

DRV2700EVM-HV500 High Voltage Piezo Driver Evaluation Kit

The DRV2700 is a single chip high-voltage driver with an integrated 105-V boost switch, integrated power diode, and integrated fully differential amplifier. This evaluation kit utilizes this high-voltage switch into a flyback configuration that is able to achieve (but is not limited to) up to 500 V:

- Controllable input modes: Analog input, PWM and MSP430 controllable
- Variable output voltages from 0 V to 500 V
- 2 power supply inputs to isolate power consumption on DRV2700 application circuitry
- 4 convenient max output voltage settings
- Small footprint (14 mm x 14.5 mm)

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 for driving piezo actuators, polymers, valves and many other applications. The EVM also contains a microcontroller, LDO (3.3 V) and LEDs for status and input settings.

Evaluation Kit Contents:

- DRV2700EVM-HV500 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) for MSP430
- MSP430 LaunchPad™ (MSP-EXP430G2) or MSP430-FET430UIF hardware programming tool
- DRV2700EVM firmware available on the [DRV2700EVM-HV500 tool folder](#)



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**US ECCN: 3E991
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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



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

- (a) Keep work area clean and orderly.
- (b) Qualified observer(s) must be present anytime circuits are energized.
- (c) 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.
- (d) 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.
- (e) Use stable and nonconductive work surface.
- (f) 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.

- (a) 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.
- (b) 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.
- (c) 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

- (a) 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-HV500 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-HV500 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-HV500. [Table 2](#) shows the original configuration of the jumpers, as shipped.

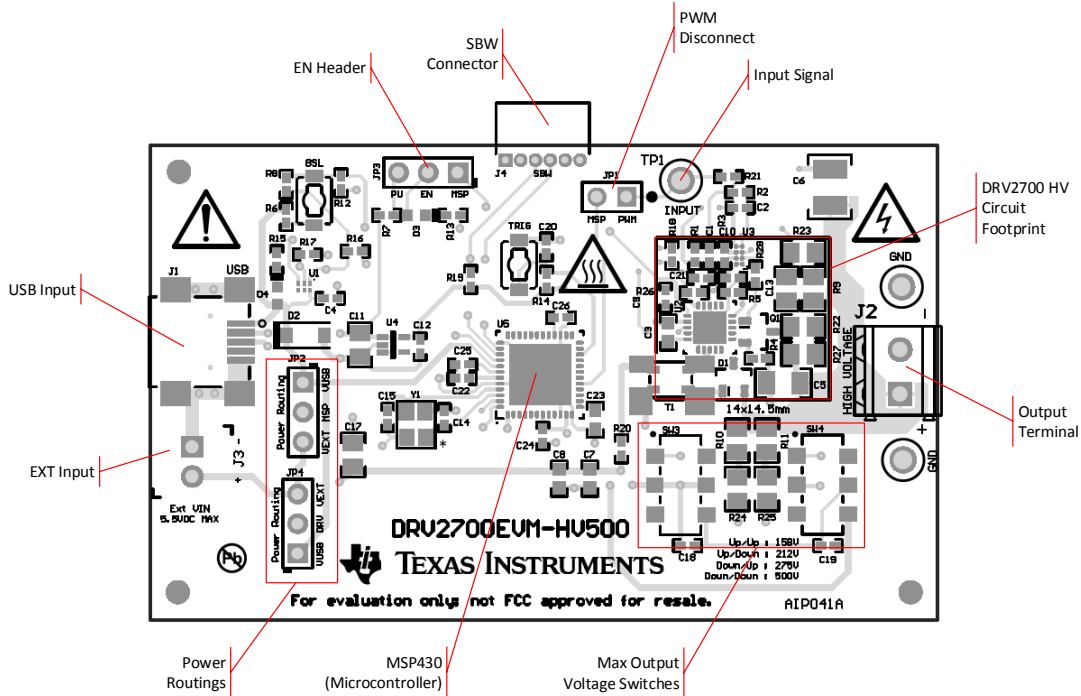


Figure 1. Board Diagram

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	500 V_P *

*Maximum output voltage will vary based on feedback resistors and opamp variability.

1.2 Quick Start Board Setup

The DRV2700EVM-HV500 comes with preprogrammed firmware to provide a 0- to 500-V_p signal between the output and GND.

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-HV500 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 (JP3) 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
JP1 PWM	Open		Disconnected PWM input and I/O of MSP430
	Connected	X	Connected PWM input and I/O of MSP430
JP4 DRV	Open		DRV2700 not connected to either power supply
	VIN ⁽¹⁾		DRV2700 connected to VIN power supply
	USB ⁽¹⁾	X	DRV2700 connected to USB power supply
JP3 EN	Open		EN pulled internally to GND through DRV2700 internal resistance
	PU ⁽¹⁾		EN pulled up to MSP power supply through external pull up resistor
	MSP ⁽¹⁾	X	EN tied to I/O of MSP430
JP4 DRV	Open		DRV2700 not connected to either power supply
	VIN ⁽¹⁾		DRV2700 connected to VIN power supply
	USB ⁽¹⁾	X	DRV2700 connected to USB power supply

⁽¹⁾ In the table, jumper setting name means that side of the terminal 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 GND and connect the positive terminal of the load to the "HIGH VOLTAGE" side of JP2.
2. Ensure the terminals are connected correctly, then enable the supply

CAUTION

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

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 JP2 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.

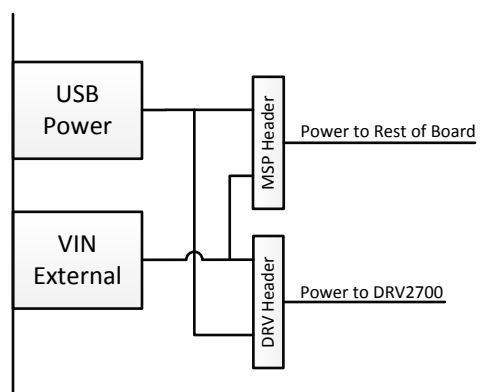


Figure 2. Power Path Diagram

If a power measurement of the DRV2700 circuitry is desired, it is best to provide the MSP jumper (JP2) with USB power and the DRV jumper (JP4) with VIN. With this configuration, measuring the provided voltage and current into VIN gives the power consumption of the DRV2700.

2.4 EN Configuration

The EN input for the DRV2700 has 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.

This signal has an LED to indicate when the signal is at a logic-level high.

2.5 Inputs

The analog input (TP1) is used for PWM and analog inputs. See [PWM and Analog Inputs](#), for more information.

2.6 Outputs

The DRV2700EVM-HV500 has a high voltage output ranging from 0–500 V. This output is routed to a terminal connector to mitigate the user touching between the high voltage node and GND. Be sure to disable power when connecting and disconnecting the high voltage node.

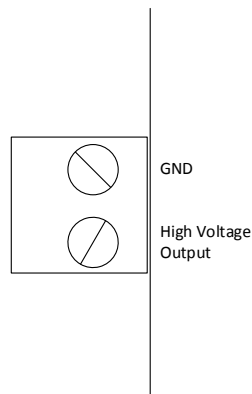


Figure 3. Output Diagram

2.7 TRIG Button

The DRV2700EVM-HV500 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.

3 EVM Control Software (GUI)

By default, the DRV2700EVM-HV500 can be controlled programmatically through the GUI Interface. [Figure 4](#) is a screenshot of the GUI.

Run the GUI by downloading it from the [DRV2700EVM-HV500 tool folder](#), installing the GUI and then running it. When prompted, connect to the USBHID setting.

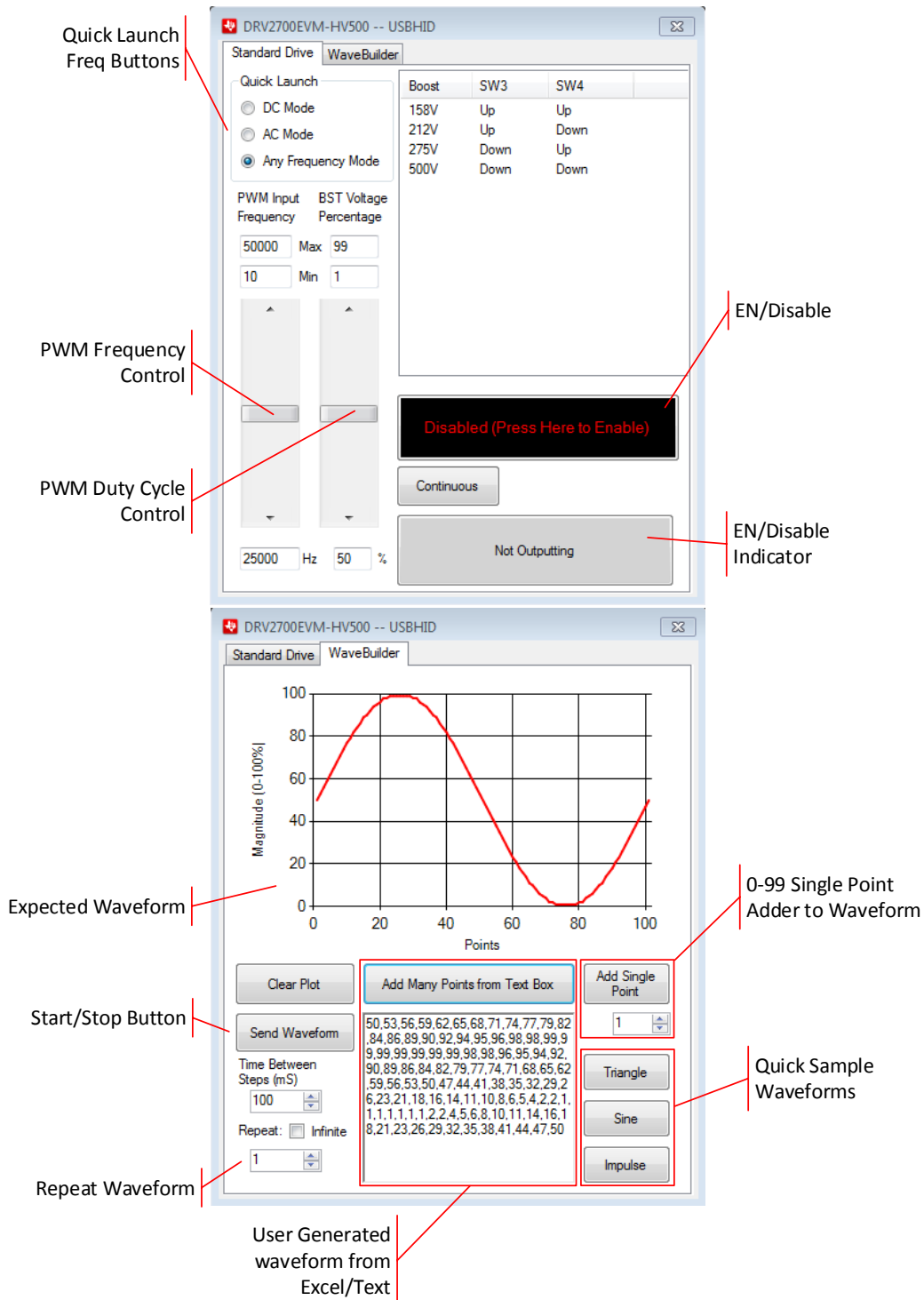
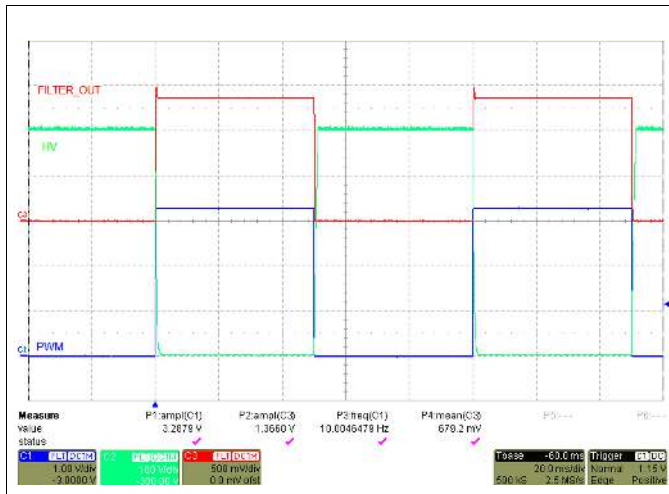


Figure 4. GUI Interface

The GUI is broken up into two tabs: *Standard Drive* and *WaveBuilder*. The *Standard Drive* utilizes changing the frequency and duty cycle of the PWM signal and is intended for easy prototyping and evaluating. The *WaveBuilder* tab is for showcasing the DRV2700 as a proportional controller that can drive a variety of user-created waveforms. On both tabs, the sections are intuitive, however, the following sections are worth describing:

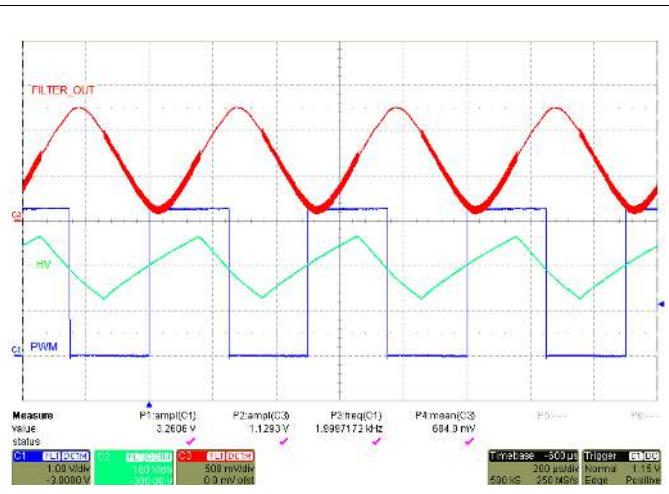
- **Output Timing:** This button has 3 different modes: *Continuous*, *Pulsed*, and *Single*. These modes help with a timed EN signal.
- **Boost Voltage Percentage:** This is the duty cycle of the PWM waveform and after filtered will be a DC value to modulate the output. Note in the scopeshots in [Figure 5](#) through [Figure 8](#), that the PWM signal's duty cycle is inverse to the output. (As duty cycle increases, the output voltage percentage decreases.) This has been taken care of through software so that the slider bar will reflect the true output percentage though. The boost voltage percentage will only have a true "Boost Voltage Percentage" effect during High Frequency/DC Mode.
- **PWM Input Frequency:** This will change the frequency of the PWM signal coming from the microcontroller, which is fed into the input filter:
 - Low PWM Frequency (< 1 kHz): When below 1 kHz, the PWM signal will hardly be attenuated such that the majority of the PWM signal will propagate through. This will cause the output to try and reflect the PWM signal coming from the microcontroller and the output will try to be a square wave. The *AC Mode - Quick Launch* frequency button will set the frequency to this range.
 - Mid PWM Frequency (1 kHz < freq < 20 kHz): When the frequency is set in this range, the PWM signal will be somewhat attenuated and the output will still somewhat reflect a PWM signal. This mode can be used for audio tones, however, the output may not be able to drive to full scale, depending on the load capacitance.
 - High PWM Frequency (> 20 kHz): As the frequency starts to go higher, the PWM signal will be greatly attenuated. This will cause the PWM signal to appear DC after this filter. This mode can be used to drive the output at a DC level which is set by the Boost Voltage Percentage (that is, duty cycle). The *DC Mode - Quick Launch* frequency button will set the frequency to 50 kHz, which is in this range.
- **Time Between Steps (ms):** The time between steps on the wavebuilder tab is the time step between points. This is implemented using a series of DC set points occurring at a certain time of the waveform. The output is limited to 200 sample points.
- **Waveform From Excel/Text:** This text box will build a waveform in the graph based on a comma-separated string of integers from 0-100%.

It is best practice to have an oscilloscope measure the output to verify how the load is actually being driven, based on the conditions applied.



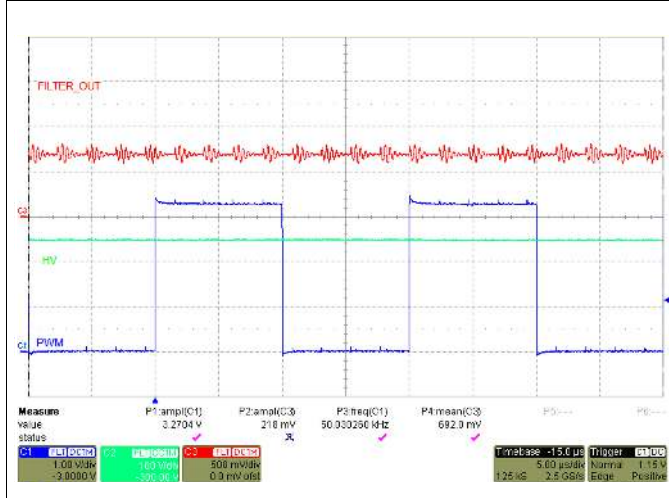
$V_{DD} = 5\text{ V}$ $C_{(LOAD)} = 22\text{ nF}$ $V_{HV} = 0\text{ to }500\text{ V}$

Figure 5. Low PWM Frequency



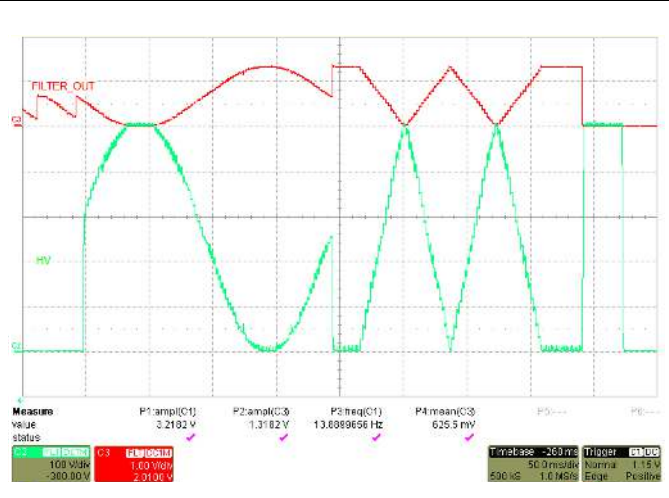
$V_{DD} = 5\text{ V}$ $C_{(LOAD)} = 22\text{ nF}$ $V_{HV} = 0\text{ to }500\text{ V}$

Figure 6. Mid PWM Frequency



$V_{DD} = 5\text{ V}$ $C_{(LOAD)} = 22\text{ nF}$ $V_{HV} = 0\text{ to }500\text{ V}$

Figure 7. High PWM Frequency



$V_{DD} = 5\text{ V}$ $C_{(LOAD)} = 22\text{ nF}$ $V_{HV} = 0\text{ to }500\text{ V}$

Figure 8. Arbitrary Waveform Using Wavebuilder Tab

4 Flyback 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.

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

See [Programming the HV Maximum Output Voltage](#) for more information on how to set the boost voltage.

4.1 Programming the HV Maximum Output Voltage

The high voltage output (HV) is set through an external network. For ease-of-use of this EVM, two switches (SW3 and SW4) are installed to change R_{FB1} and C_{FB2} with ease. For a normal application, switches should not be needed and those values can be set by passives.

Additionally, R_{FB2} is split into two resistors to provide a reference voltage for the pull-down operational amplifier (opamp) that is discussed in [Pull-down Network](#).

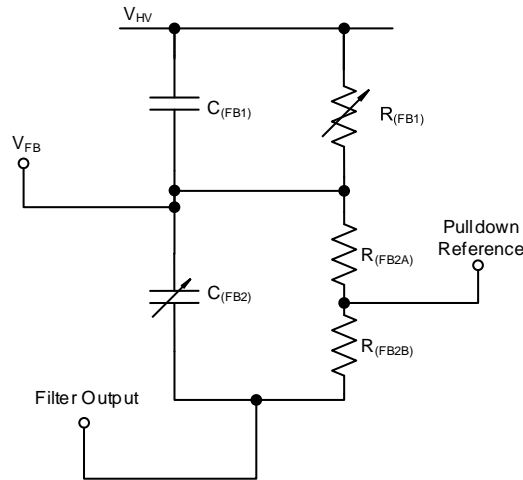


Figure 9. V_{HV} Feedback Network

The HV output voltage is given by: [Equation 2](#)

$$V_{HV} = V_{FB} \left(1 + \frac{R_{FB1}}{R_{FB2}} \right) - \left(\frac{R_{FB1}}{R_{FB2}} \right) V_{OP} \quad (1)$$

where $V_{FB} = 1.30 \text{ V}$ and V_{OP} is the V_{OL} of the opamp since it cannot go all the way to ground. TI recommends the sum of the resistance of R_{FB1} and R_{FB2} be between 500 k Ω and 1 M Ω .

The capacitors are needed in the feedback network to increase the performance at low and high frequencies. Because the charge storage is inversely proportional to the capacitance, use [Equation 2](#) to calculate the values of the capacitors. In general, select a value around 22 pF for C_{FB1} and size C_{FB2} accordingly.

$$\frac{R_{FB1}}{R_{FB2}} = \frac{C_{FB2}}{C_{FB1}} \quad (2)$$

Refer to [Table 3](#) for the switch setting to change the maximum output voltage.

CAUTION

Be sure not to hot switch the SW3 and SW4 connection. This should only be switched while the output is disabled or the board is unpowered.

Table 3. V_{HV} Setting Based on the Jumper Configuration

SW3	SW4	R_{FB2}	C_{FB2}	R_{FB1}	C_{FB1}	V_{MAX}
Down	Down	5.49 k Ω	8200 pF	2.05 M Ω	22 pF	500 V
Down	Up	5.49 k Ω	4505 pF	1.122 M Ω	22 pF	275 V
Up	Down	5.49 k Ω	3717 pF	0.866 M Ω	22 pF	212 V
Up	Down	5.49 k Ω	2710 pF	0.642 M Ω	22 pF	158 V

4.2 Programming the Flyback Current Limit

The peak inductor current is set with resistor R3 (R_{EXT}). 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 R_{EXT} to I_{LIM} is approximated with [Equation 3](#) where I_{LIM} is the current limit set by R_{EXT} , $K = 10500$, $V_{REF} = 1.35\text{ V}$ and $R_{INT} = 60\ \Omega$.

$$R_{EXT} = \left(K \frac{V_{REF}}{I_{LIM}} \right) - R_{INT} \quad (3)$$

4.3 Transformer Selection

Transformer selection plays a critical role in the performance of the DRV2700. The range of recommended primary-side inductance values is $3.3\ \mu\text{H}$ to $22\ \mu\text{H}$. When a larger inductance is chosen, the DRV2700 flyback converter automatically runs at a lower switching frequency and incurs less switching losses; however, the larger inductances may also have a higher equivalent series resistance (ESR), which will increase the parasitic inductor losses.

Another factor to consider for transformers is the winding ratio. In general, if a 200-V output is desired then, because the SW node can boost up to 100 V, a transformer of 1:2 (100 V:200 V) is the minimum required winding. However, selecting a slightly higher winding ratio to ensure that the 100 V on the primary side is not surpassed while trying to boost up to the desired voltage is good design practice.

The transformer used on this EVM is a 1:10 winding ratio with a primary side inductance of $7\ \mu\text{H}$.

4.4 HV Capacitor Selection

The HV output voltage may be programmed as high as 500 V on this EVM. A capacitor must have a voltage rating equivalent to the boost output voltage or higher. Because the output can be unloaded, a 1-nF output capacitor is added to ensure some amount of stability on the output.

Additionally, a non-populated landing pad (C6) is provided for additional capacitance, if desired.

5 PWM and Analog Inputs

The flyback configuration on this EVM uses a low-pass (two pole) filtered PWM waveform from the microcontroller or an analog signal from the user. By default, the DRV2700EVM-HV500 uses the MSP430 PWM input mode. This section describes each input mode in detail and the modifications necessary for operation of each.

The DRV2700EVM supports two input modes for driving the DRV2700:

- **PWM 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.
- **Analog input:** An external source supplies an analog waveform to the TP1 header which is sent through the low-pass input filter to the DRV2700.

Because the low-pass filter will try to pass the DC components of the signal, the PWM/Analog input's frequency will determine if the filtered signal will still appear AC.

- **Low Frequency/AC Mode (< 1 kHz):** When below 1 kHz, the PWM signal will hardly be attenuated such that the majority of the PWM signal will propagate through. This will cause the output to try and reflect the PWM signal coming from the microcontroller and the output will try to be a square wave.
- **Mid Frequency (1 kHz < freq < 20 kHz):** When the frequency is set in this range, the PWM signal will be attenuated but it will still somewhat reflect a PWM signal. This mode can be used for audio tones, however the output may not be able to drive to full scale, depending on the load capacitance.
- **High Frequency/DC Mode (> 20 kHz):** As the frequency starts to go higher, the PWM signal will be greatly attenuated. This will cause the PWM signal to appear DC after this filter. This mode can be used to drive the output at a DC level which is set by the Boost Voltage Percentage (that is, duty cycle).

See the scopeshots in [Section 3](#) for example waveforms.

5.1 PWM Input Using MSP430

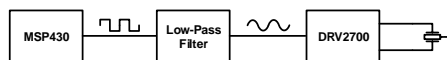


Figure 10. PWM Signal

When using the DRV2700EVM-HV500 in MSP430 PWM input mode, the onboard MSP430 generates a PWM signal that is sent through a low-pass filter to the DRV2700. The DRV2700EVM-HV500 is set up to use this mode by default. Set to the 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-HV500 Spy-Bi-Wire to the computer. The TI website offers an MSP430 USB-to-JTAG hardware interface (MSP-FET430UIF) for updating and debugging MSP430 code.

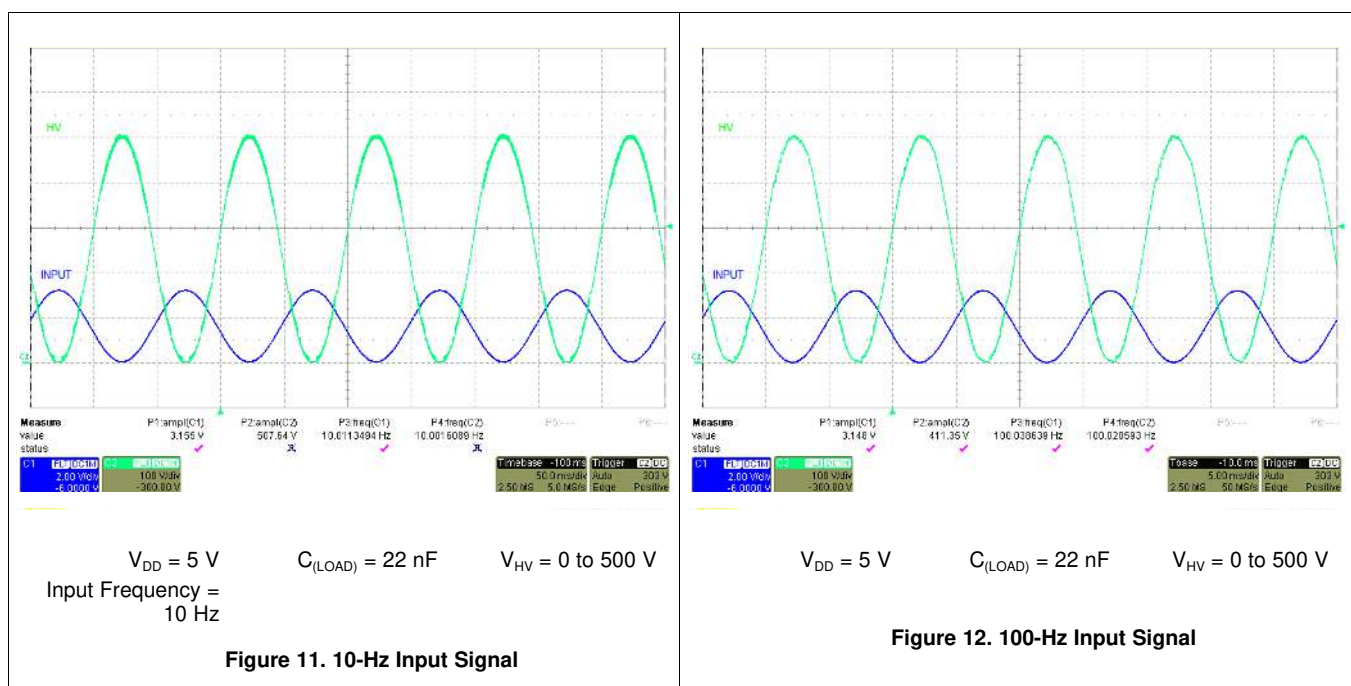
NOTE: Sample code is also available on the [DRV2700](#) product web page.

5.2 Analog Input

The following instructions are provided to use an external analog source to drive the DRV2700:

1. Disconnect the MSP430 output pin from the DRV2700 input pins by removing jumper JP1
2. Connect the DRV2700 EN signal:
 - (a) Use the onboard MSP430 and GUI to control the EN pin by connecting JP3 between EN and MSP
 - (b) EN the output all the time by connecting JP3 between PU and EN
 - (c) Use an external control signal by connecting source to the middle header of JP3
3. Connect the analog input signal to TP1 (INPUT). Note, the default input range is from 0–3.3 V (same as PWM signal). Therefore, if a voltage divider is needed, R21 and R2 can be changed accordingly.
4. Enable the power supply
5. Enable the analog input signal (and EN)

Figure 11 and Figure 12 show waveforms using an external sine wave.



6 Output

The DRV2700 has an output terminal header for connecting the piezo load.

6.1 Load Selection

The DRV2700 is intended to drive piezo (capacitive) loads. 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. Figure 13 shows the typical instantaneous maximum load current versus output voltage.

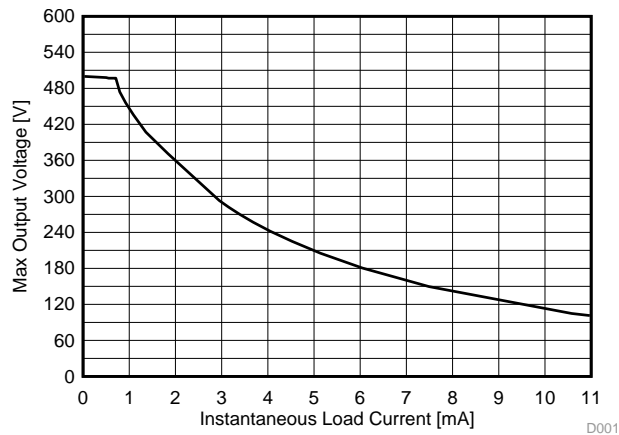


Figure 13. Instantaneous Max Load Current vs Max Output Voltage

6.2 Pulldown Network

The pulldown FET and one or more resistors are used to remove the charge on the high-voltage output faster than just simply using the feedback resistors. Because the FET must be driven from a comparator, an NMOS FET must be used. During normal operation, the V_{DS} of the NMOS is subject to any voltage from approximately 0 V when the FET is on, to the output on the flyback configuration (V_{HV}) when the FET is off. Therefore, selecting a FET with a V_{DS} breakdown higher than the maximum V_{HV} is required. Additionally, placing a resistor in series with this FET (on the source side) to limit the current going through the FET is recommended. This resistor can be sized according to the maximum current allowed per the data sheet of the FET, such that when current flows through the resistor, it raises the source voltage and thereby lowers the V_{GS} and shuts the FET off. Using Equation 4 provides a good value of R_S where V_G is the V_{OH} of the opamp, $V_{GS(th)}$ is the threshold voltage of the FET and $I_{DS(Max)}$ is the maximum current allowed through the FET. As an additional measure, one or more resistors can be placed on the drain and gate side to protect the pulldown FET by minimizing sharp transients that can be coupled to the other terminals of the FET.

$$R_S = \frac{V_G - V_{GS(th)}}{I_{DS(Max)}} \quad (4)$$

Because the output voltage will ripple (based on the load current and cap) the threshold at which the opamp turns on the FET needs to be set effectively. To try and eliminate the need for external references, two references from the basic circuit configuration are used. The R_{EXT} voltage at ≈ 1.3 V is regulated internally by the DRV2700; however, it cannot source or sink very much current. Therefore, by connecting this reference to a high impedance input to an opamp, which draws zero current, this reference can be used.

The second reference voltage is set to about 93% of V_{FB} by creating an additional resistor divider in the feedback network (V_{FB2A} and V_{FB2B}). This works, such that when the output is rippling during normal operation, the threshold will not be triggered. However, when the input signal changes so that the output needs to be discharged, the feedback network will be changed so this reference will become higher than V_{REXT} and therefore turn on the output FET.

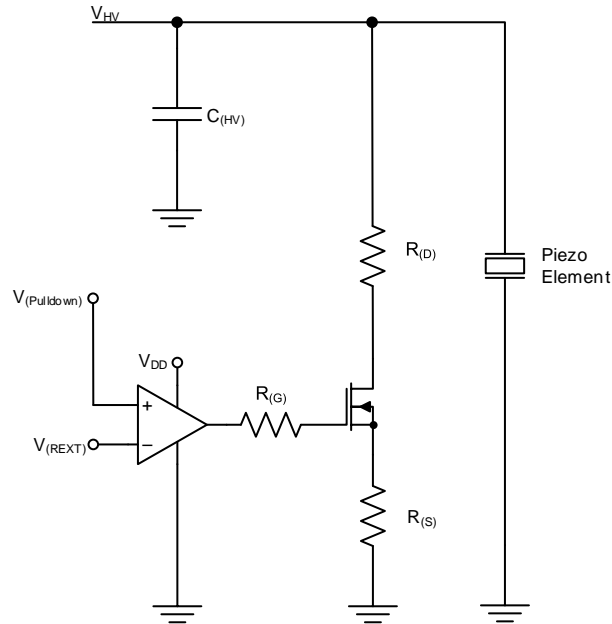
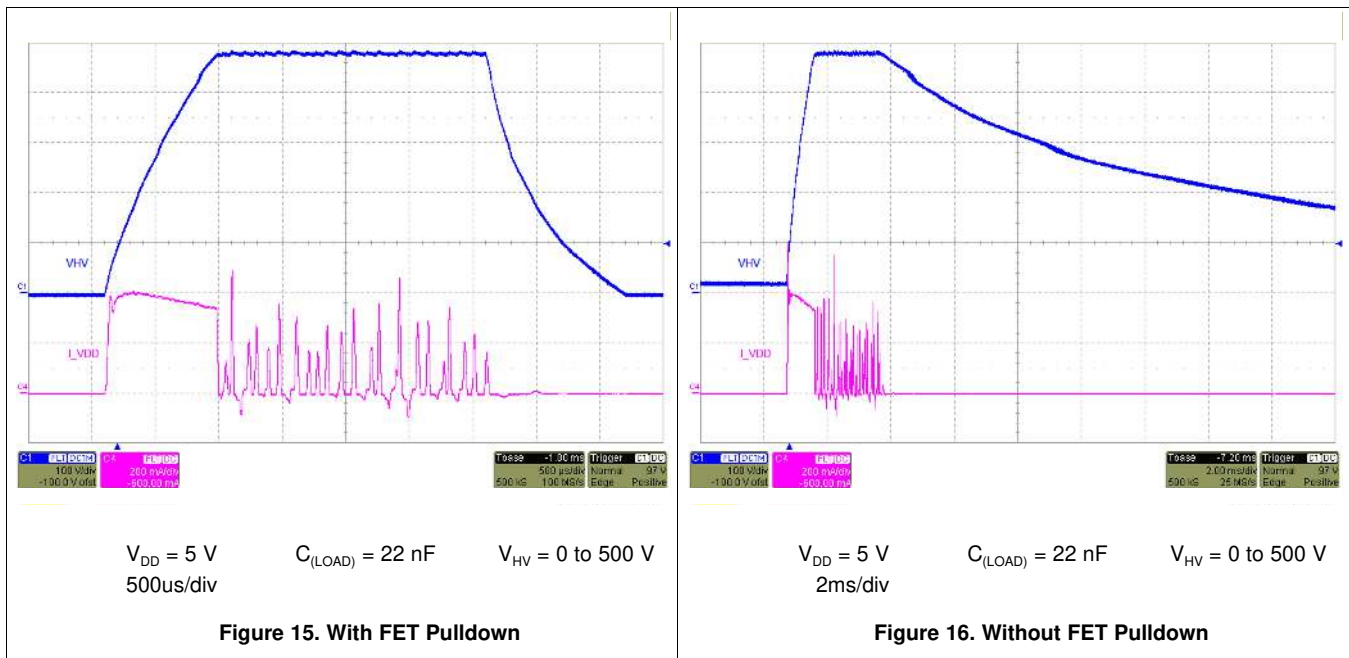


Figure 14. Pulldown Network

Figure 15 and Figure 16 show the different discharge times with and without the pulldown network. Note the 4x timescale in Figure 16.



7 Input Filter

The DRV2700EVM-HV500 has an active low-pass input filter to attenuate high frequency PWM signals coming from the input source. Depending on the 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. The filter can be modified by the user, however be sure that the 3-dB point is no higher than 5 kHz.

See scopeshots in [Section 3](#) for example waveforms.

7.1 First Order Filter

In order to attenuate the high frequency PWM signal, a first order filter was used prior to the integrator to attenuate the high-frequency components. This RC network has a 3-dB point around 1.75 kHz.

7.2 Integrator

In order to attenuate the PWM signal even further, a non-inverting integrator is used.

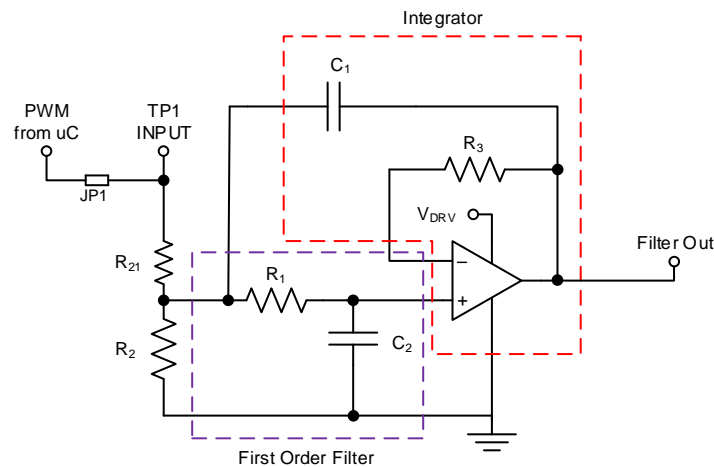


Figure 17. Input Filter

8 Reference

This section includes the DRV2700EVM-HV500 schematic, PCB layout, and bill of materials.

8.1 Schematic

Figure 18 illustrates the DRV2700EVM-HV500 schematic.

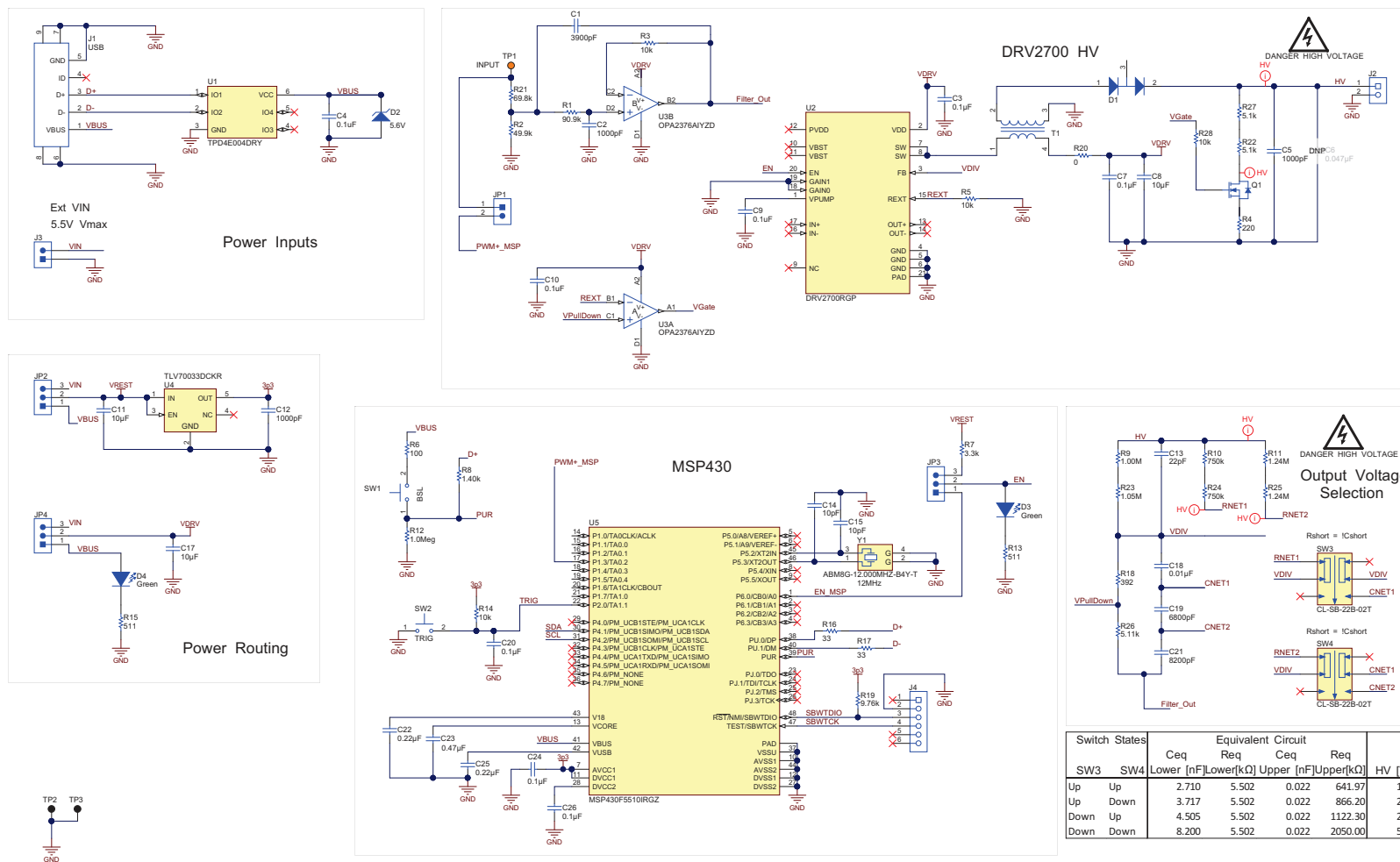


Figure 18. DRV2700EVM-HV500 Schematic

8.2 PCB Layout

Figure 19 shows the DRV2700EVM-HV500 PCB layout.

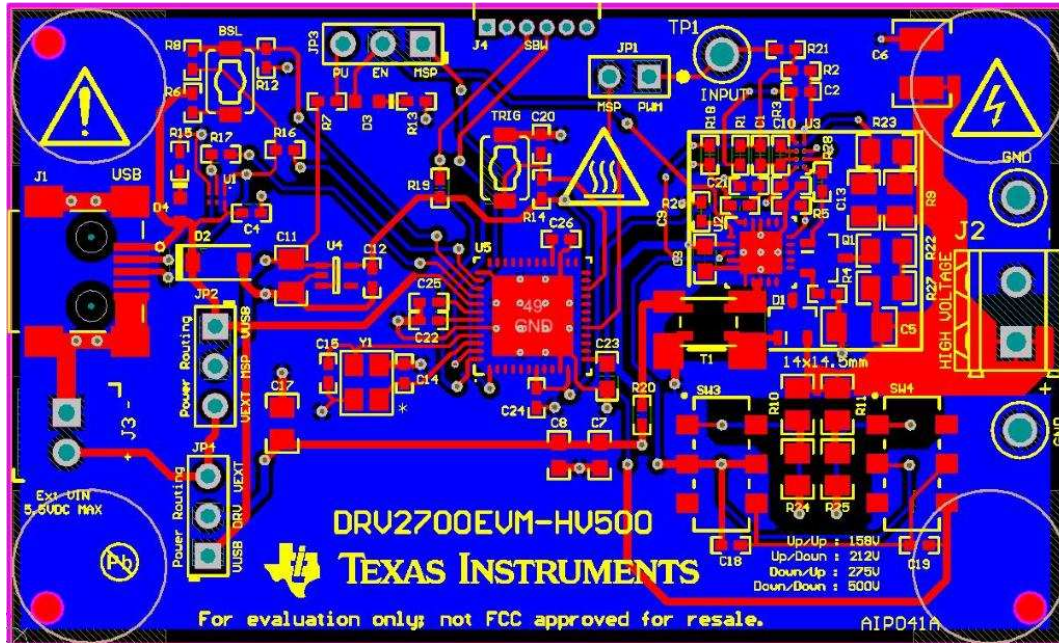


Figure 19. Top and Bottom Layers

8.3 Bill of Materials

Table 4 lists the DRV2700EVM-HV500 bill of materials.

Table 4. Bill of Materials⁽¹⁾

Designator	Qty	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
!PCB	1		Printed Circuit Board		AIP041	Any		
C1	1	3900pF	CAP, CERM, 3900 pF, 50 V, +/- 10%, X7R, 0402	0402	GRM155R71H392KA01D	Murata		
C2	1	1000pF	CAP, CERM, 1000 pF, 10 V, +/- 10%, X5R, 0402	0402	GRM155R61A102KA01D	Murata		
C3, C7	2	0.1uF	CAP, CERM, 0.1 μF, 25 V, +/- 10%, X7R, 0603	0603	GRM188R71E104KA01D	Murata		
C4, C9, C10	3	0.1uF	CAP CER 0.1UF 16V 5% X7R 0402	0402	GRM155R71C104JA88D	Murata Electronics North America		
C5	1	1000pF	CAP, CERM, 1000 pF, 630 V, +/- 5%, COG/NP0, 1206	1206	GRM31B5C2J102JW01L	Murata		
C8	1	10uF	CAP, CERM, 10 μF, 25 V, +/- 20%, X5R, 0603	0603	GRM188R61E106MA73	Murata		
C11, C17	2	10uF	CAP, CERM, 10uF, 16V, +/-20%, X5R, 0805	0805	0805YD106MAT2A	AVX		
C12	1	1000pF	CAP, CERM, 1000pF, 6.3V, +/-10%, X5R, 0402	0402	GRM155R60J102KA01D	Murata		
C13	1	22pF	CAP, CERM, 22 pF, 630 V, +/- 10%, X7R, 0805_140	0805_140	C0805C220KBRCTU	Kemet		
C14, C15	2	10pF	CAP, CERM, 10pF, 50V, +/-5%, C0G/NP0, 0402	0402	GRM1555C1H100JA01D	Murata		
C18	1	0.01uF	CAP, CERM, 0.01 μF, 16 V, +/- 10%, X7R, 0402	0402	GRM155R71C103KA01D	Murata		
C19	1	6800pF	CAP, CERM, 6800 pF, 25 V, +/- 10%, X7R, 0402	0402	GRM155R71E682KA01D	Murata		
C20, C24, C26	3	0.1uF	CAP, CERM, 0.1uF, 6.3V, +/-10%, X5R, 0402	0402	C1005X5R0J104K	TDK		
C21	1	8200pF	CAP, CERM, 8200 pF, 16 V, +/- 10%, X7R, 0402	0402	GRM155R71C822KA01D	Murata		
C22, C25	2	0.22uF	CAP, CERM, 0.22uF, 6.3V, +/-10%, X6S, 0402	0402	GRM155C80J224KE01D	Murata		
C23	1	0.47uF	CAP, CERM, 0.47uF, 10V, +/-10%, X7R, 0603	0603	C0603C474K8RACTU	Kemet	-	-
D1	1	350V	Diode, Switching, 350 V, 0.225 A, SOT-23	SOT-23	MMBD3004S-7-F	Diodes Inc.		
D2	1	5.6V	Diode, Zener, 5.6V, 500 mW, SOD-123	SOD-123	MMSZ5232B-7-F	Diodes Inc.		
D3, D4	2	Green	LED, Green, SMD	1.6x0.8x0.8mm	LTST-C190KGKT	Lite-On		
H1, H2, H3, H4	4		Bumpon, Hemisphere, 0.375 X 0.235, Black	Black Bumpon	SJ61A2	3M		
J1	1		Connector, USB Mini B	Connector, Mini B	897-43-005-00-100001	Mill-Max		
J2	1		Terminal Block, 2x1, 3.81mm, 24-16 AWG, 10A, 300VAC, TH	2x1 Terminal Block	691214310002	Würth Elektronik eiSos		
J3	1		Header, 2 Pos, 6A, 63V, TH	6.2x8.5x5.54 mm	1725656	Phoenix Contact		
J4	1		Receptacle, 50mil, 6x1, R/A, TH	6x1 Receptacle	LPPB061NGCN-RC	Sullins Connector Solutions		

⁽¹⁾ Unless otherwise noted in the Alternate Part Number and/or Alternate Manufacturer columns, all parts may be substituted with equivalents.

Table 4. Bill of Materials⁽¹⁾ (continued)

Designator	Qty	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
JP1	1		Header, 100mil, 2x1, Gold, TH	Header, 2x1, 100mil	5-146261-1	TE Connectivity		
JP2, JP3, JP4	3		Header, 100mil, 3x1, Tin, TH	Header, 3x1, 100mil, TH	5-146278-3	TE Connectivity		
Q1	1	600V	MOSFET, N-CH, 600 V, 0.021 A, SOT-23	SOT-23	BSS127 H6327XTSA2	Infineon Technologies		None
R1	1	90.9k	RES, 90.9 k, 1%, 0.063 W, 0402	0402	CRCW040290K9FKED	Vishay-Dale		
R2	1	49.9k	RES, 49.9 k, 1%, 0.063 W, 0402	0402	CRCW040249K9FKED	Vishay-Dale		
R3, R5, R28	3	10k	RES, 10 k, 5%, 0.063 W, 0402	0402	CRCW040210K0JNED	Vishay-Dale		
R4	1	220	RES, 220, 5%, 0.063 W, 0402	0402	CRCW0402220RJNED	Vishay-Dale		
R6	1	100	RES, 100 ohm, 1%, 0.063W, 0402	0402	CRCW0402100RFKED	Vishay-Dale		
R7	1	3.3k	RES, 3.3k ohm, 5%, 0.063W, 0402	0402	CRCW04023K30JNED	Vishay-Dale		
R8	1	1.40k	RES, 1.40k ohm, 1%, 0.063W, 0402	0402	CRCW04021K40FKED	Vishay-Dale		
R9	1	1.00Meg	RES, 1.00 M, 1%, 0.125 W, 0805	0805	CRCW08051M00FKEA	Vishay-Dale		
R10, R24	2	750k	RES, 750 k, 0.1%, 0.125 W, 0805	0805	RT0805BRD07750KL	Yageo America		
R11, R25	2	1.24Meg	RES, 1.24 M, 1%, 0.125 W, 0805	0805	CRCW08051M24FKEA	Vishay-Dale		
R12	1	1.0Meg	RES, 1.0Meg ohm, 5%, 0.063W, 0402	0402	CRCW04021M00JNED	Vishay-Dale		
R13, R15	2	511	RES, 511 ohm, 1%, 0.063W, 0402	0402	CRCW0402511RFKED	Vishay-Dale		
R14	1	10k	RES, 10k ohm, 5%, 0.063W, 0402	0402	CRCW040210K0JNED	Vishay-Dale		
R16, R17	2	33	RES, 33 ohm, 5%, 0.063W, 0402	0402	CRCW040233R0JNED	Vishay-Dale		
R18	1	392	RES, 392, 1%, 0.063 W, 0402	0402	CRCW0402392RFKED	Vishay-Dale		
R19	1	9.76k	RES, 9.76k ohm, 1%, 0.063W, 0402	0402	CRCW04029K76FKED	Vishay-Dale		
R20	1	0	RES, 0, 5%, 0.063 W, 0402	0402	RC0402JR-070RL	Yageo America		
R21	1	69.8k	RES, 69.8 k, 1%, 0.063 W, 0402	0402	CRCW040269K8FKED	Vishay-Dale		
R22, R27	2	5.1k	RES, 5.1 k, 5%, 0.125 W, 0805	0805	CRCW08055K10JNEA	Vishay-Dale		
R23	1	1.05Meg	RES, 1.05 M, 1%, 0.125 W, 0805	0805	CRCW08051M05FKEA	Vishay-Dale		
R26	1	5.11k	RES, 5.11 k, 1%, 0.063 W, 0402	0402	CRCW04025K11FKED	Vishay-Dale		
SH-JP1, SH-JP2, SH-JP3, SH-JP4	4	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		
SW3, SW4	2		Switch, Slide, DPDT, 0.2A, GULL, 12V, SMD	SMD, 6-Leads, Body 8.5x3.5mm, Pitch 2.5mm	CL-SB-22B-02T	Copal Electronics		
T1	1	7uH	Transformer, Xenon Flash, 7uH, SMT	3.2x1.5x2.5mm	ATB322515-0110	TDK		
TP1	1	Orange	Test Point, Multipurpose, Orange, TH	Orange Multipurpose Testpoint	5013	Keystone		
TP2, TP3	2	Black	Test Point, Multipurpose, Black, TH	Black Multipurpose Testpoint	5011	Keystone		
U1	1		4-CHANNEL ESD-PROTECTION ARRAY FOR HIGH-SPEED DATA INTERFACES, DRY006A	DRY0006A	TPD4E004DRY	Texas Instruments		None
U2	1		Piezo Driver with Integrated Boost Converter, RGP0020D	RGP0020D	DRV2700RGP	Texas Instruments		Texas Instruments

Table 4. Bill of Materials⁽¹⁾ (continued)

Designator	Qty	Value	Description	Package Reference	Part Number	Manufacturer	Alternate Part Number	Alternate Manufacturer
U3	1		Low-Noise, Low Quiescent Current, Precision Operational Amplifier e-trim Series	YZD0008ANAP	OPA2376AIYZD	Texas Instruments		Texas Instruments
U4	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 to 125 degC, Green (RoHS & no Sb/Br)	DCK0005A	TLV70033DCKR	Texas Instruments	Equivalent	None
U5	1		Mixed Signal MicroController, RGZ0048A	RGZ0048A	MSP430F5510IRGZ	Texas Instruments		None
Y1	1		CRYSTAL 12.000MHZ 10PF SMD	3.2x0.55x2.5mm	ABM8G-12.000MHZ-B4Y-T	Abracon Corporation		
C6	0	0.047uF	CAP, CERM, 0.047 μ F, 630 V, +/- 10%, X7R, 1210	1210	GRM32DR72J473KW01L	Murata		
FID1, FID2, FID3	0		Fiducial mark. There is nothing to buy or mount.	Fiducial	N/A	N/A		

Revision History

Changes from Original (April 2015) to A Revision	Page
• Changed <i>GUI Interface</i> image.	10

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

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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.

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http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page

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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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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:*

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