

# LM78S40

*LM78S40 Universal Switching Regulator Subsystem*



Literature Number: SNVS021

## LM78S40 Universal Switching Regulator Subsystem

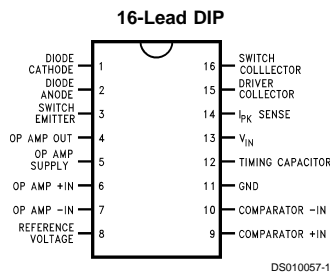
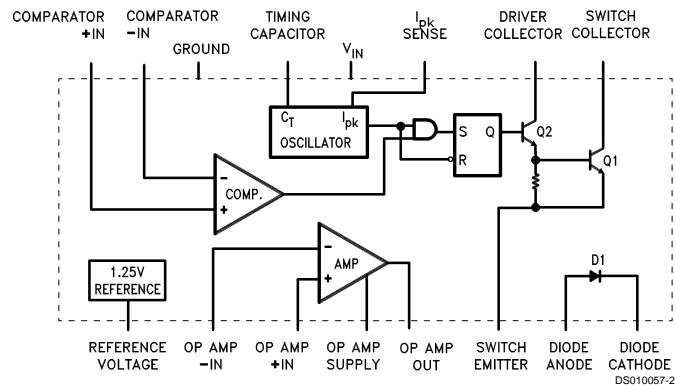
### General Description

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 Ratings (Note 1)

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

Storage Temperature Range		to GND	40V
Ceramic DIP	-65°C to +175°C	Common Mode Input Range (Comparator and Op Amp)	-0.3 to V+
Molded DIP	-65°C to +150°C	Differential Input Voltage (Note 4)	±30V
Operating Temperature Range		Output Short Circuit Duration (Op Amp)	Continuous
Extended (LM78S40J)	-55°C to +125°C	Current from V <sub>REF</sub>	10 mA
Industrial (LM78S40N)	-40°C to +125°C	Voltage from Switch Collectors to GND	40V
Commercial (LM78S40CN)	0°C to +70°C	Voltage from Switch Emitters to GND	40V
Lead Temperature		Voltage from Switch Collectors to Emitter	40V
Ceramic DIP (Soldering, 60 sec.)	300°C	Voltage from Power Diode to GND	40V
Molded DIP (Soldering, 10 sec.)	265°C	Reverse Power Diode Voltage	40V
Internal Power Dissipation (Note 2) (Note 3)		Current through Power Switch	1.5A
16L-Ceramic DIP	1.50W	Current through Power Diode	1.5A
16L-Molded DIP	1.04W	ESD Susceptibility	(to be determined)
Input Voltage from V <sub>IN</sub> to GND	40V		
Input Voltage from V <sup>+</sup> (Op Amp)			

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### Electrical Characteristics (Note 5)

T<sub>A</sub> = Operating temperature range, V<sub>IN</sub> = 5.0V, V<sup>+</sup>(Op Amp) = 5.0V, unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>GENERAL CHARACTERISTICS</b>						
I <sub>CC</sub>	Supply Current (Op Amp Disconnected)	V <sub>IN</sub> = 5.0V		1.8	3.5	mA
		V <sub>IN</sub> = 40V		2.3	5.0	mA
I <sub>CC</sub>	Supply Current (Op Amp Connected)	V <sub>IN</sub> = 5.0V			4.0	mA
		V <sub>IN</sub> = 40V			5.5	mA
<b>REFERENCE SECTION</b>						
V <sub>REF</sub>	Reference Voltage	I <sub>REF</sub> = 1.0 mA Extend -55°C < T <sub>A</sub> < +125°C, Comm 0 < T <sub>A</sub> < +70°C, Indus -40°C < T <sub>A</sub> < +85°C	1.180	1.245	1.310	V
V <sub>R LINE</sub>	Reference Voltage Line Regulation	V <sub>IN</sub> = 3.0V to V <sub>IN</sub> = 40V, I <sub>REF</sub> = 1.0 mA, T <sub>A</sub> = 25°C		0.04	0.2	mV/V
V <sub>R LOAD</sub>	Reference Voltage Load Regulation	I <sub>REF</sub> = 1.0 mA to I <sub>REF</sub> = 10 mA, T <sub>A</sub> = 25°C		0.2	0.5	mV/mA
<b>OSCILLATOR SECTION</b>						
I <sub>CHG</sub>	Charging Current	V <sub>IN</sub> = 5.0V, T <sub>A</sub> = 25°C	20		50	μA
I <sub>CHG</sub>	Charging Current	V <sub>IN</sub> = 40V, T <sub>A</sub> = 25°C	20		70	μA
I <sub>DISCHG</sub>	Discharge Current	V <sub>IN</sub> = 5.0V, T <sub>A</sub> = 25°C	150		250	μA
I <sub>DISCHG</sub>	Discharge Current	V <sub>IN</sub> = 40V, T <sub>A</sub> = 25°C	150		350	μA
V <sub>OSC</sub>	Oscillator Voltage Swing	V <sub>IN</sub> = 5.0V, T <sub>A</sub> = 25°C		0.5		V
t <sub>on</sub> /t <sub>off</sub>	Ratio of Charge/Discharge Time			6.0		μs/μs
<b>CURRENT LIMIT SECTION</b>						
V <sub>CLS</sub>	Current Limit Sense Voltage	T <sub>A</sub> = 25°C	250		350	mV
<b>OUTPUT SWITCH SECTION</b>						
V <sub>SAT 1</sub>	Output Saturation Voltage 1	I <sub>SW</sub> = 1.0A (Figure 1)		1.1	1.3	V
V <sub>SAT 2</sub>	Output Saturation Voltage 2	I <sub>SW</sub> = 1.0A (Figure 2)		0.45	0.7	V

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### Electrical Characteristics (Note 5) (Continued)

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

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>OUTPUT SWITCH SECTION</b>						
$h_{FE}$	Output Transistor Current Gain	$I_C = 1.0A, V_{CE} = 5.0V, T_A = 25^\circ C$		70		
$I_L$	Output Leakage Current	$V_O = 40V, T_A = 25^\circ C$		10		nA
<b>POWER DIODE</b>						
$V_{FD}$	Forward Voltage Drop	$I_D = 1.0A$		1.25	1.5	V
$I_{DR}$	Diode Leakage Current	$V_D = 40V, T_A = 25^\circ C$		10		nA
<b>COMPARATOR</b>						
$V_{IO}$	Input Offset Voltage	$V_{CM} = V_{REF}$		1.5	15	mV
$I_{IB}$	Input Bias Current	$V_{CM} = V_{REF}$		35	200	nA
$I_{IO}$	Input Offset Current	$V_{CM} = V_{REF}$		5.0	75	nA
$V_{CM}$	Common Mode Voltage Range	$T_A = 25^\circ C$	0		$V_{IN}-2$	V
PSRR	Power Supply Rejection Ratio	$V_{IN} = 3.0V \text{ to } 40V, T_A = 25^\circ C$	70	96		dB
<b>OPERATIONAL AMPLIFIER</b>						
$V_{IO}$	Input Offset Voltage	$V_{CM} = 2.5V$		4.0	15	mV
$I_{IB}$	Input Bias Current	$V_{CM} = 2.5V$		30	200	nA
$I_{IO}$	Input Offset Current	$V_{CM} = 2.5V$		5.0	75	nA
$A_{VS}^+$	Voltage Gain <sup>+</sup>	$R_L = 2.0 \text{ k}\Omega \text{ to GND};$ $V_O = 1.0V \text{ to } 2.5V, T_A = 25^\circ C$	25	250		V/mV
$A_{VS}^-$	Voltage Gain <sup>-</sup>	$R_L = 2.0 \text{ k}\Omega \text{ to } V^+ \text{ (Op Amp)}$ $V_O = 1.0V \text{ to } 2.5V, T_A = 25^\circ C$	25	250		V/mV
$V_{CM}$	Common Mode Voltage Range	$T_A = 25^\circ C$	0		$V_{CC} - 2$	V
CMR	Common Mode Rejection	$V_{CM} = 0V \text{ to } 3.0V, T_A = 25^\circ C$	76	100		dB
PSRR	Power Supply Rejection Ratio	$V^+ \text{ (Op Amp)} = 3.0V \text{ to } 40V, T_A = 25^\circ C$	76	100		dB
$I_{O}^+$	Output Source Current	$T_A = 25^\circ C$	75	150		mA
$I_{O}^-$	Output Sink Current	$T_A = 25^\circ C$	10	35		mA
SR	Slew Rate	$T_A = 25^\circ C$		0.6		V/ $\mu$ s
$V_{OL}$	Output Voltage LOW	$I_L = -5.0 \text{ mA}, T_A = 25^\circ C$			1.0	V
$V_{OH}$	Output Voltage High	$I_L = 50 \text{ mA}, T_A = 25^\circ C$		$V^+ \text{ (Op Amp)} - 3V$		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 2:**  $T_{J \text{ Max}} = 150^\circ C$  for the Molded DIP, and  $175^\circ C$  for the Ceramic DIP.

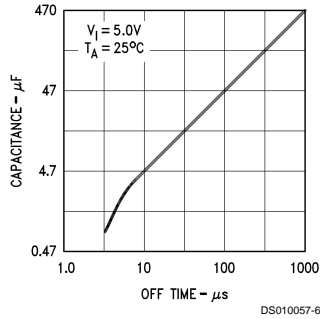
**Note 3:** Ratings apply to ambient temperature at  $25^\circ C$ . Above this temperature, derate the 16L-Ceramic DIP at  $10 \text{ mW}/^\circ C$ , and the 16L-Molded DIP at  $8.3 \text{ mW}/^\circ C$ .

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

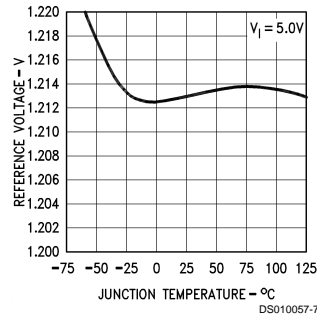
**Note 5:** A military RETS specification is available on request. At the time of printing, the LM78S40 RETS specification complied with the Min and Max limits in this table. The LM78S40J may also be procured as a Standard Military Drawing.

## Typical Performance Characteristics

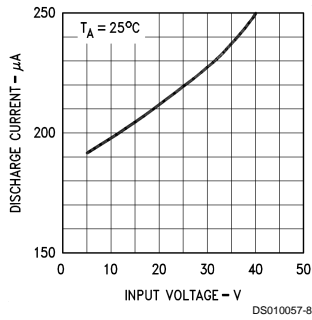
$C_T$  vs OFF Time



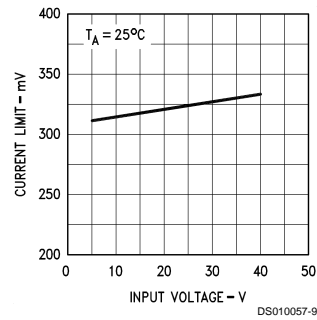
Reference Voltage vs Junction Temperature



Discharge Current vs Input Voltage



Current Limit Sense Voltage vs Input Voltage



## Design Formulas

Characteristic	Step-Down	Step-Up	Inverting	Units
$\frac{t_{on}}{t_{off}}$	$\frac{V_O + V_D}{V_I - V_{SAT} - V_O}$	$\frac{V_O + V_D - V_I}{V_I - V_{SAT}}$	$\frac{ V_O  + V_D}{V_I - V_{SAT}}$	
$(t_{on} + t_{off})_{Max}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{MIN}}$	μs
$C_T$	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	μF
$I_{pk}$	$2 I_{O Max}$	$2 I_{O Max} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	$2 I_{O Max} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	A
$L_{Min}$	$\left( \frac{V_I - V_{SAT} - V_O}{I_{pk}} \right) t_{on Max}$	$\left( \frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on Max}$	$\left( \frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on Max}$	μH
$R_{SC}$	$0.33/I_{pk}$	$0.33/I_{pk}$	$0.33/I_{pk}$	Ω
$C_O$	$\frac{I_{pk} (t_{on} + t_{off})}{8 V_{ripple}}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	μF

**Note 6:**  $V_{SAT}$  = Saturation voltage of the switching element.  
 $V_D$  = 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 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 ( $V_{CC}$ ) and lead 14 ( $I_{pk}$ ). This potential is intended to result when designed for peak current flows through  $R_{SC}$ . 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  $\mu\text{F}$  directly to the ground pin (pin 11) of the LM78S40, to assure its stability.

$V_{FD}$  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  $V_{FD}$ .

$V_{SAT}$  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  $V_{SAT}$ .

## Typical Applications

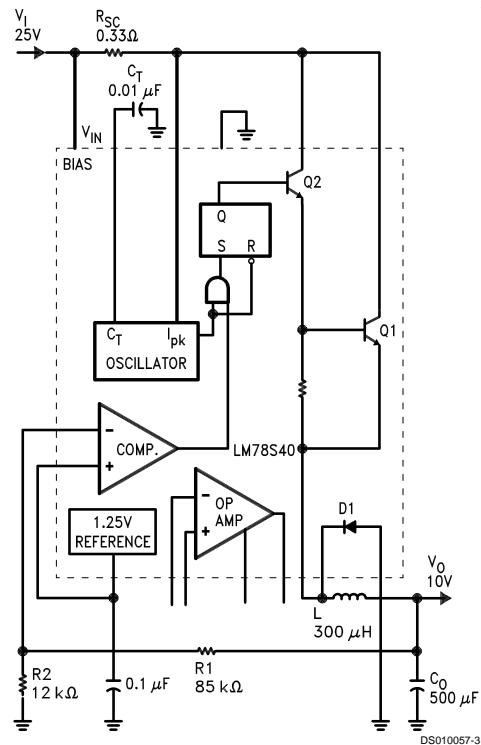


FIGURE 1. Typical Step-Down Regulator and Operational Performance ( $T_A = 25^\circ\text{C}$ )

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 200 \text{ mA}$	10V
Line Regulation	$20\text{V} \leq V_I \leq 30\text{V}$	1.5 mV
Load Regulation	$5.0 \text{ mA} \leq I_O \leq 300 \text{ mA}$	3.0 mV
Max Output Current	$V_O = 9.5\text{V}$	500 mA
Output Ripple	$I_O = 200 \text{ mA}$	50 mV
Efficiency	$I_O = 200 \text{ mA}$	74%
Standby Current	$I_O = 200 \text{ mA}$	2.8 mA

**Note 7:** For  $I_O \geq 200 \text{ mA}$  use external diode to limit on-chip power dissipation.

## Typical Applications (Continued)

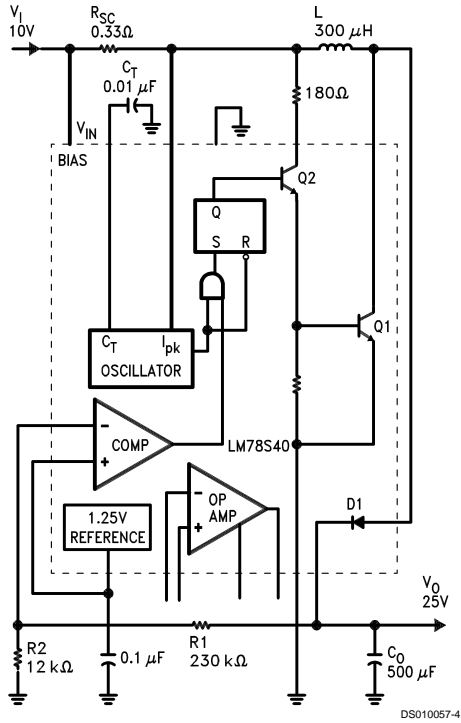


FIGURE 2. Typical Step-Up Regulator and Operational Performance ( $T_A = 25^\circ\text{C}$ )

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 50\text{ mA}$	25V
Line Regulation	$5.0\text{V} \leq V_I \leq 15\text{V}$	4.0 mV
Load Regulation	$5.0\text{ mA} \leq I_O$ $I_O \leq 100\text{ mA}$	2.0 mV
Max Output Current	$V_O = 23.75\text{V}$	160 mA
Output Ripple	$I_O = 50\text{ mA}$	30 mV
Efficiency	$I_O = 50\text{ mA}$	79%
Standby Current	$I_O = 50\text{ mA}$	2.6 mA

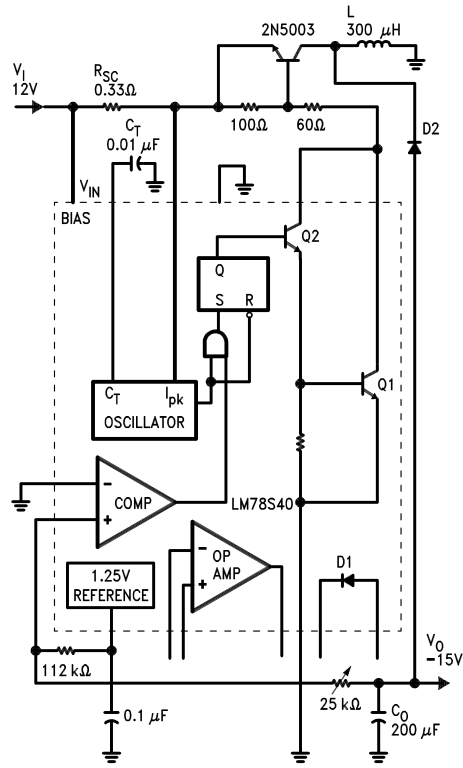
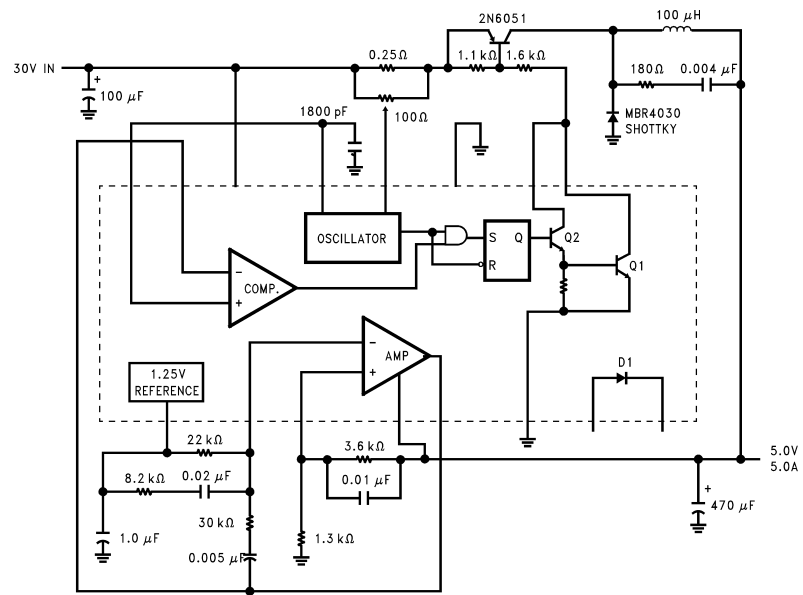


FIGURE 3. Typical Inverting Regulator and Operational Performance ( $T_A = 25^\circ\text{C}$ )

Characteristic	Condition	Typical Value
Output Voltage	$I_O = 100\text{ mA}$	-15V
Line Regulation	$8.0\text{V} \leq V_I \leq 18\text{V}$	5.0 mV
Load Regulation	$5.0\text{ mA} \leq I_O$ $I_O \leq 150\text{ mA}$	3.0 mV
Max Output Current	$V_O = 14.25\text{V}$	160 mA
Output Ripple	$I_O = 100\text{ mA}$	20 mV
Efficiency	$I_O = 100\text{ mA}$	70%
Standby Current	$I_O = 100\text{ mA}$	2.3 mA



## Typical Applications (Continued)



DS010057-10

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

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Fax: 1-800-737-7018  
Email: support@nsc.com

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Fax: 65-2504466  
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**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM78S40CN/NOPB	ACTIVE	PDIP	NFG	16	25	Pb-Free (RoHS)	SN	Level-1-NA-UNLIM	-55 to 125	LM78S40CN	<a href="#">Samples</a>
LM78S40N/NOPB	ACTIVE	PDIP	NFG	16	25	Pb-Free (RoHS)	CU SN	Level-1-NA-UNLIM	-55 to 125	LM78S40N	<a href="#">Samples</a>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

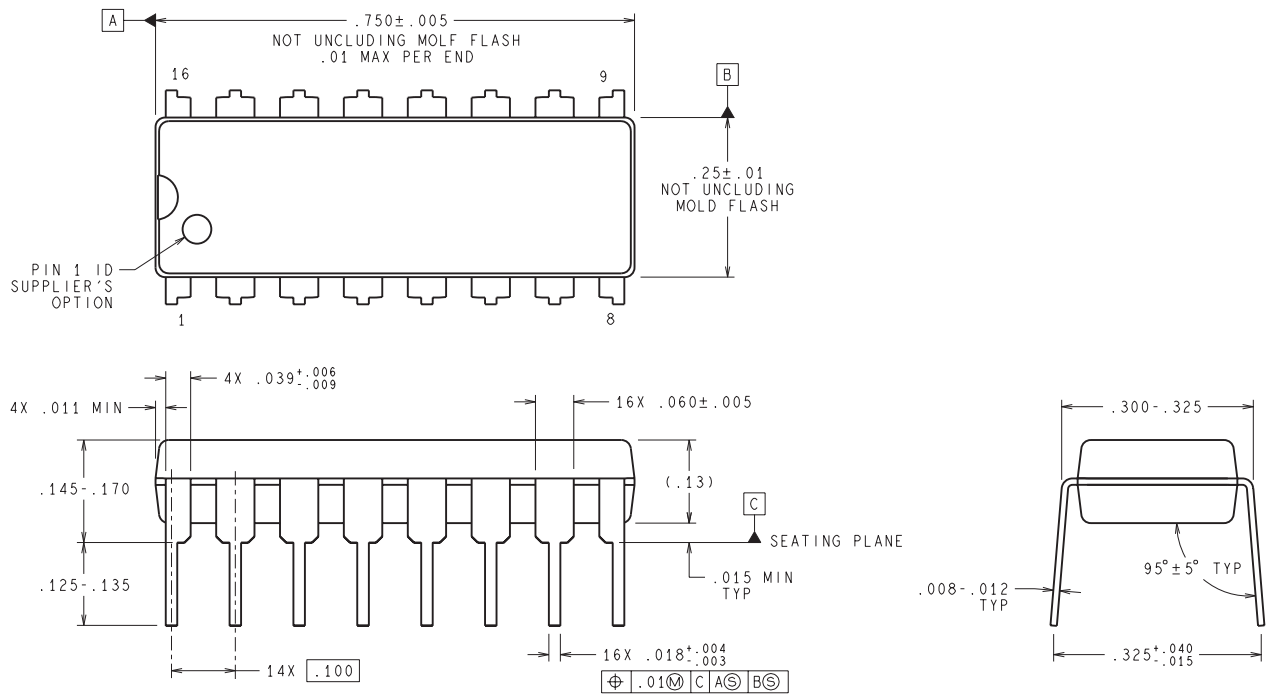
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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