

# Regulating Pulse Width Modulator

## FEATURES

- 8V to 35V Operation
- *Guaranteed*  $\pm 1\%$  5V Reference
- *Guaranteed* 10mV/1000 Hrs. Long Term Stability
- *Guaranteed*  $\pm 3\%$  Oscillator Temperature Stability
- Undervoltage Lockout
- 100mA Source/Sink Outputs

## APPLICATIONS

- Switching Power Supplies
- Motor Speed Control
- Power Converters

## DESCRIPTION

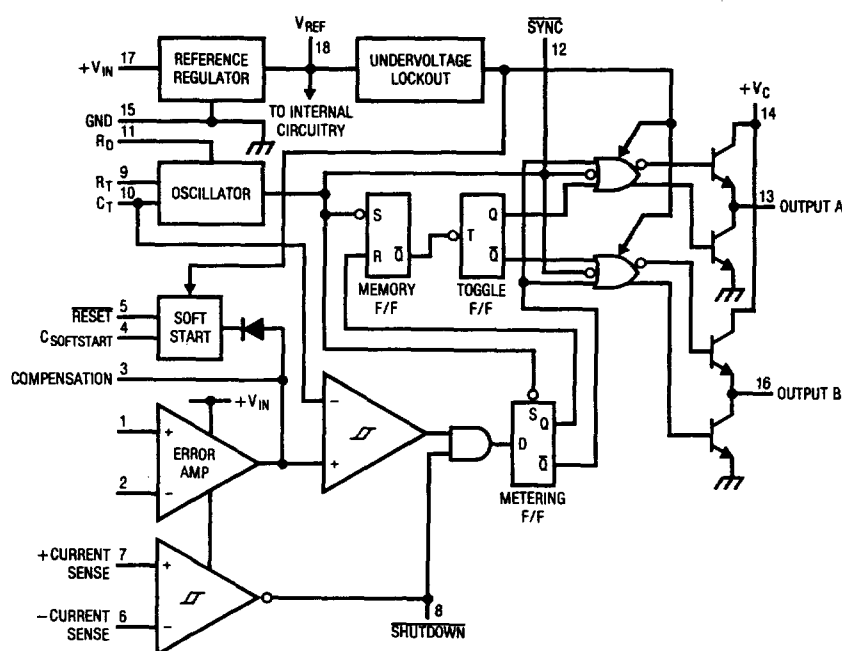
The LT1526 is an improved general purpose switching regulator control circuit. Included on the chip are a 1% voltage reference, oscillator, error amplifier, pulse width modulator and low impedance output drivers. Also included are protective features such as a current limit comparator, undervoltage lockout, soft-start circuitry, and adjustable deadtime. This versatile device can be used to implement single-ended or push-pull switching regulators of either polarity, both transformerless and transformer-coupled.

Although pin-for-pin and functionally compatible with industry standard 1526 and 3526 devices, Linear Technology has incorporated several improvements in the design of the LT1526. A subsurface zener has been used to provide excellent reference voltage stability and the reference offers improved line regulation and load regulation. The current limit comparator sense voltage initial accuracy and temperature stability have been greatly improved.

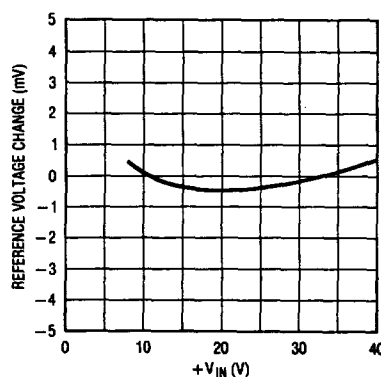
The combination of improved features and advanced linear processing for high reliability make Linear Technology's switching regulators a superior choice.

**5**

## BLOCK DIAGRAM



Reference Line Regulation

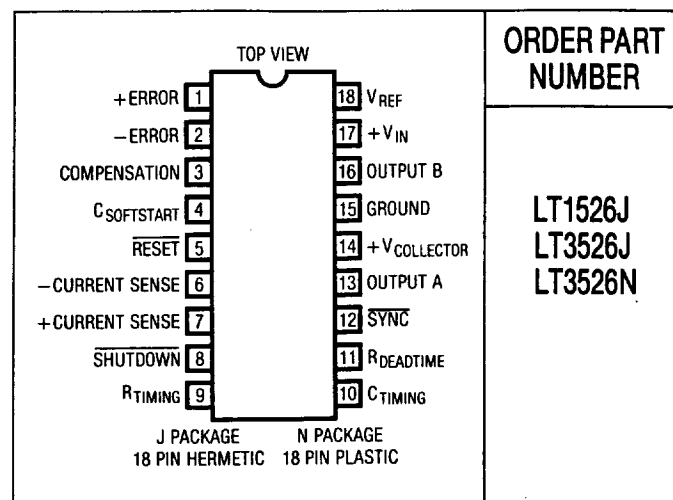


# ABSOLUTE MAXIMUM RATINGS

(Note 1)

|                                              |                             |
|----------------------------------------------|-----------------------------|
| Input Voltage (+ V <sub>IN</sub> )           | + 40V                       |
| Collector Supply Voltage (+ V <sub>C</sub> ) | + 40V                       |
| Logic Inputs                                 | – 0.3V to + 5.5V            |
| Analog Inputs                                | – 0.3V to + V <sub>IN</sub> |
| Source/Sink Load Current (each output)       | 200mA                       |
| Reference Load Current                       | 50mA                        |
| Logic Sink Current                           | 15mA                        |
| Operating Junction Temperature Range         |                             |
| LT1526                                       | – 55°C to + 150°C           |
| LT3526                                       | 0°C to + 125°C              |
| Storage Temperature Range                    | – 65°C to + 150°C           |
| Lead Temperature (Soldering, 10sec)          | + 300°C                     |

# PACKAGE/ORDER INFORMATION



# RECOMMENDED OPERATING CONDITIONS (Note 2)

|                                        |                 |                                   |               |
|----------------------------------------|-----------------|-----------------------------------|---------------|
| Input Voltage                          | + 8V to + 35V   | Oscillator Frequency Range        | 1Hz to 400kHz |
| Collector Supply Voltage               | + 4.5V to + 35V | Oscillator Timing Resistor        | 2kΩ to 150kΩ  |
| Sink/Source Load Current (each output) | 0mA to 100mA    | Oscillator Timing Capacitor       | 1nF to 20μF   |
| Reference Load Current                 | – 5mA to 20mA   | Available Deadtime Range at 40kHz | 3% to 50%     |

# ELECTRICAL CHARACTERISTICS

(+ V<sub>IN</sub> = 15V, and over operating junction temperature, unless otherwise specified.)

| PARAMETER                   | CONDITIONS                            |   | LT1526 |      |      | LT3526 |      |      | UNITS   |
|-----------------------------|---------------------------------------|---|--------|------|------|--------|------|------|---------|
|                             |                                       |   | MIN    | TYP  | MAX  | MIN    | TYP  | MAX  |         |
| REFERENCE SECTION (Note 3)  |                                       |   |        |      |      |        |      |      |         |
| Output Voltage              | T <sub>J</sub> = + 25°C               |   | 4.95   | 5.00 | 5.05 | 4.90   | 5.00 | 5.10 | V       |
| Line Regulation             | + V <sub>IN</sub> = 8V to 35V         | ● | 2      | 10   |      | 2      | 15   |      | mV      |
| Load Regulation             | I <sub>L</sub> = – 5mA to + 20mA      | ● | 5      | 10   |      | 5      | 20   |      | mV      |
| Temperature Stability       |                                       | ● | 15     | 50   |      | 15     | 50   |      | mV      |
| Total Output Voltage Range  | Over Recommended Operating Conditions | ● | 4.90   | 5.00 | 5.10 | 4.85   | 5.00 | 5.15 | V       |
| Short Circuit Current       | V <sub>REF</sub> = 0V                 | ● | 25     | 50   | 100  | 25     | 50   | 100  | mA      |
| Long Term Stability         | T <sub>J</sub> = 125°C                |   | 2      | 10   |      | 2      | 10   |      | mV/√khr |
| UNDERVOLTAGE LOCKOUT        |                                       |   |        |      |      |        |      |      |         |
| RESET Output Voltage        | V <sub>REF</sub> = 3.8V               | ● | 0.2    | 0.4  |      | 0.2    | 0.4  |      | V       |
| RESET Output Voltage        | V <sub>REF</sub> = 4.8V               | ● | 2.4    | 4.8  |      | 2.4    | 4.8  |      | V       |
| OSCILLATOR SECTION (Note 4) |                                       |   |        |      |      |        |      |      |         |
| Initial Accuracy            | T <sub>J</sub> = + 25°C               |   | ± 3    | ± 8  |      | ± 3    | ± 8  |      | %       |
| Voltage Stability           | + V <sub>IN</sub> = 8V to 35V         | ● | 0.5    | 1    |      | 0.5    | 1    |      | %       |
| Temperature Stability       |                                       | ● | 1      | 3    |      | 1      | 3    |      | %       |

# ELECTRICAL CHARACTERISTICS

(+  $V_{IN}$  = 15V, and over operating junction temperature, unless otherwise specified.)

| PARAMETER                                 | CONDITIONS                                                 |   | LT1526 |      |       | LT3526 |      |       | UNITS   |
|-------------------------------------------|------------------------------------------------------------|---|--------|------|-------|--------|------|-------|---------|
|                                           |                                                            |   | MIN    | TYP  | MAX   | MIN    | TYP  | MAX   |         |
| OSCILLATOR SECTION (Note 4)               |                                                            |   |        |      |       |        |      |       |         |
| Minimum Frequency                         | $R_T = 150k\Omega$ , $C_T = 20\mu F$                       | ● |        |      | 1     |        |      | 1     | Hz      |
| Maximum Frequency                         | $R_T = 2k\Omega$ , $C_T = 1.0nF$                           | ● |        | 400  |       |        | 400  |       | kHz     |
| Sawtooth Peak Voltage                     | $+V_{IN} = 35V$                                            | ● |        | 3.0  | 3.5   |        | 3.0  | 3.5   | V       |
| Sawtooth Valley Voltage                   | $+V_{IN} = 8V$                                             | ● | 0.5    | 1.0  |       | 0.5    | 1.0  |       | V       |
| ERROR AMPLIFIER SECTION (Note 5)          |                                                            |   |        |      |       |        |      |       |         |
| Input Offset Voltage                      | $R_S \leq 2k\Omega$                                        | ● |        | 2    | 5     |        | 2    | 10    | mV      |
| Input Bias Current                        |                                                            | ● |        | -350 | -1000 |        | -350 | -2000 | nA      |
| Input Offset Current                      |                                                            | ● |        | 35   | 100   |        | 35   | 200   | nA      |
| DC Open Loop Gain                         | $R_L \geq 10M\Omega$                                       | ● | 64     | 72   |       | 60     | 72   |       | dB      |
| High Output Voltage                       | $V_{pin1} - V_{pin2} \geq 150mV$ , $I_{source} = 100\mu A$ | ● | 3.6    | 4.2  |       | 3.6    | 4.2  |       | V       |
| Low Output Voltage                        | $V_{pin2} - V_{pin1} \geq 150mV$ , $I_{sink} = 100\mu A$   | ● |        | 0.2  | 0.4   |        | 0.2  | 0.4   | V       |
| Common-Mode Rejection                     | $R_S \leq 2k\Omega$                                        | ● | 70     | 94   |       | 70     | 94   |       | dB      |
| Supply Voltage Rejection                  | $+V_{IN} = 12V$ to $18V$                                   | ● | 66     | 80   |       | 66     | 80   |       | dB      |
| PWM COMPARATOR (Note 4)                   |                                                            |   |        |      |       |        |      |       |         |
| Minimum Duty Cycle                        | $V_{compensation} = +0.4V$                                 | ● |        |      | 0     |        |      | 0     | %       |
| Maximum Duty Cycle                        | $V_{compensation} = +3.6V$                                 | ● | 45     | 49   |       | 45     | 49   |       | %       |
| DIGITAL PORTS (SYNC, SHUTDOWN, and RESET) |                                                            |   |        |      |       |        |      |       |         |
| HIGH Output Voltage                       | $I_{source} = 40\mu A$                                     | ● | 2.4    | 4.0  |       | 2.4    | 4.0  |       | V       |
| LOW Output Voltage                        | $I_{sink} = 3.6mA$                                         | ● |        | 0.2  | 0.4   |        | 0.2  | 0.4   | V       |
| HIGH Input Current                        | $V_{IH} = +2.4V$                                           | ● |        | -125 | -200  |        | -125 | -200  | $\mu A$ |
| LOW Input Current                         | $V_{IL} = +0.4V$                                           | ● |        | -225 | -360  |        | -225 | -360  | $\mu A$ |
| CURRENT LIMIT COMPARATOR (Note 6)         |                                                            |   |        |      |       |        |      |       |         |
| Sense Voltage                             | $R_S \leq 50\Omega$                                        | ● | 90     | 100  | 110   | 80     | 100  | 120   | mV      |
| Input Bias Current                        |                                                            | ● |        | -3   | -10   |        | -3   | -10   | $\mu A$ |
| SOFT-START SECTION                        |                                                            |   |        |      |       |        |      |       |         |
| Error Clamp Voltage                       | $\overline{RESET} = +0.4V$                                 | ● |        | 0.1  | 0.4   |        | 0.1  | 0.4   | V       |
| $C_S$ Charging Current                    | $\overline{RESET} = +2.4V$                                 | ● | 50     | 100  | 150   | 50     | 100  | 150   | $\mu A$ |
| OUTPUT DRIVERS (Each Output) (Note 7)     |                                                            |   |        |      |       |        |      |       |         |
| HIGH Output Voltage                       | $I_{source} = 20mA$                                        | ● | 12.5   | 13.5 |       | 12.5   | 13.5 |       | V       |
|                                           | $I_{source} = 100mA$                                       | ● | 12     | 13   |       | 12     | 13   |       | V       |
| LOW Output Voltage                        | $I_{sink} = 20mA$                                          | ● |        | 0.2  | 0.3   |        | 0.2  | 0.3   | V       |
|                                           | $I_{sink} = 100mA$                                         | ● |        | 1.2  | 2.0   |        | 1.2  | 2.0   | V       |
| Collector Leakage                         | $V_C = 40V$                                                | ● |        | 50   | 150   |        | 50   | 150   | $\mu A$ |
| Rise Time                                 | $C_L = 1000pF$                                             | ● |        | 0.3  | 0.6   |        | 0.3  | 0.6   | $\mu s$ |
| Fall Time                                 | $C_L = 1000pF$                                             | ● |        | 0.1  | 0.2   |        | 0.1  | 0.2   | $\mu s$ |
| POWER CONSUMPTION (Note 8)                |                                                            |   |        |      |       |        |      |       |         |
| Standby Current                           | SHUTDOWN = +0.4V                                           | ● |        | 18   | 30    |        | 18   | 30    | mA      |

The ● denotes specifications that apply over the full operating temperature range.

The shaded electrical specifications indicate those parameters which have been improved or guaranteed test limits provided for the first time.

**Note 1:** Values beyond which damage may occur.

**Note 2:** Range over which the device is functional and parameter limits are guaranteed.

**Note 3:**  $I_L = 0mA$ .

**Note 4:**  $f_{OSC} = 40kHz$  ( $R_T = 4.12k\Omega \pm 1\%$ ,  $C_T = 0.01\mu F \pm 1\%$ ,  $R_D = 0\Omega$ ).

**Note 5:**  $V_{CM} = 0V$  to  $+5.2V$ .

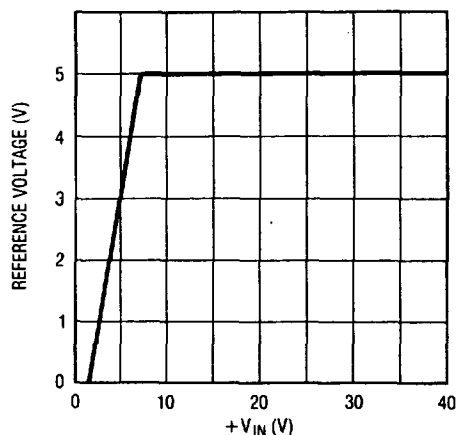
**Note 6:**  $V_{CM} = 0$  to  $V_{IN} - 3V$ . The current limit sense voltage for the LT1526 is  $80mV \leq V_{SENSE} \leq 120mV$  for temperatures less than  $0^\circ C$  or greater than  $125^\circ C$ .

**Note 7:**  $V_C = +15V$ .

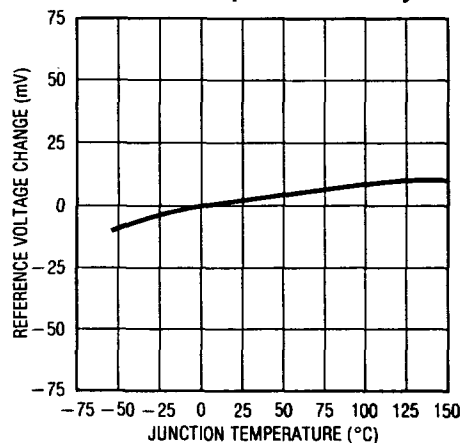
**Note 8:** +  $V_{IN} = +35V$ ,  $R_T = 4.12k\Omega$ .

# TYPICAL PERFORMANCE CHARACTERISTICS

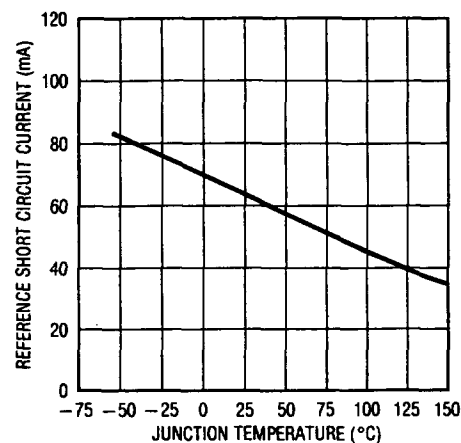
**Reference Voltage vs Supply Voltage**



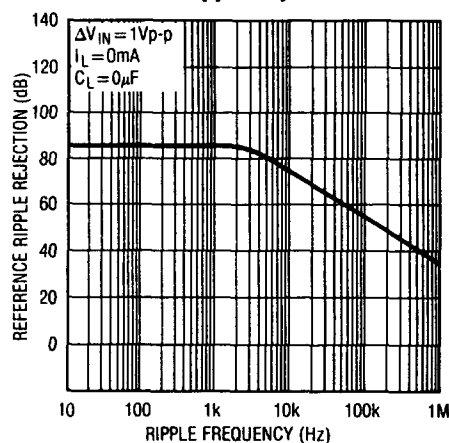
**Reference Temperature Stability**



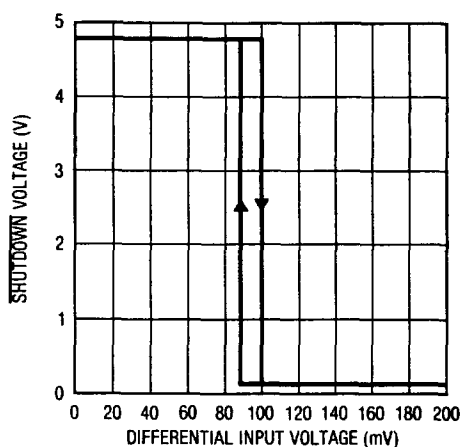
**Reference Short Circuit Current**



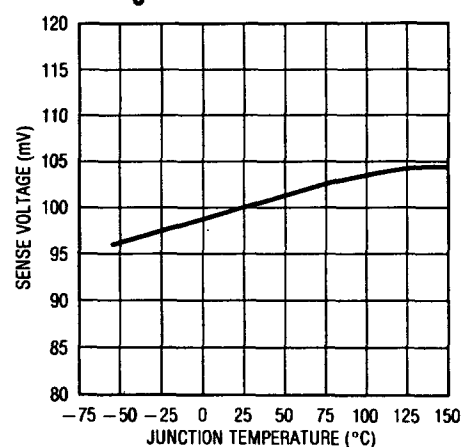
**Reference Ripple Rejection**



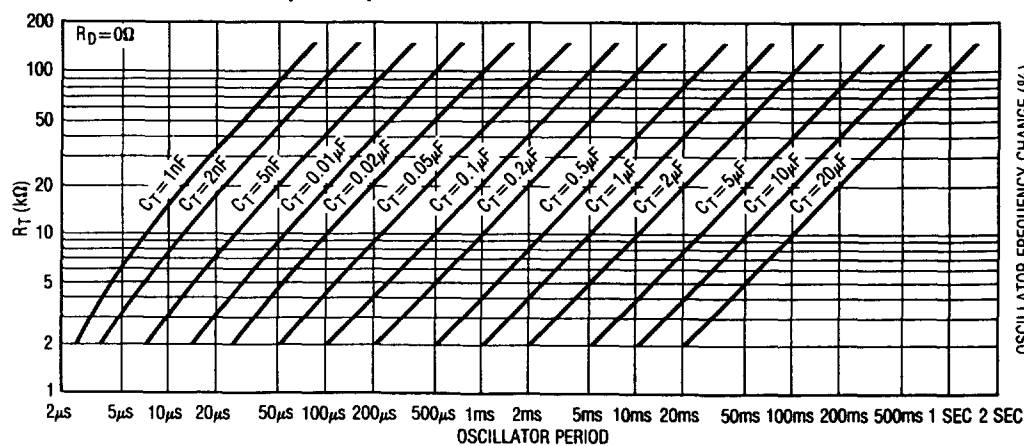
**Current Limit Comparator Transfer Function**



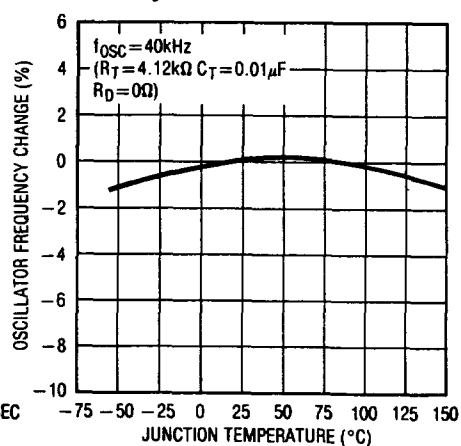
**Current Limit Comparator Sense Voltage**



**Oscillator Period vs R\_T and C\_T**

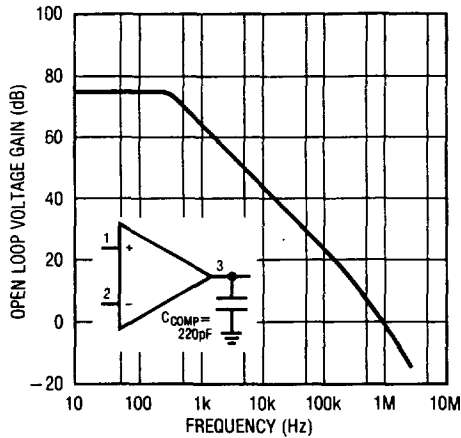


**Oscillator Frequency Temperature Stability**

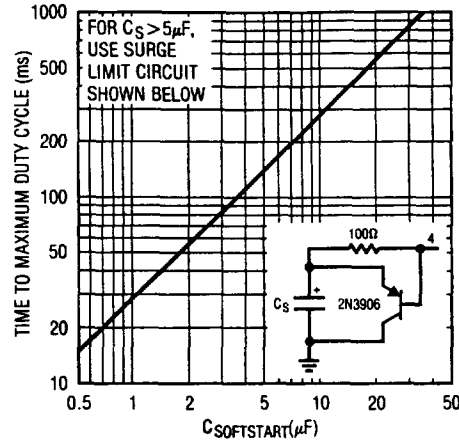


# TYPICAL PERFORMANCE CHARACTERISTICS

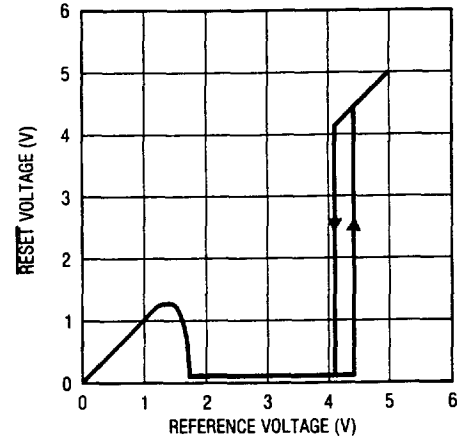
**Error Amplifier Open Loop Gain vs Frequency**



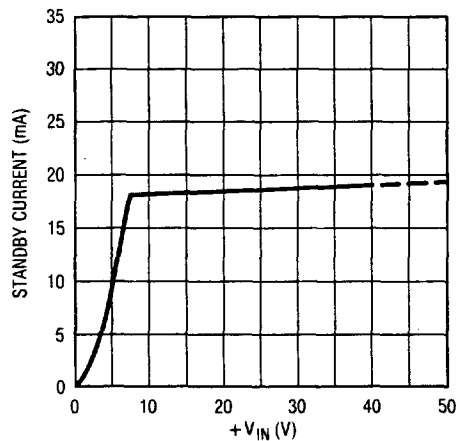
**Soft-start Time Constant vs  $C_S$**



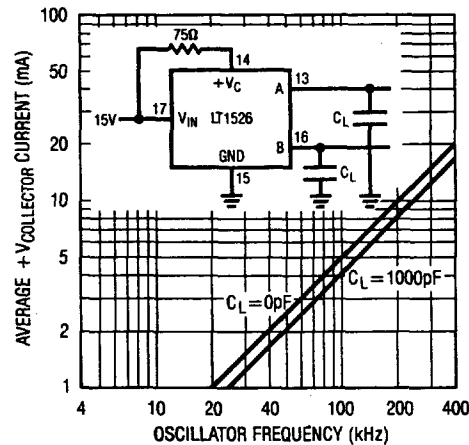
**Undervoltage Lockout Characteristic**



**Standby Current vs Supply Voltage**

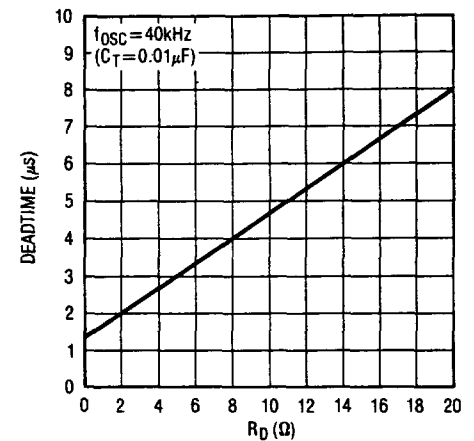


**+V<sub>COLLECTOR</sub> Current (Note 9)**

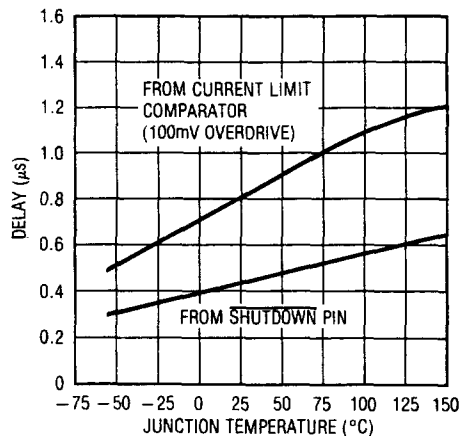


NOTE 9: TRANSIENT CURRENTS OCCUR WITHIN THE OUTPUT STAGES DURING SWITCHING. INDEPENDENT OF LOADING. THE GRAPH SHOWS THE AVERAGE (DC) VALUE OF THE TRANSIENT CURRENTS.

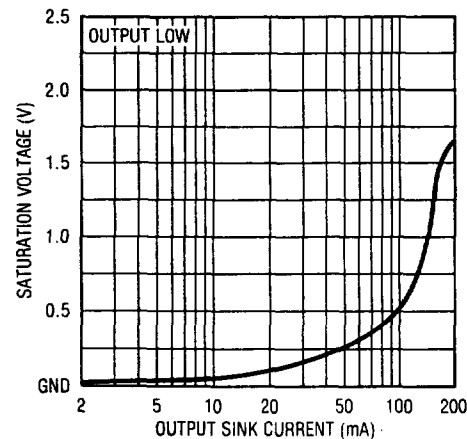
**Output Driver Deadtime vs  $R_D$**



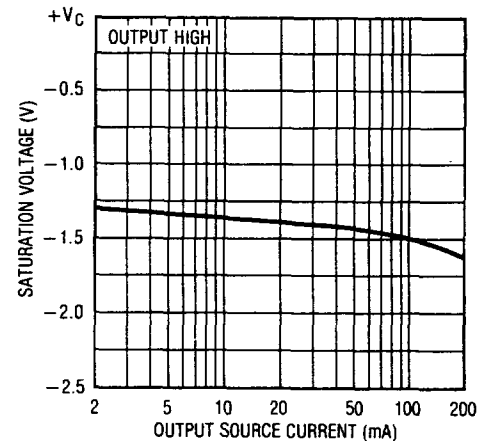
**Output Driver Shutdown Delay**



**Output Driver Saturation Voltage vs  $I_{SINK}$**



**Output Driver Saturation Voltage vs  $I_{SOURCE}$**



## APPLICATIONS INFORMATION

### FUNCTIONAL DESCRIPTION AND PIN FUNCTION

#### Voltage Reference

The reference regulator (pin 18) supplies a regulated 5.0V to all internal circuitry, as well as up to 20mA for external circuitry. It is fully active at supply voltages (pin 17) of 8V and greater.

The LT1526 can operate from a 5V supply by connecting +V<sub>IN</sub> to V<sub>REF</sub> (pin 18 to pin 17) and maintaining the supply between 4.8V and 5.2V.

#### Undervoltage Lockout

The undervoltage lockout circuitry protects both the switching regulator and the power devices it controls from inadequate supply voltage, which can result in unstable control circuitry. If +V<sub>IN</sub> is too low, the circuit turns off the output drivers, holds RESET (pin 5) low and the soft-start capacitor in a discharged state.

#### Soft-Start

The soft-start circuitry protects the power devices from high surge currents during power supply turn-on by limiting the available PWM duty cycle.

When +V<sub>IN</sub> reaches a sufficient voltage to allow RESET to go high, a 100 $\mu$ A current source charges the external C<sub>S</sub> capacitor (pin 4) linearly to 5V. The ERROR AMPLIFIER output is clamped to 600mV above the C<sub>S</sub> voltage, and the available duty cycle of the PWM increases linearly. Maximum duty cycle is available when the C<sub>S</sub> voltage reaches about 3V.

#### Digital Control Ports

The three digital control ports are bidirectional. Each port can drive TTL and 5V CMOS logic directly. They can also be driven by open-collector TTL, open-drain CMOS, and open-collector voltage comparators.

Driving SYNC (pin 12) low causes a discharge cycle in the oscillator. Driving SHUTDOWN (pin 8) low causes the outputs to turn off. Driving RESET (pin 5) low causes the outputs to turn off and discharges the C<sub>S</sub> capacitor.

#### Oscillator

The internal oscillator circuitry sets the frequency of operation for the switching regulator. Frequency is set by R<sub>T</sub> (pin 9), C<sub>T</sub> (pin 10), and R<sub>D</sub> (pin 11). With R<sub>D</sub> = 0 $\Omega$ , the values for R<sub>T</sub> and C<sub>T</sub> may be chosen from the oscillator period graph. If the desired deadtime is increased, the value of R<sub>T</sub> may need to be decreased to maintain the desired frequency.

The frequency at either output is half that of the oscillator, and the frequency at +V<sub>C</sub> (pin 14) is equal to the oscillator.

#### Synchronous Operation

Two or more switching regulators may be synchronized by setting the master to the desired frequency and sharing the oscillator signals with the slave units. Slave C<sub>T</sub> pins are tied to the master C<sub>T</sub> pin, and slave SYNC pins are tied to the master SYNC pin. Slave R<sub>T</sub> and R<sub>D</sub> pins are left open.

External logic synchronization can be used by setting the oscillator period to be 10% longer than the external clock period, and connecting the external clock to the SYNC pin. A periodic low of about 0.5 $\mu$ s wide will lock the oscillator to the external frequency.

#### Error Amplifier

The differential input (pins 1 and 2), single-ended output (pin 3) transconductance amplifier provides about 70dB of gain. The output has an impedance of 2M $\Omega$ , and since all voltage gain occurs at the output, the gain characteristics can be controlled with shunt reactance to ground.

#### Output Drivers

The totem-pole output drivers can source and sink 100mA continuously and 200mA peak. The outputs are driven 180° out of phase by the flip-flop. Loads can be driven either from the outputs or the +V<sub>C</sub> pin. Since large transient currents occur within the output stages during switching, a resistor is recommended in series with +V<sub>C</sub> (pin 14) to limit the peak current. The resistor value should be +V<sub>C</sub>/200mA.

# APPLICATIONS INFORMATION

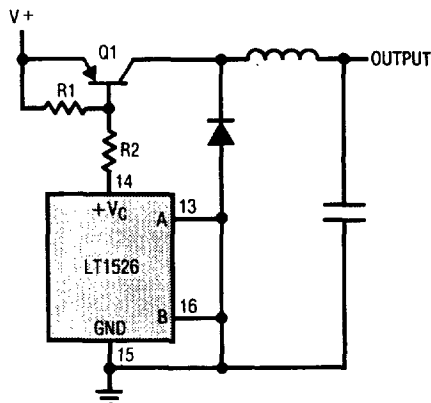
## Current Limit

The current limit comparator turns off the outputs when the input voltage (pin 7 to pin 6) exceeds 100mV. Hystere-

sis is built into the trip point, of about 10mV, to prevent oscillations.

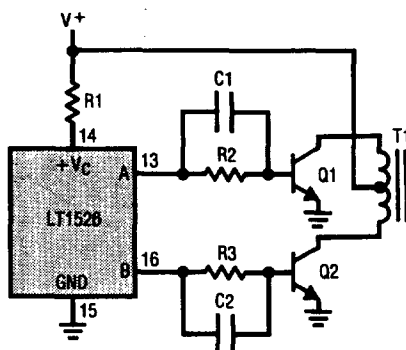
## TYPICAL APPLICATIONS

### Single Ended Supply



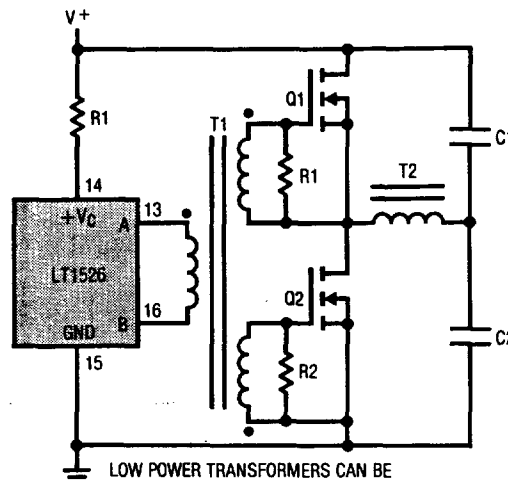
FOR SINGLE ENDED SUPPLIES, THE DRIVER OUTPUTS ARE GROUNDED. THE +V<sub>C</sub> TERMINAL IS SWITCHED TO GROUND BY THE TOTEM POLE SOURCE TRANSISTORS ON EVERY OSCILLATOR CYCLE.

### Bipolar Push-Pull Supply



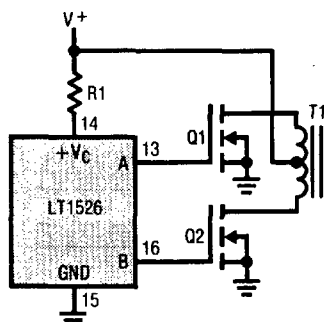
IN CONVENTIONAL BIPOLAR PUSH-PULL DESIGNS, FORWARD BASE DRIVE IS CONTROLLED BY R1-R3. RAPID TURN-OFF TIMES FOR THE POWER DEVICES ARE ACHIEVED WITH SPEED-UP CAPACITORS C1 AND C2.

### Driving Transformers Directly



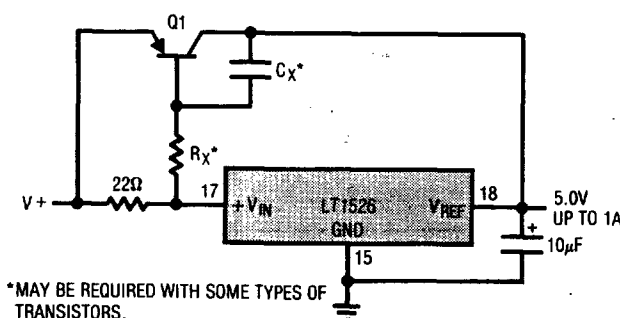
LOW POWER TRANSFORMERS CAN BE DRIVEN DIRECTLY BY THE LT1526. AUTOMATIC RESET OCCURS DURING DEAD-TIME, WHEN BOTH ENDS OF THE PRIMARY WINDING ARE SWITCHED TO GROUND.

### Power FETs Push-Pull Supply



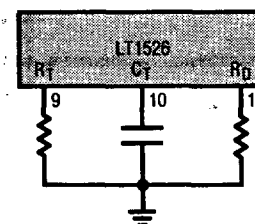
THE LOW SOURCE IMPEDANCE OF THE OUTPUT DRIVERS PROVIDES RAPID CHARGING OF POWER FET INPUT CAPACITANCE, WHILE MINIMIZING EXTERNAL COMPONENTS.

### Extending Reference Output Current

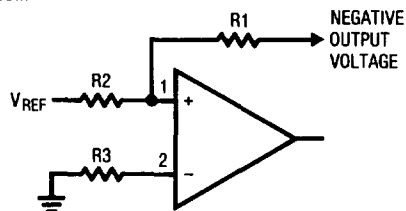


\*MAY BE REQUIRED WITH SOME TYPES OF TRANSISTORS.

### Oscillator Connections

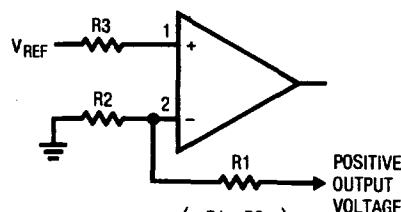


### Error Amplifier Connections



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

$$R3 = \left( \frac{R1R2}{R1 + R2} \right)$$

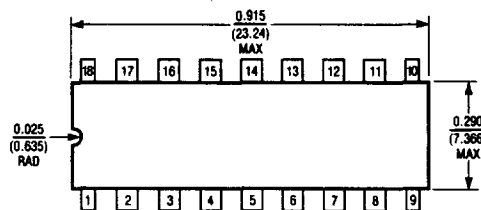
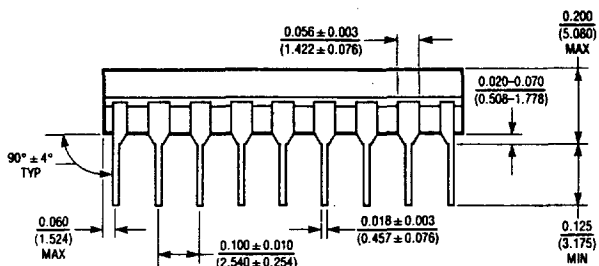


$$V_{OUT} = V_{REF} \left( \frac{R1 + R2}{R2} \right)$$

$$R3 = \left( \frac{R1R2}{R1 + R2} \right)$$

## PACKAGE DESCRIPTION

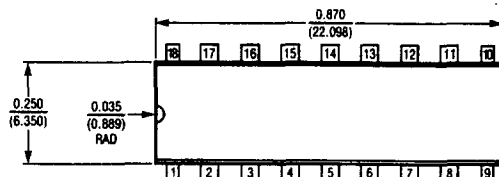
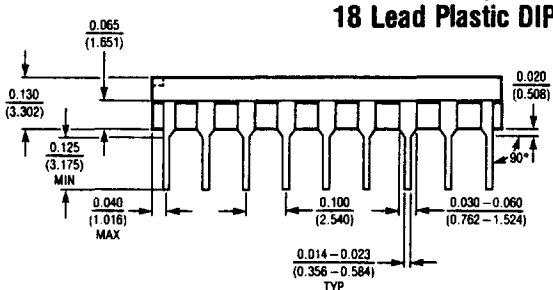
Technical drawing of a chair seat and backrest assembly. The drawing shows a side view of the chair with dimensions in millimeters (mm) and inches (in) in parentheses. The seat is rectangular with a width of 0.290-0.320 (7.366-8.128) and a height of 0.160 (4.064) MAX. The backrest is rectangular with a width of 0.008-0.012 (0.203-0.306) and a height of 0.385 ± 0.025 (9.779 ± 0.635). The backrest is attached to the seat with a 95° ± 5° angle. The drawing also shows the front view of the chair with a width of 0.385 ± 0.025 (9.779 ± 0.635).



|         | T <sub>Jmax</sub> | θ <sub>JA</sub> | θ <sub>JC</sub> |
|---------|-------------------|-----------------|-----------------|
| LT1526J | 150°C             | 100°C/W         | 40°C/W          |
| LT3526J | 150°C             | 100°C/W         | 40°C/W          |

Technical drawing of a mechanical part with dimensions and tolerances:

- Top width:  $0.310 \pm 0.010$  ( $7.874 \pm 0.254$ )
- Top width tolerance:  $0.009 - 0.011$  ( $0.229 - 0.279$ )
- Top width tolerance (alternative):  $0.325 + 0.025 - 0.015$  ( $8.255 + 0.635 - 0.381$ )
- Top width tolerance (alternative):  $0.02$  ( $0.50$  MAX)
- Top width tolerance (alternative):  $7^\circ \text{ TYP}$



|         |            |               |               |
|---------|------------|---------------|---------------|
|         | $T_{jmax}$ | $\theta_{ja}$ | $\theta_{jc}$ |
| LT3526N | 125°C      | 100°C/W       | 40°C/W        |