±3-A HIGH-EFFICIENCY H-BRIDGE (REQUIRES EXTERNAL PWM)

FEATURES

- **±3-A Maximum Output Current**
- **Requires External PWM From DC to 1 MHz With TTL-Compatible Voltages for High and Low**
- **Low Supply Voltage Operation: 2.8 V to 5.5 V**
- **High Efficiency Generates Less Heat**
- **Over-Current and Thermal Protection**
- **Fault Indicators for Over-Current, Thermal and Under-Voltage Conditions**
- **9×9 mm PowerPAD™ Quad Flatpack**

APPLICATIONS

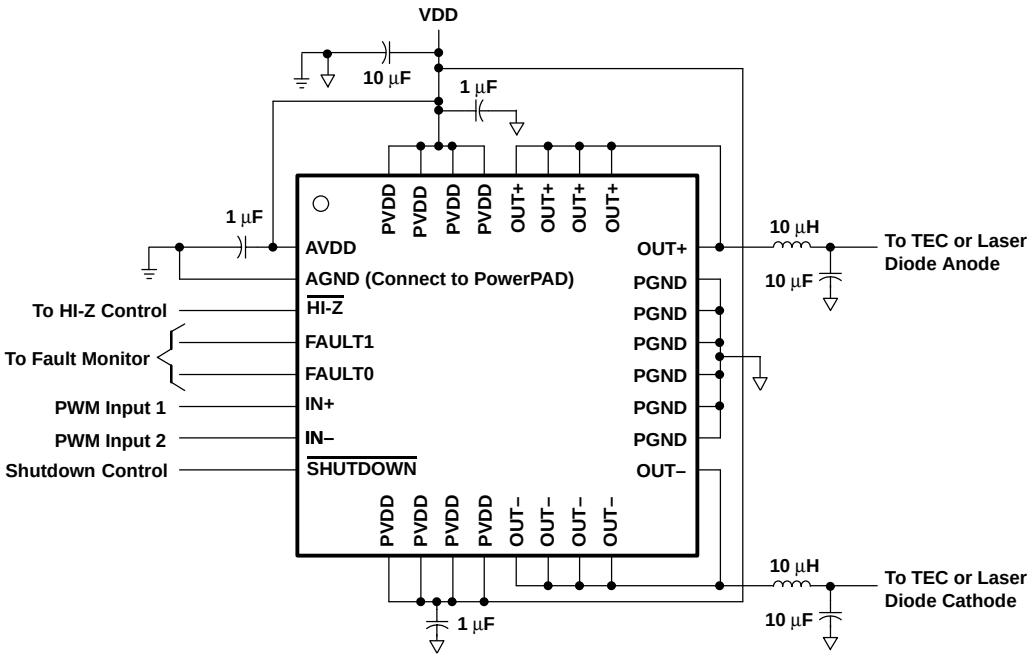
- **Thermoelectric Cooler (TEC) Driver**
- **Laser Diode Biasing**

DESCRIPTION

The DRV592 is a high-efficiency, high-current H-bridge ideal for driving a wide variety of thermoelectric cooler elements in systems powered from 2.8 V to 5.5 V. Low output stage on-resistance significantly decreases power dissipation in the amplifier.

The DRV592 may be driven from any external PWM generator such as a DSP, a microcontroller, or a FPGA. The frequency may vary from dc (i.e., on or off) to 1 MHz. The inputs are compatible with TTL logic levels.

The DRV592 is internally protected against thermal and current overloads. Logic-level fault indicators signal when the junction temperature has reached approximately 130°C to allow for system-level shutdown before the amplifier's internal thermal shutdown circuitry activates. The fault indicators also signal when an over-current event has occurred. If the over-current circuitry is tripped, the DRV592 automatically resets.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PowerPAD is a trademark of Texas Instruments.

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION

T_A	PowerPAD QUAD FLATPACK (VFP)
–40°C to 85°C	DRV592VFP(1)

(1) This package is available taped and reeled. To order this packaging option, add an R suffix to the part number (e.g., DRV592VFPR).

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range unless otherwise noted(1)

	DRV591	UNIT
Supply voltage, AVDD, PVDD	–0.3 to 5.5	V
Input voltage, V_I	–0.3 to V_{DD} + 0.3	V
Output current, I_O (FAULT0, FAULT1)	1	mA
Continuous total power dissipation	See Dissipation Rating Table	
Operating free-air temperature range, T_A	–40 to 85	°C
Operating junction temperature range, T_J	–40 to 150	°C
Storage temperature range, T_{stg}	–65 to 165	°C

(1) Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

		MIN	MAX	UNIT
Supply voltage, AVDD, PVDD		2.8	5.5	V
High-level input voltage, V_{IH}	$\overline{\text{SHUTDOWN}}$, $\overline{\text{HI-Z}}$, IN+, IN–	2		V
Low-level input voltage, V_{IL}	$\overline{\text{SHUTDOWN}}$, $\overline{\text{HI-Z}}$, IN+, IN–		0.8	V
Operating free-air temperature, T_A		–40	85	°C

PACKAGE DISSIPATION RATINGS

PACKAGE	Θ_{JA}(1) (°C/W)	Θ_{JC} (°C/W)	T_A = 25°C POWER RATING
VFP	29.4	1.2	4.1 W

(1) This data was taken using 2 oz trace and copper pad that is soldered directly to a JEDEC standard 4-layer 3 in × 3 in PCB.

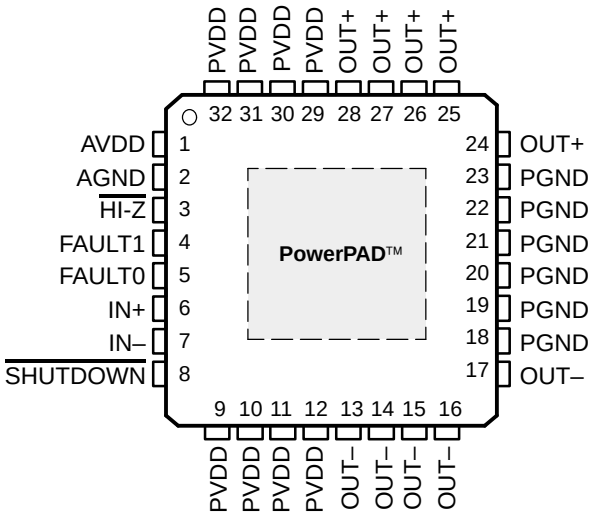
ELECTRICAL CHARACTERISTICS

over operating free-air temperature range unless otherwise noted

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_O	Voltage output (measured differentially)	V_{DD} = 5 V	I_O = ±1 A, $r_{ds(on)}$ = 65 mΩ		4.87		V
			I_O = ±3 A, $r_{ds(on)}$ = 65 mΩ		4.61		
$\|I_{IH}\|$	High-level input current	V_{DD} = 5.5V,	V_I = V_{DD}			1	µA
$\|I_{IL}\|$	Low-level input current	V_{DD} = 5.5V,	V_I = 0 V			1	µA
$r_{DS(on)}$	Output on-resistance	V_{DD} = 5 V, I_O = 4 A, T_A = 25°C	High side	25	60	95	mΩ
			Low side	25	65	95	
		V_{DD} = 3.3 V, I_O = 4 A, T_A = 25°C	High side	25	80	140	mΩ
			Low side	25	90	140	
	Maximum continuous current output				3		A
	Output resistance in shutdown	$\overline{\text{SHUTDOWN}}$ = 0.8 V		1	2	3.5	kΩ
	Switching frequency			0 (dc)		1	MHz
	Status flag output pins (FAULT0, FAULT1) Fault active (open drain output)	Sinking 200 µA				0.1	V
I_q	Quiescent current	V_{DD} = 5 V	No switching	0	0.5	1.5	mA
		V_{DD} = 3.3 V		0	0.3	1	
$I_{q(SD)}$	Quiescent current in shutdown mode	$\overline{\text{SHUTDOWN}}$ = 0.8 V			0.01	50	µA

PIN ASSIGNMENTS

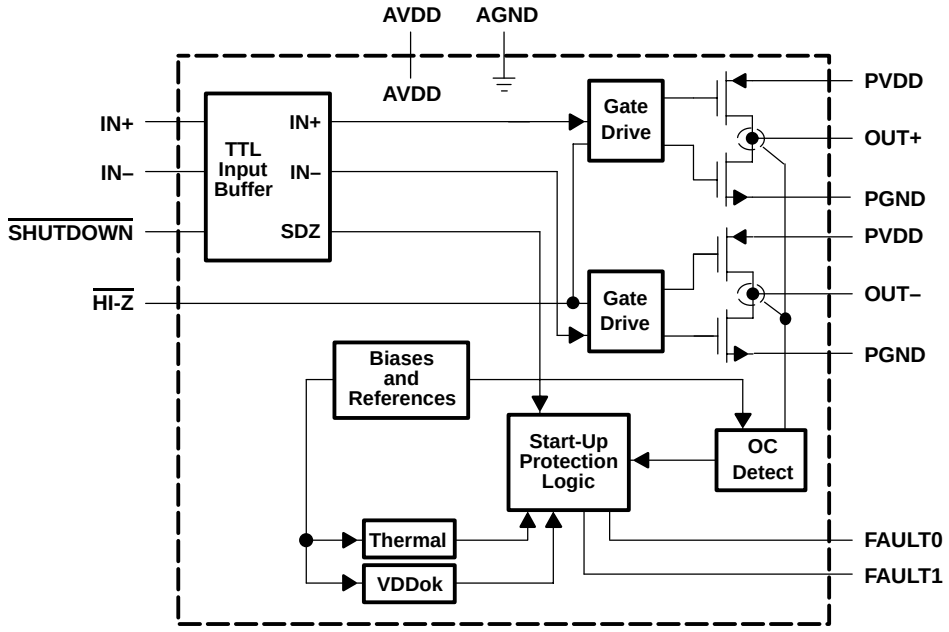
VFP PACKAGE
(TOP VIEW)



Terminal Functions

TERMINAL NAME	TERMINAL NO.	I/O	DESCRIPTION
AGND	2		Analog ground
AVDD	1	I	Analog power supply
FAULT0	5	O	Fault flag 0, low when active open drain output (see application information)
FAULT1	4	O	Fault flag 1, low when active open drain output (see application information)
$\overline{\text{HI-Z}}$	3	I	Places both outputs of the H-bridge into a high-impedance state (2 kΩ to ground) when a TTL logic low is applied to this terminal; normal operation when a TTL logic high is applied.
IN–	7	I	Negative H-bridge input
IN+	6	I	Positive H-bridge input
OUT–	13–17	O	Negative H-bridge output (5 terminals)
OUT+	24–28	O	Positive H-bridge output (5 terminals)
PGND	18–23		High-current ground (6 terminals)
PVDD	9–12, 29–32	I	High-current power supply (8 terminals)
$\overline{\text{SHUTDOWN}}$	8	I	Places the amplifier in shutdown mode when a TTL logic low is applied to this terminal; places the amplifier in normal operation when a TTL logic high is applied

FUNCTIONAL BLOCK DIAGRAM



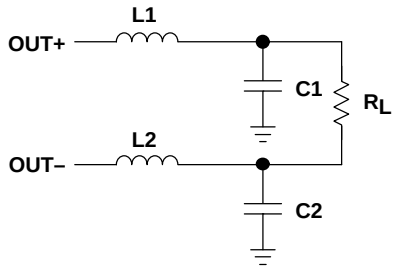
TYPICAL CHARACTERISTICS

TABLE OF GRAPHS

			FIGURE
	Efficiency	vs Load resistance	2, 3
$r_{DS(on)}$	Drain-source on-state resistance	vs Supply voltage	4
		vs Free-air temperature	5
		vs Free-air temperature	6
I_q	Supply current	vs Switching frequency	7
PSRR	Power supply rejection ratio	vs Frequency	8, 9
I_O	Maximum output current	vs Output voltage	10
		vs Ambient temperature	11

TEST SET-UP FOR GRAPHS

The LC output filter used in Figures 2, 3, 8, and 9 is shown below.



L1, L2 = 10 µH (part number: CDRH104R, manufacturer: Sumida)
C1, C2 = 10 µF (part number: ECJ-4YB1C106K, manufacturer: Panasonic)

Figure 1. LC Output Filter

TYPICAL CHARACTERISTICS

EFFICIENCY vs LOAD RESISTANCE

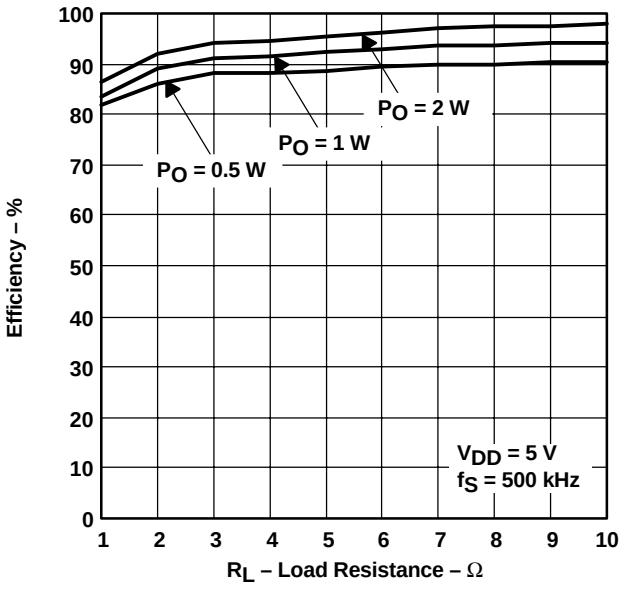


Figure 2

EFFICIENCY vs LOAD RESISTANCE

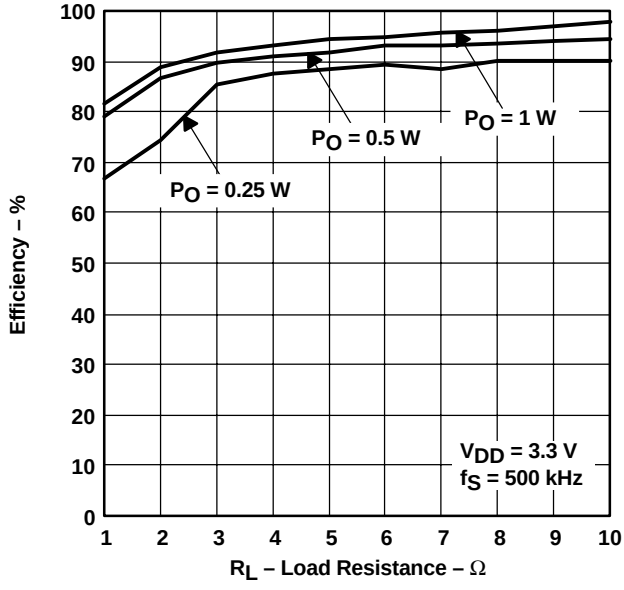


Figure 3

DRAIN-SOURCE ON-STATE RESISTANCE vs SUPPLY VOLTAGE

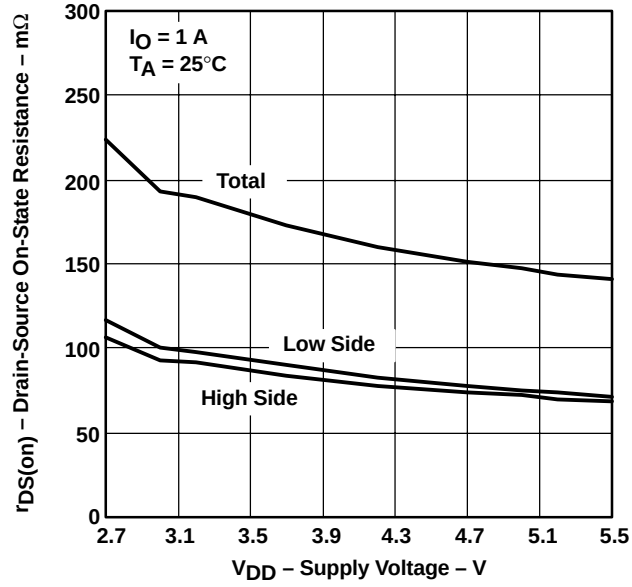


Figure 4

DRAIN-SOURCE ON-STATE RESISTANCE vs FREE-AIR TEMPERATURE

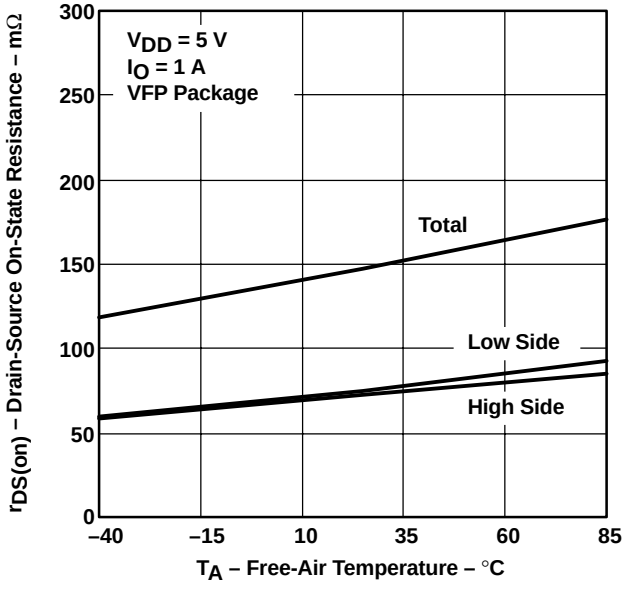


Figure 5

TYPICAL CHARACTERISTICS

DRAIN-SOURCE ON-STATE RESISTANCE vs FREE-AIR TEMPERATURE

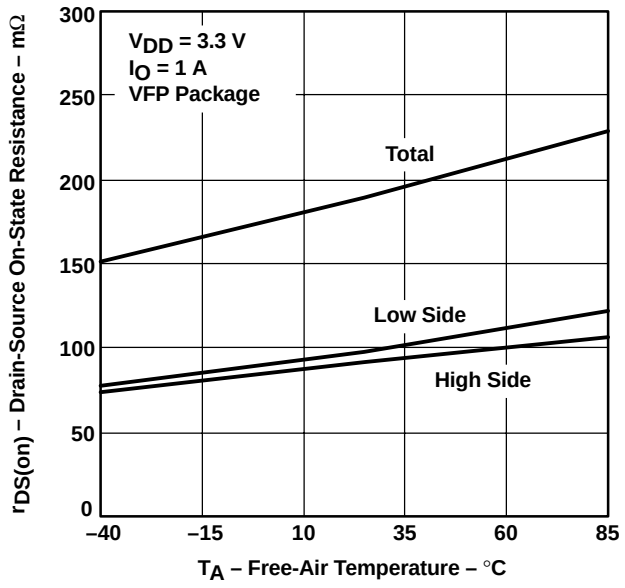


Figure 6

SUPPLY CURRENT vs SWITCHING FREQUENCY

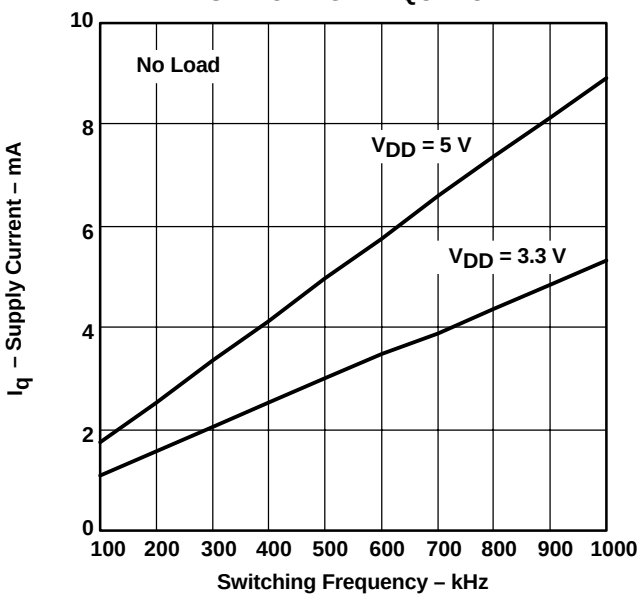


Figure 7

POWER SUPPLY REJECTION RATIO vs FREQUENCY

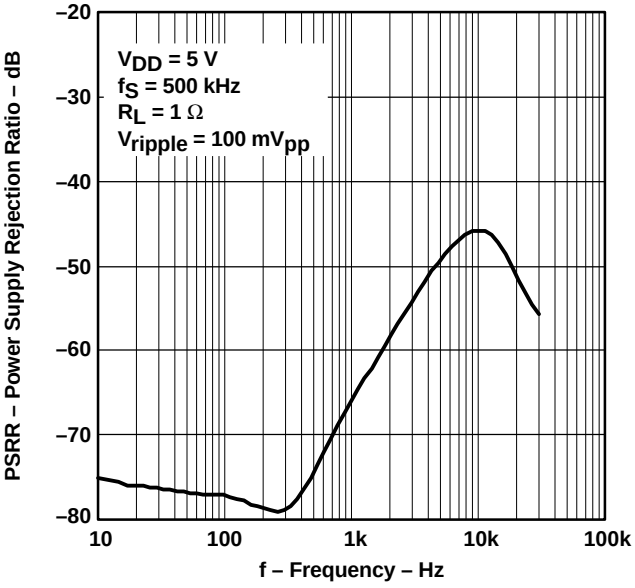


Figure 8

POWER SUPPLY REJECTION RATIO vs FREQUENCY

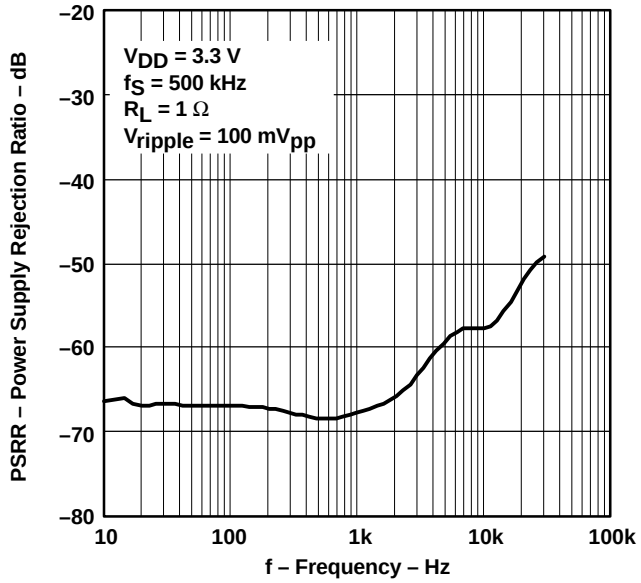


Figure 9

TYPICAL CHARACTERISTICS

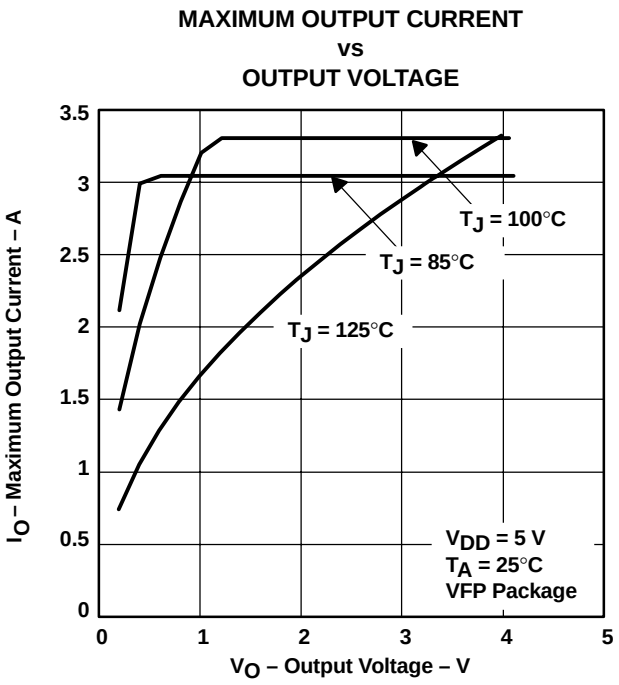


Figure 10

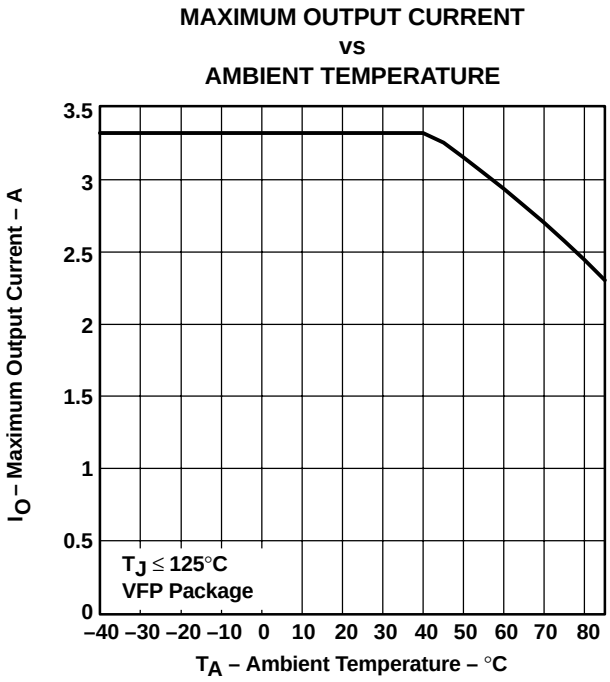


Figure 11

APPLICATION INFORMATION

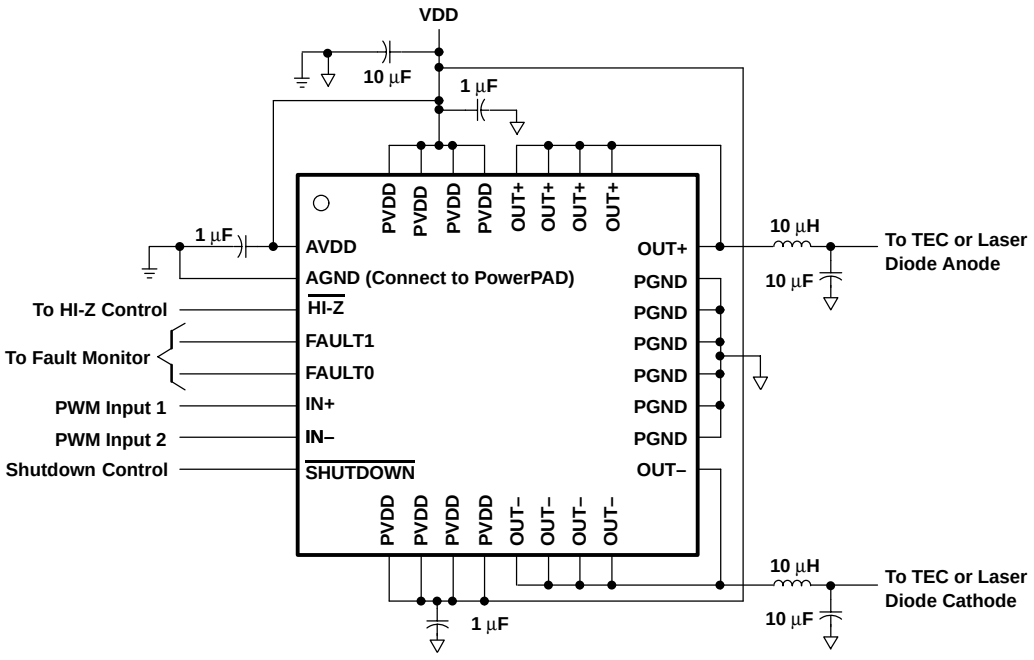


Figure 12. Typical Application Circuit

APPLICATION INFORMATION

DRIVING EXTERNALLY-GENERATED PWM TO THE DRV592 INPUTS

The DRV592 may be simply viewed as a full-H-bridge, with all the gate drive and protection circuitry fully integrated, but with no internal PWM generator.

The inputs may be driven independently with a PWM signal ranging from dc to 1 MHz. The HIGH and LOW levels must be TTL compatible. For example, when a voltage 2 V or higher is applied to IN+, then OUT+ goes to VDD. If a voltage 0.8 V or lower is applied, then the output goes to ground.

Any PWM modulation scheme may be applied to the DRV592 inputs.

OUTPUT FILTER CONSIDERATIONS

TEC element manufacturers provide electrical specifications for maximum dc current and maximum output voltage for each particular element. The maximum ripple current, however, is typically only recommended to be less than 10% with no reference to the frequency components of the current. The maximum temperature differential across the element, which decreases as ripple current increases, may be calculated with the following equation:

$$\Delta T = \frac{1}{\left(1 + N^2\right)} \times \Delta T_{max} \quad (1)$$

Where:

ΔT = actual temperature differential
ΔT_{max} = maximum temperature differential (specified by manufacturer)
N = ratio of ripple current to dc current

According to this relationship, a 10% ripple current reduces the maximum temperature differential by 1%. An LC network may be used to filter the current flowing to the TEC to reduce the amount of ripple and, more importantly, protect the rest of the system from any electromagnetic interference (EMI).

FILTER COMPONENT SELECTION

The LC filter, which may be designed from two different perspectives, both described below, will help estimate the overall performance of the system. The filter should be designed for the worst-case conditions during operation, which is typically when the differential output is at 50% duty cycle. The following section serves as a starting point for the design, and any calculations should be confirmed with a prototype circuit in the lab.

Any filter should always be placed as close as possible to the DRV592 to reduce EMI.

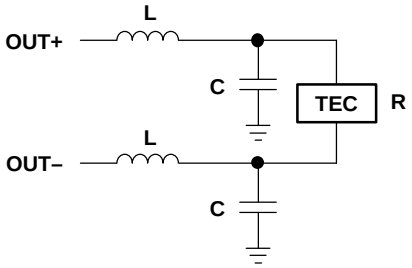


Figure 13. LC Output Filter

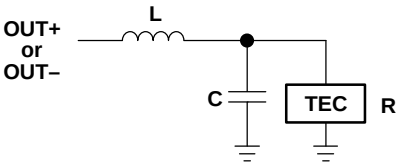


Figure 14. LC Half-Circuit Equivalent

LC FILTER IN THE FREQUENCY DOMAIN

The transfer function for a 2nd order low-pass filter (Figures 13 and 14) is shown in equation (2):

$$H_{LP}(j\omega) = \frac{1}{-\left(\frac{\omega}{\omega_0}\right)^2 + \frac{1}{Q}\frac{j\omega}{\omega_0} + 1} \quad (2)$$

$\omega_0 = \frac{1}{\sqrt{LC}}$

Q = quality factor

ω = DRV592 switching frequency

The resonant frequency for the filter is typically chosen to be at least one order of magnitude lower than the switching frequency. Equation (2) may then be simplified to give the following magnitude equation (3). These equations assume the use of the filter in Figure 13.

$$\left|H_{LP}\right|_{dB} = -40 \log\left(\frac{f_S}{f_o}\right) \quad (3)$$

$f_o = \frac{1}{2\pi\sqrt{LC}}$

f_S = 500 kHz (DRV592 switching frequency)

If L=10 µH and C=10 µF, the resonant frequency is 15.9 kHz, which corresponds to –60 dB of attenuation at the 500 kHz switching frequency. For VDD = 5 V, the amount of ripple voltage at the TEC element is approximately 5 mV.

The average TEC element has a resistance of 1.5 Ω, so the ripple current through the TEC is approximately 3.4 mA. At the 3-A maximum output current of the DRV592, this 3.4 mA corresponds to 0.011% ripple current, causing less than 0.0001% reduction of the maximum temperature differential of the TEC element (see equation 1).

LC FILTER IN THE TIME DOMAIN

The ripple current of an inductor may be calculated using equation (4):

$$\Delta I_L = \frac{\left(V_O - V_{TEC}\right) D T_S}{L} \quad (4)$$

D = duty cycle (0.5 worst case)

$T_S = 1/f_S = 1/500$ kHz

For V_O = 5 V, V_{TEC} = 2.5 V, and L = 10 μH, and a switching frequency of 500 kHz; the inductor ripple current is 250 mA. To calculate how much of that ripple current flows through the TEC element, however, the properties of the filter capacitor must be considered.

For relatively small capacitors (less than 22 μF) with very low equivalent series resistance (ESR, less than 10 mΩ), such as ceramic capacitors, the following equation (5) may be used to estimate the ripple voltage on the capacitor due to the change in charge:

$$\Delta V_C = \frac{\pi^2}{2} (1-D) \left(\frac{f_o}{f_s}\right)^2 V_{TEC} \quad (5)$$

D = duty cycle

f_S = DRV592 switching frequency

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

For L = 10 μH and C = 10 μF, the cutoff frequency, f_o, is 15.9 kHz. For worst case duty cycle of 0.5 and V_{TEC} = 2.5 V, the ripple voltage on the capacitors is 6.2 mV. The ripple current may be calculated by dividing the ripple voltage by the TEC resistance of 1.5 Ω, resulting in a ripple current through the TEC element of 4.1 mA. Note that this is similar to the value calculated using the frequency domain approach.

For larger capacitors (greater than 22 μF) with relatively high ESR (greater than 100 mΩ), such as electrolytic capacitors, the ESR dominates over the charging-discharging of the capacitor. The following simple equation (6) may be used to estimate the ripple voltage:

$$\Delta V_C = \Delta I_L \times R_{ESR} \quad (6)$$

ΔI_L = inductor ripple current

R_{ESR} = filter capacitor ESR

For a 100 μF electrolytic capacitor, an ESR of 0.1 Ω is common. If the 10 μH inductor is used, delivering 250 mA of ripple current to the capacitor (as calculated above), then the ripple voltage is 25 mV. This is over ten times that of the 10 μF ceramic capacitor, as ceramic capacitors typically have negligible ESR.

For worst case conditions, the on-resistance of the output transistors has been ignored to give the maximum theoretical ripple current. In reality, the voltage drop across the output transistors decreases the maximum V_O as the output current increases. It can be shown using equation (4) that this decreases the inductor ripple current, and therefore the TEC ripple current.

POWER SUPPLY DECOUPLING

To reduce the effects of high-frequency transients or spikes, a small ceramic capacitor, typically 0.1 μF to 1 μF, should be placed as close to each set of PVDD pins of the DRV592 as possible. For bulk decoupling, a 10 μF to 100 μF tantalum or aluminum electrolytic capacitor should be placed relatively close to the DRV592.

$\overline{\text{SHUTDOWN}}$ OPERATION

The DRV592 includes a shutdown mode that disables the outputs and places the device in a low supply current state. The $\overline{\text{SHUTDOWN}}$ pin may be controlled with a TTL logic signal. When $\overline{\text{SHUTDOWN}}$ is held high, the device operates normally. When $\overline{\text{SHUTDOWN}}$ is held low, the device is placed in shutdown. The $\overline{\text{SHUTDOWN}}$ pin must not be left floating. If the shutdown feature is unused, the pin may be connected to VDD.

FAULT REPORTING

The DRV592 includes circuitry to sense three faults:

- Overcurrent
- Undervoltage
- Overtemperature

These three fault conditions are decoded via the FAULT1 and FAULT0 terminals. Internally, these are open-drain outputs, so an external pull-up resistor of 5 kΩ or greater is required.

Table 1. Fault Indicators

FAULT1	FAULT0	
0	0	Overcurrent
0	1	Undervoltage
1	0	Overtemperature
1	1	Normal operation

The over-current fault is reported when the output current exceeds four amps. As soon as the condition is sensed, the over-current fault is set and the outputs go into a high-impedance state for approximately 3 μs to 5 μs (500 kHz operation). After 3 μs to 5 μs, the outputs are re-enabled. If the over-current condition has ended, the fault is cleared and the device resumes normal operation. If the over-current condition still exists, the above sequence repeats.

The under-voltage fault is reported when the operating voltage is reduced below 2.8 V. This fault is not latched, so as soon as the power-supply recovers, the fault is cleared

and normal operation resumes. During the under-voltage condition, the outputs are high-impedance to prevent over-dissipation due to increased $r_{DS(on)}$.

The over-temperature fault is reported when the junction temperature exceeds 130°C. The device continues operating normally until the junction temperature reaches 190°C, at which point the IC is disabled to prevent permanent damage from occurring. The system's controller must reduce the power demanded from the DRV592 once the over-temperature flag is set, or else the device switches off when it reaches 190°C. This flag is not latched, once the junction temperature drops below 130°C, the fault is cleared, and normal operation resumes.

POWER DISSIPATION AND MAXIMUM AMBIENT TEMPERATURE

Though the DRV592 is much more efficient than traditional linear solutions, the power drop across the on-resistance of the output transistors does generate some heat in the package, which may be calculated as shown in equation (7):

$$P_{DISS} = \left(I_{OUT}\right)^2 \times r_{DS(on),\ total} \quad (7)$$

For example, at the maximum output current of 3 A through a total on-resistance of 130 mΩ (at T_J = 25°C), the power dissipated in the package is 1.17 W.

The maximum ambient temperature may be calculated using equation (8):

$$T_A = T_J - \left(\theta_{JA} \times P_{DISS}\right) \quad (8)$$

PRINTED-CIRCUIT BOARD (PCB) LAYOUT CONSIDERATIONS

Since the DRV592 is a high-current switching device, a few guidelines for the layout of the printed-circuit board (PCB) must be considered:

1. **Grounding.** Analog ground (AGND) and power ground (PGND) must be kept separated, ideally back to where the power supply physically connects to the PCB, minimally back to the bulk decoupling capacitor (10 μF ceramic minimum). Furthermore, the PowerPAD ground connection should be made to AGND, not PGND. Ground planes are not recommended for AGND or PGND. Wide traces (100 mils) should be used for PGND while narrow traces (15 mils) should be used for AGND.

2. **Power supply decoupling.** A small 0.1-μF to 1-μF ceramic capacitor should be placed as close to each set of PVDD pins as possible, connecting from PVDD to PGND. A 0.1-μF to 1-μF ceramic capacitor should also be placed close to the AVDD pin, connecting from AVDD to AGND. A bulk decoupling capacitor of at least 10 μF, preferably ceramic, should be placed close to the DRV592, from PVDD to PGND.

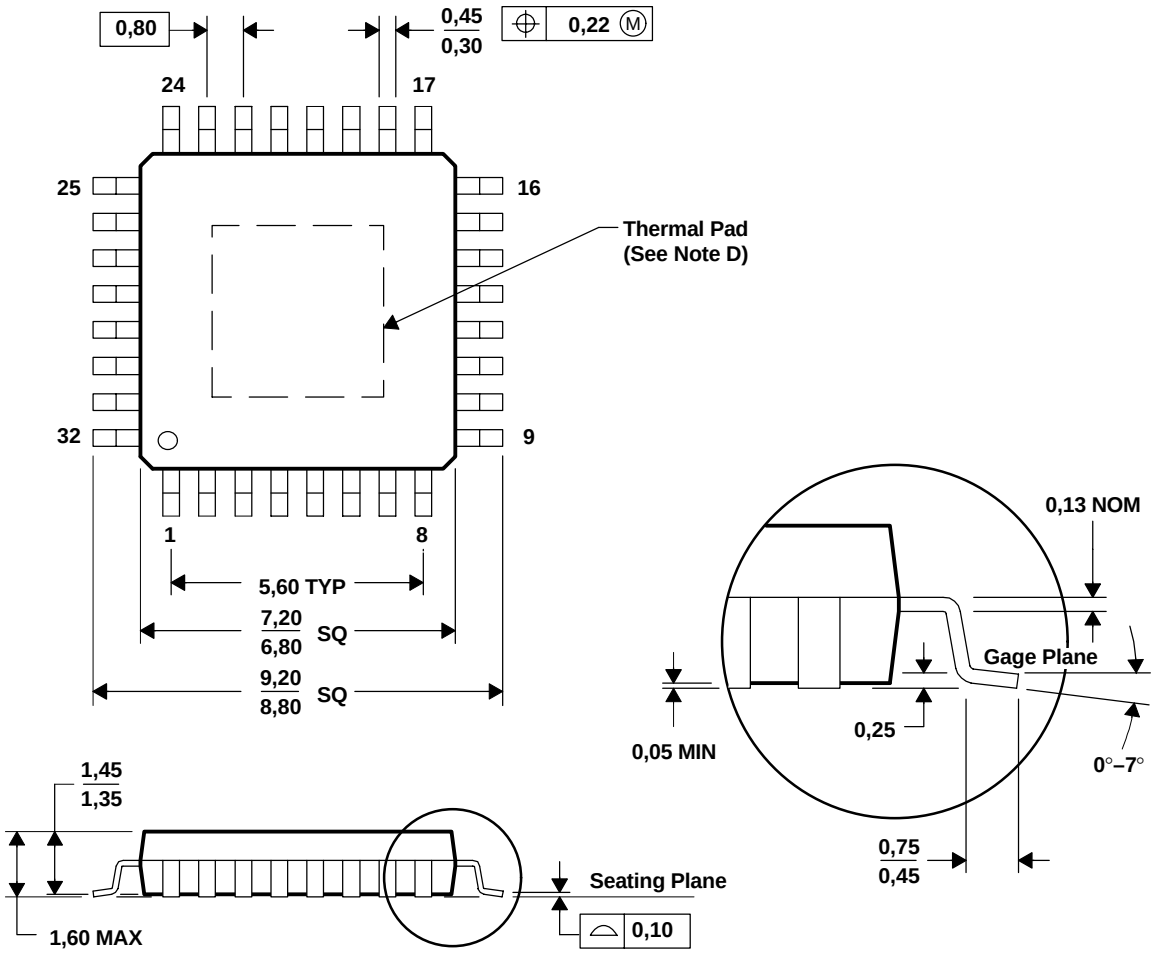
3. **Power and output traces.** The power and output traces should be sized to handle the desired maximum output current. The output traces should be kept as short as possible to reduce EMI, i.e., the output filter should be placed as close as possible to the DRV592 outputs.

4. **PowerPAD.** The DRV592 in the Quad Flatpack package uses TI's PowerPAD technology to enhance the thermal performance. The PowerPAD is physically connected to the substrate of the DRV592 silicon, which is connected to AGND. The PowerPAD ground connection should therefore be kept separate from PGND as described above. The pad underneath the AGND pin may be connected underneath the device to the PowerPAD ground connection for ease of routing. For additional information on PowerPAD PCB layout, refer to the *PowerPAD Thermally Enhanced Package* application note, TI literature number SLMA002.

5. **Thermal performance.** For proper thermal performance, the PowerPAD must be soldered down to a thermal land, as described in the *PowerPAD Thermally Enhanced Package* application note, TI literature number SLMA002. In addition, at high current levels (greater than 2 A) or high ambient temperatures (greater than 25°C), an internal plane may be used for heat sinking. The vias under the PowerPAD should make a solid connection, and the plane should not be tied to ground except through the PowerPAD connection, as described above.

MECHANICAL DATA

VFP (S-PQFP-G32) **PowerPAD™ PLASTIC QUAD FLATPACK**



NOTES:A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion.
D. The package thermal performance may be enhanced by bonding the thermal pad to an external thermal plane.
This pad is electrically and thermally connected to the backside of the die and possibly selected leads.
E. Falls within JEDEC MS-026

PowerPAD is a trademark of Texas Instruments.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
DRV592VFP	ACTIVE	HLQFP	VFP	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
DRV592VFPG4	ACTIVE	HLQFP	VFP	32		TBD	Call TI	Call TI

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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