ABSOLUTE MAXIMUM RATINGS

(Note 1)

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

```
          TOP VIEW
       ┌─────────┐
   VC  1│ o       │8  SS
   FB  2│         │7  COMP
 SHDN  3│         │6  VIN
  GND  4│         │5  SW
       └─────────┘
      MS8E PACKAGE
  8-LEAD PLASTIC MSOP
  EXPOSED PAD IS GROUND
 (MUST BE SOLDERED TO PCB)

TJMAX = 125°C, θJA = 40°C/W,
     θJC = 10°C/W
```

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 $T_A = 25°C$. $V_{IN} = 3V$, $V_{\overline{SHDN}} = V_{IN}$ 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	$V_{FB} = 1.25V$ (Note 3)	●		20	120	nA
Error Amp Transconductance	$\Delta I = 2\mu A$			40		μmhos
Error Amp Voltage Gain				300		V/V
Quiescent Current	$V_{SHDN} = 2.5V$, Not Switching			3.6	5	mA
Quiescent Current in Shutdown	$V_{SHDN} = 0V$, $V_{IN} = 3V$			0	1	μA
Reference Line Regulation	$2.6V \leq V_{IN} \leq 16V$			0.01	0.05	%/V
Switching Frequency			2.4	2.7	3	MHz
		●	2.3		3.1	MHz
Switching Frequency in Foldback	$V_{FB} = 0V$			0.85		MHz
Maximum Duty Cycle		●	73	80		%
Switch Current Limit	(Note 4)	●	1.5	2.1	3.1	A
Switch V_{CESAT}	$I_{SW} = 1A$			240	340	mV
Switch Leakage Current	$V_{SW} = 5V$			0.01	1	μA
Soft-Start Charging Current	$V_{SS} = 0.5V$		2.5	4	6	μA
SHDN Input Voltage High			2.4			V
SHDN Input Voltage Low					0.5	V
SHDN Pin Bias Current	$V_{SHDN} = 3V$			16	32	μA
	$V_{SHDN} = 0V$			0	0.1	μA

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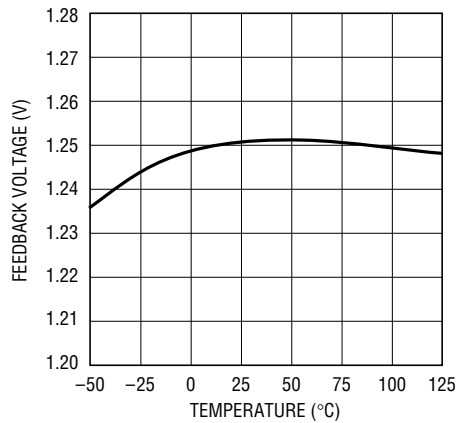
Note 3: Current flows out of the FB pin.

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.
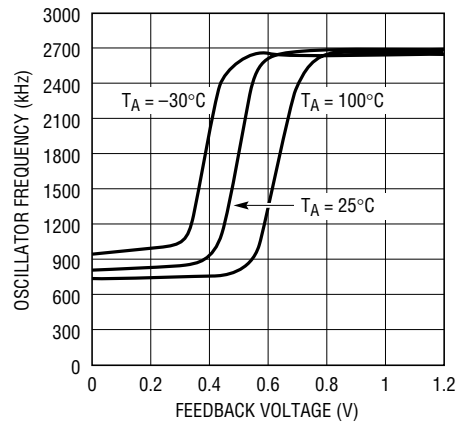
sn1946a 1946afs
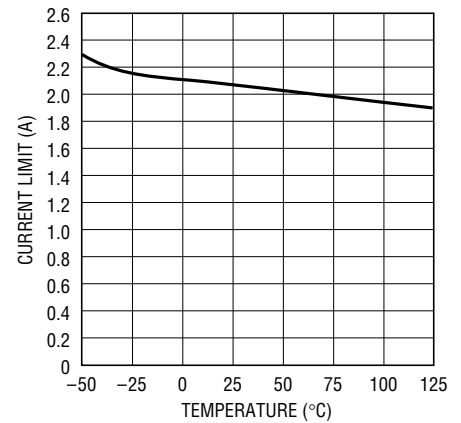
LINEAR TECHNOLOGY

TYPICAL PERFORMANCE CHARACTERISTICS

Feedback Pin Voltage

1946A G01

Oscillator Frequency

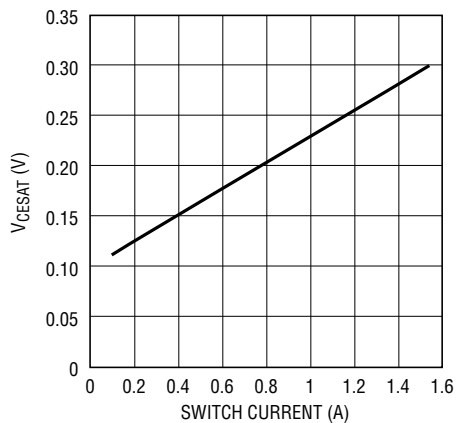$T_A = -30°C$ $T_A = 100°C$

$T_A = 25°C$
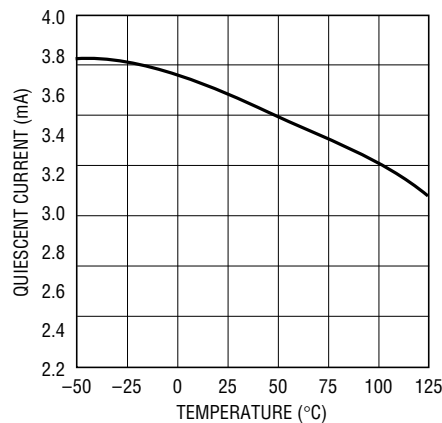
1946A G02

Current Limit

1946A G03

Switch Saturation Voltage

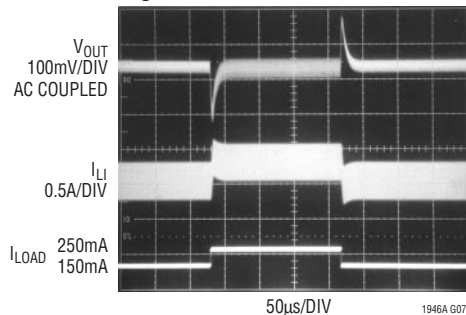1946A G04

Quiescent Current

1946A G05

Switching Waveforms for Figure 1 Circuit

V_{OUT}
100mV/DIV
AC COUPLED

V_{SW}
10V/DIV
0V

I_{LI}
0.5A/DIV
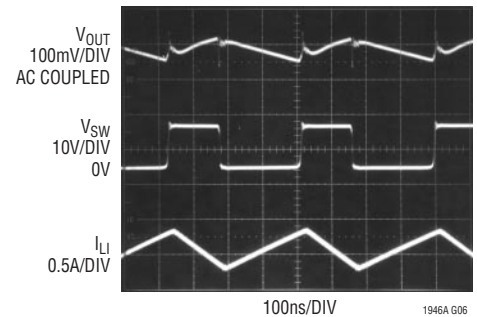
100ns/DIV   1946A G06

Transient Response for Figure 1 Circuit

V_{OUT}
100mV/DIV
AC COUPLED

I_{LI}
0.5A/DIV

I_{LOAD} 250mA
150mA

50µs/DIV   1946A G07

Start-Up Waveforms for Figure 1 Circuit

V_{OUT}
2V/DIV

I_{IN}
200mA/DIV
0A

$V_{\overline{SHDN}}$ 5V
0V

$R_{LOAD} = 250Ω$ 1ms/DIV   1946A G08

3
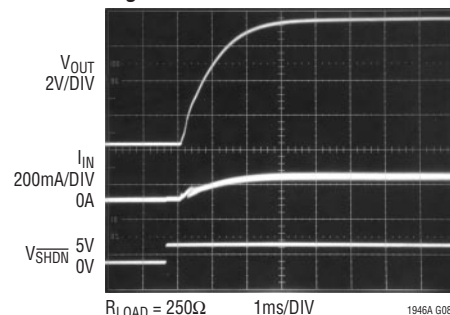
PIN FUNCTIONS

V_C (Pin 1): Error Amplifier Output Pin. Tie external compensation network to this pin or use the internal compensation network by shorting the V_C pin to the COMP pin. External compensation consists of placing a resistor and capacitor in series from V_C 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_{OUT} according to $V_{OUT} = 1.25 \cdot (1+R1/R2)$.

$\overline{SHDN}$ (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_{IN} (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_C 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.
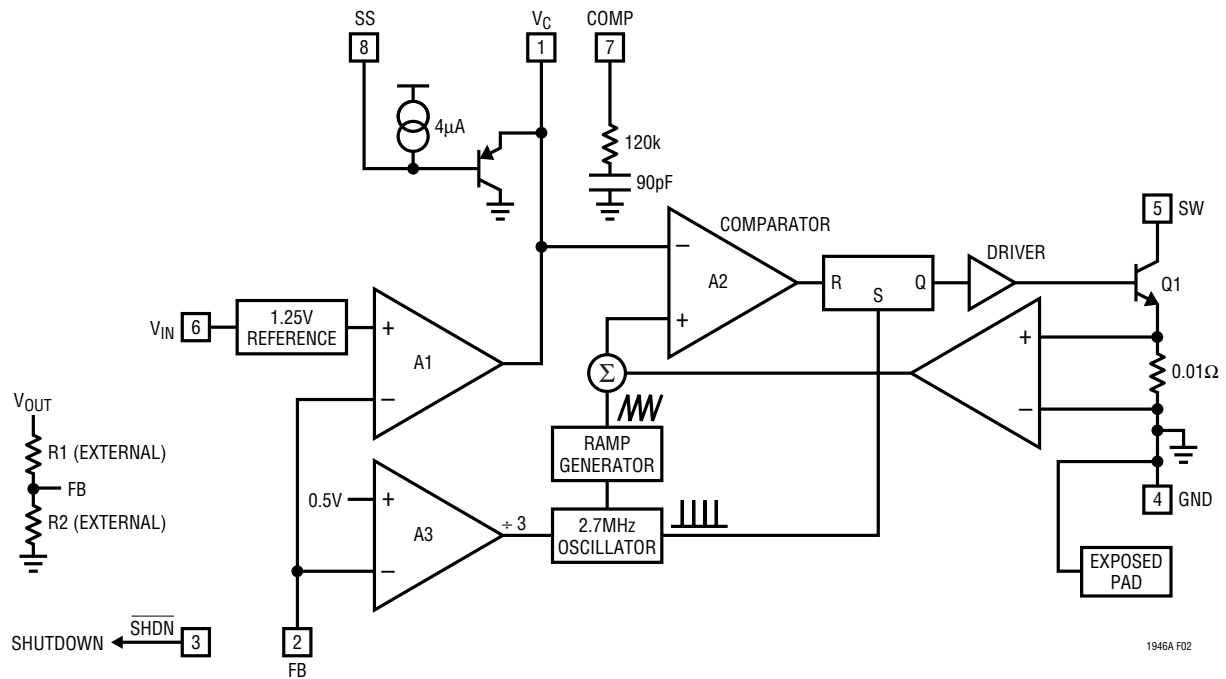
sn1946a 1946afs

BLOCK DIAGRAM

Figure 2. Block Diagram

5

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

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 2.2µF to 20µF output

sn1946a 1946afs

APPLICATIONS INFORMATION

capacitor is sufficient for most applications, but systems with very low output currents may need only a 1µF 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 2.2µF to 4.7µF 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 90pF to 470pF will suffice. A good starting value for the compensation capacitor, C_C, is 270pF. The compensation resistor, R_C, is usually in the range of 20k to 100k. A good technique to compensate a new application is to use a 100k potentiometer in place of R_C, and use a 270pF 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 2.5k. 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 6.5k, which results in a more damped response. Figure 3c shows the results when R_C is increased further to 27.4k. The transient response is nicely damped and the compensation procedure is complete. The COMP pin provides access to an internal resistor (120k) and capacitor (90pF). For some applications, these values will suffice and no external R_C and C_C will be needed.
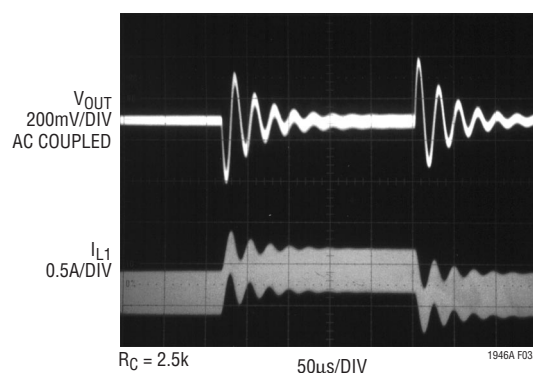

Figure 3a. Transient Response Shows Excessive Ringing
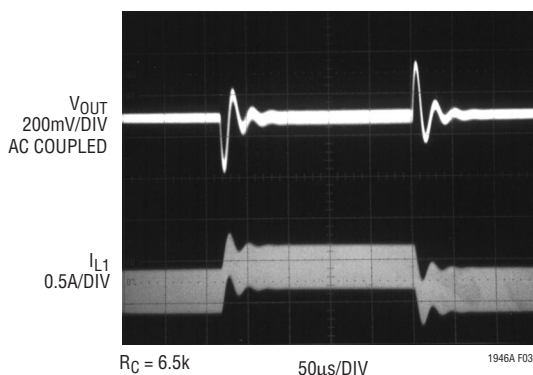

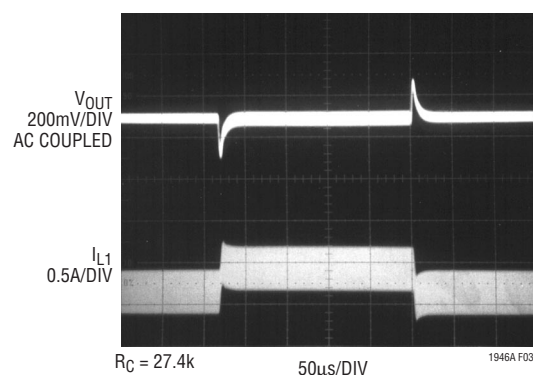Figure 3b. Transient Response is Better

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.

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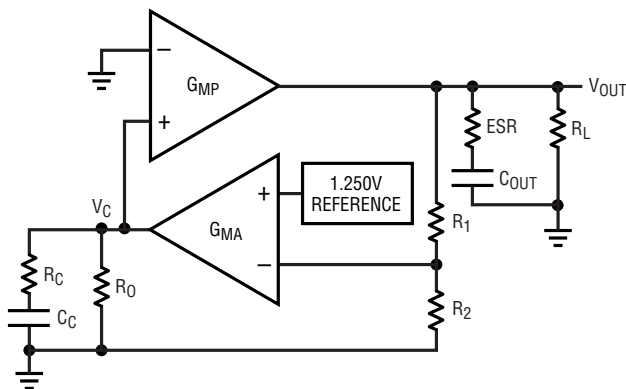
From Figure 4, the DC gain, poles and zeroes can be calculated as follows:

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

Error Amp Pole: $P_2 = \dfrac{1}{2 \cdot \pi \cdot R_O \cdot C_C}$

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

DC Gain: $A = \dfrac{1.25}{V_{OUT}} \cdot G_{MA} \cdot R_O \cdot G_{MP} \cdot R_L$

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

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

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

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	Ω	Application Specific
C_{OUT}	2.2	μF	Application Specific
R_O	10	$M\Omega$	Not Adjustable
C_C	270	pF	Adjustable
R_C	27.4	$k\Omega$	Adjustable
V_{OUT}	12	V	Application Specific
V_{IN}	5	V	Application Specific
G_{MA}	40	μmho	Not Adjustable
G_{MP}	5	mho	Not Adjustable
L	2.2	μH	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° giving a phase margin of 58°. 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 Z2. 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.

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)
R1, R2: FEEDBACK RESISTOR DIVIDER NETWORK
R_O: OUTPUT RESISTANCE OF G_{MA}
R_C: COMPENSATION RESISTOR
C_C: COMPENSATION CAPACITOR

Figure 4. Boost Converter Equivalent Model

APPLICATIONS INFORMATION
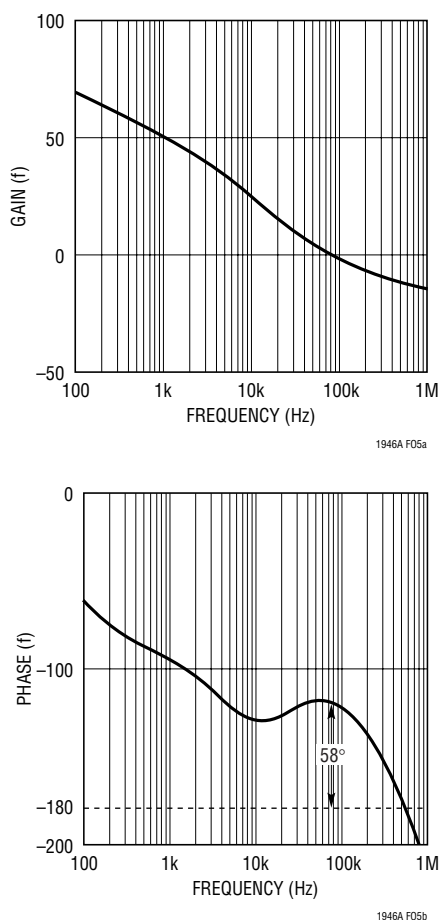

1946A F05a

58°

1946A F05b

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.
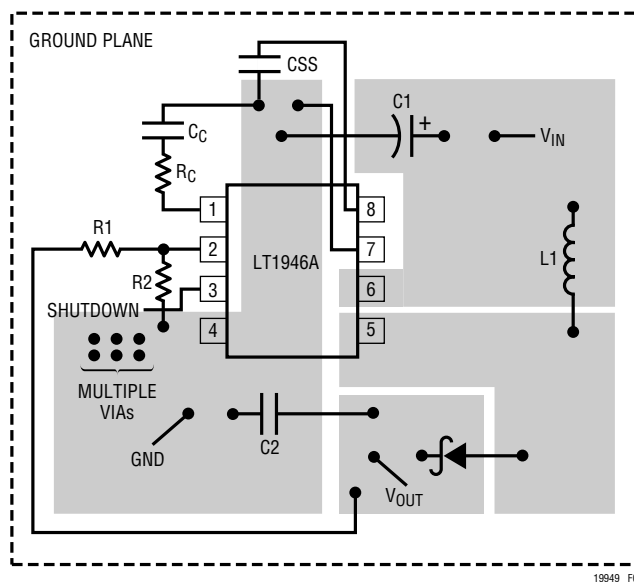
NOTE: DIRECT HIGH CURRENT PATHS USING WIDE PC TRACES. MINIMIZE TRACE AREA AT PIN 1(V_C) AND PIN 2(F_B). USE MULTIPLE VIAS TO TIE PIN 4 COPPER TO GROUND PLANE. USE VIAS AT ONE LOCATION ONLY TO AVOID INTRODUCING SWITCHING CURRENTS INTO THE GROUND PLANE.

Figure 6. Recommended Component Placement for Boost Converter

TYPICAL APPLICATIONS

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

C1–C6: X5R or X7R
C1: 4.7µF, 6.3V
C2: 2× 10µF, 10V
C3: 1µF, 25V
C4: 2.2µF, 10V
C5–C6: 0.1µF, 10V
D1: MICROSEMI UPS120 OR EQUIVALENT
D2–D5: ZETEX BAT54S OR EQUIVALENT
L1: COILCRAFT LP01704-152MC
* EXPOSED PAD MUST ALSO BE GROUNDED
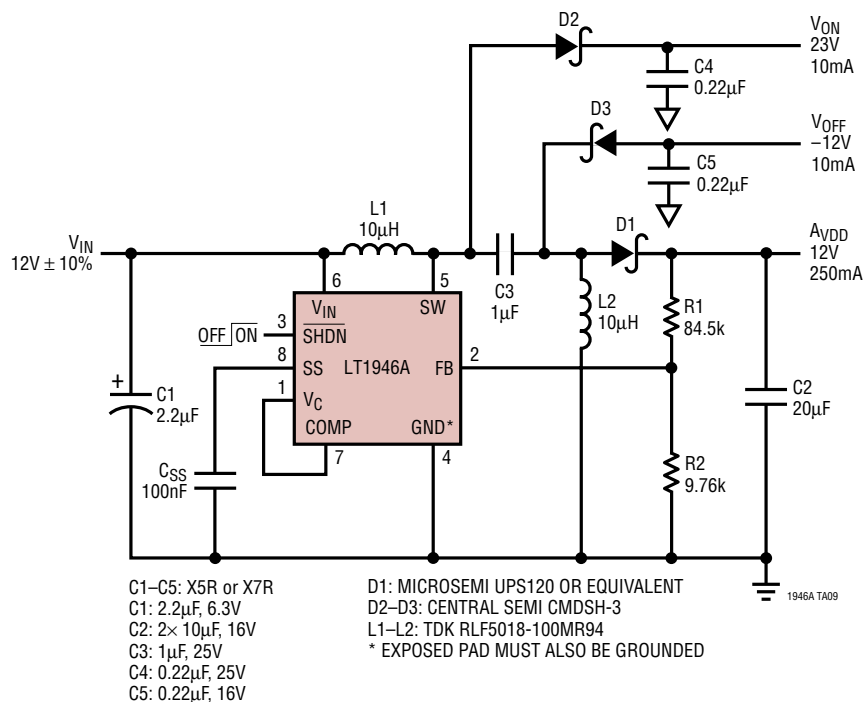
1946A TA02

Transient Response

A_{VDD} 50mV/DIV AC COUPLED

I_{LI} 0.5A/DIV

A_{VDD} LOAD 350mA 200mA

100µs/DIV

1946A TA03

Efficiency

V_{ON} LOAD = 5mA
V_{OFF} LOAD = 10mA

A_{VDD} LOAD CURRENT (mA)

1946A TA04

TYPICAL APPLICATIONS

Triple Output TFT Supply Uses SEPIC Topology for Output Disconnect

C1–C5: X5R or X7R
C1: 2.2µF, 6.3V
C2: 2× 10µF, 16V
C3: 1µF, 25V
C4: 0.22µF, 25V
C5: 0.22µF, 16V

D1: MICROSEMI UPS120 OR EQUIVALENT
D2–D3: CENTRAL SEMI CMDSH-3
L1–L2: TDK RLF5018-100MR94
* EXPOSED PAD MUST ALSO BE GROUNDED

1946A TA09

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

RECOMMENDED SOLDER PAD LAYOUT

BOTTOM VIEW OF
EXPOSED PAD OPTION

DETAIL "A"

GAUGE PLANE

DETAIL "A"

SEATING PLANE

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 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
   INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

MSOP (MS8E) 1001

sn1946a 1946afs

LT1946A

TYPICAL APPLICATIONS

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

C1–C8: X5R or X7R
C1: 4.7µF, 6.3V
C2: 2× 10µF, 10V
C3: 2.2µF, 10V
C4: 1µF, 25V
C5, C6, C8: 0.1µF, 10V
C7: 0.1µF, 16V
D1: MICROSEMI UPS120 OR EQUIVALENT
D2–D7: ZETEX BAT54S OR EQUIVALENT
L1: COILCRAFT LPO1704-122MC
* EXPOSED PAD MUST ALSO BE GROUNDED

1946A TA05

Efficiency

V_ON LOAD = 5mA
V_OFF LOAD = 10mA

1946A TA06

Transient Response

50µs/DIV   1946A TA07

Start-Up Waveforms

1ms/DIV   1946A TA08
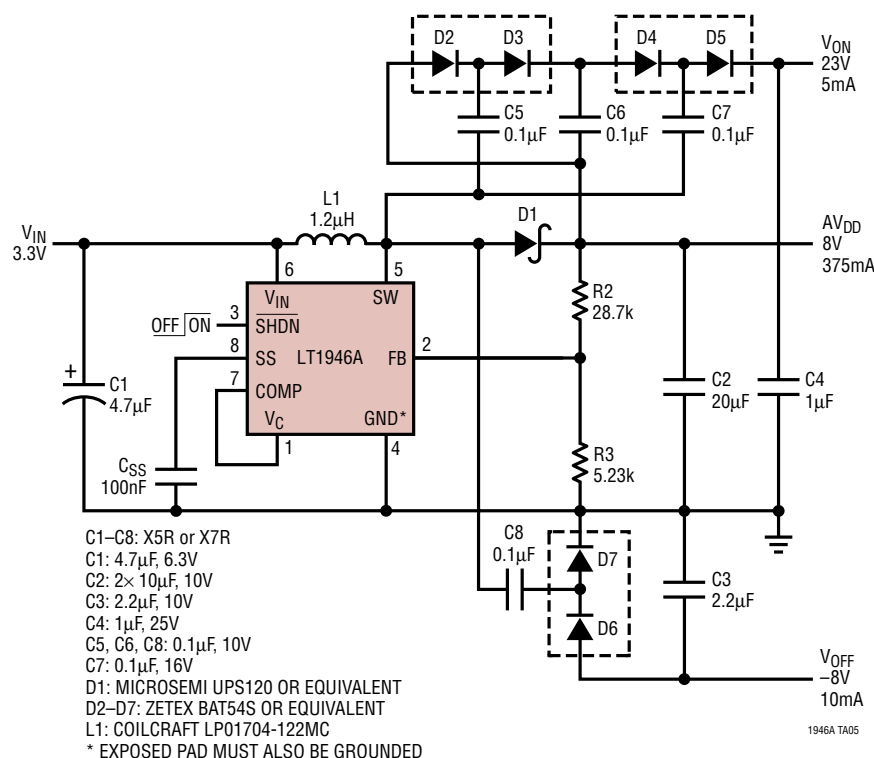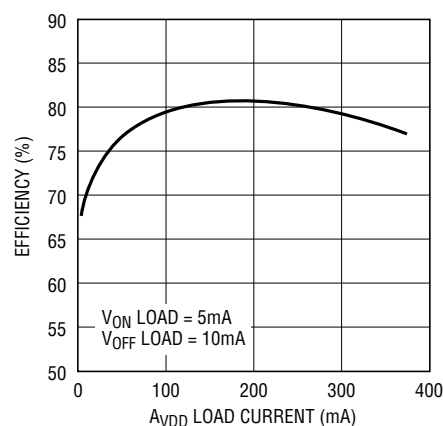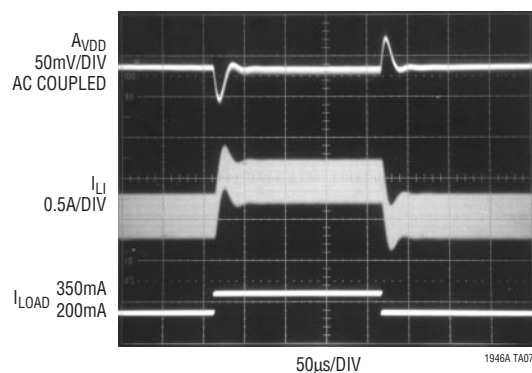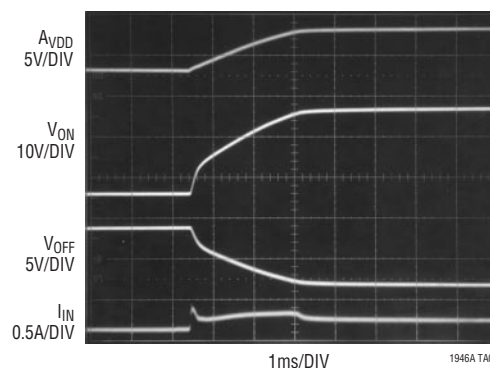
RELATED PARTS

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} < 1µA, 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 = 20µA, I_{SD} < 1µA, 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} < 1µA, 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} < 1µA, 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} < 6µA, MS8E

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