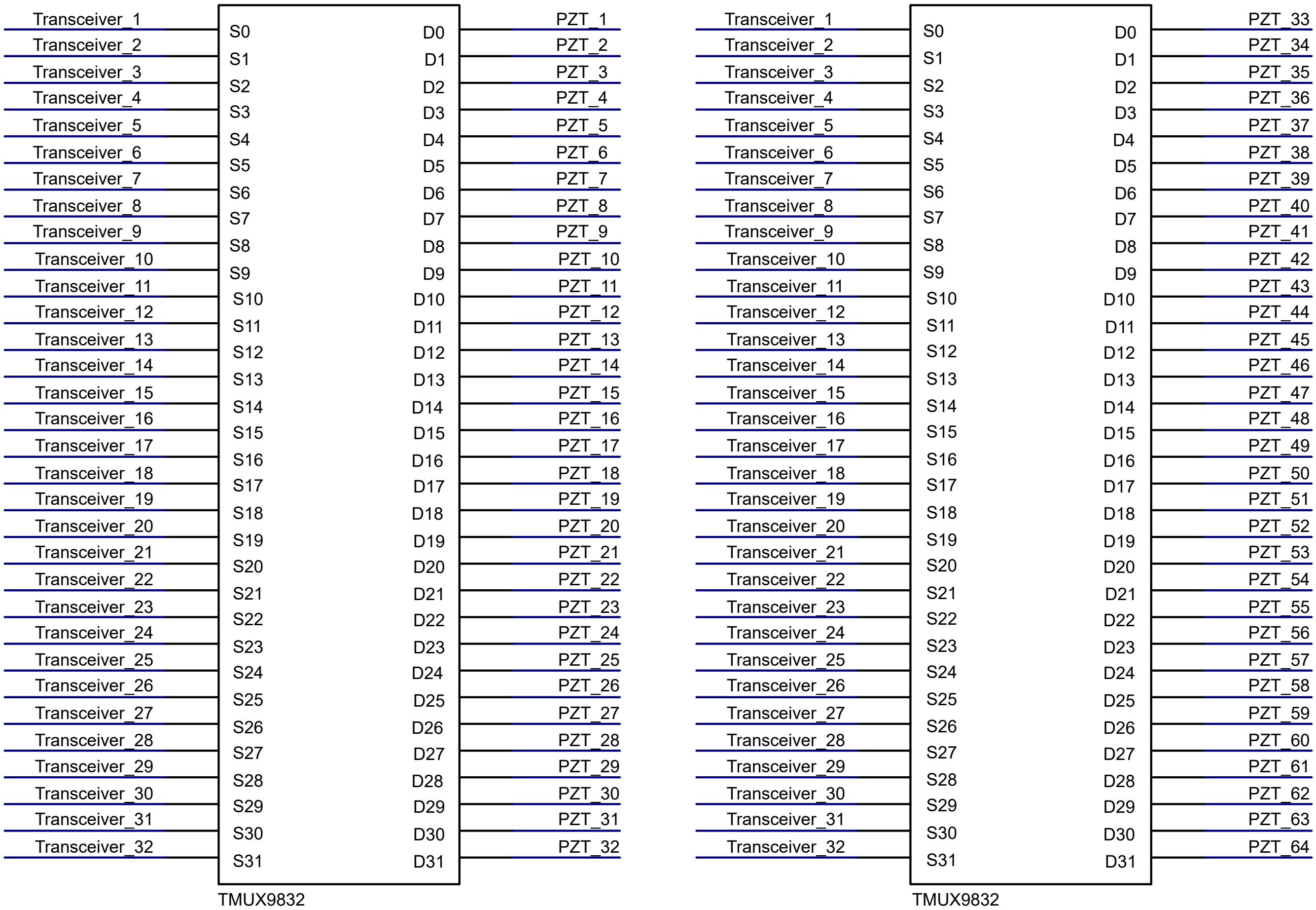

Figure 3-1. Interwoven Input Routing Topology for 64-CH Ultrasound Front End

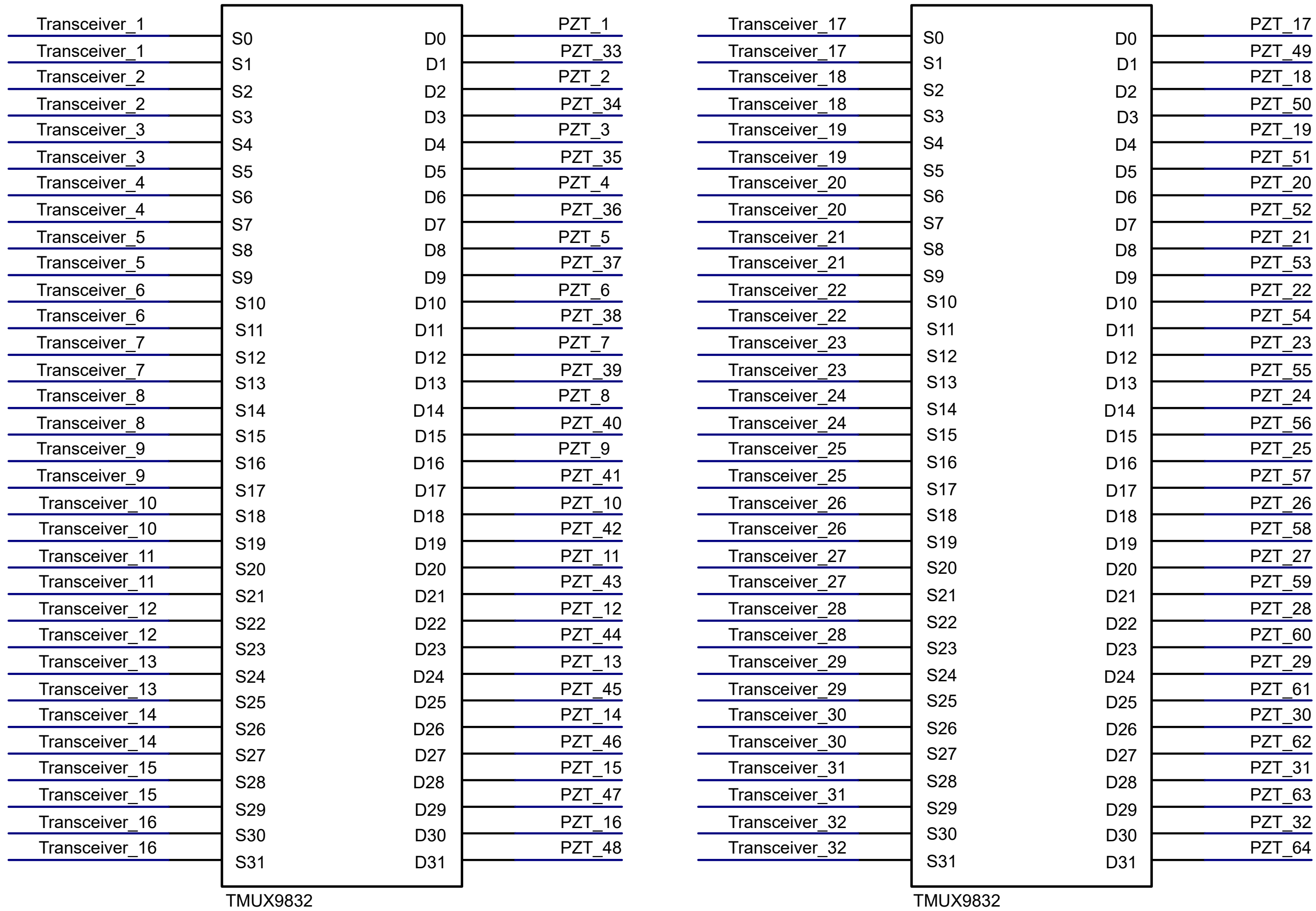

Figure 3-2. Interwoven Output Routing Topology for 64 CH Ultrasound Front End

Table 3-1 compares the tradeoffs between the interwoven input and interwoven output routing approaches.

Table 3-1. Tradeoff Comparison Between Interwoven Input and Interwoven Output Routing Styles

Topology (64-CH)	Interwoven Input	Interwoven output
Benefits	• Optimized routing between multiplexer and transducer. Output pins are ordered the same as piezo elements • Only one clock cycle required to update the state of all switch channels during scan (faster system switching time) • Depending on system use case, SET/CLR can be used to turn all channels ON/OFF with 1 GPIO only and remove need for SPI	• Optimized routing between transmitter and multiplexer. Each transmitter channel goes to one IC. Input pins on mux are adjacent to each other and can be shorted at the IC • Half of the channels are used at a time and power is dissipated between the two muxes
Limitations	• Interweaving routing required between transmitter and mux pins • Possible for all 32CH of the mux to be excited simultaneously and dissipate higher power per IC	• Interweaving routing required between mux output pins and piezo elements

4 Layout Example – Interwoven Input With TMUX9832 BGA Package

The TMUX9832 is available in 7.5mm x 7.5mm BGA and 10mm × 10mm QFN packages. Figure 4-1 shows part of a reference layout, where two TX7516 transmitters and four TMUX9832 switches are used to implement a 128-CH ultrasound system in the interwoven input style. In routing, care was taken to provide adequate spacing between each trace to minimize crosstalk to less than -50dB , as receivers typically only need around -50dB for good image quality. The 16-layer stackup was designed such that each signal has an adjacent ground plane for return currents. Ground vias are placed where signals change reference planes to mitigate EMI. Connections from the transmitter are routed in a star configuration with a via near the beginning of the trace.

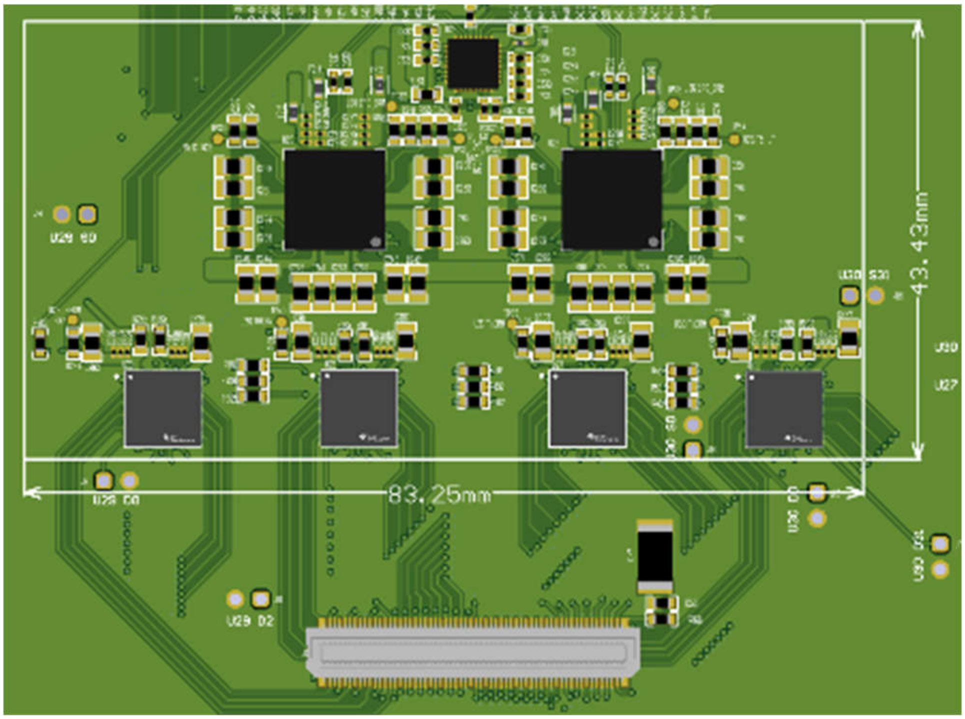

Figure 4-1. 3D View of 128-CH Ultrasound Transmitter Front End Design

A full PCB layout file of the above reference layout is available upon request. Please contact your TI representative to request and receive.

5 Extending the Architecture to Implement Higher Channel Count Systems

Fundamentally, the quantity of transmitters and switches to use is up to the designer; it can depend on the quality of the ultrasound image needed and other design constraints such as power and area mentioned previously. Additional factors can include routing layer count and PCB size, as well as thermal considerations for compact and enclosed devices. A common technique for such devices is to employ the use of board-to-board connectors in a stacked design.

6 Summary

This application note examined the benefits and limitations of using TI's high voltage multiplexers to improve the portability of ultrasound scanners. When the ultrasound design image quality targets allow for reducing max transmit aperture or image frame rate, multiplexers enable the designer to reduce power consumption, design size, and total system cost for the design. As many portable ultrasound devices can take advantage of this reduced transmit aperture for the image quality targets, utilizing ultrasound multiplexers is a great method to reduce system power consumption, design size, and cost and to increase end product portability and affordability.

As compact and power efficient ultrasound designs continue develop with the help of TI's HV multiplexer devices, this imaging technology can be made more widely available. In time, hand-held ultrasound scanners which enable non-invasive diagnostic techniques can be accessible to every doctor much like the stethoscope. Other applications of ultrasound imaging technology in fields such as non-destructive testing (used to identify flaws, inconsistencies, or defects in materials, components or structures) can benefit from power and size benefits of TI's HV multiplexer devices as well.

7 References

- Texas Instruments, *TX7516 Five-Level, 16-Channel Transmitter with T/R Switch, and On-Chip Beamformer*, data sheet.
- Texas Instruments, *TMUX9832 No High Voltage Bias, Beyond the Supply, 220 V 1:1, 32-Channel Switch With Latch-Up Immunity*, data sheet.
- Texas Instruments, *Building High-Performance NDT Systems with Ultrasound Transmitters and Receivers*, application brief.