LM1575/LM1575HV/LM2575/LM2575HV Series SIMPLE SWITCHER® 1A Step-Down Voltage Regulator

National Semiconductor

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LM1575/LM1575HV/LM2575/LM2575HV Series SIMPLE SWITCHER® 1A Step-Down Voltage Regulator

General Description

The LM2575 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 1A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2575 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors optimized for use with the LM2575 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

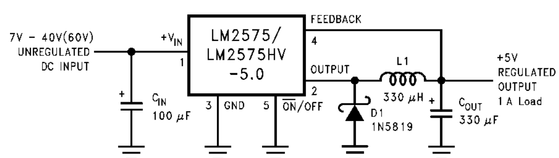
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 1A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P^+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regualtor for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

Typical Application (Fixed Output Voltage Versions)



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Note: Pin numbers are for the TO-220 package.

Block Diagram and Typical Application

3.3V, R2 = 1.7k
5V, R2 = 3.1k
12V, R2 = 8.84k
15V, R2 = 11.3k
For ADJ. Version
R1 = Open, R2 = 0Ω

Note: Pin numbers are for the TO-220 package.

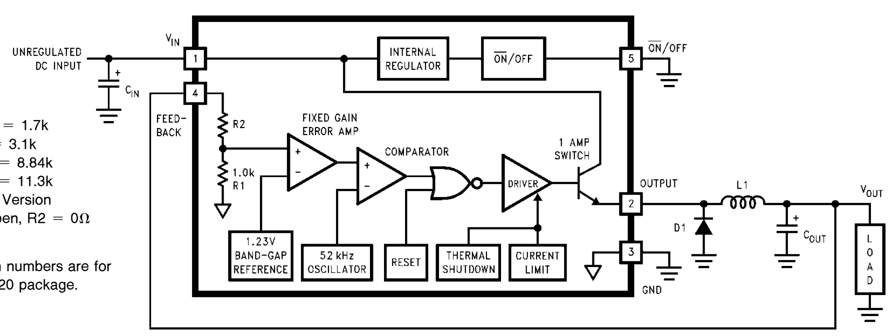

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FIGURE 1

Patent Pending

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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM1575/LM2575	45V
LM1575HV/LM2575HV	63V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	$-1V$
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM1575/LM1575HV	$-55°C \leq T_J \leq +150°C$
LM2575/LM2575HV	$-40°C \leq T_J \leq +125°C$
Supply Voltage	
LM1575/LM2575	40V
LM1575HV/LM2575HV	60V

LM1575-3.3, LM1575HV-3.3, LM2575-3.3, LM2575HV-3.3 Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-3.3 LM1575HV-3.3 Limit (Note 2)	LM2575-3.3 LM2575HV-3.3 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	3.3	3.267 3.333	3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$4.75V \leq V_{IN} \leq 40V$, $0.2A \leq I_{LOAD} \leq 1A$ Circuit of *Figure 2*	3.3	3.200/**3.168** 3.400/**3.432**	3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$4.75V \leq V_{IN} \leq 60V$, $0.2A \leq I_{LOAD} \leq 1A$ Circuit of *Figure 2*	3.3	3.200/**3.168** 3.416/**3.450**	3.168/**3.135** 3.450/**3.482**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	75			%

LM1575-5.0, LM1575HV-5.0, LM2575-5.0, LM2575HV-5.0 Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-5.0 LM1575HV-5.0 Limit (Note 2)	LM2575-5.0 LM2575HV-5.0 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	5.0	4.950 5.050	4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2A \leq I_{LOAD} \leq 1A$, $8V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	5.0	4.850/**4.800** 5.150/**5.200**	4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2A \leq I_{LOAD} \leq 1A$, $8V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	5.0	4.850/**4.800** 5.175/**5.225**	4.800/**4.750** 5.225/**5.275**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	77			%

LM1575-12, LM1575HV-12, LM2575-12, LM2575HV-12

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-12 LM1575HV-12 Limit (Note 2)	LM2575-12 LM2575HV-12 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	12	 11.88 12.12	 11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2A \leq I_{LOAD} \leq 1A$, $15V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	12	 11.64/**11.52** 12.36/**12.48**	 11.52/**11.40** 12.48/**12.60**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2A \leq I_{LOAD} \leq 1A$, $15V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	12	 11.64/**11.52** 12.42/**12.54**	 11.52/**11.40** 12.54/**12.66**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 15V$, $I_{LOAD} = 1A$	88			%

LM1575-15, LM1575HV-15, LM2575-15, LM2575HV-15

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-15 LM1575HV-15 Limit (Note 2)	LM2575-15 LM2575HV-15 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 30V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	15	 14.85 15.15	 14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2A \leq I_{LOAD} \leq 1A$, $18V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	15	 14.55/**14.40** 15.45/**15.60**	 14.40/**14.25** 15.60/**15.75**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2A \leq I_{LOAD} \leq 1A$, $18V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	15	 14.55/**14.40** 15.525/**15.675**	 14.40/**14.25** 15.68/**15.83**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 18V$, $I_{LOAD} = 1A$	88			%

LM1575-ADJ, LM1575HV-ADJ, LM2575-ADJ, LM2575HV-ADJ

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-ADJ LM1575HV-ADJ Limit (Note 2)	LM2575-ADJ LM2575HV-ADJ Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$ $V_{OUT} = 5V$ Circuit of *Figure 2*	1.230	 1.217 1.243	 1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575/LM2575	$0.2A \leq I_{LOAD} \leq 1A$, $8V \leq V_{IN} \leq 40V$ $V_{OUT} = 5V$, Circuit of *Figure 2*	1.230	 1.205/**1.193** 1.255/**1.267**	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575HV/LM2575HV	$0.2A \leq I_{LOAD} \leq 1A$, $8V \leq V_{IN} \leq 60V$ $V_{OUT} = 5V$, Circuit of *Figure 2*	1.230	 1.205/**1.193** 1.261/**1.273**	 1.193/**1.180** 1.273/**1.286**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$, $V_{OUT} = 5V$	77			%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25V$ for the 12V version, and $V_{IN} = 30V$ for the 15V version. $I_{LOAD} = 200$ mA.

Symbol	Parameter	Conditions	Typ	LM1575-XX LM1575HV-XX	LM2575-XX LM2575HV-XX	Units (Limits)
				Limit (Note 2)	Limit (Note 3)	
DEVICE PARAMETERS						
I_b	Feedback Bias Current	$V_{OUT} = 5V$ (Adjustable Version Only)	50	100/**500**	100/**500**	nA
f_O	Oscillator Frequency	(Note 13)	52	 47/**43** 58/**62**	 47/**42** 58/**63**	kHz kHz(Min) kHz(Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 1A$ (Note 5)	0.9	 1.2/**1.4**	 1.2/**1.4**	V V(Max)
DC	Max Duty Cycle (ON)	(Note 6)	98	 93	 93	% %(Min)
I_{CL}	Current Limit	Peak Current (Notes 5 and 13)	2.2	 1.7/**1.3** 3.0/**3.2**	 1.7/**1.3** 3.0/**3.2**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 7 and 8) Output = 0V Output = −1V Output = −1V	 7.5	2 30	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 7)	5	 10/**12**	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$/OFF Pin = 5V (OFF)	50	 200/**500**	 200	μA μA(Max)
θ_{JA} θ_{JC} θ_{JA} θ_{JA} θ_{JC} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case T Package, Junction to Ambient (Note 9) T Package, Junction to Ambient (Note 10) T Package, Junction to Case N Package, Junction to Ambient (Note 11) M Package, Junction to Ambient (Note 11) S Package, Junction to Ambient (Note 12)	35 1.5 65 45 2 85 100 37			°C/W
$\overline{ON}$/OFF CONTROL Test Circuit *Figure 2*						
V_{IH}	$\overline{ON}$/OFF Pin Logic	$V_{OUT} = 0V$	1.4	2.2/**2.4**	2.2/**2.4**	V(Min)
V_{IL}	Input Level	V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	1.0/**0.8**	V(Max)
I_{IH}	$\overline{ON}$/OFF Pin Input Current	$\overline{ON}$/OFF Pin = 5V (OFF)	12	 30	 30	μA μA(Max)
I_{IL}		$\overline{ON}$/OFF Pin = 0V (ON)	0	 10	 10	μA μA(Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All limts are used to calculate Average Outgoing Quality Leel, and all are 100% production tested.

Note 3: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 4: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM1575/LM2575 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 5: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output pin.

Note 6: Feedback (pin 4) removed from output and connected to 0V.

Note 7: Feedback (pin 4) removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 8: $V_{IN} = 40V$ (60V for the high voltage version).

Electrical Characteristics (Notes) (Continued)

Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

Note 10: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

Note 11: Junction to ambient thermal resistance with approxmiately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in Switchers made Simple software.

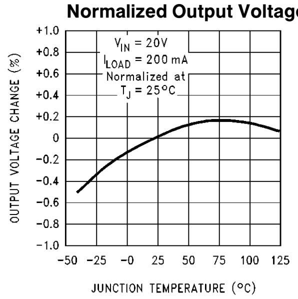
Note 12: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Note 13: The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

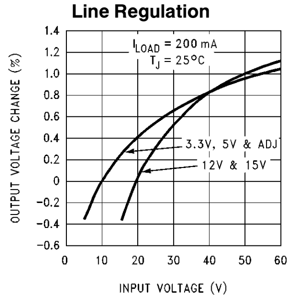
Note 14: Refer to RETS LM1575K, LM1575HVK for current revision of military RETS/SMD.

Typical Performance Characteristics (Circuit of *Figure 2*)

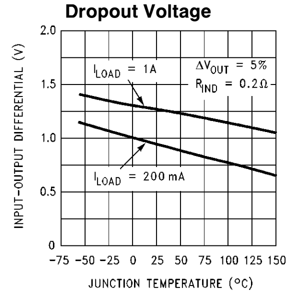
Normalized Output Voltage



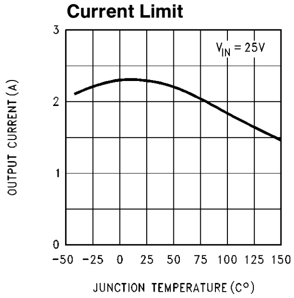
Line Regulation



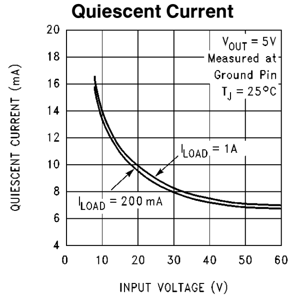
Dropout Voltage



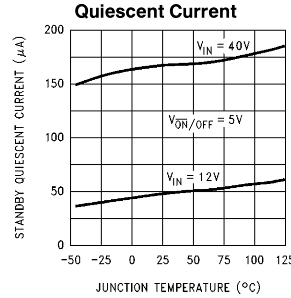
Current Limit



Quiescent Current



Standby Quiescent Current



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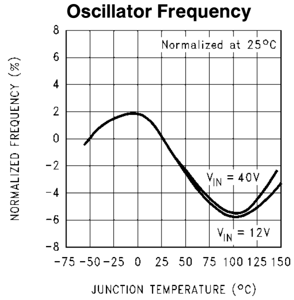
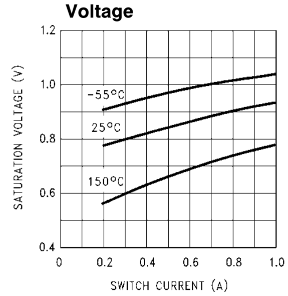
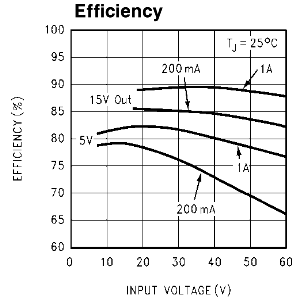
Oscillator Frequency



Switch Saturation Voltage



Efficiency



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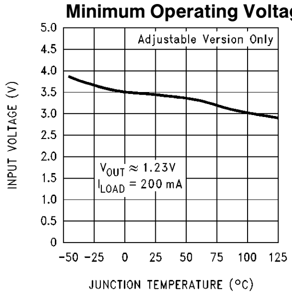
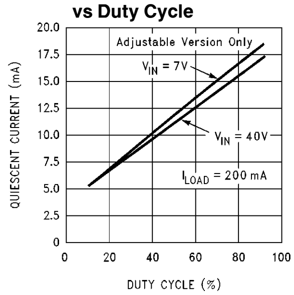
Typical Performance Characteristics (Continued)

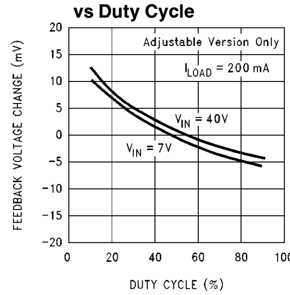
Minimum Operating Voltage



Quiescent Current vs Duty Cycle



Feedback Voltage vs Duty Cycle



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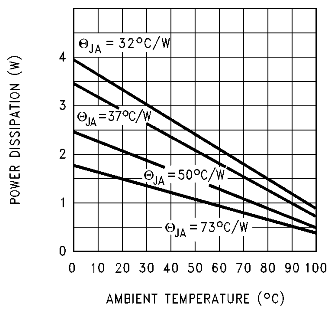
Maximum Power Dissipation (TO-263) (See Note 12)



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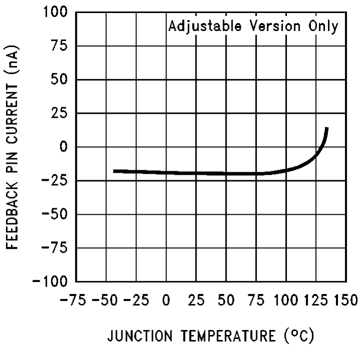
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Feedback Pin Current



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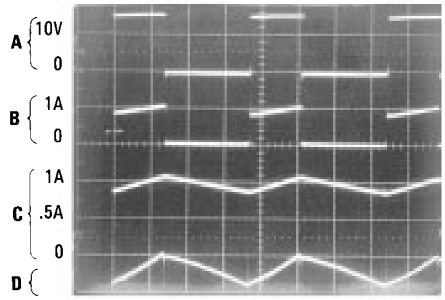
Switching Waveforms



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$V_{OUT} = 5V$

A: Output Pin Voltage, 10V/div

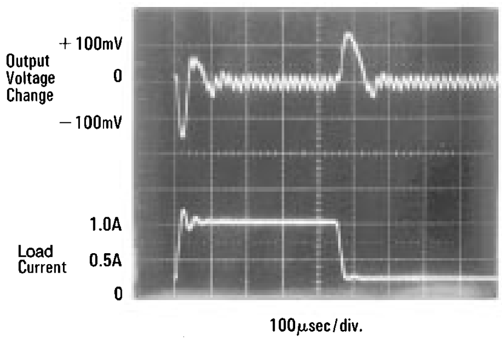
B: Output Pin Current, 1A/div

C: Inductor Current, 0.5A/div

D: Output Ripple Voltage, 20 mV/div, AC-Coupled

Horizontal Time Base: 5 μs/div

Load Transient Response



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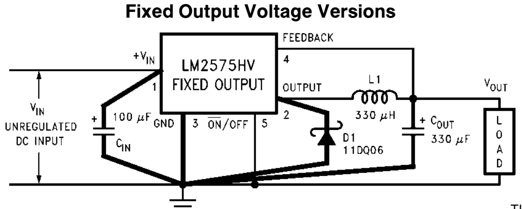
As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



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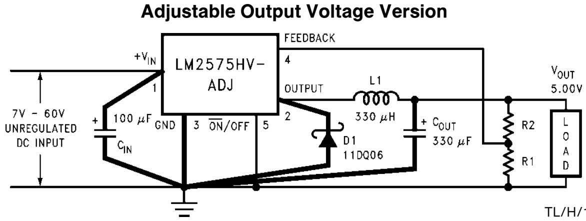
C_{IN} — 100 μF, 75V, Aluminum Electrolytic

C_{OUT} — 330 μF, 25V, Aluminum Electrolytic

D1 — Schottky, 11DQ06

L1 — 330 μH, PE-52627 (for 5V in, 3.3V out, use 100 μH, PE-92108)

Adjustable Output Voltage Version



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$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right)$$

$$R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where $V_{REF} = 1.23V$, R1 between 1k and 5k.

R1 — 2k, 0.1%

R2 — 6.12k, 0.1%

Note: Pin numbers are for the TO-220 package.

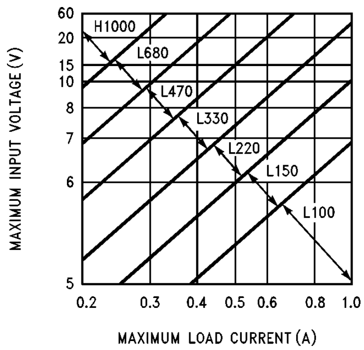
FIGURE 2

LM2575 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(Max) = 20V I_{LOAD}(Max) = 0.8A
1. Inductor Selection (L1) **A.** Select the correct Inductor value selection guide from *Figures 3, 4, 5,* or *6.* (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by V_{IN}(Max) and I_{LOAD}(Max), and note the inductor code for that region. **C.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9.* Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of 1.15 × I_{LOAD}. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1)** **A.** Use the selection guide shown in *Figure 4.* **B.** From the selection guide, the inductance area intersected by the 20V line and 0.8A line is L330. **C.** Inductor value required is 330 μH. From the table in *Figure 9,* choose AIE 415-0926, Pulse Engineering PE-52627, or RL1952.
2. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT})** **A.** C_{OUT} = 100 μF to 470 μF standard aluminum electrolytic. **B.** Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1)** **A.** For this example, a 1A current rating is adequate. **B.** Use a 30V 1N5818 or SR103 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 8.*
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 47 μF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

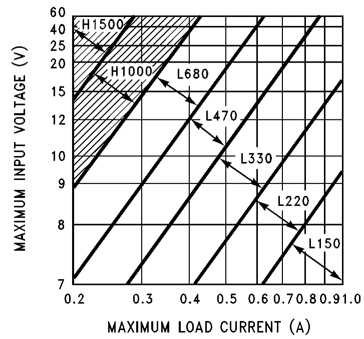
LM2575 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)



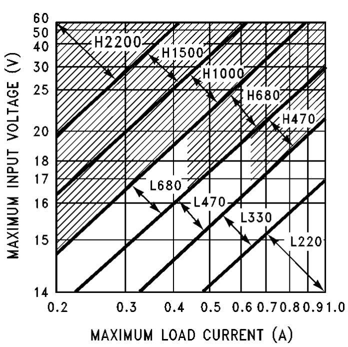
TL/H/11475–10

FIGURE 3. LM2575(HV)-3.3



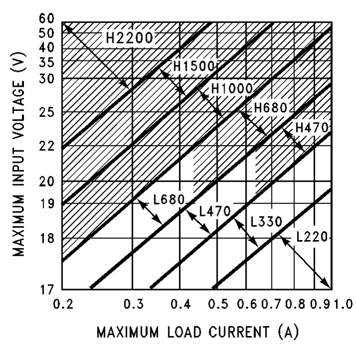
TL/H/11475–11

FIGURE 4. LM2575(HV)-5.0



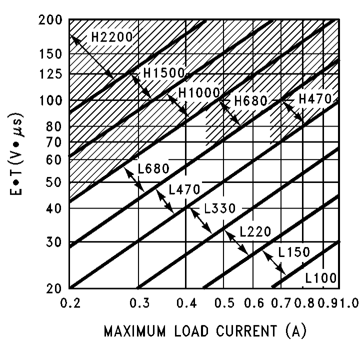
TL/H/11475–12

FIGURE 5. LM2575(HV)-12



TL/H/11475–13

FIGURE 6. LM2575(HV)-15



TL/H/11475–14

FIGURE 7. LM2575(HV)-ADJ

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current F = Switching Frequency *(Fixed at 52 kHz)*	**Given:** V_{OUT} = 10V V_{IN}(Max) = 25V I_{LOAD}(Max) = 1A F = 52 kHz
1. Programming Output Voltage *(Selecting R1 and R2, as shown in Figure 2)* Use the following formula to select the appropriate resistor values. $V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right)$ where $V_{REF} = 1.23V$ R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)* $R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$	**1. Programming Output Voltage** *(Selecting R1 and R2)* $V_{OUT} = 1.23\left(1 + \frac{R2}{R1}\right)$ Select R1 = 1k $R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$ R2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k
2. Inductor Selection (L1) **A.** Calculate the inductor Volt • microsecond constant, E • T (V • μs), from the following formula: $E \bullet T = (V_{IN} - V_{OUT})\frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (in\ kHz)}\ (V \bullet \mu s)$ **B.** Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 7*. **C.** On the horizontal axis, select the maximum load current. **D.** Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor code for that region. **E.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of 1.15 × I_{LOAD}. For additional inductor information, see the inductor section in the application hints section of this data sheet.	**2. Inductor Selection (L1)** **A.** Calculate E • T (V • μs) $E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115\ V \bullet \mu s$ **B.** E • T = 115 V • μs **C.** I_{LOAD}(Max) = 1A **D.** Inductance Region = H470 **E.** Inductor Value = 470 μH *Choose from **AIE** part #430-0634, **Pulse Engineering** part #PE-53118, or **Renco** part #RL-1961.*
3. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement: $C_{OUT} \geq 7{,}785\frac{V_{IN}(Max)}{V_{OUT} \bullet L(\mu H)}\ (\mu F)$ The above formula yields capacitor values between 10 μF and 2000 μF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields. **B.** The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.	**3. Output Capacitor Selection (C_{OUT})** **A.** $C_{OUT} > 7{,}785\frac{25}{10 \bullet 150} = 130\ \mu F$ However, for acceptable output ripple voltage select $C_{OUT} \geq 220\ \mu F$ C_{OUT} = 220 μF electrolytic capacitor

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
4. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8*. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1)** **A.** For this example, a 3A current rating is adequate. **B.** Use a 40V MBR340 or 31DQ04 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8*.
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 100 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. ***Switchers Made Simple*** *(version 3.3) is available on a (3½″) diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

V_R	Schottky		Fast Recovery	
	1A	3A	1A	3A
20V	1N5817 MBR120P SR102	1N5820 MBR320 SR302	The following diodes are all rated to 100V 11DF1 MUR110 HER102	The following diodes are all rated to 100V 31DF1 MURD310 HER302
30V	1N5818 MBR130P 11DQ03 SR103	1N5821 MBR330 31DQ03 SR303		
40V	1N5819 MBR140P 11DQ04 SR104	IN5822 MBR340 31DQ04 SR304		
50V	MBR150 11DQ05 SR105	MBR350 31DQ05 SR305		
60V	MBR160 11DQ06 SR106	MBR360 31DQ06 SR306		

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	Schott (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L100	100 μH	67127000	PE-92108	RL2444
L150	150 μH	67127010	PE-53113	RL1954
L220	220 μH	67127020	PE-52626	RL1953
L330	330 μH	67127030	PE-52627	RL1952
L470	470 μH	67127040	PE-53114	RL1951
L680	680 μH	67127050	PE-52629	RL1950
H150	150 μH	67127060	PE-53115	RL2445
H220	220 μH	67127070	PE-53116	RL2446
H330	330 μH	67127080	PE-53117	RL2447
H470	470 μH	67127090	PE-53118	RL1961
H680	680 μH	67127100	PE-53119	RL1960
H1000	1000 μH	67127110	PE-53120	RL1959
H1500	1500 μH	67127120	PE-53121	RL1958
H2200	2200 μH	67127130	PE-53122	RL2448

Note 1: Schott Corp., (612) 475-1173, 1000 Parkers Lake Rd., Wayzata, MN 55391.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12236, San Diego, CA 92112.

Note 3: Renco Electronics Inc., (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 47 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below −25°C, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

where $\frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$ for a buck regulator

and $\frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}}$ for a buck-boost regulator.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2575 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figures 3* through *7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 200 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toriod, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2575 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF–680 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND})\ (\text{ESR of } C_{OUT})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.05Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2575 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μH & 100 μF) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 × reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2575 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2575 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$/OFF INPUT

For normal operation, the $\overline{\text{ON}}$/OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$/OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$/OFF pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the TO-3 style package, the case is ground. For the 5-lead TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

With the N or M packages, all the pins labeled ground, power ground, or signal ground should be soldered directly to wide printed circuit board copper traces. This assures both low inductance connections and good thermal properties.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, no heat sink is required to keep the LM2575 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (150°C for the LM1575 or 125°C for the LM2575). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperature should be selected.
4. LM2575 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2575 can be estimated as follows:

$$P_D = (V_{IN})\,(I_Q) + (V_O/V_{IN})\,(I_{LOAD})\,(V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

Application Hints (Continued)

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

When using the LM2575 in the plastic DIP (N) or surface mount (M) packages, several items about the thermal properties of the packages should be understood. The majority of the heat is conducted out of the package through the leads, with a minor portion through the plastic parts of the package. Since the lead frame is solid copper, heat from the die is readily conducted through the leads to the printed circuit board copper, which is acting as a heat sink.

For best thermal performance, the ground pins and all the unconnected pins should be soldered to generous amounts of printed circuit board copper, such as a ground plane. Large areas of copper provide the best transfer of heat to the surrounding air. Copper on both sides of the board is also helpful in getting the heat away from the package, even if there is no direct copper contact between the two sides. Thermal resistance numbers as low as 40°C/W for the SO package, and 30°C/W for the N package can be realized with a carefully engineered pc board.

Included on the ***Switchers Made Simple*** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2575-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 0.35A. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 1.5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 µH and 220 µH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2 L_1 f_{osc}}$$

Where $f_{osc} = 52$ kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2575 is +28V, or +48V for the LM2575HV.

The ***Switchers Made Simple*** (version 3.3) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

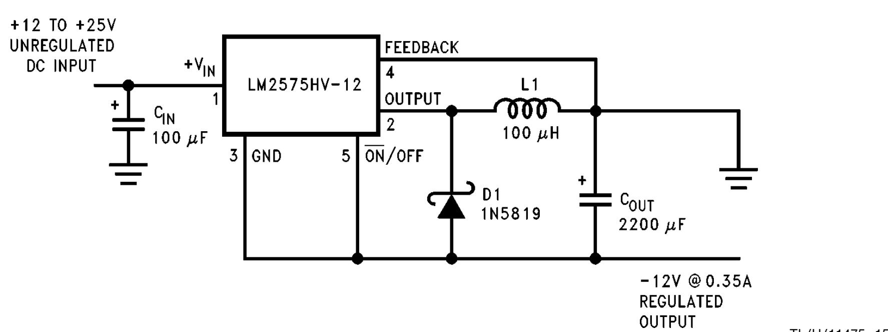


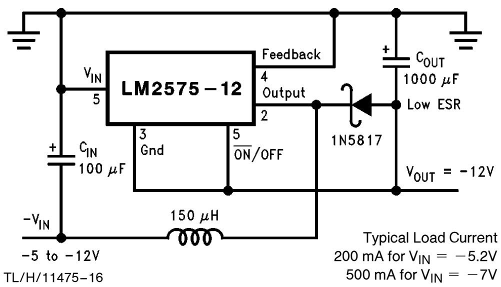
FIGURE 10. Inverting Buck-Boost Develops −12V

Additional Applications (Continued)

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.



Note: Pin numbers are for TO-220 package.

FIGURE 11. Negative Boost

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

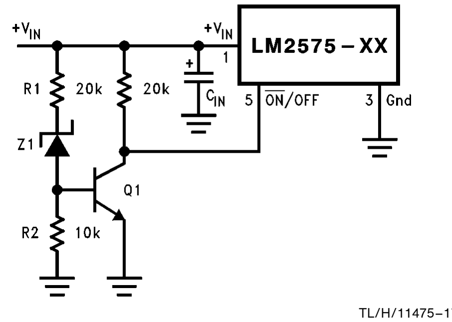
$$V_{TH} \approx V_{Z1} + 2V_{BE}\,(Q1)$$

DELAYED STARTUP

The $\overline{ON}$/OFF pin can be used to provide a delayed startup feature as shown in *Figure 14*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{ON}$/OFF pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

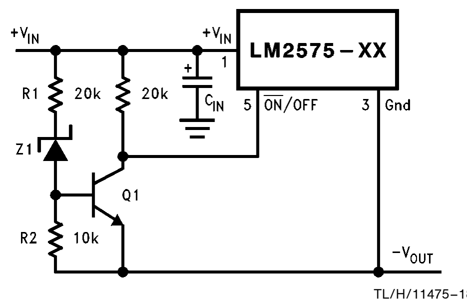
A 1A power supply that features an adjustable output voltage is shown in *Figure 15*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

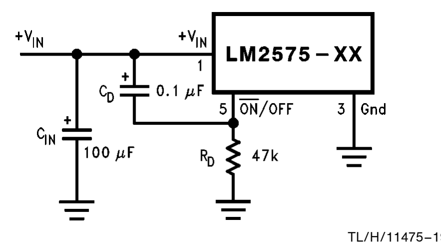
FIGURE 12. Undervoltage Lockout for Buck Circuit



Note: Complete circuit not shown (see *Figure 10*).

Note: Pin numbers are for the TO-220 package.

FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit

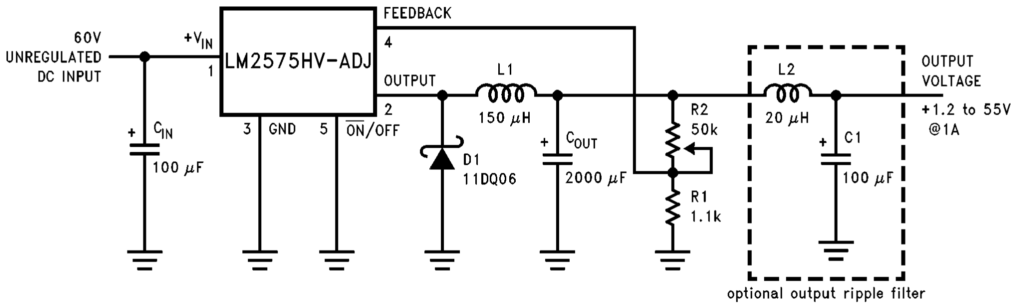


Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

FIGURE 14. Delayed Startup

Additional Applications (Continued)



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Note: Pin numbers are for the TO-220 package.

FIGURE 15. 1.2V to 55V Adjustable 1A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator $$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$$

for buck-boost regulator $$D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2575 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

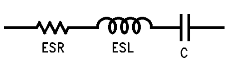

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FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 µF–1000 µF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors (''low-ESR'', ''high-frequency'', or ''low-inductance''') in the 100 µF–1000 µF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2575 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

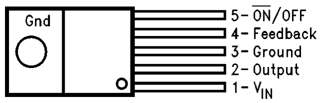
OPERATING VOLT MICROSECOND CONSTANT ($E{\bullet}T_{op}$)

The product (in Volt•µs) of the voltage applied to the inductor and the time the voltage is applied. This $E{\bullet}T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

(XX indicates output voltage option. See ordering information table for complete part number.)

Straight Leads
5-Lead TO-220 (T)

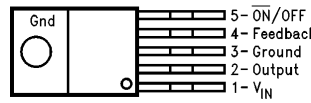


TL/H/11475–22

Top View

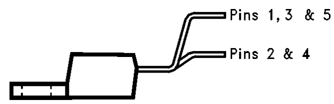
LM2575T-XX or LM2575HVT-XX
See NS Package Number T05A

Bent, Staggered Leads
5-Lead TO-220 (T)



TL/H/11475–23

Top View

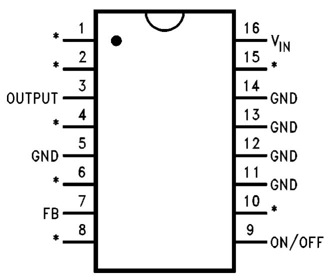


TL/H/11475–24

Side View

LM2575T-XX Flow LB03 or LM2575HVT-XX Flow LB03
See NS Package Number T05D

16-Lead DIP (N)



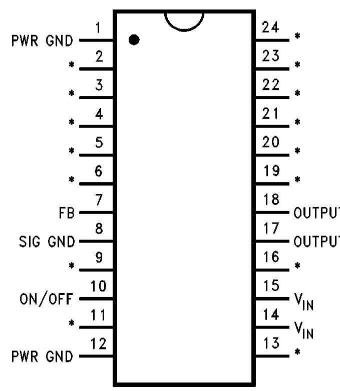
TL/H/11475–25

*No Internal Connection

Top View

LM2575N-XX or LM2575HVN-XX
See NS Package Number N16A

24-Lead Surface Mount (M)



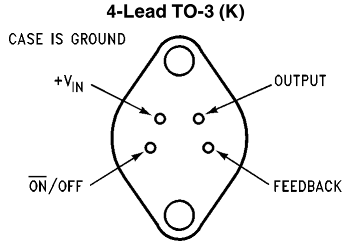
TL/H/11475–26

*No Internal Connection

Top View

LM2575M-XX or LM2575HVM-XX
See NS Package Number M24B

4-Lead TO-3 (K)



TL/H/11475–27

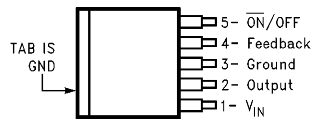
Bottom View

LM1575K-XX or LM1575HVK-XX/883
See NS Package Number K04A

Connection Diagrams (Continued)

(XX indicates output voltage option. See ordering information table for complete part number.)

TO-263(S)
5-Lead Surface-Mount Package



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Top View

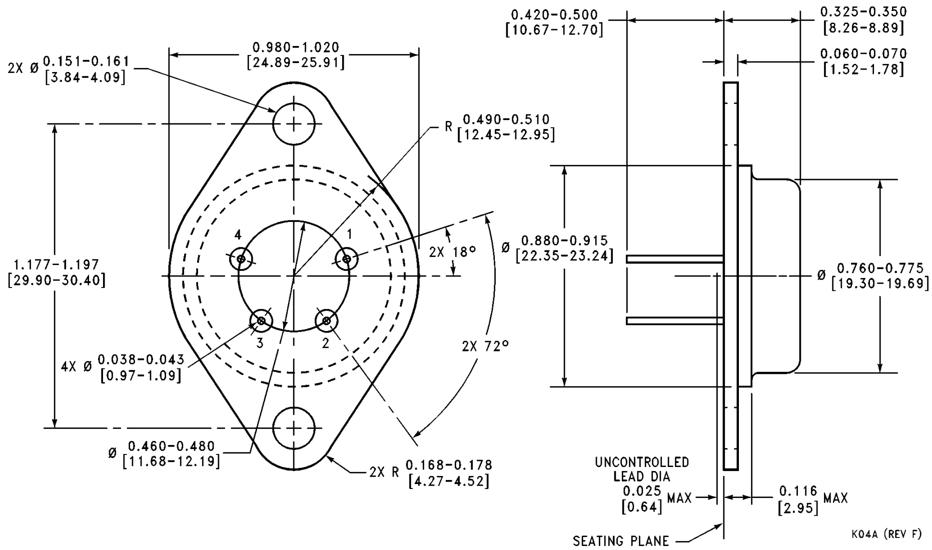
TL/H/11475–30

Side View
LM2575S-XX or LM2575HVS-XX
See NS Package Number TS5B

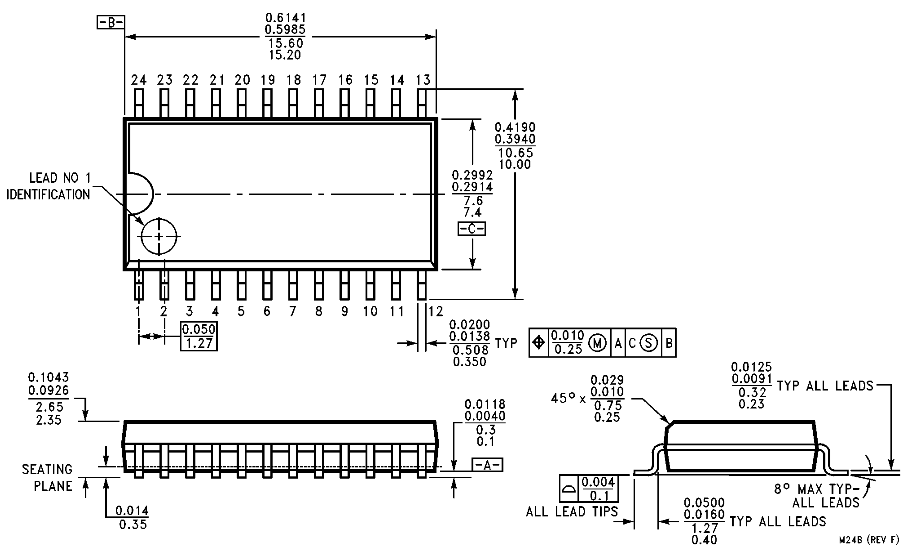
Ordering Information

Package Type	NSC Package Number	Standard Voltage Rating (40V)	High Voltage Rating (60V)	Temperature Range
5-Lead TO-220 Straight Leads	T05A	LM2575T-3.3 LM2575T-5.0 LM2575T-12 LM2575T-15 LM2575T-ADJ	LM2575HVT-3.3 LM2575HVT-5.0 LM2575HVT-12 LM2575HVT-15 LM2575HVT-ADJ	
5-Lead TO-220 Bent and Staggered Leads	T05D	LM2575T-3.3 Flow LB03 LM2575T-5.0 Flow LB03 LM2575T-12 Flow LB03 LM2575T-15 Flow LB03 LM2575T-ADJ Flow LB03	LM2575HVT-3.3 Flow LB03 LM2575HVT-5.0 Flow LB03 LM2575HVT-12 Flow LB03 LM2575HVT-15 Flow LB03 LM2575HVT-ADJ Flow LB03	
16-Pin Molded DIP	N16A	LM2575N-5.0 LM2575N-12 LM2575N-15 LM2575N-ADJ	LM2575HVN-5.0 LM2575HVN-12 LM2575HVN-15 LM2575HVN-ADJ	$-40°C \leq T_J \leq +125°C$
24-Pin Surface Mount	M24B	LM2575M-5.0 LM2575M-12 LM2575M-15 LM2575M-ADJ	LM2575HVM-5.0 LM2575HVM-12 LM2575HVM-15 LM2575HVM-ADJ	
5-Lead TO-236 Surface Mount	TS5B	LM2575S-3.3 LM2575S-5.0 LM2575S-12 LM2575S-15 LM2575S-ADJ	LM2575HVS-3.3 LM2575HVS-5.0 LM2575HVS-12 LM2575HVS-15 LM2575HVS-ADJ	
4-Pin TO-3	K04A	LM1575K-3.3/883 LM1575K-5.0/883 LM1575K-12/883 LM1575K-15/883 LM1575K-ADJ/883	LM1575HVK-3.3/883 LM1575HVK-5.0/883 LM1575HVK-12/883 LM1575HVK-15/883 LM1575HVK-ADJ/883	$-55°C \leq T_J \leq +150°C$

Physical Dimensions inches (millimeters) unless otherwise noted

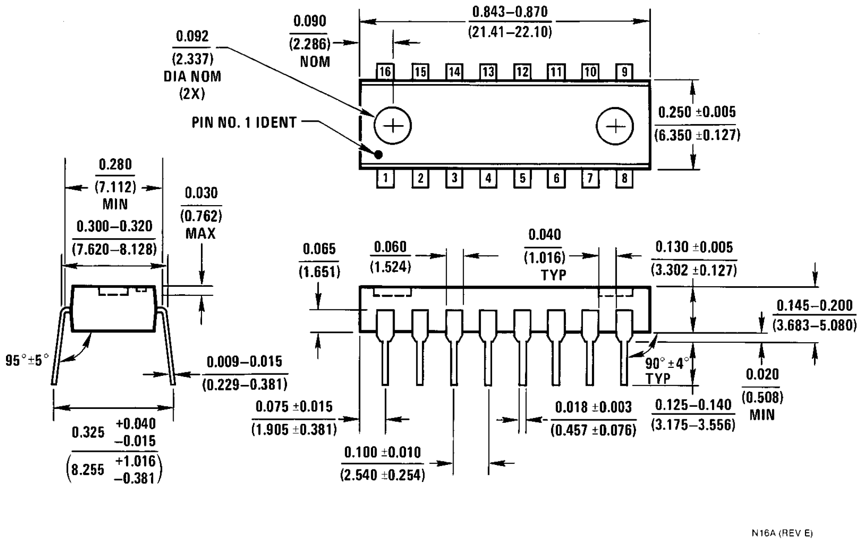


4-Lead TO-3 (K)
Order Number LM1575K-3.3/883, LM1575HVK-3.3/883, LM1575K-5.0/883, LM1575HVK-5.0/883, LM1575K-12/883, LM1575HVK-12/883, LM1575K-15/883, LM1575HVK-15/883, LM1575K-ADJ/883 or LM1575HVK-ADJ/883
NS Package Number K04A

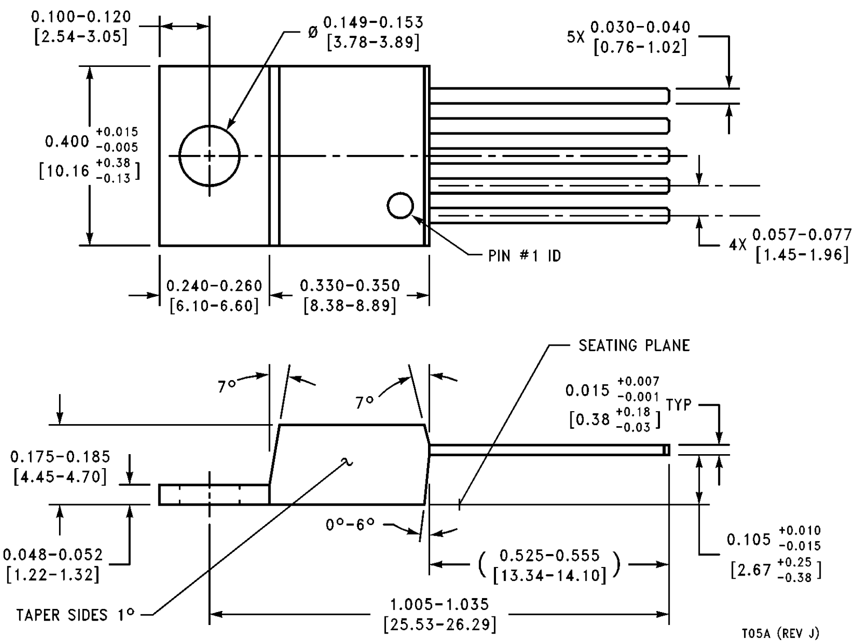


14-Lead Wide Surface Mount (WM)
Order Number LM2575M-5.0, LM2575HVM-5.0, LM2575M-12, LM2575HVM-12, LM2575M-15, LM2575HVM-15, LM2575M-ADJ or LM2575HVM-ADJ
NS Package Number M24B

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

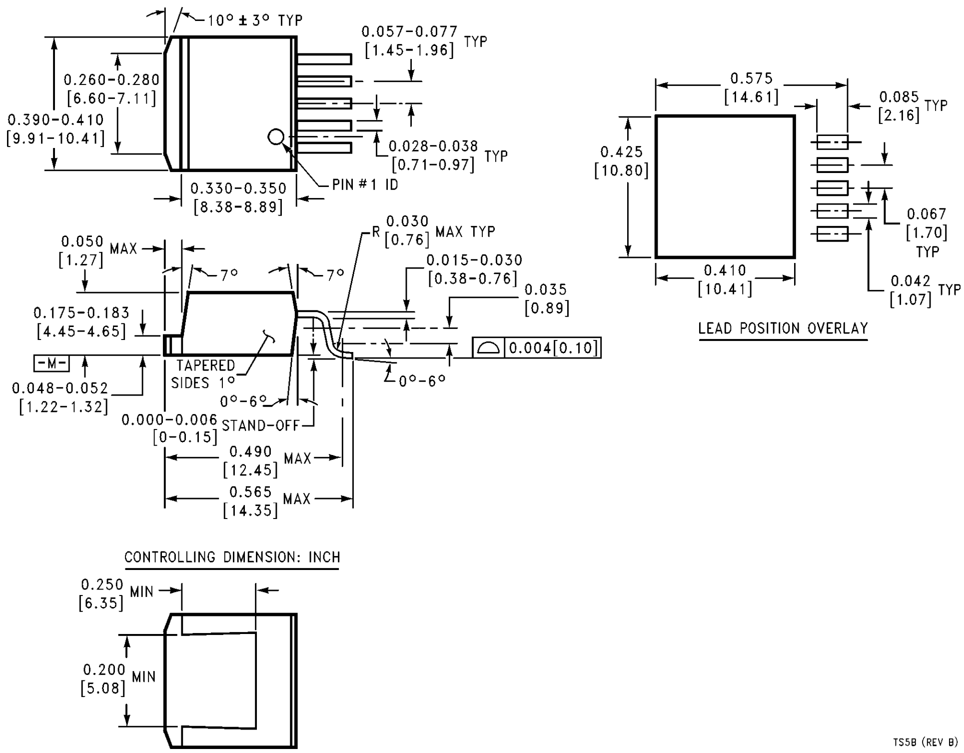


16-Lead Molded DIP (N)
Order Number LM2575N-5.0, LM2575HVN-5.0, LM2575N-12, LM2575HVN-12, LM2575N-15, LM2575HVN-15, LM2575N-ADJ or LM2575HVN-ADJ
NS Package Number N16A



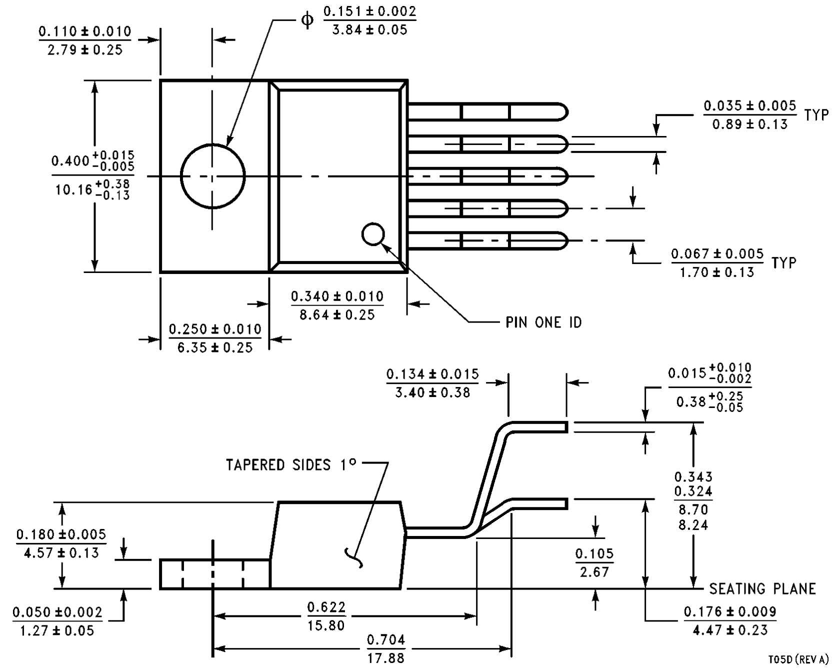
5-Lead TO-220 (T)
Order Number LM2575T-3.3, LM2575HVT-3.3, LM2575T-5.0, LM2575HVT-5.0, LM2575T-12, LM2575HVT-12, LM2575T-15, LM2575HVT-15, LM2575T-ADJ or LM2575HVT-ADJ
NS Package Number T05A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-263, Molded, 5-Lead Surface Mount
Order Number LM2575S-3.3, LM2575HVS-3.3, LM2575S-5.0, LM2575HVS-5.0, LM2575S-12,
LM2575HVS-12, LM2575S-15, LM2575HVS-15, LM2575S-ADJ or LM2575HVS-ADJ
NS Package Number TS5B

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Bent, Staggered 5-Lead TO-220 (T)
Order Number LM2575T-3.3 Flow LB03, LM2575HVT-3.3 Flow LB03,
LM2575T-5.0 Flow LB03, LM2575HVT-5.0 Flow LB03,
LM2575T-12 Flow LB03, LM2575HVT-12 Flow LB03,
LM2575T-15 Flow LB03, LM2575HVT-15 Flow LB03,
LM2575T-ADJ Flow LB03 or LM2575HVT-ADJ Flow LB03
NS Package Number T05D

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September 1996

LM2576/LM2576HV Series SIMPLE SWITCHER® 3A Step-Down Voltage Regulator

General Description

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 µA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

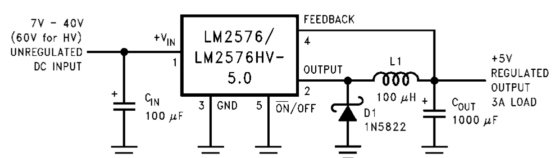
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 3A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

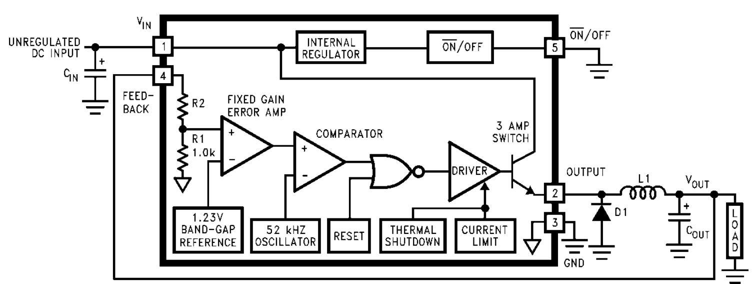
Typical Application (Fixed Output Voltage Versions)



TL/H/11476–1

FIGURE 1

Block Diagram



3.3V R2 = 1.7k
5V, R2 = 3.1k
12V, R2 = 8.84k
15V, R2 = 11.3k
For ADJ. Version
R1 = Open, R2 = 0Ω

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Patent Pending

SIMPLE SWITCHER® is a registered trademark of National Semiconductor Corporation.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM2576	45V
LM2576HV	63V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	$-1V$
Power Dissipation	Internally Limited
Storage Temperature Range	$-65°C$ to $+150°C$
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV
Lead Temperature (Soldering, 10 Seconds)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM2576/LM2576HV	$-40°C \leq T_J \leq +125°C$
Supply Voltage	
LM2576	40V
LM2576HV	60V

LM2576-3.3, LM2576HV-3.3
Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-3.3 LM2576HV-3.3		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	3.3	 3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$6V \leq V_{IN} \leq 40V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$6V \leq V_{IN} \leq 60V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.450/**3.482**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	75		%

LM2576-5.0, LM2576HV-5.0
Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-5.0 LM2576HV-5.0		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	5.0	 4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.225/**5.275**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	77		%

LM2576-12, LM2576HV-12

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-12 LM2576HV-12		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	12	 11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \le I_{LOAD} \le 3A$, $15V \le V_{IN} \le 40V$ Circuit of *Figure 2*	12	 11.52/**11.40** 12.48/**12.60**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \le I_{LOAD} \le 3A$, $15V \le V_{IN} \le 60V$ Circuit of *Figure 2*	12	 11.52/**11.40** 12.54/**12.66**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 15V$, $I_{LOAD} = 3A$	88		%

LM2576-15, LM2576HV-15

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-15 LM2576HV-15		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	15	 14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \le I_{LOAD} \le 3A$, $18V \le V_{IN} \le 40V$ Circuit of *Figure 2*	15	 14.40/**14.25** 15.60/**15.75**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \le I_{LOAD} \le 3A$, $18V \le V_{IN} \le 60V$ Circuit of *Figure 2*	15	 14.40/**14.25** 15.68/**15.83**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 18V$, $I_{LOAD} = 3A$	88		%

LM2576-ADJ, LM2576HV-ADJ

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-ADJ LM2576HV-ADJ		Units (Limits)
			Typ	Limit (Note 2)	
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ $V_{OUT} = 5V$, Circuit of *Figure 2*	1.230	 1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576	$0.5A \le I_{LOAD} \le 3A$, $8V \le V_{IN} \le 40V$ $V_{OUT} = 5V$, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576HV	$0.5A \le I_{LOAD} \le 3A$, $8V \le V_{IN} \le 60V$ $V_{OUT} = 5V$, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.273/**1.286**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$, $V_{OUT} = 5V$	77		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25V$ for the 12V version, and $V_{IN} = 30V$ for the 15V version. $I_{LOAD} = 500$ mA.

Symbol	Parameter	Conditions	LM2576-XX LM2576HV-XX Typ	LM2576-XX LM2576HV-XX Limit (Note 2)	Units (Limits)
DEVICE PARAMETERS					
I_b	Feedback Bias Current	$V_{OUT} = 5V$ (Adjustable Version Only)	50	100/**500**	nA
f_O	Oscillator Frequency	(Note 11)	52	 47/**42** 58/**63**	kHz kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 3A$ (Note 4)	1.4	 1.8/**2.0**	V V(Max)
DC	Max Duty Cycle (ON)	(Note 5)	98	 93	% %(Min)
I_{CL}	Current Limit	(Notes 4 and 11)	5.8	 4.2/**3.5** 6.9/**7.5**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6 and 7) Output = 0V Output = −1V Output = −1V	 7.5 	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$/OFF Pin = 5V (OFF)	50	 200	μA μA(Max)
θ_{JA} θ_{JA} θ_{JC} θ_{JA}	Thermal Resistance	T Package, Junction to Ambient (Note 8) T Package, Junction to Ambient (Note 9) T Package, Junction to Case S Package, Junction to Ambient (Note 10)	65 45 2 50		°C/W
$\overline{ON}$/OFF CONTROL Test Circuit *Figure 2*					
V_{IH}	$\overline{ON}$/OFF Pin Logic Input Level	$V_{OUT} = 0V$	1.4	2.2/**2.4**	V(Min)
V_{IL}		V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	V(Max)
I_{IH}	$\overline{ON}$/OFF Pin Input Current	$\overline{ON}$/OFF Pin = 5V (OFF)	12	 30	μA μA(Max)
I_{IL}		$\overline{ON}$/OFF Pin = 0V (ON)	0	 10	μA μA(Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2576/LM2576HV is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 7: $V_{IN} = 40V$ (60V for high voltage version).

Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

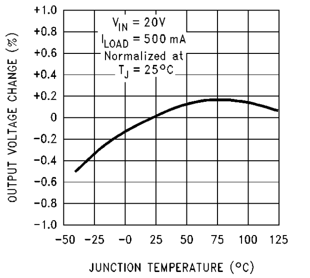
Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ¼ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

Note 10: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W, with 1 square inch of copper area, θ_{JA} is 37°C/W, and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

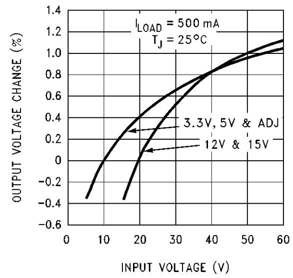
Note 11: The oscillator frequency reduces to approximately 11 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics (Circuit of *Figure 2*)

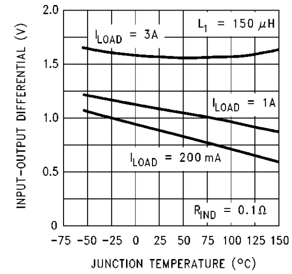
Normalized Output Voltage



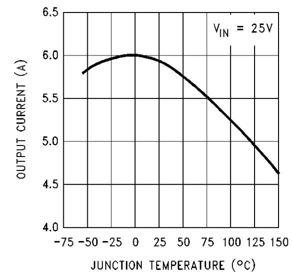
Line Regulation



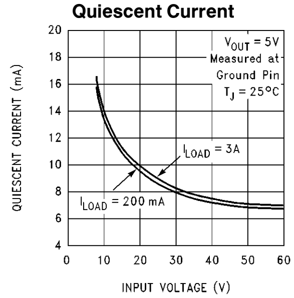
Dropout Voltage



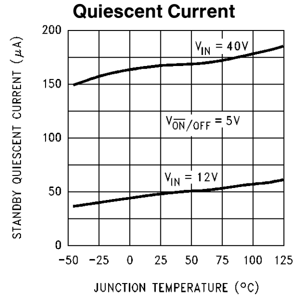
Current Limit



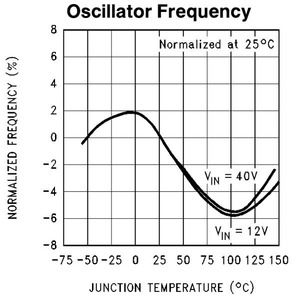
Quiescent Current



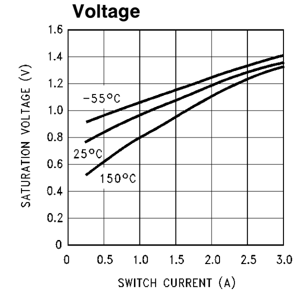
Standby Quiescent Current



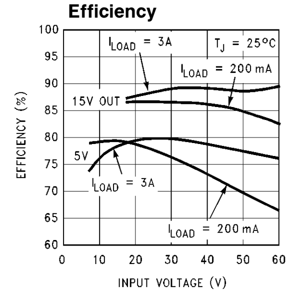
Oscillator Frequency



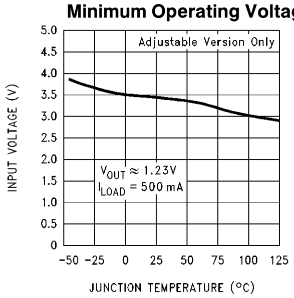
Switch Saturation Voltage



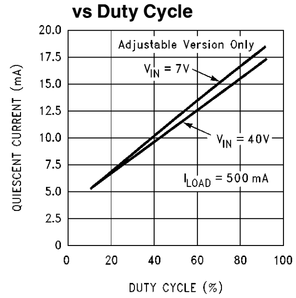
Efficiency



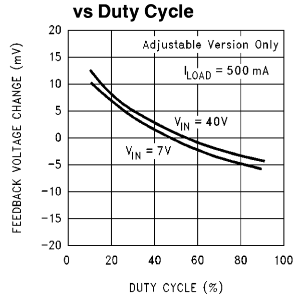
Minimum Operating Voltage



Quiescent Current vs Duty Cycle



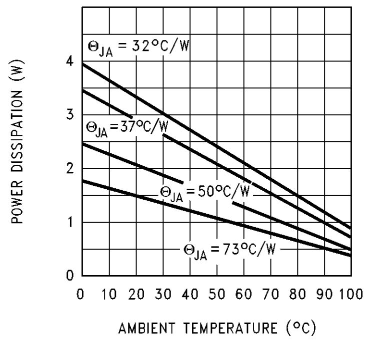
Feedback Voltage vs Duty Cycle



TL/H/11476–3

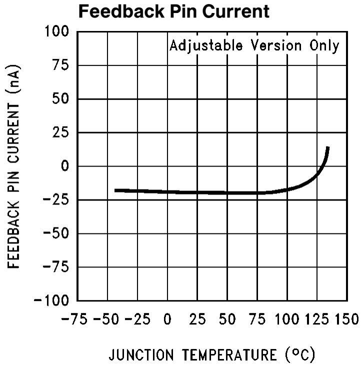
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Maximum Power Dissipation (TO-263) (See Note 10)



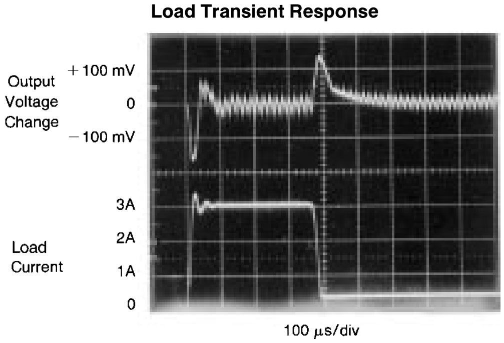
TL/H/11476–24

Feedback Pin Current



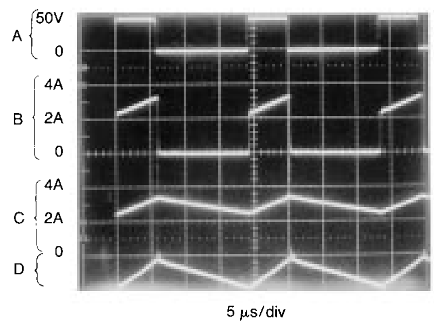
TL/H/11476–4

Load Transient Response



TL/H/11476–5

Switching Waveforms



TL/H/11476–6

V_{OUT} = 15V

A: Output Pin Voltage, 50V/div

B: Output Pin Current, 2A/div

C: Inductor Current, 2A/div

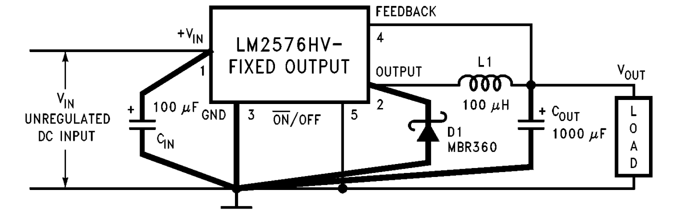
D: Output Ripple Voltage, 50 mV/div, AC-Coupled

Horizontal Time Base: 5 μs/div

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



TL/H/11476-7

C_{IN} — 100 μF, 75V, Aluminum Electrolytic

C_{OUT} — 1000 μF, 25V, Aluminum Electrolytic

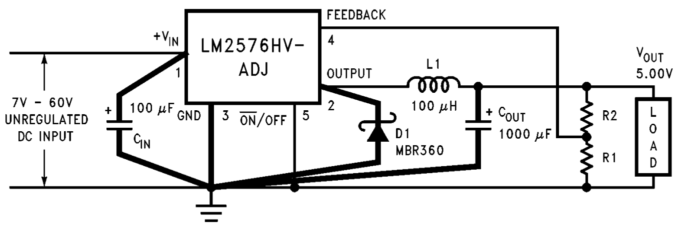
D_1 — Schottky, MBR360

L_1 — 100 μH, Pulse Eng. PE-92108

R_1 — 2k, 0.1%

R_2 — 6.12k, 0.1%

Adjustable Output Voltage Version



TL/H/11476-8

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where $V_{REF} = 1.23V$, R1 between 1k and 5k.

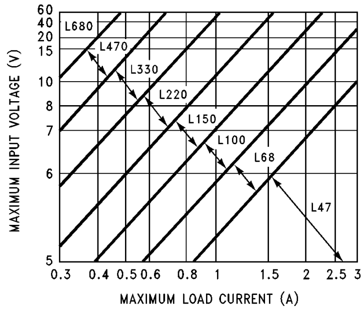
FIGURE 2

LM2576 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(Max) = 15V I_{LOAD}(Max) = 3A
1. Inductor Selection (L1) **A.** Select the correct Inductor value selection guide from *Figures 3, 4, 5,* or *6* . (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by V_{IN}(Max) and I_{LOAD}(Max), and note the inductor code for that region. **C.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 3* . Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of 1.15 × I_{LOAD}. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1)** **A.** Use the selection guide shown in *Figure 4* . **B.** From the selection guide, the inductance area intersected by the 15V line and 3A line is L100. **C.** Inductor value required is 100 µH. From the table in *Figure 3*. Choose AIE 415-0930, Pulse Engineering PE92108, or Renco RL2444.
2. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 µF and 470 µF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT})** **A.** C_{OUT} = 680 µF to 2000 µF standard aluminum electrolytic. **B.** Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1)** **A.** For this example, a 3A current rating is adequate. **B.** Use a 20V 1N5823 or SR302 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 8* .
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 100 µF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

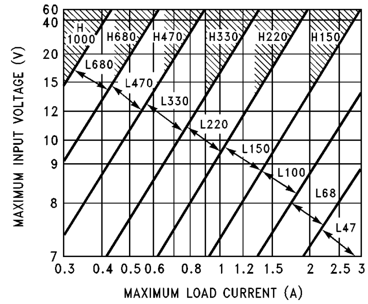
LM2576 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)



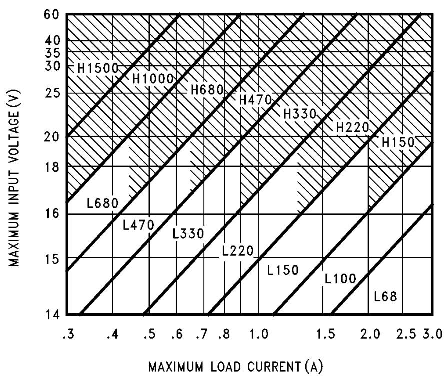
TL/H/11476–9

FIGURE 3. LM2576(HV)-3.3



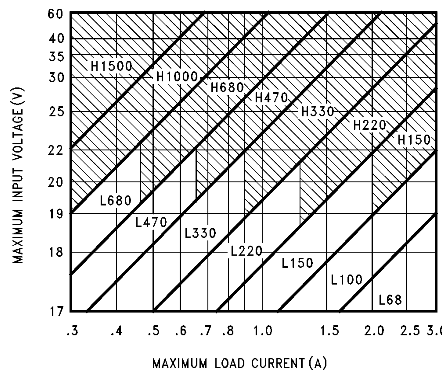
TL/H/11476–10

FIGURE 4. LM2576(HV)-5.0



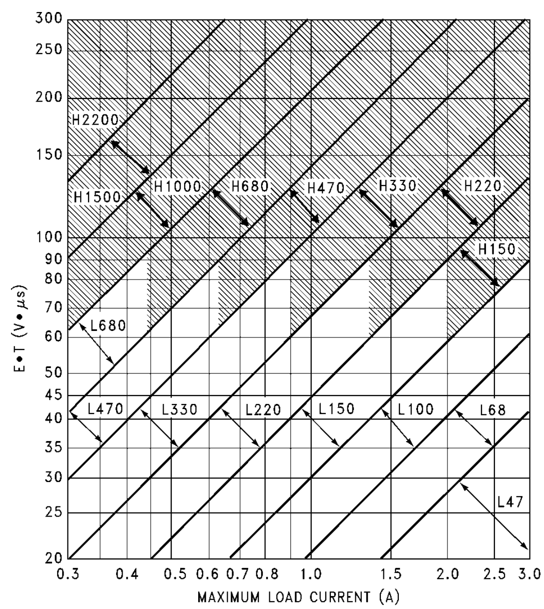
TL/H/11476–11

FIGURE 5. LM2576(HV)-12



TL/H/11476–12

FIGURE 6. LM2576(HV)-15



TL/H/11476–13

FIGURE 7. LM2576(HV)-ADJ

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
V_{IN}(Max) = Maximum Input Voltage
I_{LOAD}(Max) = Maximum Load Current
F = Switching Frequency *(Fixed at 52 kHz)*

1. Programming Output Voltage *(Selecting R1 and R2, as shown in Figure 2)*

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)*

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. Inductor Selection (L1)

A. Calculate the inductor Volt • microsecond constant, E • T (V • µs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT})\frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (\text{in kHz})}\ (V \bullet \mu s)$$

B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 7*.

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor code for that region.

E. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. Output Capacitor Selection (C_{OUT})

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 13{,}300\ \frac{V_{IN}(\text{Max})}{V_{OUT} \bullet L(\mu H)}\ (\mu F)$$

The above formula yields capacitor values between 10 µF and 2200 µF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = 10V
V_{IN}(Max) = 25V
I_{LOAD}(Max) = 3A
F = 52 kHz

1. Programming Output Voltage *(Selecting R1 and R2)*

$$V_{OUT} = 1.23\left(1 + \frac{R_2}{R_1}\right) \qquad \text{Select R1} = 1k$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$$

R_2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k

2. Inductor Selection (L1)

A. Calculate E • T (V • µs)

$$E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115\ V \bullet \mu s$$

B. E • T = 115 V • µs
C. I_{LOAD}(Max) = 3A
D. Inductance Region = H150
E. Inductor Value = 150 µH *Choose from* ***AIE*** *part #415-0936* ***Pulse Engineering*** *part #*PE-531115, or ***Renco*** *part #RL2445.*

3. Output Capacitor Selection (C_{OUT})

A. $C_{OUT} > 13{,}300\ \frac{25}{10 \bullet 150} = 22.2\ \mu F$

However, for acceptable output ripple voltage select

$C_{OUT} \geq 680\ \mu F$

C_{OUT} = 680 µF electrolytic capacitor

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
4. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8* . **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1)** **A.** For this example, a 3.3A current rating is adequate. **B.** Use a 30V 31DQ03 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8*.
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 100 µF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

V_R	Schottky		Fast Recovery	
	3A	4A–6A	3A	4A–6A
20V	1N5820 MBR320P SR302	1N5823	The following diodes are all rated to 100V 31DF1 HER302	The following diodes are all rated to 100V 50WF10 MUR410 HER602
30V	1N5821 MBR330 31DQ03 SR303	50WQ03 1N5824		
40V	1N5822 MBR340 31DQ04 SR304	MBR340 50WQ04 1N5825		
50V	MBR350 31DQ05 SR305	50WQ05		
60V	MBR360 DQ06 SR306	50WR06 50SQ060		

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the SIMPLE SWITCHER line of switching regulators. ***Switchers Made Simple*** *(Version 3.3) is available on a (3½″) diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	Schott (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L47	47 µH	671 26980	PE-53112	RL2442
L68	68 µH	671 26990	PE-92114	RL2443
L100	100 µH	671 27000	PE-92108	RL2444
L150	150 µH	671 27010	PE-53113	RL1954
L220	220 µH	671 27020	PE-52626	RL1953
L330	330 µH	671 27030	PE-52627	RL1952
L470	470 µH	671 27040	PE-53114	RL1951
L680	680 µH	671 27050	PE-52629	RL1950
H150	150 µH	671 27060	PE-53115	RL2445
H220	220 µH	671 27070	PE-53116	RL2446
H330	330 µH	671 27080	PE-53117	RL2447
H470	470 µH	671 27090	PE-53118	RL1961
H680	680 µH	671 27100	PE-53119	RL1960
H1000	1000 µH	671 27110	PE-53120	RL1959
H1500	1500 µH	671 27120	PE-53121	RL1958
H2200	2200 µH	671 27130	PE-53122	RL2448

Note 1: Schott Corporation, (612) 475-1173, 1000 Parkers Lake Road, Wayzata, MN 55391.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12235, San Diego, CA 92112.

Note 3: Renco Electronics Incorporated, (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 100 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below −25°C, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

where $\frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$ for a buck regulator

and $\frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}}$ for a buck-boost regulator.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2576 (or any of the SIMPLE SWITCHER family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figure 3* through *Figure 7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 300 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toriod, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2576 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF–1000 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND}) (\text{ESR of } C_{OUT})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2576 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 µH & 100 µF) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 × reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2576 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2576 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$/OFF INPUT

For normal operation, the $\overline{\text{ON}}$/OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$/OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$/OFF pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the 5-lead TO-220 and TO-263 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, only a small heat sink is required to keep the LM2576 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (125°C for the LM2576). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperatures should be selected.
4. LM2576 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2576 can be estimated as follows:

$$P_D = (V_{IN})(I_Q) + (V_O/V_{IN})(I_{LOAD})(V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\,(\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\,(\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

Included on the **Switcher Made Simple** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2576-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 700 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

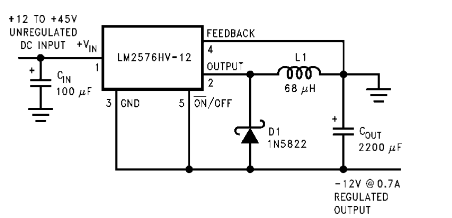
The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μH and 220 μH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}\,(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}\,|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2L_1\,f_{osc}}$$

Where f_{osc} = 52 kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.



TL/H/11476–14

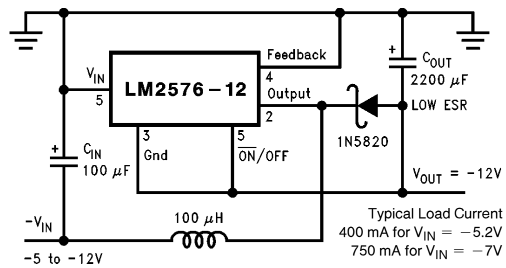
FIGURE 10. Inverting Buck-Boost Develops −12V

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2576 is +28V, or +48V for the LM2576HV.

The ***Switchers Made Simple*** (version 3.0) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.



Note: Heat sink may be required. TL/H/11476–15

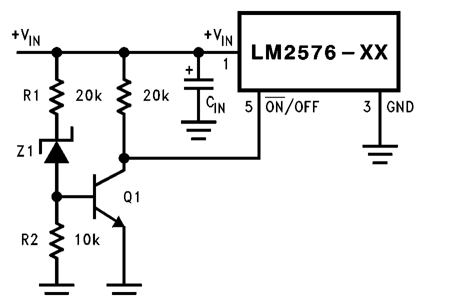
FIGURE 11. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

$$V_{TH} \approx V_{Z1} + 2V_{BE}\,(Q1)$$



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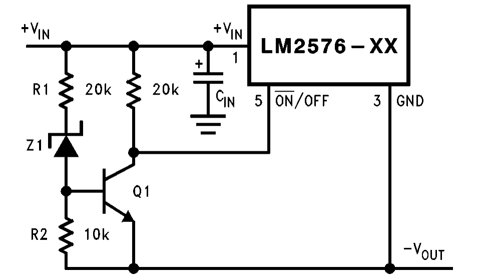
Note: Complete circuit not shown.

FIGURE 12. Undervoltage Lockout for Buck Circuit



TL/H/11476–17

Note: Complete circuit not shown (see Figure 10).

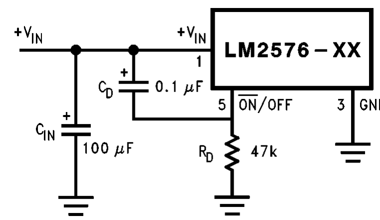
FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit

DELAYED STARTUP

The ON/OFF pin can be used to provide a delayed startup feature as shown in *Figure 14*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the ON/OFF pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 3A power supply that features an adjustable output voltage is shown in *Figure 15*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



TL/H/11476–18

Note: Complete circuit not shown.

FIGURE 14. Delayed Startup

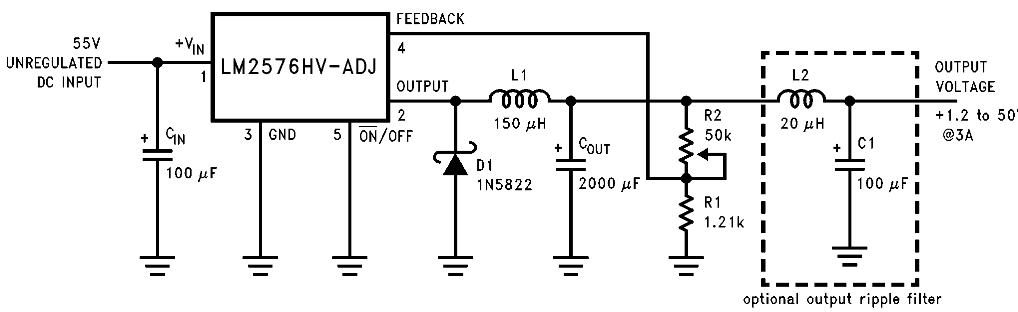


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FIGURE 15. 1.2V to 55V Adjustable 3A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator $$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$$

for buck-boost regulator $$D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2576 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

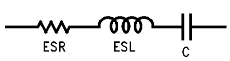

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FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 μF–1000 μF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors (''low-ESR'', ''high-frequency'', or ''low-inductance''') in the 100 μF–1000 μF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2576 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

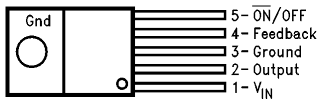
OPERATING VOLT MICROSECOND CONSTANT ($E \bullet T_{op}$)

The product (in Volt•μs) of the voltage applied to the inductor and the time the voltage is applied. This $E \bullet T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

(XX indicates output voltage option. See ordering information table for complete part number.)

Straight Leads
5-Lead TO-220 (T)
Top View



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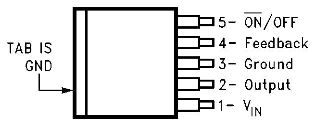
LM2576T-XX or LM2576HVT-XX
NS Package Number T05A

TO-263 (S)
5-Lead Surface-Mount Package
Top View



TL/H/11476–25

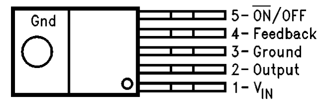
Side View

TL/H/11476–26

LM2576S-XX or LM2576HVS-XX
NS Package Number TS5B

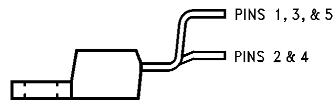
LM2576SX-XX or LM2576HVSX-XX
NS Package Number TS5B, Tape and Reel

Bent, Staggered Leads
5-Lead TO-220 (T)
Top View



TL/H/11476–22

Side View



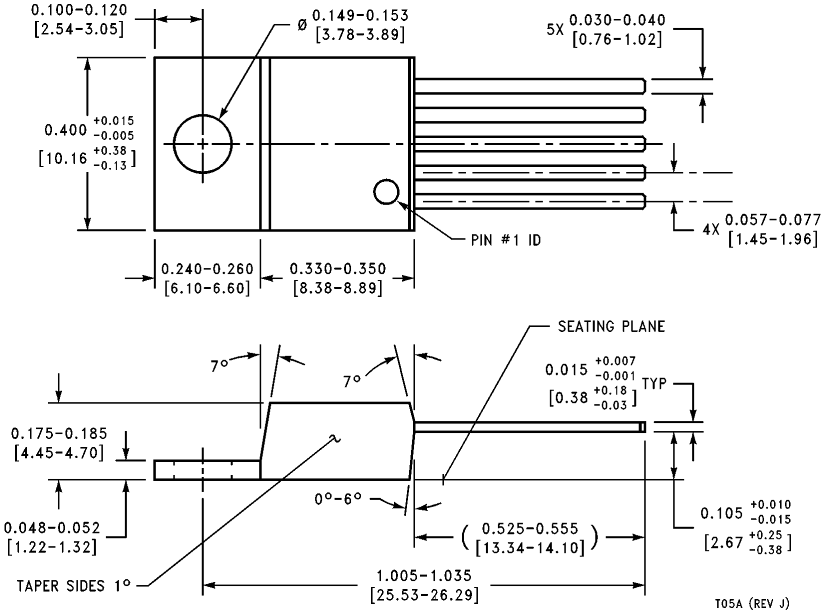
TL/H/11476–23

LM2576T-XX Flow LB03
or LM2576HVT-XX Flow LB03
NS Package Number T05D

Ordering Information

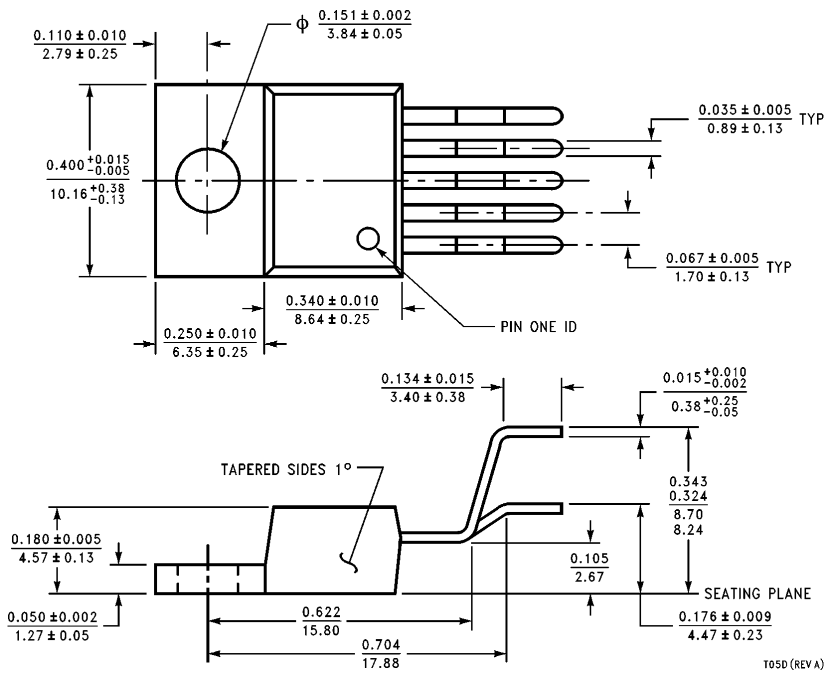
Temperature Range	Output Voltage					NS Package	Package
	3.3	5.0	12	15	ADJ	Number	Type
−40°C ≤ T_A ≤ 125°C	LM2576HVS-3.3	LM2576HVS-5.0	LM2576HVS-12	LM2576HVS-15	LM2576HVS-ADJ	TS5B	TO-263
	LM2576S-3.3	LM2576S-5.0	LM2576S-12	LM2576S-15	LM2576S-ADJ		
	LM2576HVSX-3.3	LM2576HVSX-5.0	LM2576HVSX-12	LM2576HVSX-15	LM2576HVSX-ADJ	TS5B Tape & Reel	
	LM2576SX-3.3	LM2576SX-5.0	LM2576SX-12	LM2576SX-15	LM2576SX-ADJ		
	LM2576HVT-3.3	LM2576HVT-5.0	LM2576HVT-12	LM2576HVT-15	LM2576HVT-ADJ	T05A	TO-220
	LM2576T-3.3	LM2576T-5.0	LM2576T-12	LM2576T-15	LM2576T-ADJ		
	LM2576HVT-3.3 Flow LB03	LM2576HVT-5.0 Flow LB03	LM2576HVT-12 Flow LB03	LM2576HVT-15 Flow LB03	LM2576HVT-ADJ Flow LB03	T05D	
	LM2576T-3.3 Flow LB03	LM2576T-5.0 Flow LB03	LM2576T-12 Flow LB03	LM2576T-15 Flow LB03	LM2576T-ADJ Flow LB03		

Physical Dimensions inches (millimeters) unless otherwise noted



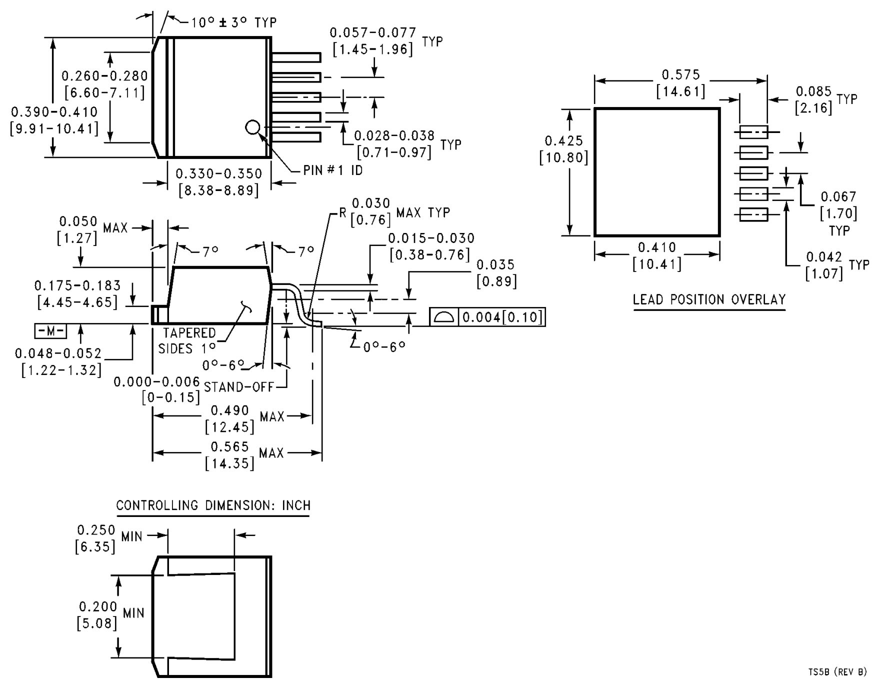
5-Lead TO-220 (T)
Order Number LM2576T-3.3, LM2576HVT-3.3, LM2576T-5.0, LM2576HVT-5.0, LM2576T-12, LM2576HVT-12, LM2576T-15, LM2576HVT-15, LM2576T-ADJ or LM2576HVT-ADJ
NS Package Number T05A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Bent, Staggered 5-Lead TO-220 (T)
Order Number LM2576T-3.3 Flow LB03, LM2576T-XX Flow LB03, LM2576HVT-3.3 Flow LB03,
LM2576T-5.0 Flow LB03, LM2576HVT-5.0 Flow LB03,
LM2576T-12 Flow LB03, LM2576HVT-12 Flow LB03,
LM2576T-15 Flow LB03, LM2576HVT-15 Flow LB03,
LM2576T-ADJ Flow LB03 or LM2576HVT-ADJ Flow LB03
NS Package Number T05D

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



5-Lead TO-263 (S)
Order Number LM2576S-3.3, LM2576S-5.0,
LM2576S-12,LM2576S-15, LM2576S-ADJ,
LM2576HVS-3.3, LM2576HVS-5.0, LM2576HVS-12,
LM2576HVS-15, or LM2576HVS-ADJ
NS Package Number TS5B

5-Lead TO-263 in Tape & Reel (SX)
Order Number LM2576SX-3.3, LM2576SX-5.0,
LM2576SX-12, LM2576SX-15, LM2576SX-ADJ,
LM2576HVSX-3.3, LM2576HVSX-5.0, LM2576HVSX-12,
LM2576HVSX-15, or LM2576HVSX-ADJ
NS Package Number TS5B

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National Semiconductor

February 1996

LM2595 SIMPLE SWITCHER® Power Converter 150 kHz 1A Step-Down Voltage Regulator

General Description

The LM2595 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 1A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation†, and a fixed-frequency oscillator.

The LM2595 series operates at a switching frequency of 150 kHz thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Available in a standard 5-lead TO-220 package with several different lead bend options, and a 5-lead TO-263 surface mount package. Typically, for output voltages less than 12V, and ambient temperatures less than 50°C, no heat sink is required.

A standard series of inductors are available from several different manufacturers optimized for use with the LM2595 series. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage under specified input voltage and output load conditions, and ±15% on the oscillator frequency. External shutdown is included, featuring typically 85 µA stand-by current. Self protection features include a two stage frequency reducing current limit for the output switch and an over temperature shutdown for complete protection under fault conditions.

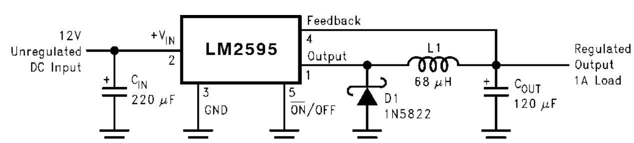
Features

- 3.3V, 5V, 12V, and adjustable output versions
- Adjustable version output voltage range, 1.2V to 37V ±4% max over line and load conditions
- Available in TO-220 and TO-263 (surface mount) packages
- Guaranteed 1A output load current
- Input voltage range up to 40V
- Requires only 4 external components
- Excellent line and load regulation specifications
- 150 kHz fixed frequency internal oscillator
- TTL shutdown capability
- Low power standby mode, I_Q typically 85 µA
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter

Typical Application (Fixed Output Voltage Versions)



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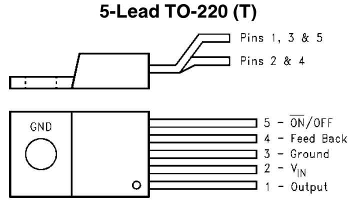
Connection Diagrams and Ordering Information

Bent and Staggered Leads, Through Hole Package
5-Lead TO-220 (T)

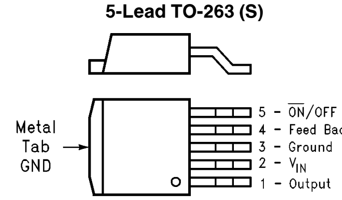


TL/H/12565–2

Side View

Top View

Surface Mount Package
5-Lead TO-263 (S)



TL/H/12565–3

Order Number LM2595T-3.3, LM2595T-5.0, LM2595T-12 or LM2595T-ADJ
See NS Package Number T05D

Order Number LM2595S-3.3, LM2595S-5.0, LM2595S-12 or LM2595S-ADJ
See NS Package Number TS5B

†Patent Number 5,382,918.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	45V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3 \le V \le +25V$
Feedback Pin Voltage	$-0.3 \le V \le +25V$
Output Voltage to Ground (Steady State)	$-1V$
Power Dissipation	Internally limited
Storage Temperature Range	−65°C to +150°C
ESD Susceptibility	
Human Body Model (Note 2)	2 kV
Lead Temperature	
S Package	
Vapor Phase (60 sec.)	+215°C
Infrared (10 sec.)	+245°C
T Package (Soldering, 10 sec.)	+260°C
Maximum Junction Temperature	+150°C

Operating Conditions

Temperature Range	$-25°C \le T_J + 125°C$
Supply Voltage	4.5V to 40V

LM2595-3.3

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2595-3.3 Typ (Note 3)	LM2595-3.3 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$4.75V \le V_{IN} \le 40V$, $0.1A \le I_{LOAD} \le 1A$	3.3		V
				3.168/**3.135**	V(min)
				3.432/**3.465**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	78		%

LM2595-5.0

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2595-5.0 Typ (Note 3)	LM2595-5.0 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$7V \le V_{IN} \le 40V$, $0.1A \le I_{LOAD} \le 1A$	5.0		V
				4.800/**4.750**	V(min)
				5.200/**5.250**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	82		%

LM2595-12

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2595-12 Typ (Note 3)	LM2595-12 Limit (Note 4)	Units (Limits)
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$15V \le V_{IN} \le 40V$, $0.1A \le I_{LOAD} \le 1A$	12.0		V
				11.52/**11.40**	V(min)
				12.48/**12.60**	V(max)
η	Efficiency	$V_{IN} = 25V$, $I_{LOAD} = 1A$	90		%

LM2595-ADJ

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**

Symbol	Parameter	Conditions	LM2595-ADJ		Units (Limits)
			Typ (Note 3)	Limit (Note 4)	
SYSTEM PARAMETERS (Note 5) Test Circuit *Figure 2*					
V_{FB}	Feedback Voltage	$4.5V \le V_{IN} \le 40V$, $0.1A \le I_{LOAD} \le 1A$ V_{OUT} programmed for 3V. Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.267/**1.280**	V V(min) V(max)
η	Efficiency	$V_{IN} = 12V$, $V_{OUT} = 3V$, $I_{LOAD} = 1A$	78		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version and $V_{IN} = 24V$ for the 12V version. $I_{LOAD} = 200$ mA

Symbol	Parameter	Conditions	LM2595-XX		Units (Limits)
			Typ (Note 3)	Limit (Note 4)	
DEVICE PARAMETERS					
I_b	Feedback Bias Current	Adjustable Version Only, $V_{FB} = 1.3V$	10	 50/**100**	nA nA (max)
f_O	Oscillator Frequency	(Note 6)	150	 127/**110** 173/**173**	kHz kHz(min) kHz(max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 1A$ (Notes 7 and 8)	1	 1.2/**1.3**	V V(max)
DC	Max Duty Cycle (ON) Min Duty Cycle (OFF)	(Note 8) (Note 9)	100 0		%
I_{CL}	Current Limit	Peak Current (Notes 7 and 8)	1.5	 1.2/**1.15** 2.4/**2.6**	A A(min) A(max)
I_L	Output Leakage Current	(Notes 7, 9, and 10) Output = 0V Output = −1V	 2	50 15	μA(max) mA mA(max)
I_Q	Quiescent Current	(Note 9)	5	 10	mA mA(max)
I_{STBY}	Standby Quiescent Current	ON/OFF pin = 5V (OFF) (Note 10)	85	 200/**250**	μA μA(max)
θ_{JC} θ_{JA} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	TO-220 or TO-263 Package, Junction to Case TO-220 Package, Junction to Ambient (Note 11) TO-263 Package, Junction to Ambient (Note 12) TO-263 Package, Junction to Ambient (Note 13) TO-263 Package, Junction to Ambient (Note 14)	2 50 50 30 20		°C/W °C/W °C/W °C/W °C/W
ON/OFF CONTROL Test Circuit *Figure 2*					
 V_{IH} V_{IL}	$\overline{ON}$/OFF Pin Logic Input Threshold Voltage	 Low (Regulator ON) High (Regulator OFF)	1.3	 **0.6** **2.0**	V V(max) V(min)
I_H	$\overline{ON}$/OFF Pin Input Current	$V_{LOGIC} = 2.5V$ (Regulator OFF)	5	 15	μA μA(max)
I_L		$V_{LOGIC} = 0.5V$ (Regulator ON)	0.02	 5	μA μA(max)

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: The human body model is a 100 pF capacitor discharged through a 1.5k resistor into each pin.

Note 3: Typical numbers are at 25°C and represent the most likely norm.

Note 4: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).

Note 5: External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2595 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 6: The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.

Note 7: No diode, inductor or capacitor connected to output pin.

Note 8: Feedback pin removed from output and connected to 0V to force the output transistor switch ON.

Note 9: Feedback pin removed from output and connected to 12V for the 3.3V, 5V, and the ADJ. version, and 15V for the 12V version, to force the output transistor switch OFF.

Note 10: V_{IN} = 40V.

Note 11: Junction to ambient thermal resistance (no external heat sink) for the TO-220 package mounted vertically, with the leads soldered to a printed circuit board with (1 oz.) copper area of approximately 1 in^2.

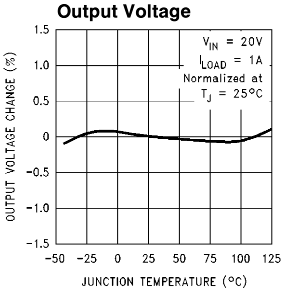
Note 12: Junction to ambient thermal resistance with the TO-263 package tab soldered to a single printed circuit board with 0.5 in^2 of (1 oz.) copper area.

Note 13: Junction to ambient thermal resistance with the TO-263 package tab soldered to a single sided printed circuit board with 2.5 in^2 of (1 oz.) copper area.

Note 14: Junction to ambient thermal resistance with the TO-263 package tab soldered to a double sided printed circuit board with 3 in^2 of (1 oz.) copper area on the LM2595S side of the board, and approximately 16 in^2 of copper on the other side of the p-c board. See Application Information in this data sheet and the thermal model in ***Switchers Made Simple®*** version 4.2 software.

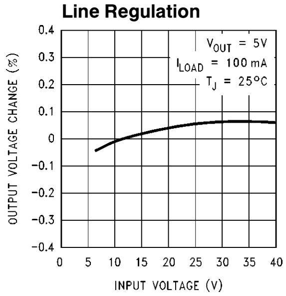
Typical Performance Characteristics (Circuit of *Figure 2*)

Normalized Output Voltage



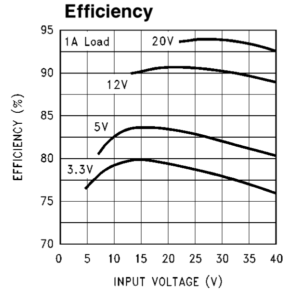
TL/H/12565–11

Line Regulation



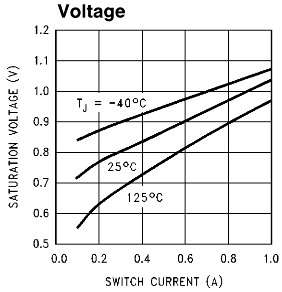
TL/H/12565–12

Efficiency



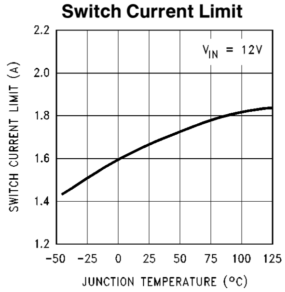
TL/H/12565–13

Switch Saturation Voltage



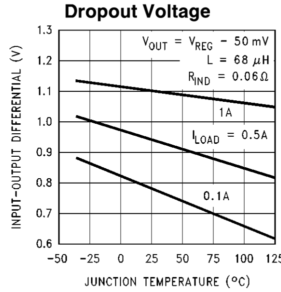
TL/H/12565–14

Switch Current Limit



TL/H/12565–15

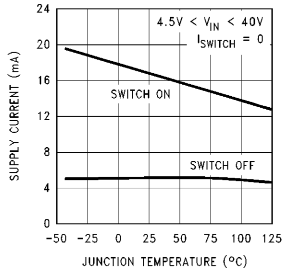
Dropout Voltage



TL/H/12565–16

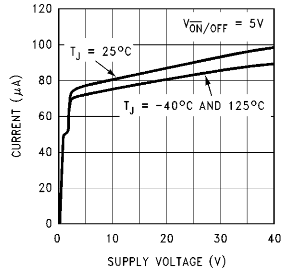
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Operating Quiescent Current



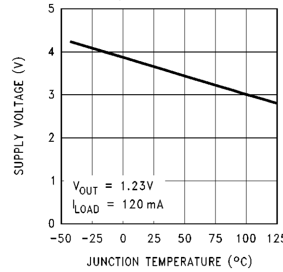
TL/H/12565–4

Shutdown Quiescent Current



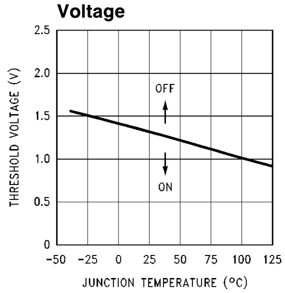
TL/H/12565–5

Minimum Operating Supply Voltage



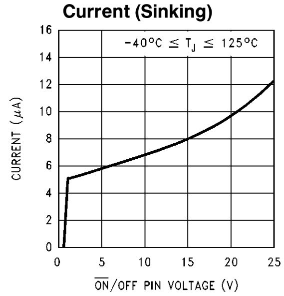
TL/H/12565–6

$\overline{ON}$/OFF Threshold Voltage



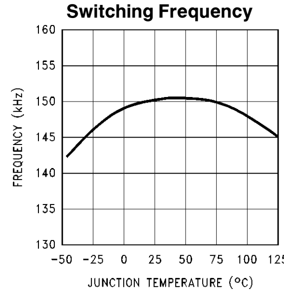
TL/H/12565–7

$\overline{ON}$/OFF Pin Current (Sinking)



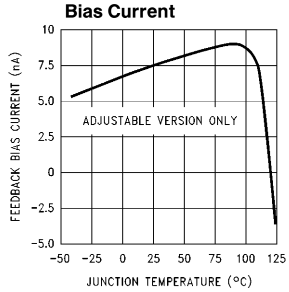
TL/H/12565–8

Switching Frequency



TL/H/12565–9

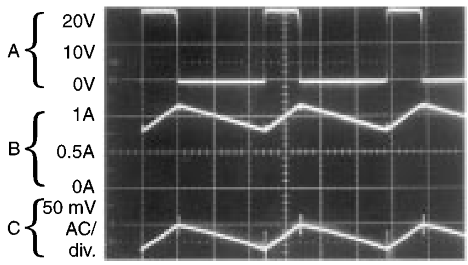
Feedback Pin Bias Current



TL/H/12565–10

Typical Performance Characteristics (Circuit of *Figure 2*)

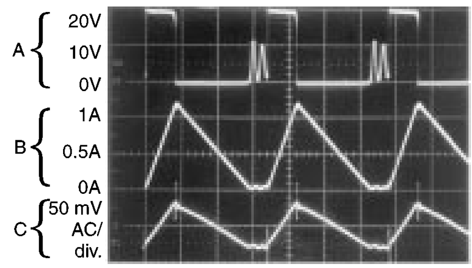
Continuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 1A
L = 68 μH, C_{OUT} = 120 μF, C_{OUT} ESR = 100 mΩ



TL/H/12565–17

A: Output Pin Voltage, 10V/div.
B: Inductor Current 0.5A/div.
C: Output Ripple Voltage, 50 mV/div.
Horizontal Time Base: 2 μs/div.

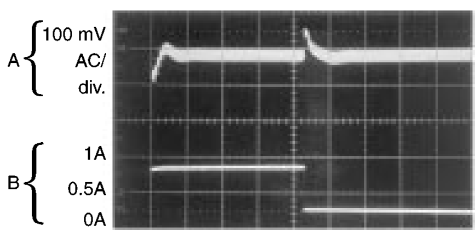
Discontinuous Mode Switching Waveforms
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 600 mA
L = 22 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



TL/H/12565–18

A: Output Pin Voltage, 10V/div.
B: Inductor Current 0.5A/div.
C: Output Ripple Voltage, 50 mV/div.
Horizontal Time Base: 2 μs/div.

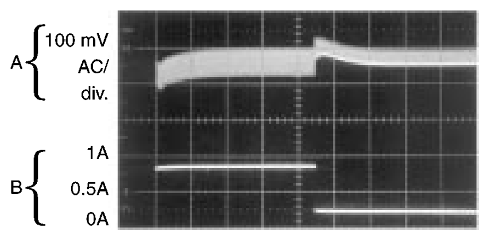
Load Transient Response for Continuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 250 mA to 750 mA
L = 68 μH, C_{OUT} = 120 μF, C_{OUT} ESR = 100 mΩ



TL/H/12565–19

A: Output Voltage, 100 mV/div. (AC)
B: 250 mA to 750 mA Load Pulse
Horizontal Time Base: 100 μs/div.

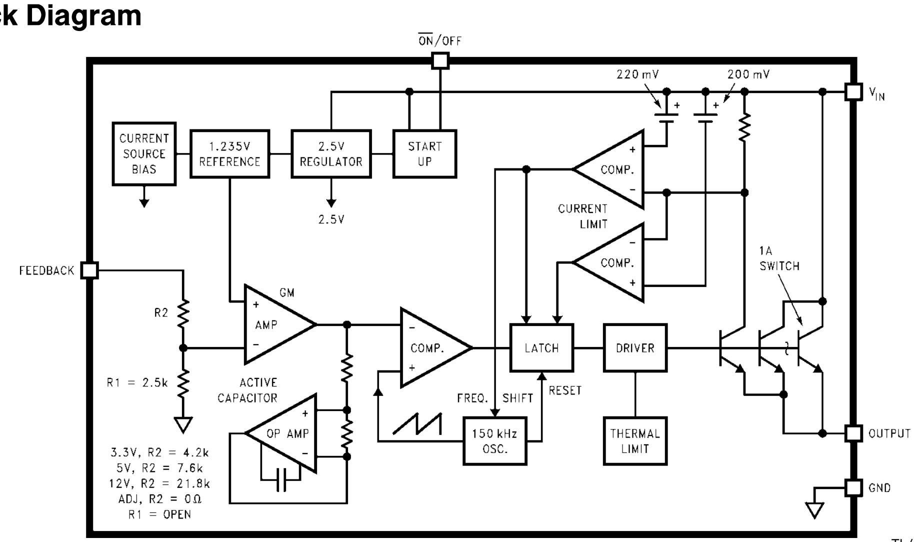
Load Transient Response for Discontinuous Mode
V_{IN} = 20V, V_{OUT} = 5V, I_{LOAD} = 250 mA to 750 mA
L = 22 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ



TL/H/12565–20

A: Output Voltage, 100 mV/div. (AC)
B: 250 mA to 750 mA Load Pulse
Horizontal Time Base: 200 μs/div.

Block Diagram

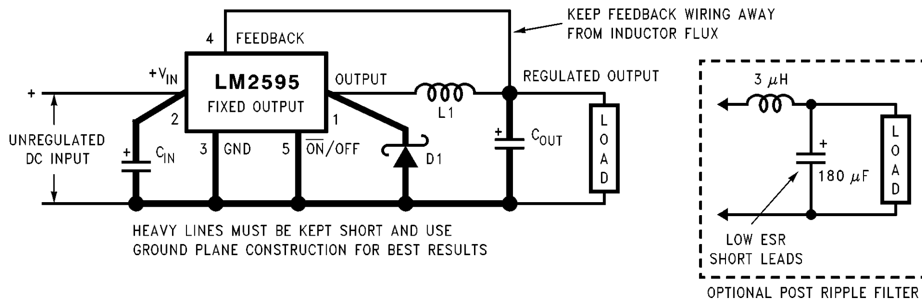


TL/H/12565–21

FIGURE 1

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



TL/H/12565–22

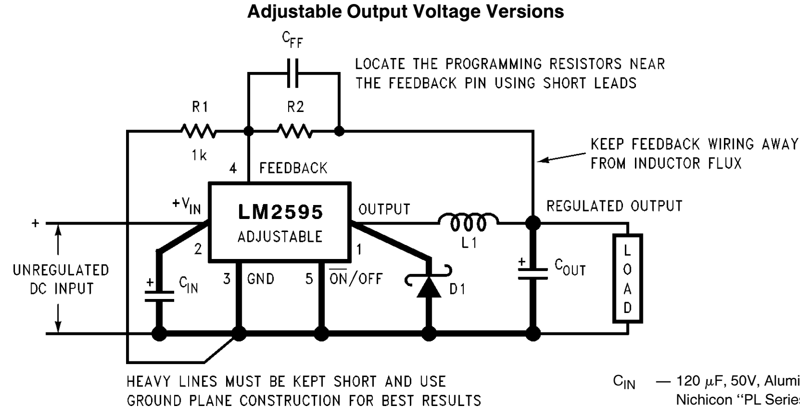
C_{IN} — 120 μF, 50V, Aluminum Electrolytic Nichicon "PL Series"

C_{OUT} — 120 μF, 25V Aluminum Electrolytic, Nichicon "PL Series"

D1 — 3A, 40V Schottky Rectifier, 1N5822

L1 — 100 μH, L29

Adjustable Output Voltage Versions



TL/H/12565–23

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$ where $V_{REF} = 1.23V$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$ Select R_1 to be approximately 1 kΩ, use a 1% resistor for best stability.

C_{IN} — 120 μF, 50V, Aluminum Electrolytic Nichicon "PL Series"

C_{OUT} — 120 μF, 25V Aluminum Electrolytic, Nichicon "PL Series"

D1 — 3A, 40V Schottky Rectifier, 1N5822

L1 — 100 μH, L29

R_1 — 1 kΩ, 1%

C_{FF} — See Application Information Section

FIGURE 2. Standard Test Circuits and Layout Guides

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance can generate voltage transients which can cause problems. For minimal inductance and ground loops, the wires indicated by **heavy lines should be wide printed circuit traces and should be kept as short as possible.** For best results, external components should be located as close to the switcher IC as possible using ground plane construction or single point grounding.

If **open core inductors are used,** special care must be taken as to the location and positioning of this type of inductor. Allowing the inductor flux to intersect sensitive feedback, IC groundpath and C_{OUT} wiring can cause problems.

When using the adjustable version, special care must be taken as to the location of the feedback resistors and the associated wiring. Physically locate both resistors near the IC, and route the wiring away from the inductor, especially an open core type of inductor. (See application section for more information.)

LM2595 Series Buck Regulator Design Procedure (Fixed Output)

PROCEDURE (Fixed Output Voltage Version)

Given:

V_{OUT} = Regulated Output Voltage (3.3V, 5V or 12V)

V_{IN}(max) = Maximum DC Input Voltage

I_{LOAD}(max) = Maximum Load Current

1. Inductor Selection (L1)

A. Select the correct inductor value selection guide from *Figures 5, 6,* or *7.* (Output voltages of 3.3V, 5V, or 12V respectively.) For all other voltages, see the design procedure for the adjustable version.

B. From the inductor value selection guide, identify the inductance region intersected by the Maximum Input Voltage line and the Maximum Load Current line. Each region is identified by an inductance value and an inductor code (LXX).

C. Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 9.*

2. Output Capacitor Selection (C_{OUT})

A. In the majority of applications, low ESR (Equivalent Series Resistance) electrolytic capacitors between 47 µF and 330 µF and low ESR solid tantalum capacitors between 56 µF and 270 µF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 330 µF.

For additional information, see section on output capacitors in application information section.

B. To simplify the capacitor selection procedure, refer to the quick design component selection table shown in *Figure 3.* This table contains different input voltages, output voltages, and load currents, and lists various inductors and output capacitors that will provide the best design solutions.

C. The capacitor voltage rating for electrolytic capacitors should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements for low output ripple voltage.

D. For computer aided design software, see ***Switchers Made Simple***® version 4.2 or later.

3. Catch Diode Selection (D1)

A. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2595. The most stressful condition for this diode is an overload or shorted output condition.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

C. This diode must be fast (short reverse recovery time) and must be located close to the LM2595 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-

Procedure continued on next page.

EXAMPLE (Fixed Output Voltage Version)

Given:

V_{OUT} = 5V

V_{IN}(max) = 12V

I_{LOAD}(max) = 1A

1. Inductor Selection (L1)

A. Use the inductor selection guide for the 5V version shown in *Figure 6.*

B. From the inductor value selection guide shown in *Figure 6,* the inductance region intersected by the 12V horizontal line and the 1A vertical line is 68 µH, and the inductor code is L30.

C. The inductance value required is 68 µH. From the table in *Figure 9,* go to the L30 line and choose an inductor part number from any of the four manufacturers shown. (In most instance, both through hole and surface mount inductors are available.)

2. Output Capacitor Selection (C_{OUT})

A. See section on output capacitors in application information section.

B. From the quick design component selection table shown in *Figure 3,* locate the 5V output voltage section. In the load current column, choose the load current line that is closest to the current needed in your application, for this example, use the 1A line. In the maximum input voltage column, select the line that covers the input voltage needed in your application, in this example, use the 15V line. Continuing on this line are recommended inductors and capacitors that will provide the best overall performance.

The capacitor list contains both through hole electrolytic and surface mount tantalum capacitors from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturer's series that are listed in the table be used.

In this example aluminum electrolytic capacitors from several different manufacturers are available with the range of ESR numbers needed.

220 µF 25V Panasonic HFQ Series

220 µF 25V Nichicon PL Series

C. For a 5V output, a capacitor voltage rating at least 7.5V or more is needed. But, in this example, even a low ESR, switching grade, 220 µF 10V aluminum electrolytic capacitor would exhibit approximately 225 mΩ of ESR (see the curve in *Figure 14* for the ESR vs voltage rating). This amount of ESR would result in relatively high output ripple voltage. To reduce the ripple to 1% of the output voltage, or less, a capacitor with a higher voltage rating (lower ESR) should be selected. A 16V or 25V capacitor will reduce the ripple voltage by approximately half.

3. Catch Diode Selection (D1)

A. Refer to the table shown in *Figure 12.* In this example, a 3A, 20V, 1N5820 Schottky diode will provide the best performance, and will not be overstressed even for a shorted output.

Example continued on next page.

PROCEDURE (Fixed Output Voltage Version)	EXAMPLE (Fixed Output Voltage Version)

PROCEDURE (Fixed Output Voltage Version)

Efficiency rectifiers also provide good results. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.

4. Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin to prevent large voltage transients from appearing at the input. This capacitor should be located close to the IC using short leads. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

For an aluminum electrolytic, the capacitor voltage rating should be approximately 1.5 times the maximum input voltage. Caution must be exercised if solid tantalum capacitors are used (see Application Information on input capacitor). The tantalum capacitor voltage rating should be 2 times the maximum input voltage and it is recommended that they be surge current tested by the manufacturer.

Use caution when using ceramic capacitors for input bypassing, because it may cause severe ringing at the V_{IN} pin.

For additional information, see section on input capacitors in Application Information section.

EXAMPLE (Fixed Output Voltage Version)

4. Input Capacitor (C_{IN})

The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 12V, an aluminum electrolytic capacitor with a voltage rating greater than 18V (1.5 × V_{IN}) would be needed. The next higher capacitor voltage rating is 25V.

The RMS current rating requirement for the input capacitor in a buck regulator is approximately ½ the DC load current. In this example, with a 1A load, a capacitor with a RMS current rating of at least 500 mA is needed. The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 25V line and note which capacitor values have RMS current ratings greater than 500 mA. Either a 180 μF or 220 μF, 25V capacitor could be used.

For a through hole design, a 220 μF/25V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate.

For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rating (see Application Information on input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

Conditions			Inductor		Output Capacitor			
					Through Hole Electrolytic		Surface Mount Tantalum	
Output Voltage (V)	Load Current (A)	Max Input Voltage (V)	Inductance (μH)	Inductor (#)	Panasonic HFQ Series (μF/V)	Nichicon PL Series (μF/V)	AVX TPS Series (μF/V)	Sprague 595D Series (μF/V)
3.3	1	5	22	L24	330/16	330/16	220/10	330/10
		7	33	L23	270/25	270/25	220/10	270/10
		10	47	L31	220/25	220/35	220/10	220/10
		40	68	L30	180/35	220/35	220/10	180/10
	0.5	6	47	L13	220/25	220/16	220/10	220/10
		10	68	L21	150/35	150/25	100/16	150/16
		40	100	L20	150/35	82/35	100/16	100/20
5	1	8	33	L28	330/16	330/16	220/10	270/10
		10	47	L31	220/25	220/25	220/10	220/10
		15	68	L30	180/35	180/35	220/10	150/16
		40	100	L29	180/35	120/35	100/16	120/16
	0.5	9	68	L21	180/16	180/16	220/10	150/16
		20	150	L19	120/25	1200/25	100/16	100/20
		40	150	L19	100/25	100/25	68/20	68/25
12	1	15	47	L31	220/25	220/25	68/20	120/20
		18	68	L30	180/35	120/25	68/20	120/20
		30	150	L36	82/25	82/25	68/20	100/20
		40	220	L35	82/25	82/25	68/20	68/25
	0.5	15	68	L21	180/25	180/25	68/20	120/20
		20	150	L19	82/25	82/25	68/20	100/20
		40	330	L26	56/25	56/25	68/20	68/25

FIGURE 3. LM2595 Fixed Voltage Quick Design Component Selection Table

LM2595 Series Buck Regulator Design Procedure (Adjustable Output)

PROCEDURE (Adjustable Output Voltage Version)

Given:

V_{OUT} = Regulated Output Voltage

$V_{IN}(max)$ = Maximum Input Voltage

$I_{LOAD}(max)$ = Maximum Load Current

F = Switching Frequency *(Fixed at a nominal 150 kHz).*

1. **Programming Output Voltage** (Selecting R_1 and R_2, as shown in *Figure 2*)

   Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

   Select a value for R_1 between 240Ω and 1.5 kΩ. The lower resistor values minimize noise pickup in the sensitive feedback pin. (For the lowest temperature coefficient and the best stability with time, use 1% metal film resistors.)

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. **Inductor Selection (L1)**

   A. Calculate the inductor Volt • microsecond constant E • T (V • μs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT} - V_{SAT}) \bullet \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D} \bullet \frac{1000}{150\ kHz}\ (V \bullet \mu s)$$

   where V_{SAT} = internal switch saturation voltage = 1V

   and V_D = diode forward voltage drop = 0.5V

   B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the Inductor Value Selection Guide shown in *Figure 8.*

   C. on the horizontal axis, select the maximum load current.

   D. Identify the inductance region intersected by the E • T value and the Maximum Load Current value. Each region is identified by an inductance value and an inductor code (LXX).

   E. Select an appropriate inductor from the four manufacturer's part numbers listed in *Figure 9.*

3. **Output Capacitor Selection (C_{OUT})**

   A. In the majority of applications, low ESR electrolytic or solid tantalum capacitors between 47 μF and 330 μF provide the best results. This capacitor should be located close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 330 μF. **For additional information, see section on output capacitors in application information section.**

   B. To simplify the capacitor selection procedure, refer to the quick design table shown in *Figure 4.* This table contains different output voltages, and lists various output capacitors that will provide the best design solutions.

   C. The capacitor voltage rating should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements needed for low output ripple voltage.

Procedure continued on next page.

EXAMPLE (Adjustable Output Voltage Version)

Given:

V_{OUT} = 20V

$V_{IN}(max)$ = 28V

$I_{LOAD}(max)$ = 1A

F = Switching Frequency *(Fixed at a nominal 150 kHz).*

1. **Programming Output Voltage** (Selecting R_1 and R_2, as shown in *Figure 2*)

   Select R_1 to be 1 kΩ, 1%. Solve for R_2.

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{20V}{1.23V} - 1\right)$$

   R_2 = 1k (16.26 − 1) = 15.26k, closest 1% value is 15.4 kΩ.

   R_2 = 15.4 kΩ.

2. **Inductor Selection (L1)**

   A. Calculate the inductor Volt • microsecond constant (E • T),

$$E \bullet T = (28 - 20 - 1) \bullet \frac{20 + 0.5}{28 - 1 + 0.5} \bullet \frac{1000}{150}\ (V \bullet \mu s)$$

$$E \bullet T = (7) \bullet \frac{20.5}{27.5} \bullet 6.67\ (V \bullet \mu s) = 34.8\ (V \bullet \mu s)$$

   B. E • T = 34.8 (V • μs)

   C. $I_{LOAD}(max)$ = 1A

   D. From the inductor value selection guide shown in *Figure 8,* the inductance region intersected by the 35 (V • μs) horizontal line and the 1A vertical line is 100 μH, and the inductor code is L29.

   E. From the table in *Figure 9,* locate line L29, and select an inductor part number from the list of manufacturers part numbers.

3. **Output Capacitor Selection (C_{OUT})**

   A. See section on C_{OUT} in Application Information section.

   B. From the quick design table shown in *Figure 4,* locate the output voltage column. From that column, locate the output voltage closest to the output voltage in your application. In this example, select the 24V line. Under the output capacitor section, select a capacitor from the list of through hole electrolytic or surface mount tantalum types from four different capacitor manufacturers. It is recommended that both the manufacturers and the manufacturers series that are listed in the table be used.

   In this example, through hole aluminum electrolytic capacitors from several different manufacturers are available.

   82 μF, 35V Panasonic HFQ Series

   82 μF, 35V Nichicon PL Series

Example continued on next page.

LM2595 Series Buck Regulator Design Procedure (Adjustable Output)

PROCEDURE (Adjustable Output Voltage Version)

4. **Feedforward Capacitor (C_{FF})** (See *Figure 2*)

For output voltages greater than approximately 10V, an additional capacitor is required. The compensation capacitor is typically between 50 pF and 10 nF, and is wired in parallel with the output voltage setting resistor, R_2. It provides additional stability for high output voltages, low input-output voltages, and/or very low ESR output capacitors, such as solid tantalum capacitors.

$$C_{FF} = \frac{1}{31 \times 10^3 \times R_2}$$

This capacitor type can be ceramic, plastic, silver mica, etc. (Because of the unstable characteristics of ceramic capacitors made with Z5U material, they are not recommended.)

5. **Catch Diode Selection (D1)**

A. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2595. The most stressful condition for this diode is an overload or shorted output condition.

B. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

C. This diode must be fast (short reverse recovery time) and must be located close to the LM2595 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications. Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turn-off characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N4001 series are much too slow and should not be used.

6. **Input Capacitor (C_{IN})**

A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground to prevent large voltage transients from appearing at the input. In addition, the RMS current rating of the input capacitor should be selected to be at least ½ the DC load current. The capacitor manufacturers data sheet must be checked to assure that this current rating is not exceeded. The curve shown in *Figure 13* shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

This capacitor should be located close to the IC using short leads and the voltage rating should be approximately 1.5 times the maximum input voltage.

If solid tantalum input capacitors are used, it is recomended that they be surge current tested by the manufacturer.

Use caution when using a high dielectric constant ceramic capacitor for input bypassing, because it may cause severe ringing at the V_{IN} pin.

For additional information, see section on input capacitors in application information section.

EXAMPLE (Adjustable Output Voltage Version)

C. For a 20V output, a capacitor rating of at least 30V or more is needed. In this example, either a 35V or 50V capacitor would work. A 35V rating was chosen, although a 50V rating could also be used if a lower output ripple voltage is needed.

Other manufacturers or other types of capacitors may also be used, provided the capacitor specifications (especially the 100 kHz ESR) closely match the types listed in the table. Refer to the capacitor manufacturers data sheet for this information.

4. **Feedforward Capacitor (C_{FF})**

The table shown in *Figure 4* contains feed forward capacitor values for various output voltages. In this example, a 1 nF capacitor is needed.

5. **Catch Diode Selection (D1)**

A. Refer to the table shown in *Figure 12.* Schottky diodes provide the best performance, and in this example a 3A, 40V, 1N5822 Schottky diode would be a good choice. The 3A diode rating is more than adequate and will not be overstressed even for a shorted output.

6. **Input Capacitor (C_{IN})**

The important parameters for the Input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 28V, an aluminum electrolytic aluminum electrolytic capacitor with a voltage rating greater than 42V ($1.5 \times V_{IN}$) would be needed. Since the the next higher capacitor voltage rating is 50V, a 50V capacitor should be used. The capacitor voltage rating of ($1.5 \times V_{IN}$) is a conservative guideline, and can be modified somewhat if desired.

The RMS current rating requirement for the input capacitor of a buck regulator is approximately ½ the DC load current. In this example, with a 1A load, a capacitor with a RMS current rating of at least 500 mA is needed.

The curves shown in *Figure 13* can be used to select an appropriate input capacitor. From the curves, locate the 50V line and note which capacitor values have RMS current ratings greater than 500 mA. Either a 100 μF or 120 μF, 50V capacitor could be used.

For a through hole design, a 120 μF/50V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. Other types or other manufacturers capacitors can be used provided the RMS ripple current ratings are adequate.

For surface mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rting (see Application Information or input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line ot switching regulators. ***Switchers Made Simple*** *(version 4.2 or later) is available on a 3½″ diskette for IBM compatible computers.*

LM2595 Series Buck Regulator Design Procedure (Adjustable Output)

(Continued)

Output Voltage (V)	Through Hole Electrolytic Output Capacitor			Surface Mount Tantalum Output Capacitor		
	Panasonic HFQ Series (μF/V)	Nichicon PL Series (μF/V)	Feedforward Capacitor	AVX TPS Series (μF/V)	Sprague 595D Series (μF/V)	Feedforward Capacitor
1.2	330/50	330/50	0	330/6.3	330/6.3	0
4	220/25	220/25	4.7 nF	220/10	220/10	4.7 nF
6	220/25	220/25	3.3 nF	220/10	220/10	3.3 nF
9	180/25	180/25	1.5 nF	100/16	180/16	1.5 nF
12	120/25	120/25	1.5 nF	68/20	120/20	1.5 nF
15	120/25	120/25	1.5 nF	68/20	100/20	1.5 nF
24	82/35	82/35	1 nF	33/25	33/35	220 pF
28	82/50	82/50	1 nF	10/35	33/35	220 pF

FIGURE 4. Output Capacitor and Feedforward Capacitor Selection Table

LM2595 Series Buck Regulator Design Procedure

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

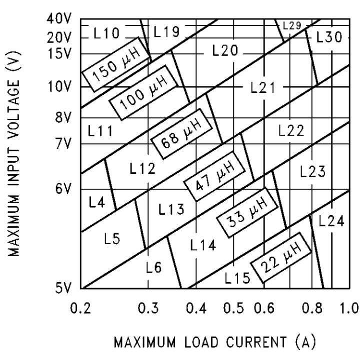


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FIGURE 5. LM2595-3.3

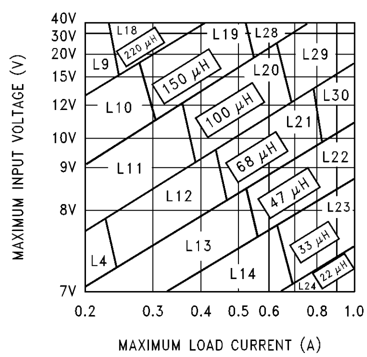

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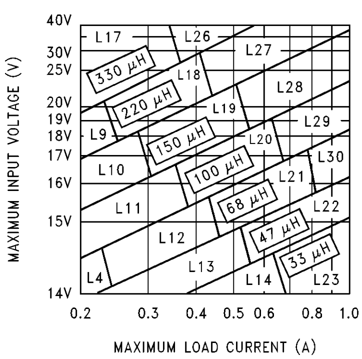
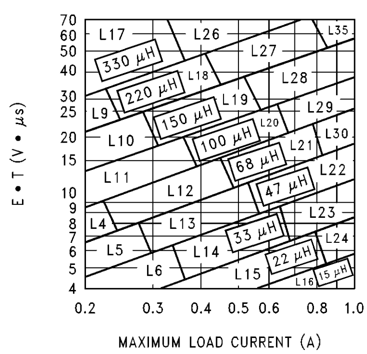
FIGURE 6. LM2595-5.0



TL/H/12565–26

FIGURE 7. LM2595-12



TL/H/12565–27

FIGURE 8. LM2595-ADJ

	Inductance (μH)	Current (A)	Schott		Renco		Pulse Engineering		Coilcraft
			Through Hole	Surface Mount	Through Hole	Surface Mount	Through Hole	Surface Mount	Surface Mount
L4	68	0.32	67143940	67144310	RL-1284-68-43	RL1500-68	PE-53804	PE-53804-S	DO1608-68
L5	47	0.37	67148310	67148420	RL-1284-47-43	RL1500-47	PE-53805	PE-53805-S	DO1608-473
L6	33	0.44	67148320	67148430	RL-1284-33-43	RL1500-33	PE-53806	PE-53806-S	DO1608-333
L9	220	0.32	67143960	67144330	RL-5470-3	RL1500-220	PE-53809	PE-53809-S	DO3308-224
L10	150	0.39	67143970	67144340	RL-5470-4	RL1500-150	PE-53810	PE-53810-S	DO3308-154
L11	100	0.48	67143980	67144350	RL-5470-5	RL1500-100	PE-53811	PE-53811-S	DO3308-104
L12	68	0.58	67143990	67144360	RL-5470-6	RL1500-68	PE-53812	PE-53812-S	DO3308-683
L13	47	0.70	67144000	67144380	RL-5470-7	RL1500-47	PE-53813	PE-53813-S	DO3308-473
L14	33	0.83	67148340	67148450	RL-1284-33-43	RL1500-33	PE-53814	PE-53814-S	DO3308-333
L15	22	0.99	67148350	67148460	RL-1284-22-43	RL1500-22	PE-53815	PE-53815-S	DO3308-223
L16	15	1.24	67148360	67148470	RL-1284-15-43	RL1500-15	PE-53816	PE-53816-S	DO3308-153
L17	330	0.42	67144030	67144410	RL-5471-1	RL1500-330	PE-53817	PE-53817-S	DO3316-334
L18	220	0.55	67144040	67144420	RL-5471-2	RL1500-220	PE-53818	PE-53818-S	DO3316-224
L19	150	0.66	67144050	67144430	RL-5471-3	RL1500-150	PE-53819	PE-53819-S	DO3316-154
L20	100	0.82	67144060	67144440	RL-5471-4	RL1500-100	PE-53820	PE-53820-S	DO3316-104
L21	68	0.99	67144070	67144450	RL-5471-5	RL1500-68	PE-53821	PE-53821-S	DO3316-683
L22	47	1.17	67144080	67144460	RL-5471-6	—	PE-53822	PE-53822-S	DO3316-473
L23	33	1.40	67144090	67144470	RL-5471-7	—	PE-53823	PE-53823-S	DO3316-333
L24	22	1.70	67148370	67144480	RL-1283-22-43	—	PE-53824	PE-53824-S	DO3316-223
L26	330	0.80	67144100	67144480	RL-5471-1	—	PE-53826	PE-53826-S	DO5022P-334
L27	220	1.00	67144110	67144490	RL-5471-2	—	PE-53827	PE-53827-S	DO5022P-224
L28	150	1.20	67144120	67144500	RL-5471-3	—	PE-53828	PE-53828-S	DO5022P-154
L29	100	1.47	67144130	67144510	RL-5471-4	—	PE-53829	PE-53829-S	DO5022P-104
L30	68	1.78	67144140	67144520	RL-5471-5	—	PE-53830	PE-53830-S	DO5022P-683
L35	47	2.15	67144170	—	RL-5473-1	—	PE-53935	PE-53935-S	—

FIGURE 9. Inductor Manufacturers Part Numbers

Coilcraft Inc.	Phone	(800) 322-2645
	FAX	(708) 639-1469
Coilcraft Inc., Europe	Phone	+11 1236 730 595
	FAX	+44 1236 730 627
Pulse Engineering Inc.	Phone	(619) 674-8100
	FAX	(619) 674-8262
Pulse Engineering Inc., Europe	Phone	+353 93 24 107
	FAX	+353 93 24 459
Renco Electronics Inc.	Phone	(800) 645-5828
	FAX	(516) 586-5562
Schott Corp.	Phone	(612) 475-1173
	FAX	(612) 475-1786

FIGURE 10. Inductor Manufacturers Phone Numbers

Nichicon Corp.	Phone	(708) 843-7500
	FAX	(708) 843-2798
Panasonic	Phone	(714) 373-7857
	FAX	(714) 373-7102
AVX Corp.	Phone	(803) 448-9411
	FAX	(803) 448-1943
Sprague/Vishay	Phone	(207) 324-4140
	FAX	(207) 324-7223

FIGURE 11. Capacitor Manufacturers Phone Numbers

VR	1A Diodes				3A Diodes			
	Surface Mount		Through Hole		Surface Mount		Through Hole	
	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery	Schottky	Ultra Fast Recovery
20V	SK12	All of these diodes are rated to at least 50V.	1N5817	All of these diodes are rated to at least 50V.		All of these diodes are rated to at least 50V.	1N5820	All of these diodes are rated to at least 50V.
			SR102		SK32		SR302	
							MBR320	
30V	SK13		1N5818				1N5821	
	MBRS130		SR103		SK33		MBR330	
			11DQ03				31DQ03	
40V	SK14						1N5822	
	MBRS140		1N5819		SK34		SR304	
	10BQ040		SR104		MBRS340		MBR340	
	10MQ040	MURS120	11DQ04	MUR120	30WQ04	MURS320	31DQ04	MUR320
50V or More	MBRS160	10BF10	SR105		SK35	30WF10	SR305	30WF10
	10BQ050		MBR150		MBR360		MBR350	
	10MQ060		11DQ05		30WQ05		31DQ05	

FIGURE 12. Diode Selection Table

Application Information

PIN FUNCTIONS

$+$**V_{IN}**—This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents needed by the regulator.

Ground—Circuit ground.

Output—Internal switch. The voltage at this pin switches between ($+V_{IN} - V_{SAT}$) and approximately $-0.5V$, with a duty cycle of approximately V_{OUT}/V_{IN}. To minimize coupling to sensitive circuitry, the PC board copper area connected to this pin should be kept to a minimum.

Feedback—Senses the regulated output voltage to complete the feedback loop.

$\overline{ON}$/OFF—Allows the switching regulator circuit to be shut down using logic level signals thus dropping the total input supply current to approximately 85 μA. Pulling this pin below a threshold voltage of approximately 1.3V turns the regulator on, and pulling this pin above 1.3V (up to a maximum of 25V) shuts the regulator down. If this shutdown feature is not needed, the $\overline{ON}$/OFF pin can be wired to the ground pin or it can be left open, in either case the regulator will be in the ON condition.

EXTERNAL COMPONENTS

C_{IN}—A low ESR aluminum or tantalum bypass capacitor is needed between the input pin and ground pin. It must be located near the regulator using short leads. This capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous current needed each time the switch turns on.

The important parameters for the Input capacitor are the voltage rating and the RMS current rating. Because of the relatively high RMS currents flowing in a buck regulator's input capacitor, this capacitor should be chosen for its RMS current rating rather than its capacitance or voltage ratings, although the capacitance value and voltage rating are directly related to the RMS current rating.

The RMS current rating of a capacitor could be viewed as a capacitor's power rating. The RMS current flowing through the capacitors internal ESR produces power which causes the internal temperature of the capacitor to rise. The RMS current rating of a capacitor is determined by the amount of current required to raise the internal temperature approximately 10°C above an ambient temperature of 105°C. The ability of the capacitor to dissipate this heat to the surrounding air will determine the amount of current the capacitor can safely sustain. Capacitors that are physically large and have a large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating.

The consequences of operating an electrolytic capacitor above the RMS current rating is a shortened operating life. The higher temperature speeds up the evaporation of the capacitor's electrolyte, resulting in eventual failure.

Selecting an input capacitor requires consulting the manufacturers data sheet for maximum allowable RMS ripple current. For a maximum ambient temperature of 40°C, a general guideline would be to select a capacitor with a ripple current rating of approximately 50% of the DC load current. For ambient temperatures up to 70°C, a current rating of 75% of the DC load current would be a good choice for a conservative design. The capacitor voltage rating must be at least 1.25 times greater than the maximum input voltage, and often a much higher voltage capacitor is needed to satisfy the RMS current requirements.

A graph shown in *Figure 13* shows the relationship between an electrolytic capacitor value, its voltage rating, and the RMS current it is rated for. These curves were obtained from the Nichicon "PL" series of low ESR, high reliability electrolytic capacitors designed for switching regulator applications. Other capacitor manufacturers offer similar types of capacitors, but always check the capacitor data sheet.

"Standard" electrolytic capacitors typically have much higher ESR numbers, lower RMS current ratings and typically have a shorter operating lifetime.

Because of their small size and excellent performance, surface mount solid tantalum capacitors are often used for input bypassing, but several precautions must be observed. A small percentage of solid tantalum capacitors can short if the inrush current rating is exceeded. This can happen at turn on when the input voltage is suddenly applied, and of course, higher input voltages produce higher inrush currents. Several capacitor manufacturers do a 100% surge current testing on their products to minimize this potential problem. If high turn on currents are expected, it may be necessary to limit this current by adding either some resistance or inductance before the tantalum capacitor, or select a higher voltage capacitor. As with aluminum electrolytic capacitors, the RMS ripple current rating must be sized to the load current.

FEEDFORWARD CAPACITOR

(Adjustable Output Voltage Version)

C_{FF}-A Feedforward Capacitor C_{FF}, shown across R2 in *Figure 2* is used when the output voltage is greater than 10V or when C_{OUT} has a very low ESR. This capacitor adds lead compensation to the feedback loop and increases the phase margin for better loop stability. For C_{FF} selection, see the design procedure section.

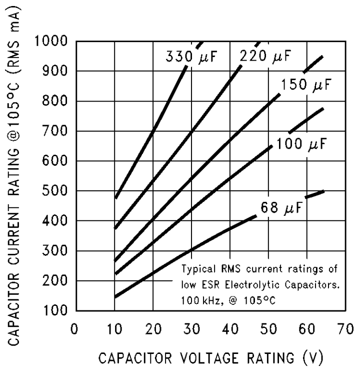


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FIGURE 13. RMS Current Ratings for Low ESR Electrolytic Capacitors (Typical)

OUTPUT CAPACITOR

C_{OUT}—An output capacitor is required to filter the output and provide regulator loop stability. Low impedance or low ESR Electrolytic or solid tantalum capacitors designed for switching regulator applications must be used. When selecting an output capacitor, the important capacitor parameters are; the 100 kHz Equivalent Series Resistance (ESR), the RMS ripple current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter.

The output capacitor requires an ESR value that has an upper and lower limit. For low output ripple voltage, a low ESR value is needed. This value is determined by the maximum allowable output ripple voltage, typically 1% to 2% of the output voltage. But if the selected capacitor's ESR is extremely low, there is a possibility of an unstable feedback loop, resulting in an oscillation at the output. Using the capacitors listed in the tables, or similar types, will provide design solutions under all conditions.

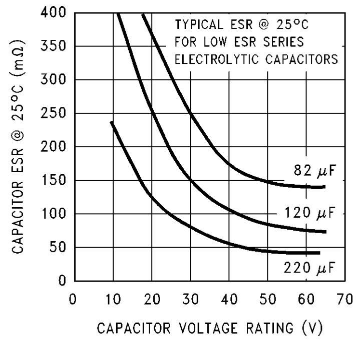
If very low output ripple voltage (less than 15 mV) is required, refer to the section on Output Voltage Ripple and Transients for a post ripple filter.

An aluminum electrolytic capacitor's ESR value is related to the capacitance value and its voltage rating. In most cases, higher voltage electrolytic capacitors have lower ESR values (see *Figure 14*). Often, capacitors with much higher voltage ratings may be needed to provide the low ESR values required for low output ripple voltage.

The output capacitor for many different switcher designs often can be satisfied with only three or four different capacitor values and several different voltage ratings. See the quick design component selection tables in *Figures 3* and *4* for typical capacitor values, voltage ratings, and manufacturers capacitor types.

Electrolytic capacitors are not recommended for temperatures below −25°C. The ESR rises dramatically at cold temperatures and typically rises 3X @ −25°C and as much as 10X at −40°C. See curve shown in *Figure 15.*

Solid tantalum capacitors have a much better ESR spec for cold temperatures and are recommended for temperatures below −25°C.



TL/H/12565–29

FIGURE 14. Capacitor ESR vs Capacitor Voltage Rating (Typical Low ESR Electrolytic Capacitor)

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch turns off. This must be a fast diode and must be located close to the LM2595 using short leads and short printed circuit traces.

Because of their very fast switching speed and low forward voltage drop, Schottky diodes provide the best performance, especially in low output voltage applications (5V and lower). Ultra-fast recovery, or High-Efficiency rectifiers are also a good choice, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and should not be used.

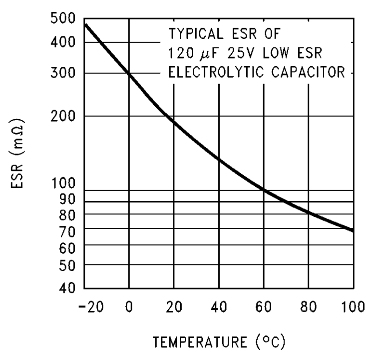


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FIGURE 15. Capacitor ESR Change vs Temperature

INDUCTOR SELECTION

All switching regulators have two basic modes of operation; continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulators performance and requirements. Most switcher designs will operate in the discontinuous mode when the load current is low.

The LM2595 (or any of the Simple Switcher family) can be used for both continuous or discontinuous modes of operation.

Application Information (Continued)

In many cases the preferred mode of operation is the continuous mode. It offers greater output power, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. But it does require larger inductor values to keep the inductor current flowing continuously, especially at low output load currents and/or high input voltages.

To simplify the inductor selection process, an inductor selection guide (nomograph) was designed (see *Figures 5* through *8*). This guide assumes that the regulator is operating in the continuous mode, and selects an inductor that will allow a peak-to-peak inductor ripple current to be a certain percentage of the maximum design load current. This peak-to-peak inductor ripple current percentage is not fixed, but is allowed to change as different design load currents are selected. (See *Figure 16*.)

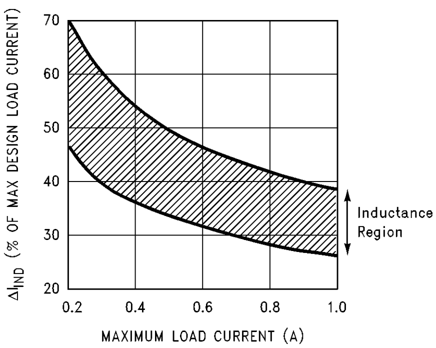

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FIGURE 16. (ΔI_{IND}) Peak-to-Peak Inductor Ripple Current (as a Percentage of the Load Current) vs Load Current

By allowing the percentage of inductor ripple current to increase for low load currents, the inductor value and size can be kept relatively low.

When operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage), with the average value of this current waveform equal to the DC output load current.

Inductors are available in different styles such as pot core, toroid, E-core, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin, rod or stick core, consists of wire wound on a ferrite bobbin. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more Electro-Magnetic Interference (EMI). This magnetic flux can induce voltages into nearby printed circuit traces, thus causing problems with both the switching regulator operation and nearby sensitive circuitry, and can give incorrect scope readings because of induced voltages in the scope probe. Also see section on Open Core Inductors.

When multiple switching regulators are located on the same PC board, open core magnetics can cause interference between two or more of the regulator circuits, especially at high currents. A torroid or E-core inductor (closed magnetic structure) should be used in these situations.

The inductors listed in the selection chart include ferrite E-core construction for Schott, ferrite bobbin core for Renco and Coilcraft, and powdered iron toroid for Pulse Engineering.

Exceeding an inductor's maximum current rating may cause the inductor to overheat because of the copper wire losses, or the core may saturate. If the inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the switch current to rise very rapidly and force the switch into a cycle-by-cycle current limit, thus reducing the DC output load current. This can also result in overheating of the inductor and/or the LM2595. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

DISCONTINUOUS MODE OPERATION

The selection guide chooses inductor values suitable for continuous mode operation, but for low current applications and/or high input voltages, a discontinuous mode design may be a better choice. It would use an inductor that would be physically smaller, and would need only one half to one third the inductance value needed for a continuous mode design. The peak switch and inductor currents will be higher in a discontinuous design, but at these low load currents (400 mA and below), the maximum switch current will still be less than the switch current limit.

Discontinuous operation can have voltage waveforms that are considerable different than a continuous design. The output pin (switch) waveform can have some damped sinusoidal ringing present. (See *Figure 1* photo titled; Discontinuous Mode Switching Waveforms) This ringing is normal for discontinuous operation, and is not caused by feedback loop instabilities. In discontinuous operation, there is a period of time where neither the switch or the diode are conducting, and the inductor current has dropped to zero. During this time, a small amount of energy can circulate between the inductor and the switch/diode parasitic capacitance causing this characteristic ringing. Normally this ringing is not a problem, unless the amplitude becomes great enough to exceed the input voltage, and even then, there is very little energy present to cause damage.

Different inductor types and/or core materials produce different amounts of this characteristic ringing. Ferrite core inductors have very little core loss and therefore produce the most ringing. The higher core loss of powdered iron inductors produce less ringing. If desired, a series RC could be placed in parallel with the inductor to dampen the ringing. The computer aided design software ***Switchers Made Simple*** (version 4.2) will provide all component values for continuous and discontinuous modes of operation.

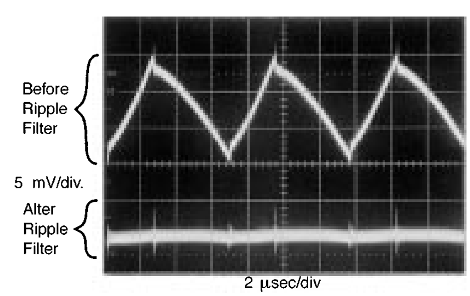

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FIGURE 17. Post Ripple Filter Waveform

Application Information (Continued)

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply operating in the continuous mode will contain a sawtooth ripple voltage at the switcher frequency, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

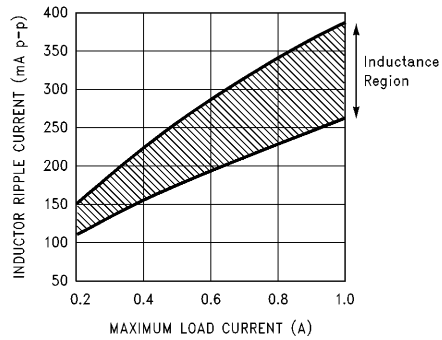
The output ripple voltage is a function of the inductor sawtooth ripple current and the ESR of the output capacitor. A typical output ripple voltage can range from approximately 0.5% to 3% of the output voltage. To obtain low ripple voltage, the ESR of the output capacitor must be low, however, caution must be exercised when using extremely low ESR capacitors because they can affect the loop stability, resulting in oscillation problems. If very low output ripple voltage is needed (less than 20 mV), a post ripple filter is recommended. (See *Figure 2*.) The inductance required is typically between 1 μH and 5 μH, with low DC resistance, to maintain good load regulation. A low ESR output filter capacitor is also required to assure good dynamic load response and ripple reduction. The ESR of this capacitor may be as low as desired, because it is out of the regulator feedback loop. The photo shown in *Figure 17* shows a typical output ripple voltage, with and without a post ripple filter.

When observing output ripple with a scope, it is essential that a short, low inductance scope probe ground connection be used. Most scope probe manufacturers provide a special probe terminator which is soldered onto the regulator board, preferable at the output capacitor. This provides a very short scope ground thus eliminating the problems associated with the 3 inch ground lead normally provided with the probe, and provides a much cleaner and more accurate picture of the ripple voltage waveform.

The voltage spikes are caused by the fast switching action of the output switch and the diode, and the parasitic inductance of the output filter capacitor, and its associated wiring. To minimize these voltage spikes, the output capacitor should be designed for switching regulator applications, and the lead lengths must be kept very short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

When a switching regulator is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current increases or decreases, the entire sawtooth current waveform also rises and falls. The average value (or the center) of this current waveform is equal to the DC load current.

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will smoothly change from a continuous to a discontinuous mode of operation. Most switcher designs (irregardless how large the inductor value is) will be forced to run discontinuous if the output is lightly loaded. This is a perfectly acceptable mode of operation.



TL/H/12565–33

FIGURE 18. Peak-to-Peak Inductor Ripple Current vs Load Current

In a switching regulator design, knowing the value of the peak-to-peak inductor ripple current (ΔI_{IND}) can be useful for determining a number of other circuit parameters. Parameters such as, peak inductor or peak switch current, minimum load current before the circuit becomes discontinuous, output ripple voltage and output capacitor ESR can all be calculated from the peak-to-peak ΔI_{IND}. When the inductor nomographs shown in *Figures 5* through *8* are used to select an inductor value, the peak-to-peak inductor ripple current can immediately be determined. The curve shown in *Figure 18* shows the range of (ΔI_{IND}) that can be expected for different load currents. The curve also shows how the peak-to-peak inductor ripple current (ΔI_{IND}) changes as you go from the lower border to the upper border (for a given load current) within an inductance region. The upper border represents a higher input voltage, while the lower border represents a lower input voltage (see Inductor Selection Guides).

These curves are only correct for continuous mode operation, and only if the inductor selection guides are used to select the inductor value

Consider the following example:

V_{OUT} = 5V, maximum load current of 800 mA

V_{IN} = 12V, nominal, varying between 10V and 14V.

The selection guide in *Figure 6* shows that the vertical line for a 0.8A load current, and the horizontal line for the 12V input voltage intersect approximately midway between the upper and lower borders of the 68 μH inductance region. A 68 μH inductor will allow a peak-to-peak inductor current (ΔI_{IND}) to flow that will be a percentage of the maximum load current. Referring to *Figure 18,* follow the 0.8A line approximately midway into the inductance region, and read the peak-to-peak inductor ripple current (ΔI_{IND}) on the left hand axis (approximately 300 mA p-p).

As the input voltage increases to 14V, it approaches the upper border of the inductance region, and the inductor ripple current increases. Referring to the curve in *Figure 18,* it can be seen that for a load current of 0.8A, the peak-to-peak inductor ripple current (ΔI_{IND}) is 300 mA with 12V in, and can range from 340 mA at the upper border (14V in) to 225 mA at the lower border (10V in).

Application Information (Continued)

Once the ΔI_{IND} value is known, the following formulas can be used to calculate additional information about the switching regulator circuit.

1. Peak Inductor or peak switch current

$$= \left(I_{LOAD} + \frac{\Delta I_{IND}}{2}\right) = \left(0.8A + \frac{0.30}{2}\right) = 0.95A$$

2. Minimum load current before the circuit becomes discontinuous

$$= \frac{\Delta I_{IND}}{2} = \frac{0.3}{2} = 0.15A$$

3. Output Ripple Voltage $= (\Delta I_{IND}) \times (\text{ESR of } C_{OUT})$

$= 0.30A \times 0.16\Omega = 48$ mV p-p

or

4. ESR of C_{OUT} $= \frac{\text{Output Ripple Voltage } (\Delta V_{OUT})}{\Delta I_{IND}}$

$$= \frac{0.048V}{0.30A} = 0.16\Omega$$

OPEN CORE INDUCTORS

Another possible source of increased output ripple voltage or unstable operation is from an open core inductor. Ferrite bobbin or stick inductors have magnetic lines of flux flowing through the air from one end of the bobbin to the other end. These magnetic lines of flux will induce a voltage into any wire or PC board copper trace that comes within the inductor's magnetic field. The strength of the magnetic field, the orientation and location of the PC copper trace to the magnetic field, and the distance between the copper trace and the inductor, determine the amount of voltage generated in the copper trace. Another way of looking at this inductive coupling is to consider the PC board copper trace as one turn of a transformer (secondary) with the inductor winding as the primary. Many millivolts can be generated in a copper trace located near an open core inductor which can cause stability problems or high output ripple voltage problems.

If unstable operation is seen, and an open core inductor is used, it's possible that the location of the inductor with respect to other PC traces may be the problem. To determine if this is the problem, temporarily raise the inductor away from the board by several inches and then check circuit operation. If the circuit now operates correctly, then the magnetic flux from the open core inductor is causing the problem. Substituting a closed core inductor such as a toroid or E-core will correct the problem, or re-arranging the PC layout may be necessary. Magnetic flux cutting the IC device ground trace, feedback trace, or the positive or negative traces of the output capacitor should be minimized.

Sometimes, locating a trace directly beneath a bobbin inductor will provide good results, provided it is exactly in the center of the inductor (because the induced voltages cancel themselves out), but if it is off center one direction or the other, then problems could arise. If flux problems are present, even the direction of the inductor winding can make a difference in some circuits.

This discussion on open core inductors is not to frighten the user, but to alert the user on what kind of problems to watch out for when using them. Open core bobbin or ''stick'' inductors are an inexpensive, simple way of making a compact efficient inductor, and they are used by the millions in many different applications.

THERMAL CONSIDERATIONS

The LM2595 is available in two packages, a 5-pin TO-220 (T) and a 5-pin surface mount TO-263 (S).

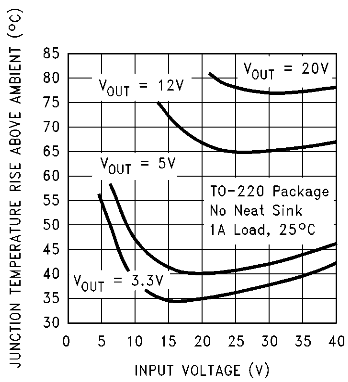
The TO-220 package can be used without a heat sink for ambient temperatures up to approximately 50°C (depending on the output voltage and load current). The curves in *Figure 19* show the LM2595T junction temperature rises above ambient temperature for different input and output voltages. The data tor these curves was taken with the LM2595T (TO-220 package) operating as a switching regutator in an ambient temperature of 25°C (still air). These temperature rise numbers are all approximate and there are many factors that can affect these temperatures. Higher ambient temperatures require some heat sinking, either to the PC board or a small external heat sink.

The TO-263 surface mount package tab is designed to be soldered to the copper on a printed circuit board. The copper and the board are the heat sink for this package and the other heat producing components, such as the catch diode and inductor. The PC board copper area that the package is soldered to should be at least 0.4 in^2, and ideally should have 2 or more square inches of 2 oz. (0.0028 in) copper. Additional copper area improves the thermal characteristics, but with copper areas greater than approximately 3 in^2, only small improvements in heat dissipation are realized. If further thermal improvements are needed, double sided or multilayer PC-board with large copper areas are recommended.

The curves shown in *Figure 20* show the LM2595S (TO-263 package) junction temperature rise above ambient temperature with a 1A load for various input and output voltages. This data was taken with the circuit operating as a buck switching regulator with all components mounted on a PC board to simulate the junction temperature under actual operating conditions. This curve can be used for a quick check for the approximate junction temperature for various conditions, but be aware that there are many factors that can affect the junction temperature.

For the best thermal performance, wide copper traces and generous amounts of printed circuit board copper should be used in the board layout. (One exception to this is the output (switch) pin, which should not have large areas of copper.) Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and moving air lowers the thermal resistance even further.

Package thermal resistance and junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers. Some of these factors include board size, shape, thickness, position, location, and even board temperature. Other factors are, trace width, total printed circuit copper area, copper thickness, single- or double-sided, multilayer board and the amount of solder on the board. The effectiveness of the PC board to dissipate heat also depends on the size, quantity and spacing of other components on the board, as well as whether the surrounding air is still or moving. Furthermore, some of these components such as the catch diode will add heat to the PC board and the heat can vary as the input voltage changes. For the inductor, depending on the physical size, type of core material and the DC resistance, it could either act as a heat sink taking heat away from the board, or it could add heat to the board.



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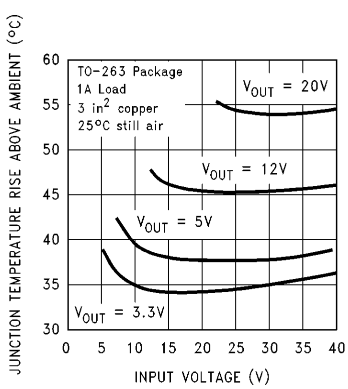
Circuit Data for Temperature Rise Curve TO-220 Package (T)	
Capacitors	Through hole electrolytic
Inductor	Through hole, Schott, 68 μH
Diode	Through hole, 3A 40V, Schottky
PC board	3 square inches single sided 2 oz. copper (0.0028″)

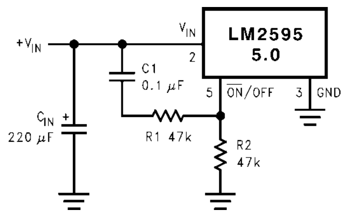
FIGURE 19. Junction Temperature Rise, TO-220



TL/H/12565–35

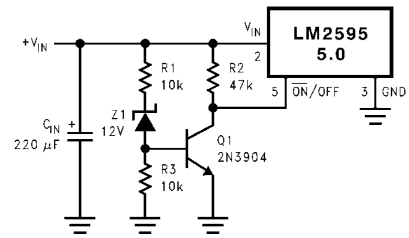
Circuit Data for Temperature Rise Curve TO-263 Package (S)	
Capacitors	Surface mount tantalum, molded "D" size
Inductor	Surface mount, Schottky, 68 μH
Diode	Surface mount, 3A 40V, Schottky
PC board	3 square inches single sided 2 oz. copper (0.0028″)

FIGURE 20. Junction Temperature Rise, TO-263



TL/H/12565–36

FIGURE 21. Delayed Startup



TL/H/12565–37

FIGURE 22. Undervoltage Lockout for Buck Regulator

DELAYED STARTUP

The circuit in *Figure 21* uses the the $\overline{ON}$/OFF pin to provide a time delay between the time the input voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start up is shown). As the input voltage rises, the charging of capacitor C1 pulls the $\overline{ON}$/OFF pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, and resistor R_2 pulls the $\overline{ON}$/OFF pin low, thus allowing the circuit to start switching. Resistor R_1 is included to limit the maximum voltage applied to the $\overline{ON}$/OFF pin (maximum of 25V), reduces power supply noise sensitivity, and also limits the capacitor, C1, discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the $\overline{ON}$/OFF pin and cause problems.

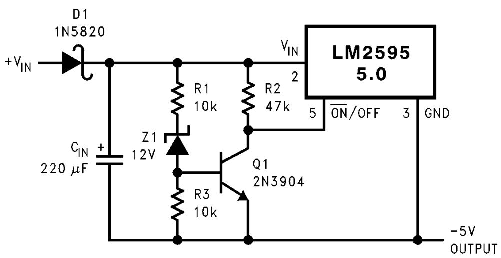
This delayed startup feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

UNDERVOLTAGE LOCKOUT

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. An undervoltage lockout feature applied to a buck regulator is shown in *Figure 22,* while *Figures 23* and *24* applies the same feature to an inverting circuit. The circuit in *Figure 23* features a constant threshold voltage for turn on and turn off (zener voltage plus approximately one volt). If hysteresis is needed, the circuit in *Figure 24* has a turn ON voltage which is different than the turn OFF voltage. The amount of hysteresis is approximately equal to the value of the output voltage. If zener voltages greater than 25V are used, an additional 47 kΩ resistor is needed from the $\overline{ON}$/OFF pin to the ground pin to stay within the 25V maximum limit of the $\overline{ON}$/OFF pin.

INVERTING REGULATOR

The circuit in *Figure 25* converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the regulator's ground pin to the negative output voltage, then grounding the feedback pin, the regulator senses the inverted output voltage and regulates it.



TL/H/12565–46

This circuit has an ON/OFF threshold of approximately 13V.

FIGURE 23. Undervoltage Lockout for Inverting Regulator

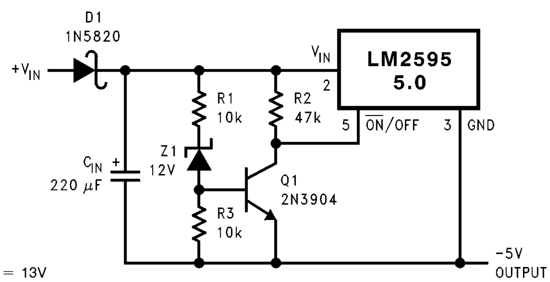
This example uses the LM2595-5.0 to generate a −5V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version.

Since this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. The curve shown in *Figure 26* provides a guide as to the amount of output load current possible for the different input and output voltage conditions.

The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 40V. For example, when converting +20V to −12V, the regulator would see 32V between the input pin and ground pin. The LM2595 has a maximum input voltage spec of 40V.

Additional diodes are required in this regulator configuration. Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closley resemble a buck configuration thus providing good closed loop stability. A Schottky diode is recommended for low input voltages, (because of its lower voltage drop) but for higher input voltages, a fast recovery diode could be used.

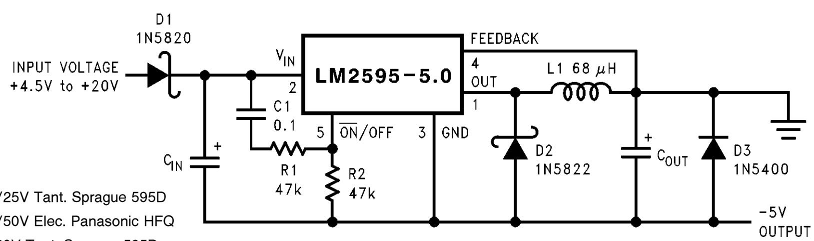
Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.



This circuit has hysteresis
Regulator starts switching at V_{IN} = 13V
Regulator stops switching at V_{IN} = 8V

TL/H/12565–39

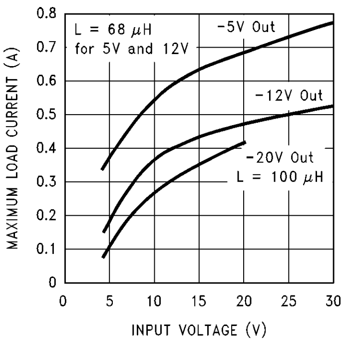
FIGURE 24. Undervoltage Lockout with Hysteresis for Inverting Regulator



C_{IN} — 220 µF/25V Tant. Sprague 595D
120 µF/50V Elec. Panasonic HFQ
C_{OUT} — 22 µF/20V Tant. Sprague 595D
120 µF/25V Elec. Panasonic HFQ

TL/H/12565–40

FIGURE 25. Inverting −5V Regulator with Delayed Startup



TL/H/12565–41

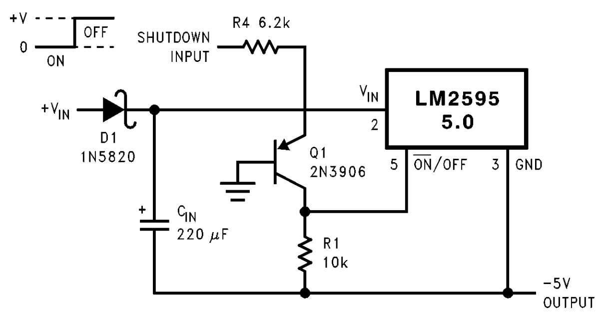
FIGURE 26. Inverting Regulator Typical Load Current

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 68 μH, 1.5A inductor is the best choice. Capacitor selection can also be narrowed down to just a few values. Using the values shown in *Figure 25* will provide good results in the majority of inverting designs.

This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the LM2595 current limit (approx 1.5A) are needed for at least 2 ms or more, until the output reaches its nominal output voltage. The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, may not work correctly. Because of the relatively high startup currents required by the inverting topology, the delayed startup feature (C1, R_1 and R_2) shown in *Figure 25* is recommended. By delaying the regulator startup, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current needed for startup is now supplied by the input capacitor (C_{IN}). For severe start up conditions, the input capacitor can be made much larger than normal.

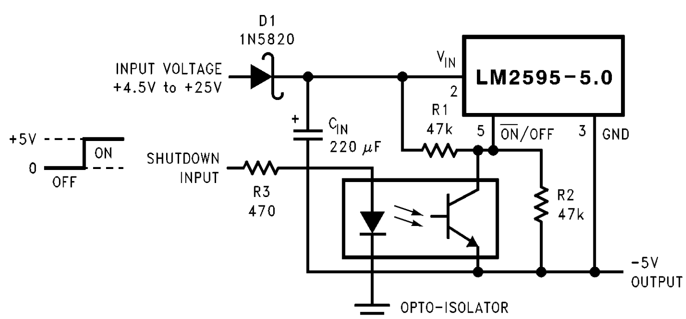
INVERTING REGULATOR SHUTDOWN METHODS

To use the $\overline{ON}$/OFF pin in a standard buck configuration is simple, pull it below 1.3V (@25°C, referenced to ground) to turn regulator ON, pull it above 1.3V to shut the regulator OFF. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in *Figures 27* and *28.*



TL/H/12565–42

FIGURE 27. Inverting Regulator Ground Referenced Shutdown

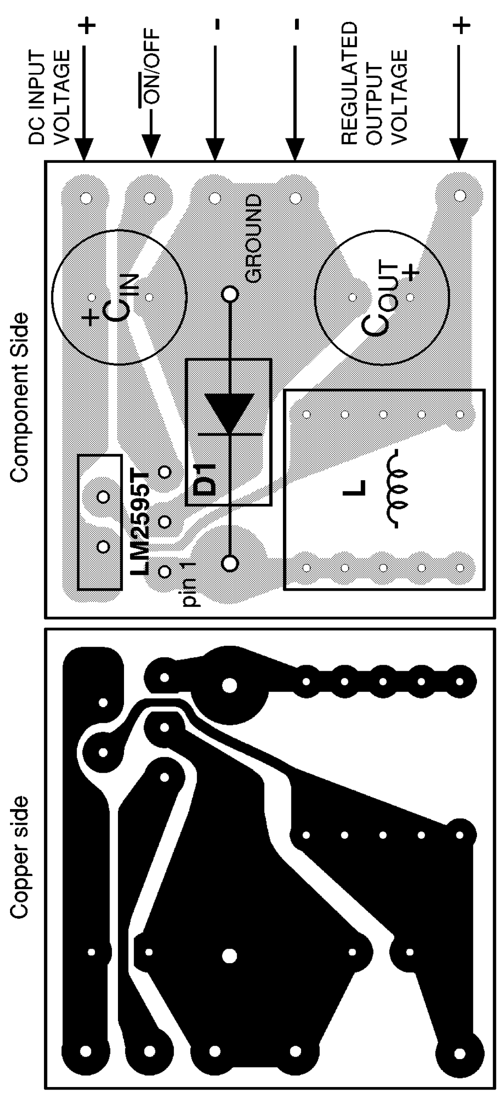


TL/H/12565–43

FIGURE 28. Inverting Regulator Ground Referenced Shutdown using Opto Device

Application Information (Continued)

TYPICAL THROUGH HOLE PC BOARD LAYOUT, FIXED OUTPUT (2X SIZE)



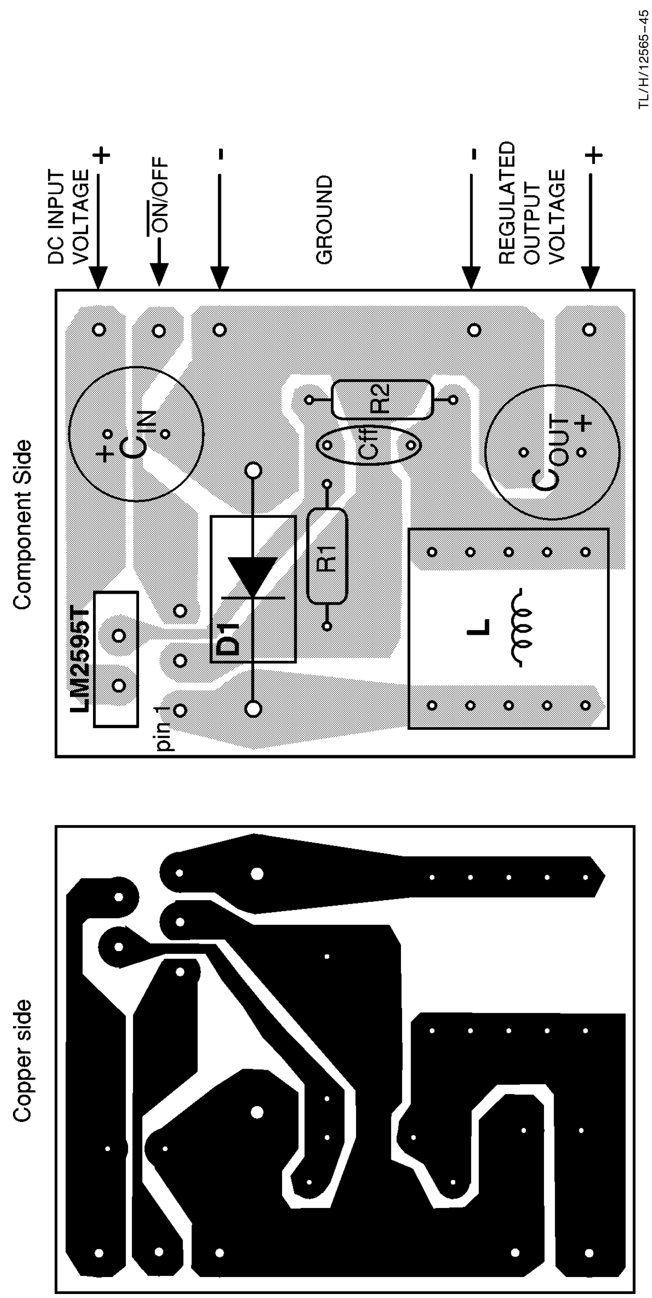
TL/H/12565–44

C_{IN} - 150 μF, 50V, Aluminium Electrolytic Nichicon, "PL series"
C_{OUT} - 120 μF, 25V Aluminium Electrolytic Nichicon, "PL series"
D1 - 3A, 40V Schottky Rectifier, 1N5822
L1 - 68 μH, L30, Schott, Through hole

FIGURE 29. PC Board Layout

Application Information (Continued)

TYPICAL THROUGH HOLE PC BOARD LAYOUT, ADJUSTABLE OUTPUT (2X SIZE)



C_{IN} - 150 µF, 50V, Aluminium Electrolytic Nichicon, "PL series"

C_{OUT} - 120 µF, 25V Aluminium Electrolytic Nichicon, "PL series"

D1 - 3A, 40V Schottky Rectifier, 1N5822

L1 - 68 µH, L30, Schott, Through hole

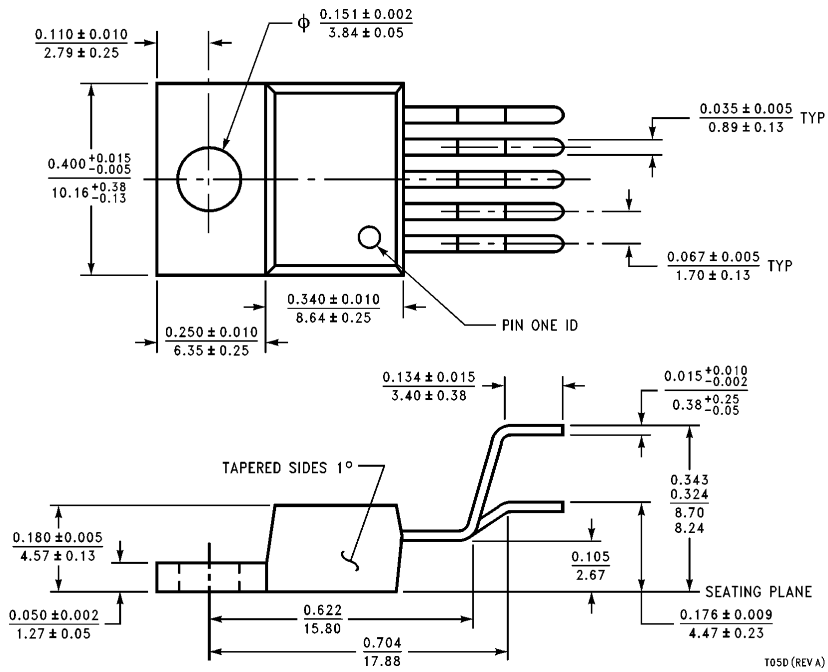
R1 - 1 kΩ, 1%

R2 - Use formula in Design Procedure

C_{FF} - See *Figure 4*

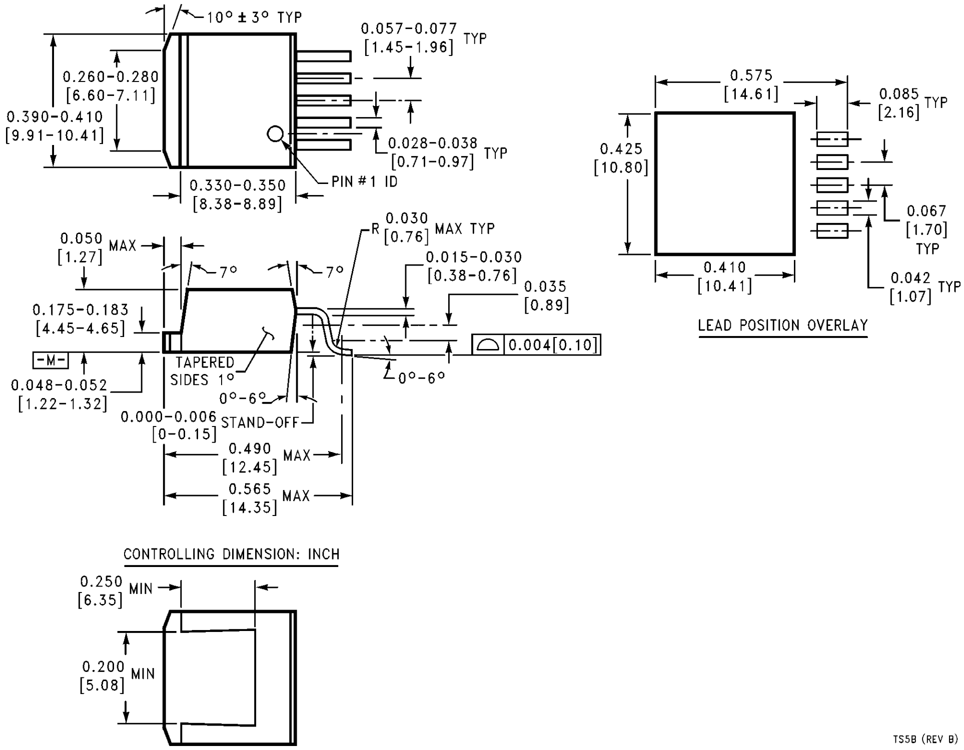
FIGURE 29. PC Board Layout (Continued)

Physical Dimensions inches (millimeters)



5-Lead TO-220 (T)
Order Number LM2595T-3.3, LM2595T-5.0,
LM2595T-12 or LM2595T-ADJ
NS Package Number T05D

Physical Dimensions inches (millimeters) (Continued)



5-Lead TO-263 Surface Mount Package (S)
Order Number LM2595S-3.3, LM2595S-5.0,
LM2595S-12 or LM2595S-ADJ
NS Package Number TS5B

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