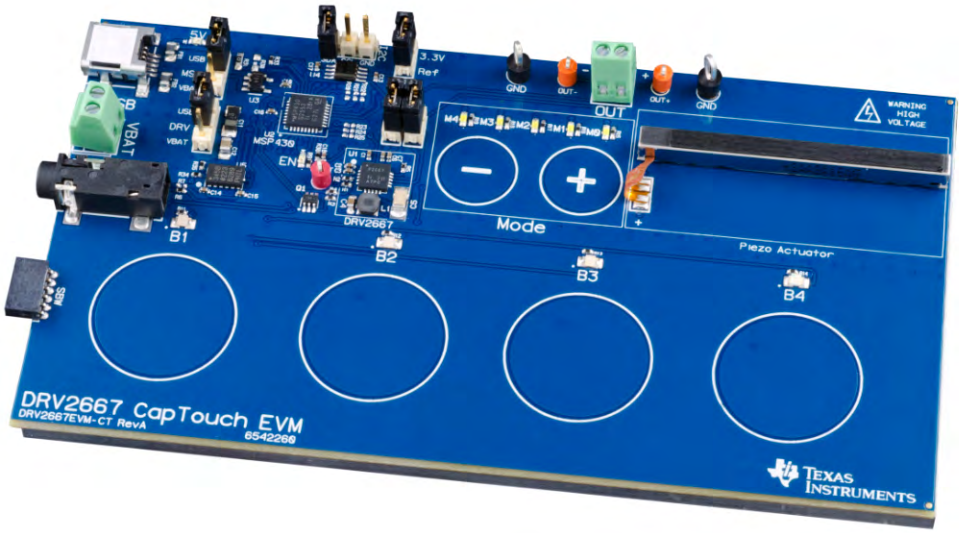
DRV2667 Evaluation Module

The DRV2667 is a digital interface, high-voltage driver designed to control Piezo actuators with voltages between 40 Vpp and 200 Vpp. The DRV2667 eliminates many design complexities of driving Piezo by including an integrated 100-Vpp boost converter and 200-Vpp differential output amplifier. In addition, the digital control interface (I^2C™) includes real-time waveform playback, a waveform generator, and embedded RAM for waveform storage.

The DRV2667EVM-CT Evaluation Module (EVM) kit is a complete demonstration and evaluation platform for the DRV2667. The kit includes a microcontroller, Piezo actuator, sample waveforms, and capacitive touch buttons which can be used to completely demonstrate and evaluate the DRV2667.

This document contains instructions for setup and operation of the DRV2667EVM-CT, as well as an in-depth description and examples of haptic waveforms for Piezo actuators.



Evaluation kit contents

- DRV2667EVM-CT demonstration and evaluation board
- Mini-USB cable

Tools needed for programming and advanced configuration

- Code Composer Studio™ (CCS) or IAR Embedded Workbench IDE for MSP430
- MSP430 LaunchPad (MSP-EXP430G2) or MSP430-FET430UIF hardware programming tool
- DRV2667EVM-CT firmware

WARNING

This evaluation board contains high voltages, up to 200 Vpp. Please use the necessary precautions when using this board.

Code Composer Studio is a trademark of Texas Instruments.
I^2C is a trademark of NXP.

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1 Getting Started

The DRV2667EVM-CT can be used as a demonstration and evaluation tool. The DRV2667EVM-CT comes pre-programmed with a basic demonstration program that includes sample haptic waveforms to use with the on-board actuator.

To begin, power the board by connecting the DRV2667EVM-CT to an available USB port using the included mini-USB cable. The board begins with a power-up sequence, and finishes by entering Demo mode. In Demo mode, the four larger buttons (B1–B4) are used to sample haptic effects with the on-board Piezo in the top-right corner. The two smaller mode buttons (**–**, **+**) are used to change between the different modes or sets of effects. See DRV2667 Demonstration Program for a more detailed description.

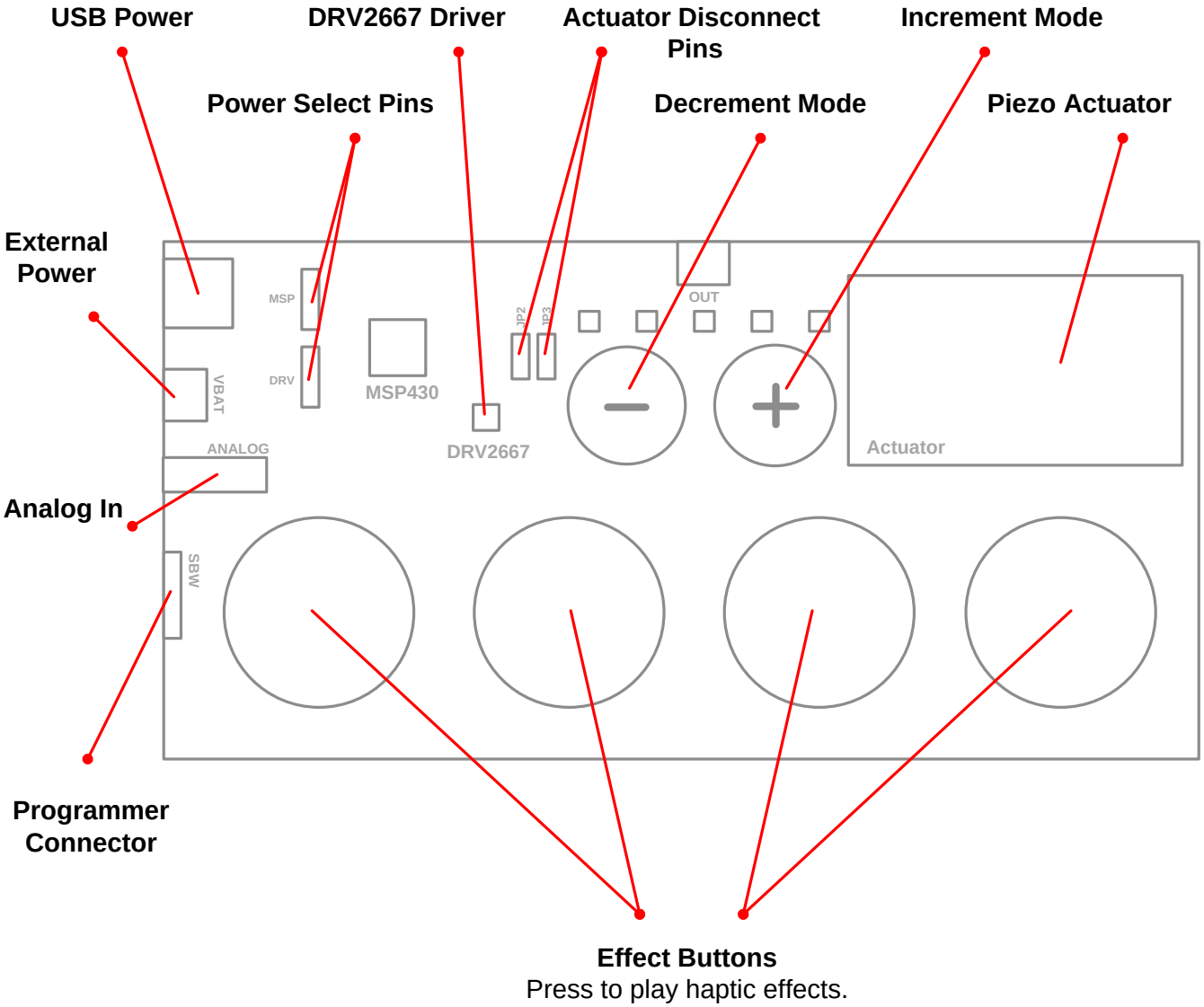

Figure 1. Board Diagram

1.1 Evaluation Module Operating Parameters

Table 1 lists the operating conditions of the DRV2667. More detailed information can be found in the DRV2667 datasheet on ti.com (http://www.ti.com/product/drv2667).

Table 1. EVM Operating Parameters

Parameter	Specification
Supply voltage range	3.0 V to 5.5 V
Power supply current rating	700 mA

1.2 Quick-Start Board Setup

The DRV2667EVM-CT firmware contains sample haptic waveforms which showcase the features and benefits of the DRV2667. See the instructions below to power the board and begin using Demo mode.

1. Out of the box, the jumpers are set to begin demo mode using USB power. The default jumper settings are found in Table 2.

Table 2. Default Jumper Settings

Jumper	Default Position	Description
JP1	Shorted	3.3-V reference for I^2C
JP2, JP3	Shorted	Connect the on-board actuator to the DRV2667
MSP	USB to MSP	Selects USB (5 V) for the MSP430 power rail
DRV	USB to DRV	Selects USB (5 V) for the DRV2667 power rail

2. Connect the mini-USB cable (included) to the USB connector on the DRV2667EVM-CT board.
3. Connect the other end of the USB cable to an available USB port on a computer, USB charger, or USB battery pack.
4. If the board is powered correctly, the four colored LEDs will light, the four mode LEDs will flash, and the Piezo will buzz, indicating the board has been successfully initialized.

2 DRV2667 Embedded Software

The DRV2667EVM-CT contains a microcontroller with embedded software to operate and control the board. The software consists of multiple sets of modes and effects that showcase the features of the DRV2667 driver. There are three sets of modes that are accessed by pressing and holding the "**+**" button. The diagram below shows how to access the different sets.

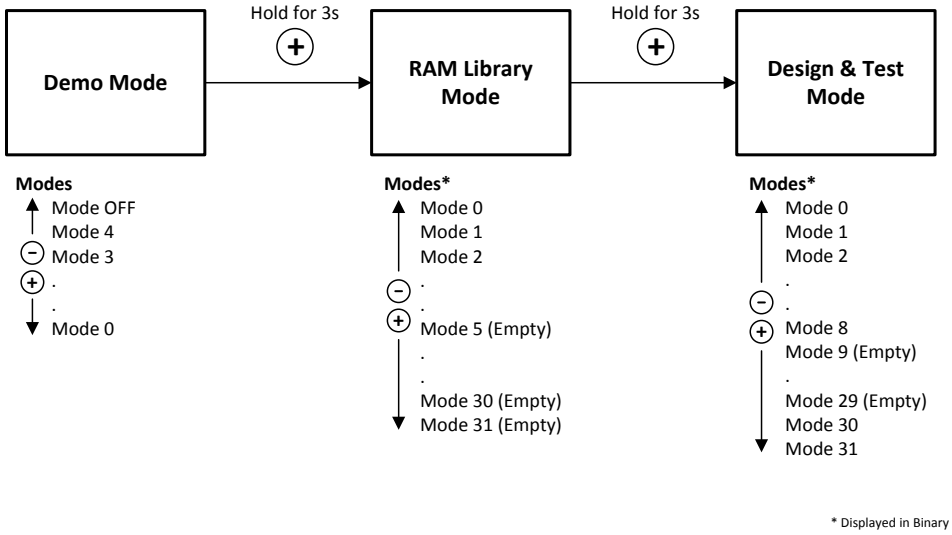

Figure 2. DRV2667EVM-CT Mode Sets

Set Descriptions:

1. Demo Mode – contains a set of pre-designed effects that use the features of the DRV2667. This mode is great for demonstrating the DRV2667.
2. RAM Library Mode – a library created and stored in the RAM of the DRV2667. Library mode implements a RAM-based library of effects that are triggered by the MSP430 microcontroller.
3. Design & Test Mode – a set of modes used to build waveforms, perform life tests, and control the DRV2667 externally.

2.1 Demo Mode

The demo effects are listed in Table 3. The modes are selected using the "**–**" and "**+**" mode buttons in the center of the board. The current mode is indicated by the white LEDs directly above the mode buttons. Buttons B1–B4 trigger the effects listed in the description column and change based on the current mode.

Table 3. DRV2667EVM-CT Demo Mode

Mode	Button	Description	Notes
Mode Off LEDs Off	B1	Alert 1	Mode 3 – Waveform generation
	B2	Alert 2	
	B3	Alert 3	
	B4	Alert 4	
Mode 4 LED M4 On	B1	Short click	Mode 3 – Waveform generation
	B2	Click and release 1	
	B3	Click and release 2	
	B4	Ramp and release	
Mode 3 LED M3 On	B1	Ramp up (200 Hz)	Mode 3 – Waveform generation
	B2	Bounce (250 Hz)	
	B3	Click bounce	
	B4	Pulse (hold to repeat)	
Mode 2 LED M2 On	B1	Sharp click	Mode 1 – FIFO
	B2	Bump	
	B3	Alert	
	B4	Robotic (two-tone) click	Mode 2 – RAM mode
Mode 1 LED M1 On	B1	Concentration/Simon game	Mode 3 – Waveform generation
	B2		
	B3		
	B4		
Mode 0 LED M0 On	B1	28.8 dB, 50 Vpp, Boost = 30 V	Analog Input – Press a button to set the gain, voltage and enable the part for analog input. Disable by changing modes.
	B2	34.8 dB, 100 Vpp, Boost = 55 V	
	B3	38.4 dB, 150 Vpp, Boost = 80 V	
	B4	40.7 dB, 200 Vpp, Boost = 105 V	

2.2 Demo Mode Descriptions

The modes and effects in Table 3 are described in the following sections. Use this as a starting point for creating your own waveforms.

2.2.1 Mode Off – Alert Effects

The effects in Mode Off are basic alert effects that use the DRV2667 waveform generator. The waveform generator reduces the demand of the host processor by creating the output waveform based on five parameters set in the DRV2667 register map. This eliminates the need for the host processor to output waveform samples continuously. The only thing the host processor must do is “trigger” the waveform.

For effects that repeat continuously, simply program the DRV2667 to repeat the waveform and then “trigger” the waveform; once triggered, the waveform will repeat continuously until stopped.

The following waveforms are generated when buttons B1–B4 are pressed.

Button B1 – Alert 1

Alert 1 is a single waveform that produces a bump or buzz feel.

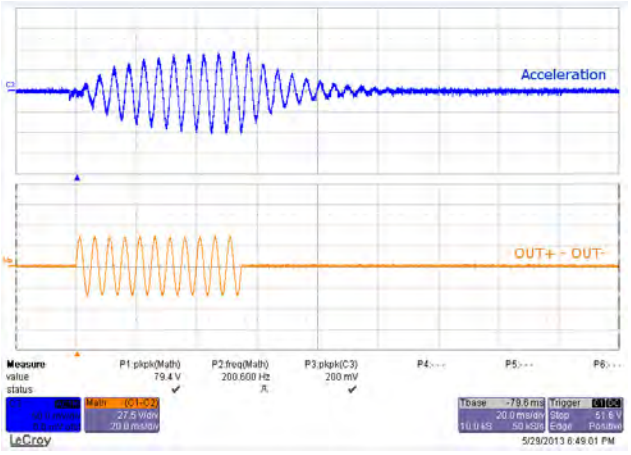

Figure 3. B1 – Alert 1

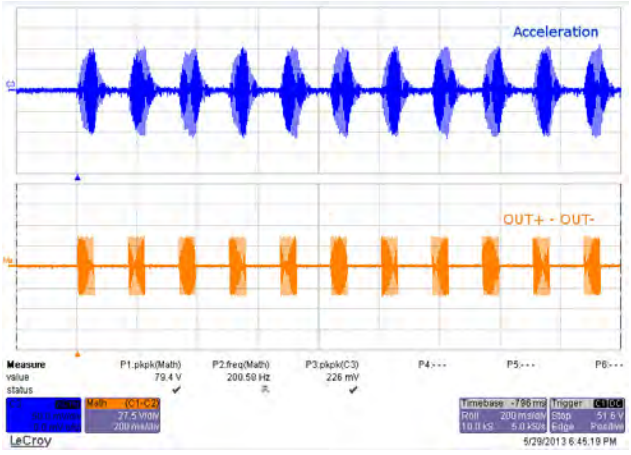

Figure 4. B1 – Alert 1 Continuous Repeat

Button B2 – Alert 2

Alert 2 is a sequence of two waveforms that produces a buzz and click waveform.

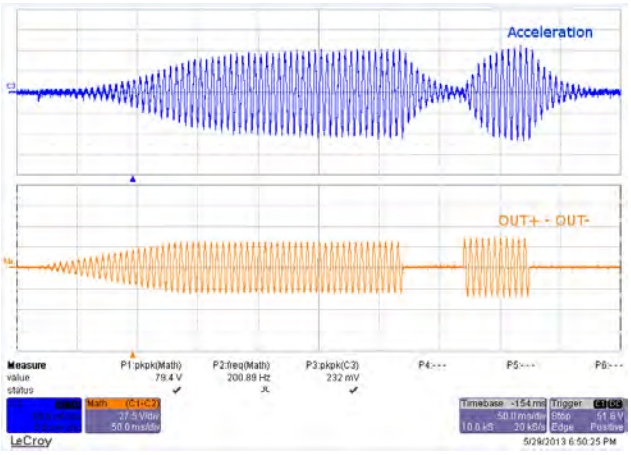

Figure 5. B2 – Alert 2

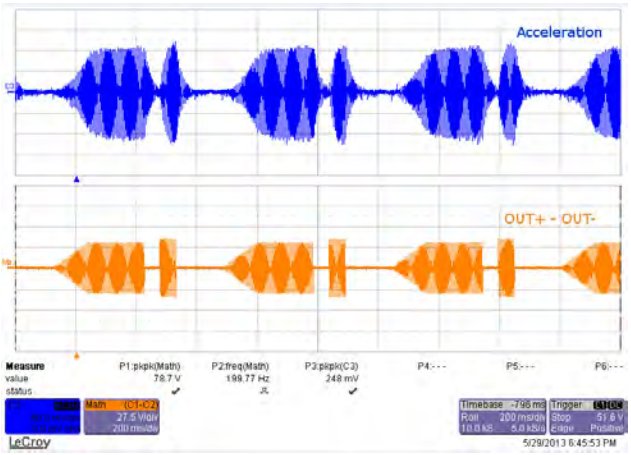

Figure 6. B2 - Alert 2 Continuous Repeat

Button B3 – Alert 3

Alert 3 is a sequence of five waveforms that produces a gallop like feel.

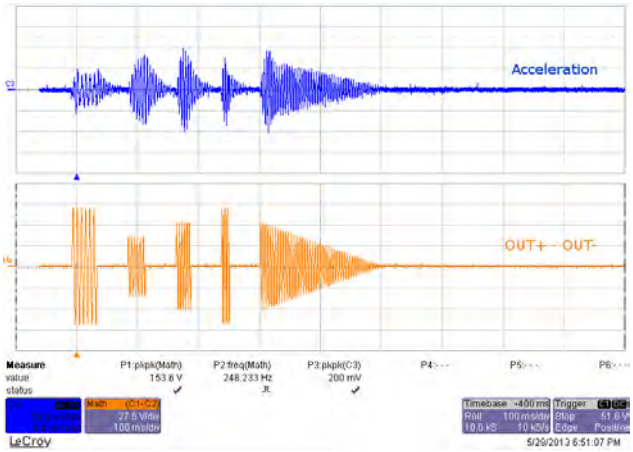

Figure 7. B3 – Alert 3

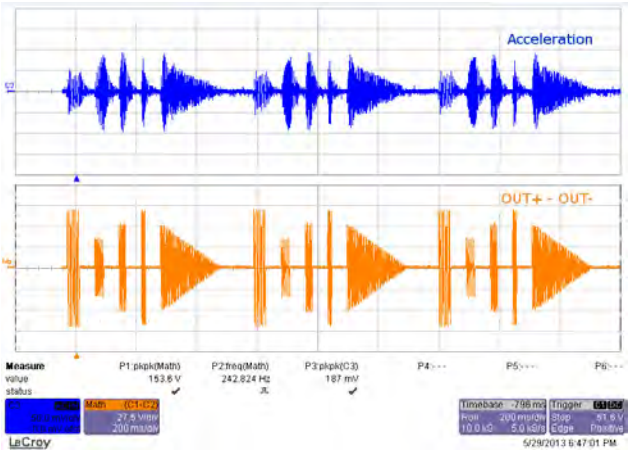

Figure 8. B3 – Alert 3 Continuous Repeat

Button B4 – Alert 4

Alert 4 is a single waveform that produces a buzz.

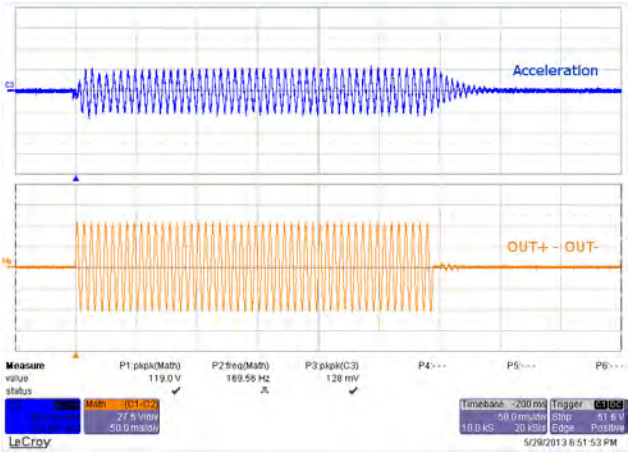

Figure 9. B4 – Alert 4

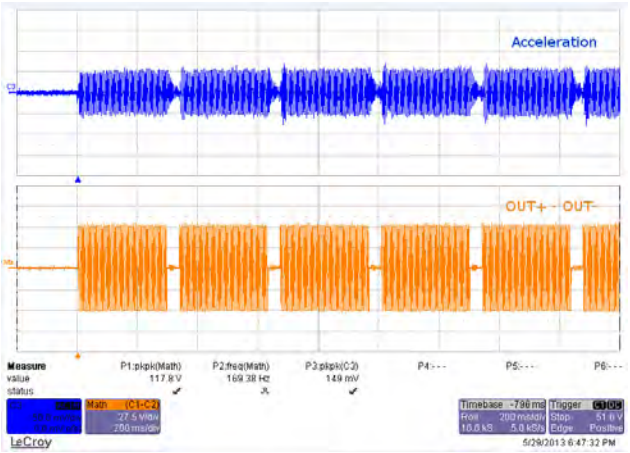

Figure 10. B4 – Alert 4 Continuous Repeat

2.2.2 Mode 4 – Click and Release Effects

The effects in Mode 4 are clicks and click and release effects. A click and release effect produces a click feel when the button is pressed and another click when the button is released.

Button B2 – Click and Release

The click and release effect on button B2 is shown in the two images below. In Figure 11, the release is nearby the press click, because the button was pressed and released quickly. In Figure 12, the release is further from the press click, because the button was released slower.

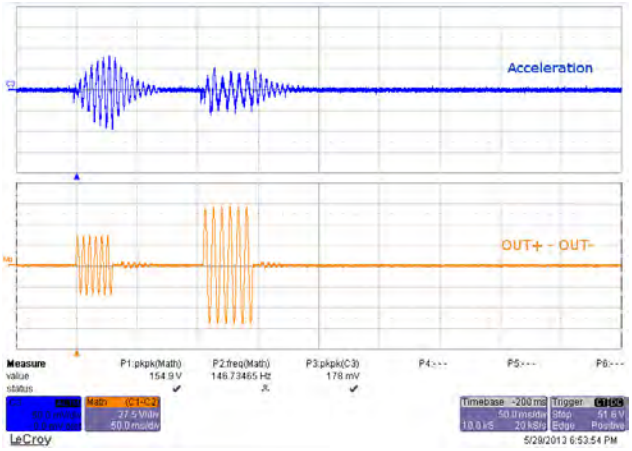

Figure 11. B2 – Click and Release 1

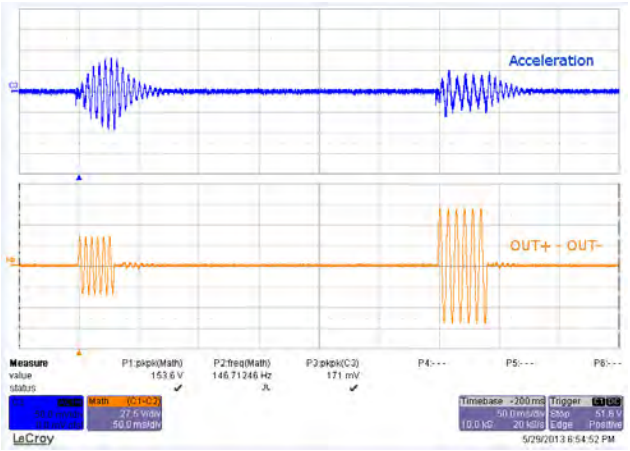

Figure 12. B2 – Click and Release 2

Button 4 – Ramp and Release

The effect on button four is a ramp and release effect. When the button is pressed the waveform ramps up and when released it ramps down.

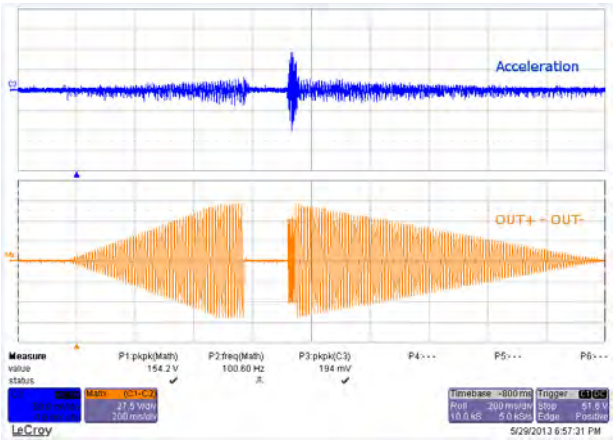

Figure 13. Ramp and Release

2.2.3 Mode 3 – Gaming Effects

The effects in mode 3 are unique effects that can be used for gaming.

Button 1 – Ramp Up

Button 1 is a ramp up waveform which can be easily programmed using the waveform generator.

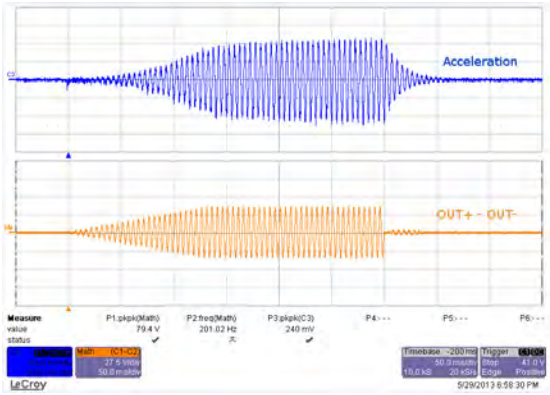

Figure 14. B1 – Ramp Up

Button 2 – Click Bounce

Button 2 consists of two waveforms, a click, and then a ramp down. This produces a click bounce feel.

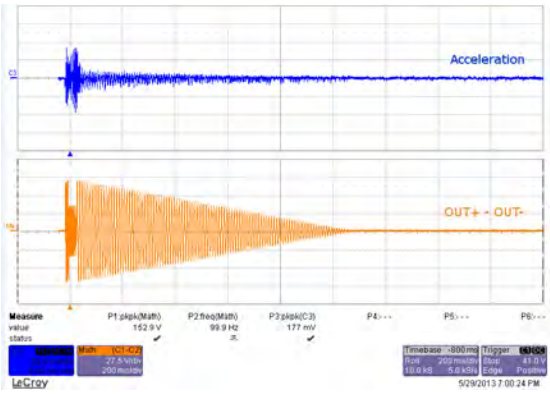

Figure 15. B3 – Click Bounce

Button 4 – Pulse

Button 4 consists of two waveforms a ramp up and ramp down. This produces a pulsating effect.

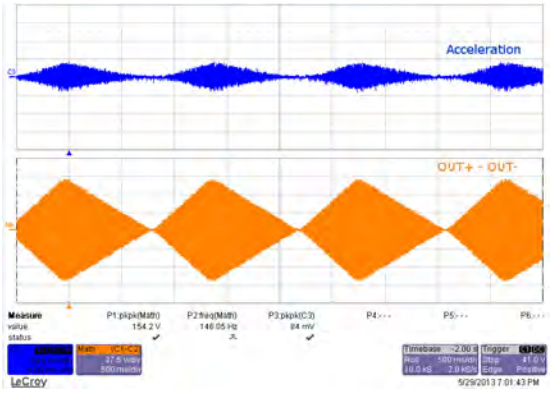

Figure 16. B4 – Pulse

2.2.4 Mode 2 – FIFO and RAM Effects

The effects in Mode 2 are very similar to the previous modes; however, they do not use the DRV2667 waveform generator. Instead they use either the FIFO streaming mode or the internal RAM. The advantage of using FIFO or RAM is that the waveforms can be completely arbitrary.

In Figure 17 and Figure 18, the click and bump were created using FIFO mode.

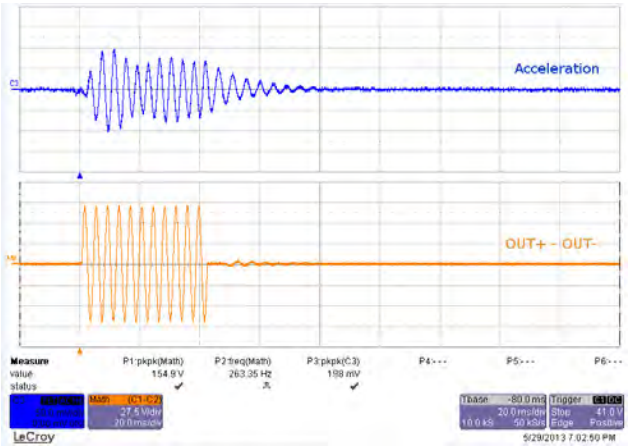

Figure 17. B1 – Sharp Click Using FIFO

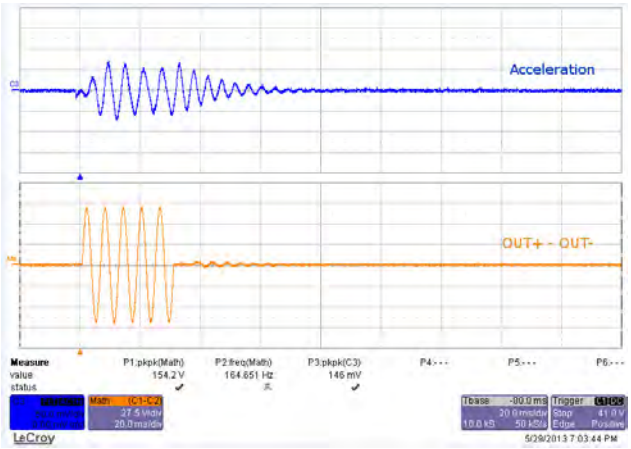

Figure 18. B2 – Bump using FIFO

If you choose to use the embedded RAM you can create waveforms like the two-tone robotic click waveform in Figure 19.

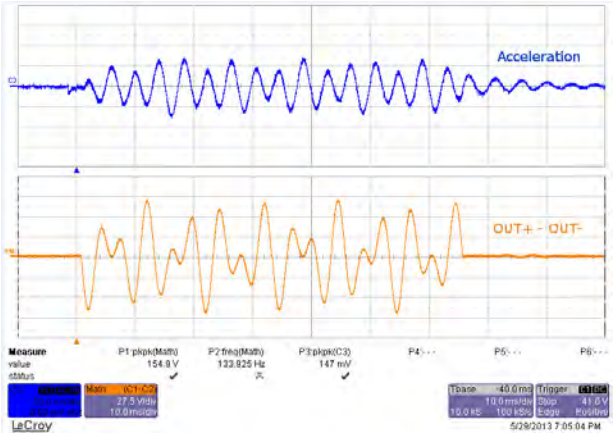

Figure 19. B4 – Robotic Click using RAM

2.2.5 Mode 1 – Concentration Game

Mode 1 is a game that incorporates the various Piezo effects. This can be used to demonstrate haptics in a real application.

To begin playing Concentration:

1. Press any of the large effect buttons.
2. The game will then count down.
3. Once the countdown completes, a button will turn on and an effect will play.
4. Repeat the pattern by pressing the same button.
5. After each successfully repeated pattern, the board will repeat the same pattern and add one additional button to the sequence.

2.2.6 Mode 0 – Analog or Audio Input

Mode 0 allows you to connect an analog input source to the DRV2667EVM-CT. See Analog/PWM Input for the hardware configuration.

This shows the advantage of Piezo over other actuator technologies. Piezo actuators have a much faster response time than ERM and LRA actuators, so the Piezo actuator can be driven with an analog or audio signal and reproduce the input frequencies well.

Figure 20 is an illustration of an audio signal producing vibration on the Piezo actuator.

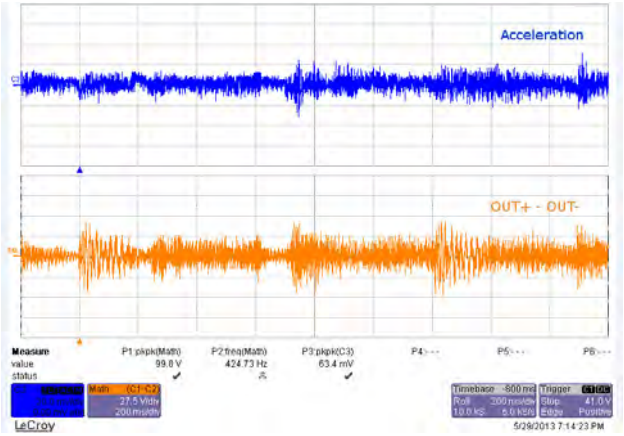

Figure 20. B3 – Audio In

2.3 RAM Library Mode

The second set of modes is called *Library Mode*, which implements a haptic effect library using the DRV2667 RAM. The effects in RAM are accessed in sequential order using the capacitive touch buttons. For example, with all Mode LEDs off, B1 is waveform 1, B2 is waveform 2, and so on. Then when Mode LED M0 is on, B1 is waveform 5, B2 is waveform 6, and so on. Enter *Library Mode* and access the DRV2667 RAM Library using the following steps:

1. Press and hold the increment mode button ("**+**") for approximately 3 seconds until the mode LEDs flash and the colored LEDs flash once.
2. Now use the "**+**" and "**–**" buttons to select the mode and press buttons B1–B4 to play an effect.

The equations for calculating the Mode and Button of an effect are:

Mode = RoundDown([Effect No.] / 4) (1)

Button = ([Effect No.] – 1) % 4 + 1 (2)

% – modulo operator

See Table 4 for a list effects stored in the DRV2667 RAM.

2.4 RAM Library Effects List

Table 4 is a description of the effects stored in the DRV2667 RAM.

Table 4. DRV2667EVM-CT Library Modes

Effect ID	Waveform Name
1	Click150
2	Click200
3	Click250
4	Click300
5	Bounce100
6	Bounce150
7	Bounce200
8	Bounce250
9	Transition100
10	Transition150
11	Transition200
12	Transistion250
13	Click + Bounce
14	Transition + Click
15	Flyby
16	Long Click + Bounce
17	Alert 1
18	Alert 2
19	Alert 3
20	Alert 4

2.5 Design & Test Mode

Design & Test contains modes that are used to design, test, and characterize the DRV2667. To access *Design & Test* modes use the following instructions:

1. Press and hold the increment mode button ("**+**") for approximately 3 seconds until the mode LEDs flash and the colored LEDs flash once.
2. Press and hold the increment mode button ("**+**") one more time until the mode LEDs flash and the colored LEDs flash twice.
3. Select from the *Design & Test* modes using the "**+**" and "**–**" buttons.

Table 5 lists the modes available for design and testing.

Table 5. DRV2667EVM-CT Binary Modes

Mode	Button	Description	Notes
Mode 0 GUI Mode LEDs: 00000	B1	Memory store enabled	GUI Mode – use this mode to trigger and store the sequencer set by a GUI. Store the sequencer by first pressing B1 (the mode LEDs turn on). Then press either B2 or B3, storing the sequencer values. Press B1 again to exit memory storage. B4 triggers the active sequencer.
	B2	Store/Play memory 1	
	B3	Store/Play memory 2	
	B4	Trigger active sequencer	
Mode 1 Dynamic Waveform Playback LEDs: 00001	B1	Disable	**Effect Building** Modes 1–6 can be used to create a unique effect by adjusting the frequency, amplitude, duration, and envelope of a single waveform. Button B1 in each mode is a continuous buzz with the frequency set in mode 2 and the amplitude set in mode 3. Button 2 in each mode is the effect created using the frequency, amplitude, duration, and envelope set by the respective modes. It is recommended to use an oscilloscope to measure the output when creating effects. **Create a Waveform** 1) Select the frequency using B3 and B4 in Mode 2 2) Select the amplitude using B3 and B4 in Mode 3 3) Select the duration using B3 and B4 in Mode 4 4) Select the ramp up time using B3 and B4 in Mode 5 (Default is 0) 5) Select the ramp down time using B3 and B4 in Mode 6 (Default is 0) **Waveform Playback (Mode 1)*** Use Mode 1 to playback the waveform created above. B2 – Play the effect once B3 – Continuously repeat the effect B4 – Continuously repeat the effect with a 1-s pause in between * Mode 1 is used for conducting a life test
	B2	Play effect once	
	B3	Infinite playback	
	B4	Infinite playback with 1-s wait	
Mode 2 Frequency Adjust LEDs: 00010	B1	Continuous buzz	
	B2	Dynamic effect	
	B3	Decrease frequency	
	B4	Increase frequency	
Mode 3 Amplitude Adjust LEDs: 00011	B1	Continuous buzz	
	B2	Dynamic effect	
	B3	Decrease amplitude	
	B4	Increase amplitude	
Mode 4 Duration Adjust LEDs: 00100	B1	Continuous buzz	
	B2	Dynamic effect	
	B3	Decrease duration	
	B4	Increase duration	
Mode 5 Ramp Up Adjust LEDs: 00101	B1	Continuous buzz	
	B2	Dynamic effect	
	B3	Decrease ramp up	
	B4	Increase ramp up	
Mode 6 Ramp Down Adjust LEDs: 00110	B1	Continuous buzz	
	B2	Dynamic Effect	
	B3	Decrease Ramp Down	
	B4	Increase Ramp Down	
Mode 7 Analog Input LEDs: 00111	B1	28.8 dB, 50 Vpp, Boost = 30 V	Analog Input – Press a button to set the gain, voltage, and enable the part for analog input. Disable by changing modes.
	B2	34.8 dB, 100 Vpp, Boost = 55 V	
	B3	38.4 dB, 150 Vpp, Boost = 80 V	
	B4	40.7 dB, 200 Vpp, Boost = 105 V	
Mode 8 Recorder LEDs: 01000	B1	Begin recording	Recorder – use this mode to create a single amplitude pattern. Start by pressing the record button (B1), then use B2 to create the pattern by tapping the button. When finished, press the playback button (B3).
	B2	Create pattern	
	B3	Playback	
	B4		
Mode 30 Default Gain & Boost Voltage LEDs: 11110	B1	28.8 dB, 50 Vpp, Boost = 30 V	Default Gain & Boost Voltage – Use this mode to set the default gain and boost voltage used by the other modes. Select a gain and boost voltage setting by pressing buttons B1–B4. The setting is saved until changed or the board is powered down.
	B2	34.8 dB, 100 Vpp, Boost = 55 V	
	B3	38.4 dB, 150 Vpp, Boost = 80 V	
	B4	40.7 dB, 200 Vpp, Boost = 105 V	
Mode 31 About the Board LEDs: 11111	B1	Device ID	About the Board – the value appears on the mode LEDs in binary.
	B2	Silicon revision	
	B3	Code revision	
	B4		

2.6 Return to Demo Mode

To exit *Library Mode* or *Design & Test Mode* and return to *Demo Mode*:

1. Press and hold the decrement mode button ("**–**") for approximately 3 seconds.
2. Release the button when the actuator buzzes and the mode LEDs flash.
3. Select from the *Demo* modes using the "**+**" and "**–**" buttons.

3 Hardware Configuration

The DRV2667EVM-CT is very flexible and can be used to completely evaluate the DRV2667. The following sections list the various hardware configuration options.

3.1 Input and Output Overview

The DRV2667EVM-CT allows for complete evaluation of the DRV2667 through the use of test points, jacks, and connectors. Table 6 gives a brief description of the hardware.

Table 6. Hardware Overview

Signal	Description	I/O
Analog	Optional analog input to DRV2667 IN+/IN– Pins	Input
I^2C	MSP430 and DRV2667 I^2C Bus	Input/Output
OUT+/OUT–	Output test points for test and measurement	Output
OUT	Output terminal block to connect actuator	Output
SBW	MSP430 programming header	Input/Output
USB	USB power (5 V)	Power
VBAT	External Supply Power (3.0 V–5.0 V)	Power

3.2 Power Supply

The DRV2667EVM-CT can be powered by USB or an external power supply (VBAT). Jumpers *DRV* and *MSP* are used to select the supply for the DRV2667 and the MSP430G2553, respectively. See the Table 7 for configuration options.

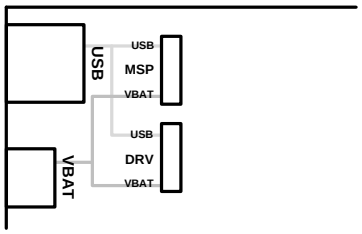

Figure 21. DRV2667EVM-CT Power Diagram

Table 7. Power Supply Configuration Options [1]

Supply Configuration	DRV	MSP	DRV2667 Supply Voltage
USB – Both	USB	USB	5 V
DRV2667 External Supply, MSP430 USB	VBAT	USB	VBAT (3.0–5.5 V)
External Supply – Both	VBAT	VBAT	VBAT (3.0–5.5 V)

(1) The DRV2667 should be enabled before enabling the MSP430. I^2C transactions do not work when the DRV2667 is powered down.

3.3 External Actuator

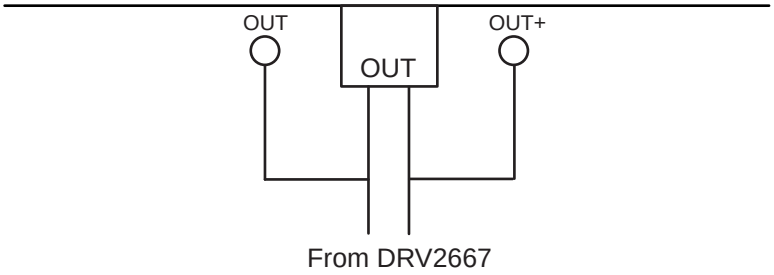

Figure 22. Output Terminal Block and Test Points

The DRV2667EVM-CT can be used with an external actuator. Follow the instructions below to attach an actuator to the *OUT* terminal block.

1. Ensure the board is powered down.
2. Remove jumpers JP2 and JP3, which disconnects the on-board actuator.
3. Attach the positive and negative leads of the actuator to the green *OUT* terminal block.
4. Screw down the terminal block to secure the actuator leads.

WARNING

Before connecting a load, ensure that the Piezo actuator (or other load) is rated for 150 Vpp. If not, see Programming the Boost Converter to adjust the DRV2667 maximum output voltage.

3.4 External I²C Input

Figure 23 is an illustration of the external I²C input.

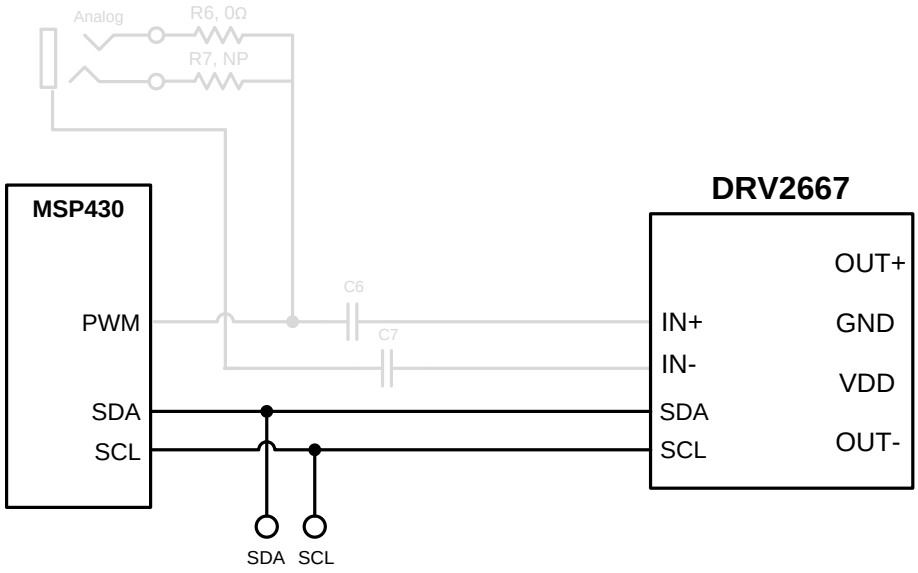

Figure 23. External I²C Input

The DRV2667 can be controlled by an external I2C source. To control externally, attach the external controller to the I2C header at the top of the board; be sure to connect SDA, SCL, and GND from the external source. If the DRV2667EVM-CT is powered, the DRV2667 will be ready to accept I2C transactions.

There is also a special mode in the *Design & Test* set that allows you to save the DRV2667's sequencer registers settings for playback at a later time. To store the sequencer:

1. Enter *Design & Test Modes*. Select Mode 0 – GUI Mode (00000'b) using the increment mode button ("**+**").
2. Press the **B1** button to enter storage mode. (The mode LEDs will all turn on.)
3. Press the **B2** or **B3** button to save the current sequencer to the respective button.
4. Press the **B1** button again to exit storage mode. (The mode LEDs will all turn off.)
5. Press either the **B2** or **B3** button to reload the DRV2667 sequencer with the saved sequence and play.

3.5 Analog/PWM Input

Figure 24 is an illustration of the external analog and PWM input.

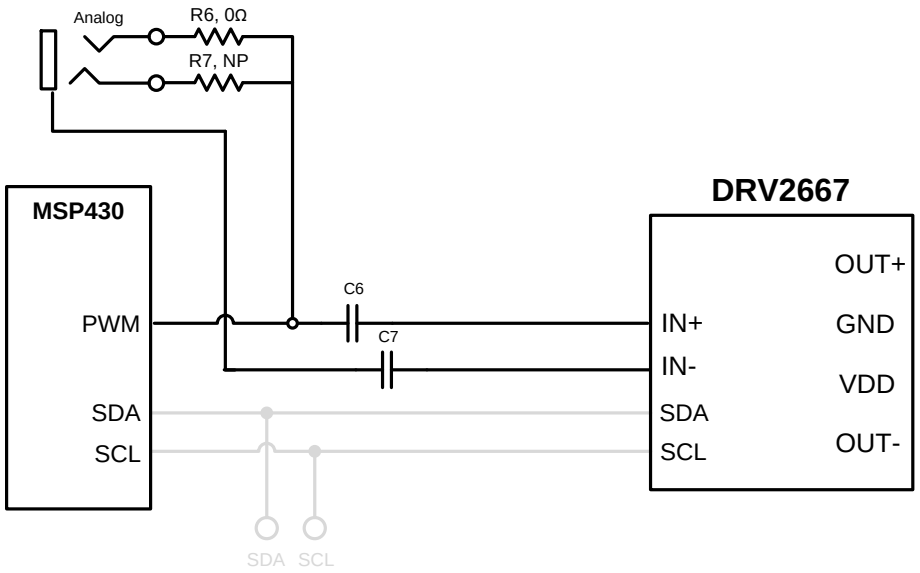

Figure 24. External Analog/PWM Input

The DRV2667EVM-CT accepts analog or PWM inputs for the analog IN+/IN- pins of the DRV2667. To use the IN+/IN- pins of the DRV2667 follow the instructions below:

1. Enter *Design & Test Modes*. Select Mode 7 (00111'b) using the increment mode button ("**+**").
2. Select the gain and voltage using buttons B1–B4:
   - B1 – 28.8 dB, 50 Vpp
   - B2 – 34.8 dB, 100 Vpp
   - B3 – 38.4 dB, 150 Vpp
   - B4 – 40.7 dB, 200 Vpp
3. Turn on the signal source to begin output.

3.6 Programming the Boost Converter

The integrated boost converter provides the necessary voltage to drive 200 Vpp. The boost converter is applied differentially across the load to achieve output voltage of two times the boost voltage. The DRV2667 maximum output voltage should be adjusted so that it does not exceed the maximum rated voltage of the load. This not only prevents damage to the load, but also helps improve efficiency. To adjust the output voltage, adjust the boost converter voltage and DRV2667 internal gain settings using the instructions in Section 3.6.1 to Section 3.6.2.

3.6.1 Adjusting the Boost Voltage Using Software

The boost output voltage (VBST) is programmed by two external feedback resistors R1 and R2, as shown in the Figure 25. The DR2667EVM-CT includes two additional resistors, R3 and R4, which allow the MSP430 to programmatically adjust VBST using a combination of the four resistors to produce four different voltage levels. Refer to Table 8 for VBST at each gain setting and the equivalent low-side resistance.

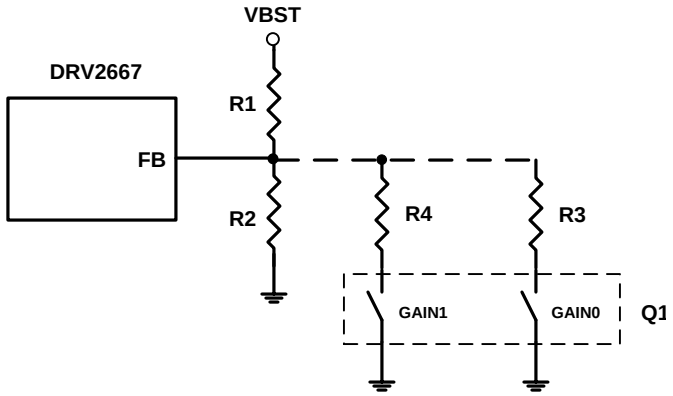

Figure 25. Boost Voltage Programming Resistors

NOTE: Remove R3 and R4 if adjusting VBST using resistors R1 and R2.

Table 8. Boost Voltage using MSP430 GPIO Control

GAIN1	GAIN0	V_{FB} Low-Side Resistance	VBST
0	0	35.7 kΩ	30
0	1	19.1 kΩ	54
1	0	12.8 kΩ	80
1	1	9.8 kΩ	105

To change the default boost voltage on the DRV2667EVM-CT using the embedded software, follow the instructions below:

1. Enter *Design & Test Modes*.
2. Select Mode 30 (11110'b) using the increment mode button ("**+**").
3. Select the gain and voltage using buttons B1–B4:
   - B1 – 28.8 dB, 50 Vpp
   - B2 – 34.8 dB, 100 Vpp
   - B3 – 38.4 dB, 150 Vpp
   - B4 – 40.7 dB, 200 Vpp
4. Exit Mode 30 and use the board as normal.

NOTE: the DRV2667EVM-CT will revert to the original voltage setting (150 Vpp) on power down.

3.6.2 Adjusting the Boost Voltage Using Hardware

The boost voltage is adjustable using the two GPIOs; GAIN1 and GAIN0, in code. In most applications, however, the boost voltage is fixed so R3 and R4 are not necessary and the boost voltage can simply be set by R1 and R2. To replace R1 and R2, first remove R3 and R4 and use Equation 3 to calculate the boost output voltage.

$$V_{BOOST} = V_{FB}\left(1 + \frac{R_1}{R_2}\right) \quad (3)$$

where V_{FB} = 1.32 V.

Table 9 shows the typical values for R1 and R2 and the corresponding output voltages.

Table 9. Boost Voltage and Gain Settings (R1 and R2 Only)

R1	R2	GAIN1	GAIN0	VBST	Vout (Peak to Peak)
402 kΩ	18.2 kΩ	0	0	30	50
392 kΩ	9.76 kΩ	0	1	55	100
768 kΩ	13 kΩ	1	0	80	150
768 kΩ	9.76 kΩ	1	1	105	200

The maximum boost output voltage is 105 V. Program VBST to a value 5 V greater than the largest peak voltage expected in the system to allow adequate amplifier headroom. Because the programming range for the boost voltage extends to 105 V, the current through the resistor divider can become significant. The sum of the feedback resistors R1 and R2 should be greater than 500 kΩ.

NOTE: When the feedback resistor values are greater than 1 MΩ, PCB contamination may cause boost voltage inaccuracies. Keep the board clean from excess solder and flux when modifying.

3.6.3 Boost Current Limit

The peak inductor current is set by resistor R5 (R_{EXT}). The current limit is not a safety mechanism, but the highest value current the inductor sees each cycle. The inductor must be capable of handling this programmed limit during normal operation. This can be used to limit the peak current drawn by the boost converter. The relationship of R_{EXT} to I_{LIM} is approximated using:

$$R_{EXT} = \left(K \frac{V_{REF}}{I_{LIM}}\right) \; R_{INT} \quad (4)$$

where I_{LIM} is the current limit set by R_{EXT}, K = 10500, V_{REF} = 1.35 V and R_{INT} = 60 Ω.

3.6.4 Boost Inductor Selection

Inductor selection plays a critical role in the performance of the DRV2667. The range of recommended inductor values is 3.3 µH to 22 µH. When a larger inductance is chosen, the DRV2667 boost converter automatically runs at a lower switching frequency and incurs less switching losses. The larger inductors; however, may also have a higher equivalent series resistance (ESR), which increases the parasitic inductor losses. Smaller inductances generally have higher saturation currents; therefore, they are better suited for maximizing the output current of the boost converter. Table 10 lists several sample inductors that provide adequate performance.

Table 10. Boost Converter Inductor Selection

Manufacturer	Part Number	DCR (Ω)	Inductance (µH)	ISAT (A)	R_{EXT} (Ω)	I_{LIM} (A)
Coilcraft	LPS4018-332MLB	0.08	3.3	1.9	7.32 k	1.9
Coilcraft	LPS4018-472MLB	0.125	4.7	1.8	7.5 k	1.8
TDK	VLS3012T-3R3M1R3	0.100	3.3	1.5	9.31 k	1.5
TDK	VLS3010	0.130	3.3	1.3	11 k	1.28

3.6.5 Boost Capacitor Selection

The boost output voltage may be programmed as high as 105 V. A capacitor must have a voltage rating equivalent to the boost output voltage or higher. A 250-V rated, 100-nF capacitor of X5R or X7R type is recommended for a boost converter voltage of 105 V. The selected capacitor should have a minimum derated capacitance of 50 nF.

A rule of thumb for ceramic capacitors: the de-rated capacitance is approximately equal to the rated capacitance multiplied by one minus the applied voltage over the rated voltage.

$$C_{de\text{-}rated} = C_{rated} (1 - V_{applied}/V_{rated}) \quad (5)$$

For example, when 50 V is applied to a 100-V rated capacitor, the capacitance will decrease by about 50%. Most capacitor vendors provide a capacitance versus voltage curve for reference.

4 MSP430 Control and Firmware

The DRV2667EVM-CT is controlled by a programmable MSP430. This section contains information for programming and controlling the board using the MSP430.

4.1 Modifying and Loading Firmware

The MSP430 firmware on the DRV2667EVM-CT can be modified or reprogrammed to create new haptic effects or behaviors. Find the latest firmware source code and binaries on ti.com. Follow the instructions below to modify or reprogram the DRV2667EVM-CT.

1. Purchase one of the following MSP430G2553 compatible hardware programmers:
   - MSP430 LaunchPad – MSP-EXP430G2 – this board requires the additional purchase of a header for J4 (Digi-key: ED8650-ND or Mouser: 575-500201)
     - Solder the header to J4
     - Remove jumpers TEST and RST to ensure there is no interference with the LaunchPad MSP430 (IC1).
   - MSP430-FET430UIF – this programmer requires the JTAG to Spy-Bi-Wire adapter (MSP-JTAG2SBW, if available)
2. Download and install Code Compose Studio or IAR Embedded Workbench IDE.
3. Download the DRV2667EVM-CT source code and binaries from ti.com.
4. Connect the programmer to an available USB port.
5. Connect the programmer to the *SBW* header on the DRV2667EVM-CT.
6. In CCS:
   - Open the project file by selecting Project→Import Existing CCS Project.
   - Select Browse and navigate to the DRV2667EVM-CT project folder, then press **OK**.
   - Select the checkbox next to the DRV2667EVM-CT project in the *Discovered projects* window and then press **Finish**.
   - Before compiling, navigate to Project→Properties→Build→MSP430 Compiler→Advanced Options→Language Options and ensure that the checkbox for *Enable support for GCC extensions (--gcc)* is checked.
7. In IAR:
   - Create a new MSP430 project in IAR
   - Select the MSP430G2553 device
   - Copy the .h and .c files in the DRV2667EVM-CT project folder downloaded from ti.com into the new project directory

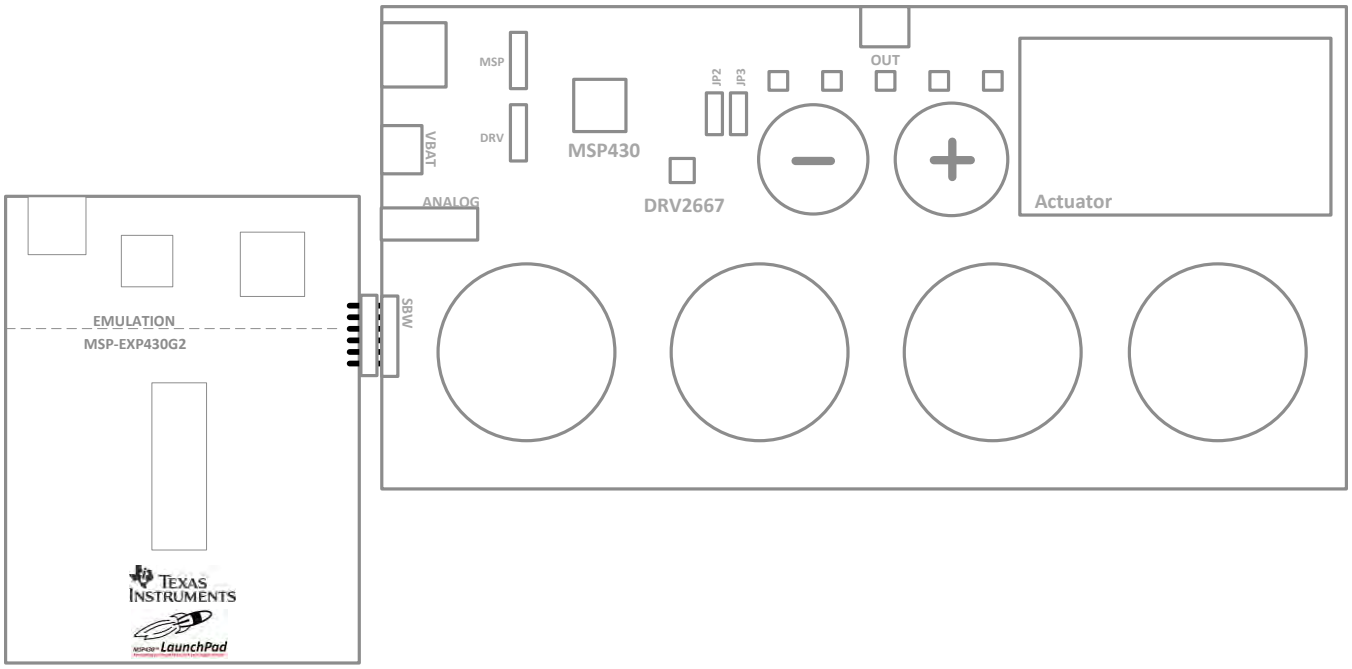

Figure 26. DRV2667EVM-CT LaunchPad Connection

4.2 MSP430 Pin-Out

The DRV2667EVM-CT contains an MSP430G2553 low-cost microcontroller which controls the board and contains sample haptic effects. The pin-out for the microcontroller is found in Table 11.

Table 11. MSP430 Pin-Out

#	Label	Description
1	P1.1	Green LED
2	P1.2	Yellow LED
3	P1.3	Blue LED
4	P1.4	
5	P1.5	
6	P3.1	Enable LED
7	P3.0	PWM
8	NC	
9	P2.0	Button 1
10	P2.1	Button 2
11	P2.2	Button 3
12	P3.2	
13	P3.3	WLED 0
14	P3.4	WLED 1
15	P2.3	Button 4
16	P2.4	+ button
17	P2.5	– button
18	P3.5	WLED 2
19	P3.6	WLED 3
20	P3.7	WLED 4
21	P1.6/SCL	I^2C clock
22	P1.7/SDA	I^2C data
23	SBWTDIO	Spy-Bi-Wire data
24	SBWTCK	Spy-Bi-Wire clock
25	P2.7	GAIN1, feedback resistor control
26	P2.6	GAIN0, feedback resistor control
27	AVSS	Analog ground
28	DVSS	Digital ground
29	AVCC	Analog supply
30	DVCC	Digital supply
31	P1.0	Red LED
32	NC	

5 Schematic, Printed-Circuit Board Layouts, and Bill of Materials

Section 5.1 through Section 5.3 contain the schematic, printed-circuit board (PCB) layouts, and bill of materials (BOM) for this EVM.

5.1 Schematics

Figure 27 is the schematic for this EVM.

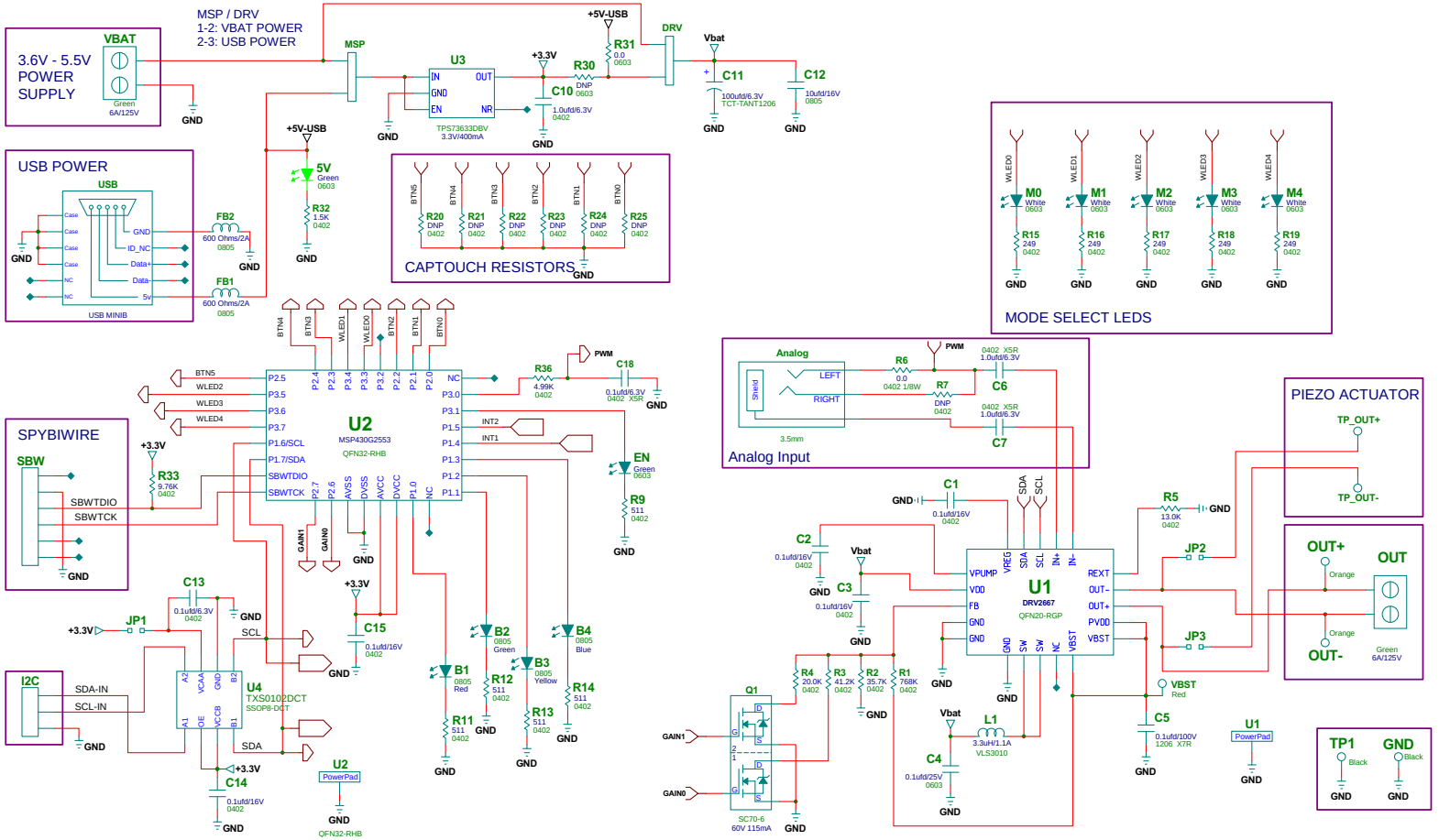

Figure 27. DRV2667EVM-CT Schematic

5.2 PCB Layouts

Figure 28 through Figure 32 are the PCB layouts for this EVM.

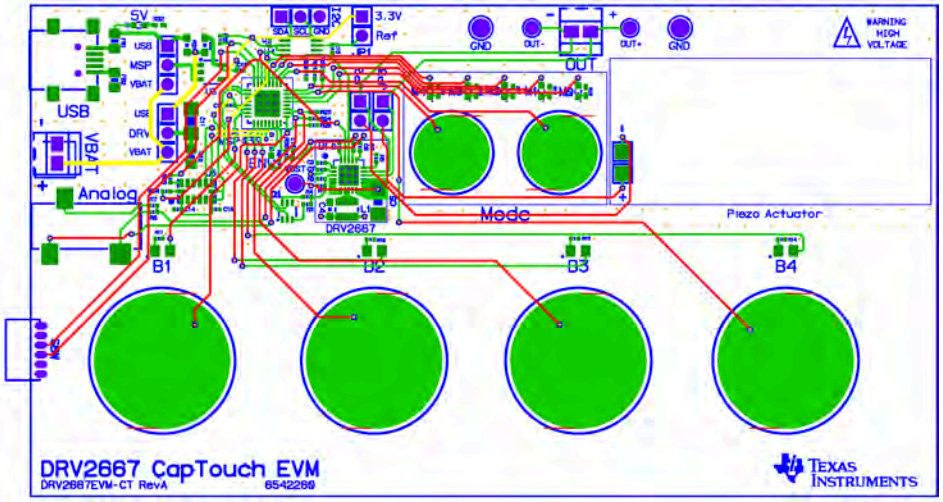

Figure 28. DRV2667EVM-CT Top Silkscreen

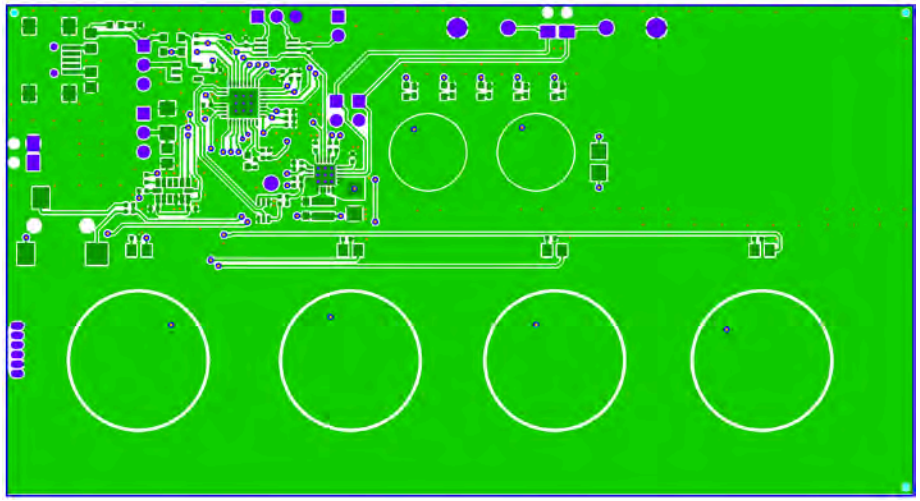

Figure 29. DRV2667EVM-CT Top Copper

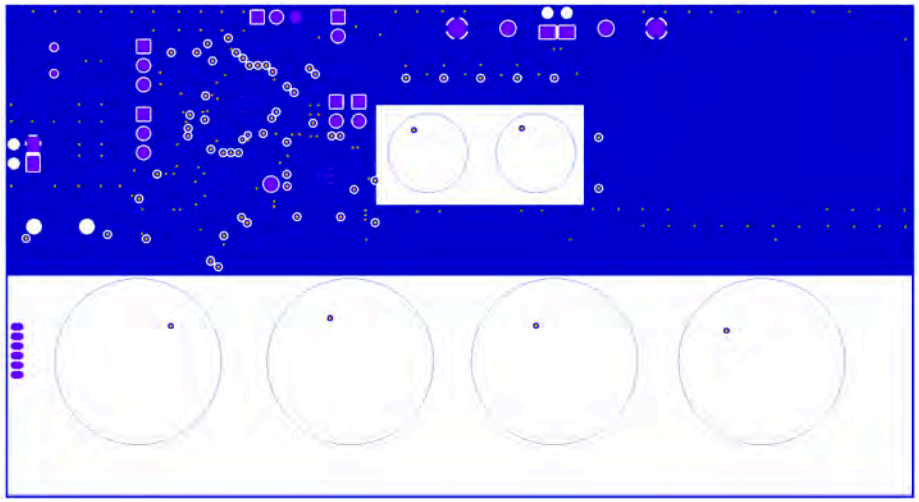

Figure 30. DRV2667EVM-CT Copper Layer 2

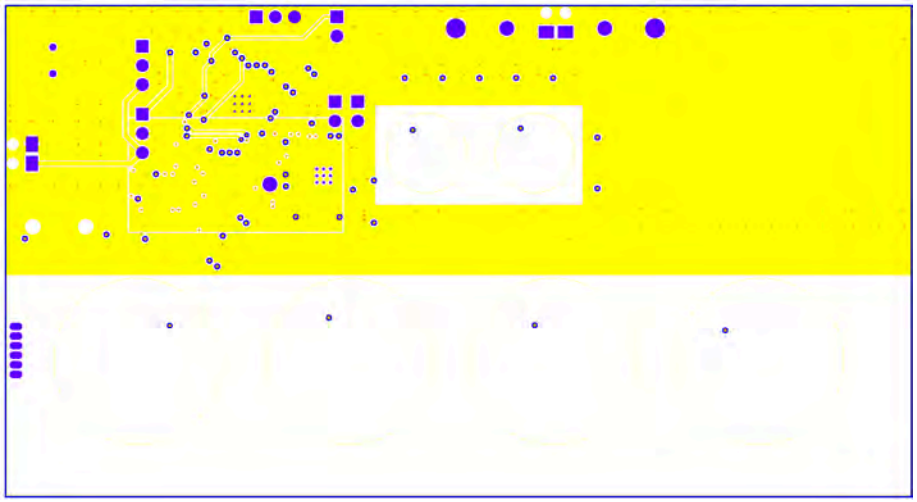

Figure 31. DRV2667EVM-CT Copper Layer 3

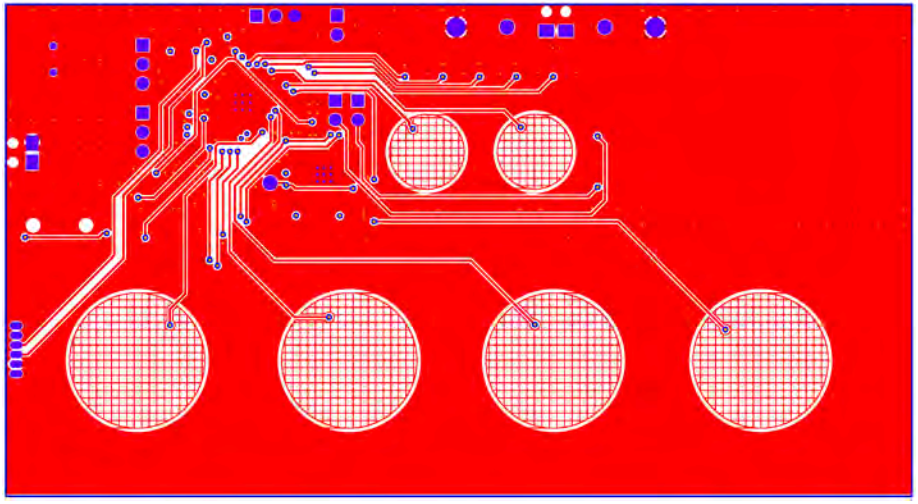

Figure 32. DRV2667EVM-CT Bottom Copper Layer

5.3 Bill of Materials

Table 12 is the BOM for this EVM.

Table 12. DRV2667EVM-CT Bill of Materials

Manu Part #	Quan	Reference Designators	Description	Manufacturer	Vendor	Vendor PartNum
LTST-C190KGKT	2	5V,EN	LED,GREEN,2.0V,SMD0603,ROHS	LITE-ON INC.	DIGI-KEY	160-1435-1-ND
SJ-3523-SMT	1	Analog	JACK AUDIO-STEREO MINI(3.5MM ,3-COND SMT-RA ROHS	CUI STACK	DIGI-KEY	CP-3523SJCT-ND
SML-LXT0805SRW-TR	1	B1	LED, RED 2.0V SMD0805 ROHS	LUMEX OPTO	DIGI-KEY	67-1555-1
SML-LXT0805GW-TR	1	B2	LED, GREEN 2.0V SMD0805 ROHS	LUMEX OPTO	DIGI-KEY	67-1553-1
SML-LXT0805YW-TR	1	B3	LED, YELLOW 2.0V SMD0805 ROHS	LUMEX OPTO	DIGI-KEY	67-1554-1
LTST-C171TBKT	1	B4	LED, BLUE 3.3V SMD0805 ROHS	LITE-ON INC.	DIGI-KEY	160-1645-1-ND
GRM155R71C104KA88D	7	C1,C2,C3,C14,C15,C16,C17	CAP SMD0402 CERM 0.1UFD 16V X7R 10% ROHS	MURATA	DIGI-KEY	490-3261-1-ND
TCTAL0J107M8R	1	C11	CAP TANT1206 100UFD 6.3V 20% TCT SERIES ROHS	ROHM	DIGI-KEY	511-1498-1-ND
0805YD106KAT2A	1	C12	CAP SMD0805 CERM 10UFD 16V X5R 10% ROHS	AVX	DIGI-KEY	478-5165-1
C1005X5R0J104K	2	C13,C18	CAP SMD0402 CERM 0.1UFD 6.3V 10% X5R ROHS	TDK CORP	DIGI-KEY	445-1266-1
06033D104KAT2A	1	C4	CAP SMD0603 CERM 0.1UFD 25V 10% X5R ROHS	AVX	DIGI-KEY	478-1244-1
C1206F104K1RACTU	1	C5	CAP SMD1206 CERM 0.1UFD 100V 10% X7R ROHS	KEMET	DIGI-KEY	399-5113-1-ND
GRM155R60J105KE19D	3	C6,C7,C10	CAP SMD0402 CERM 1.0UFD 6.3V X5R 10% ROHS	MURATA	DIGI-KEY	490-1320-1
PBC03SAAN	3	DRV,I2C,MSP	HEADER THRU MALE 3 PIN 100LS GOLD ROHS	SULLINS	DIGI-KEY	S1011E-03-ND
MPZ2012S601A	2	FB1,FB2	FERRITE BEAD SMD0805 600 Ohms 2A ROHS	TDK	DIGI-KEY	445-2206-1
5011	2	GND,TP1	PC TESTPOINT BLACK 063 HOLE ROHS	KEYSTONE ELECTRONICS	DIGI-KEY	5011K
PBC02SAAN	3	JP1,JP2,JP3	HEADER THRU MALE 2 PIN 100LS GOLD ROHS	SULLINS	DIGI-KEY	S1011E-02
VLS3010ET-3R3M	1	L1	POWER NDUCTOR SMT VLS SHIELDED 3.3uH 156mOHMS 1.1A ROHS	TDK CORP.	DIGI-KEY	445-6656-1-ND
LNJ037X8ARA	5	M0,M1,M2,M3,M4	LED, WHITE 2.9V SMD0805 ROHS	PANASONIC	DIGI-KEY	LNJ037X8ARACT-ND
1725656	2	OUT,VBAT	TERMINAL BLOCK MPT COMBICON 2PIN 6A/125V GREEN 100LS ROHS	PHOENIX CONTACT	DIGI-KEY	277-1273
5003	2	OUT+,OUT-	PC TESTPOINT, ORANGE, ROHS	KEYSTONE ELECTRONICS	DIGI-KEY	5003K
2N7002DW	1	Q1	N CHANNEL FET ENHANCEMENT MODE 60V 115mA SC70-6 ROHS	FAIRCHILD	DIGI-KEY	2N7002DWCT-ND
RC0402FR-07768KL	1	R1	RESISTOR SMD0402 THICK FILM 768K OHM 1% 1/16W ROHS	YAGEO	DIGI-KEY	311-768KLRCT-ND
ERJ-2RKF2490X	5	R15,R16,R17,R18,R19	RESISTOR,SMT,0402,249 OHM,1%,1/16W	Panasonic	DIGI-KEY	P249LTR-ND
CRCW040235K7FKED	1	R2	RESISTOR SMD0402 35.7K OHMS 1% 1/16W ROHS	VISHAY/DALE	DIGI-KEY	541-35.7KLCT-ND
R0402_DNP	6	R20,R21,R22,R23,R24,R25	R0402_DNP			
RMCF0402FT41K2	1	R3	RESISTOR SMD0402 41.2K OHMS 1% 1/16W ROHS	STACKPOLE ELECTRONICS	DIGI-KEY	RMCF0402FT41K2CT-ND
R0603_DNP	1	R30	R0603_DNP			
RMCF0603ZT0R00	1	R31	RESISTOR SMD0603 ZERO OHMS 1/10W ROHS	STACKPOLE ELECTRONICS	DIGI-KEY	RMCF0603ZT0R00CT-ND
ERJ-2GEJ152	1	R32	RESISTOR,SMT,0402,THICK FILM,5%,1/16W,1.5K	Panasonic		
ERJ-2RKF9761X	1	R33	RESISTOR SMD0402 THICK FILM 9.76K OHMS 1/10W 1% ROHS	PANASONIC	DIGI-KEY	P9.76KLCT-ND
ERJ-2RKF4991X	1	R36	RESISTOR SMD0402 4.99K 1%,1/16W ROHS	PANASONIC	DIGI-KEY	P4.99KLCT-ND

Table 12. DRV2667EVM-CT Bill of Materials (continued)

Manu Part #	Quan	Reference Designators	Description	Manufacturer	Vendor	Vendor PartNum
CRCW040220K0FKED	1	R4	RESISTOR SMT 0402 1% 1/16W 20.0K ROHS	VISHAY	DIGI-KEY	541-20.0KLCT
CRCW040213K0FKED	1	R5	RESISTOR SMD0402 13.0K OHMS 1% 1/16W ROHS	VISHAY	DIGI-KEY	541-13.0KLCT-ND
CRCW04020000Z0ED	3	R6,R34,R35	ZERO OHM JUMPER SMT 0402 0 OHM 1/16W,5% ROHS	VISHAY	DIGI-KEY	541-0.0JCT
R0402_DNP	1	R7	R0402_DNP			
RC0402FR-07511RL	5	R9,R11,R12,R13,R14	RESISTOR SMD0402 THICK FILM 511 OHMS 1% 1/16W ROHS	YAGEO	DIGI-KEY	311-511LRCT-ND
LPPB061NGCN-RC	1	SBW	HEADER THRU FEMALE 1X6-RA 50LS GOLD ROHS	SULLINS	DIGI-KEY	S9010E-06
DRV2667RGP	1	U1	PIEZO HAPTIC DRIVER WITH DIG FRONT END QFN20-RGP ROHS	TEXAS INSTRUMENTS	TEXAS INSTRUMENTS	DRV2667RGP
MSP430G2553IRHB32T	1	U2	MIXED SIGNAL MICRO 16KB FLASH 512B RAM QFN32-RHB ROHS	TEXAS INSTRUMENTS	MOUSER	595-P430G2553IRHB32T
TPS73633MDBVREP	1	U3	VOLT REG 3.3V 400MA LDO CAP FREE NMOS SOT23-DBV5 ROHS	TEXAS INSTRUMENTS	DIGI-KEY	296-21283-1
TXS0102DCTR	1	U4	2-BIT BIDIR LEVEL TRANSLATOR SSOP8-DCT ROHS	TEXAS INSTRUMENTS	DIGI-KEY	296-21978-1
ADXL345BCCZ-RL7	1	U5	DIGITAL ACCELEROMETER SPI/I2C CC-14-1 ROHS	ANALOG DEVICES	DIGI-KEY	ADXL345BCCZ-RL7CT-ND
UX60-MB-5ST	1	USB	JACK USB MINIB SMT-RA 5PIN ROHS	HIROSE	DIGI-KEY	H2959CT
TP5000	1	VBST	PC TESTPOINT, RED, ROHS	KEYSTONE ELECTRONICS	DIGI-KEY	5000K
PHAT423535XX	1	Actuator	PIEZO Vibration Actuator	Samsung Electro-Mechanics	-	-

STANDARD TERMS AND CONDITIONS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms and conditions that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for any defects that are caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.

   2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

3 *Regulatory Notices:*

   3.1 *United States*

      3.1.1 *Notice applicable to EVMs not FCC-Approved:*

      This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

      3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

      CAUTION

      This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

      Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

      FCC Interference Statement for Class A EVM devices

      NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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2. 実験局の免許を取得後ご使用いただく。
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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

   6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

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7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS AND CONDITIONS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS ANDCONDITIONS OR THE USE OF THE EVMS PROVIDED HEREUNDER, REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN ONE YEAR AFTER THE RELATED CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY WARRANTY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS AND CONDITIONS, OR ANY USE OF ANY TI EVM PROVIDED HEREUNDER, EXCEED THE TOTAL AMOUNT PAID TO TI FOR THE PARTICULAR UNITS SOLD UNDER THESE TERMS AND CONDITIONS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM AGAINST THE PARTICULAR UNITS SOLD TO USER UNDER THESE TERMS AND CONDITIONS SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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