

DRV2700EVM High Voltage Piezo Driver Evaluation Kit

The DRV2700 is a single-chip, high-voltage piezo driver with an integrated 105-V boost switch, integrated power diode, and integrated fully differential amplifier. This evaluation kit demonstrates:

- Multiple input modes including: 0- to 10-V single ended, PWM, and AC input modes
- Multiple output modes including: 0- to 200-Vpp differential, 0- to 105-V single and multiple ended
- 2 power supply inputs to isolate power consumption on DRV2700
- 8 convenient boost voltage settings and 4 different gain settings
- Small footprint (9 mm x 13 mm)
- Breakout for usage as a boost converter

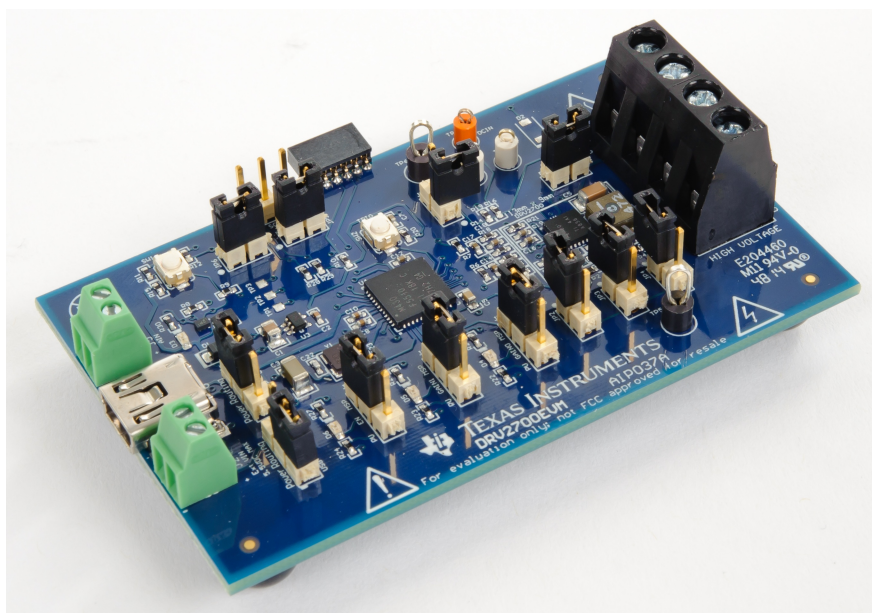
The evaluation kit is designed for all-around use and can be used not only for evaluation but can also be used for prototyping into systems. The EVM also contains a microcontroller, LDO (3.3 V) and LEDs for status and input settings.

Evaluation Kit Contents:

- DRV2700EVM evaluation board
- Demonstration mode firmware preloaded onto microcontroller
- Downloadable software to control EVM
- Mini-B USB cable

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
- DRV2700EVM firmware available on the [DRV2700EVM tool folder](#)
- MSP-JTAG2SBW JTAG to Spy-Bi-Wire adapter



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WARNING

EXPORT NOTICE

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And may require export or re-export license for shipping it in compliance with the applicable regulations of certain countries.

Cautions and Warnings

CAUTION:



Warning! Do not leave EVM powered when unattended.

HOT SURFACE:



Warning Hot Surface! Contact may cause burns. Do not touch. Please take the proper precautions when operating.

HIGH VOLTAGE:



Danger High Voltage! Electric shock possible when connecting board to live wire. Board should be handled with care by a professional. For safety, use of isolated test equipment with overvoltage/overcurrent protection is highly recommended.

General Texas Instruments High Voltage Evaluation (TI HV EVM) User Safety Guidelines

**WARNING**

Always follow TI's setup and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and those working around you. Contact TI's Product Information Center <http://support/ti.com> for further information.

Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is **intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments.** If you are not suitable qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety

1. Keep work area clean and orderly.
2. Qualified observer(s) must be present anytime circuits are energized.
3. Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
4. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
5. Use stable and nonconductive work surface.
6. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

2. Electrical Safety

As a precautionary measure, it is always a good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.

1. De-energize the TI HV EVM and all its inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
2. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment connection, and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
3. After EVM readiness is complete, energize the EVM as intended.

WARNING: WHILE THE EVM IS ENERGIZED, NEVER TOUCH THE EVM OR ITS ELECTRICAL CIRCUITS AS THEY COULD BE AT HIGH VOLTAGES CAPABLE OF CAUSING ELECTRICAL SHOCK HAZARD.

3. Personal Safety

1. Wear personal protective equipment (for example, latex gloves or safety glasses with side shields) or protect EVM in an adequate lucent plastic box with interlocks to protect from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

1 Getting Started

The DRV2700EVM is designed for flexible use for prototyping as well as evaluation. Figure 1 shows the names and locations of the various elements on the EVM. To power the board, connect the DRV2700EVM to an available USB port on your computer using a mini-B USB cable. The default board settings cause the microcontroller (MSP430) to control the inputs of the DRV2700 at power up. The MSP430 has each of these control settings low which disables the DRV2700, by default. Figure 1 shows the basic board diagram of the DRV2700EVM. Table 2 shows the original configuration of the jumpers, as shipped.

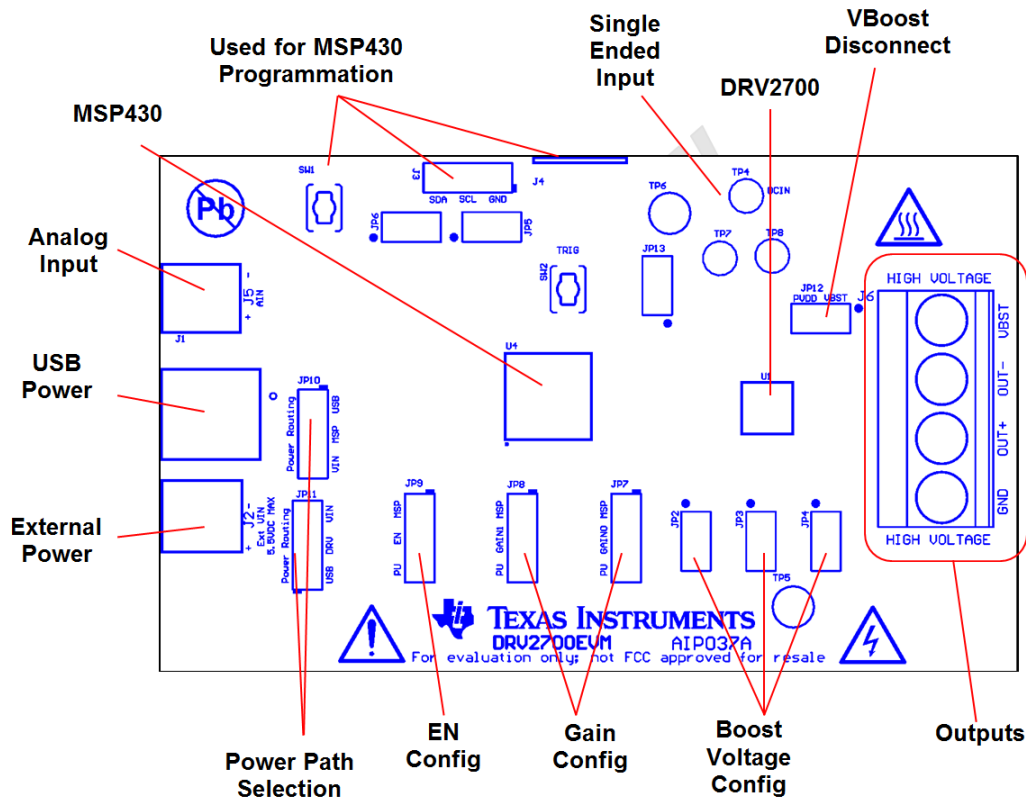


Figure 1. Board Diagram

1.1 Evaluation Module Operating Parameters

Table 1 lists the operating conditions for the DRV2700 on the evaluation module.

Table 1. Typical Operating Conditions

Parameter	Specification
Supply voltage range	3.6 V to 5.5 V
Power-supply current rating	500 mA
Input Voltage	0 V to V_{DD}
Max Output Voltage	200 Vpp

1.2 Quick Start Board Setup

The DRV2700EVM comes with preprogrammed firmware to provide a 0- to 200-V_{pp} signal between OUT+ and OUT–.

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](#).
2. Connect a mini-USB cable to the USB connector on the DRV2700EVM 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 5-V LED is on.
5. Enable the output using the GUI or programmatically through the computer, see [GUI Interface](#) for additional assistance. If using an external input signal, EN the output by changing the jumper (JP9) or equivalent control signal.
6. Once the output is EN, the device allows for the high-voltage output.

Table 2. Default Jumper Settings

Parameter	Jumper Setting	Default	Specification
JP10 MSP	Open		MSP not connected to either power supply
	USB (top) ⁽¹⁾	X	MSP connected to USB power supply
	VIN (bottom) ⁽¹⁾		MSP connected to VIN power supply
JP11 DRV	Open		DRV2700 not connected to either power supply
	VIN (top) ⁽¹⁾		DRV2700 connected to VIN power supply
	USB (bottom) ⁽¹⁾	X	DRV2700 connected to USB power supply
JP5 and JP6	Open		Disconnected PWM± and I/O of MSP430
	Connected	X	Connected PWM± and I/O of MSP430
JP9-EN JP8-G1 JP7-G0	Open		EN/G1/G0 pulled internally to GND through DRV2700 internal resistance
	MSP (top) ⁽¹⁾	X	EN/G1/G0 tied to I/O of MSP430
	PU (bottom) ⁽¹⁾		EN/G1/G0 pulled up to MSP power supply through external pull up resistor
JP13-DCIN	Open	X	DC input not connected (PWM and AC input mode)
	Connected		DC input connected (single-ended input mode)
JP12-VBST	Open		PVDD disconnected to BST (boost only mode)
	Connected	X	PVDD connected to BST (normal operation)
I2C	Open		Always leave open. Never jumper together.
J2, J3, J4	Open		Disconnects particular FB resistor (lowers BST)
	Connected	X	Connects particular FB resistor (raises BST)

⁽¹⁾ In the table, (top) or (bottom) means the (top) or (bottom) is connected to the middle of the 3-terminal header. For questions, refer to [Figure 1](#).

1.3 Connecting a Load

1. With the power supply off, connect the negative terminal of the load to OUT– and connect the positive terminal of the load to OUT+.
2. Ensure the terminals are connected correctly, then enable the supply.

WARNING

Before connecting the load, ensure that the load is rated for the selected output voltage. If not, see the [Boost Voltage Setting Resistors](#) section to adjust the DRV2700 maximum output voltage.

See [Figure 13](#) for a diagram of the input configuration.

2 Overview of EVM

The following sections provide a description of each of the blocks identified in [Figure 1](#).

2.1 DRV2700

The DRV2700 is a single-chip, high-voltage piezo driver with an integrated 105-V boost switch, integrated power diode, and integrated fully-differential amplifier. This EVM allows the designer to evaluate this device and appropriately prototype it into their design. See the DRV2700 ([SLOS861](#)) datasheet for more in-depth information.

2.2 Microcontroller (MSP430)

An onboard MSP430F5510 is used to control the various input signals as well as communicate through the USB to the GUI. See the [Quick Start Board Setup](#) section for how to setup and run with the GUI.

2.3 Power Supply Inputs and Path

Two power supply inputs are available to power the EVM: USB power and V_{EXTERNAL} (Ext VIN on the EVM). Each of these inputs can be used to power the entire board or parts of the board.

2.3.1 USB Power Input

The USB power input can be supplied from a standard USB port on a computer, USB charger, or USB battery pack. This input is intended for ease-of-use and can be routed to power all circuitry on the EVM. Additionally, this input has a 5-V LED indicator showing that power is being supplied to the EVM. If the GUI is going to be used, the USB must be connected to the computer and JP10 routed to USB connection.

2.3.2 VIN/External Power Input

Provide the VIN power input with an external 3.6- to 5.5-V power supply. Additionally, this input can power the entire board.

2.3.3 Power Path Selection

Each of the two power supply inputs can be routed to the DRV2700 or the rest of the IC. The positions of the jumpers are described in [Table 2](#) or can be read from the silkscreen of the EVM. [Figure 2](#) shows the basic diagram of the power paths.

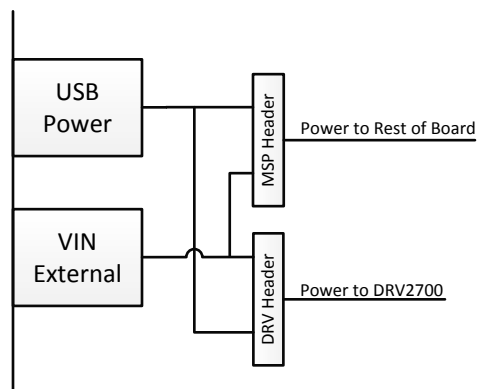


Figure 2. Power Path Diagram

If a power measurement of the DRV2700 circuitry is desired, it is best to provide the MSP jumper (JP10) with USB power and the DRV jumper (JP11) with VIN. With this configuration, measuring the provided voltage and current into VIN gives the power consumption of the DRV2700.

2.4 EN and Gain Configuration

The EN, GAIN0, and GAIN1 inputs into the DRV2700 have 4 different driving configurations:

- Driven through the MSP430. This is done by connecting the configuration jumper to the “MSP” state (default).
- Pulled to a logic level high through pullup resistor. This is done by connecting the configuration jumper to the “PU” state.
- Pulled to a logic level low through internal pulldown resistor. This is done by removing the configuration jumper.
- Driven externally. This is done by connecting the external control signal to the center 100-mil header.

Each of these signals have an LED to indicate when the signal is at a logic-level high.

Additionally, the GAIN pins control the internal gain of the high voltage amplifier. Table 3 shows the 4 gain settings

Table 3. Gain Settings

GAIN1	GAIN0	Gain (dB)
Low	Low	28.8
Low	High	34.8
High	Low	38.4
High	High	40.7

Figure 3 through Figure 6 showcase all 4 gain settings with BST set to max of 105 V (JP2, JP3, and JP4 closed). C3 = BST, C1 = VOUT(+), C2 = VOUT(–), and MATH = OUT(+) – OUT (–). PWM input from MSP430 of 0–3.3 V, 300 Hz and 50% duty cycle.

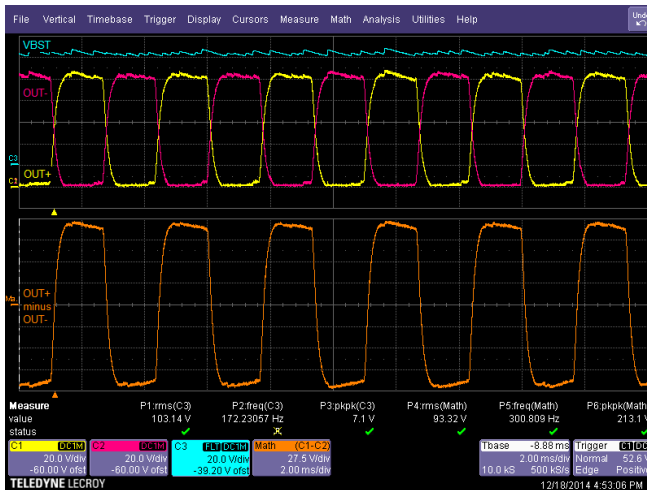


Figure 3. Gain = 40.7 dB

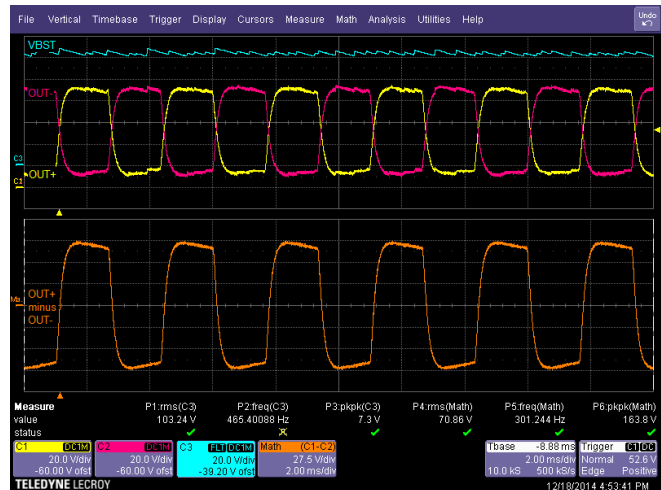


Figure 4. Gain = 38.4 dB

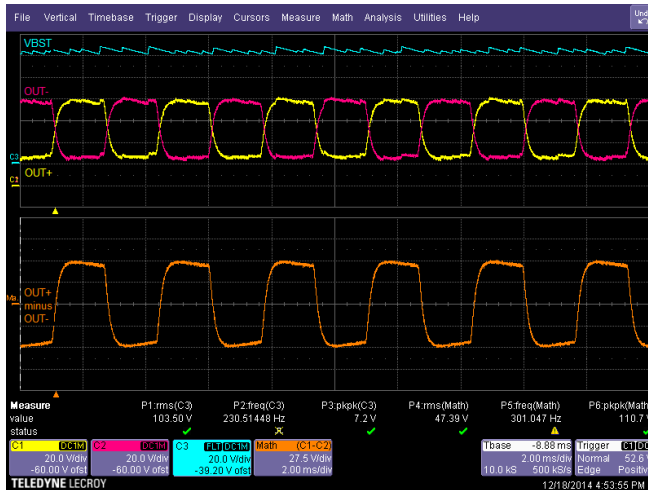


Figure 5. Gain = 34.8 dB

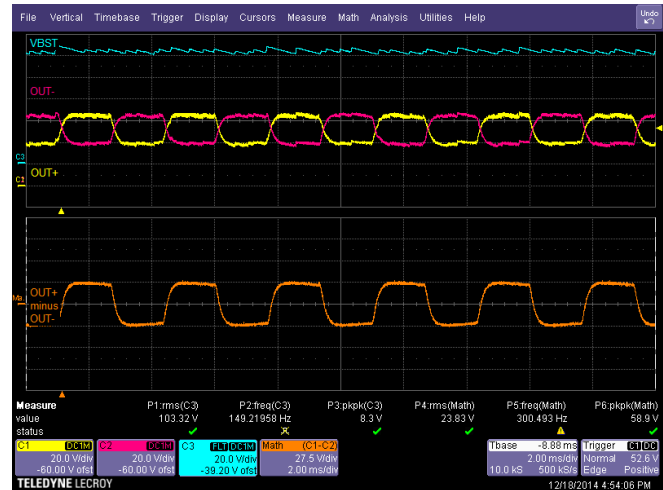


Figure 6. Gain = 28.8 dB

2.5 Inputs

The analog input (AIN) is used for PWM and analog inputs. The single-ended (DC) input test point is used when a DC input is desired. See [PWM, Analog, and Single-Ended Inputs](#), for more information.

2.6 Outputs

The DRV2700EVM has 4 referenced outputs (BST, OUT–, OUT+, and GND). They are output from a terminal block to mitigate touching between two high voltage lines. See the [Output](#) section for additional information.

2.7 BST/PVDD Disconnect

The BST jumper (JP12) is provided to allow disconnecting between PVDD and BST. This enables the DRV2700EVM to be configured purely as a boost converter. See [Disconnecting BST/PVDD](#), for additional information.

2.8 TRIG Button

The DRV2700EVM has a built-in trigger button for user prototyping. If different modes of operation are desired without using the GUI, the MSP430 can be programmed such that the trigger button can cycle through different modes. Additionally, there are 3 test point pads that be can be used in a similar manner through MSP430 firmware programming.

See [Figure 13](#) for a diagram of the input configuration.

3 EVM Control Software (GUI)

By default, the DRV2700EVM can be controlled programmatically through the GUI Interface. [Figure 7](#) is a screenshot of the GUI.

Run the GUI by downloading it from the [DRV2700 product page](#), installing the GUI and then running it. When prompted, connect to the USBHID setting.

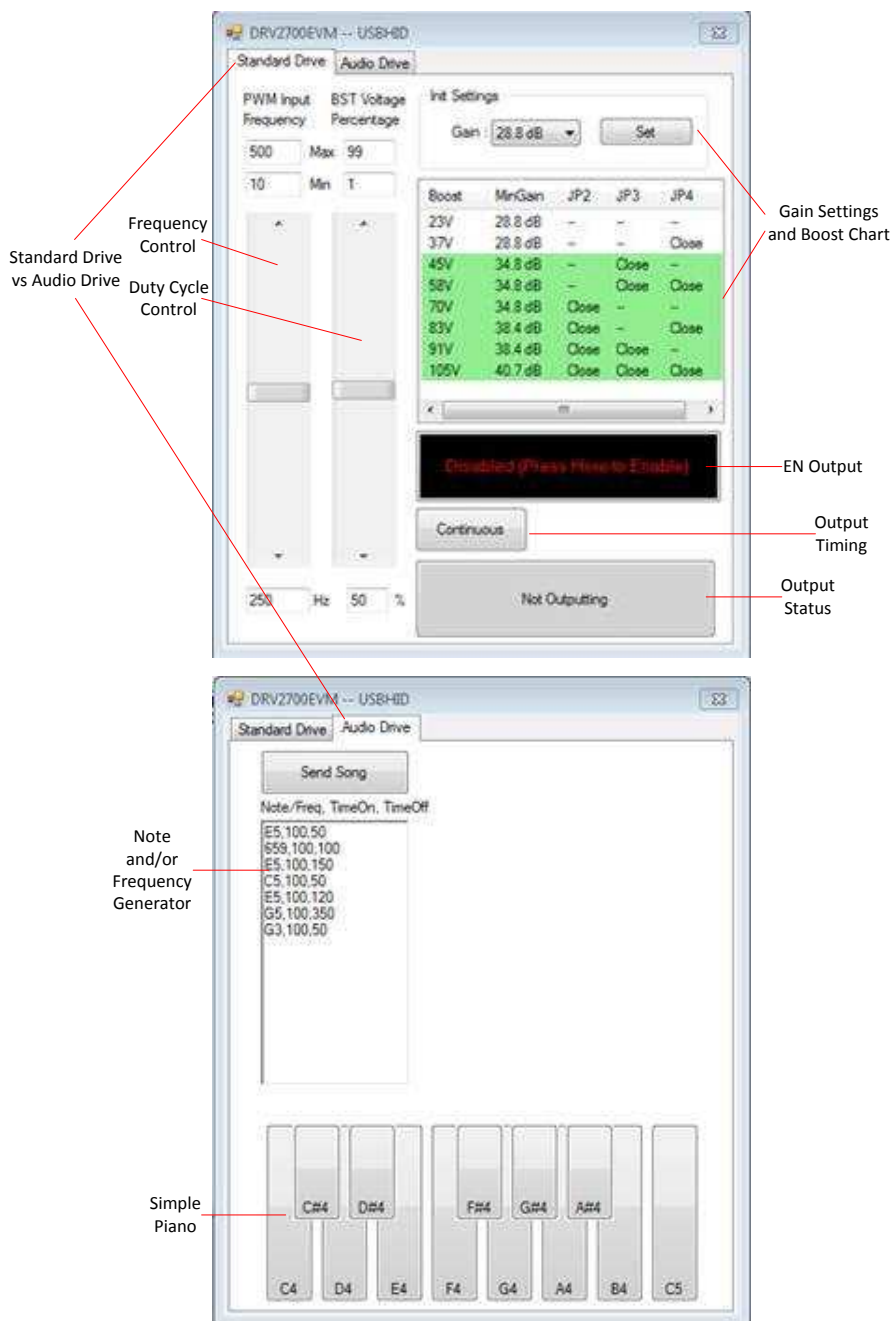


Figure 7. GUI Interface

The GUI is broken up into two sections: *Standard Drive* and *Audio Drive*. The *Standard Drive* utilizes changing the frequency and duty cycle of the PWM signal and is intended for easy prototyping. The *Audio Drive* tab is for showcasing the DRV2700 as a Piezo buzzer/speaker. On both tabs, the sections are intuitive, however, the following sections are worth describing:

- **Gain Settings and Boost Chart:** After changing the gain and clicking the *Set* button, the MSP430 changes the G0 and G1 GPIO therefore changing the gain of the DRV2700. The chart then updates to reflect the recommended voltage ranges by **not highlighting them**.
- **Output Timing:** This button has 3 different modes: *Continuous*, *Pulsed*, and *Single*. These modes help with a timed EN signal.
- **Duty Cycle:** This allows control of the power that gets through the DC blocking input filter. *Duty Cycle* can be thought of as an amplitude control. Additionally, the PWM signal can be connected through external wires using JP5 and JP6 headers to IN+ and IN–, in order to control the output.
- **Note Generator and Simple Piano:** The DRV2700 is capable of also driving piezo loads used in many alarms and buzzers. To sample this, the simple piano sends the corresponding frequency of the notes when pressed. If a series of notes and/or frequencies with specific timing is desired, the note generator can be used in the format of “[Note],[TimeOn],[TimeOff]” as shown in [Figure 7](#). The note format is A–G (including sharps “#” but not flats “b”) followed by the octave, and the frequency is in Hz rounded to the nearest integer. Some examples include: A4, C#5, E5 (or 659), and so forth. All time inputs are based in milliseconds.

See [Figure 13](#) for a diagram of the input configuration.

4 Boost Converter

The DRV2700 device creates a boosted supply rail with an integrated DC-DC converter that can go up to 105 V. The switch-mode power supplies have a few different sources of losses. When boosting to very high voltages, the efficiency begins to degrade because of these losses. The DRV2700 device has a hysteretic boost design to minimize switching losses and therefore increase efficiency. A hysteretic controller is a self-oscillation circuit that regulates the output voltage by keeping the output voltage within a hysteresis window set by a reference voltage regulator and, in this case, the current-limit comparator. Hysteretic converters typically have a larger ripple as a trade off because of the minimized switching. This ripple is a function of the output capacitor, internal delays, and the hysteresis of the control loop. The power FET and power diode of the boost converter are both integrated within the device to provide the required switching while minimizing external components. Additionally, the boost voltage output (BST) can be easily fed into the high-voltage amplifier through the adjacent pin (PVDD) to help minimize routing inductance and resistance on the board.

Before connecting the load, ensure the load is rated for the current boost voltage setting.

See [Boost Voltage Setting Resistors](#) for more information on how to set the boost voltage.

4.1 Boost Voltage Setting Resistors

The boost voltage (BST) is set through a resistor network and through the use of jumpers JP2, JP3, and JP4 as shown in [Figure 8](#).

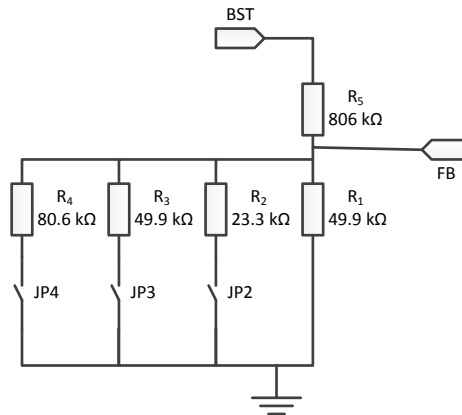


Figure 8. BST Network JP2, JP3, and JP4

The boost output voltage is given by [Equation 1](#)

$$V_{BST} = V_{FB} \left(1 + \frac{R_1}{R_{EQ}} \right) \quad (1)$$

where $V_{FB} = 1.32 \text{ V}$ and R_{EQ} is the equivalent resistor between all the connected resistors in parallel. Refer to [Table 4](#) for BST setting based on the jumper configuration.

WARNING

Be sure not to hot switch the JP2, JP3, or JP4 connection. This can be accomplished by only removing or connecting the JP2, JP3, or JP4 jumpers while the board is unpowered.

Table 4. BST Setting Based on the Jumper Configuration

BST	R_{EQ}	JP2	JP3	JP4
23 V	50 kΩ	Open	Open	Open
37 V	30.8 kΩ	Open	Open	Closed
45 V	25 kΩ	Open	Closed	Open
58 V	19.0 kΩ	Open	Closed	Closed
70 V	15.7 kΩ	Closed	Open	Open
83 V	13.2 kΩ	Closed	Open	Closed
91 V	12 kΩ	Closed	Closed	Open
105 V	10.4 kΩ	Closed	Closed	Closed

If another voltage is desired, replace R1 and R5 using [Equation 1](#) and leave JP2–4 disconnected.

4.2 Disconnecting BST/PVDD

The DRV2700 has two essential blocks: the boost converter and the amplifier. If only using the DRV2700's boost converter, JP_VBST allows the user to disconnect PVDD from BST to shut down the amplifier to save power.

WARNING

Be sure not to hot switch the BST and PVDD connection. This can only be accomplished by removing or connecting the JP_VBST jumper while the board is unpowered.

4.3 Programming the Boost Current Limit

The peak inductor current is set with resistor R3 (REXT). The current limit is not a safety mechanism, but the highest value current the inductor will see each cycle. The inductor must be capable of handling this programmed limit during normal operation. The relationship of REXT to ILIM is approximated with Equation 2 where ILIM is the current limit set by REXT, K = 10500, VREF = 1.35 V and RINT = 60 Ω.

$$R_{EXT} = \left(K \frac{V_{REF}}{I_{LIM}} \right) - R_{INT} \quad (2)$$

4.4 Boost Inductor Selection

Inductor selection plays a critical role in the performance of the DRV2700. The range of recommended inductor values is 3.3 μH to 22 μH. When a larger inductance is chosen, the DRV2700 boost converter automatically runs at a lower switching frequency and incurs less switching losses; however, the larger inductors may also have a higher equivalent series resistance (ESR), which will increase 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 5 lists several sample inductors that provide adequate performance.

Table 5. Sample Inductors

Manufacturer	Part Number	DCR (Ω)	Inductance (μH)	ISAT (A)	REXT (Ω)	ILIM (A)
Coilcraft	LPS4018-332MLB	0.080	3.3	1.9	7.32k	1.9
Coilcraft	LPS4018-472MLB	0.125	4.7	1.8	7.5k	1.8
TDK	VLS3012T-3R3M1R3	0.100	3.3	1.5	9.31k	1.5

4.5 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.

See Figure 13 for a diagram of the input configuration.

5 PWM, Analog, and Single-Ended Inputs

The DRV2700 requires a low-pass filtered PWM waveform, an analog signal or a single-ended input to drive capacitive loads. By default, the DRV2700EVM uses the MSP430 PWM input mode with a low-pass filter. This section describes each input mode in detail and the modifications necessary for operation of each. See [Filtering and Adapting PWM Waveforms](#) for more details on adapting the PWM waveform using a low-pass filter.

The DRV2700EVM supports four input modes for driving the DRV2700:

- **PWM (AC coupled) input using MSP430:** In this mode, the onboard MSP430 generates a PWM waveform that is sent through the low-pass input filter to the DRV2700.
- **PWM (AC coupled) input using AIN:** An external source supplies a PWM waveform to the EXTIN header which is sent through the low-pass input filter to the DRV2700.
- **External analog (AC coupled) input:** An external source supplies an analog waveform (sine wave) to the IN+ and IN– header. The low-pass input filter can be removed in this case.
- **Single-ended (DC coupled) input:** A DC input signal can be used to drive the output in a steady state.

5.1 PWM (AC Coupled) Input Using MSP430

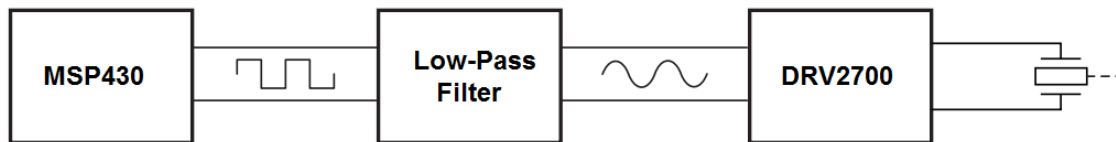


Figure 9. PWM Signal

When using the DRV2700EVM in MSP430 PWM input mode, the onboard MSP430 generates a differential PWM signal that is sent through a low-pass filter to the DRV2700. The DRV2700EVM is setup to use this mode by default. Set to default settings to use this input mode.

If specific waveforms (other than those already on the MSP430) are needed, the firmware can be updated. To update the firmware, download Code Composer Studio (or a third-party MSP430 IDE) and connect the DRV2700EVM SpyBiWire to the computer. The TI website offers an MSP430 USB-to-JTAG hardware interface (MSP-FET430UIF) for updating and debugging MSP430 code.

NOTE: Sample code is also available on the [DRV2700](#) product web page.

5.2 PWM (AC Coupled) Input Using AIN

The PWM input mode can be used with an external processor or PWM source. The PWM signal is a carrier wave (duty-cycle modulated) at a frequency much higher than the analog signal it represents. The PWM input mode can be used with an external processor or PWM source.

To use an external PWM source to drive the DRV2700, follow these instructions to modify the board:

1. Disconnect the MSP430 output pins from the DRV2700 input pins by removing jumpers JP5 and JP6
2. Depending on the input source, follow the instructions in the [Filtering and Adapting PWM Waveforms](#) section to adjust the input filter.
3. Connect DRV2700 control signals:
 - a. Use the onboard MSP430 and GUI to control the EN, GAIN0, and GAIN1 pins.
 - b. Use an external controller or jumpers to control the EN, GAIN0, and GAIN1 pins.
4. Connect the positive terminal of the input signal source to AIN+ and the negative terminal to AIN–
5. Enable the power supply

5.3 External Analog (AC Coupled) Input

The following instructions are provided to use an external analog source (sine wave) to drive the DRV2700:

1. Disconnect the MSP430 output pins from the DRV2700 input pins by removing jumpers JP6 and JP5
2. Modify the input filter according to the [Filtering and Adapting PWM Waveforms](#) section. The default PWM filter is no longer necessary.
3. Connect the DRV2700 control signals:
 - a. Use the onboard MSP430 and GUI to control the EN, GAIN0, and GAIN1 pins
 - b. Use an external controller or jumpers to control the EN, GAIN0, and GAIN1 pins
4. Connect the positive terminal of the input signal source to AIN+ and the negative terminal to AIN–
5. Enable the power supply

5.4 Single-Ended (DC Coupled) Input

The DRV2700EVM can be operated with a DC input. There are two configurations available in this EVM that show:

- Set reference
- Floating reference

In some applications, it is critical that the output does not go above or below a certain threshold. To help mitigate this, landing pads for a zener diode on the DC input have been provided. Installing a properly-selected zener can help assure the input does not go above the set voltage and therefore not allow the output to swing above or below the undesired voltage.

5.4.1 Set Reference

The set reference configuration is used when the output needs to be controlled linearly. Just like a normal amplifier, the output will be amplified based on the difference of the inputs. The DRV2700EVM has the inputs connected to TP7 (IN+) and TP8 (IN–).

To use the DC input with a set reference to drive the DRV2700, follow these instructions:

1. Disconnect the MSP430 output pins from the DRV2700 input pins by removing jumpers JP6 and JP5
2. Connect JP_DC
3. Connect DRV2700 control signals:
 - a. Use the onboard MSP430 and GUI to control the EN, GAIN0, and GAIN1 pins
 - b. Use an external controller or jumpers to control the EN, GAIN0, and GAIN1 pins
4. DC reference input:
Connect the DC reference to TP8 (IN–)
5. Amplifying signal:
 - a. For 0–10 V range, connect jumper JP_DC and apply 0–10 V on DC_IN
 - b. For 0–5 V range, disconnect jumper JP_DC and apply 0–5 V on TP7 (IN+)
6. Enable the power supply

[Figure 10](#) is with the EVM powered through USB (5 V).

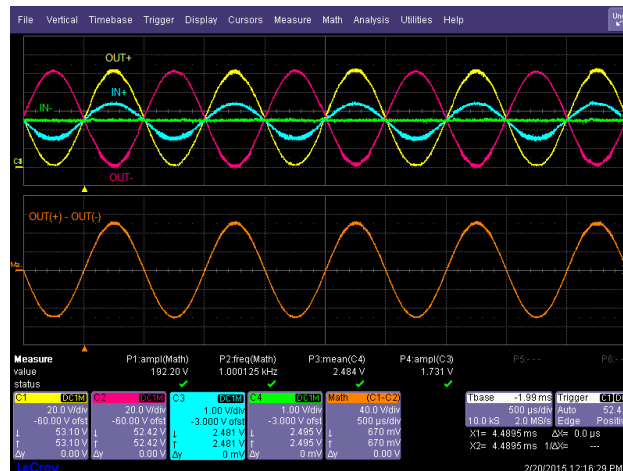


Figure 10. Set Reference to External 2.5 V

See [Figure 13](#) for a diagram of the input configuration.

5.4.2 Floating Reference

If the application is to create a high voltage square wave where the output goes from $\pm V_{BST}$, this floating reference configuration is beneficial. Unlike most amplifiers where both input terminals need to be biased to control the output, the DRV2700 has an internal compensated common mode to try and keep the inputs near $V_{DD} / 2$. This allows the application to eliminate the need of a reference voltage, by instead applying a capacitor to ground on one of the input terminals. Because there is compensation between the two inputs, the common mode will have some drift based on the other input signal. If the DRV2700 is going to be operated in the linear region, the set reference configuration should be used.

Use the DC input with a floating reference to drive the DRV2700 with the following instructions:

1. Disconnect the MSP430 output pins from the DRV2700 input pins by removing jumpers JP6 and JP5
2. Connect DRV2700 control signals:
 - a. Use the onboard MSP430 and GUI to control the EN, GAIN0, and GAIN1 pins
 - b. Use an external controller or jumpers to control the EN, GAIN0, and GAIN1 pins
3. Amplifying signal:
 - a. For 0–10 V range, connect jumper JP_DC and apply 0–10 V on DC_IN
 - b. For 0–5 V range, disconnect jumper JP_DC and apply 0–5 V on TP7 (IN+)
4. Enable the power supply

[Figure 11](#) and [Figure 12](#) show this mode at 3 Hz and 1 KHz. Notice that the floating reference (IN-) will vary based on the IN+ signal. This drift can be minimized by increasing the frequency. This configuration should only be used as long as the application can handle this drift. Each application should be properly evaluated to verify if this configuration will be acceptable per its system requirements. [Figure 11](#) and [Figure 12](#) are with the EVM powered through USB (5 V).

See [Figure 13](#) for a diagram of the input configuration.

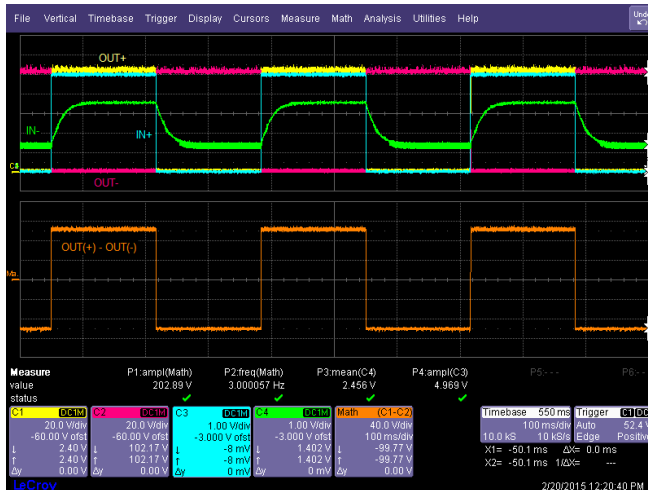


Figure 11. Floating Reference at 3 Hz and No Load

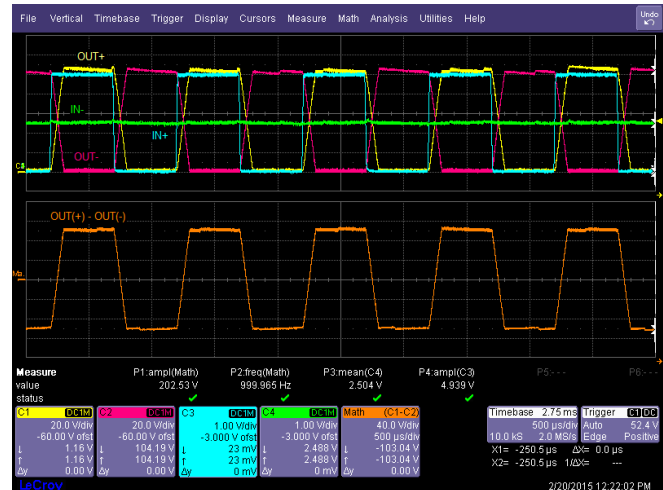


Figure 12. Floating Reference at 1 Hz and No Load

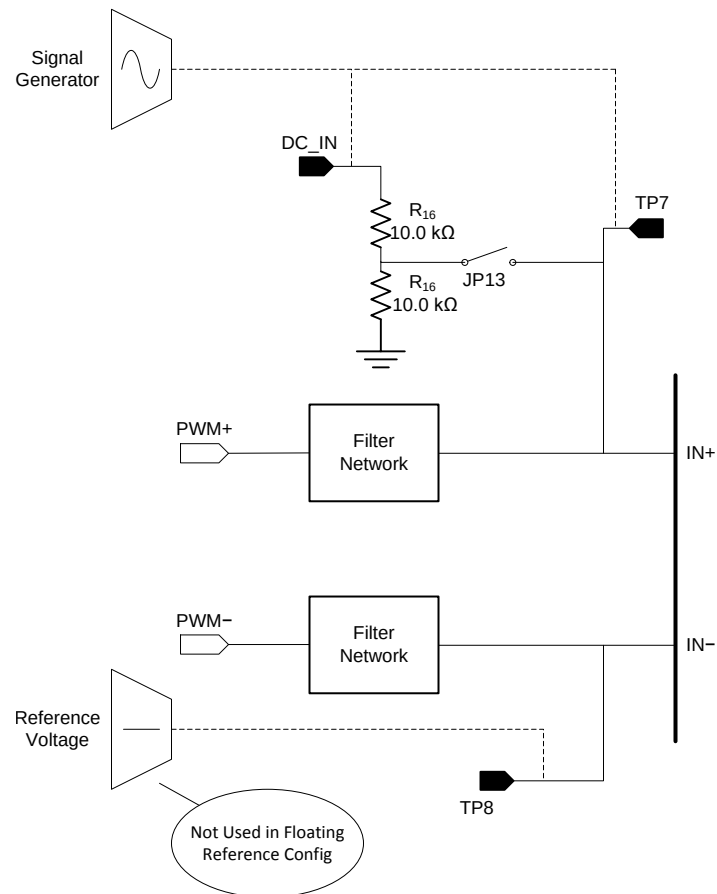


Figure 13. DC Coupled Input Diagram

6 Output

The DRV2700 has 3 main outputs and GND on the 4-terminal output:

1. The output of the boost converter (BST)
2. The positive output of the amplifier (OUT+)
3. The negative output of the amplifier (VOUT–)

These outputs can be configured in a variety of ways and are described in more detail in this section.

6.1 Two Terminal Differential Output Configuration (OUT+ – OUT–)

The typical output configuration is a 2 terminal differential output with one terminal connected to OUT+ and the other connected to OUT–. This configuration can achieve 200 Vpp.

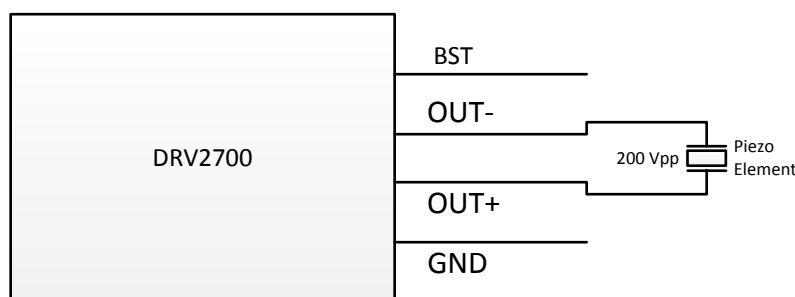


Figure 14. Two Terminal Differential Output

6.2 Two Terminal Single Ended Output Configuration (OUT± to BST/GND)

This output configuration allows for 2 outputs that are 180 degrees out of phase. This is configured with OUT+ and/or OUT– referenced to GND with a voltage that can swing up to 100 V. Additionally, they can be referenced to BST.

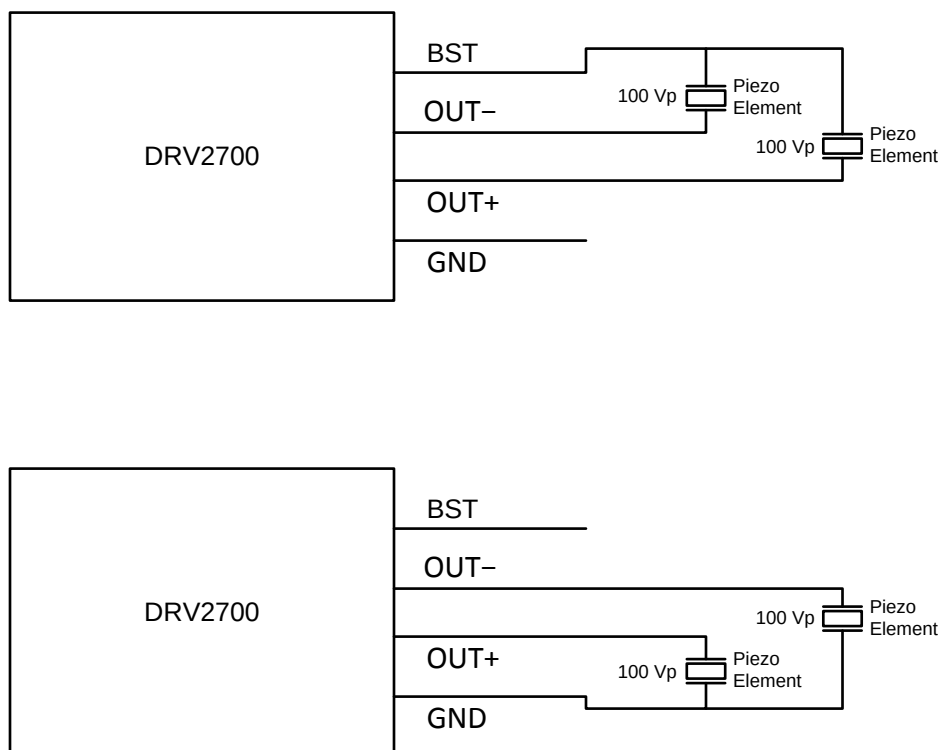


Figure 15. Two Terminal Single Ended Output

6.3 Three Terminal Single Ended Output Configuration (BST to OUT± to GND)

The output configuration is very similar to the two terminal, however, only one output pin is used. This ensures that the two voltage potentials (BST to OUTx and OUTx to GND) always add up to BST.

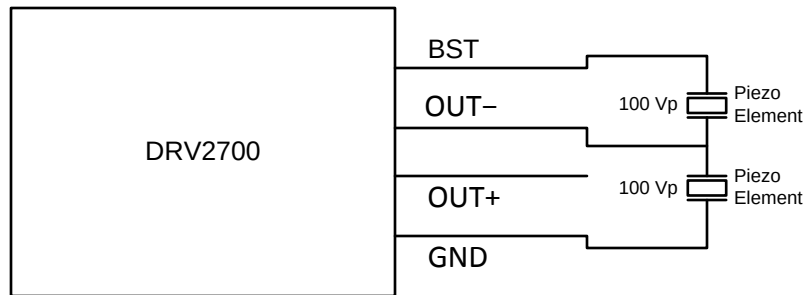


Figure 16. Three Terminal Single Ended Output

7 Load Selection

The DRV2700 is intended to drive Piezo (capacitive) loads, however, an improper load driven at certain levels can cause the device to heat up and hit thermal shutdown. Therefore, there are several key specifications to consider when choosing a Piezo load; such as dimensions, blocking force, and displacement. However, the key electrical specifications from the driver perspective are voltage rating and capacitance. At the maximum frequency of 500 Hz, the DRV2700 is optimized to drive up to 50 nF at 200 VPP, which is the highest voltage swing capability. The DRV2700 will drive larger capacitances if the programmed boost voltage is lowered or the user limits the input frequency range to lower frequencies (for example, 300 Hz). For more information, see the *Piezo Load Selection* section of the DRV2700 data sheet (SLOS861).

See [Figure 13](#) for a diagram of the input configuration.

8 Filtering and Adapting PWM Waveforms

The DRV2700EVM has the capability to support many different input filter configurations. Depending on the input mode, input frequency, and input voltage, the filter can be adapted to attenuate any undesired out-of-band content. This section describes the input filter requirements and the various respective configurations.

8.1 PWM Input

When using a high-frequency PWM input, a low-pass filter is required. The primary parameters for determining the input filter are the PWM input frequency and sample rate. Because of the power ratings of the DRV2700, the input filter has been designed to attenuate frequencies above 500 Hz. For sample rates above 20 kHz, a simple first-order RC filter is recommended; however, for sample rates much lower (such as 8 kHz), a first-order filter may not sufficiently attenuate the high-frequency content. Thus, for lower sampling rates, a second order RC filter may be required. The following sections describe example filter configurations for both first- and second-order filters. The DRV2700EVM default configuration uses a second-order differential filter, but it can be replaced by a first-order, single-ended, or differential filter.

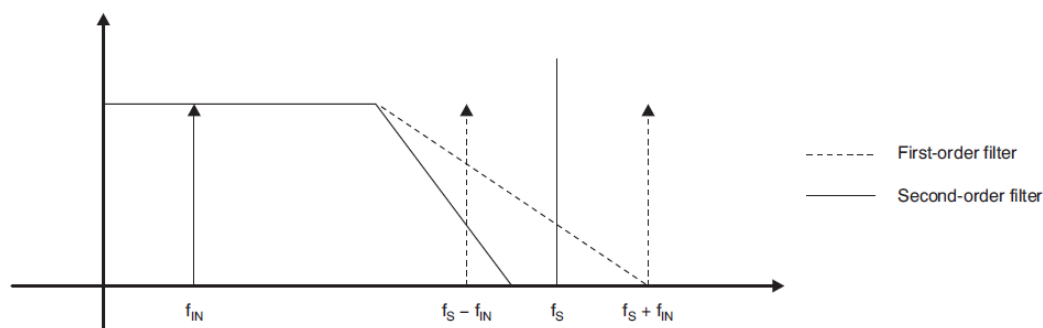


Figure 17. DRV2700EVM First- and Second-Order Filters

8.2 Filter Selection Criteria

Apply these criteria to select an input filter:

1. First-order RC filters, both single-ended and differential, are recommended for 20 kHz and higher data sample rates. The first-order filters have adequate settling time and the fewest components.
2. Second-order filters are recommended for noiseless operation when using a lower data sample rate where a sharper cutoff is necessary
3. The attenuation at the PWM carrier frequency should be at least –40 dB

8.2.1 First-Order Filter

For sample rates 20 kHz and greater, a first-order filter is recommended. The first-order filter is used in both single-ended or differential configurations. [Figure 18](#) shows a differential, first-order filter. The PWM input filter is optimized for a 3.3-V differential PWM input signal (–11-dB attenuation); remove R17 and R18 when applying a 1.8-V input signal.

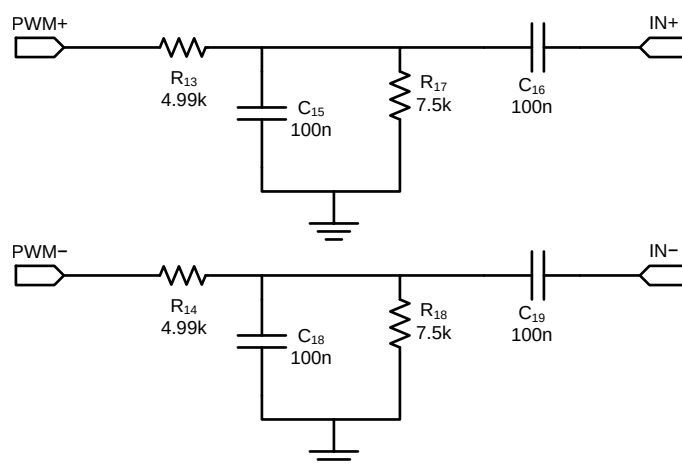


Figure 18. Differential, First-Order Filter

The first-order filter in [Figure 18](#) contains one pole with a slope of –20 dB. [Figure 19](#) shows the frequency response of the first-order filter.

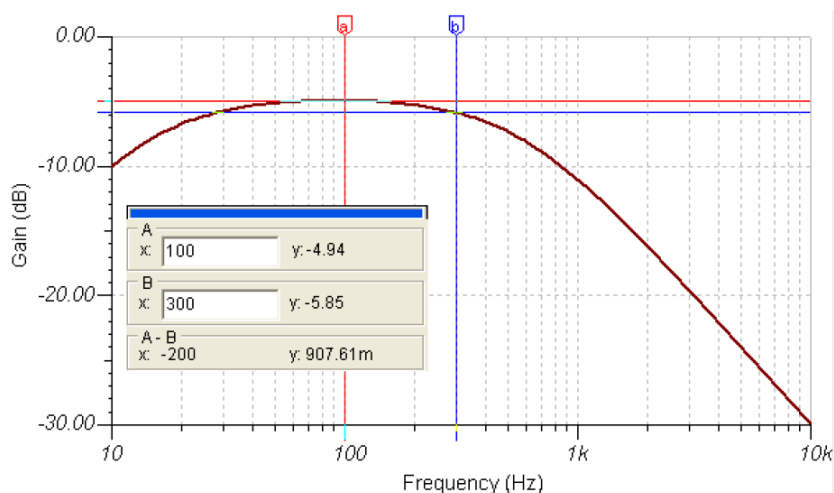


Figure 19. Frequency Response of the First-Order Filter

8.2.2 Second-Order Filter, Differential

For data sample rates less than 20 kHz, a second-order filter is recommended. A differential input signal is recommended for use with a second-order filter because of the longer settling time. Figure 20 shows the differential, second-order filter that is the default filter configuration for the EVM. The PWM input filter is optimized for a 3.3-V differential PWM input signal (–1-dB attenuation); remove R17 and R18 when applying a 1.8-V input signal.

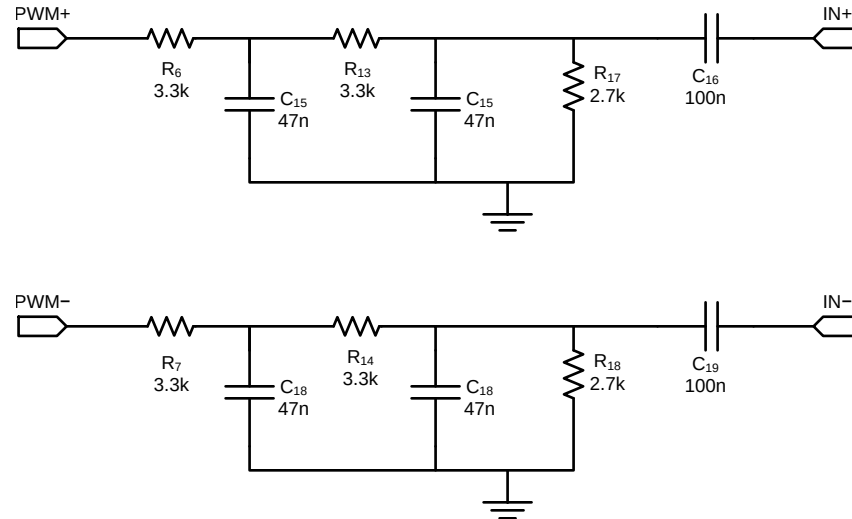


Figure 20. Differential, Second-Order Filter

The second-order filter in Figure 20 contains two poles resulting in a slope of –40 dB. Figure 21 shows the frequency response of the second-order filter.

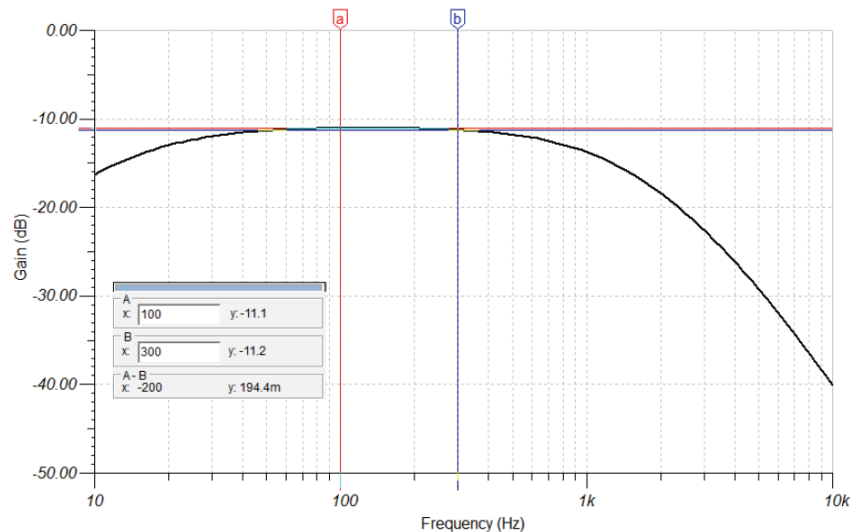


Figure 21. Frequency Response of the Second-Order Filter

8.2.3 Remove Filter for Analog Input

If the input signal is an analog waveform, as opposed to a PWM, then an input filter may not be necessary. Before removing the filter, ensure that a simple RC filter is not needed to remove any artifacts from the digital-to-analog converter (DAC) output or other input source. Follow these instructions to remove the input filter completely.

1. Replace resistors R6, R7, R13, and R14 with 0- Ω resistors
2. Remove resistors R17 and R18
3. Remove capacitors C8, C9, C13, and C14. Do not remove ac coupling capacitors C4 and C5.

See [Figure 13](#) for a diagram of the input configuration.

9 Reference

This section includes the DRV2700EVM schematic, PCB Layout, and Bill of Materials.

9.1 Schematic

Figure 22 illustrates the DRV2700EVM schematic.

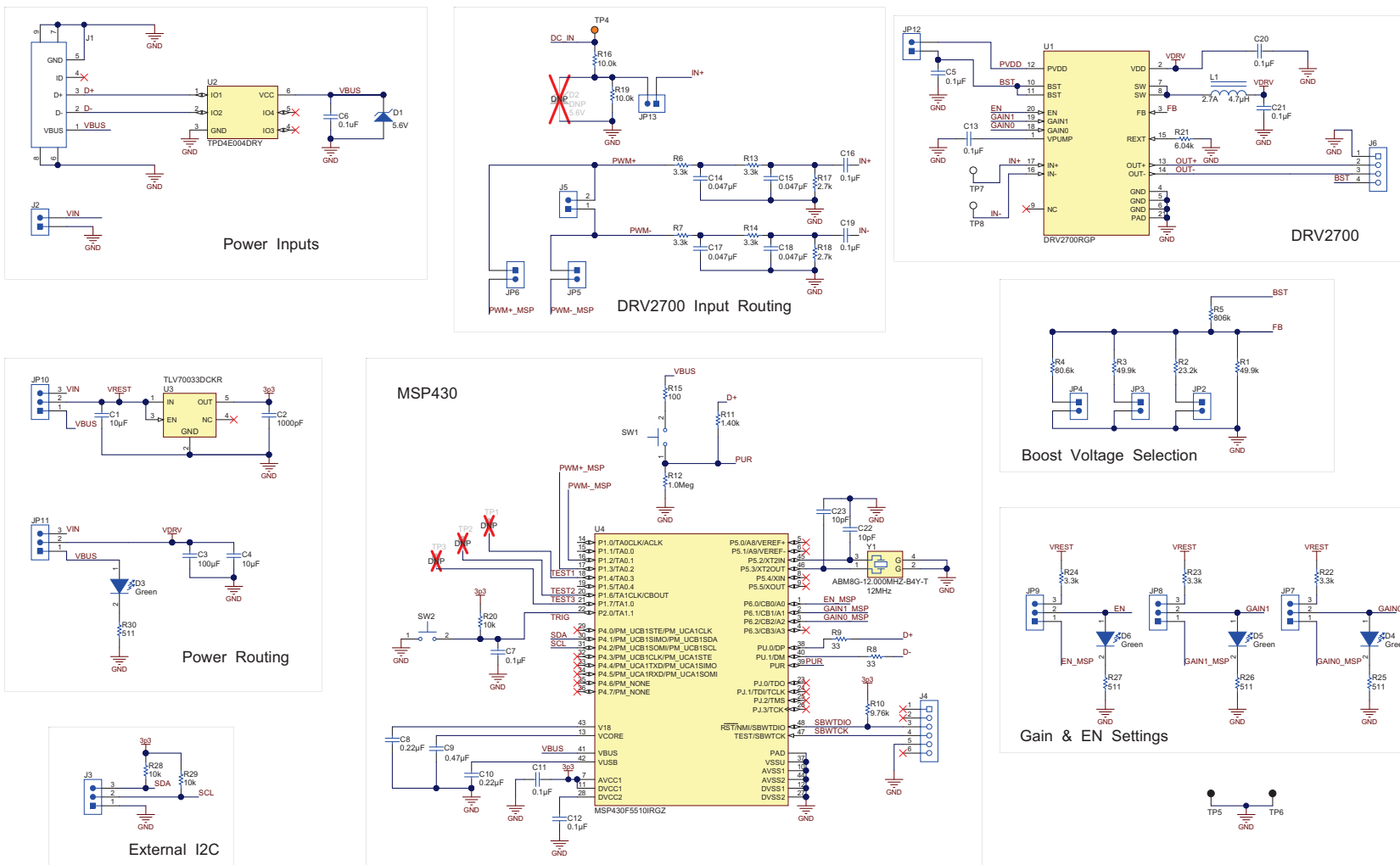


Figure 22. DRV2700EVM Schematic

9.2 PCB Layout

Figure 23 through Figure 27 show the DRV2700EVM PCB layouts.

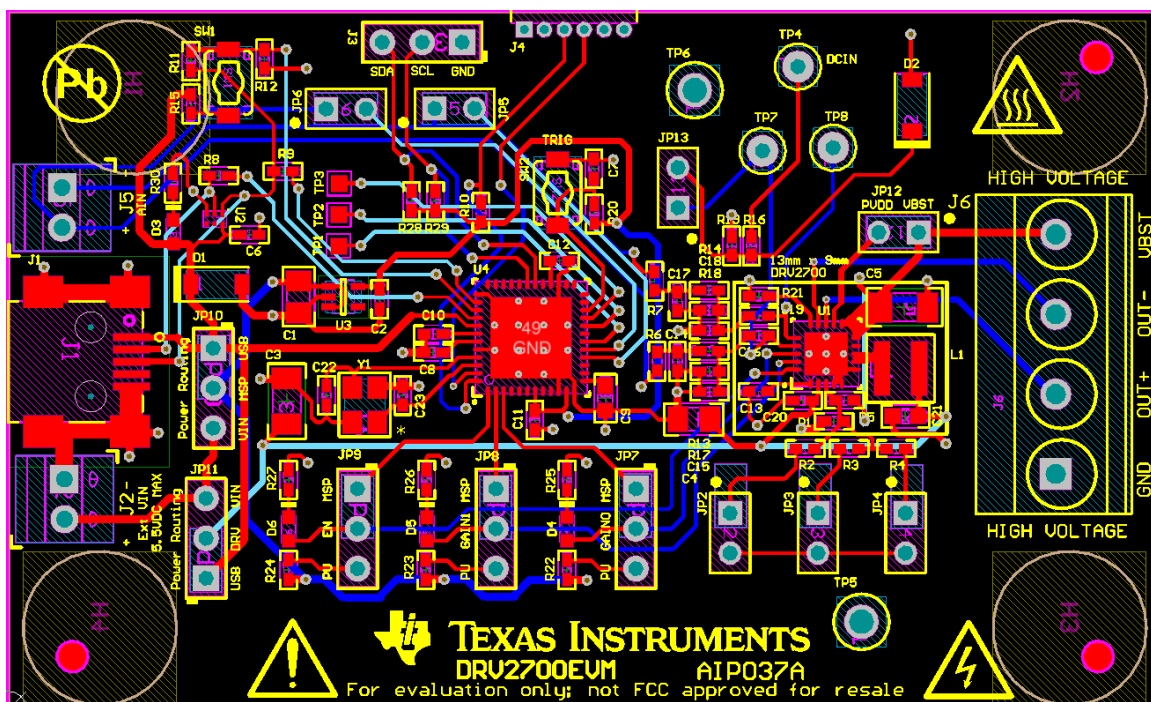


Figure 23. All Layers

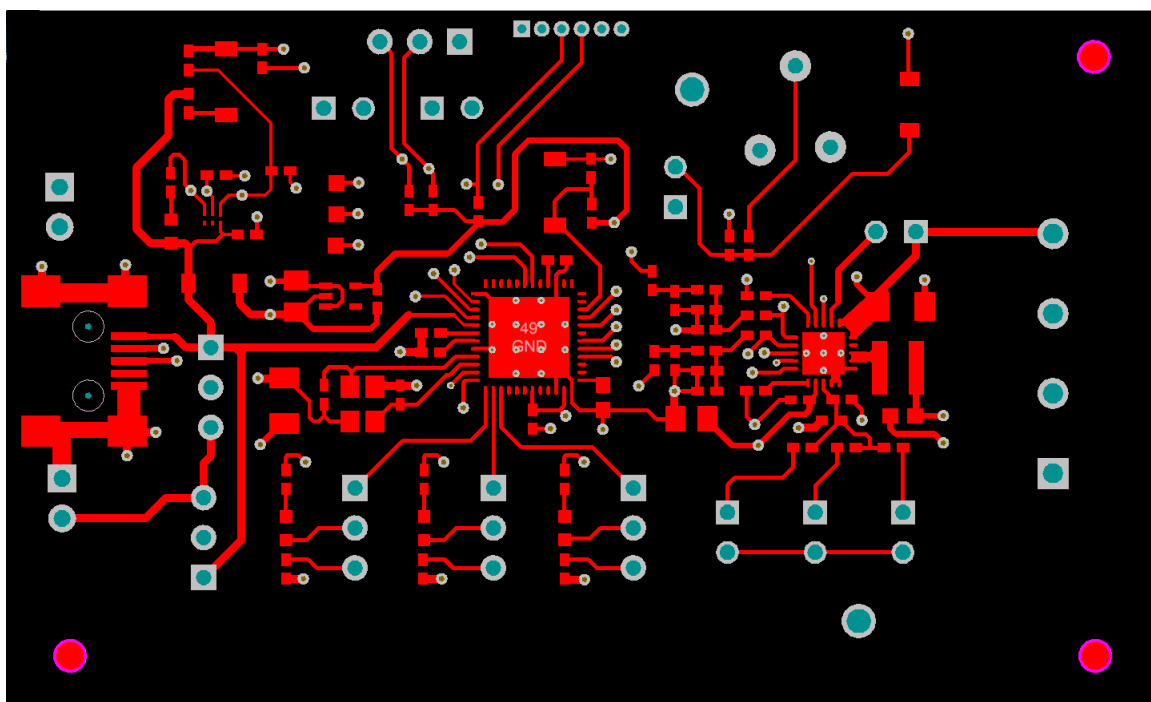


Figure 24. Top Layer

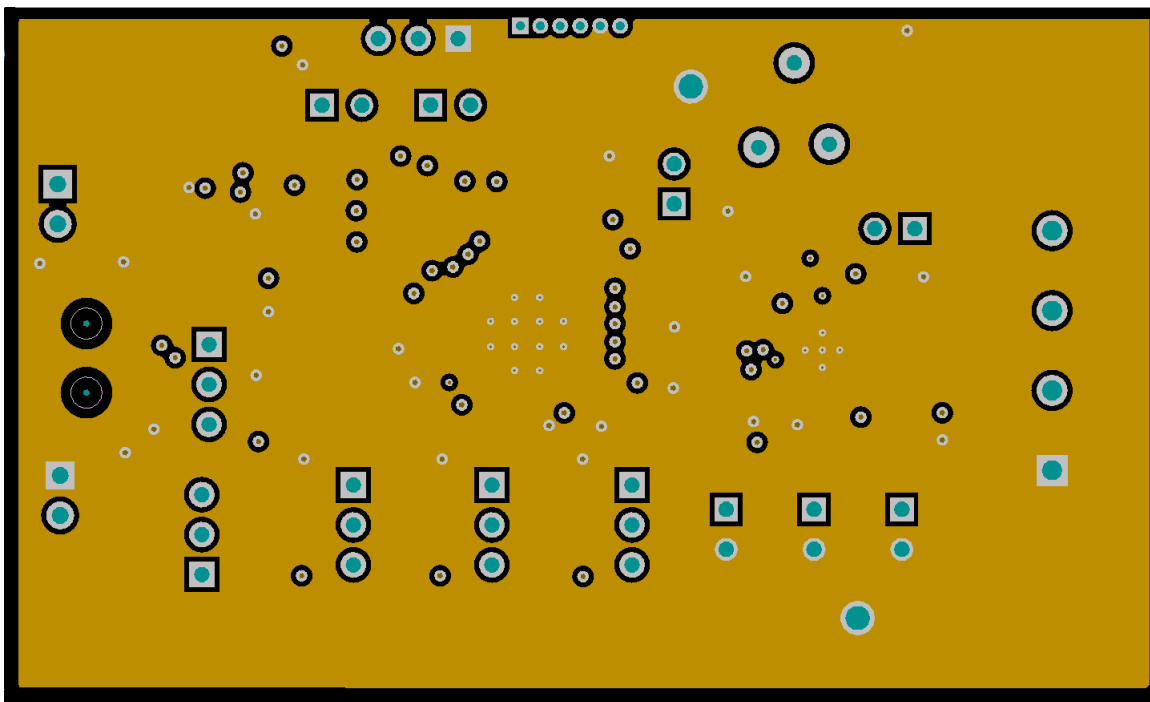


Figure 25. Mid Layer 1

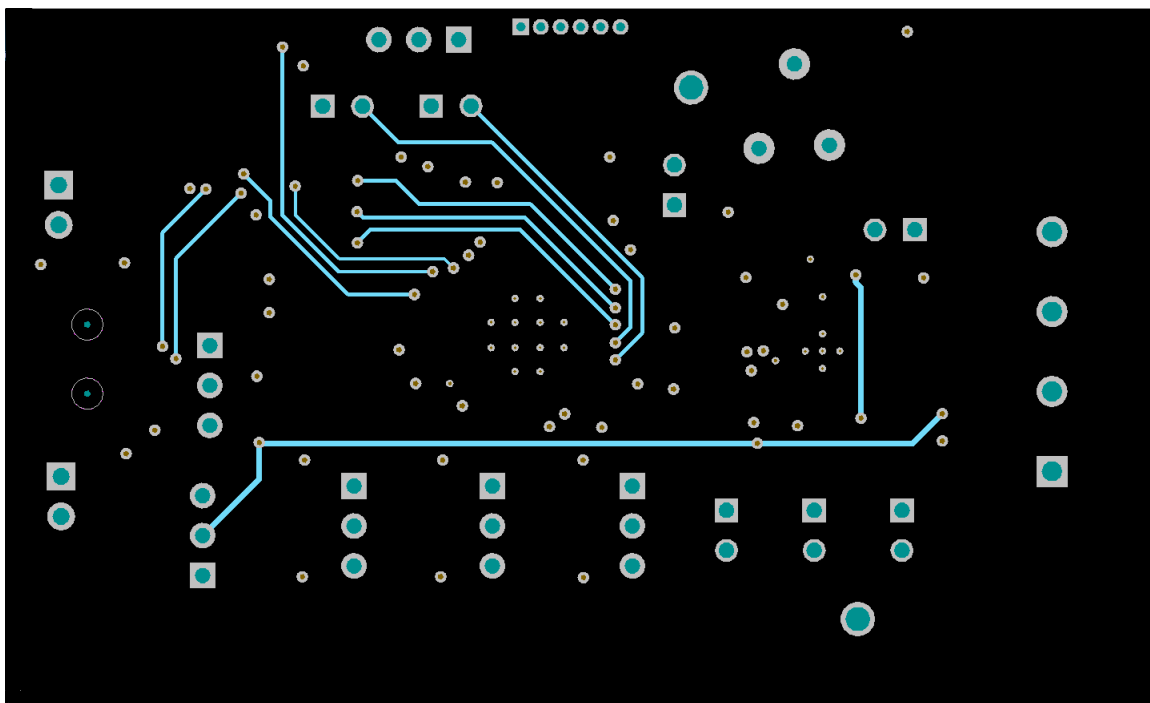


Figure 26. Mid Layer 2

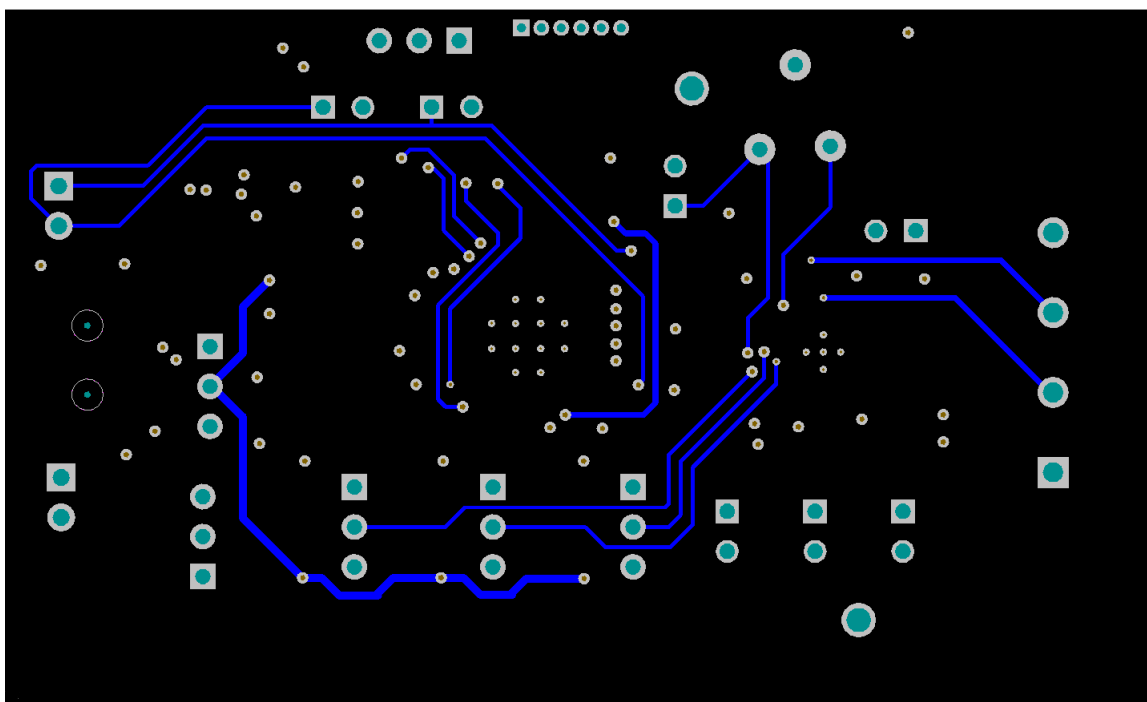


Figure 27. Bottom Layer

9.3 Bill of Materials

Table 6 lists the DRV2700EVM bill of materials.

Table 6. Bill of Materials

Designator	Qty.	Value	Description	Package Reference	Part Number	Manufacturer
PCB	1		Printed Circuit Board		AIP037	Any
C1, C4	2	10 μ F	CAP, CERM, 10 μ F, 16V, $\pm$ 20%, X5R, 0805	805	0805YD106MAT2A	AVX
C2	1	1000 pF	CAP, CERM, 1000pF, 6.3V, $\pm$ 10%, X5R, 0402	402	GRM155R60J102KA01D	Murata
C3	1	100 μ F	CAP, CERM, 100 μ F, 6.3V, $\pm$ 20%, X5R, 1206	1206	GRM31CR60J107ME39L	Murata
C5	1	0.1 μ F	CAP, CERM, 0.1 μ F, 250V, $\pm$ 10%, X7R, 1206	1206	C3216X7R2E104K	TDK
C6	1	0.1 μ F	CAP CER 0.1UF 16V 5% X7R 0402	402	GRM155R71C104JA88D	Murata Electronics North America
C7, C11, C12	3	0.1 μ F	CAP, CERM, 0.1 μ F, 6.3V, $\pm$ 10%, X5R, 0402	402	C1005X5R0J104K	TDK
C8, C10	2	0.22 μ F	CAP, CERM, 0.22 μ F, 6.3V, $\pm$ 10%, X6S, 0402	402	GRM155C80J224KE01D	Murata
C9	1	0.47 μ F	CAP, CERM, 0.47 μ F, 10V, $\pm$ 10%, X7R, 0603	603	C0603C474K8RACTU	Kemet
C13, C16, C19, C20	4	0.1 μ F	CAP, CERM, 0.1 μ F, 16V, $\pm$ 10%, X7R, 0402	402	GRM155R71C104KA88D	Murata
C14, C15, C17, C18	4	0.047 μ F	CAP, CERM, 0.047 μ F, 16V, $\pm$ 10%, X7R, 0402	402	GRM155R71C473KA01D	Murata
C21	1	0.1 μ F	CAP, CERM, 0.1 μ F, 25V, $\pm$ 10%, X5R, 0603	603	06033D104KAT2A	AVX
C22, C23	2	10 pF	CAP, CERM, 10pF, 50V, $\pm$ 5%, C0G/NP0, 0402	402	GRM1555C1H100JA01D	Murata
D1	1	5.6 V	Diode, Zener, 5.6V, 500 mW, SOD-123	SOD-123	MMSZ5232B-7-F	Diodes Inc.
D3, D4, D5, D6	4	Green	LED, Green, SMD	1.6x0.8x0.8mm	LTST-C190KGKT	Lite-On
H1, H2, H3, H4	4		Bumpon, Hemisphere, 0.375 $\times$ 0.235, Black	Black Bumpon	SJ61A2	3M
J1	1		Connector, USB Mini B	Connector, Mini B	897-43-005-00-100001	Mill-Max
J2, J5	2		Header, 2 Pos, 6A, 63V, TH	6.2x8.5x5.54 mm	1725656	Phoenix Contact
J3, JP7–JP10, JP11	6		Header, 100mil, 3x1, Tin, TH	Header, 3x1,100mil,TH	5-146278-3	TE Connectivity
J4	1		Receptacle, 50mil, 6x1, R/A, TH	6x1 Receptacle	LPPB061NGCN-RC	Sullins Connector Solutions
J6	1		Terminal Block, 4x1, 5.08 mm, TH	4x1 Terminal Block	39544-3004	Molex
JP2–JP6, JP12, JP13	7		Header, 100mil, 2x1, Tin, TH	Header,2 Pin,100mil,Tin	PEC02SAAN	Sullins Connector Solutions

Table 6. Bill of Materials (continued)

Designator	Qty.	Value	Description	Package Reference	Part Number	Manufacturer
L1	1	4.7 μ H	Inductor, Shielded, Composite, 4.7 μ H, 2.7A, 0.05 Ω , SMD	4x2x4mm	XFL4020-472MEB	Coilcraft
R1, R3	2	49.9 k	RES, 49.9 k Ω , 1%, 0.063W, 0402	402	CRCW040249K9FKED	Vishay-Dale
R2	1	23.2 k	RES, 23.2 k Ω , 1%, 0.063W, 0402	402	CRCW040223K2FKED	Vishay-Dale
R4	1	80.6 k	RES, 80.6 k Ω , 1%, 0.063W, 0402	402	CRCW040280K6FKED	Vishay-Dale
R5	1	806 k	RES, 806 k Ω , 1%, 0.063W, 0402	402	CRCW040280K6FKED	Vishay-Dale
R6, R7, R13, R14, R22–R24	7	3.3 k	RES, 3.3 k Ω , 5%, 0.063W, 0402	402	CRCW04023K30JNED	Vishay-Dale
R8, R9	2	33	RES, 33 Ω , 5%, 0.063W, 0402	402	CRCW040233R0JNED	Vishay-Dale
R10	1	9.76 k	RES, 9.76 k Ω , 1%, 0.063W, 0402	402	CRCW04029K76FKED	Vishay-Dale
R11	1	1.40 k	RES, 1.40 k Ω , 1%, 0.063W, 0402	402	CRCW04021K40FKED	Vishay-Dale
R12	1	1.0 Meg	RES, 1.0 M Ω , 5%, 0.063W, 0402	402	CRCW04021M00JNED	Vishay-Dale
R15	1	100	RES, 100 Ω , 1%, 0.063W, 0402	402	CRCW0402100RFKED	Vishay-Dale
R16, R19	2	10.0 k	RES, 10.0 k Ω , 1%, 0.063W, 0402	402	CRCW040210K0FKED	Vishay-Dale
R17, R18	2	2.7 k	RES, 2.7 k Ω , 5%, 0.063W, 0402	402	CRCW04022K70JNED	Vishay-Dale
R20, R28, R29	3	10 k	RES, 10 k Ω , 5%, 0.063W, 0402	402	CRCW040210K0JNED	Vishay-Dale
R21	1	6.04 k	RES, 6.04 k Ω , 1%, 0.063W, 0402	402	CRCW04026K04FKED	Vishay-Dale
R25, R26, R27, R30	4	511	RES, 511 Ω , 1%, 0.063W, 0402	402	CRCW0402511RFKED	Vishay-Dale
SH-JP1–SH-JP11	11	1x2	Shunt, 2mm, Gold plated, Black	2mm Shunt,Closed Top	2SN-BK-G	Samtec
SW1, SW2	2		Switch, Tactile, SPST-NO, 0.05A, 12V, SMT	Switch, 4.4x2x2.9 mm	TL1015AF160QG	E-Switch
TP4	1	Orange	Test Point, Miniature, Orange, TH	Orange Miniature Testpoint	5003	Keystone
TP5, TP6	2	Black	Test Point, Multipurpose, Black, TH	Black Multipurpose Testpoint	5011	Keystone
TP7, TP8	2	White	Test Point, Miniature, White, TH	White Miniature Testpoint	5002	Keystone
U1	1		Piezo Driver with Integrated Boost Converter, RGP0020D	RGP0020D	DRV2700RGP	Texas Instruments
U2	1		4-Channel ESD-protection array for high-speed data interfaces, DRY006A	DRY0006A	TPD4E004DRY	Texas Instruments
U3	1		Single Output LDO, 200 mA, Fixed 3.3 V Output, 2 to 5.5 V Input, with Low IQ, 5-pin SC70 (DCK), –40°C to 125°C, Green (RoHS and no Sb/Br)	DCK0005A	TLV70033DCKR	Texas Instruments
U4	1		Mixed Signal MicroController, RGZ0048A	RGZ0048A	MSP430F5510IRGZ	Texas Instruments
Y1	1		CRYSTAL 12.000 MHz 10PF SMD	3.2x0.55x2.5mm	ABM8G-12.000MHZ-B4Y-T	Abracon Corporation

10 Trademarks

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All other trademarks are the property of their respective owners.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (March 2015) to A Revision

- | | Page |
|---|------|
| • Changed value on R ₅ in <i>BST Network JP2, JP3, and JP4</i> image. | 13 |

Revision History

Changes from A Revision (April 2015) to B Revision

- | | Page |
|---|------|
| • Changed content in JP11 row of the <i>Default Jumper Settings</i> table. | 7 |
| • Changed connector lines in <i>Power Path Diagram</i> | 8 |

Revision History

Changes from B Revision (April 2015) to C Revision

- | | Page |
|--|------|
| • Added: "MSP-JTAG2SBW JTAG to Spy-Bi-Wire adapter" to the advanced configuration list..... | 1 |
| • Deleted sentence: "The DRV2700EVM kit includes a JTAG-to-SpyBiWire adapter for connecting the JTAG interface to the DRV2700EVM SpyBiWire connector" from Section 5.1 | 15 |

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

FCC NOTICE: 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.
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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 or RSS-247

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. 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/lstds/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/lstds/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 to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

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。
3. 技術基準適合証明を取得後ご使用いただく。

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3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):*

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

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 MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS 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 EPIDEMIC FAILURE WARRANTY OR 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.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

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. 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 OR THE USE OF THE EVMS, 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 TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

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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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