# LM78S40

LM78S40 Universal Switching Regulator Subsystem



Literature Number: SNVS021



#### LM78S40

# **Universal Switching Regulator Subsystem**

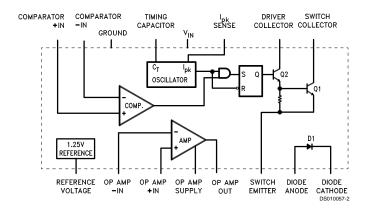
### **General Description**

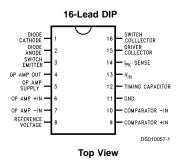
The LM78S40 is a monolithic regulator subsystem consisting of all the active building blocks necessary for switching regulator systems. The device consists of a temperature compensated voltage reference, a duty-cycle controllable oscillator with an active current limit circuit, an error amplifier, high current, high voltage output switch, a power diode and an uncommitted operational amplifier. The device can drive external NPN or PNP transistors when currents in excess of 1.5A or voltages in excess of 40V are required. The device can be used for step-down, step-up or inverting switching regulators as well as for series pass regulators. It features wide supply voltage range, low standby power dissipation, high efficiency and low drift. It is useful for any stand-alone, low part count switching system and works extremely well in battery operated systems.

#### **Features**

- Step-up, step-down or inverting switching regulators
- Output adjustable from 1.25V to 40V
- Peak currents to 1.5A without external transistors
- Operation from 2.5V to 40V input
- Low standby current drain
- 80 dB line and load regulation
- High gain, high current, independent op amp
- Pulse width modulation with no double pulsing

#### **Block and Connection Diagrams**





# **Ordering Information**

Part Number	NS Package	Temperature Range
LM78S40J/883	J16A Ceramic DIP	–55°C to +125°C
LM78S40N	N16E Molded DIP	-40°C to +125°C
LM78S40CN	N16E Molded DIP	0°C to +70°C

Absolute Maximum Rat	ings (Note 1)	to GND	40V
If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.		Common Mode Input Range (Comparator and Op Amp) Differential Input Voltage	-0.3 to V+
Storage Temperature Range		(Note 4)	±30V
Ceramic DIP	-65°C to +175°C	Output Short Circuit	
Molded DIP	-65°C to +150°C	Duration (Op Amp)	Continuous
Operating Temperature Range		Current from V <sub>REF</sub>	10 mA
Extended (LM78S40J)	-55°C to +125°C	Voltage from Switch	
Industrial (LM78S40N)	-40°C to +125°C	Collectors to GND	40V
Commercial (LM78S40CN)	0°C to +70°C	Voltage from Switch	
Lead Temperature		Emitters to GND	40V
Ceramic DIP (Soldering, 60 sec.)	300°C	Voltage from Switch	
Molded DIP (Soldering, 10 sec.)	265°C	Collectors to Emitter	40V
Internal Power Dissipation (Note 2) (N	ote 3)	Voltage from Power Diode to GND	40V
16L-Ceramic DIP	1.50W	Reverse Power Diode Voltage	40V
16L-Molded DIP	1.04W	Current through Power Switch	1.5A
Input Voltage from V <sub>IN</sub> to GND	40V	Current through Power Diode	1.5A
Input Voltage from V <sup>+</sup> (Op Amp)		ESD Susceptibility	(to be determined)

**LM78S40 Electrical Characteristics** (Note 5)  $T_A = Operating temperature range, V_{IN} = 5.0V, V^+(Op Amp) = 5.0V, unless otherwise specified.$ 

Symbol	Parameter		Conditions	Min	Тур	Max	Units
GENERA	L CHARACTERISTICS						•
I <sub>cc</sub>	Supply Current	V <sub>IN</sub> = 5.0V			1.8	3.5	mA
	(Op Amp Disconnected)	V <sub>IN</sub> = 40V			2.3	5.0	mA
I <sub>cc</sub>	Supply Current	V <sub>IN</sub> = 5.0V				4.0	mA
	(Op Amp Connected)	V <sub>IN</sub> = 40V				5.5	mA
REFERE	NCE SECTION			•			•
$V_{REF}$	Reference Voltage	I <sub>REF</sub> = 1.0 mA	Extend $-55^{\circ}$ C < T <sub>A</sub> < +125°C,				
			Comm $0 < T_A < +70^{\circ}C$ , Indus $-40^{\circ}C < T_A < +85^{\circ}C$	1.180	1.245	1.310	V
V <sub>R LINE</sub>	Reference Voltage	V <sub>IN</sub> = 3.0V to V	.,		0.04	0.2	mV/V
KLINE	Line Regulation	I <sub>REF</sub> = 1.0 mA,					
V <sub>R LOAD</sub>	Reference Voltage		to I <sub>REF</sub> = 10 mA,		0.2	0.5	mV/mA
11 20/12	Load Regulation	$T_A = 25^{\circ}C$					
OSCILLA	TOR SECTION						
I <sub>CHG</sub>	Charging Current	V <sub>IN</sub> = 5.0V, T <sub>A</sub>	V <sub>IN</sub> = 5.0V, T <sub>A</sub> = 25°C			50	μA
I <sub>CHG</sub>	Charging Current	V <sub>IN</sub> = 40V, T <sub>A</sub> =	V <sub>IN</sub> = 40V, T <sub>A</sub> = 25°C			70	μΑ
I <sub>DISCHG</sub>	Discharge Current	$V_{IN} = 5.0V, T_A$	V <sub>IN</sub> = 5.0V, T <sub>A</sub> = 25°C			250	μA
I <sub>DISCHG</sub>	Discharge Current	V <sub>IN</sub> = 40V, T <sub>A</sub> =	= 25°C	150		350	μA
Vosc	Oscillator Voltage Swing	$V_{IN} = 5.0V, T_A$	= 25°C		0.5		V
t <sub>on</sub> /t <sub>off</sub>	Ratio of Charge/				6.0		µs/µs
	Discharge Time						
CURREN	T LIMIT SECTION						
$V_{\text{CLS}}$	Current Limit Sense Voltage	T <sub>A</sub> = 25°C		250		350	mV
OUTPUT	SWITCH SECTION			•			•
V <sub>SAT 1</sub>	Output Saturation Voltage 1	I <sub>SW</sub> = 1.0A ( <i>Figure 1</i> )			1.1	1.3	V
V <sub>SAT 2</sub>	Output Saturation Voltage 2	I <sub>SW</sub> = 1.0A (Fig	ure 2)		0.45	0.7	V

# LM78S40 Electrical Characteristics (Note 5) (Continued)

 $T_A$  = Operating temperature range,  $V_{INI}$  = 5.0V,  $V^+$ (Op Amp) = 5.0V, unless otherwise specified.

Symbol	Parameter	Conditions	Min	Тур	Max	Units
OUTPUT	SWITCH SECTION			•		
h <sub>FE</sub>	Output Transistor Current Gain	$I_C = 1.0A, V_{CE} = 5.0V, T_A = 25^{\circ}C$		70		
IL	Output Leakage Current	V <sub>O</sub> = 40V, T <sub>A</sub> = 25°C		10		nA
POWER I	DIODE					
V <sub>FD</sub>	Forward Voltage Drop	I <sub>D</sub> = 1.0A		1.25	1.5	V
I <sub>DR</sub>	Diode Leakage Current	V <sub>D</sub> = 40V, T <sub>A</sub> = 25°C		10		nA
COMPAR	ATOR					
V <sub>IO</sub>	Input Offset Voltage	V <sub>CM</sub> = V <sub>REF</sub>		1.5	15	mV
I <sub>IB</sub>	Input Bias Current	V <sub>CM</sub> = V <sub>REF</sub>		35	200	nA
I <sub>IO</sub>	Input Offset Current	V <sub>CM</sub> = V <sub>REF</sub>		5.0	75	nA
V <sub>CM</sub>	Common Mode Voltage Range	T <sub>A</sub> = 25°C	0		V <sub>IN</sub> -2	V
PSRR	Power Supply Rejection Ratio	$V_{IN} = 3.0V \text{ to } 40V, T_A = 25^{\circ}C$	70	96		dB
OPERATI	ONAL AMPLIFIER			•		
V <sub>IO</sub>	Input Offset Voltage	V <sub>CM</sub> = 2.5V		4.0	15	mV
I <sub>IB</sub>	Input Bias Current	V <sub>CM</sub> = 2.5V		30	200	nA
I <sub>IO</sub>	Input Offset Current	V <sub>CM</sub> = 2.5V		5.0	75	nA
A <sub>VS</sub> <sup>+</sup>	Voltage Gain+	$R_L = 2.0 \text{ k}\Omega \text{ to GND};$	25	250		V/mV
		$V_{O} = 1.0V \text{ to } 2.5V, T_{A} = 25^{\circ}C$				ĺ
A <sub>VS</sub> <sup>-</sup>	Voltage Gain <sup>-</sup>	$R_L = 2.0 \text{ k}\Omega \text{ to V}^+ \text{ (Op Amp)}$ $V_Q = 1.0 \text{V to } 2.5 \text{V}, T_A = 25 ^{\circ}\text{C}$	25	250		V/mV
$V_{CM}$	Common Mode Voltage Range	T <sub>A</sub> = 25°C	0		V <sub>CC</sub> - 2	V
CMR	Common Mode Rejection	V <sub>CM</sub> = 0V to 3.0V, T <sub>A</sub> = 25°C	76	100		dB
PSRR	Power Supply Rejection Ratio	V <sup>+</sup> (Op Amp) = 3.0V to 40V, T <sub>A</sub> = 25°C	76	100		dB
lo <sup>+</sup>	Output Source Current	T <sub>A</sub> = 25°C	75	150		mA
lo <sup>-</sup>	Output Sink Current	T <sub>A</sub> = 25°C	10	35		mA
SR	Slew Rate	T <sub>A</sub> = 25°C		0.6		V/µs
V <sub>OL</sub>	Output Voltage LOW	I <sub>L</sub> = -5.0 mA, T <sub>A</sub> = 25°C			1.0	V
V <sub>OH</sub>	Output Voltage High	I <sub>L</sub> = 50 mA, T <sub>A</sub> = 25°C	V + (Op Amp) – 3V			V

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when ordering the device beyond its rated operating conditions.

Note 3: Ratings apply to ambient temperature at 25°C. Above this temperature, derate the 16L-Ceramic DIP at 10 mW/°C, and the 16L-Molded DIP at 8.3 mW/°C.

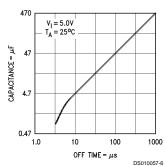
Note 5: A military RETS specification is available on request. At the time of printing, the LM78S40 RETS specification complied with the Min and Max limits in this table. The LM78S40J may also be procured as a Standard Military Drawing.

Note 2: T<sub>J Max</sub> = 150°C for the Molded DIP, and 175°C for the Ceramic DIP.

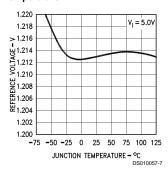
Note 4: For supply voltages less than 30V, the absolute maximum voltage is equal to the supply voltage.

# **Typical Performance Characteristics**

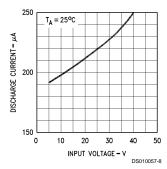
C<sub>T</sub> vs OFF Time



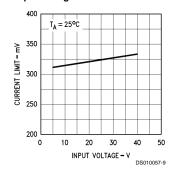
#### Reference Voltage vs Junction Temperature



#### Discharge Current vs Input Voltage



#### Current Limit Sense Voltage vs Input Voltage



## **Design Formulas**

Characteristic	Step-Down	Step-Up	Inverting	Units
t <sub>on</sub> t <sub>off</sub>	$\frac{V_{O} + V_{D}}{V_{I} - V_{SAT} - V_{O}}$	$\frac{V_O + V_D - V_I}{V_I - V_SAT}$	$\frac{ V_O  + V_D}{V_I - V_{SAT}}$	
(t <sub>on</sub> + t <sub>off</sub> ) Max	1 f <sub>Min</sub>	1 f <sub>Min</sub>	1 f <sub>MIN</sub>	μs
Ст	4 x 10 <sup>-5</sup> t <sub>on</sub>	4 x 10 <sup>-5</sup> t <sub>on</sub>	4 x 10 <sup>-5</sup> t <sub>on</sub>	μF
l <sub>pk</sub>	2 I <sub>O Max</sub>	2 I <sub>O Max</sub> • $\frac{t_{on} + t_{off}}{t_{off}}$	2 I <sub>O Max</sub> • $\frac{t_{on} + t_{off}}{t_{off}}$	A
L <sub>Min</sub>	$\left(\frac{V_I - V_{SAT} - V_O}{I_{pk}}\right) t_{on\;Max}$	$\left(\frac{V_{I} - V_{SAT}}{I_{pk}}\right) t_{on Max}$	$\left(\frac{V_{I} - V_{SAT}}{I_{pk}}\right) t_{on Max}$	μH
R <sub>sc</sub>	0.33/l <sub>pk</sub>	0.33/l <sub>pk</sub>	0.33/I <sub>pk</sub>	Ω
C <sub>o</sub>	l <sub>pk</sub> (t <sub>on</sub> + t <sub>off)</sub> 8 V <sub>ripple</sub>	$\approx \frac{I_{O}}{V_{ripple}} \bullet t_{on}$	$pprox rac{I_{O}}{V_{ripple}} leftharpoons t_{on}$	μF

Note 6:  $V_{SAT}$  = Saturation voltage of the switching element.

V<sub>D</sub> = Forward voltage of the flyback diode.

#### **Functional Description**

#### SWITCHING FREQUENCY CONTROL

The LM78S40 is a variable frequency, variable duty cycle device. The initial switching frequency is set by the timing capacitor. (Oscillator frequency is set by a single external capacitor and may be varied over a range of 100 Hz to 100 kHz). The initial duty cycle is 6:1. This switching frequency and duty cycle can be modified by two mechanisms — the current limit circuitry ( $I_{pk\ sense}$ ) and the comparator.

The comparator modifies the OFF time. When the output voltage is correct, the comparator output is in the HIGH state and has no effect on the circuit operation. If the output voltage is too high then the comparator output goes LOW. In the LOW state the comparator inhibits the turn-on of the output stage switching transistors. As long as the comparator is LOW the system is in OFF time. As the output current rises the OFF time decreases. As the output current nears its maximum the OFF time approaches its minimum value. The comparator can inhibit several ON cycles, one ON cycle or any portion of an ON cycle. Once the ON cycle has begun the comparator cannot inhibit until the beginning of the next ON cycle.

The current limit modifies the ON time. The current limit is activated when a 300 mV potential appears between lead 13 (V $_{\rm CC}$ ) and lead 14 (I $_{\rm pk}$ ). This potential is intended to result when designed for peak current flows through R $_{\rm SC}$ . When the peak current is reached the current limit is turned on. The current limit circuitry provides for a quick end to ON time and the immediate start of OFF time.

Generally the oscillator is free running but the current limit action tends to reset the timing cycle.

Increasing load results in more current limited ON time and less OFF time. The switching frequency increases with load current.

# USING THE INTERNAL REFERENCE, DIODE, AND SWITCH

The internal 1.245V reference (pin 8) must be bypassed, with 0.1  $\mu$ F directly to the ground pin (pin 11) of the LM78S40, to assure its stability.

 $V_{\text{FD}}$  is the forward voltage drop across the internal power diode. It is listed on the data sheet as 1.25V typical, 1.5V maximum. If an external diode is used, then its own forward voltage drop must be used for  $V_{\text{FD}}.$ 

 $\rm V_{SAT}$  is the voltage across the switch element (output transistors Q1 and Q2) when the switch is closed or ON. This is listed on the data sheet as Output Saturation Voltage.

"Output saturation voltage 1" is defined as the switching element voltage for Q2 and Q1 in the Darlington configuration with collectors tied together. This applies to *Figure 1*, the step down mode.

"Output saturation voltage 2" is the switching element voltage for Q1 only when used as a transistor switch. This applies to *Figure 2*, the step up mode.

For the inverting mode, Figure 3, the saturation voltage of the external transistor should be used for  $V_{\rm SAT}$ .

#### **Typical Applications**

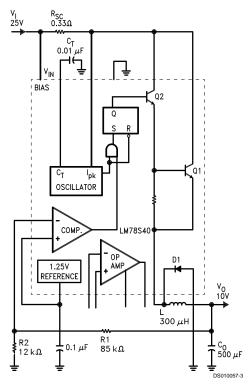


FIGURE 1. Typical Step-Down Regulator and Operational Performance ( $T_A = 25^{\circ}C$ )

Characteristic	Condition	Typical
		Value
Output Voltage	I <sub>O</sub> = 200 mA	10V
Line Regulation	$20V \le V_I \le 30V$	1.5 mV
Load Regulation	5.0 mA ≤ I <sub>O</sub>	3.0 mV
	I <sub>O</sub> ≤ 300 mA	
Max Output Current	V <sub>O</sub> = 9.5V	500 mA
Output Ripple	I <sub>O</sub> = 200 mA	50 mV
Efficiency	I <sub>O</sub> = 200 mA	74%
Standby Current	I <sub>O</sub> = 200 mA	2.8 mA

Note 7: For  $\rm I_{O} \geq 200~mA$  use external diode to limit on-chip power dissipation.

# Typical Applications (Continued)

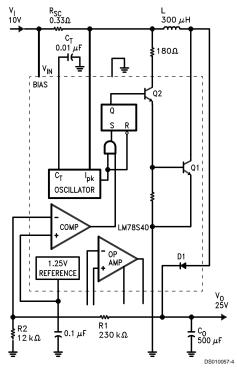


FIGURE 2. Typical Step-Up Regulator and Operational Performance (T<sub>A</sub> = 25°C)

Characteristic	Condition	Typical Value
Output Voltage	I <sub>O</sub> = 50 mA	25V
Line Regulation	5.0V ≤ V <sub>I</sub> ≤ 15V	4.0 mV
Load Regulation	5.0 mA ≤ I <sub>O</sub>	2.0 mV
	I <sub>O</sub> ≤ 100 mA	
Max Output Current	V <sub>O</sub> = 23.75V	160 mA
Output Ripple	I <sub>O</sub> = 50 mA	30 mV
Efficiency	I <sub>O</sub> = 50 mA	79%
Standby Current	I <sub>O</sub> = 50 mA	2.6 mA

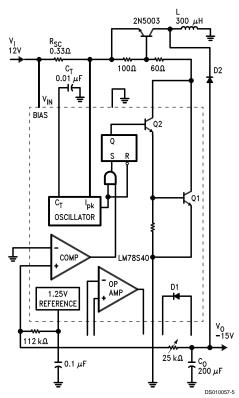


FIGURE 3. Typical Inverting Regulator and Operational Performance ( $T_A = 25^{\circ}C$ )

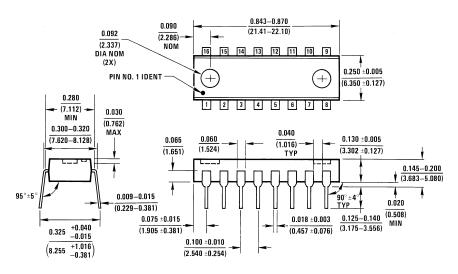
Characteristic	Condition	Typical	
		Value	
Output Voltage	I <sub>O</sub> = 100 mA	-15V	
Line Regulation	8.0V ≤ V <sub>I</sub> ≤ 18V	5.0 mV	
Load Regulation	5.0 mA ≤ I <sub>O</sub>	3.0 mV	
	I <sub>O</sub> ≤ 150 mA		
Max Output Current	V <sub>O</sub> = 14.25V	160 mA	
Output Ripple	I <sub>O</sub> = 100 mA	20 mV	
Efficiency	I <sub>O</sub> = 100 mA	70%	
Standby Current	I <sub>O</sub> = 100 mA	2.3 mA	

# Typical Applications (Continued) 30V IN 100 μF 100 μF 1800 pF 100 μF 1800 pF 100 μF 1.25V 3.6 kΩ 1.0 μF 1.0 μF 1.0 μF 1.0 μF 1.0 μF 1.0 μF 1.3 kΩ 1.5 κΩ 1.

FIGURE 4. Pulse Width Modulated Step-Down Regulator ( $f_{\rm OSC}$  = 20 kHz)

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16-Lead Ceramic Dual-In-Line Package (J) Order Number LM78S40J/883 NS Package Number J16A



N16A (REV E)

16-Lead Molded Dual-In-Line Package (N) Order Number LM78S40N or LM78S40CN NS Package Number N16A

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