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PT6510 Series

**8-A 5-V/3.3-V Input Adjustable ISR
with Short-Circuit protection**

SLTS220 FEBRUARY 2004



Features

- 8-A Rated Output Current
- Replaces PT6500 Series
- High Efficiency (91% for PT6511)
- Small Footprint (0.75 in², Suffix 'N')
- Output On/Off Standby Control
- Output Short-Circuit Protection
- Over-Temperature Protection
- Adjustable Output Voltage
- Soft Startup
- 16-pin Mount Option (Suffixes L & F)

Description

The PT6510 series of power modules is the recommended direct replacement for the PT6500 series in existing designs. The modules have the same output current rating as the PT6500 series (8 A) and were designed to be functionally identical in as many aspects as possible. This includes the input voltage range, on/off standby control, and output voltage adjustment.

When used as a replacement, a PT6510 series part exhibits a number of performance enhancements over its PT6500 series equivalent. These include improved power dissipation and efficiency, significantly reduced inrush current, and better line and load regulation.

The modules are housed in the same 14-Pin SIP (Single In-line Package), and include the same package options.

Ordering Information

PT6511□	= 3.3 Volts
† PT6512□	= 1.5 Volts
PT6513□	= 2.5 Volts
PT6514□	= 3.6 Volts
† PT6515□	= 1.2 Volts
† PT6516□	= 1.8 Volts

† 3.3V Input Bus Capable

PT Series Suffix (PT1234x)

Case/Pin Configuration	Order Suffix	Package Code *
Vertical	N	(EED)
Horizontal	A	(EEA)
SMD	C	(EEC)
Horizontal, Top Tab	H	(EEH)
SMD, 2-Pin Tab	L	(EEL)
SMD, 2-Pin Ext Tab	F	(EEF)
Vertical, Side Tab	R	(EEE)
Horizontal, Side Tab	G	(EEG)
SMD, Side Tab	B	(EEK)

* Previously known as package styles 400/410.

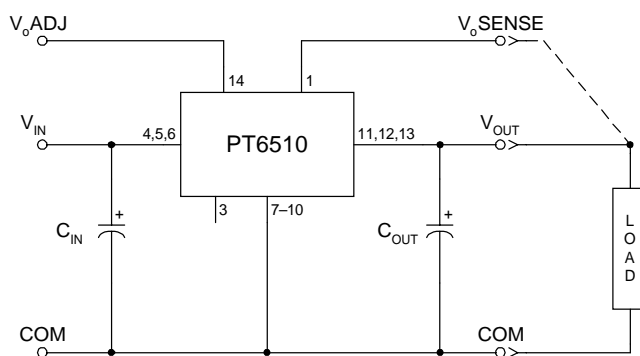
(Package availability varies with output voltage option. Reference the applicable package code drawing for the dimensions and PC board layout)

Pin-Out Information

Pin	Function
1	V _o Sense
2	Do Not Connect
3	STBY*
4	V _{in}
5	V _{in}
6	V _{in}
7	GND
8	GND
9	GND
10	GND
11	V _{out}
12	V _{out}
13	V _{out}
14	V _{out} Adjust

* For further information, see application notes.

Standard Application



C_{in} = Required 330 µF electrolytic capacitor.
C_{out} = Required 330 µF electrolytic capacitor.

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Specifications (Unless otherwise stated, $T_a = 25^\circ\text{C}$, $V_{in} = 5\text{ V}$, $C_{in} = 330\text{ }\mu\text{F}$, $C_{out} = 330\text{ }\mu\text{F}$, and $I_o = I_{o,max}$)

Characteristic	Symbol	Conditions	PT6510 SERIES			Units
			Min	Typ	Max	
Output Current	I_o	Over V_{in} range	0.1 ⁽¹⁾	—	8	A
Input Voltage Range	V_{in}	Over I_o Range	$V_o \geq 2.5\text{ V}$	4.5 ⁽²⁾	—	VDC
			$V_o \leq 1.8\text{ V}$	3.1 ⁽²⁾	6	
			$V_o = 3.6\text{ V}$	4.8 ⁽²⁾	6	
				—	6	
Output Voltage Tolerance	$V_o\text{ tol}$	$T_a = -40\text{ to }+85^\circ\text{C}$	$V_o - 0.1$	—	$V_o + 0.1$	V
Line Regulation	Reg_{line}	Over V_{in} range	± 2	—	± 10	mV
Load Regulation	Reg_{load}	Over I_o range	± 2	—	± 10	mV
Efficiency	η	$I_o = 3\text{ A}$	$V_o = 3.3\text{ V}$	—	92	%
			$V_o = 2.5\text{ V}$	—	89	
			$V_o = 1.8\text{ V}$	—	83	
			$V_o = 1.5\text{ V}$	—	80	
			$V_o = 1.2\text{ V}$	—	75	
		$I_o = 8\text{ A}$	$V_o = 3.3\text{ V}$	—	91	%
			$V_o = 2.5\text{ V}$	—	87	
			$V_o = 1.8\text{ V}$	—	81	
			$V_o = 1.5\text{ V}$	—	77	
			$V_o = 1.2\text{ V}$	—	72	
V_o Ripple (pk-pk)	V_r	20 MHz bandwidth	—	15	—	mV _{pp}
Over-Current Threshold	$I_{o,trip}$	Reset, followed by auto-recovery	—	15	—	A
Transient Response	t_{tr}	1 A/ μs load step, 50 % to 100 % $I_{o,max}$	—	100	—	μs
	ΔV_{tr}	V_o over/undershoot	—	± 150	—	mV
Switching Frequency	f_s	Over V_{in} and I_o range	475	550	725	kHz
On/Off Standby (Pin 3)	V_{IH} V_{IL} I_{IL}	Referenced to $-V_{in}$ (pin 7)	—	—	Open ⁽³⁾	V
			—0.1	—	+0.4	
			—	—0.5	—	
			—	1	5	
Standby Input Current	$I_{in, stby}$	Pins 3 & 7 connected	—	1	5	mA
External Output Capacitance	C_{out}	See application schematic	330	—	5,000 ⁽⁴⁾	μF
External Input Capacitance	C_{in}	See application schematic	330 ⁽⁵⁾	—	—	μF
Operating Temperature Range	T_a	Over V_{in} range	—40	—	+85 ⁽⁶⁾	$^\circ\text{C}$
Storage Temperature	T_s	—	—40	—	+125	$^\circ\text{C}$
Reliability	MTBF	Per Bellcore TR-332 50 % stress, $T_a = 40^\circ\text{C}$, ground benign	6.4	—	—	10 ⁶ Hrs
Mechanical Shock	—	Per Mil-Std-883D, method 2002.3, 1 ms, half-sine, mounted to a fixture	—	500	—	G's
Mechanical Vibration	—	Per Mil-Std-883D, method 2007.2, 20-2000 Hz	—	10	—	G's
Weight	—	Suffixes N, A, & C	—	12.5	—	grams
		Suffixes R, G & B	—	16.5	—	
		Suffix H	—	18.5	—	
		Suffix L	—	15.5	—	
		Suffix F	—	22	—	
Flammability	—	Materials meet UL 94V-0	—	—	—	—

Notes: (1) The ISR will operate at no load with reduced specifications.

(2) The minimum input voltage required by the part is $V_{out} + 1.2\text{ V}$ or 3.1 V , whichever is greater.

(3) The STBY* control (pin 3) has an internal pull-up and if it is left open circuit the module will operate when input power is applied. The open-circuit voltage is the input voltage, V_{in} . Refer to the application notes for other interface considerations.

(4) The module requires a 330 μF output capacitor for proper operation in all applications. For transient or dynamic load applications, additional output capacitance (C_{out}) may be necessary. The maximum allowable output capacitance is 5,000 μF .

(5) In addition, the input capacitance (C_{in}) must be rated for a minimum of 1.2 Arms ripple current rating. For more information consult the related application note on capacitor recommendations.

(6) See Safe Operating Area curves or contact the factory for the appropriate derating.

(7) The tab pins on the 16-pin mount package types (suffix L) must be soldered. For more information see the applicable package outline drawing.

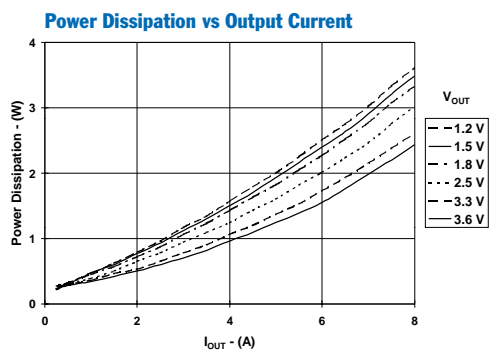
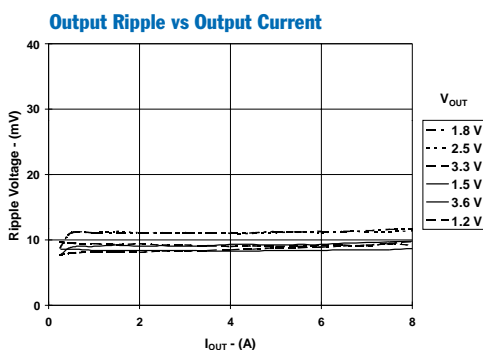
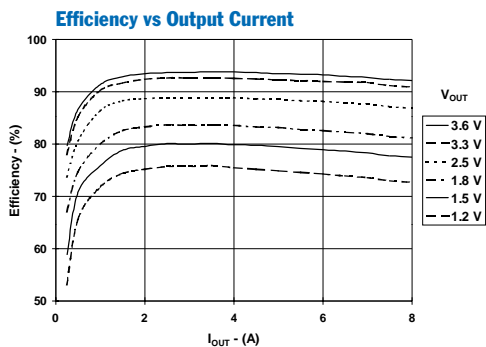
PT6510 Series

Typical Characteristics

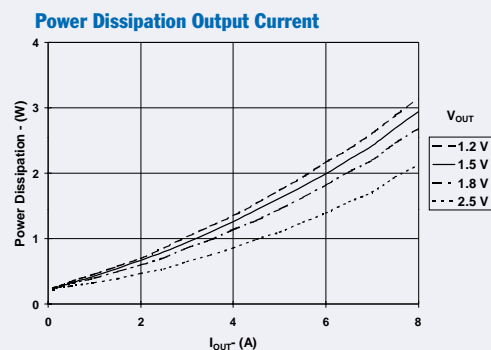
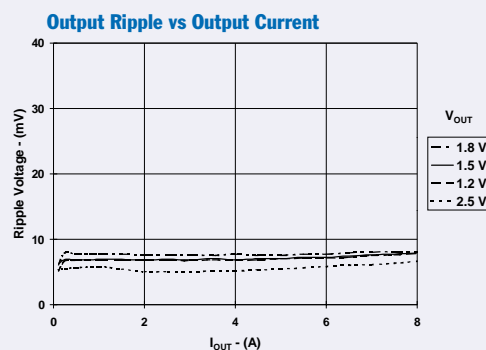
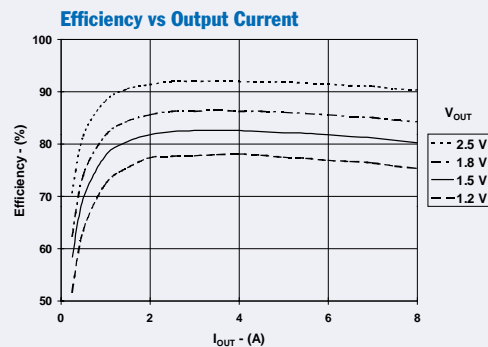
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Characteristic Data; $V_{in} = 5\text{ V}$ (See Note A)



Characteristic Data; $V_{in} = 3.3\text{ V}$ (See Note A)



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

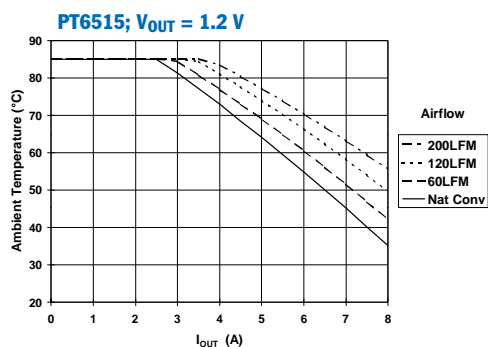
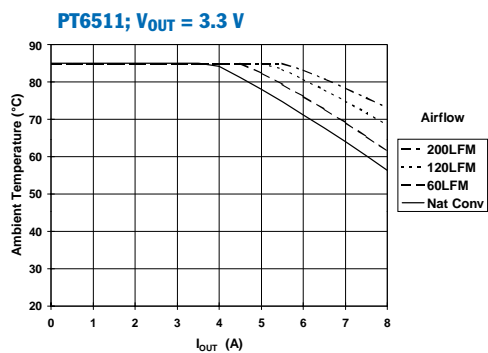
PT6510 Series

Typical Characteristics

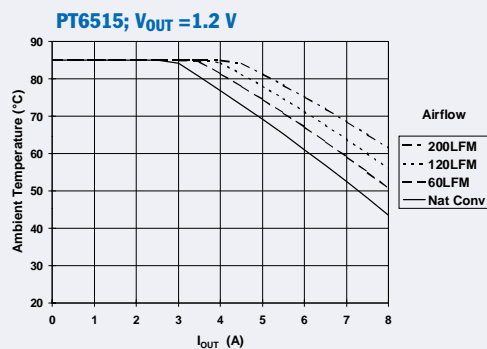
**8-A 5-V/3.3-V Input Adjustable ISR
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Safe Operating Area; $V_{in} = 5\text{ V}$ (See Note B)



Safe Operating Area; 3.3 V (See Note B)



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

Application Notes

PT6510 Series

Using the PT6510 Series as a Replacement for the PT6500 Series in Existing Designs

Scope

The PT6510 series of power modules is the recommended plug-in replacement for PT6500 series parts. The PT6510 series uses the same single-in-line package (SIP) outlines and footprint as the PT6500 series, and was designed to be functionally identical to the PT6500. This application note highlights the differences in electrical performance between a PT6510 series replacement compared to an original PT6500 series part.

Overview

The features that the PT6510 series share with the PT6500 series includes the output current rating, thermal shutdown, and on/off standby. The input voltage range, output voltage adjustment, and output voltage options are also the same. In addition, applications that use the PT6510 series as a replacement will experience a number of performance enhancements. These include improved efficiency and power dissipation, lower in-rush current and output ripple voltage. The 'off' standby current is also significantly reduced. Table 1-1 provides a cross reference between the current PT6500 series part numbers and their equivalent PT6510 series part.

Table 1-1; PT6500 / PT6510 Series Equivalent Parts

PT6500 Series	V _{OUT}	PT6510 Series
PT6501	3.3 V	PT6511
PT6502	1.5 V	PT6512
PT6503	2.5 V	PT6513
PT6504	3.6 V	PT6514
PT6505	1.2 V	PT6515
PT6506	1.8 V	PT6516

Electrical and Functional Differences

Although the PT6510 series was designed as a drop-in replacement for PT6500 series, there are minor differences in the electrical characteristics. These are described in the following text and should be used to assess the replacement part's compatibility with the system or end product. A replacement part's compatibility with the system can be further verified with appropriate board-level tests.

On/Off Standby: The Standby input of the PT6510 series is compatible with both the logic polarity and thresholds of PT6500 series. One exception is the internal pull-up voltage, which is slightly higher on the PT6510 parts. The open-circuit voltage for the PT6510 series is the input voltage, V_{in}, versus about 1 V for the PT6500 series. This should not be a problem if the standby input is controlled with an open-drain transistor with a sufficient max-V_{ds} rating.

Over-Current & Over-Temperature Protection:

To protect against short circuits and load impedance faults, the PT6500 employs a constant output current limit combined with over-temperature shutdown. The PT6500 will feed a limited steady-state current into a load fault. When limiting output current, the PT6500 exhibits higher power dissipation, which increases the module's operating temperature. When its internal temperature rises above the over-temperature threshold, the module will shut itself down for a few seconds. The module will then continue to periodically shut down until the load fault is removed.

The over-current protection mechanism of the PT6510 series is different. If the output current increases above the modules over-current threshold, its output voltage is momentarily turned off. It then attempts to recover by executing a soft-start power up. The module will continue in a rapid succession of shutdowns and restarts until the load fault is removed. During this period the output current is not steady state, but a series of short high-amplitude pulses (frequency <100 Hz). However, when operating into a short-circuit load fault, the average output current and power dissipation are significantly lower than under normal operation.

Power-Up Characteristic: Following the application of a valid input source, the PT6510 series modules exhibit a slightly longer time delay than the equivalent PT6500 series part. The PT6510 series has a soft-start power-up feature, which lowers the in-rush current at its input.

Figure 1-1 and Figure 1-2 show the power-up characteristics of the PT6501 and PT6511 respectively. Both modules have a 3.3-V regulated output, and rise to their regulated output voltage in a similar period. Note that the output voltage of the PT6501 begins to rise when the input voltage reaches 2.2 V, whereas the output voltage of the PT6511 doesn't begin to rise until the input voltage has reached 3.5 V.

Application Notes *continued*

PT6510 Series

Figure 1-1 PT6501 Power-Up Characteristics

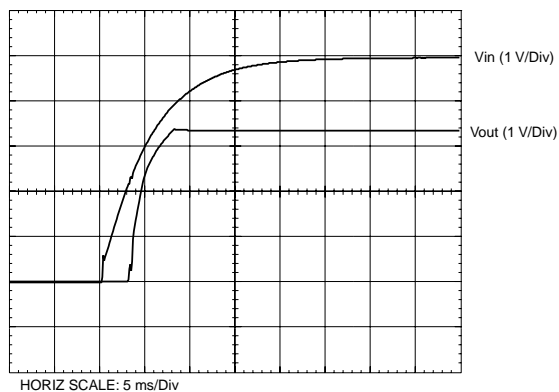
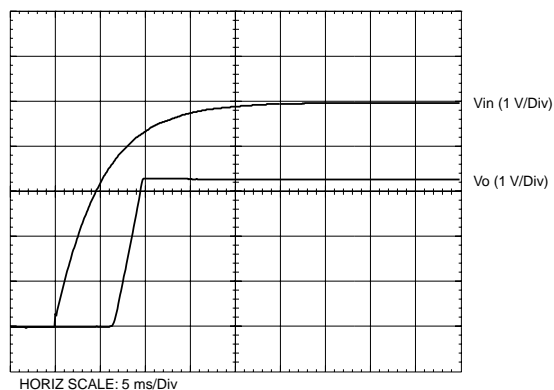


Figure 1-2; PT6511 Power-Up Characteristic



Conclusion

The differences in electrical performance between the PT6500 series and the PT6510 series are small. This should result in only a few, if any, compatibility issues when a PT6510 series part is used to replace a PT6500 series part in an existing application. In most cases, the use of a PT6510 part will improve the performance of the end product over the original PT6500. The performance differences are described to help customers work through any compatibility issues, and thereby minimize the impact to their end products. For additional information and questions call Texas Instrument's product information center (PIC) and request application assistance for plug-in power products.

Application Notes

PT6510 Series

Capacitor Recommendations for the PT6510 Series of Integrated Switching Regulators

Input Capacitors:

The recommended input capacitance is determined by 330 μ F minimum value (300 μ F for Oscon or low-ESR tantalum types), and 1 A minimum ripple current rating. Ripple current and less than 100 m Ω equivalent series resistance (ESR) are the major parameters, along with temperature, when selecting an input capacitor. Tantalum capacitors have a recommended minimum voltage rating of twice 2 \times (max. DC voltage + AC ripple). This is standard practice to insure reliability.

Output Capacitors:

The ESR of the required output capacitor must not be greater than 150 m Ω . Electrolytic capacitors have poor ripple performance at frequencies greater than 400 kHz but excellent low-frequency transient response. Above the ripple frequency, ceramic capacitors are necessary to improve the transient response and reduce any high frequency noise components apparent during higher current excursions. Preferred low-ESR type capacitor part numbers are identified in Table 2-1.

Tantalum Capacitors

Tantalum type capacitors may be used for the output but only the AVX TPS, Sprague 593D/594/595, or Kemet T495/T510 series. These capacitors are recommended over many other tantalum types due to their higher rated surge, power dissipation, and ripple current capability. As a caution the TAJ series by AVX is not recommended. This series has considerably higher ESR, reduced power dissipation, and lower ripple current capability. The TAJ series is less reliable than the AVX TPS series when determining power dissipation capability. Tantalum or Oscon types are recommended for applications where ambient temperatures fall below 0 $^{\circ}$ C.

Capacitor Table

Table 2-1 identifies the characteristics of capacitors from a number of vendors with acceptable ESR and ripple current (rms) ratings. The number of capacitors required at both the input and output buses is identified for each capacitor type.

This is not an extensive capacitor list. Capacitors from other vendors are available with comparable specifications. Those listed are for guidance. The RMS ripple current rating and ESR (at 100 kHz) are critical parameters necessary to insure both optimum regulator performance and long capacitor life.

Table 2-1: Suggested Input/Output Capacitors

Capacitor Vendor/ Component Series	Capacitor Characteristics					Quantity		Vendor Number
	Working Voltage	Value (μ F)	Max. ESR at 100 kHz	Max. Ripple Current at 85 $^{\circ}$ C (Irms)	Physical Size (mm)	Input Bus	Output Bus	
Panasonic FC	25 V	560 μ F	0.0065 Ω	1205 mA	12.5x15	1	1	EEUFC1E561S
	35 V	390 μ F	0.065 Ω	1205 mA	12.5x15	2	1	EEUFC1V391S
	35 V	330 μ F	0.117 Ω	555 mA	8x11.5	N/R	1	EEUFC1C331
United Chemi-Con LXV/FS/LXZ	16 V	330 μ F	0.120 Ω	555 mA	8x12	N/R	1	LXZ16VB331M8X12LL
	35 V	470 μ F	0.052 Ω	122 0mA	10x20	1	1	LXZ35VB471M10X20LL
	10 V	330 μ F	0.025 Ω	3500 mA	10x10.5	1	1	10FS330M
	20 V	150 μ F	0.030 \pm 2 Ω	3200 mA	10x10.5	2	2	20FS150M
Nichicon PL/ PM	35 V	560 μ F	0.048 Ω	1360 mA	16x15	1	1	UPL1V561MHH6
	35 V	330 μ F	0.065 \pm 2 Ω	1020 mA	12.5x15	1	1	UPL1V331MHH6
	50 V	470 μ F	0.046 Ω	1470 mA	18x15	1	1	UPM1H471MHH6
Panasonic FC (Surface Mtg)	10 V	1000 μ F	0.043 Ω	1205 mA	12x16.5	1	1	EEVFC1A102LQ
	35 V	330 μ F	0.065 Ω	1205 mA	12.5x16	1	1	EEVFC1V331LQ
	16 V	330 μ F	0.150 Ω	670 mA	10x10.2	N/R	1	EEVFC1C331P
Oscon- SS SV	10 V	330 μ F	0.025 Ω	>3500 mA	10.0x10.5	1	1	10SS330M
	10 V	330 μ F	0.025 Ω	>3800 mA	10.3x10.3	1	1	10SV330M
	20 V	150 μ F	0.024 \pm 2 Ω	3600 mA	10.3x10.3	2	2	20SV150M SV= Surface Mount
AVX Tantalum TPS	10 V	330 μ F	0.100 \pm 2 Ω	>2500 mA	7.3Lx	2	1	TPSV337M010R0100
	10 V	330 μ F	0.100 \pm 2 Ω	>3000 mA	4.3Wx	2	1	TPSV337M010R0060
	10 V	220 μ F	0.095 Ω	>2000 mA	4.1H	2	2	TPSV227M0105R0100
Kemet T510/T495	10 V	330 μ F	0.033 Ω	1400 mA	7.3Lx5.7W x 4.0H	2	1	T510X337M010AS
	10 V	220 μ F	0.07 Ω \pm 2 =0.035 Ω	>2000 mA		2	2	T495X227M010AS
Sprague 594D	10 V	330 μ F	0.045 Ω	2350 mA	7.3Lx 6.0Wx 4.1H	2	1	4D337X0010R2T
	10 V	220 μ F	0.065 Ω	>2000 mA		2	2	594D227X0010D2T

N/R –Not recommended. The ripple current rating and ESR does not meet the requirements.

Application Notes

PT6510 Series

Using the Standby Function of the PT6510 Series of Integrated Switching Regulators

The PT6510 series of power modules incorporate a *Standby* function. This may be used in applications that require power-up/shutdown sequencing, and wherever there is a requirement for the output status of the module to be controlled by external circuitry.

The standby function is provided by the *STBY** control, pin 3. If pin 3 is left open-circuit¹ the regulator operates normally, and provides a regulated output whenever a valid supply voltage is present at applied to V_{in} (pins 4-6) with respect to GND (pins 7-10). Applying a ground signal to pin 3 disables the regulator's output and reduces the input current to about 1 mA⁴. The standby control may also be used to hold off the regulator output during the period that input power is applied.

Pin 3 is ideally controlled with an open-drain discrete transistor¹ (See Figure 3-1). It may also be driven directly from a dedicated TTL³ compatible gate. Table 3-1 gives the circuit parameters for the control of this input.

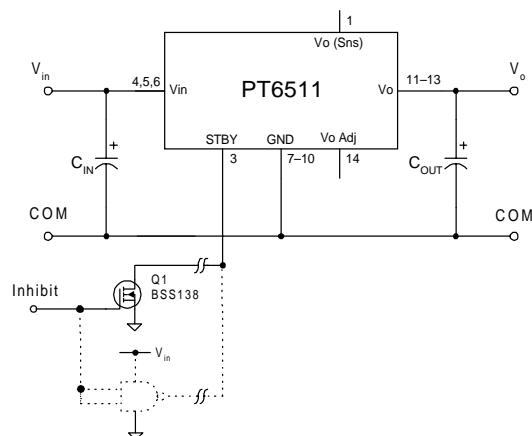
Table 3-1 Standby Control Requirements⁽²⁾

Parameter	Min	Typ	Max
Input Low (V_{IL})	-0.1 V		0.4 V
Input High (V_{IH})	2 V		V_{in}
Input Low Current (I_{IL})		-0.4 mA	

Notes:

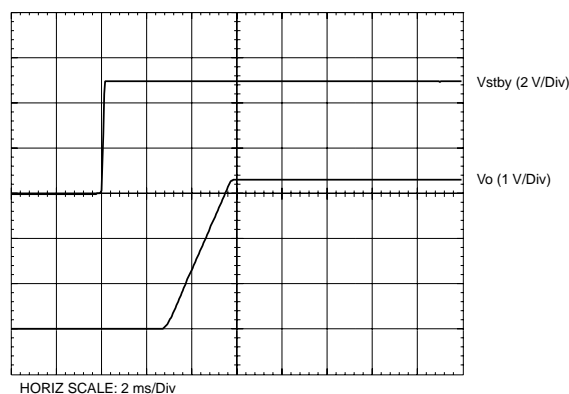
1. The standby control input is ideally controlled using an open-drain discrete transistor. An external pull-up resistor is not necessary. The open-circuit voltage of the *STBY** pin is the input voltage, V_{in} .
2. To ensure the regulator output is disabled, the control pin must be pulled to less than 0.4 Vdc with a low-level 0.5-mA sink to ground.
3. The *STBY** input is also compatible with a differential output from standard TTL logic, providing the IC shares the same supply voltage as the module.
4. When the regulator output is disabled the current drawn from the input source is typically reduced to about 1 mA.

Figure 3-1



Turn-On Time: In the circuit of Figure 3-1, turning Q_1 on applies a low voltage to the *STBY* control (pin 3) and disables the regulator output. Correspondingly, turning Q_1 off removes the low-voltage signal and enables the output. Once enabled, the output will typically experience a 10–15 ms delay followed by a predictable ramp-up of voltage. The regulator should provide a fully regulated output voltage within 40 ms. The waveform of Figure 3-2 shows the output voltage and input current waveforms of a PT6511 (3.3 V) following the turn-off of Q_1 . The turn off of Q_1 corresponds to the rise in V_{stby} . The waveforms were measured with a 5 Vdc input voltage, and 4.5 A resistive load.

Figure 3-2



Application Notes

PT6510 Series

Adjusting the Output Voltage of the PT6510 5V/3.3V Bus Converters

The output voltage of the PT6510 series switching regulators may be adjusted higher or lower than the factory trimmed pre-set voltage with the addition of a single external resistor. Table 4-1 gives the allowable adjustment range for each model in the series as V_a (min) and V_a (max).

Adjust Up: An increase in the output voltage is obtained by adding a resistor R_2 , between V_o Adjust (pin 14) and GND (pins 7-10).

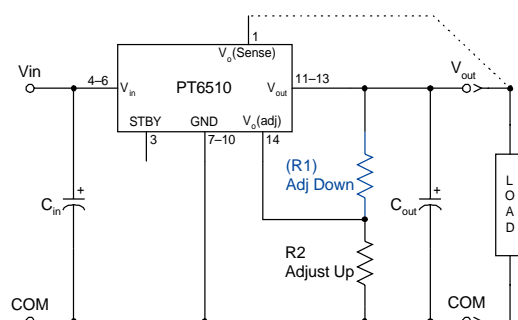
Adjust Down: Add a resistor (R_1), between V_o Adjust (pin 14) and V_{out} (pins 11-13).

Refer to Figure 4-1 and Table 4-2 for both the placement and value of the required resistor, either (R_1) or R_2 as appropriate.

Notes:

1. Use only a single 1 % resistor in either the (R_1) or R_2 location. Place the resistor as close to the ISR as possible.
2. Never connect capacitors from V_o Adjust to either GND, V_{out} , or the V_o Sense pin. Any capacitance added to the V_o Adjust pin will affect the stability of the ISR.
3. If the remote sense feature is used, connecting the resistor (R_1) between V_o Adjust (pin 14) and V_o Sense (pin 1) can benefit load regulation.
4. The minimum input voltage required by the part is $V_{out} + 1.2$ or $V_{in(min)}$ from Table 4-1, whichever is higher.

Figure 4-1



The values of (R_1) [adjust down], and R_2 [adjust up], can also be calculated using the following formulae.

$$(R_1) = \frac{R_o (V_a - 1.0)}{(V_o - V_a)} - R_s \quad k\Omega$$

$$R_2 = \frac{R_o}{V_a - V_o} - R_s \quad k\Omega$$

Where: V_o = Original output voltage
 V_a = Adjusted output voltage
 R_o = The resistance value in Table 4-1
 R_s = The series resistance from Table 4-1

Table 4-1

PT6510 ADJUSTMENT AND FORMULA PARAMETERS						
Series Pt #	PT6515	PT6512	PT6516	PT6513	PT6511	PT6514
V_o (nom)	1.2	1.5	1.8	2.5	3.3	3.6
V_a (min)	1.14	1.27	1.4	1.8	2.25	2.5
V_a (max)	2.35	2.65	2.95	3.5	4.2	4.3
R_o (k Ω)	2.49	2.49	2.49	4.99	12.1	10
R_s (k Ω)	2	2	2	4.22	12.1	12.1
$V_{in(min)}$	3.1	3.1	3.1	4.5	4.5	4.5

Application Notes continued

PT6510 Series

Table 4-2

PT6500 ADJUSTMENT RESISTOR VALUES

Series Pt #	PT6515	PT6512	PT6516	PT6513	PT6511	PT6514
V ₀ (nom)	1.2 V	1.5 V	1.8 V	2.5 V	3.3 V	3.6 V
V _a (req'd)						
1.15	(5.5) kΩ					
1.2						
1.25	47.8 kΩ					
1.3	22.9 kΩ	(1.7) kΩ				
1.35	14.6 kΩ	(3.8) kΩ				
1.4	10.5 kΩ	(8.0) kΩ	(0.5) kΩ			
1.45	8.0 kΩ	(20.4) kΩ	(1.2) kΩ			
1.5	6.3 kΩ		(2.2) kΩ			
1.55	5.1 kΩ	47.8 kΩ	(3.5) kΩ			
1.6	4.2 kΩ	22.9 kΩ	(5.5) kΩ			
1.65	3.5 kΩ	14.6 kΩ	(8.8) kΩ			
1.7	3.0 kΩ	10.5 kΩ	(15.4) kΩ			
1.75	2.5 kΩ	8.0 kΩ	(35.4) kΩ			
1.8	2.2 kΩ	6.3 kΩ		(1.5) kΩ		
1.85	1.8 kΩ	5.1 kΩ	47.8 kΩ	(2.3) kΩ		
1.9	1.6 kΩ	4.2 kΩ	22.9 kΩ	(3.3) kΩ		
1.95	1.3 kΩ	3.5 kΩ	14.6 kΩ	(4.4) kΩ		
2.0	1.1 kΩ	3.0 kΩ	10.5 kΩ	(5.8) kΩ		
2.05	0.9 kΩ	2.5 kΩ	8.0 kΩ	(7.4) kΩ		
2.1	0.8 kΩ	2.2 kΩ	6.3 kΩ	(9.5) kΩ		
2.15	0.6 kΩ	1.8 kΩ	5.1 kΩ	(12.2) kΩ		
2.2	0.5 kΩ	1.6 kΩ	4.2 kΩ	(15.7) kΩ		
2.25	0.4 kΩ	1.3 kΩ	3.5 kΩ	(20.7) kΩ	(2.3) kΩ	
2.3	0.3 kΩ	1.1 kΩ	3.0 kΩ	(28.2) kΩ	(3.6) kΩ	
2.35	0.2 kΩ	0.9 kΩ	2.5 kΩ	(40.7) kΩ	(5.1) kΩ	
2.4		0.8 kΩ	2.2 kΩ	(65.6) kΩ	(6.7) kΩ	
2.45		0.6 kΩ	1.8 kΩ	(140.0) kΩ	(8.5) kΩ	
2.5		0.5 kΩ	1.6 kΩ		(10.6) kΩ	(1.5) kΩ
2.55		0.4 kΩ	1.3 kΩ	95.6 kΩ	(12.9) kΩ	(2.7) kΩ
2.6		0.3 kΩ	1.1 kΩ	45.7 kΩ	(15.6) kΩ	(3.9) kΩ
2.65		0.2 kΩ	6.9 kΩ	29.0 kΩ	(18.6) kΩ	(5.3) kΩ
2.7			0.8 kΩ	20.7 kΩ	(22.2) kΩ	(6.8) kΩ
2.75			0.6 kΩ	15.7 kΩ	(26.4) kΩ	(8.5) kΩ
2.8			0.5 kΩ	12.4 kΩ	(31.5) kΩ	(10.4) kΩ
2.85			0.4 kΩ	10.0 kΩ	(37.6) kΩ	(12.6) kΩ
2.9			0.3 kΩ	8.3 kΩ	(45.4) kΩ	(15.0) kΩ
2.95			0.2 kΩ	0.9 kΩ	(55.3) kΩ	(17.9) kΩ
3.0				5.8 kΩ	(68.6) kΩ	(21.2) kΩ
3.1				4.1 kΩ	(115.0) kΩ	(29.9) kΩ
3.2				2.9 kΩ	(254.0) kΩ	(42.9) kΩ
3.3				2.0 kΩ		(64.6) kΩ
3.4				1.3 kΩ	109.0 kΩ	(108.0) kΩ
3.5				0.8 kΩ	48.4 kΩ	(238.0) kΩ
3.6					28.2 kΩ	
3.7					18.2 kΩ	87.9 kΩ
3.8					12.1 kΩ	37.9 kΩ
3.9			4/. V _{out} >3.8 Vdc requires V _{in} >5 Vdc !		8.1 kΩ	21.2 kΩ
4.0					5.2 kΩ	12.9 kΩ
4.1					3.0 kΩ	7.9 kΩ
4.2					1.3 kΩ	4.6 kΩ
4.3						2.2 kΩ

R1 = (Blue) R2 = Black

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