

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

$V_{IN}$ Voltage .....	16V
SW Voltage .....	-0.4V to 36V
FB Voltage .....	2.5V
SHDN Voltage .....	16V
Current Into FB Pin .....	$\pm 1\text{mA}$

Maximum Junction Temperature .....	125°C
Operating Temperature Range (Note 2) ..	-40°C to 85°C
Storage Temperature Range .....	-65°C to 150°C
Lead Temperature (Soldering, 10 sec) .....	300°C

## PACKAGE/ORDER INFORMATION

<div><p>TOP VIEW</p><p>MS8E PACKAGE 8-LEAD PLASTIC MSOP EXPOSED PAD (PIN 9) IS GROUND (MUST BE SOLDERED TO PCB)</p><p><math>T_{JMAX} = 125^{\circ}\text{C}</math>, <math>\theta_{JA} = 40^{\circ}\text{C/W}</math>, <math>\theta_{JC} = 10^{\circ}\text{C/W}</math></p></div>	<div><p>ORDER PART NUMBER</p><p>LT1946EMS8E</p><p>MS8 PART MARKING</p><p>LTCBNW</p></div>	<div><p>TOP VIEW</p><p>MS8 PACKAGE 8-LEAD PLASTIC MSOP <math>T_{JMAX} = 125^{\circ}\text{C}</math>, <math>\theta_{JA} = 125^{\circ}\text{C/W}</math> (4-LAYER BOARD)</p></div>	<div><p>ORDER PART NUMBER</p><p>LT1946EMS8</p><p>MS8 PART MARKING</p><p>LTUG</p></div>
<p><b>Order Options</b> Tape and Reel: Add #TR Lead Free: Add #PBF Lead Free Tape and Reel: Add #TRPBF Lead Free Part Marking: <a href="http://www.linear.com/leadfree/">http://www.linear.com/leadfree/</a></p>			

Consult LTC Marketing for parts specified with wider operating temperature ranges.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^{\circ}\text{C}$ .  $V_{IN} = 3\text{V}$ ,  $V_{SHDN} = V_{IN}$  unless otherwise specified. (Note 2)

SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Operating Voltage			2.45	2.6	V
Maximum Operating Voltage				16	V
Feedback Voltage		● 1.230 1.220	1.250	1.270 1.270	V V
FB Pin Bias Current	$V_{FB} = 1.250\text{V}$ (Note 3)	●	20	120	nA
Error Amp Transconductance	$\Delta I = 2\mu\text{A}$		40		$\mu\text{mhos}$
Error Amp Voltage Gain			300		V/V
Quiescent Current	$V_{SHDN} = 2.5\text{V}$ , Not Switching		3.2	5	mA
Quiescent Current in Shutdown	$V_{SHDN} = 0\text{V}$ , $V_{IN} = 3\text{V}$		0	1	$\mu\text{A}$
Reference Line Regulation	$2.6\text{V} \leq V_{IN} \leq 16\text{V}$		0.01	0.05	%/V
Switching Frequency		● 0.9 0.8	1.2	1.4 1.5	MHz MHz
Switching Frequency in Foldback	$V_{FB} = 0\text{V}$		0.4		MHz
Maximum Duty Cycle		● 86	90		%
Switch Current Limit	(Note 4)	● 1.5	2.1	3.1	A
Switch $V_{CESAT}$	$I_{SW} = 1\text{A}$		240	340	mV
Switch Leakage Current	$V_{SW} = 5\text{V}$		0.01	1	$\mu\text{A}$
Soft-Start Charging Current	$V_{SS} = 0.5\text{V}$		2.5	4	$\mu\text{A}$

1946fb

# ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{IN} = 3\text{V}$ ,  $V_{SHDN} = V_{IN}$  unless otherwise specified. (Note 2)

SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SHDN Input Voltage High		2.4			V
SHDN Input Voltage Low				0.5	V
SHDN Pin Bias Current	$V_{SHDN} = 3\text{V}$ $V_{SHDN} = 0\text{V}$		16 0	32 0.1	$\mu\text{A}$ $\mu\text{A}$

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** The LT1946E is guaranteed to meet performance specifications from  $0^\circ\text{C}$  to  $70^\circ\text{C}$ . Specifications over the  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  operating

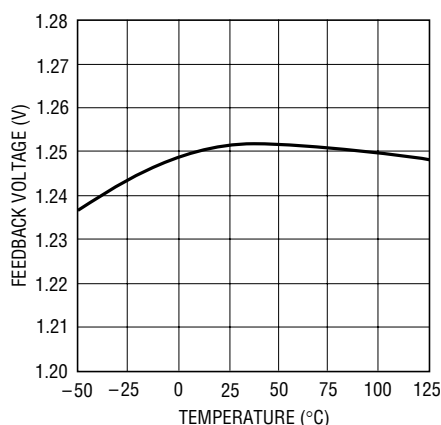
temperature range are assured by design, characterization and correlation with statistical process controls.

**Note 3:** Current flows out of FB pin.

**Note 4:** Current limit guaranteed by design and/or correlation to static test. Current limit is independent of duty cycle and is guaranteed by design.

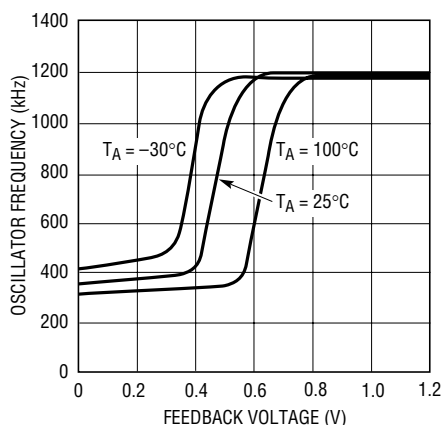
# TYPICAL PERFORMANCE CHARACTERISTICS

Feedback Pin Voltage



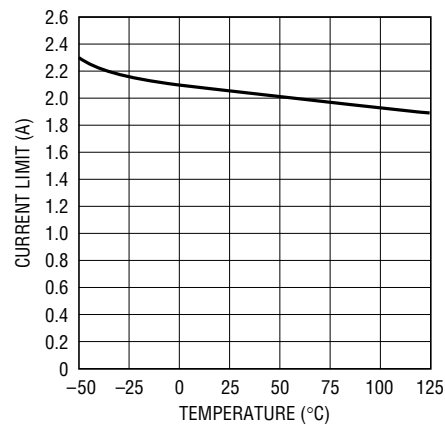
1946 G01

Oscillator Frequency



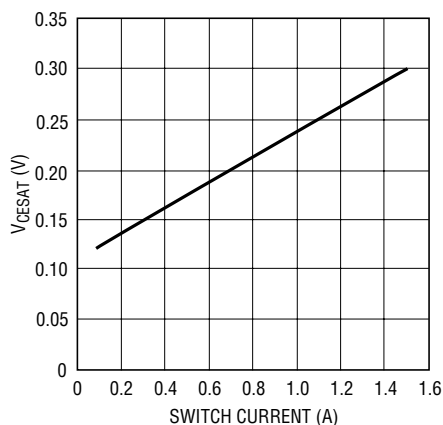
1946 G02

Current Limit



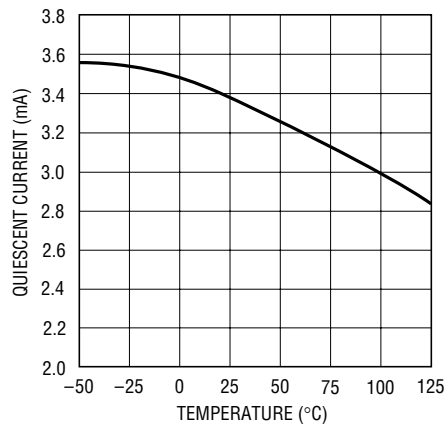
1946 G03

Switch Saturation Voltage



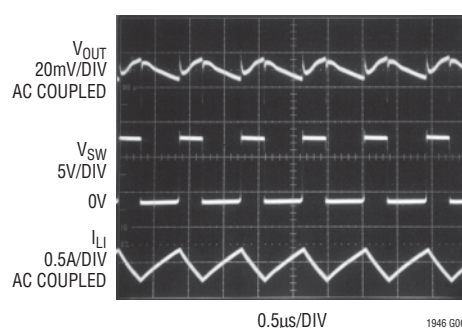
1946 G04

Quiescent Current



1946 G05

Switching Waveforms for Figure 1 Circuit



1946 G06

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# PIN FUNCTIONS

**V<sub>C</sub> (Pin 1):** Error Amplifier Output Pin. Tie external compensation network to this pin, or use the internal compensation network by shorting the V<sub>C</sub> pin to the COMP pin.

**FB (Pin 2):** Feedback Pin. Reference voltage is 1.250V. Connect resistive divider tap here. Minimize trace area at FB. Set V<sub>OUT</sub> according to  $V_{OUT} = 1.250(1 + R1/R2)$ .

**SHDN (Pin 3):** Shutdown Pin. Tie to 2.4V or more to enable device. Ground to shut down. Do not float this pin.

**GND (Pin 4):** Ground. Tie directly to local ground plane.

**SW (Pin 5):** Switch Pin. This is the collector of the internal NPN power switch. Minimize the metal trace area connected to this pin to minimize EMI.

**V<sub>IN</sub> (Pin 6):** Input Supply Pin. Must be locally bypassed.

**COMP (Pin 7):** Internal Compensation Pin. Provides an internal compensation network. Tie directly to the V<sub>C</sub> pin for internal compensation. Tie to GND if not used.

**SS (Pin 8):** Soft-Start Pin. Place a soft-start capacitor here. Upon start-up, 4μA of current charges the capacitor to 1.5V. Use a larger capacitor for slower start-up. Leave floating if not in use.

**Exposed Pad (MS8E, Pin 9):** Ground. Must be soldered to PCB.

# BLOCK DIAGRAM

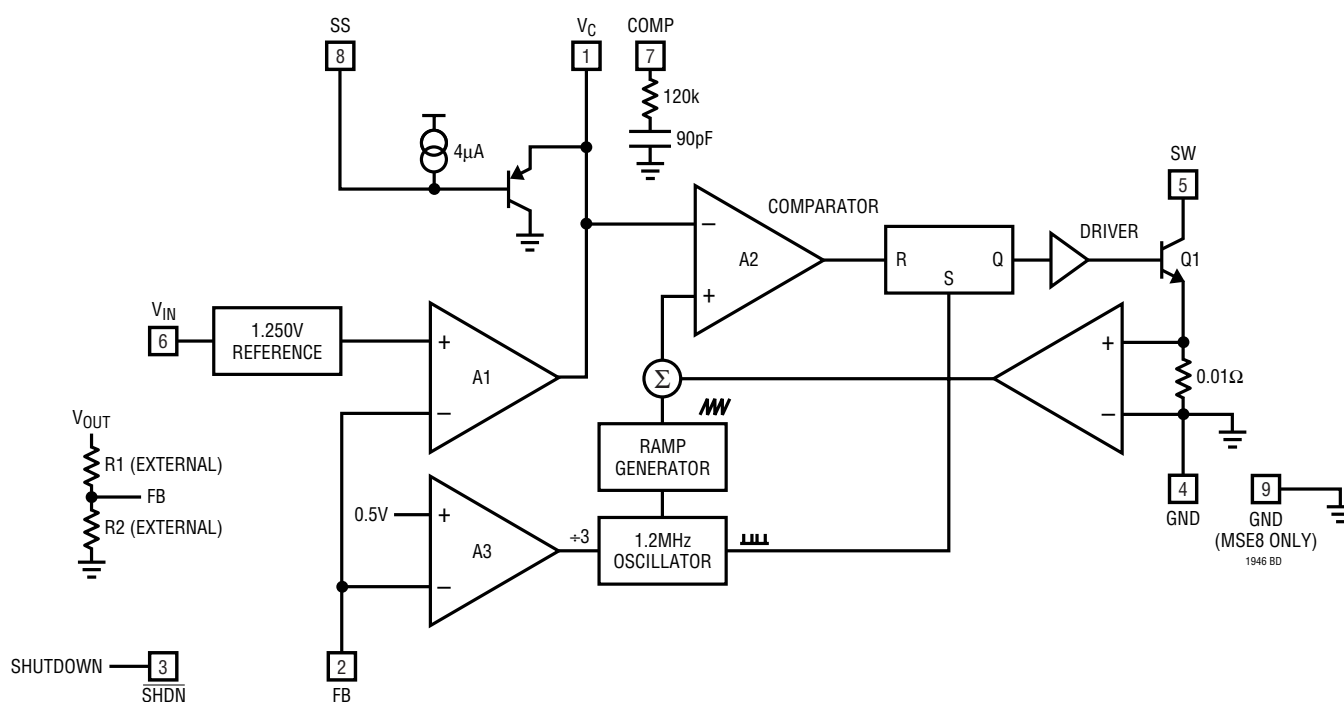


Figure 2. Block Diagram

## OPERATION

The LT1946 uses a constant frequency, current mode control scheme to provide excellent line and load regulation. Please refer to Figure 2 for the following description of the part's operation. At the start of the oscillator cycle, the SR latch is set, turning on the power switch Q1. The switch current flows through the internal current sense resistor generating a voltage. This voltage is added to a stabilizing ramp and the resulting sum is fed into the positive terminal of the PWM comparator A2. When this voltage exceeds the level at the negative input of A2, the SR latch is reset, turning off the power switch. The level at the negative input of A2 ( $V_C$  pin) is set by the error amplifier (A1) and is simply an amplified version of the difference between the feedback voltage and the reference voltage of 1.250V. In this manner, the error amplifier sets the correct peak current level to keep the output in regulation.

Two functions are provided to enable a very clean start-up for the LT1946. Frequency foldback is used to reduce the oscillator frequency by a factor of 3 when the FB pin is

below a nominal value of 0.5V. This is accomplished via comparator A3. This feature reduces the minimum duty cycle that the part can achieve thus allowing better control of the switch current during start-up. When the FB pin voltage exceeds 0.5V, the oscillator returns to the normal frequency of 1.2MHz. A soft-start function is also provided by the LT1946. When the part is brought out of shutdown, 4 $\mu$ A of current is sourced out of the SS pin. By connecting an external capacitor to the SS pin, the rate of voltage rise on the pin can be set. Typical values for the soft-start capacitor range from 10nF to 200nF. The SS pin directly limits the rate of rise on the  $V_C$  pin, which in turn limits the peak switch current. Current limit is not shown in Figure 2. The switch current is constantly monitored and not allowed to exceed the nominal value of 2.1A. If the switch current reaches 2.1A, the SR latch is reset regardless of the output of comparator A2. This current limit helps protect the power switch as well as the external components connected to the LT1946.

## APPLICATIONS INFORMATION

### Inductor Selection

Several inductors that work well with the LT1946 are listed in Table 1. This table is not exclusive; there are many other manufacturers and inductors that can be used. Consult each manufacturer for more detailed information and for their entire selection of related parts, as many different sizes and shapes are available. Ferrite core inductors should be used to obtain the best efficiency, as core losses at 1.2MHz are much lower for ferrite cores than for the cheaper powdered-iron ones. Choose an inductor that can handle at least 1.5A without saturating, and ensure that the inductor has a low DCR (copper wire resistance) to minimize  $I^2R$  power losses. A 4.7 $\mu$ H to 10 $\mu$ H inductor will be the best choice for most LT1946 designs. Note that in some applications, the current handling requirements of the inductor can be lower, such as in the SEPIC topology where each inductor only carries one-half of the total switch current.

The inductors shown in Table 1 were chosen for small size. For better efficiency, use similar valued inductors with a larger volume.

**Table 1. Recommended Inductors**

PART	L (μH)	MAX	SIZE	VENDOR
		DCR (mΩ)	L × W × H (mm)	
CDRH5D18-4R1	4.1	57	5.7 × 5.7 × 2	Sumida (847) 956-0666 www.sumida.com
CDRH5D18-5R4	5.4	76	5.7 × 5.7 × 3	
CDRH5D28-5R3	5.3	38		
CDRH5D28-6R2	6.2	45		
CDRH5D28-8R2	8.2	53		
ELL6SH-4R7M	4.7	50	6.4 × 6 × 3	Panasonic (408) 945-5660 www.panasonic.com
ELL6SH-5R6M	5.6	59		
ELL6SH-6R8M	6.8	62		
RLF5018T-4R7M1R4	4.7	45	5.6 × 5.2 × 1.8	TDK (847) 803-6100 www.tdk.com

## APPLICATIONS INFORMATION

### Capacitor Selection

Low ESR (equivalent series resistance) capacitors should be used at the output to minimize the output ripple voltage. Multilayer ceramic capacitors are an excellent choice, as they have an extremely low ESR and are available in very small packages. X5R or X7R dielectrics are preferred, as these materials retain the capacitance over wide voltage and temperature ranges. A  $4.7\mu\text{F}$  to  $20\mu\text{F}$  output capacitor is sufficient for most applications, but systems with very low output currents may need only a  $1\mu\text{F}$  or  $2.2\mu\text{F}$  output capacitor. Solid tantalum or OS-CON capacitors can be used, but they will occupy more board area than a ceramic and will have a higher ESR. Always use a capacitor with a sufficient voltage rating.

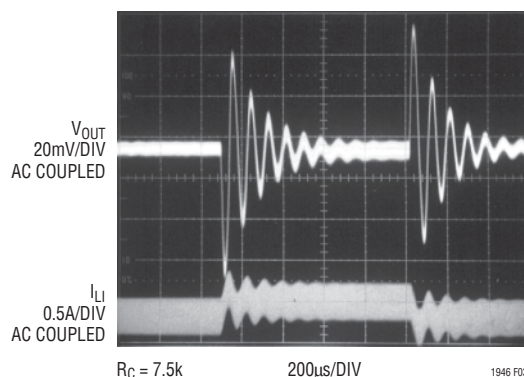
Ceramic capacitors also make a good choice for the input decoupling capacitor, which should be placed as close as possible to the LT1946. A  $2.2\mu\text{F}$  to  $4.7\mu\text{F}$  input capacitor is sufficient for most applications. Table 2 shows a list of several ceramic capacitor manufacturers. Consult the manufacturers for detailed information on their entire selection of ceramic parts.

**Table 2. Ceramic Capacitor Manufacturers**

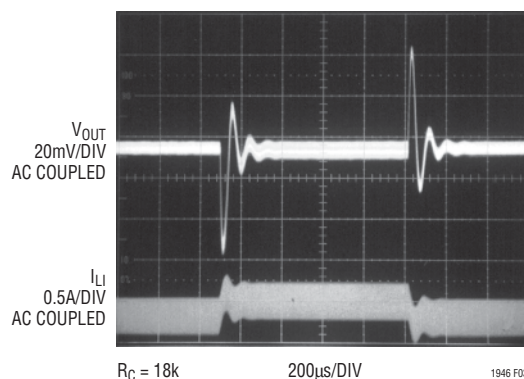
Taiyo Yuden	(408) 573-4150 www.t-yuden.com
AVX	(803) 448-9411 www.avxcorp.com
Murata	(714) 852-2001 www.murata.com

### Compensation—Adjustment

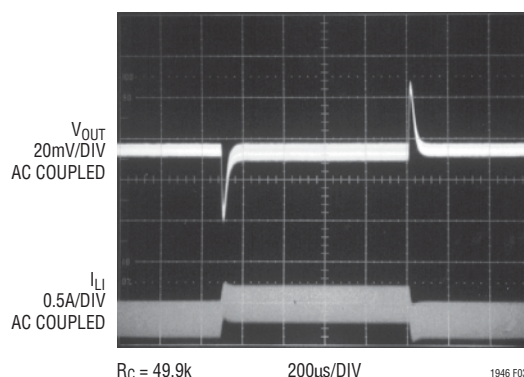
To compensate the feedback loop of the LT1946, a series resistor-capacitor network should be connected from the COMP pin to GND. For most applications, a capacitor in the range of  $220\text{pF}$  to  $680\text{pF}$  will suffice. A good starting value for the compensation capacitor,  $C_C$ , is  $470\text{pF}$ . The compensation resistor,  $R_C$ , is usually in the range of  $20\text{k}$  to  $100\text{k}$ . A good technique to compensate a new application is to use a  $100\text{k}\Omega$  potentiometer in place of  $R_C$ , and use a  $470\text{pF}$  capacitor for  $C_C$ . By adjusting the potentiometer while observing the transient response, the optimum value for  $R_C$  can be found. Figures 3a to 3c illustrate this process for the circuit of Figure 1 with a load current stepped from  $250\text{mA}$  to  $300\text{mA}$ . Figure 3a shows the transient response with  $R_C$  equal to  $7.5\text{k}$ . The phase margin is



**Figure 3a. Transient Response Shows Excessive Ringing**



**Figure 3b. Transient Response is Better**



**Figure 3c. Transient Response is Well Damped**

poor as evidenced by the excessive ringing in the output voltage and inductor current. In Figure 3b, the value of  $R_C$  is increased to  $18\text{k}$ , which results in a more damped response. Figure 3c shows the results when  $R_C$  is increased further to  $49.9\text{k}$ . The transient response is nicely damped and the compensation procedure is complete. The COMP pin provides access to an internal resistor ( $120\text{k}$ ) and capacitor ( $90\text{pF}$ ). For some applications, these values will suffice and no external  $R_C$  and  $C_C$  will be needed.

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## APPLICATIONS INFORMATION

### Compensation—Theory

Like all other current mode switching regulators, the LT1946 needs to be compensated for stable and efficient operation. Two feedback loops are used in the LT1946: a fast current loop which does not require compensation, and a slower voltage loop which does. Standard Bode plot analysis can be used to understand and adjust the voltage feedback loop.

As with any feedback loop, identifying the gain and phase contribution of the various elements in the loop is critical. Figure 4 shows the key equivalent elements of a boost converter. Because of the fast current control loop, the power stage of the IC, inductor and diode have been replaced by the equivalent transconductance amplifier  $g_{mp}$ .  $g_{mp}$  acts as a current source where the output current is proportional to the  $V_C$  voltage. Note that the maximum output current of  $g_{mp}$  is finite due to the current limit in the IC.

From Figure 4, the DC gain, poles and zeroes can be calculated as follows:

$$\text{Output Pole: } P1 = \frac{2}{2 \cdot \pi \cdot R_L \cdot C_{OUT}}$$

$$\text{Error Amp Pole: } P2 = \frac{1}{2 \cdot \pi \cdot R_O \cdot C_C}$$

$$\text{Error Amp Zero: } Z1 = \frac{1}{2 \cdot \pi \cdot R_C \cdot C_C}$$

$$\text{DC GAIN: } A = \frac{1.25V_{IN}}{V_{OUT}^2} \cdot g_{ma} \cdot R_O \cdot g_{mp} \cdot \frac{R_L}{2}$$

$$\text{ESR Zero: } Z2 = \frac{1}{2 \cdot \pi \cdot \text{ESR} \cdot C_{OUT}}$$

$$\text{RHP Zero: } Z3 = \frac{V_{IN}^2 \cdot R_L}{2 \cdot \pi \cdot V_{OUT}^2 \cdot L}$$

$$\text{High Frequency Pole: } P3 > \frac{f_S}{3}$$

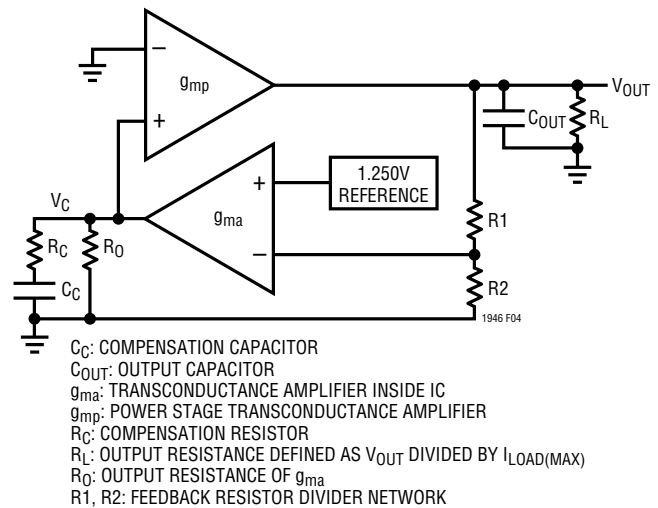


Figure 4. Boost Converter Equivalent Model

The Current Mode zero is a right half plane zero which can be an issue in feedback control design, but is manageable with proper external component selection.

Using the circuit of Figure 1 as an example, the following table shows the parameters used to generate the Bode plot shown in Figure 5.

Table 3. Bode Plot Parameters

Parameter	Value	Units	Comment
$R_L$	18.6	$\Omega$	Application Specific
$C_{OUT}$	20	$\mu F$	Application Specific
$R_O$	10	$M\Omega$	Not Adjustable
$C_C$	470	$pF$	Adjustable
$R_C$	49.9	$k\Omega$	Adjustable
$V_{OUT}$	8	V	Application Specific
$V_{IN}$	3.3	V	Application Specific
$g_{ma}$	40	$\mu mho$	Not Adjustable
$g_{mp}$	5	$mho$	Not Adjustable
$L$	5.4	$\mu H$	Application Specific
$f_S$	1.2	MHz	Not Adjustable

From Figure 5, the phase is  $120^\circ$  when the gain reaches 0dB giving a phase margin of  $60^\circ$ . This is more than adequate. The crossover frequency is 25kHz, which is about three times lower than the frequency of the right half plane zero Z2. It is important that the crossover frequency be at least three times lower than the frequency of the RHP zero to achieve adequate phase margin.



# APPLICATIONS INFORMATION

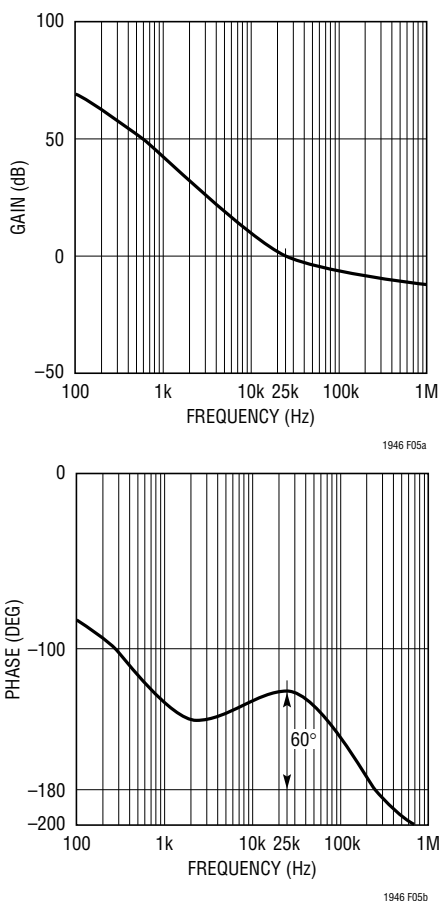


Figure 5. Bode Plot of Figure 1's Circuit

## Diode Selection

A Schottky diode is recommended for use with the LT1946. The Microsemi UPS120 is a very good choice. Where the input to output voltage differential exceeds 20V, use the UPS140 (a 40V diode). These diodes are rated to handle an average forward current of 1A. For applications where the average forward current of the diode is less than 0.5A, an ON Semiconductor MBR0520 diode can be used

## Setting Output Voltage

To set the output voltage, select the values of R1 and R2 (see Figure 1) according to the following equation:

$$R1 = R2 \left( \frac{V_{OUT}}{1.25V} - 1 \right)$$

A good range for R2 is from 5k to 30k.

## Layout Hints

The high speed operation of the LT1946 demands careful attention to board layout. You will not get advertised performance with careless layout. Figure 6 shows the recommended component placement for a boost converter.

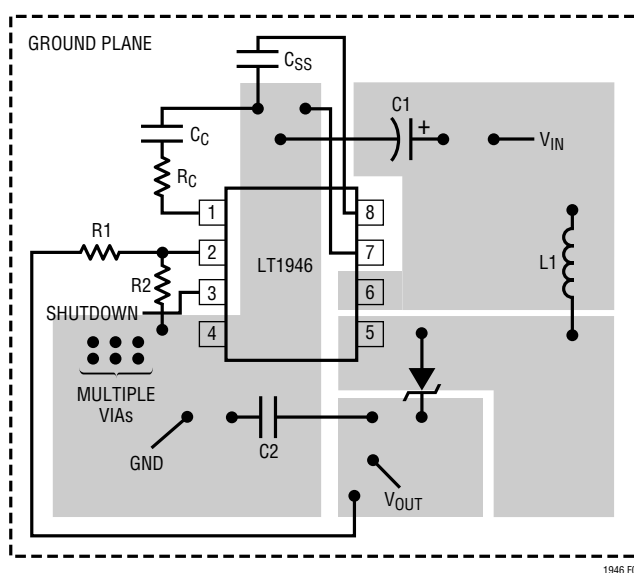
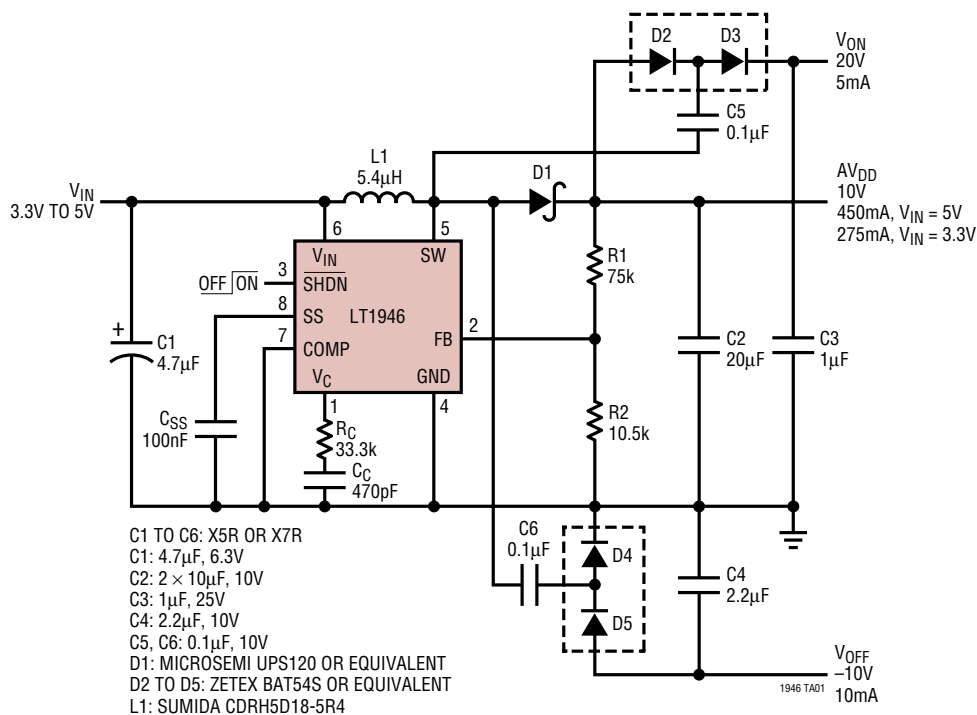


Figure 6. Recommended Component Placement for Boost Converter. Note Direct High Current Paths Using Wide PC Traces. Minimize Trace Area at Pin 1 (V<sub>C</sub>) and Pin 2 (FB). Use Multiple Vias to Tie Pin 4 Copper to Ground Plane. Use Vias at One Location Only to Avoid Introducing Switching Currents Into the Ground Plane

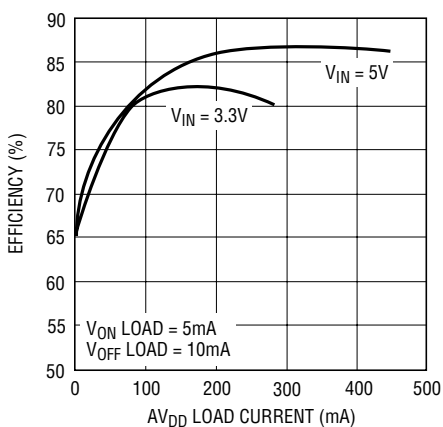
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## TYPICAL APPLICATIONS

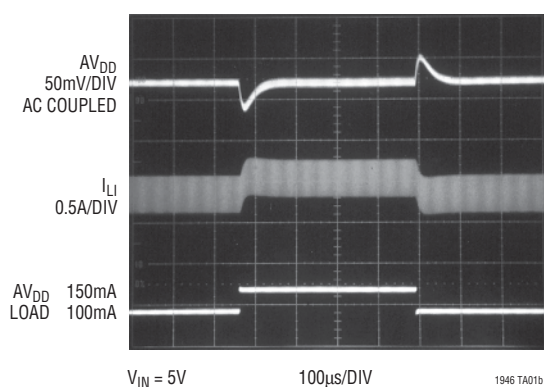
### Low Profile, Triple Output TFT Supply (10V, -10V, 20V)



## Efficiency



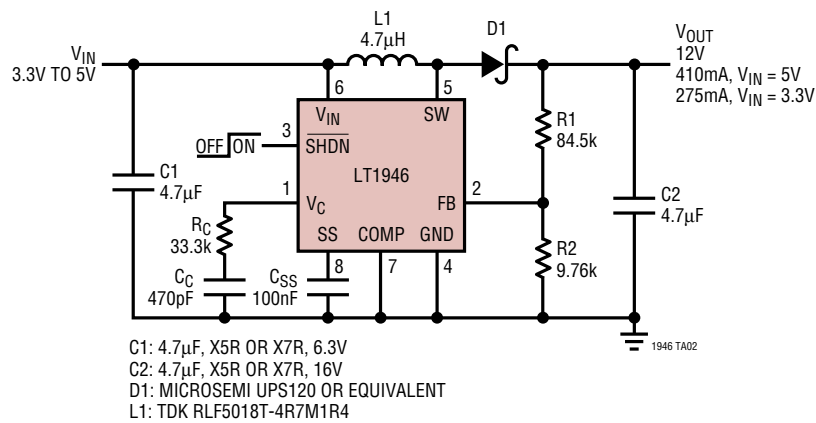
## Transient Response



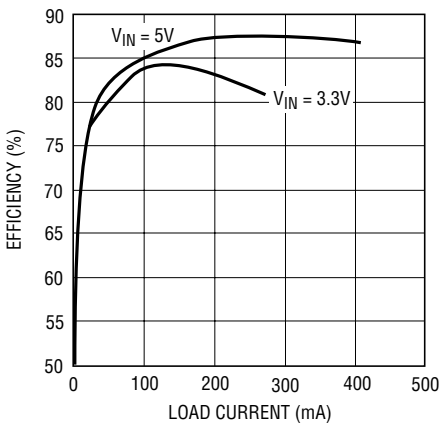


TYPICAL APPLICATIONS

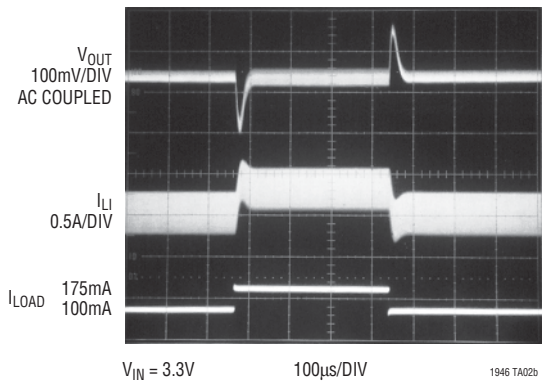
12V Output Boost Converter



Efficiency

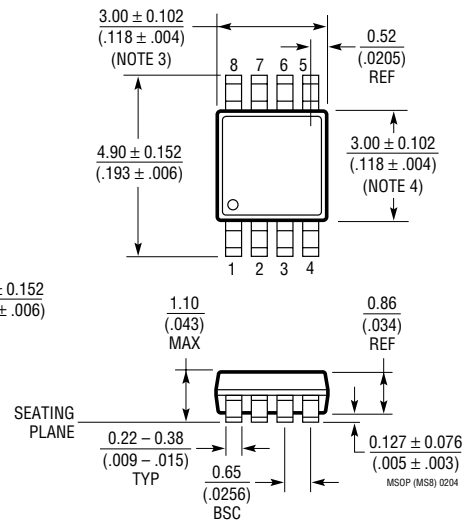
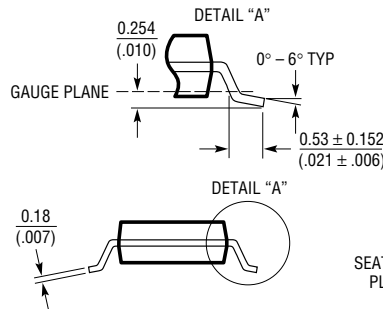
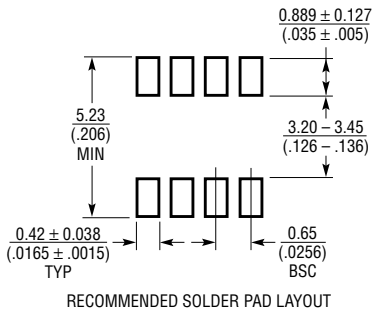


Transient Response



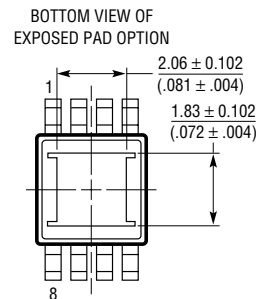
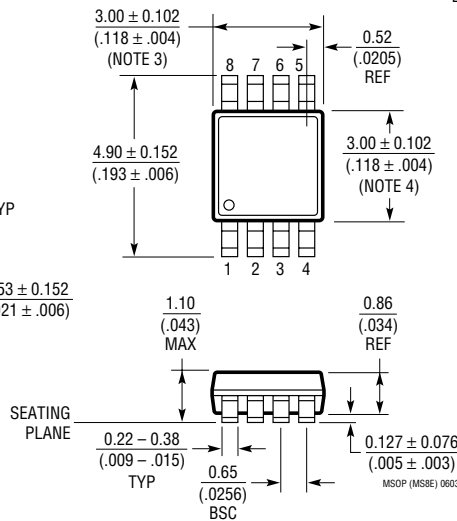
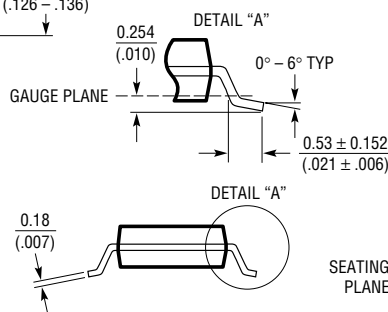
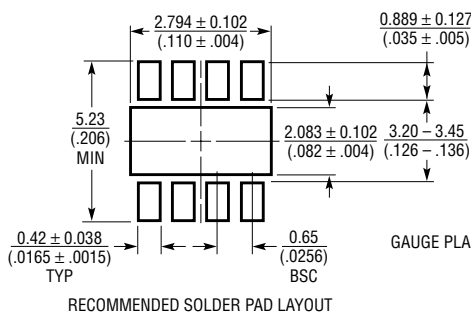
# PACKAGE DESCRIPTION

## MS8 Package 8-Lead Plastic MSOP (Reference LTC DWG # 05-08-1660)



- NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
  2. DRAWING NOT TO SCALE
  3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.  
MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED  $0.152\text{mm}$  ( $.006''$ ) PER SIDE
  4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.  
INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED  $0.152\text{mm}$  ( $.006''$ ) PER SIDE
  5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE  $0.102\text{mm}$  ( $.004''$ ) MAX

## MS8E Package 8-Lead Plastic MSOP (Reference LTC DWG # 05-08-1662)



- NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
  2. DRAWING NOT TO SCALE
  3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.  
MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED  $0.152\text{mm}$  ( $.006''$ ) PER SIDE
  4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.  
INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED  $0.152\text{mm}$  ( $.006''$ ) PER SIDE
  5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE  $0.102\text{mm}$  ( $.004''$ ) MAX

