

### Features

- 18V to 36V Input Voltage Range
- Programmable Output Voltage Range: 6.5V to 17.5V
- -40° to +85°C Ambient
- 1500 VDC Isolation
- 89% Efficiency
- On/Off Inhibit
- Differential Remote Sense
- 17A Output with PT4493
- Over-Current Protection
- Over-Temperature Protection
- Over-Voltage Protection
- Space-Saving Package
- Solderable Copper Case
- Safety Approvals:
  - UL 60950
  - CSA 22.2 950
  - VDE EN60950 Pending

### Description

The PT4476 Excalibur™ DC/DC converter module combines state-of-the-art power conversion technology with un-paralleled flexibility. Incorporating high efficiency and ultra-fast transient response, these modules provide up to 8.5A of output current over the programmable voltage range of 6.5V to 17.5V.

The modules include a number of inbuilt features to facilitate system integration. These include a foldback output current limit, over-temperature protection, and an inhibit on/off control. A differential remote sense is also provided to compensate for voltage drop between the converter and load.

For additional output current, one PT4476 may be operated with up to two PT4493 compatible booster modules. Each PT4493 adds an additional 8.5A of output current capability.

### Ordering Information

PT4476□ = 6.5 to 17.5 Volts  
PT4493□ = 8.5-A Booster

### PT Series Suffix (PT1234 x)

Case/Pin Configuration	Order Suffix	Package Code *
Vertical	<b>N</b>	(EKD)
Horizontal	<b>A</b>	(EKA)
SMD	<b>C</b>	(EKC)

\* Previously known as package styles 1200, 1210, and 1215.

(Reference the applicable package code drawing for the dimensions and PC board layout)

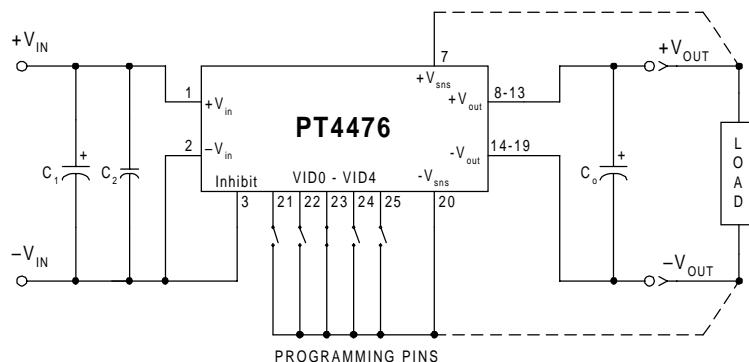
### Pin-Out Information

Pin	Function	Pin	Function
1	+V <sub>in</sub>	14	-V <sub>out</sub>
2	-V <sub>in</sub>	15	-V <sub>out</sub>
3	Inhibit	16	-V <sub>out</sub>
4	V <sub>r</sub> †	17	-V <sub>out</sub>
5	V <sub>a</sub> †	18	-V <sub>out</sub>
6	Do not connect	19	-V <sub>out</sub>
7	(+)Remote Sense	20	(-)Remote Sense
8	+V <sub>out</sub>	21	VID0
9	+V <sub>out</sub>	22	VID1
10	+V <sub>out</sub>	23	VID2
11	+V <sub>out</sub>	24	VID3
12	+V <sub>out</sub>	25	VID4
13	+V <sub>out</sub>	26	DRV †

† Pins 4, 5, & 26 are used for booster applications. For stand-alone operation, leave open circuit.

• Shaded functions indicate those pins that are referenced to primary-side potential.

### Standard Application



- C<sub>o</sub> = Optional 33μF electrolytic capacitor
- C<sub>1</sub> = Optional 33μF, 50V electrolytic capacitor
- C<sub>2</sub> = Optional 1μF, 50V ceramic capacitor
- Programming pins, VID0–VID4, are shown configured for V<sub>o</sub> = 12V
- For normal operation, pin 3 (Inhibit) must be connected to -Vin.

Programming Information

VID3	VID2	VID1	VID0	VID4=1 Vout	VID4=0 Vout
1	1	1	1	10.0V	6.50V
1	1	1	0	10.5V	6.75V
1	1	0	1	11.0V	7.00V
1	1	0	0	11.5V	7.25V
1	0	1	1	12.0V	7.50V
1	0	1	0	12.5V	7.75V
1	0	0	1	13.0V	8.00V
1	0	0	0	13.5V	8.25V
0	1	1	1	14.0V	8.50V
0	1	1	0	14.5V	8.75V
0	1	0	1	15.0V	9.00V
0	1	0	0	15.5V	9.25V
0	0	1	1	16.0V	9.50V
0	0	1	0	16.5V	9.75V
0	0	0	1	17.0V	10.00V
0	0	0	0	17.5V	10.25V

Logic 0 = Connect to (-)Remote Sense, pin 20  
 Logic 1 = Open circuit (no pull-up resistors)  
 VID3 & VID4 must not be changed while the unit is operating.

PT4470 Series Comparison

	Functionality	Output Voltage Program Range	Configuration for Current Sharing
<b>PT4471</b>	Regulator	1.3V– 3.5V	N+1 with other PT4471s
<b>PT4472</b>	Regulator	1.3V– 3.5V	With PT4495 boosters
<b>PT4495</b>	PT4472 Booster	N/A	Used only with PT4472
<b>PT4473</b>	Regulator	4.6V–5.7V	N+1 with other PT4473s
<b>PT4474</b>	Regulator	4.6V–5.7V	With PT4494 boosters
<b>PT4494</b>	PT4474 Booster	N/A	Used only with PT4474
<b>PT4475</b>	Regulator	6.5V– 17.5V	N+1 with other PT4475s
# <b>PT4476</b>	Regulator	6.5V–17.5V	With PT4493 boosters
# <b>PT4493</b>	PT4476 Booster	N/A	Used only with PT4476

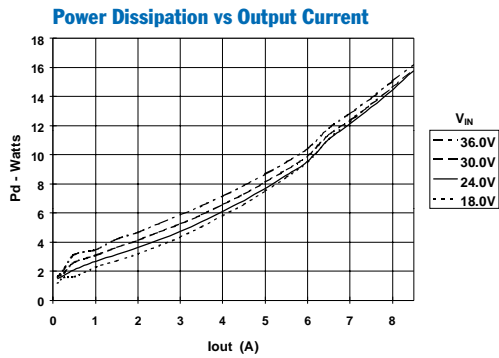
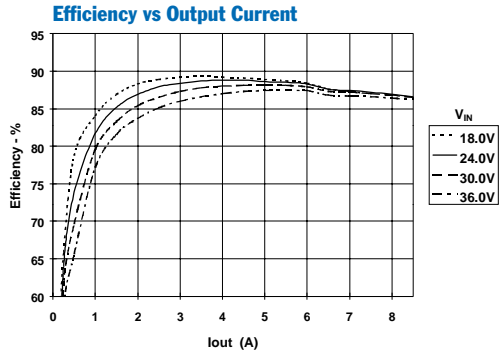
# This specification covers only the PT4476 regulator and PT4493 current booster.

Specifications (Unless otherwise stated, T<sub>a</sub> =25°C, V<sub>in</sub> =24V, V<sub>o</sub> =12V, C<sub>o</sub> =0μF, and I<sub>o</sub> =I<sub>o</sub>max)

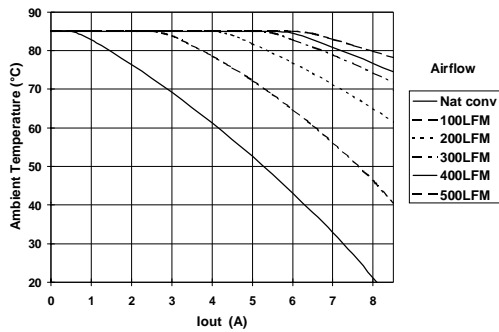
Characteristic	Symbol	Conditions	PT4476			Units	
			Min	Typ	Max		
Output Current	I <sub>o</sub>	Over V <sub>in</sub> range	0	—	8.5 (1)	A	
Input Voltage Range	V <sub>in</sub>	Over I <sub>o</sub> Range	18	24	36	VDC	
Set Point Voltage Tolerance	V <sub>o</sub> tol		—	±1	±1.5	%V <sub>o</sub>	
Temperature Variation	Reg <sub>temp</sub>	-40° ≤ T <sub>case</sub> ≤ +100°C, I <sub>o</sub> =0	—	±0.5	—	%V <sub>o</sub>	
Line Regulation	Reg <sub>line</sub>	Over V <sub>in</sub> range	—	±0.1	±1	%V <sub>o</sub>	
Load Regulation	Reg <sub>load</sub>	Over I <sub>o</sub> range	—	±0.5	±1	%V <sub>o</sub>	
Total Output Voltage Variation	ΔV <sub>o</sub> tot	Includes set-point, line, load, -40° ≤ T <sub>case</sub> ≤ +100°C	—	±2	±3	%V <sub>o</sub>	
Efficiency	η	I <sub>o</sub> =5A	—	89	—	%	
V <sub>o</sub> Ripple (pk-pk)	V <sub>r</sub>	20MHz bandwidth	—	120	150	mV <sub>pp</sub>	
Transient Response	t <sub>tr</sub>	0.1A/μs load step, 50% to 75% I <sub>o</sub> max	—	N/A	—	μs	
	ΔV <sub>tr</sub>	V <sub>o</sub> over/undershoot	—	1	—	%V <sub>o</sub>	
Current Limit	I <sub>lim</sub>	1A/μs load step, 50% to 100% I <sub>o</sub> max	—	200	—	μs	
		V <sub>o</sub> over/undershoot	—	±5	—	%V <sub>o</sub>	
Current Share Tolerance	I <sub>shr</sub> tol	V <sub>in</sub> =18V, ΔV <sub>o</sub> = -1% foldback continuous limit	—	10	—	A	
Over-Voltage Protection	OVP	with PT4493 booster	—	±10	—	%	
Switching Frequency	f <sub>s</sub>	Shutdown and latch off	—	125	—	%V <sub>o</sub>	
Under-Voltage Lockout	UVLO	Over V <sub>in</sub> range	270	300	350	kHz	
Inhibit (Pin 3)	Input High Voltage Input Low Voltage Input Low Current	Referenced to -V <sub>in</sub> (pin 2)	—	17	—	V	
			V <sub>IH</sub>	2.5	—	Open (2)	V
			V <sub>IL</sub>	-0.5	—	+0.8	
Standby Input Current	I <sub>in</sub> standby	I <sub>IL</sub>	—	-0.2	—	mA	
Internal Input Capacitance	C <sub>in</sub>	I <sub>in</sub> standby pins 3 & 2 connected	—	4	10	mA	
External Output Capacitance	C <sub>out</sub>	C <sub>in</sub>	—	3	—	μF	
Isolation Voltage	—	C <sub>out</sub>	0	—	10,000	μF	
Capacitance Resistance	—	Between +V <sub>o</sub> and -V <sub>o</sub>	1500	—	—	V	
		Input-output/input-case	—	1100	—	pF	
		Input to output	10	—	—	MΩ	
Operating Temperature Range	T <sub>c</sub>	Input to output	-40	—	+100 (3)	°C	
Over-Temperature Shutdown	OTP	Case temperature, over V <sub>in</sub> range	—	110	—	°C	
Storage Temperature	T <sub>s</sub>	Case temperature, auto reset	-40	—	+125	°C	
Reliability	MTBF	T <sub>s</sub>	—	—	—	°C	
Mechanical Shock	—	Per Bellcore TR-332 50% stress, T <sub>a</sub> =40°C, ground benign	1.7	—	—	10 <sup>6</sup> Hrs	
		Per Mil-Std-883D, method 2002.3, 1mS, half-sine, mounted to a fixture	—	500	—	G's	
Mechanical Vibration	—	Mil-Std-883D, Method 2007.2 20-2000Hz, pcb mounted	—	20 (4)	—	G's	
Weight	—	—	—	90	—	grams	
Flammability	—	Materials meet UL 94V-0	—	—	—	—	

- Notes:** (1) The maximum output current is limited to 8.5A or 100/V<sub>OUT</sub>, whichever is less.  
 (2) The Inhibit (pin 3) has an internal pull-up, which if left open circuit allows the converter to operate when input power is applied. The open-circuit is limited to 6.5V. Refer to the application notes for interface considerations.  
 (3) See Safe Operating Area curves or contact the factory for the appropriate derating.  
 (4) The case pins on through-hole pin configuration (suffix A) must be soldered. For more information see the applicable package outline drawing.

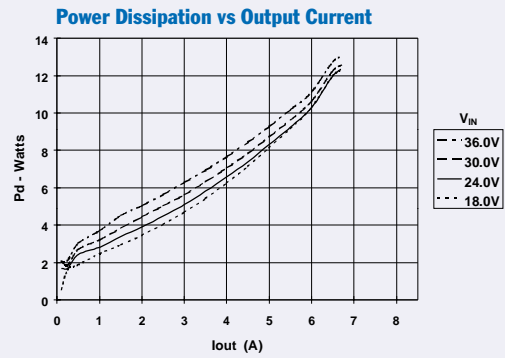
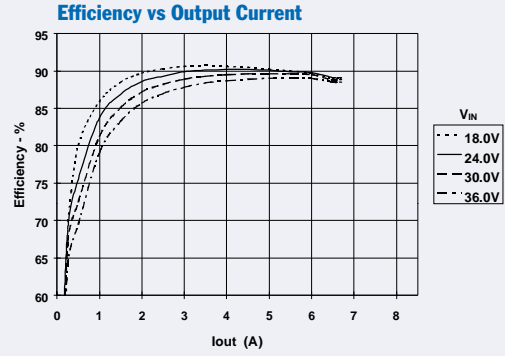
**Performance Characteristics,  $V_o = 12V$**  (See Note A)



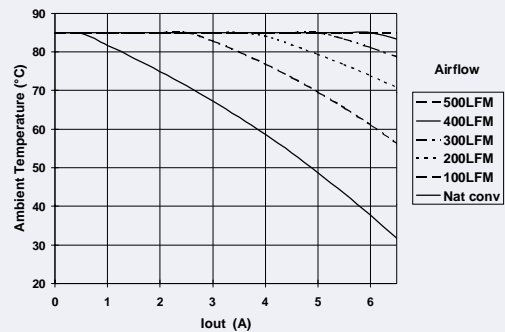
**Safe Operating Area,  $V_o = 12V, V_{in} = 24V$**  (See Note B)



**Performance Characteristics,  $V_o = 15V$**  (See Note A)



**Safe Operating Area,  $V_o = 15V, V_{in} = 24V$**  (See Note B)



**Note A:** Characteristic data has been developed from actual products tested at 25°C. This data is considered typical data for the Converter.

**Note B:** SOA curves represent the conditions at which internal components are at or below the manufacturer's maximum operating temperatures

## Increasing the Output Current of the PT4476 with the PT4493 Compatible Current Booster

The PT4493 is a 8.5-A “Current Booster” module designed specifically for the PT4476 programmable DC/DC converter. The booster is controlled directly by the regulator, and effectively adds an additional output stage that operates in parallel. This allows the system to run synchronously, providing a low noise solution. Up to two booster modules can be connected to a PT4476 converter. Each booster module increases the available output current by 8.5A. A combination of one PT4476 converter and two PT4493 booster modules can supply up to 25.5A of output current; enough power to supply a moderately sized rack-mounted system. Figure 1-1 shows the connection schematic for the regulator and current booster combination.

A current booster is not a stand-alone product, and can only operate with a regulator. It is housed in the same package as its compatible regulator, and shares the same mechanical outline. Except for an increase in output current, the overall performance of a converter/booster combination is identical to that of a stand-alone converter.

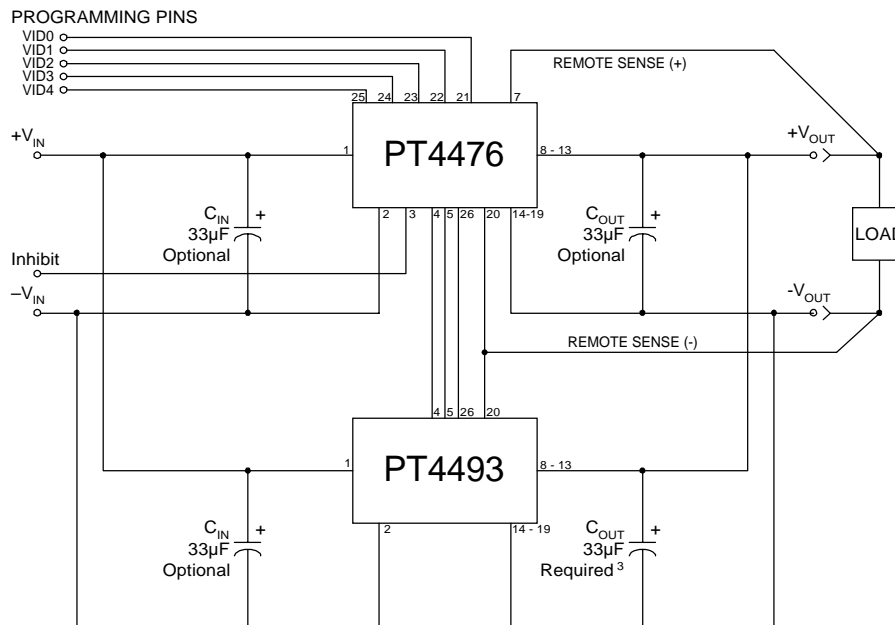
### Notes:

1. Refer to the PT4476 specification table for the performance of the regulator/booster combination.
2. The pin-out of the current booster modules include a number pins identified, “Do not connect” (see Table 1-1). These pins are not connected internally to the module but must be soldered to a pad to preserve the unit’s mechanical integrity.
3. A minimum of 33µF of output capacitance is required across the output of each PT4493 booster for proper operation. A value greater than 33µF will further reduce transients due to large and/or fast load steps.
4. **The converter and all boosters must be located on the same printed circuit board.** A similar footprint and trace layout for each module will also facilitate current sharing.

**Table 1-1; Booster Pin-Out Information**

Pin	Function	Pin	Function	Pin	Function
1	+V <sub>in</sub>	10	+V <sub>out</sub>	19	-V <sub>out</sub>
2	-V <sub>in</sub>	11	+V <sub>out</sub>	20	(-)V <sub>sense</sub>
3	Do not connect	12	+V <sub>out</sub>	21	Do not connect
4	V <sub>r</sub>	13	+V <sub>out</sub>	22	Do not connect
5	V <sub>a</sub>	14	-V <sub>out</sub>	23	Do not connect
6	Do not connect	15	-V <sub>out</sub>	24	Do not connect
7	Do not connect	16	-V <sub>out</sub>	25	Do not connect
8	+V <sub>out</sub>	17	-V <sub>out</sub>	26	DRV
9	+V <sub>out</sub>	18	-V <sub>out</sub>		

**Figure 1-1; Current Booster Application Schematic**



## Operating Features of the PT4470 and PT4480 Series of Isolated DC/DC Converters

### Under-Voltage Lockout

An Under-Voltage Lock-Out (UVLO) inhibits the operation of the converter until the input voltage is above the UVLO threshold (see the applicable data sheet specification). Below this voltage, the module's output is held off, irrespective of the state of the *Inhibit* control (pin 3). If the *Inhibit* control is connected to  $-V_{in}$  (pin 2), the module will automatically power up when the input voltage rises above the UVLO threshold. The UVLO allows the module to produce a clean transition during both power-up and power-down, even when the input voltage is rising or falling slowly. It also reduces the high start-up current during normal power-up of the converter, and minimizes the current drain from the input source during low-input voltage conditions. The UVLO threshold includes about 2V of hysteresis. Once operational, the converter will conform to its operating specifications when the minimum specified input voltage is reached.

### Over-Current Protection

To protect against load faults, the PT4470/80 series of DC/DC converters incorporate an output current limit. Once the load current drawn from the module reaches the current limit threshold, any attempt by the load to draw additional current will result in a significant drop in the module's regulated output voltage. The current limit circuitry incorporates a limited amount of foldback. This has the effect of slightly reducing the output current from the module when supplying an absolute short circuit. Upon removal of the load fault, the output voltage from the converter will automatically recover to its programmed regulation voltage.

### Output Over-Voltage Protection

The PT4470/80 series of DC/DC converters incorporate circuitry that continually senses the output for an over-voltage (OV) condition. The OV threshold automatically tracks the VID output voltage program setting to a level 25% higher than that programmed at the control pins, VID0 through VID4. If the converter output voltage exceeds the OV threshold, the converter is immediately shut down and remains in a latched-off state. To resume normal operation the converter must be actively reset. This is accomplished by either cycling the status of the *Inhibit* control (pin 3) from "On" to "Off" and then back "On" again, or by momentarily removing the input power to the converter. For failsafe operation and redundancy, the OV protection uses circuitry that is independent of the converter's internal feedback loop.

### Over-Temperature Protection

Over-temperature protection is provided by an internal temperature sensor, which closely monitors the temperature of the converter's metal case. If the case temperature exceeds the specified limit (see applicable data sheet), the converter will shut down. The converter will then automatically restart when the sensed temperature drops by about 10°C. When operated outside its recommended thermal derating envelope (see data sheet SOA curves), the converter will typically cycle on and off at intervals from a few seconds to one or two minutes. This is to ensure that the internal components are not permanently damaged from excessive thermal stress.

### Primary-Secondary Isolation

Electrical isolation is provided between the input terminals (primary) and the output terminals (secondary). All converters are production tested to a primary-secondary withstand voltage of 1500VDC. This specification complies with UL60950 and EN60950 and the requirements for operational isolation. Operational isolation allows these converters to be configured for either a positive or negative input voltage source. The data sheet 'Pin-Out Information' uses shading to indicate which pins are associated with the primary. They include pins 1 through 5, inclusive.

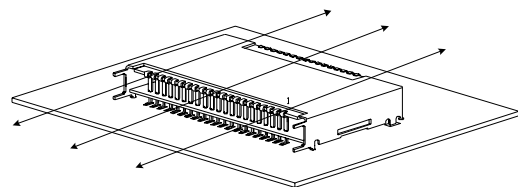
### Fuse Recommendations

If desired, an input fuse may be added to protect against the application of a reverse input voltage.

### Thermal Considerations

Airflow may be necessary to ensure that the module can supply the desired load current in environments with elevated ambient temperatures. The required airflow rate may be determined from the Safe Operating Area (SOA) thermal derating chart (see converter specifications). The recommended direction for airflow is into the longest side of the module's metal case. See Figure 1.

Figure 1



Recommended direction for airflow is into (perpendicular to) the longest side.

## Using the Inhibit Function on the PT4470 & PT4480 Series of Isolated DC/DC Converters

The PT4470/44480 series of DC/DC converters incorporate an On/Off Inhibit function. This function may be used in applications that demand battery conservation, power-up/shutdown sequencing, and/or to coordinate power-up for active in-rush current control.

The On/Off feature is provided by the *Inhibit* control, pin 3. The *Inhibit* pin of the PT4470/4480 series of converters is an active low enable. The pin must be either connected, or actively pulled low, to  $-V_{in}$  (pin 2) to enable the converter output (see standard application schematic). When pins 2 & 3 are connected, the converter provides a regulated output whenever a valid source voltage<sup>3</sup> is applied between  $+V_{in}$  (pin 1), and  $-V_{in}$  (pin 2). If pin 3 is disconnected, or allowed to become high impedance, the regulator output will be disabled.<sup>5</sup>

Table 2-1 provides details of the interface requirements for the *Inhibit* pin. Figure 2-1 shows how a discrete MOSFET ( $Q_1$ )<sup>4</sup>, may be referenced to  $-V_{in}$  and used to control the input.

**Table 2-1 Inhibit Control Requirements**

Parameter	Min	Max
Enable ( $V_{IH}$ )	-0.5V	0.8V
Disable ( $V_{IL}$ )	2.5V	(Open Circuit)

**Notes:**

1. The *Inhibit* control uses  $-V_{in}$  (pin 2), on the primary side of the converter, as its ground reference. All voltages specified are with respect to  $-V_{in}$ .
2. The internal circuitry is simple pull-up resistor. The open-circuit voltage may be as high as 6.5Vdc.
3. These converters incorporate an “Under-Voltage Lockout” (UVLO) function. This function automatically disables the converter output until there is sufficient input voltage to produce a regulated output. Table 2 gives the applicable UVLO thresholds.

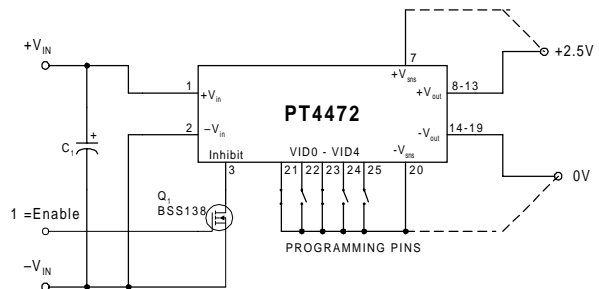
**Table 2-2 UVLO Thresholds<sup>1</sup>**

Series	UVLO Threshold	$V_{in}$ Range
PT4470	17.0V Typical	18 – 36V
PT4480	34.5V Typical	36 – 75V

4. The *Inhibit* input must be controlled with an open-collector (or open-drain) discrete transistor or MOSFET. Do not use a pull-up resistor.
5. When the converter output is disabled, the current drawn from the input supply is typically reduced to 4mA (10mA maximum).

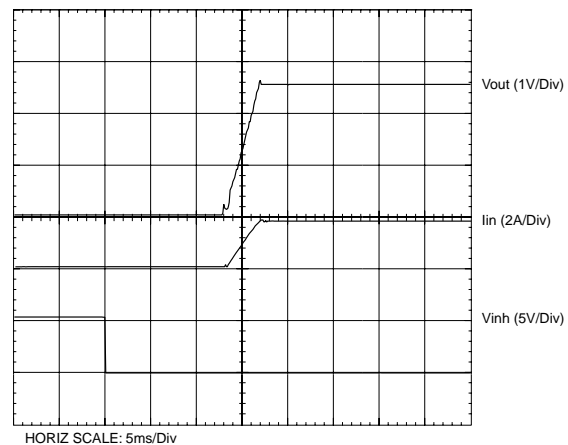
6. Keep the on/off transition to less than 1ms. This prevents erratic operation of the ISR, whereby the output voltage may drift un-regulated between 0V and the rated output during power-up.

**Figure 2-1**



**Turn-On Time:** With input power applied, the converter typically produces a fully regulated output voltage within 25ms after applying a low-voltage signal to the *Inhibit* control pin. The actual turn-on time will vary with the input voltage, output load, and the total amount of capacitance connected to the output. Using the circuit of Figure 2-1, Figure 2-2 shows the typical output voltage and input current waveforms of a PT4472 after  $Q_1$  is turned on. The turn on of  $Q_1$  correlates to the fall in  $V_{inh}$ . The output voltage was set to 2.5V. The waveform was measured with a 48-Vdc input voltage, and 15-A load current.

**Figure 2-2**



**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
PT4476A	NRND	SIP MOD ULE	EKA	26	6	TBD	Call TI	Level-1-215C-UNLIM

<sup>(1)</sup> 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.

<sup>(2)</sup> 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)

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

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