



# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

## General Description

The MAX1729 micropower step-up/step-down DC-DC converter is ideally suited for electrically controlled birefringence (ECB) and liquid-crystal-display (LCD) bias-supply generation. It provides step-up/step-down voltage conversion and reduces output ripple by using a step-up DC-DC converter followed by a linear regulator. This architecture permits a physically smaller inductor than those used in competing SEPIC and flyback topologies. This device features low quiescent current (67 $\mu$ A typical). A logic-controlled shutdown mode further reduces quiescent current to 0.4 $\mu$ A typical.

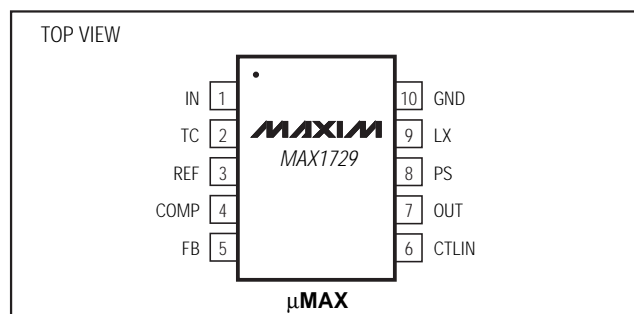
The MAX1729 features an input that dynamically adjusts the output voltage to control display color or contrast. It offers two feedback modes: internal and external. Internal feedback mode allows output voltages between 2.5V and 16V, and is specifically designed to hold temperature drift to  $\pm 11$ ppm/ $^{\circ}$ C. External feedback mode allows the MAX1729 output voltage range to be tailored for various displays.

An on-chip temperature sensor with a positive temperature coefficient provides compensation for LCD/ECB display temperature characteristics. In internal feedback mode, the buffered temperature sensor output is read and used to adjust the output voltage via a digital control signal. External feedback mode features an additional compensation method in which the temperature output is summed directly into the feedback network to provide first-order negative temperature compensation of the output voltage. The MAX1729 is available in the space-saving 10-pin  $\mu$ MAX package.

## Applications

ECB Display Bias & Color Adjustment  
LCD Display Bias & Contrast Adjustment  
Cellular Phones  
Personal Digital Assistants

## Pin Configuration



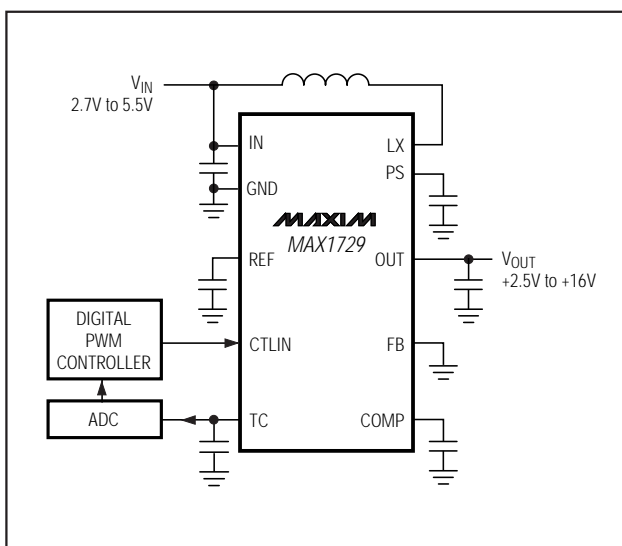
## Features

- ♦ High-Accuracy Reference Voltage ( $\pm 1\%$ )
- ♦  $\pm 11$ ppm/ $^{\circ}$ C Output Voltage Drift
- ♦ On-Chip Temperature Sensor Output
- ♦ Accurate Voltage and Temperature Provide:
  - Consistent ECB Colors
  - Consistent LCD Gray-Scale Contrast
- ♦ +2.7V to +5.5V Input Voltage Range
- ♦ Output Voltage Range
  - +2.5V to +16V in Internal Feedback Mode
  - Programmable in External Feedback Mode
- ♦ Dynamic Control of the Output Voltage
- ♦ 67 $\mu$ A Supply Current
- ♦ 0.4 $\mu$ A Shutdown Current
- ♦ 10-Pin  $\mu$ MAX Package (1.09mm max height)
- ♦ Evaluation Kit Available (MAX1729EVKIT)

## Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1729EUB	-40 $^{\circ}$ C to +85 $^{\circ}$ C	10 $\mu$ MAX

## Typical Operating Circuit



# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

## ABSOLUTE MAXIMUM RATINGS

IN to GND .....-0.3V to +6V  
 LX, PS, OUT to GND .....-0.3V to +20V  
 CTLIN, FB, REF, COMP, TC to GND .....-0.3V to ( $V_{IN} + 0.3V$ )  
 LX to PS .....-20V to +1.0V  
 LX, PS, OUT Current .....60mA  
 Continuous Power Dissipation ( $T_A = +70^\circ\text{C}$ )  
 10-pin  $\mu\text{MAX}$  (derate 5.6mW/ $^\circ\text{C}$  above  $+70^\circ\text{C}$ ) .....444mW

Operating Temperature Range .....-40 $^\circ\text{C}$  to +85 $^\circ\text{C}$   
 Junction Temperature .....+150 $^\circ\text{C}$   
 Storage Temperature Range .....-65 $^\circ\text{C}$  to +160 $^\circ\text{C}$   
 Lead Temperature (soldering, 10sec) .....+300 $^\circ\text{C}$

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

( $V_{IN} = +3V$ , CTLIN = IN, FB = GND,  $T_A = -40^\circ\text{C}$  to  $+85^\circ\text{C}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ\text{C}$ .) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Voltage Range	V <sub>IN</sub>			2.7		5.5	V
Undervoltage Lockout Threshold (Note 2)	V <sub>LO</sub>			2.0		2.6	V
IN Supply Current	I <sub>IN</sub>				37	50	μA
PS Supply Current	I <sub>PS</sub>				30	40	μA
Shutdown Supply Current	I <sub>SHDN</sub>	CTLIN = GND, I <sub>SHDN</sub> = I <sub>IN</sub> + I <sub>PS</sub>			0.4	2	μA
Reference Output Voltage	V <sub>REF</sub>	I <sub>REF</sub> = 0	T <sub>A</sub> = +25°C	1.215	1.228	1.241	V
			T <sub>A</sub> = -40°C to +85°C	1.200		1.256	
Minimum Output Voltage	V <sub>OUT</sub> (MIN)	FB = GND, CTLIN = 0.1% duty cycle, I <sub>OUT</sub> = 0 to 0.5mA	T <sub>A</sub> = 0°C to +85°C	2.35	2.45	2.5	V
			T <sub>A</sub> = -40°C to +85°C	2.35		2.52	
Maximum Output Voltage	V <sub>OUT</sub> (MAX)	I <sub>OUT</sub> = 0 to 0.5mA		16	16.40		V
CTLIN to V <sub>OUT</sub> Gain		FB = GND, CTLIN = 0.1% to 100% duty cycle, I <sub>OUT</sub> = 0	T <sub>A</sub> = 0°C to +85°C	13.90	13.95	14.00	V/100%
			T <sub>A</sub> = -40°C to +85°C	13.60		14.20	
Output Voltage Temperature Coefficient	TC <sub>OUT</sub>	V <sub>PS</sub> = +18V (Note 3)	T <sub>A</sub> = 0°C to +85°C		±11	±30	ppm/°C
			T <sub>A</sub> = -40°C to +85°C		±18	±65	
Maximum Output Current	I <sub>OUT</sub>			0.5	2.5		mA
TC Output Voltage	V <sub>TC</sub>	T <sub>A</sub> = +25°C		1.178	1.228	1.278	V
TC Output Temperature Coefficient (Note 3)	TC <sub>TC</sub>	T <sub>A</sub> = 0°C to +85°C		15.5	16.5	17.5	mV/°C
		T <sub>A</sub> = -40°C to +85°C		14.5	16.5	18.5	
TC Output Current	I <sub>TC</sub>			±50			μA
Feedback Set Voltage (FB)	V <sub>FB</sub>	T <sub>A</sub> = +25°C		1.215	1.228	1.241	V
		T <sub>A</sub> = -40°C to +85°C		1.200		1.256	
FB Mode Threshold	V <sub>MODE</sub>			90	122	150	mV
FB Bias Current	I <sub>FB</sub>	V <sub>FB</sub> = +1.25V			5	50	nA
CTLIN High Voltage	V <sub>IH</sub>	V <sub>IN</sub> = +5.5V		2			V
		V <sub>IN</sub> = +2.7V		1.3			

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

MAX1729

## ELECTRICAL CHARACTERISTICS

( $V_{IN} = +3V$ ,  $CTLIN = IN$ ,  $FB = GND$ ,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = +25^{\circ}C$ .) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
CTLIN Low Voltage	$V_{IL}$	$V_{IN} = +2.7V$ to $+5.5V$				0.4	V
CTLIN Bias Current	$I_{IHL}$	$V_{IN} = +5.5V$ , $CTLIN = GND$ or $IN$				$\pm 1$	$\mu A$
COMP Impedance	$R_{COMP}$	$V_{FB} = 0$ , Internal Feedback Mode			33		$k\Omega$
		$V_{FB} = +1.25V$ , External Feedback Mode			60	150	$\Omega$
CTLIN Minimum Pulse Width for Shutdown	$t_{OFF}$	(Note 4)		700	1250	2400	$\mu s$
CTLIN Minimum Pulse Width for $V_{OUT}$ Control	$t_{CTLIN}$				25		ns
COMP Rise/Fall Time	$t_R/t_F$	$V_{FB} = +1.25V$			20		ns
Switch On-Resistance	$R_{ON}$	$I_{LX} = 30mA$	$V_{IN} = +2.7V$		2.5	5.0	$\Omega$
			$V_{IN} = +5.5V$		1.5		
Switch Off-Leakage Current	$I_{LX(OFF)}$	$V_{LX} = 18V$			0.1	1	$\mu A$
LX to PS Diode Forward Voltage	$V_{LX-PS}$	$I_{DIODE} = 30mA$			700	970	mV
PFM On-Time Constant	K	$T_A = +25^{\circ}C$		6	8	10	V- $\mu s$
		$T_A = -40^{\circ}C$ to $+85^{\circ}C$		5		11	
PS to OUT Voltage (Note 5)				0.4	0.6	1.0	V

**Note 1:** Specifications to  $-40^{\circ}C$  are guaranteed by design, not production tested.

**Note 2:** When  $V_{IN}$  is below this level, the boost and LDO outputs are disabled.

**Note 3:** Guaranteed by design.

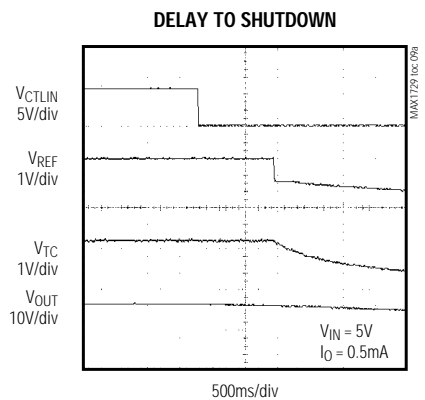
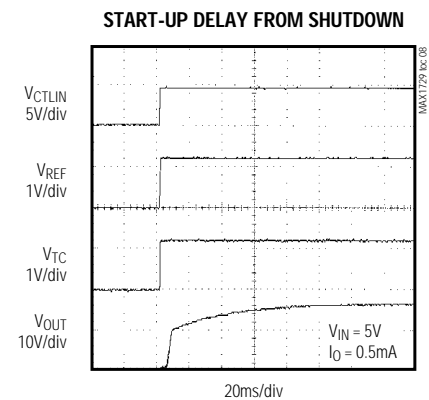
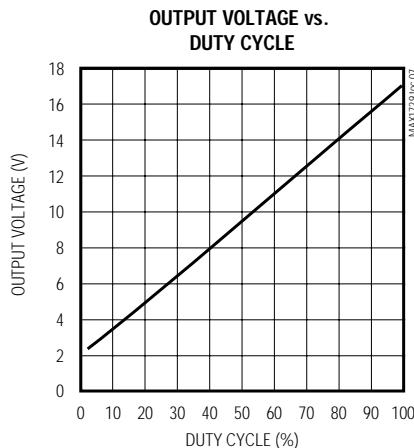
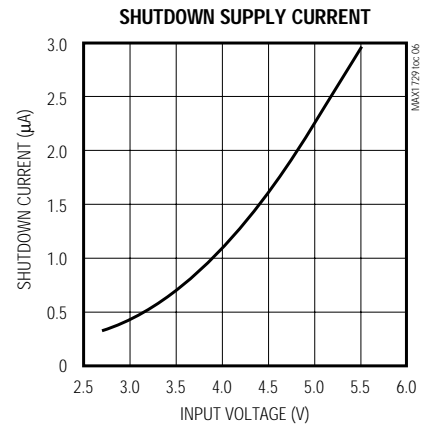
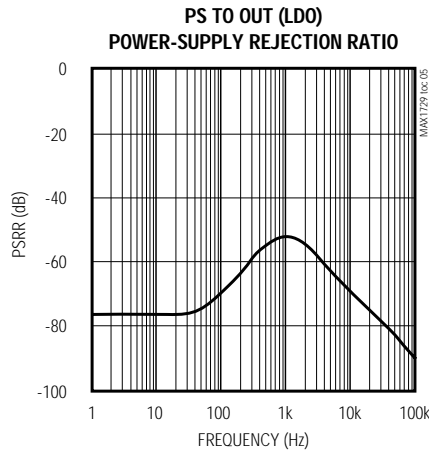
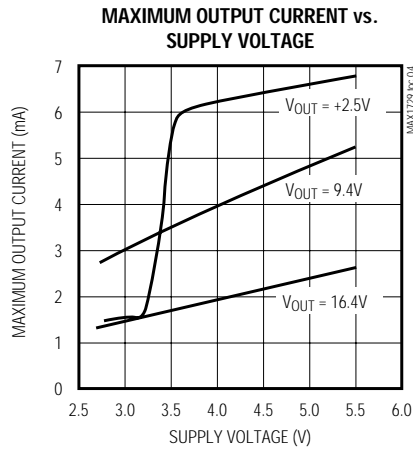
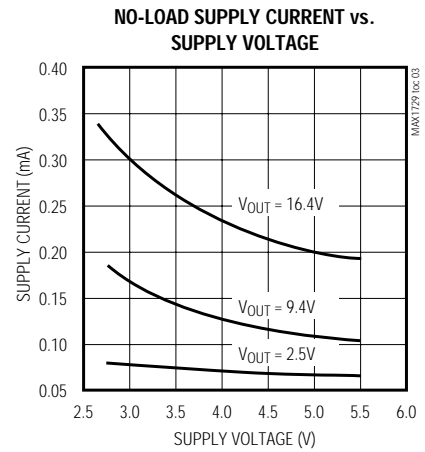
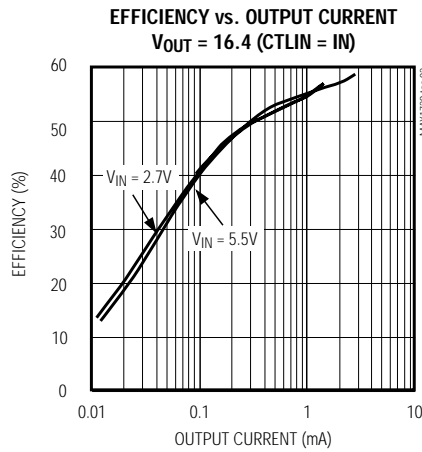
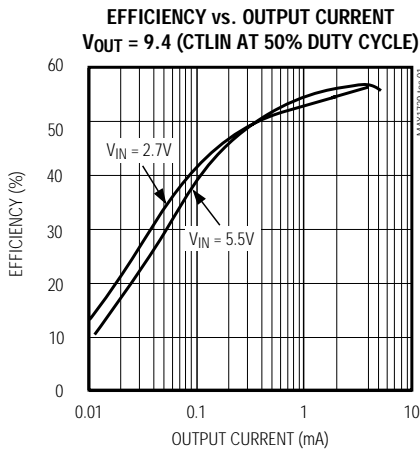
**Note 4:** Minimum time to hold  $CTLIN$  low to invoke shutdown. If  $CTLIN$  is held low for less than  $t_{OFF}$ , device does not enter shutdown.

**Note 5:** Switching regulator regulates this voltage to keep LDO from dropping out.

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

## Typical Operating Characteristics

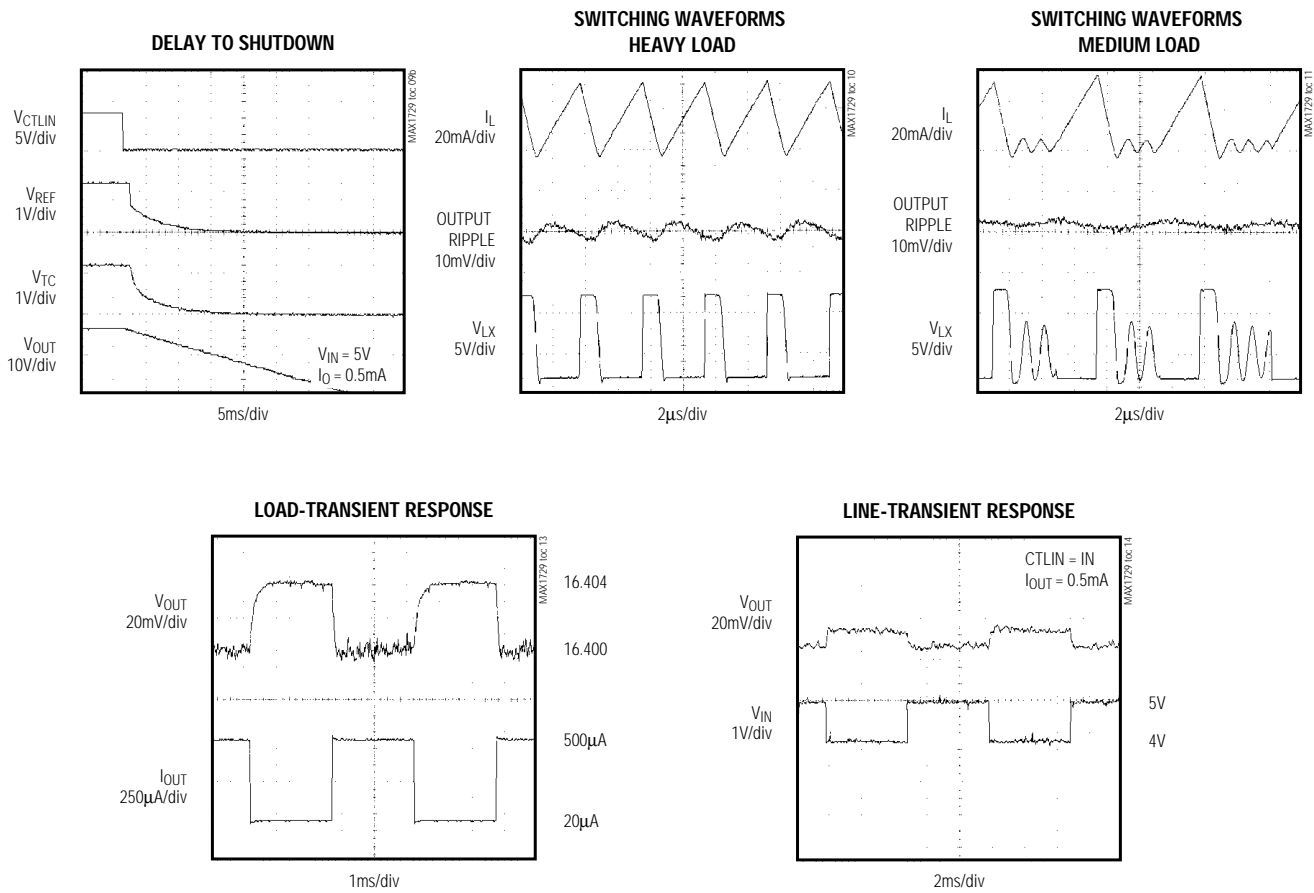
(Circuit of Figure 2,  $T_A = +25^\circ\text{C}$ , unless otherwise noted.)



# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

MAX1729

Typical Operating Characteristics (continued)  
(Circuit of Figure 2,  $T_A = +25^\circ\text{C}$ , unless otherwise noted.)



# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

## Pin Description

PIN	NAME	FUNCTION
1	IN	Supply Input. Bypass with 0.1μF capacitor to ground. Connect to supply side of inductor (L1).
2	TC	Temperature-Sensor Output. Bypass to GND with a 1000pF capacitor.
3	REF	Reference Voltage Output. Bypass to GND with a 0.1μF capacitor.
4	COMP	Compensation Pin. In internal feedback mode (Figure 2), bypass with a 1μF capacitor. In external feedback mode, COMP is a buffered inverse version of CTLIN (Figure 3).
5	FB	Feedback and Mode Control Input. Connect to GND for internal feedback mode operation.
6	CTLIN	Control Input. Drive low for more than 1.2ms to put the device into shutdown.
7	OUT	Bypass to GND with a 1.0μF capacitor.
8	PS	Output of boost converter and input to LDO. Bypass to GND with a 0.068μF capacitor.
9	LX	Drain of the internal MOSFET Switch
10	GND	Ground

## Detailed Description

The MAX1729 is designed to provide bias voltage for ECB or LCD displays. It is composed of a step-up DC-DC converter followed by a linear regulator (Figure 1), a combination that provides step-up/step-down voltage conversion while minimizing output ripple. The device allows you to adjust a display's color or contrast by dynamically adjusting the MAX1729's output voltage using a PWM control signal. In internal feedback mode, the output voltage is adjustable between +2.5V and +16V. In external feedback mode, the output voltage is adjustable, and its range is set by a resistor network that is programmed to match the output voltage range of LCD/ECB displays needing a maximum output up to +18V.

### Boost Converter

The MAX1729's DC-DC boost converter is implemented with an on-chip N-channel MOSFET, a diode, and an error comparator. The IC's unique PFM control system varies the on-time and off-time of the switch based on the

boost converter's input and output voltage values, as follows:

$$t_{ON} = \frac{K}{V_{IN}}$$

$$t_{OFF} \geq \frac{K}{V_{PS} - V_{IN}}$$

where K is typically 8V-μs. This timing maintains discontinuous conduction and sets the peak inductor current ( $I_{PEAK}$ ) to:

$$I_{PEAK} = \frac{K}{L}$$

where L is the inductance of L1 (Figures 2, 3, and 4).

When the error comparator detects that the drop across the linear regulator ( $V_{PS} - V_{OUT}$ ) is less than approximately 0.6V, the internal switch is turned on ( $t_{ON}$  initiates) and current through the inductor ramps to  $I_{PEAK}$ . At the end of  $t_{ON}$ , the switch is turned off for at least  $t_{OFF}$ , allowing the

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

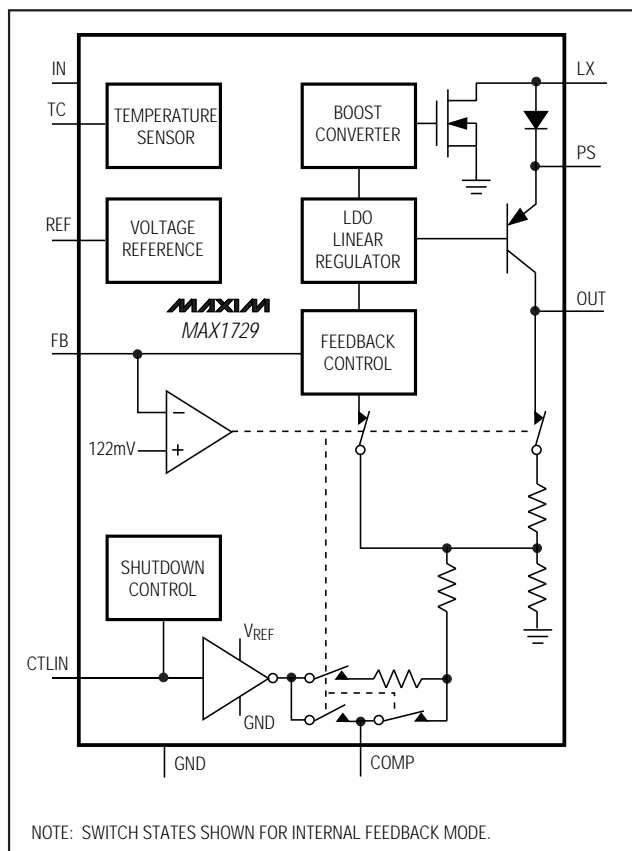


Figure 1. Internal Block Diagram

inductor current to ramp down and  $V_{PS}$  to increase. If, at the end of  $t_{OFF}$ ,  $V_{PS} - V_{OUT}$  is still too low, then another  $t_{ON}$  is initiated immediately. Otherwise, the boost converter remains idle in a low-quiescent-current state until  $V_{PS} - V_{OUT}$  drops again and the error comparator initiates another cycle.

## Linear Regulator

The PNP low-dropout linear regulator of the MAX1729 regulates the boost-converter output to the desired output voltage. The boost converter's regulation circuitry holds the linear regulator's input voltage ( $V_{PS}$ ) approximately 0.6V above the output voltage to keep the regulator out of dropout, thereby enhancing ripple rejection. The linear regulator incorporates short-circuit protection, which limits the output current to approximately 6mA.

## Temperature Sensor Output

The MAX1729 generates a temperature sensor voltage ( $V_{TC}$ ) that varies at 16.5mV/°C (typ) and is nominally

equal to the reference voltage at room temperature. TC is capable of sinking or sourcing 50μA. This output is used to compensate for ECB color or LCD contrast variations caused by changes in temperature. It may be read with an ADC and used to modify an external PWM control signal or, in external feedback mode, summed directly into the feedback-resistor network.

## Control Signal

An externally generated PWM control signal on CTLIN controls  $V_{OUT}$  in internal feedback mode and influences  $V_{OUT}$  in external feedback mode. In either mode, if CTLIN is held low for longer than 1.24ms, the MAX1729 enters shutdown mode, decreasing the supply current below 2μA. Shutdown mode limits the minimum duty cycle and frequency that may be used to keep the device active. CTLIN frequencies between 2kHz and 12kHz are recommended.

## Internal Feedback Mode

In internal feedback mode, the signal at CTLIN is inversely buffered, level-shifted, and output at COMP through a resistor. Internal resistance (33kΩ typical) and C6 then filter the signal before it is used by the internal feedback network to set  $V_{OUT}$ . If temperature compensation is used, the temperature sensor output voltage is read by an ADC and used to adjust the duty cycle of the PWM control signal. See the *Designing for Internal Feedback Mode* section for more information.

## External Feedback Mode

In external feedback mode, the output voltage of the MAX1729 is controlled by the duty cycle of the PWM control signal and an external resistor network, as shown in Figure 3. In this mode, the signal at CTLIN is inverted, level-shifted, and presented directly to COMP. R3, R4, and C6 filter the signal, before it is summed into the feedback node.

## Design Procedure

### Designing for Internal Feedback Mode

For a 3kHz PWM control signal use a 1μF low-leakage ceramic capacitor for C6. For applications requiring a higher-frequency PWM control signal, reduce the value of C6 to between 1μF and 0.22μF for frequencies between 3kHz and 12kHz. Higher C6 values reduce output ripple. In Figure 2,  $V_{OUT}$  is governed by the following equation:

$$V_{OUT} = V_{OUT(MIN)} + \text{Duty Cycle} \cdot \text{Gain}$$

where  $V_{OUT(MIN)}$  is 2.45V and Gain is nominally 13.95V/100%, as listed in the *Electrical Characteristics*.

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

To use a DC control signal to adjust the output voltage, use the circuit shown in Figure 4. In this configuration,  $V_{OUT}$  is governed by the following equation:

$$V_{OUT} \approx 24.67V_{FB} - 22.71V_{COMP}$$

The impedance looking into COMP is nominally 33k $\Omega$ . A source output impedance of less than 500 $\Omega$  is recommended. Also, ensure  $V_{OUT} \leq 18V$  by keeping  $V_{COMP}$  above 0.6V.

## Designing for External Feedback Mode

To solve for  $V_{OUT}$  in external feedback mode, assume the current into the FB pin is zero and the voltage at FB is 1.228V. Then take the sum of the currents into FB and solve for  $V_{OUT}$ :

$$V_{OUT} = R1 \left( \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3+R4} + \frac{1}{R5} \right) V_{FB} - \left( \frac{R1}{R3+R4} \right) V_{COMP} - \left( \frac{R1}{R5} \right) V_{TC}$$

Using the following formulas, calculate the external component values required for MAX1729 operation in external feedback mode, as shown in Figure 3. An example follows the formulas.

## External Component Value Formulas

1) Given the maximum output voltage needed ( $V_{MAX}$ ), choose the maximum feedback current and solve for  $R1$  (10 $\mu A$  to 30 $\mu A$  is recommended for maximum feedback current) as follows:

$$R1 = \frac{V_{MAX} - V_{FB}}{I_{FB}}$$

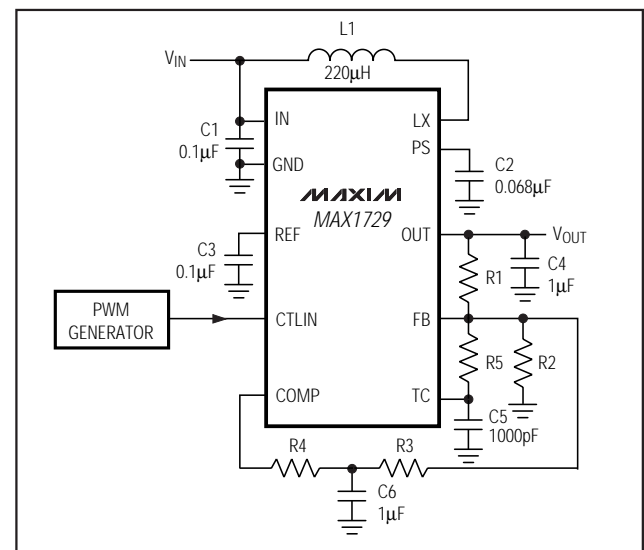


Figure 3. External Feedback Mode

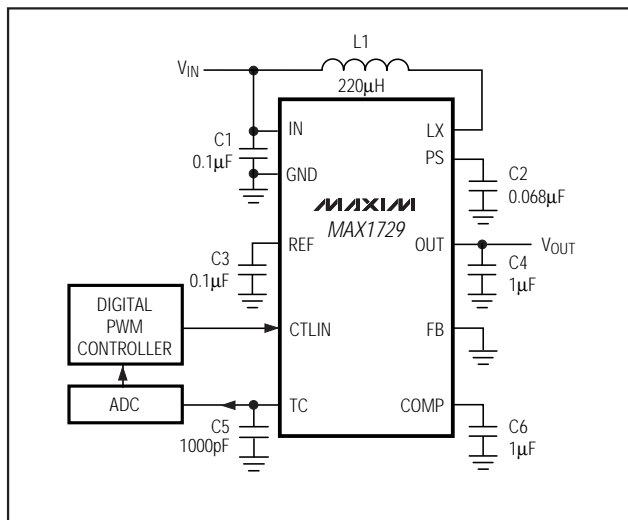


Figure 2. Internal Feedback Mode

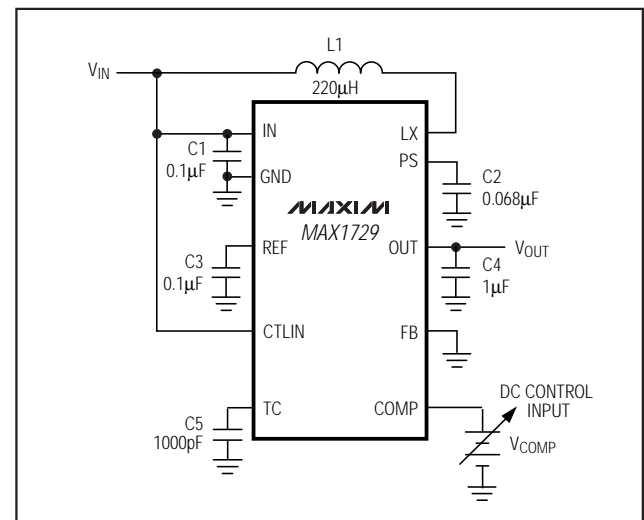


Figure 4. Using a DC Control Signal



# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

2) Given the maximum output voltage ( $V_{MAX}$ ) and minimum output voltage ( $V_{MIN}$ ), calculate values for R3 and R4 as follows:

$$R3 = 1/2 \left( \frac{R1}{V_{MAX} - V_{MIN}} \right) V_{FB}$$

$$R4 = R3$$

3) For first-order temperature compensation, calculate R5 as shown below. (If temperature compensation is not used, leave R5 open.)

$$R5 = \left( \frac{R1}{Tempco} \right) 16.5mV/^{\circ}C$$

where Tempco is the negative temperature coefficient needed to compensate the ECB or LCD display for changes in temperature.

4) Solve for  $V_{COMP}$ . The duty cycle used here corresponds to the duty cycle that yields the maximum output voltage, not including first-order temperature compensation.

$$V_{COMP} = V_{FB} \left[ 1 - \left( \text{Duty Cycle} \cdot \frac{R4}{R3 + R4} \right) \right]$$

where a 90% duty cycle corresponds to Duty Cycle = 0.9.

5) Use the results from the above calculations to solve for R2. (For applications not utilizing temperature compensation, use  $1/R5 = 0$ .)

$$\frac{1}{R2} = \frac{1}{V_{FB}} \left( \frac{V_{OUT}}{R1} + \frac{V_{COMP}}{R3} + \frac{V_{FB}}{R5} \right) - \left( \frac{1}{R1} + \frac{1}{R3} + \frac{1}{R5} \right)$$

## External Component Value Example

The example application requires the output voltage to adjust between 5V and 10V, using the circuit shown in Figure 3. The device in our example needs a temperature coefficient of 33mV/ $^{\circ}C$ , which yields the following results.

1)  $V_{MAX} = 10V$  and  $I_{FB} = 29.24\mu A$  is within the limits and yields a reasonable resistor value, therefore:

$$R1 = \frac{10V - 1.228V}{29.24\mu A} = 300k\Omega$$

2)  $V_{MAX} = 10V$  and  $V_{MIN} = 5V$ , therefore:

$$R3 = 1/2 \left( \frac{300k\Omega}{5V} \right) 1.228 = 36,840\Omega$$

with  $R3 = 36.7k\Omega$ , then  $V_{MIN} = 5.019V$ . Let  $R4 = R3 = 36.7k\Omega$ .

3) Tempco = 33mV/ $^{\circ}C$ , therefore:

$$R5 = \left( \frac{300k\Omega}{33mV/^{\circ}C} \right) 16.5mV/^{\circ}C = 150k\Omega$$

4) If external circuitry limits the duty cycle to 90%, the following equation is true:

$$V_{COMP} = 1.228 \left( 1 - \frac{0.9}{2} \right) = 0.6754V$$

5) Solving for R2:

$$\frac{1}{R2} = \left( \frac{V_{OUT}}{R1} + \frac{V_{COMP}}{R3} + \frac{V_{FB}}{R5} \right) \frac{1}{V_{FB}} - \left( \frac{1}{R1} + \frac{1}{R3} + \frac{1}{R5} \right) = \frac{1}{56560}$$

With  $R2 = 56k\Omega$ , a duty cycle of 87.4% generates a  $V_{OUT}$  of 10V.

## Component Selection

### Inductors

Use a 220 $\mu H$  inductor to maximize output current (2.5mA typical). Use an inductor with DC resistance less than 10 $\Omega$  and a saturation current exceeding 35mA. For lower peak inductor current, use a 470 $\mu H$  inductor with DC resistance less than 20 $\Omega$  and a saturation current over 18mA. This limits output current to typically less than 1mA. See Table 1 for a list of recommended inductors. The inductor should be connected from the battery to the LX pin, as close to the IC as possible.

### Capacitors

The equivalent series resistance (ESR) of output capacitor C2 directly affects output ripple. To minimize output ripple, use a low-ESR capacitor. A physically smaller capacitor, such as a common ceramic capacitor, minimizes board space and cost while creating an output ripple that's acceptable in most applications. Refer to Table 2 for recommended capacitor values.

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

**Table 1. Recommended Inductors**

SUPPLIER	PART	INDUCTANCE (μH)	DC RESISTANCE (Ω)	SATURATION CURRENT (mA)	MAX HEIGHT (mm)
Murata	LQH3C221K04M00	220	8.4	70	2.2
Panasonic	ELT3KN115B	470	19	40	1.6

**Table 2. Recommended Capacitor Values**

CAPACITOR	CAPACITANCE (μF)
C1	0.1
C2	0.068
C3	0.1
C4	1
C5	1000pF
C6*	1

\*Use a low-leakage capacitor.

## Applications Information

### PC Board Layout Considerations

Proper PC board layout minimizes output ripple and increases efficiency. For best results, use a ground plane, minimize the space between C1, C2, and GND of the MAX1729, and place the inductor as close to LX and IN as possible. For an example of proper PC board layout, refer to the MAX1729 Evaluation Kit.

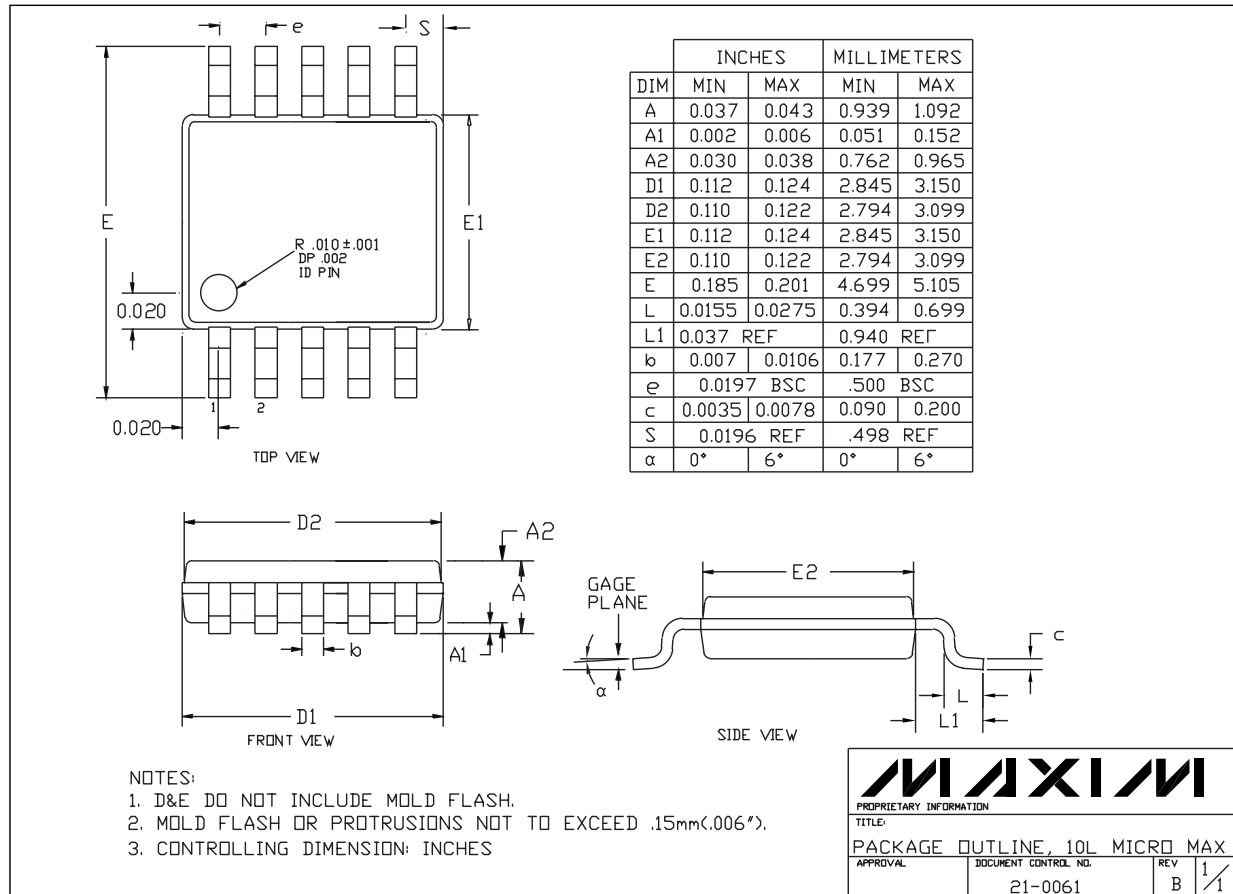
## Chip Information

TRANSISTOR COUNT: 1154

# ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation

## Package Information

MAX1729



# *ECB and LCD Display Bias Supply with Accurate Output Voltage and Temperature Compensation*

## NOTES