19-1406; Rev 1; 1/99

EVALUATION KIT FOLLOWS DATA SHEET

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 (67µA typical). A logic-controlled shutdown mode further reduces quiescent current to 0.4µA typical.

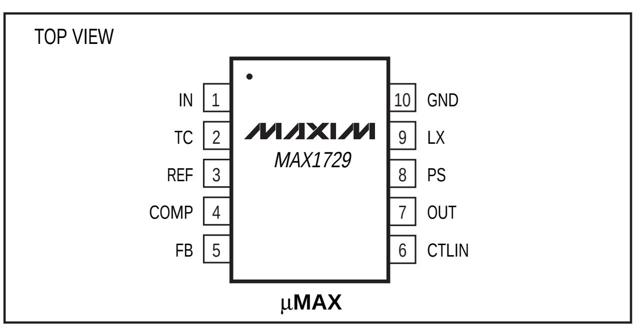
The MAX1729 features an input that dynamically adjusts the output voltage to control display color or contrast. It offers two feedback modes: internal and external. Internal feedback mode allows output voltages between 2.5V and 16V, and is specifically designed to hold temperature drift to ±11ppm/°C. 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 µMAX package.

Applications

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

Pin Configuration



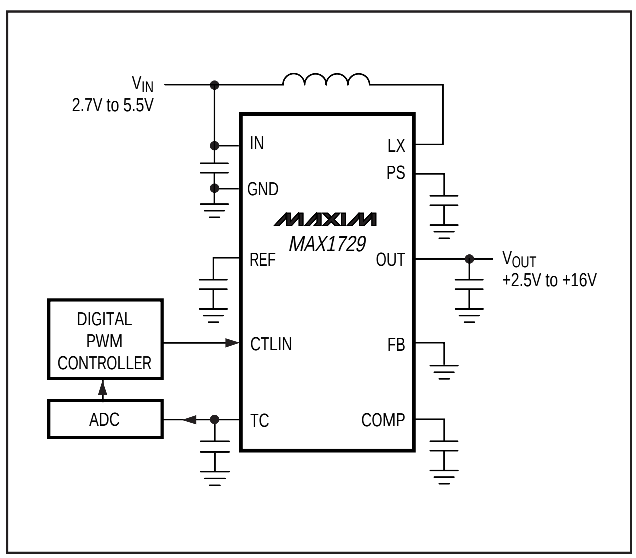
Features

- ♦ High-Accuracy Reference Voltage (±1%)
- ♦ ±11ppm/°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
- ♦ 67µA Supply Current
- ♦ 0.4µA Shutdown Current
- ♦ 10-Pin µMAX Package (1.09mm max height)
- ♦ Evaluation Kit Available (MAX1729EVKIT)

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX1729EUB	-40°C to +85°C	10 µMAX

Typical Operating Circuit



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°C)
10-pin µMAX (derate 5.6mW/°C above +70°C) 444mW

Operating Temperature Range ....-40°C to +85°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°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°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1)

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

ELECTRICAL CHARACTERISTICS

(V_{IN} = +3V, CTLIN = IN, FB = GND, T_A = -40°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°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				±1	µA
COMP Impedance	R_{COMP}	V_{FB} = 0, Internal Feedback Mode			33		kΩ
		V_{FB} = +1.25V, External Feedback Mode			60	150	Ω
CTLIN Minimum Pulse Width for Shutdown	t_{OFF}	(Note 4)		700	1250	2400	µs
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	Ω
			V_{IN} = +5.5V		1.5		
Switch Off-Leakage Current	$I_{LX(OFF)}$	V_{LX} = 18V			0.1	1	µA
LX to PS Diode Forward Voltage	V_{LX-PS}	I_{DIODE} = 30mA			700	970	mV
PFM On-Time Constant	K	T_A = +25°C		6	8	10	V-µs
		T_A = -40°C to +85°C		5		11	
PS to OUT Voltage (Note 5)				0.4	0.6	1.0	V

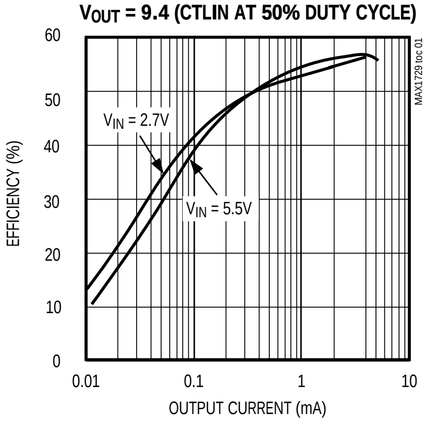
Note 1: Specifications to -40°C are guaranteed by design, not production tested.
Note 2: When V_{IN} is below this level, the boost and LDO outputs are disabled.
Note 3: Guaranteed by design.
Note 4: Minimum time to hold CTLIN low to invoke shutdown. If CTLIN is held low for less than t_{OFF}, device 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

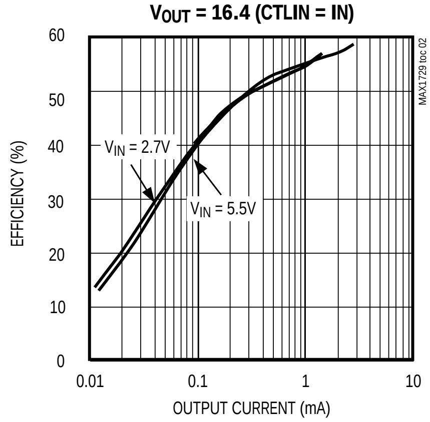
Typical Operating Characteristics

(Circuit of Figure 2, T_A = +25°C, unless otherwise noted.)

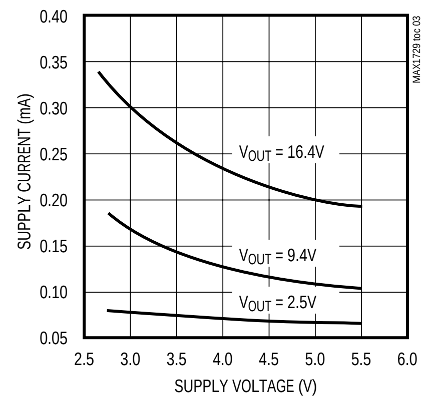
EFFICIENCY vs. OUTPUT CURRENT
V_{OUT} = 9.4 (CTLIN AT 50% DUTY CYCLE)



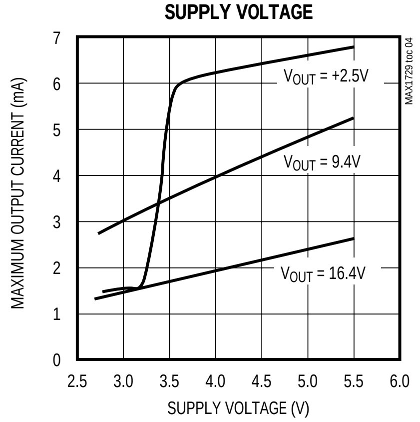
EFFICIENCY vs. OUTPUT CURRENT
V_{OUT} = 16.4 (CTLIN = IN)



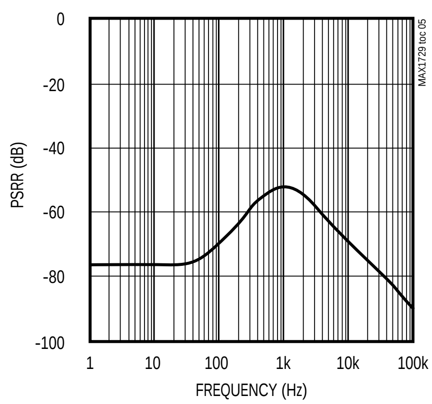
NO-LOAD SUPPLY CURRENT vs. SUPPLY VOLTAGE



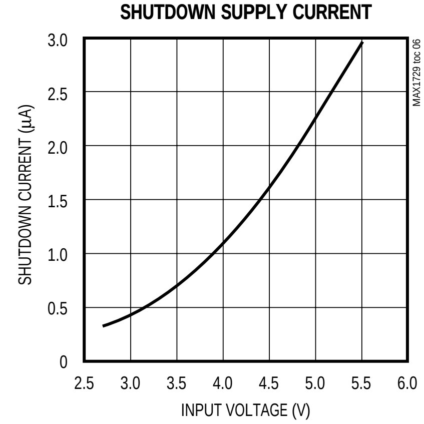
MAXIMUM OUTPUT CURRENT vs. SUPPLY VOLTAGE



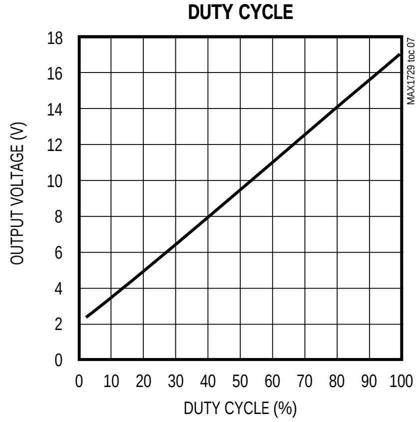
PS TO OUT (LDO) POWER-SUPPLY REJECTION RATIO



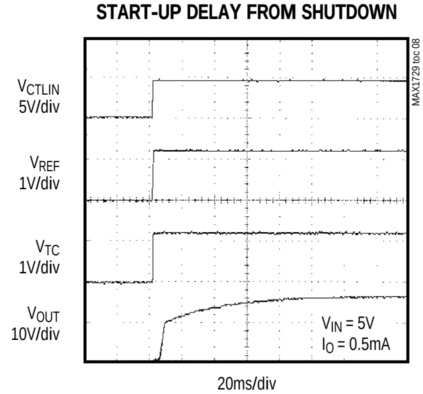
SHUTDOWN SUPPLY CURRENT



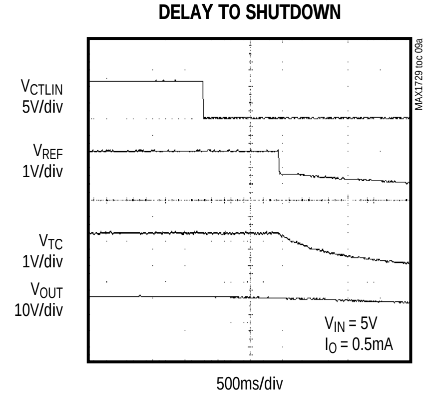
OUTPUT VOLTAGE vs. DUTY CYCLE



START-UP DELAY FROM SHUTDOWN

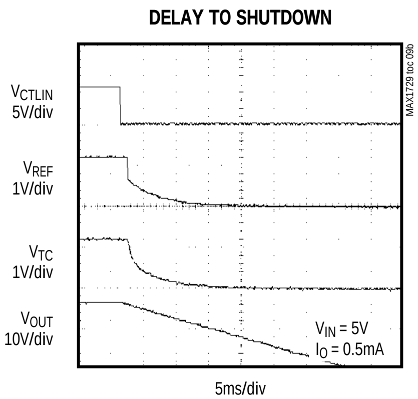


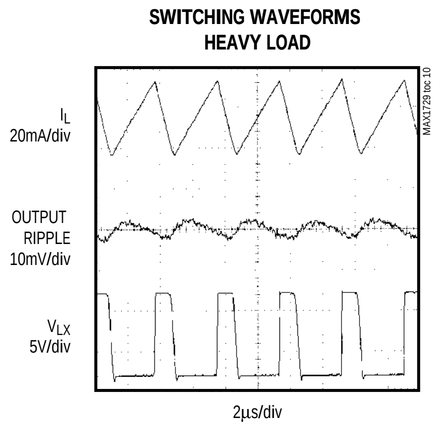
DELAY TO SHUTDOWN

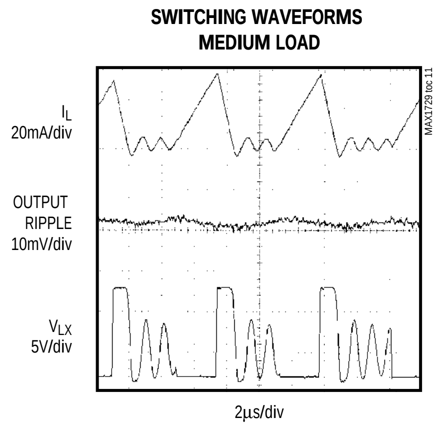


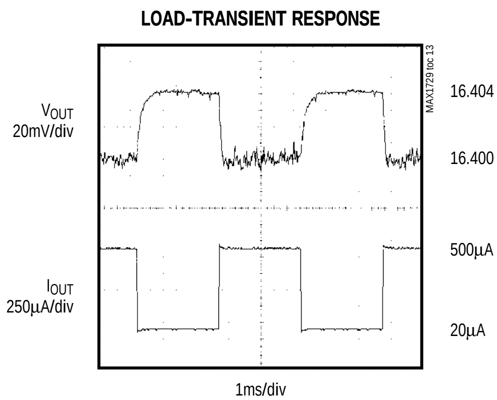
Typical Operating Characteristics (continued)

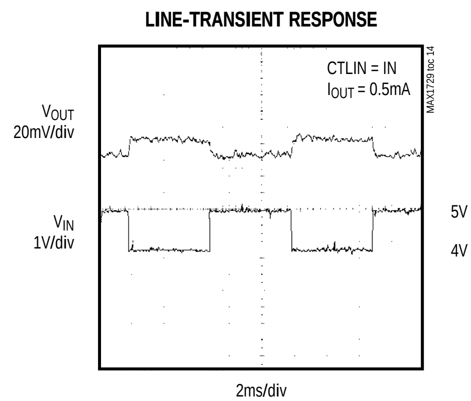
(Circuit of Figure 2, T_A = +25°C, unless otherwise noted.)











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

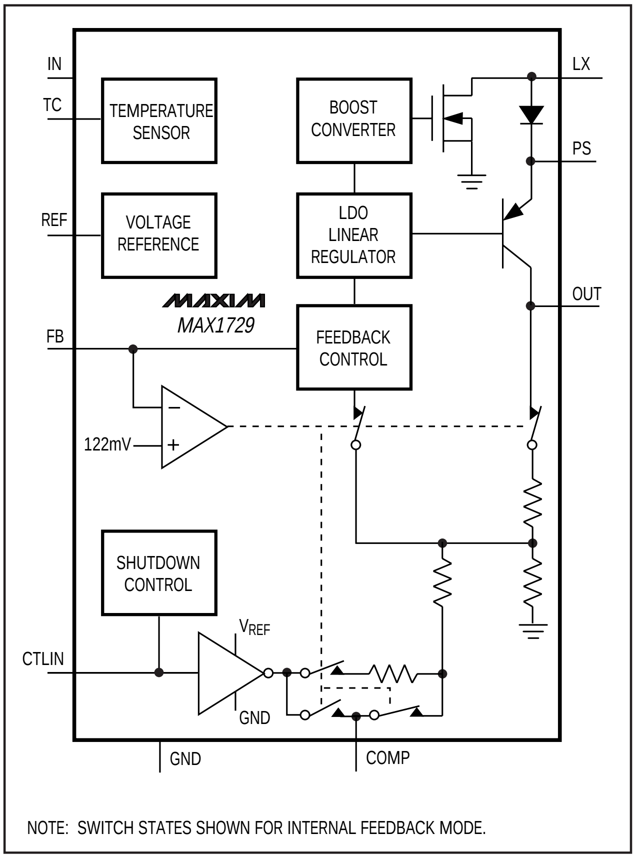


Figure 1. Internal Block Diagram

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 33kΩ. A source output impedance of less than 500Ω 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 (10µA to 30µA is recommended for maximum feedback current) as follows:

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

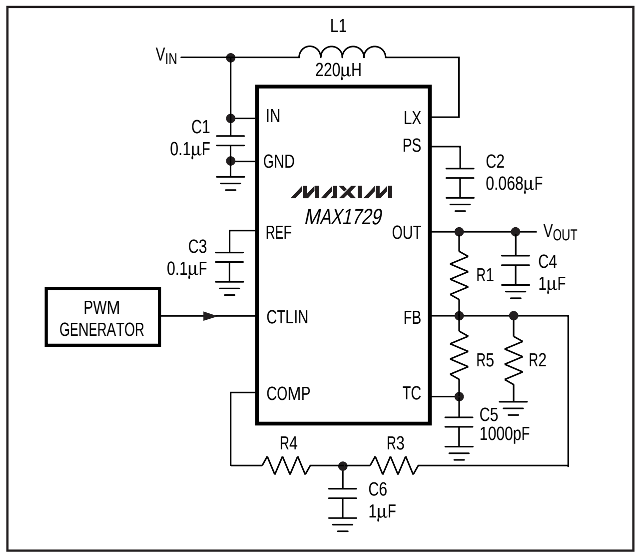


Figure 3. External Feedback Mode

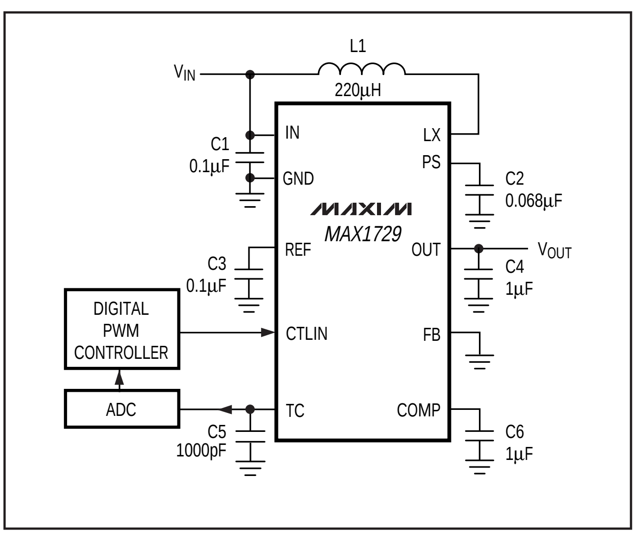


Figure 2. Internal Feedback Mode

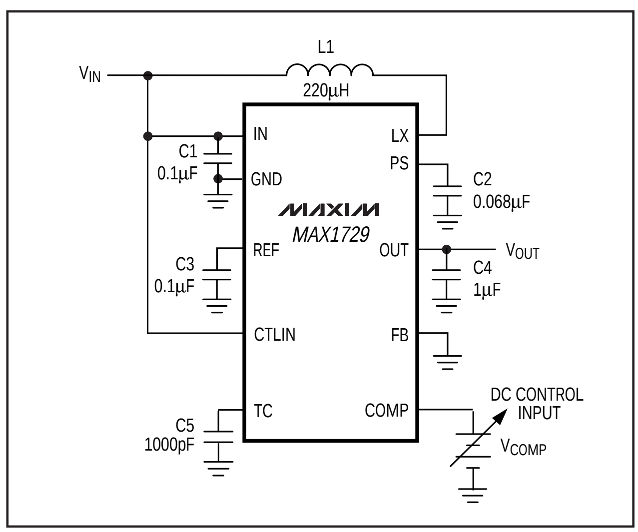


Figure 4. Using a DC Control Signal

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.)

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

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/°C, which yields the following results.

1) V_{MAX} = 10V and I_{FB} = 29.24µA 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 = 36.7kΩ, then V_{MIN} = 5.019V. Let R4 = R3 = 36.7kΩ.

3) Tempco = 33mV/°C, therefore:

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

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 = 56kΩ, a duty cycle of 87.4% generates a V_{OUT} of 10V.

Component Selection

Inductors

Use a 220µH inductor to maximize output current (2.5mA typical). Use an inductor with DC resistance less than 10Ω and a saturation current exceeding 35mA. For lower peak inductor current, use a 470µH inductor with DC resistance less than 20Ω 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

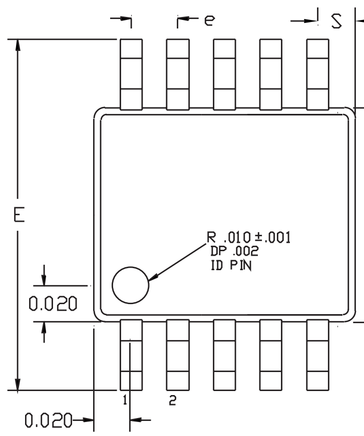
Proper PC board layout minimizes output ripple and increases efficiency. For best results, use a ground plane, minimize the space between C1, C2, and GND of the MAX1729, and place the inductor as close to LX and IN as possible. For an example of proper PC board layout, refer to the MAX1729 Evaluation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

Chip Information

TRANSISTOR COUNT: 1154

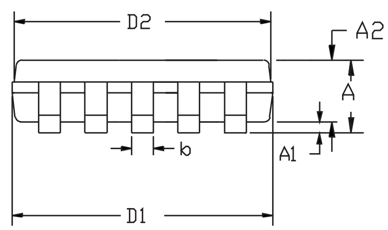
Package Information

10LUMAXB.EPS

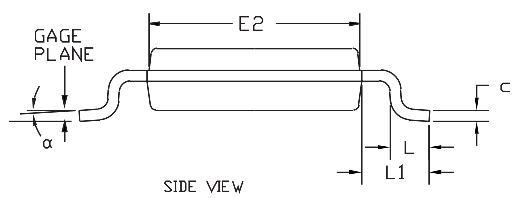


TOP VIEW

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.037	0.043	0.939	1.092
A1	0.002	0.006	0.051	0.152
A2	0.030	0.038	0.762	0.965
D1	0.112	0.124	2.845	3.150
D2	0.110	0.122	2.794	3.099
E1	0.112	0.124	2.845	3.150
E2	0.110	0.122	2.794	3.099
E	0.185	0.201	4.699	5.105
L	0.0155	0.0275	0.394	0.699
L1	0.037 REF		0.940 REF	
b	0.007	0.0106	0.177	0.270
e	0.0197 BSC		.500 BSC	
c	0.0035	0.0078	0.090	0.200
S	0.0196 REF		.498 REF	
α	0°	6°	0°	6°



FRONT VIEW



SIDE VIEW

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm(.006").
3. CONTROLLING DIMENSION: INCHES

MAXIM
PROPRIETARY INFORMATION
TITLE:
PACKAGE OUTLINE, 10L MICRO MAX

APPROVAL	DOCUMENT CONTROL NO.	REV	
	21-0061	B	1/1

NOTES