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# μA78S40 Universal Switching Regulator Subsystem

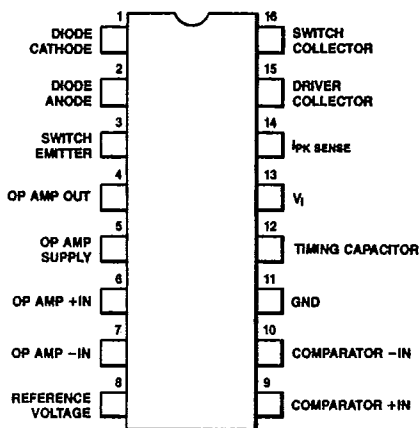
Linear Division Voltage Regulators

### Description

The μA78S40 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 1.5 A or voltages in excess of 40 V 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.

- Step-Up, Step-Down or Inverting Switching Regulators
- Output Adjustable From 1.25 V to 40 V
- Peak Currents To 1.5 A Without External Transistors
- Operation From 2.5 V to 40 V 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

### Connection Diagram 16-Lead DIP (Top View)

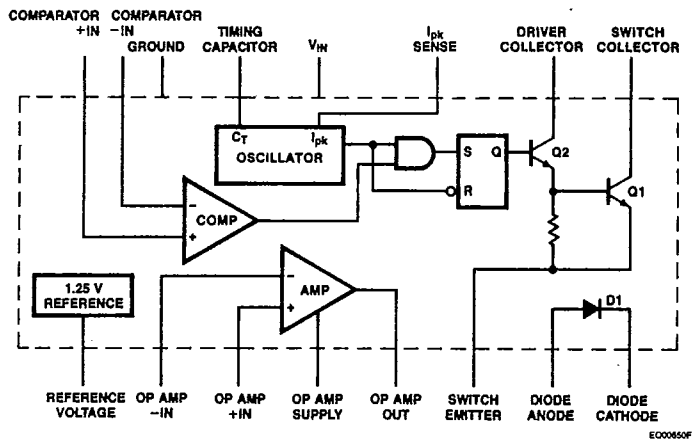


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### Order Information

Device Code	Package Code	Package Description
μA78S40DM	7B	Ceramic DIP
μA78S40PV	9B	Molded DIP
μA78S40DC	7B	Ceramic DIP
μA78S40PC	9B	Molded DIP

### Block Diagram



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**Absolute Maximum Ratings**

<b>Storage Temperature Range</b>	
Ceramic DIP	-65°C to +175°C
Molded DIP	-65°C to +150°C
<b>Operating Temperature Range</b>	
Extended ( $\mu$ A78S40M)	-55°C to +125°C
Industrial ( $\mu$ A78S40V)	-40°C to +125°C
Commercial ( $\mu$ A78S40C)	0°C to +70°C
<b>Lead Temperature</b>	
Ceramic DIP (soldering, 60 s)	300°C
Molded DIP (soldering, 10 s)	265°C
<b>Internal Power Dissipation<sup>1,2</sup></b>	
16L-Ceramic DIP	1.50 W
16L-Molded DIP	1.04 W
Input Voltage from V+ to V-	40 V
Input Voltage from V+ Op Amp to V-	40 V

**Notes**

- $T_{J \text{ Max}}$  = 150°C for the Molded DIP, and 175°C for the Ceramic DIP.
- 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.
- For supply voltages less than 30 V, the absolute maximum voltage is equal to the supply voltage.

**Functional Description**

The  $\mu$ A78S40 is a variable frequency, variable duty cycle device. The initial switching frequency is set by the timing capacitor.<sup>1</sup> 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 ( $V_{CC}$ ) 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.

**Note**

- Oscillator frequency is set by a single external capacitor and may be varied over a range of 100 Hz to 100 kHz.

Common Mode Input Range (Error Amplifier and Op Amp)	-0.3 to V+
Differential Input Voltage <sup>3</sup>	$\pm 30$ V
Output Short Circuit Duration (Op Amp)	Indefinite
Current from $V_{REF}$	10 mA
Voltage from Switch Collectors to GND	40 V
Voltage from Switch Emitters to GND	40 V
Voltage from Switch Collectors to Emitter	40 V
Voltage from Power Diode to GND	40 V
Reverse Power Diode Voltage	40 V
Current through Power Switch	1.5 A
Current through Power Diode	1.5 A

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.

$V_{FD}$  is the forward voltage drop across the internal power diode. It is listed on the data sheet as 1.25 V typical, 1.5 V 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—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—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  $V_{SAT}$ .

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**Electrical Characteristics**  $T_A$  = Operating temperature range,  $V_I = 5.0$  V,  $V_{Op Amp} = 5.0$  V, unless otherwise specified.

Symbol	Characteristic	Condition	Min	Typ	Max	Unit
<b>General Characteristics</b>						
$I_{CC}$	Supply Current (Op Amp Disconnected)	$V_I = 5.0$ V		1.8	3.5	mA
		$V_I = 40$ V		2.3	5.0	mA
$I_{CC}$	Supply Current (Op Amp Connected)	$V_I = 5.0$ V			4.0	mA
		$V_I = 40$ V			5.5	mA
<b>Reference Section</b>						
$V_{REF}$	Reference Voltage <sup>1</sup>	$I_{REF} = 1.0$ mA Extend $-55^\circ\text{C} < T_A < +125^\circ\text{C}$ , Comm $0 < T_A < +70^\circ\text{C}$ , Indus $-40^\circ\text{C} < T_A < +85^\circ\text{C}$	1.180	1.245	1.310	V
$V_{R LINE}$	Reference Voltage Line Regulation	$V_I = 3.0$ V to $V_I = 40$ V, $I_{REF} = 1.0$ mA, $T_A = 25^\circ\text{C}$		0.04	0.2	mV/V
$V_{R LOAD}$	Reference Voltage Load Regulation	$I_{REF} = 1.0$ mA to $I_{REF} = 10$ mA, $T_A = 25^\circ\text{C}$		0.2	0.5	mV/mA
<b>Oscillator Section</b>						
$I_{CHG}$	Charging Current	$V_I = 5.0$ V, $T_A = 25^\circ\text{C}$	20		50	$\mu$ A
$I_{CHG}$	Charging Current	$V_I = 40$ V, $T_A = 25^\circ\text{C}$	20		70	$\mu$ A
$I_{DISCHG}$	Discharge Current	$V_I = 5.0$ V, $T_A = 25^\circ\text{C}$	150		250	$\mu$ A
$I_{DISCHG}$	Discharge Current	$V_I = 40$ V, $T_A = 25^\circ\text{C}$	150		350	$\mu$ A
$V_{OSC}$	Oscillator Voltage Swing	$V_I = 5.0$ V, $T_A = 25^\circ\text{C}$		0.5		V
$t_{on}/t_{off}$	Ratio of Charge/ Discharge Time			6.0		$\mu$ s/ $\mu$ s
<b>Current Limit Section</b>						
$V_{CLS}$	Current Limit Sense Voltage	$T_A = 25^\circ\text{C}$	250		350	mV
<b>Output Switch Section</b>						
$V_{SAT 1}$	Output Saturation Voltage 1	$I_{SW} = 1.0$ A, Figure 1		1.1	1.3	V
$V_{SAT 2}$	Output Saturation Voltage 2	$I_{SW} = 1.0$ A, Figure 2		0.45	0.7	V
$h_{FE}$	Output Transistor Current Gain	$I_C = 1.0$ A, $V_{CE} = 5.0$ V, $T_A = 25^\circ\text{C}$		70		
$I_L$	Output Leakage Current	$V_O = 40$ V, $T_A = 25^\circ\text{C}$		10		nA
<b>Power Diode</b>						
$V_{FD}$	Forward Voltage Drop	$I_D = 1.0$ A		1.25	1.5	V
$I_{DR}$	Diode Leakage Current	$V_D = 40$ V, $T_A = 25^\circ\text{C}$		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

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**Electrical Characteristics**  $T_A$  = Operating temperature range,  $V_I = 5.0$  V,  $V_{Op Amp} = 5.0$  V, unless otherwise specified.

Symbol	Characteristic	Condition	Min	Typ	Max	Unit
$V_{CM}$	Common Mode Voltage Range	$T_A = 25^\circ\text{C}$	0		$V_I - 2$	V
PSRR	Power Supply Rejection Ratio	$V_I = 3.0$ V to 40 V, $T_A = 25^\circ\text{C}$	70	96		dB
<b>Output Operational Amplifier</b>						
$V_{IO}$	Input Offset Voltage	$V_{CM} = 2.5$ V		4.0	15	mV
$I_{IB}$	Input Bias Current	$V_{CM} = 2.5$ V		30	200	nA
$I_{IO}$	Input Offset Current	$V_{CM} = 2.5$ V		5.0	75	nA
$A_{VS+}$	Voltage Gain +	$R_L = 2.0$ k $\Omega$ to GND; $V_O = 1.0$ V to 2.5 V, $T_A = 25^\circ\text{C}$	25	250		V/mV
$A_{VS-}$	Voltage Gain -	$R_L = 2.0$ k $\Omega$ to $V+$ (Op Amp) $V_O = 1.0$ V to 2.5 V, $T_A = 25^\circ\text{C}$	25	250		V/mV
$V_{CM}$	Common Mode Voltage Range	$T_A = 25^\circ\text{C}$	0		$V_{CC} - 2$	V
CMR	Common Mode Rejection	$V_{CM} = 0$ V to 3.0 V, $T_A = 25^\circ\text{C}$	76	100		dB
PSRR	Power Supply Rejection Ratio	$V+$ Op Amp = 3.0 to 40 V, $T_A = 25^\circ\text{C}$	76	100		dB
$I_{O+}$	Output Source Current	$T_A = 25^\circ\text{C}$	75	150		mA
$I_{O-}$	Output Sink Current	$T_A = 25^\circ\text{C}$	10	35		mA
SR	Slew Rate	$T_A = 25^\circ\text{C}$		0.6		V/ $\mu$ s
$V_{OL}$	Output Voltage LOW	$I_L = -5.0$ mA, $T_A = 25^\circ\text{C}$			1.0	V
$V_{OH}$	Output Voltage HIGH	$I_L = 50$ mA, $T_A = 25^\circ\text{C}$	$V + OP$ Amp -3.0 V			V

**Note**

1. Selected devices with tightened tolerance reference voltage available.

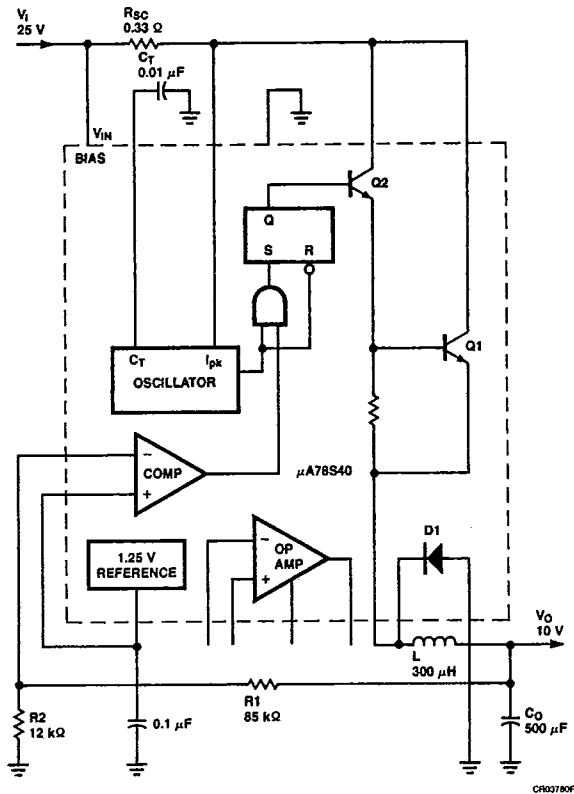
**Design Formulas**

CHARACTERISTIC	STEP-DOWN	STEP-UP	INVERTING	UNIT
$\frac{t_{on}}{t_{off}}$	$\frac{V_O + V_D}{V_I - V_{SAT} - V_O}$	$\frac{V_O + V_D - V_I}{V_I - V_{SAT}}$	$\frac{ V_O  + V_D}{V_I - V_{SAT}}$	
$(t_{on} + t_{off}) \text{ Max}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{Min}}$	μs
C <sub>T</sub>	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	$4 \times 10^{-5} t_{on}$	μF
I <sub>pk</sub>	$2 I_O \text{ Max}$	$2 I_O \text{ Max} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	$2 I_O \text{ Max} \cdot \frac{t_{on} + t_{off}}{t_{off}}$	A
L <sub>Min</sub>	$\left( \frac{V_I - V_{SAT} - V_O}{I_{pk}} \right) t_{on} \text{ Max}$	$\left( \frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on} \text{ Max}$	$\left( \frac{V_I - V_{SAT}}{I_{pk}} \right) t_{on} \text{ Max}$	μH
R <sub>SC</sub>	$0.33/I_{pk}$	$0.33/I_{pk}$	$0.33/I_{pk}$	Ω
C <sub>O</sub>	$\frac{I_{pk} (t_{on} + t_{off})}{8 V_{ripple}}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	$\approx \frac{I_O}{V_{ripple}} \cdot t_{on}$	μF

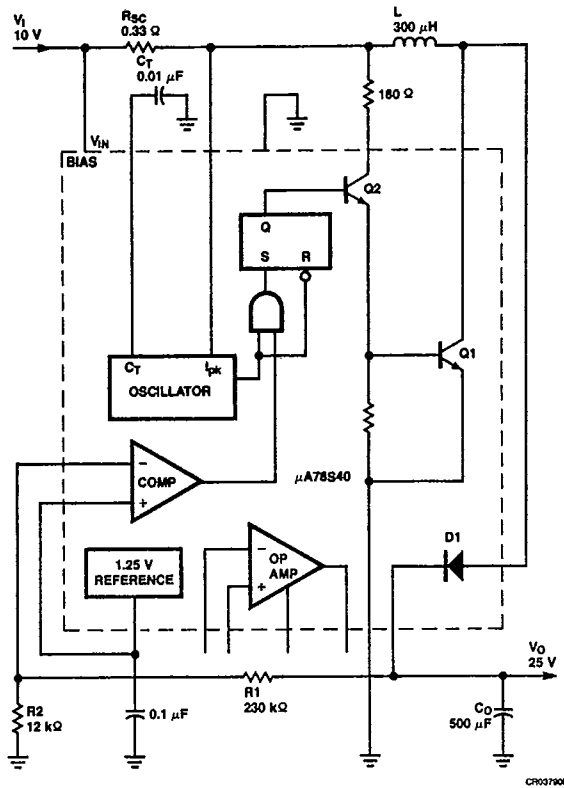
**Note**  
 V<sub>SAT</sub> = Saturation voltage of the switching element  
 V<sub>O</sub> = Forward voltage of the flyback diode

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**Figure 1 Typical Step-Down Operational Performance**  
 (T<sub>A</sub> = 25°C)



**Figure 2 Typical Step-Up Operational Performance**  
 (T<sub>A</sub> = 25°C)

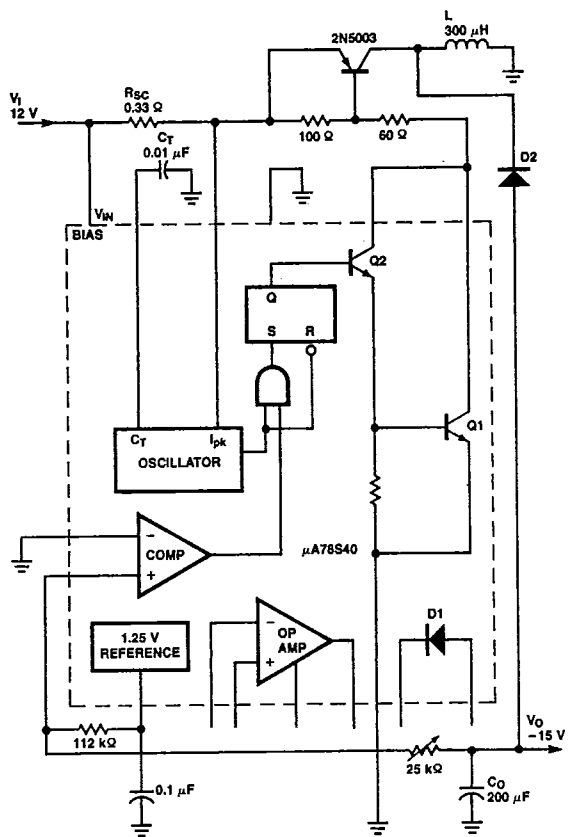


Characteristic	Condition	Typical Value
Output Voltage	I <sub>O</sub> = 200 mA	10 V
Line Regulation	20 ≤ V <sub>I</sub> ≤ 30 V	1.5 mV
Load Regulation	5.0 mA ≤ I <sub>O</sub>	3.0 mV
	I <sub>O</sub> ≤ 300 mA	500 mA
Max Output Current	V <sub>O</sub> = 9.5 V	50 mV
Output Ripple	I <sub>O</sub> = 200 mA	74%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

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

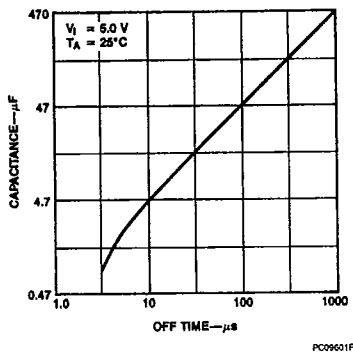
- Notes**
1. For I<sub>O</sub> ≥ 200 mA use external diode to limit on-chip power dissipation.
  2. It is recommended that the internal reference (lead 8) be bypassed by a 0.1 μF capacitor directly to (lead 11) the ground point of the μA78S40.

Figure 3 Typical Inversion Operational Performance (T<sub>A</sub> = 25°C)

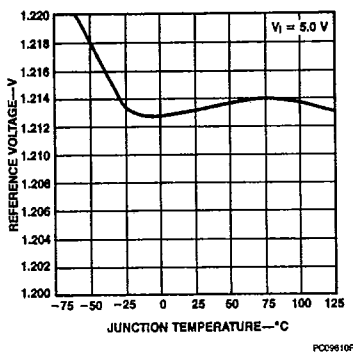


Typical Performance Curves

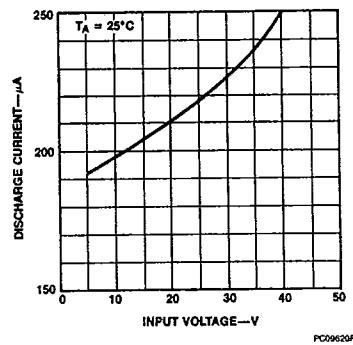
Capacitance vs OFF Time



Reference Voltage vs Junction Temperature



Discharge Current vs Input Voltage

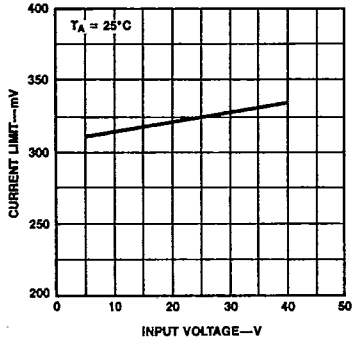


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Characteristic	Condition	Typical Value
Output Voltage	I <sub>O</sub> = 100 mA	-15 V
Line Regulation	8.0 V ≤ V <sub>I</sub> < 18 V	5.0 mV
Load Regulation	5.0 mA ≤ I <sub>O</sub>	3.0 mV
Max Output Current	V <sub>O</sub> = 14.25 V	160 mA
Output Ripple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

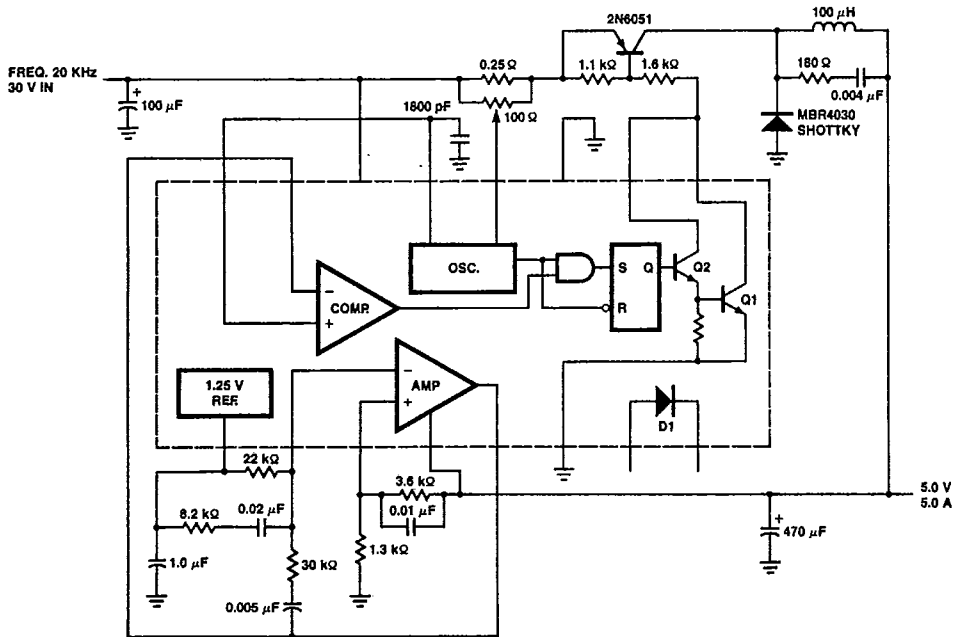
Typical Performance Curves (Cont.)

Current Limit Sense Voltage vs Input Voltage



PC9630F

Typical Pulse Width Modulator Application



CR0291F