Application Report
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Supporting Elastography (Shear Wave) and CW Doppler Modes in Ultrasound Using Power Reference TI Designs

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ABSTRACT

The power supply for the Ultrasound Transmit devices need to support programmability with high varying current capabilities. Depending on the mode of operation selected, TI's latest TI Designs (TIDA-01352, TIDA-01371 and TIDA-01458) can be connected together to support high-voltage, high-current shear wave sonography as well as Continuous Wave (CW) Doppler modes. This application report explains how to use these three designs to support different modes.

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Trademarks

1 Overview of Ultrasound Modes

A medical ultrasound application requires high-voltage pulses to be transmitted inside a human body (through piezo sensors) to get information about blood, organs, tissues, and so on. These pulses are bipolar in nature and are transmitted by pulsers.

There are two modes in general:

- Pulse (Brightness or B, PW, CFM, Power Doppler and M modes) mode where high-voltage pulses (–100 and 100 V) are transmitted for a particular short time only.
- Continuous Wave (CW) mode where low-voltage pulses are continuously transmitted.

Note that the same power supply is used for both the modes meaning the output of power supply is ranging from ±2.5 to ±100 V. Such a powering scheme is typically implemented using a switched mode power supply (SMPS) followed by Low noise regulators. The voltage noise on the output signal is very important when CW mode is used because the signal amplitudes are low. Within Pulse mode, there is a special mode called Elastography (or Shear wave) mode. The current requirements are huge (sometimes more than 100 A) for a short period of time (may be up to a millisecond). Delivering such a high current at high voltages without dropping the output voltage is a challenge. To cover for the droop in output voltage, the high value of capacitors is also used at the output of SMPS.

2 Example of Power Calculations—Standard Imaging Mode

The following is an example of pulse mode for medical imaging. The standard mode has a driving waveform as shown in Figure 1.

Assume the following nomenclatures:

- t_{on} = total on-time
- t_{off} = total off-time
- f = operating frequency of the probe
- n = number of pulses
- C = capacitance of the probe at operating frequency f
- N = number of transducers

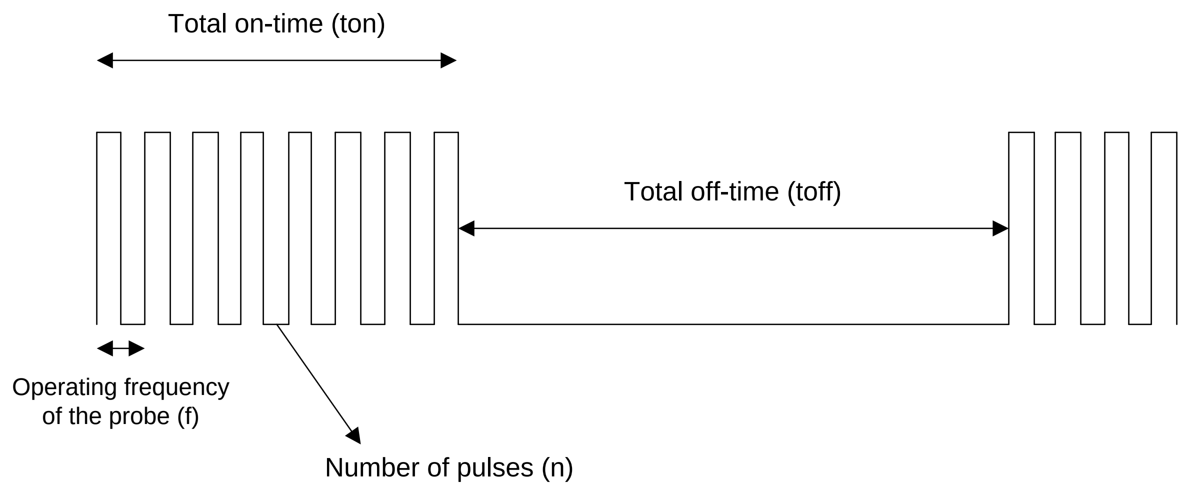

Figure 1. Standard Driving Waveform for Ultrasound Transducers

For a 128-channel transducer ultrasound system, N = 128. For this example, consider a probe with the following specifications:

- C = 470 pF
- f = 7.5 MHz
- Total number of pulses n = 10
- t_{off} = 300 µs
- t_{on} = 1.3 µs (calculated using n = 10 and f = 7.5 MHz)
- Voltage for transition is from –100 to 0 V or 0 V to 100 V

$$\text{Peak power consumption} = 4 \times 128 \times 470\text{p} \times 100^2 \times 7.5\text{M} = 18\text{ kW} \quad (1)$$

$$\text{Peak output current} = \frac{18\text{ kW}}{100} = 180\text{ A} \quad (2)$$

$$\text{Average power consumption} = \frac{18\text{ kW}}{300} \times 1.3 = 78\text{ W} \quad (3)$$

For a 20-V dip on the output capacitor of SMPS (that is, input capacitor of floating regulators):

$$C_{OUT} > \frac{I_{OUT} \times \text{ton}}{20} > \frac{180 \times 1.3\,\mu}{20} > 11.7\,\mu\text{F} \quad (4)$$

This means that with an output capacitor of SMPS = 470 µF, the dip on the output voltage (of the SMPS) is 0.49 V. In such a case, there is no need to use the floating regulator. The output capacitor of the SMPS is enough to provide the required ability to drive the transducers.

However, there are some special imaging modes like Elastography where the requirements are different.

3 Example of Power Calculations—Special Imaging Mode (Elastography)

The special imaging mode Elastography has a driving waveform as shown in Figure 2.

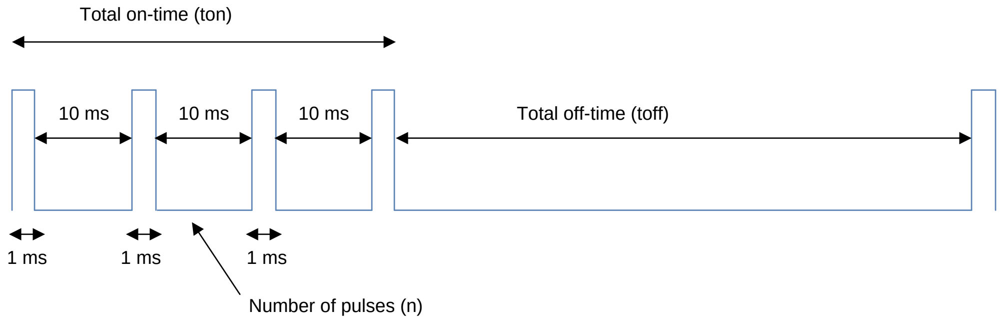

Figure 2. Elastography—Driving Waveform for Ultrasound Transducers

Considering the same nomenclature as explained before:

- n = 5 pulses
- t_{on} = 55 ms
- t_{off} = 2 seconds

$$P_{AVG} = P_C \times \frac{1}{11} \times \frac{55}{2055} = 43.7\ W \tag{5}$$

The average power needed for Elastography is less than the standard imaging mode. Assuming the same voltage dip of 20 V:

$$C_{OUT} > \frac{I_{OUT} \times ton}{V_{dip}} > \frac{180 \times 1\,m}{20} > 9000\ \mu F \tag{6}$$

However, this needs to be replenished in time periods of 10 ms between the two 1-ms pulses as shown in Figure 2. If the SMPS is a 80-W rated power supply, the system would be current limited to 80/100 = 0.8 A only. The charging current needed in such case is:

$$I_{charge} = \frac{20 \times 9000\ \mu}{10\ m} = 18\ A \tag{7}$$

4 Introduction to the TI Designs Used for Powering Ultrasound Transmitters

TIDA-01352 is 400-W Continuous, Scalable, ±2.5- to ±150-V, Programmable Ultrasound Power Supply Reference Design. It enables modular and efficient power scaling capabilities by providing a solution for digitally programmable power supplies to power ultrasound transmit circuits. The design uses push-pull topology to generate high-voltage (HV) and low- (LV) or MID-voltage power supplies. The HV rails are programmable from ±50 to ±150 V, whereas the LV or MID rails are programmable from ±2.5 to ±50 V. The power supply is capable of providing continuous power of 100 W on each rail. The programmability is implemented using onboard, 12-bit digital-to-analog converters (DACs). All the power supply rails can be synced to a master clock. The design is scalable and modular allowing same supply to be duplicated or removed depending on number of channels and number of levels of pulser. The design also consists of other LV power supplies necessary for the pulser operation.

TIDA-01371 is Programmable, High-Current, floating Linear Regulator Reference Design. It demonstrates a positive and negative linear regulator that can provide output voltages varying from ±2.5 to ±100 V. The programmability (meant to come from a DAC) is implemented using external control voltages. The low-noise performance helps in replacing passive and active noise filters with off-the-shelf low-noise positive and negative LDO regulators and a circuit to float the ground of the regulators. In addition, it uses external power MOSFETs to scale the current capability of regulators to support special imaging modes such as shear wave, or elastography, mode. In order to provide extremely high currents to the transducers, large input capacitors can provide high energy for 1 ms, keeping the average current drawn from this power supply very low.

TIDA-01458 is a Low-Noise, Fixed Drop-Out, Power Supply Reference Design for Ultrasound CW Pulser (Uses only one control voltage each for +ve and one for -ve – to adjust the output voltages and the post LDO that follows). It allows a digitally programmable power supply to power an ultrasound transmit circuit for continuous wave (CW) mode from a 24-V bus. There are two outputs adjustable from ±2.5 to ±12 V under user software control. These outputs can provide up to 2A with very low ripple and noise on both positive and negative regulator outputs. The LDOs are operated as power filters with fixed 1v drop from input to output. The power supply is scalable for higher output currents up to 3-A by adding more regulators in parallel. It can also be synchronized to an external clock.

5 Combining These TI Designs

All the three designs can be combined together as shown in the block diagram in Figure 3 and board-level image in Figure 4. Note that the control voltages for all the boards are not shown in the figure. TIDA-01352 board is an SMPS, powered from a 24-V input and has four output rails. The upper two rails are low voltage, programmable from ±2.5 V to ±50 V, whereas, the lower two rails are high voltage programmable from ±55 V to ±150 V. Each of these rails can support continuous output power of 100W.

The outputs of TIDA-01352 board can be fed into the inputs of TIDA-01371 boards, which is a floating regulator reference design. We have a capacitor bank of 1000uF to store the large currents required to support bursts of elastography mode, while keeping the output stable.

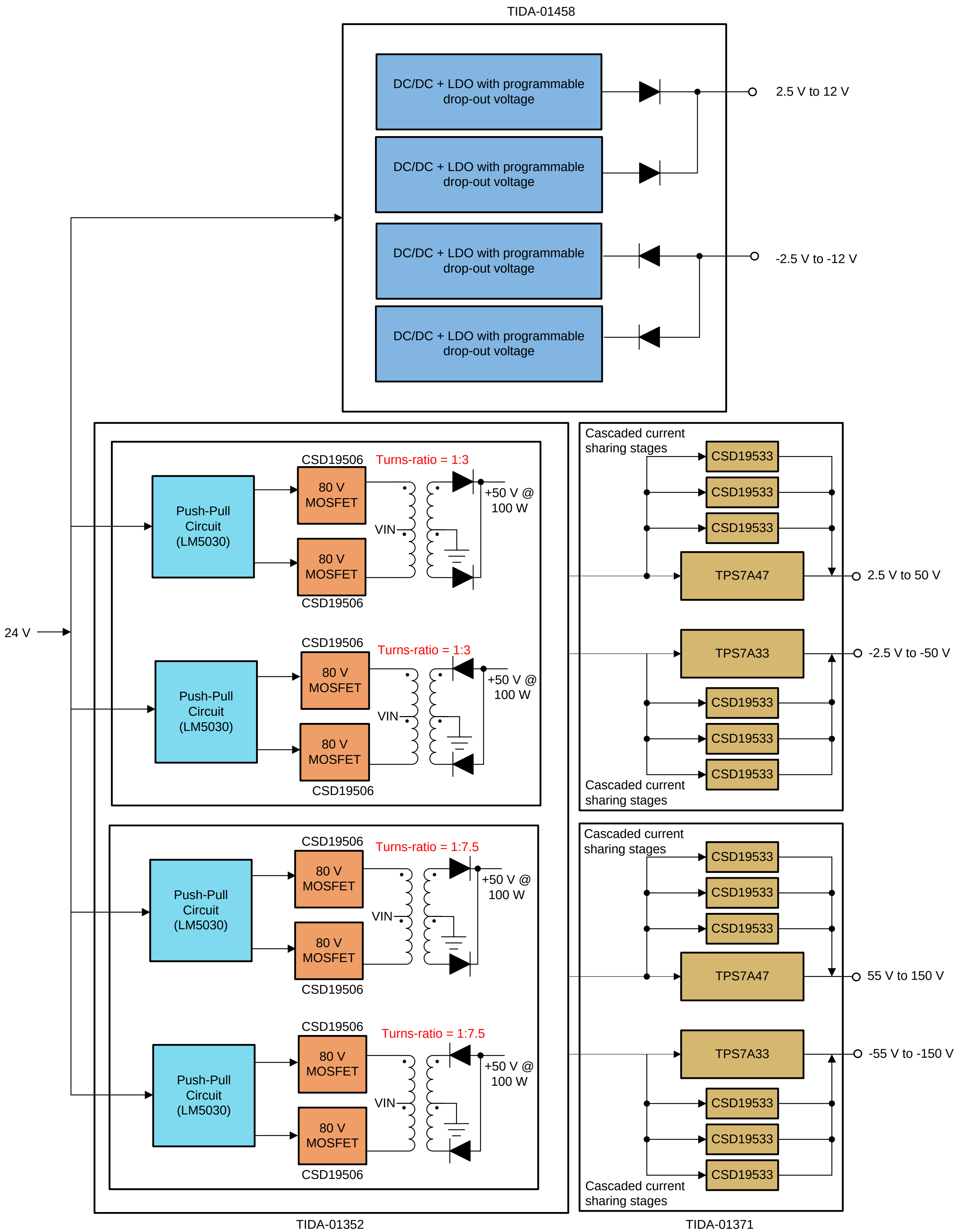

Figure 3. Combining TI Designs Block Diagram

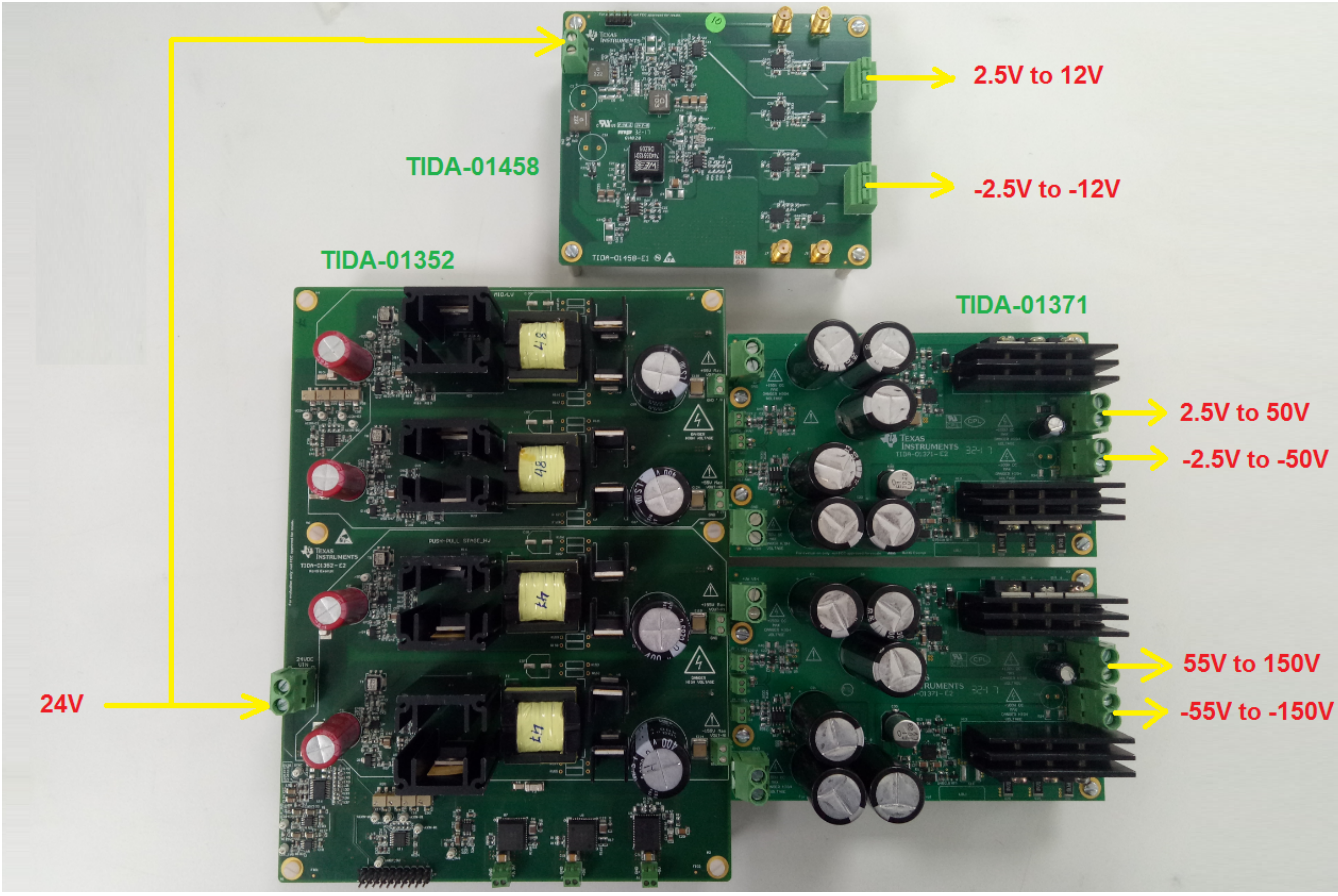

Figure 4. Combining TI Designs (Boards)

The individual design details for each TI Designs are available on their respective pages on TI web. Depending on the mode of operation selected, the TI designs can be connected together to support high-voltage, high-current shear wave sonography as well as Continuous Wave (CW) Doppler modes.

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

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