

# 2.7MHz Boost DC/DC Converter with 1.5A Switch and Soft-Start

## FEATURES

- 1.5A, 36V Internal Switch
- 2.7MHz Switching Frequency
- Integrated Soft-Start Function
- Adjustable Output from  $V_{IN}$  to 35V
- Low  $V_{CESAT}$  Switch: 300mV at 1.5A (Typical)
- 12V at 430mA from a 5V Input
- Small Thermally Enhanced 8-Lead MSOP Package

## APPLICATIONS

- TFT-LCD Bias Supplies
- GPS Receivers
- DSL Modems
- Local Power Supply

## DESCRIPTION

The LT<sup>®</sup>1946A is a fixed frequency step-up DC/DC converter containing an internal 1.5A, 36V switch. Capable of generating 12V at 430mA from a 5V input, the LT1946A is ideal for powering large TFT-LCD panels. The LT1946A switches at 2.7MHz, allowing the use of tiny, low profile inductors and low value ceramic capacitors. Loop compensation can be either internal or external, giving the user flexibility in setting loop compensation and allowing optimized transient response with low ESR ceramic output capacitors. Soft-start is controlled with an external capacitor which determines the input current ramp rate during start up. The 8-lead MSOP package and high switching frequency ensure a low profile overall solution less than 1.1mm high.

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## TYPICAL APPLICATION

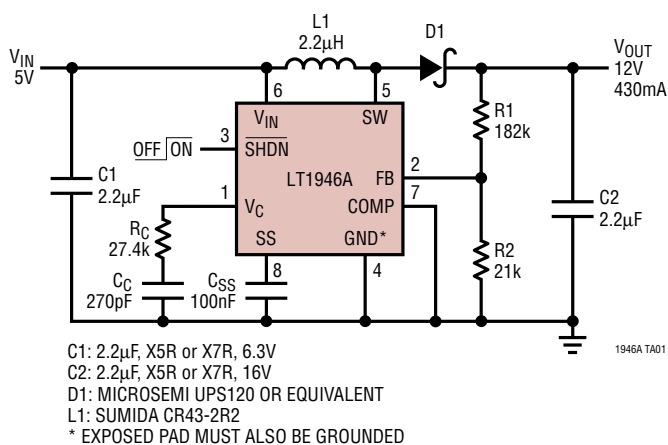
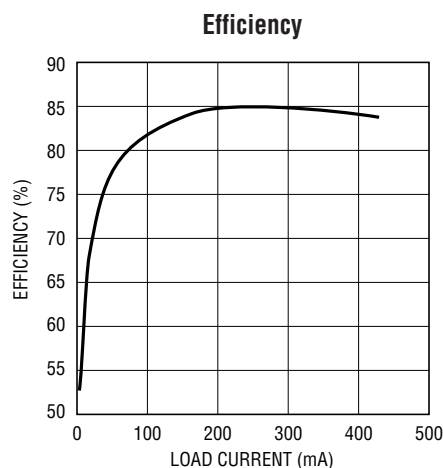


Figure 1. 5V to 12V, 430mA Step-Up DC/DC Converter



1946A TA01

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

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

	ORDER PART NUMBER
	LT1946AEMS8E
	MS8E PART MARKING
	LTYZ

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 noted. (Note 2)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Operating Voltage			2.45	2.6	V
Maximum Operating Voltage				16	V
Feedback Voltage		● 1.23	1.25	1.27	V
		● 1.22		1.27	V
FB Pin Bias Current	$V_{FB} = 1.25\text{V}$ (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		3.6	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		● 2.4	2.7	3	MHz
		● 2.3		3.1	MHz
Switching Frequency in Foldback	$V_{FB} = 0\text{V}$		0.85		MHz
Maximum Duty Cycle		● 73	80		%
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	$\mu\text{A}$
SHDN Input Voltage High			2.4		V
SHDN Input Voltage Low				0.5	V
SHDN Pin Bias Current	$V_{SHDN} = 3\text{V}$		16	32	$\mu\text{A}$
	$V_{SHDN} = 0\text{V}$		0	0.1	$\mu\text{A}$

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** The LT1946AE is guaranteed to meet performance specifications from 0°C to 70°C. Specifications over the -40°C to 85°C operating

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

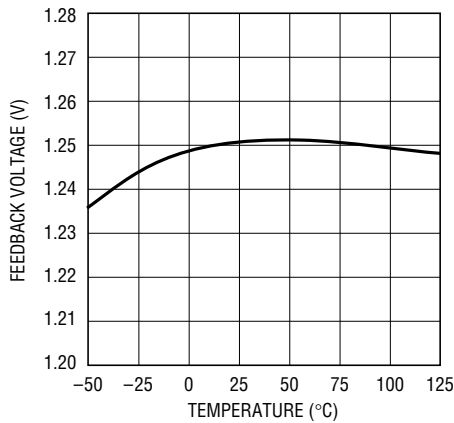
**Note 3:** Current flows out of the FB pin.

**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.

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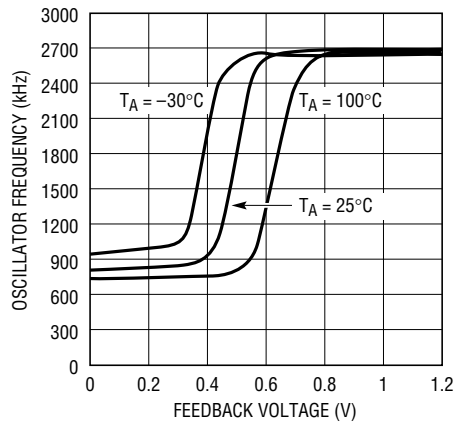
# TYPICAL PERFORMANCE CHARACTERISTICS

**Feedback Pin Voltage**



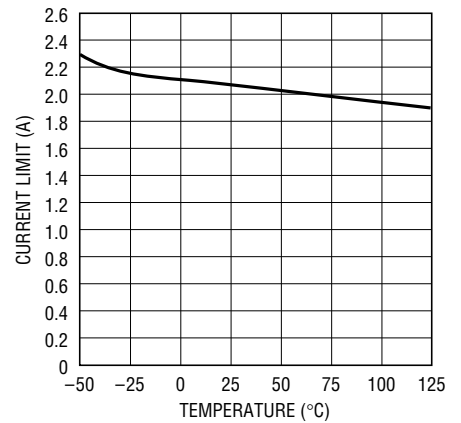
1946A G01

**Oscillator Frequency**



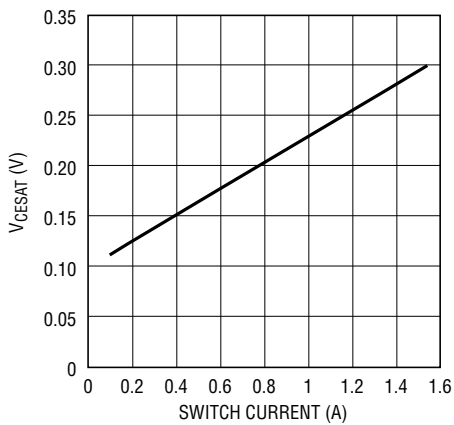
1946A G02

**Current Limit**



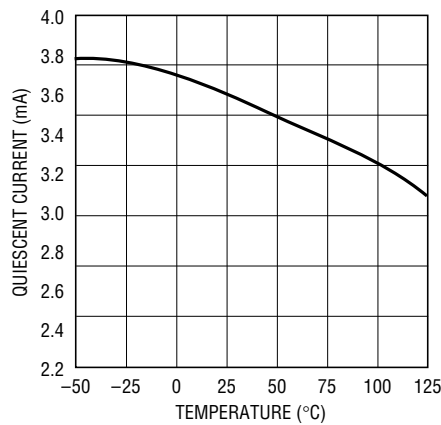
1946A G03

**Switch Saturation Voltage**



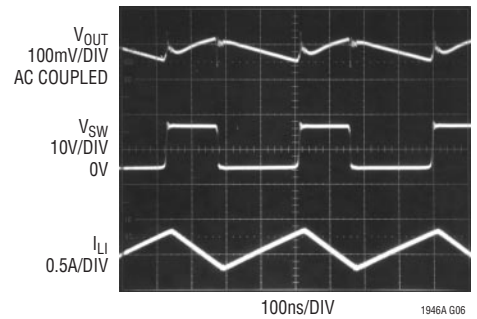
1946A G04

**Quiescent Current**



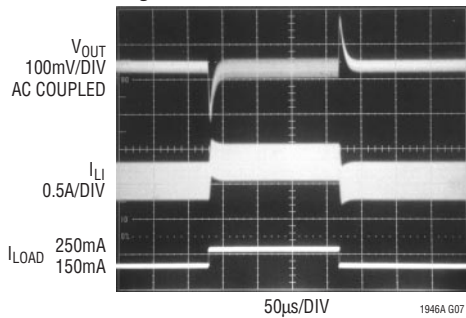
1946A G05

**Switching Waveforms for Figure 1 Circuit**



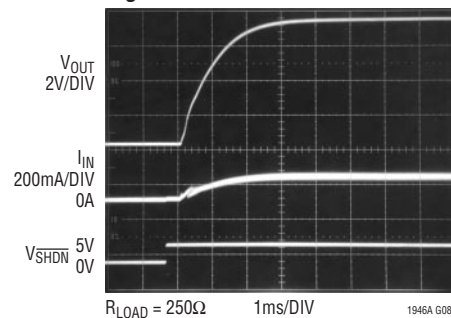
1946A G06

**Transient Response for Figure 1 Circuit**



1946A G07

**Start-Up Waveforms for Figure 1 Circuit**



$R_{LOAD} = 250\Omega$  1ms/DIV

1946A G08

## 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. External compensation consists of placing a resistor and capacitor in series from V<sub>C</sub> to GND. Typical capacitor range is from 90pF to 270pF. Typical resistor range is from 25k to 120k.

**FB (Pin 2):** Feedback Pin. Reference voltage is 1.25V. Connect resistive divider tap here. Minimize trace area at FB. Set V<sub>OUT</sub> according to  $V_{OUT} = 1.25 \cdot (1 + R1/R2)$ .

**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, Exposed Pad):** Ground. **Tie both Pin 4 and the exposed pad directly to local ground plane.** The ground metal to the exposed pad should be wide for better heat dissipation. Multiple vias (local ground plane ↔ ground backplane) placed close to the exposed pad can further aid in reducing thermal resistance.

**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.

# BLOCK DIAGRAM

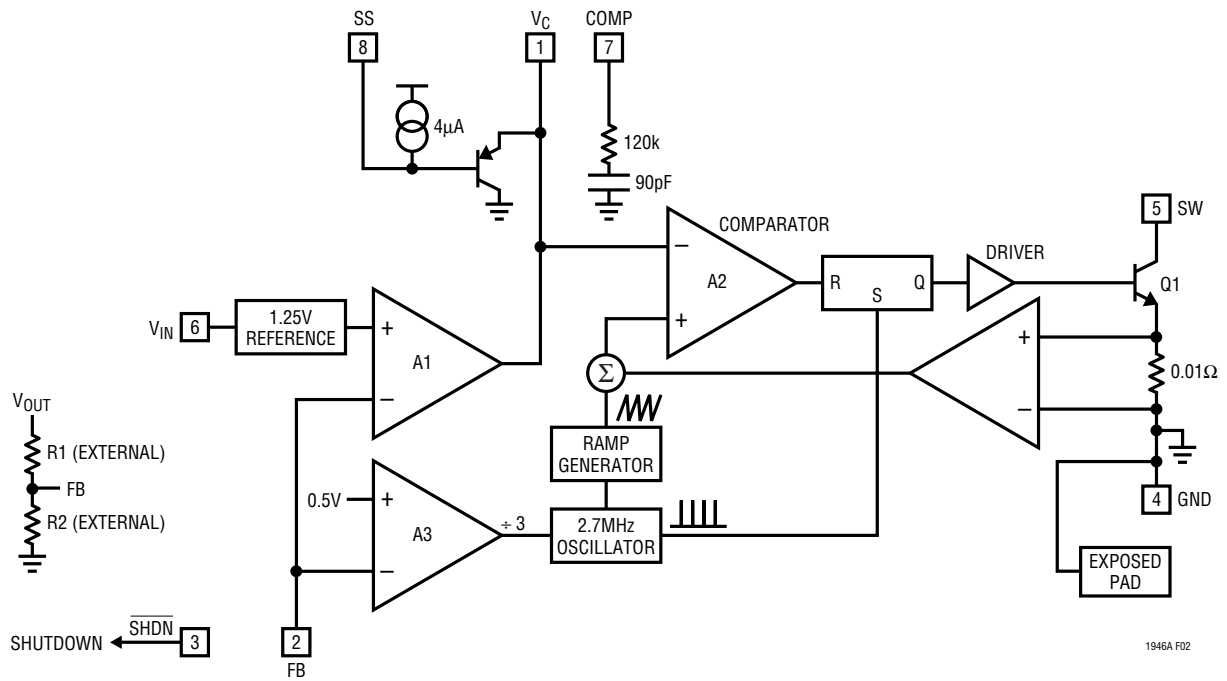


Figure 2. Block Diagram

1946A F02

## OPERATION

The LT1946A 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 LT1946A. Frequency foldback is used to reduce the oscillator frequency by one-third 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 goes above 0.5V, the oscillator returns to the normal frequency of 2.7MHz. A soft-start function is also provided by the LT1946A. When the part is brought out of shut-down, 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 protects the power switch as well as various external components connected to the LT1946A.

## APPLICATIONS INFORMATION

### Inductor Selection

Several inductors that work well with the LT1946A are listed in Table 1. This table is not complete, and there are many other manufacturers and devices 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 2.7MHz 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 1.5 $\mu$ H to 4.7 $\mu$ H inductor will be the best choice for most LT1946A 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 - LT1946A

PART	L ( $\mu$ H)	MAX DCR (m $\Omega$ )	Size LxWxH (mm)	VENDOR
RLF5018-1R5M2R1	1.5	25	5.2x5.6x1.8	TDK (847) 803-6100 www.tdk.com
RLF5018-2R7M1R8	2.7	33		
RLF5018-4R7M1R4	4.7	45		
RLF5018-100MR94	10.0	67		
LPO1704-122MC	1.2	80	5.5x6.6x1.0	Coilcraft (800) 322-2645 www.coilcraft.com
LPO1704-222MC	2.2	120		
CR43-2R2	2.2	71	4.5x4.0x3.2	Sumida (847) 956-0666 www.sumida.com
CR43-3R3	3.3	86		

### 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 dielectrics are preferred, followed by X7R, as these materials retain the capacitance over wide voltage and temperature ranges. A 2.2 $\mu$ F to 20 $\mu$ F output

## APPLICATIONS INFORMATION

capacitor is sufficient for most applications, but systems with very low output currents may need only a  $1\mu\text{F}$  or smaller output capacitor. Solid tantalum or OSCON 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.

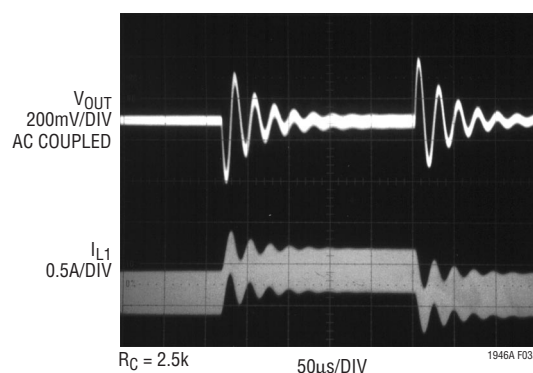
Ceramic capacitors also make a good choice for the input decoupling capacitor, which should be placed as close as possible to the LT1946A. A  $2.2\mu\text{F}$  to  $4.7\mu\text{F}$  input capacitor is sufficient for most applications. Table 2 shows a list of several ceramic capacitor manufacturers. Consult the manufacturers for detailed information on their entire selection of ceramic parts.

**Table 2. Ceramic Capacitor Manufacturers**

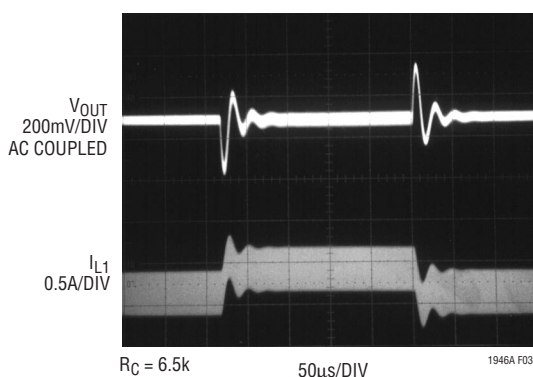
Taiyo Yuden	(408) 573-4150	www.t-yuden.com
AVX	(803) 448-9411	www.avxcorp.com
Murata	(714) 852-2001	www.murata.com

### Compensation

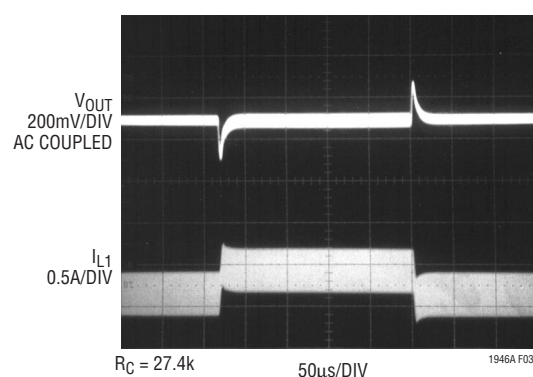
To compensate the feedback loop of the LT1946A, a series resistor-capacitor network should be connected from the COMP pin to GND. For most applications, a capacitor in the range of  $90\text{pF}$  to  $470\text{pF}$  will suffice. A good starting value for the compensation capacitor,  $C_C$ , is  $270\text{pF}$ . 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  $100\text{k}$  potentiometer in place of  $R_C$ , and use a  $270\text{pF}$  capacitor for  $C_C$ . By adjusting the potentiometer while observing the transient response, the optimum value for  $R_C$  can be found. Figures 3a-3c illustrate this process for the circuit of Figure 1. Figure 3a shows the transient response with  $R_C$  equal to  $2.5\text{k}$ . The phase margin is 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  $6.5\text{k}$ , which results in a more damped response. Figure 3c shows the results when  $R_C$  is increased further to  $27.4\text{k}$ . 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.



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



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



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

### Compensation-Theory

Like all other current mode switching regulators, the LT1946A needs to be compensated for stable and efficient operation. Two feedback loops are used in the LT1946A: 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.



## APPLICATIONS INFORMATION

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.

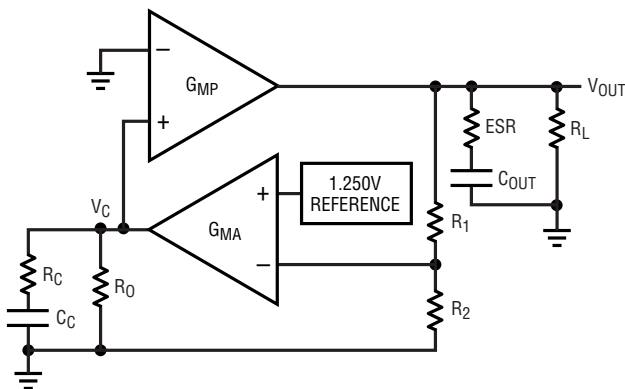
From Figure 4, the DC gain, poles and zeroes can be calculated as follows:

$$\text{Output Pole: } P_1 = \frac{2}{2 \cdot \pi \cdot R_L \cdot C_{OUT}}$$

$$\text{Error Amp Pole: } P_2 = \frac{1}{2 \cdot \pi \cdot R_0 \cdot C_C}$$

$$\text{Error Amp Zero: } Z_1 = \frac{1}{2 \cdot \pi \cdot R_C \cdot C_C}$$

$$\text{DC Gain: } A = \frac{1.25}{V_{OUT}} \cdot G_{MA} \cdot R_0 \cdot G_{MP} \cdot R_L$$



$G_{MA}$ : TRANSCONDUCTANCE AMPLIFIER INSIDE IC  
 $G_{MP}$ : POWER STAGE TRANSCONDUCTANCE AMPLIFIER  
 $C_{OUT}$ : OUTPUT CAPACITOR  
 $R_L$ : OUTPUT RESISTANCE DEFINED AS  $V_{OUT}$  DIVIDED BY  $I_{LOAD}$  (MAX)  
 $R_1, R_2$ : FEEDBACK RESISTOR DIVIDER NETWORK  
 $R_0$ : OUTPUT RESISTANCE OF  $G_{MA}$   
 $R_C$ : COMPENSATION RESISTOR  
 $C_C$ : COMPENSATION CAPACITOR

Figure 4. Boost Converter Equivalent Model

$$\text{ESR Zero: } Z_2 = \frac{1}{2 \cdot \pi \cdot \text{ESR} \cdot C_{OUT}}$$

$$\text{RHP Zero: } Z_3 = \frac{V_{IN}^2 \cdot R_L}{2 \cdot \pi \cdot V_{OUT}^2 \cdot L}$$

$$\text{High Frequency Pole: } P_3 > \frac{F_S}{3}$$

Using the circuit of Figure 1 as an example, Table 3 shows the parameters used to generate the bode plot shown in Figure 5.

Table 3. Bode Plot Parameters

Parameter	Value	Units	Comment
$R_L$	28	$\Omega$	Application Specific
$C_{OUT}$	2.2	$\mu F$	Application Specific
$R_0$	10	$M\Omega$	Not Adjustable
$C_C$	270	$\mu F$	Adjustable
$R_C$	27.4	$k\Omega$	Adjustable
$V_{OUT}$	12	V	Application Specific
$V_{IN}$	5	V	Application Specific
$G_{MA}$	40	$\mu mho$	Not Adjustable
$G_{MP}$	5	$mho$	Not Adjustable
$L$	2.2	$\mu H$	Application Specific
$F_S$	2.7	MHz	Not Adjustable
ESR	10	$m\Omega$	Not Adjustable

From Figure 5, the phase when the gain reaches 0dB is  $122^\circ$  giving a phase margin of  $58^\circ$ . This is more than adequate. The cross-over frequency is 90kHz, which is about 30 times lower than the frequency of the right half plane zero  $Z_2$ . It is important that the cross-over frequency be at least 3 times lower than the frequency of the RHP zero to achieve adequate phase margin.



## APPLICATIONS INFORMATION

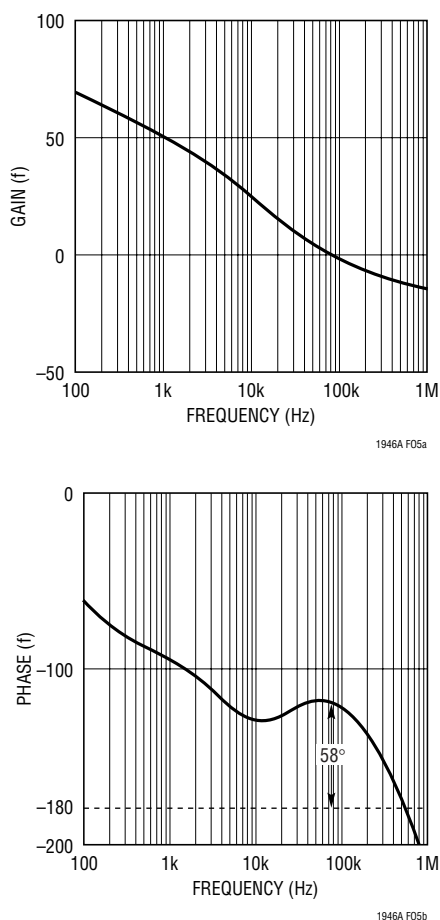


Figure 5. Gain and Phase Plots of Figure 1 Circuit

### Diode Selection

A Schottky diode is recommended for use with the LT1946A. 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

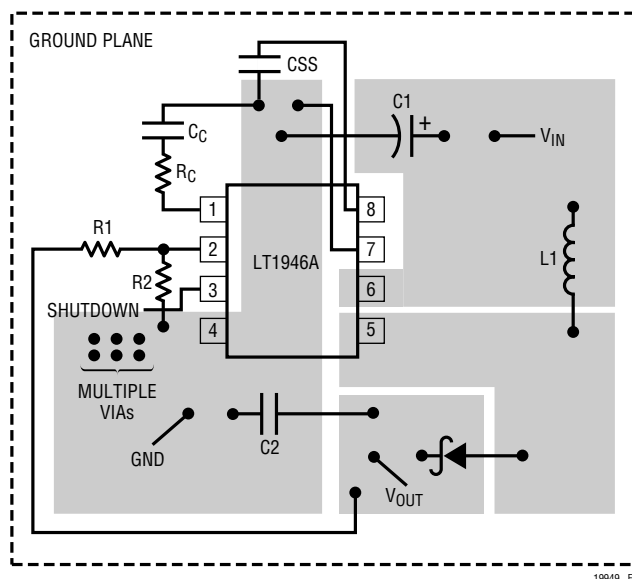
To set the output voltage, select the values of R1 and R2 (see Figure 1) according to the following equation:

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

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

### Layout Hints

The high speed operation of the LT1946A demands careful attention to board layout. You will not get advertised performance with careless layouts. Figure 6 shows the recommended component placement for a boost converter.

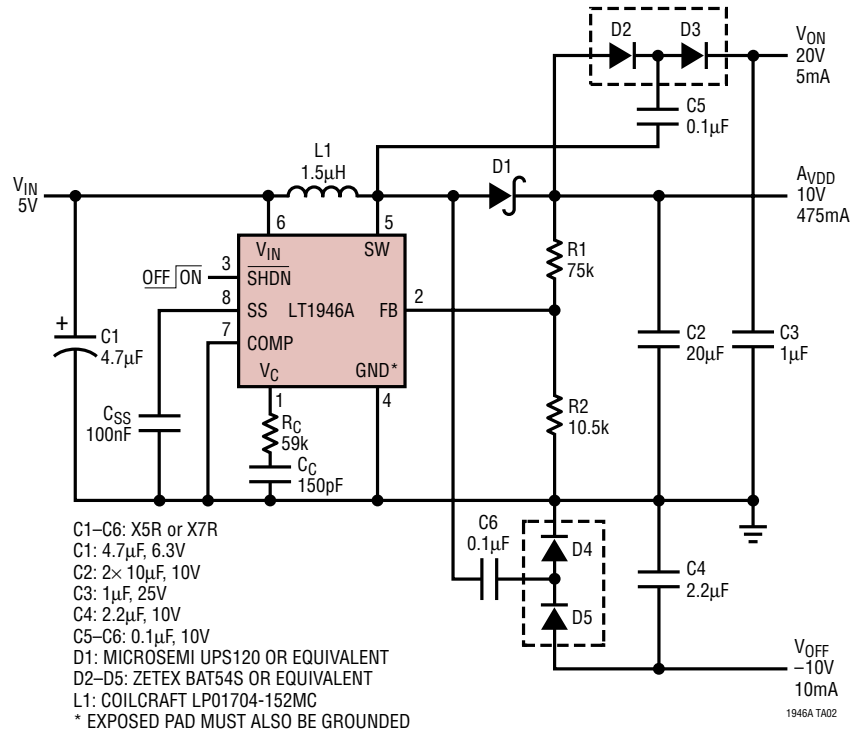


NOTE: DIRECT HIGH CURRENT PATHS USING WIDE PC TRACES. MINIMIZE TRACE AREA AT PIN 1 (V<sub>C</sub>) AND PIN 2 (F<sub>B</sub>). USE MULTIPLE VIAS TO TIE PIN 4 COPPER TO GROUND PLANE. USE VIAS AT ONE LOCATION ONLY TO AVOID INTRODUCING SWITCHING CURRENTS INTO THE GROUND PLANE.

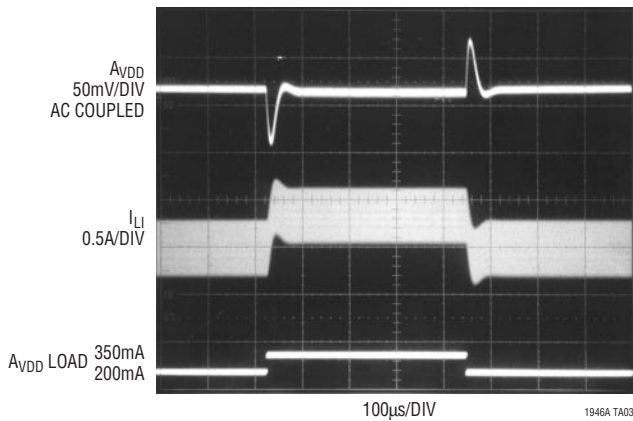
Figure 6. Recommended Component Placement for Boost Converter

## TYPICAL APPLICATIONS

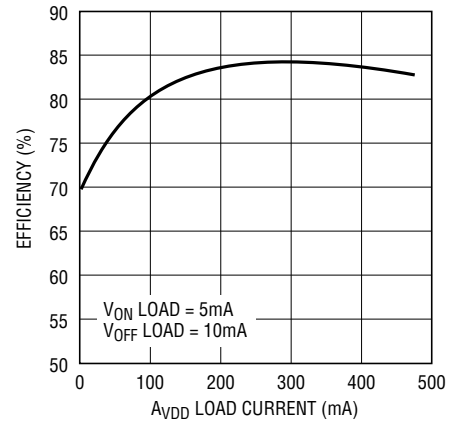
Low Profile (<1.1mm Tall) Triple Output TFT Supply (10V, -10V, 20V)



Transient Response

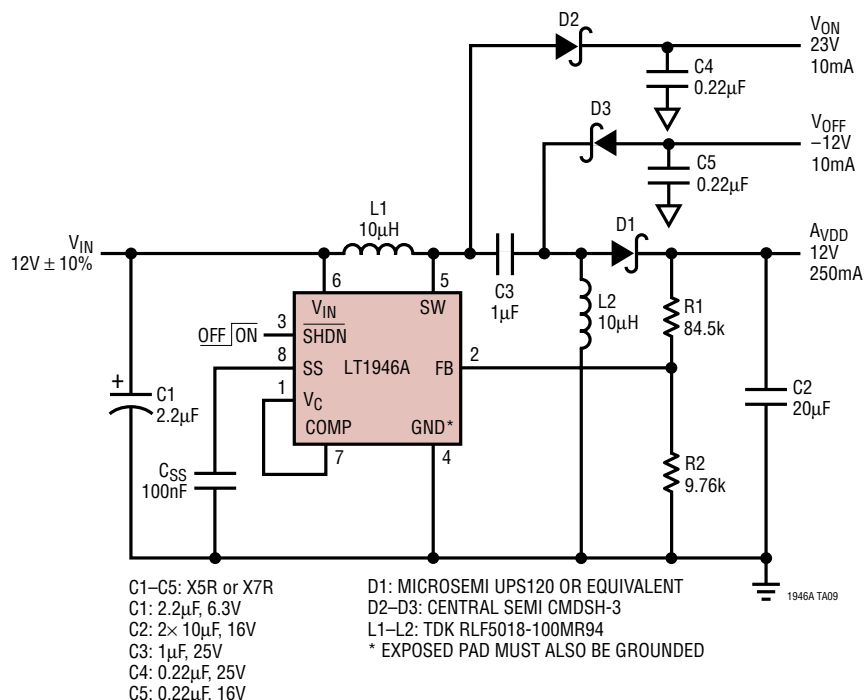


Efficiency

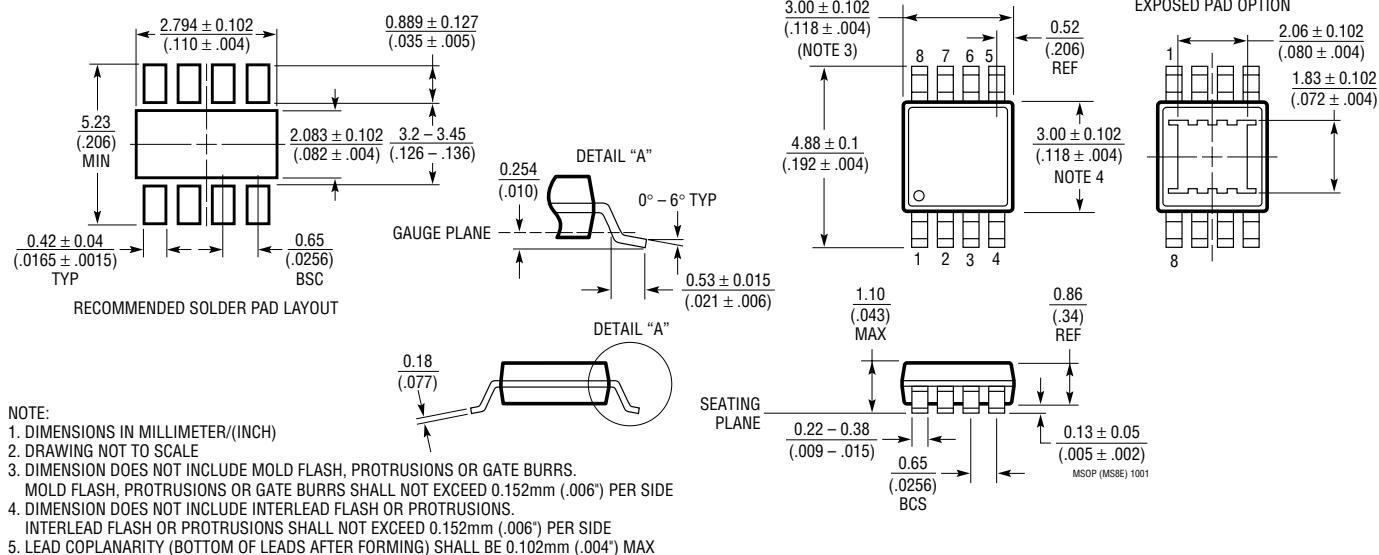


# TYPICAL APPLICATIONS

Triple Output TFT Supply Uses SEPIC Topology for Output Disconnect



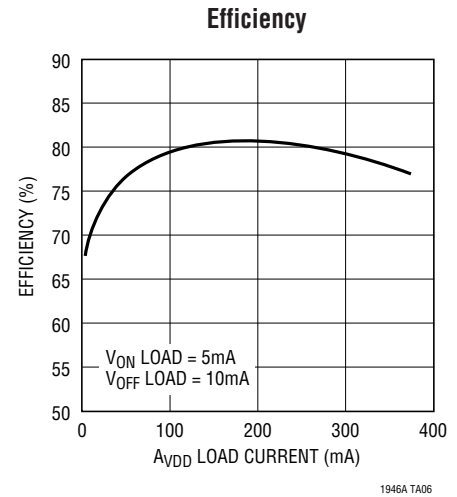
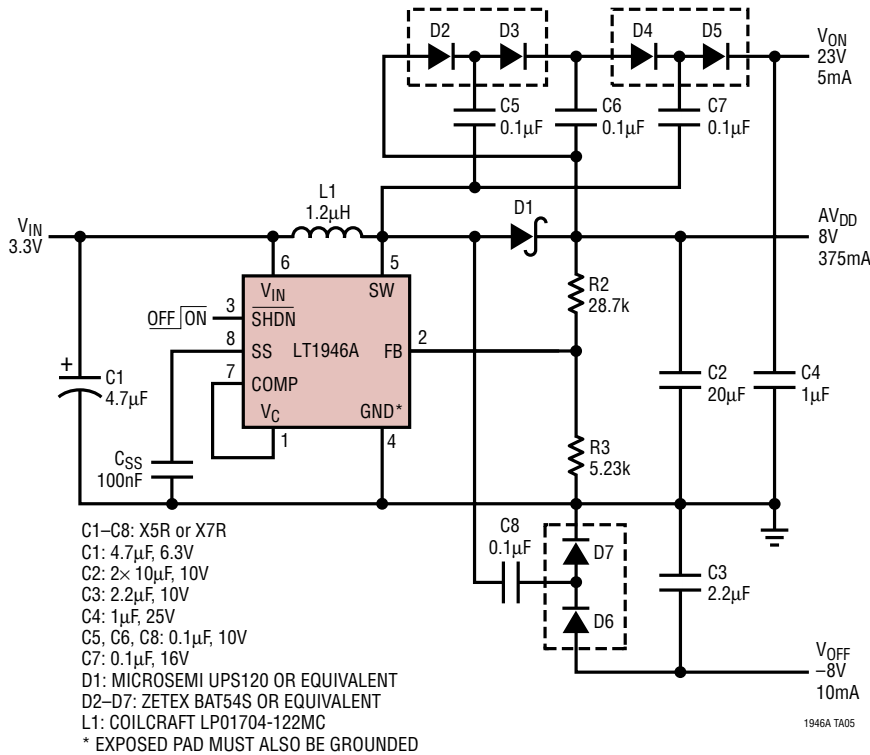
**MS8E Package**  
**8-Lead Plastic MSOP**  
 (Reference LTC DWG # 05-08-1662)



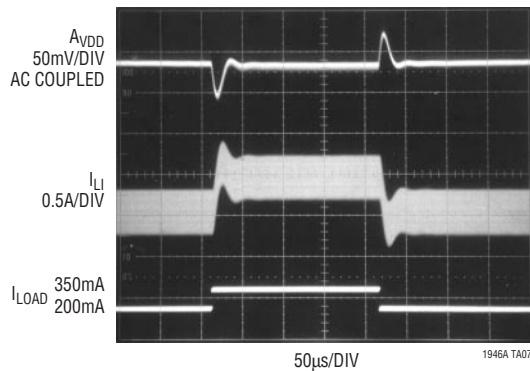
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## TYPICAL APPLICATIONS

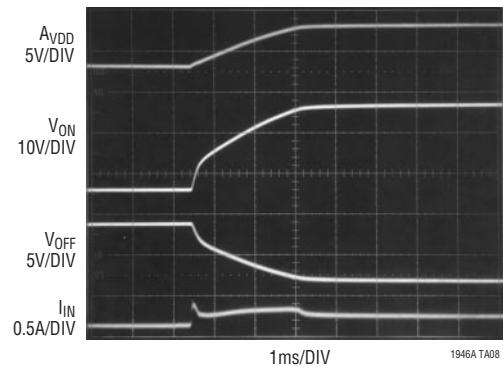
### Low Profile (<1.1mm Tall) Triple Output TFT Supply (8V, -8V, 24V)



### Transient Response



### Start-Up Waveforms



## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1613	550mA ( $I_{SW}$ ), 1.4MHz, Step-Up DC/DC Converter	$V_{IN} = 0.9V$ to 10V, $V_{OUT}$ to 34V, $I_Q = 3mA$ , $I_{SD} < 1\mu A$ , ThinSOT™
LT1615/LT1615-1	300mA/0.75mA ( $I_{SW}$ ), Constant Off-Time Step-Up DC/DC Converter	$V_{IN} = 1V$ to 15V, $V_{OUT}$ to 34V, $I_Q = 20\mu A$ , $I_{SD} < 1\mu A$ , ThinSOT
LT1930/LT1930A	1A ( $I_{SW}$ ), 1.2MHz/2.2MHz, Step-Up DC/DC Converter	$V_{IN} = 2.6V$ to 16V, $V_{OUT}$ to 34V, $I_Q = 4.2mA/5.5mA$ , $I_{SD} < 1\mu A$ , ThinSOT
LT1946	1.5A ( $I_{SW}$ ), 1.2MHz, Step-Up DC/DC Converter	$V_{IN} = 2.45V$ to 16V, $V_{OUT}$ to 34V, $I_Q = 3.2mA$ , $I_{SD} < 1\mu A$ , MS8
LT1961	1.5A ( $I_{SW}$ ), 1.25MHz, Step-Up DC/DC Converter	$V_{IN} = 3V$ to 25V, $V_{OUT}$ to 35V, $I_Q = 0.9mA$ , $I_{SD} < 6\mu A$ , MS8E

ThinSOT is a trademark of Linear Technology Corporation.

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