This application note presents solutions for generating the voltages required by Liquid Crystal Displays. Temperature compensation of the display voltages and other functions are also discussed.

Introduction

LCDs prevail as the display of choice in most electronic devices such as notebook computers, pagers, phones and hand-held games. LCDs are passive devices: instead of generating light, they reflect ambient light. They consume very little power, are compact, and are well suited for battery-powered applications. Other advantages of the LCD are a relatively low driving voltage (5V to 60V), full-color display capability, fast writing speed, and good availability from different vendors.

The power requirements for LCDs vary widely and are dependent on size, type, and manufacturer. The power consumption of an LCD is proportional to the update frequency, capacitive load, supply voltage, and LCD driver voltage swing.

$$P_{display} \propto f_{update} \cdot C_{load} \cdot V_{LC(supply)} \cdot V_{swing}$$

The capacitive load (C_{load}) is proportional to the number of rows and columns in the display.

Three voltages are required by a LCD display:

- V_{DD}
- V_{LC}
- Backlight supply (optional)

The V_{DD} supply is required for the display's driver and controller circuits. This voltage is usually either +3.3V or +5V. The liquid crystal drive voltage (V_{LC}) controls the orientation of the crystals in the display. V_{LC} is either positive or negative and varies between 5V and 60V, depending on the display. The backlight supply voltage is used to power the display's backlight. This voltage is dependent upon the type of lamp or backlighting scheme used.

There are other factors to consider when supplying power to a LCD display. They are:

- Efficiency
- Battery life
- Output disable
- Turn-on time
- Contrast adjustment
- LCD drive-voltage temperature compensation

Power Topologies

Four switching converter topologies may be used to provide bias for the LCD display are outlined in Table 1.

V_{DD} Bias Generation

In many systems, especially those with off-line power sources, a well regulated +5V or +3.3V voltage is available for the V_{DD} supply. LCD displays can usually be chosen to match the V_{DD} voltage of the system components. When the voltage requirements between system components and the LCD cannot be matched, a buck converter (+5V input to +3.3V output) or a boost converter (+3.3V input to +5V output) is used.

The function of a buck converter is to step down the input voltage. The MIC2179 IC shown in Figure 1 is a high-efficiency 200kHz synchronous buck converter with an input voltage range of 4.5V to 16.5V and a 1.5A maximum output current capability.

| Topology	Description	Comments	Recommended Controller
Buck	Steps down input voltage	Simple, self-contained switching regulator ICs	MIC2574 (52kHz) MIC4754 (200kHz) MIC2179 (200kHz)
Boost	Steps up input voltage	Good for positive and negative outputs	MIC3172 (100kHz) MIC2570 (20kHz) MIC2571 (20kHz)
Buck-Boost	Step up or step down, depending on duty cycle	Inverting topology. V_{IN} may vary greater or less than V_{OUT}	MIC2574 (52kHz) MIC4754 (200kHz)
SEPIC	Step up or step down, depending on duty cycle	Noninverting topology. V_{IN} may vary greater or less than V_{OUT}	MIC3172 (100kHz) MIC2570 (20kHz) MIC2571 (20kHz)

Table 1 . Switching Converter Topology Summary
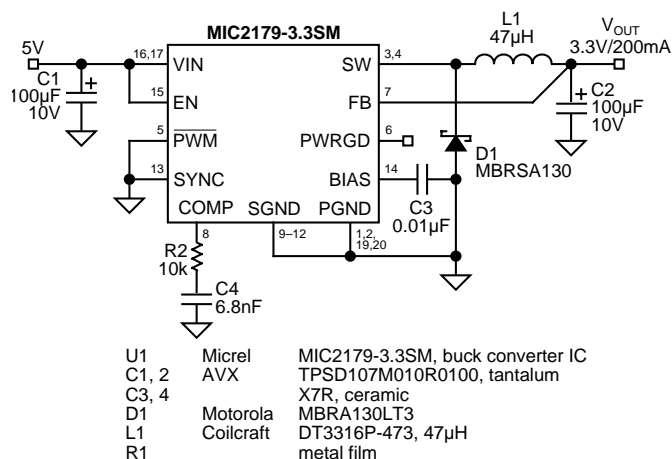
Figure 1. Buck Converter (MIC2179)

operation down to an input voltage of 3.0V. The switching regulator uses a PWM control scheme with a 100kHz switching frequency.

Battery-powered applications require active voltage regulation to power LCDs because of the wide voltage difference between a fully charged and a discharged battery. If the V_{DD} output voltage is always greater than the input voltage, a boost regulator is used. If the V_{DD} output voltage is always less than the input voltage, then a buck regulator is used.

Consideration of the topology selected is important if the output voltage is between the minimum and maximum input voltage. A buck converter cannot be used because the input voltage must always be greater than the output voltage. A boost converter may be used with a linear post regulator as shown in Figure 3. This is effective when the input voltage rises above the desired output but suffers from the low conversion efficiency of the linear regulator.

A boost converter steps up the input voltage. The MIC3172 shown in Figure 2 is a boost converter controller with a maximum output voltage of 60V. It features guaranteed

SEPIC (single-ended primary inductance converter) is a topology which may be used when the output voltage falls between the minimum and maximum input voltage (Fig-
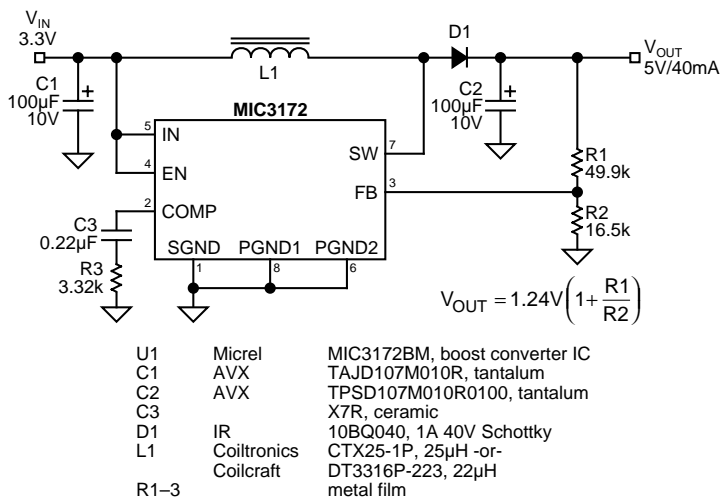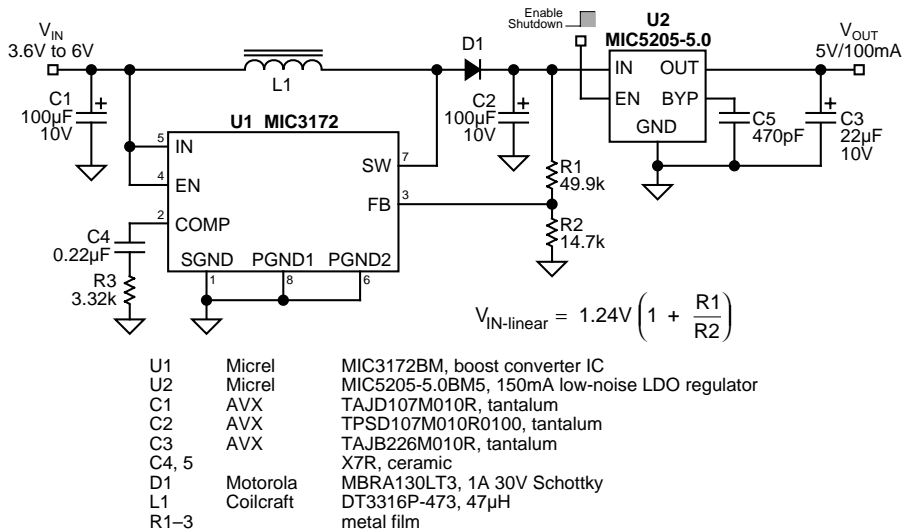

$$V_{OUT} = 1.24V \left(1 + \frac{R1}{R2}\right)$$

Figure 2. Boost Converter (MIC3172)

$$V_{IN\text{-linear}} = 1.24V \left(1 + \frac{R1}{R2}\right)$$

Figure 3. Linear Post-Regulated Boost Converter (MIC3172, MIC5205)

$$V_{OUT} = 1.24V\left(1+\frac{R1}{R2}\right)$$

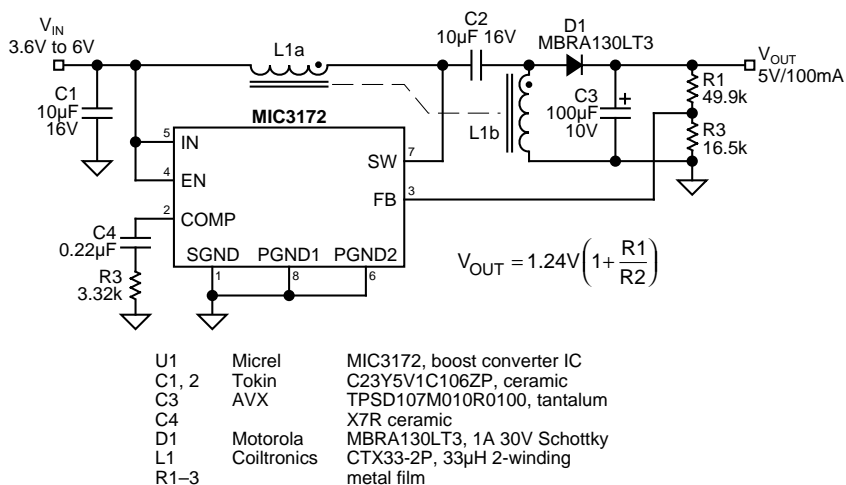| U1	Micrel	MIC3172, boost converter IC
C1, 2	Tokin	C23Y5V1C106ZP, ceramic
C3	AVX	TPSD107M010R0100, tantalum
C4		X7R ceramic
D1	Motorola	MBRA130LT3, 1A 30V Schottky
L1	Coiltronics	CTX33-2P, 33µH 2-winding
R1–3		metal film

Figure 4. SEPIC Converter (MIC3172)

ure 4). A SEPIC can increase or decrease the input voltage. It has the advantage of isolating the input and output with a capacitor, which allows the output voltage to fully discharge when the converter is turned off. The two inductors, L1a and L1b, may be coupled together in a two winding inductor. This reduces the amount of board space used by the inductor. The SEPIC converter shown in Figure 4 regulates a 5V output over a 4-cell input voltage range.

V_{LC} Bias Generation

LCDs operate by applying a bias voltage (V_{LC}) across the liquid crystal. This changes the crystal's orientation and therefore the contrast of the display. Some displays require a positive voltage, but many displays—including the extended temperature models—require a negative bias voltage.

There are three factors to consider when deciding on a biasing topology for an LCD:

- Voltage polarity and magnitude
- Contrast adjustment
- Temperature compensation

The voltage polarity and magnitude depend on the display chosen. A positive V_{LC} bias is developed using the same circuits that generated the V_{DD} bias. A negative V_{LC} bias is created using either a buck-boost converter or a negative output boost converter. Examples of these topologies are shown in the next section.

Varying the voltage across the LCD provides contrast adjustment. This is done with a potentiometer connected to the display or varying the V_{LC} voltage generated by the power supply. These circuits are presented in Figures 14 through 17.

The ambient temperature around the screen affects the display screen contrast and viewing angle. A temperature compensation circuit is used to provide a negative temperature coefficient to the V_{LC} voltage to keep the contrast constant. As with adjusting the contrast, temperature compensation may be performed by an external circuit connected

to the display or adjusting the V_{LC} voltage output of the power supply. Circuits to perform these functions are discussed later in this application note.

V_{LC} Bias Topologies

Micrel Semiconductor switching converters, used for LCD bias applications, have an input voltage range of 0.9V to 40V. The topologies shown below are divided four categories.

- Low voltage input (V_{IN} < 3.0V)
- Higher voltage input (V_{IN} > 3.0V)
- An input voltage range which is both greater or less than the output voltage
- High voltage output (> switch voltage rating)

Generating $-V_{LC}$ Bias From V_{IN} < 3V

Use the MIC2570 or MIC2571 boost converter to develop a negative V_{LC} voltage from a 1- to 3-cell battery. Figure 5 shows the MIC2570 connected as a 2-cell to –24V switching regulator. The maximum output voltage for a boost converter using the MIC2570 or MIC2571 is 32V.
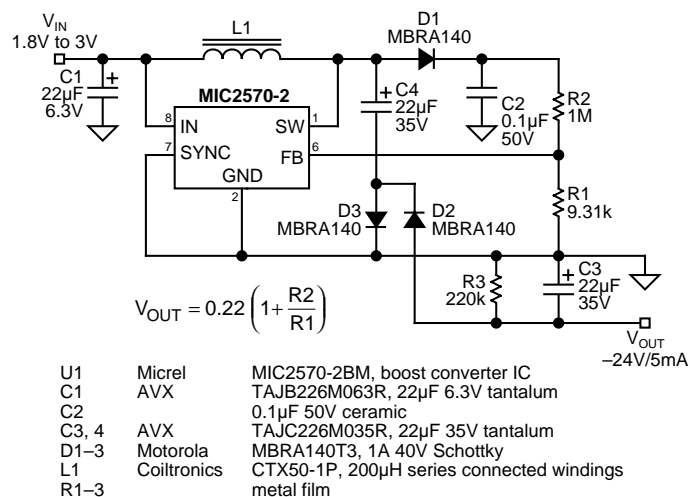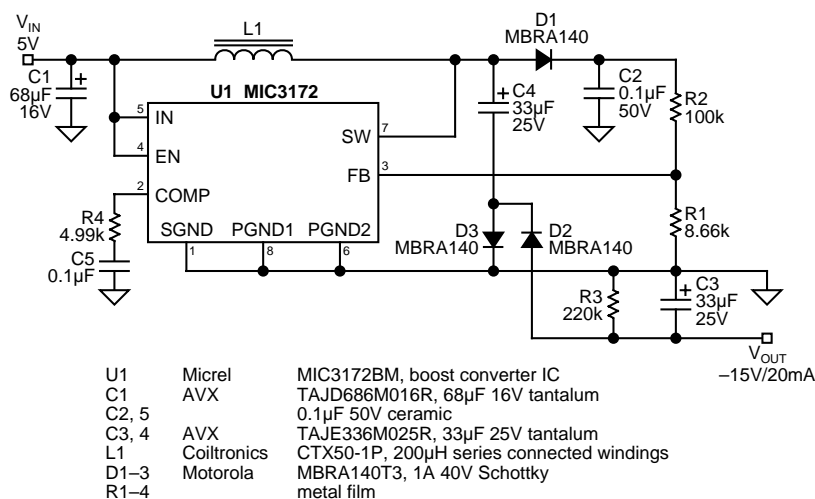

$$V_{OUT} = 0.22\left(1+\frac{R2}{R1}\right)$$

U1	Micrel	MIC2570-2BM, boost converter IC
C1	AVX	TAJB226M063R, 22µF 6.3V tantalum
C2		0.1µF 50V ceramic
C3, 4	AVX	TAJC226M035R, 22µF 35V tantalum
D1–3	Motorola	MBRA140T3, 1A 40V Schottky
L1	Coiltronics	CTX50-1P, 200µH series connected windings
R1–3		metal film

Figure 5. Negative-Output Boost (MIC2570)

Figure 6. Negative Output Boost (MIC3172)

U1   Micrel   MIC3172BM, boost converter IC
C1   AVX   TAJD686M016R, 68µF 16V tantalum
C2, 5   0.1µF 50V ceramic
C3, 4   AVX   TAJE336M025R, 33µF 25V tantalum
L1   Coiltronics CTX50-1P, 200µH series connected windings
D1–3   Motorola   MBRA140T3, 1A 40V Schottky
R1–4   metal film

Generating −V_{LC} Bias From V_{IN} > 3V

Inputs from 3- or 4-cells (3V to 6V), or inputs of greater voltage, should use the MIC3172 as the boost regulator IC with the negative-output boost converter topology. The 100kHz switching frequency of the MIC3172 allows the use of smaller inductors at higher input voltages. The MIC3172 has an enable input which will turn off the regulator IC. It draws only 5µA of current when it is disabled. Another advantage of the MIC3172 is the 65V switching transistor rating. This allows higher output voltages to be generated without voltage doublers or tapped inductors. C4 in Figure 6 provides dc decoupling between the input and output, which prevents the output from drawing current when the MIC3172 is not switching.

The circuit in Figure 6 uses a boost converter to generate a negative output voltage from a positive input voltage. The MIC3172 switching regulator is used to convert a +5V input to a −15V output. The enable function may be used to turn off the output and the IC. While disabled, the current drawn is 5µA into the MIC3172 and 45µA through R2 and R1.

Generating −V_{EE} Bias From V_{IN} < V_{OUT} or V_{IN} > V_{OUT}

The topology shown in Figure 7 is a buck-boost converter. It will generate a negative output voltage from a positive input voltage. The magnitude of the output voltage can be greater or less than the input voltage. The MIC2574 switching regulator will convert a +10V to +14V input to a −12V output when used in the buck-boost configuration. The algebraic sum of V_{IN} + |V_{OUT}| must be less than 40V, the maximum rated voltage across the MIC2574 internal switching transistor.

Generating High V_{LC} Bias Voltages

The tapped-inductor boost converter circuit shown in Figure 8 is used when the output voltage is greater than the rated switching voltage of the boost controller IC. The voltage on the switching node is equal to the output voltage divided by the turns ratio.

$$V_{SW} = V_{IN} + \left[\left(V_{OUT} + V_D - V_{IN} \right) \frac{N2}{N1+N2} \right]$$

A center-tapped inductor will cut the output voltage stress on the boost switch in half. It is important to closely couple the
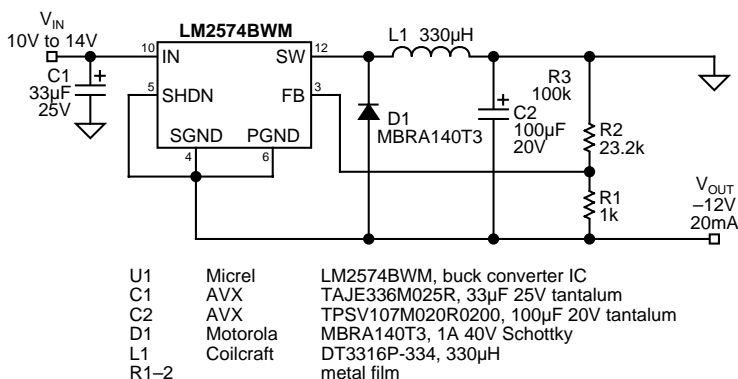
Figure 7. Negative-Output Buck-Boost (MIC2574)

U1   Micrel   LM2574BWM, buck converter IC
C1   AVX   TAJE336M025R, 33µF 25V tantalum
C2   AVX   TPSV107M020R0200, 100µF 20V tantalum
D1   Motorola   MBRA140T3, 1A 40V Schottky
L1   Coilcraft   DT3316P-334, 330µH
R1–2   metal film

two windings of the inductor to reduce the voltage spikes on the switching pin of the IC. The negative output boost topology (shown in Figure 7), may be similarly configured to generate a higher negative voltage.

Note that the output capacitors are connected in series to meet the output voltage requirement since there are no commonly available tantalum capacitors with a voltage rating sufficient for a 60V output.
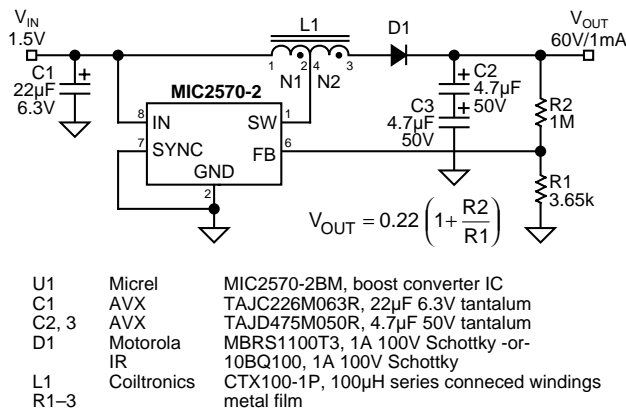

$$V_{OUT} = 0.22 \left(1 + \frac{R2}{R1}\right)$$

U1	Micrel	MIC2570-2BM, boost converter IC
C1	AVX	TAJC226M063R, 22µF 6.3V tantalum
C2, 3	AVX	TAJD475M050R, 4.7µF 50V tantalum
D1	Motorola	MBRS1100T3, 1A 100V Schottky -or-
	IR	10BQ100, 1A 100V Schottky
L1	Coiltronics	CTX100-1P, 100µH series conneced windings
R1–3		metal film

Figure 8. Positive-Output HV Boost (MIC2570)

Backlighting

The three commonly used backlighting technologies are electroluminescent (EL), light emitting diode (LED) and cold cathode fluorescent lamp (CCFL).

Electroluminescent lamps provide even lighting. They have the advantage of being thin, lightweight, rugged, and have low power consumption. These lamps must be driven from an ac voltage. The optimum voltage and frequency depend on the lamp design and are in the range of 200Hz to 1000Hz at 50Vac to 250Vac. The inverters that supply the ac voltage to these lamps require an input voltage of 5Vdc to 24Vdc.

LEDs have the advantage of operating directly from a 5V source and have the longest operating life of all the backlighting technologies. No separate power supply is required. Their disadvantage is higher power consumption: therefore more heat is generated. A current-limited power source is required.

Cold cathode fluorescent lamps (CCFLs) are more popular in the larger LCDs. They provide a very bright white light. The power source is an inverter which supplies the 200Vac to 1000Vac at a frequency of 50kHz to 250kHz. The voltage and frequency is very specific to the type of bulb. Inverters for CCFL tubes require an input of 5Vdc to 24Vdc.

LCD Power Circuit Considerations

Output Power

The maximum output power for a given circuit depends on the inductor value, the input voltage, the maximum peak switch current and the mode of operation (continuous or discontinuous).

Efficiency Calculations

With battery powered applications, efficiency is paramount. Efficiency is measured as the ratio of output power to input power.

$$\text{Efficiency} = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{LOSS} + P_{OUT}}$$

An efficiency number of 1 means there is no power lost in the switching converter. Although this is not realizable, the closer to unity efficiency, the longer the battery life, and the less heat dissipated in the unit.

Each of the components in a switching power supply contribute to power loss (P_{LOSS}) and reduced efficiency. Power is dissipated in the output diode, inductor, and switching regulator IC. The power dissipated in the regulator IC is the sum of the power lost in the internal switching transistor and power lost by the IC's input bias supply.

Battery Life

Two modes of operation that must be considered when calculating battery life: operating and standby. When the power supply is operating, power drawn from the battery is equal to the output power divided by the efficiency. While the power supply is in standby mode (disabled), the power drawn from the battery is equal to the battery voltage times I_Q (standby quiescent current). The standby quiescent current is specified in the switching regulator data sheet.

Output Disable

Turning off the outputs is simpler in some regulator topologies than in others. The positive output boost regulator has a dc path from input to output. When the regulator IC is turned off, input voltage is still present at the output. The buck and buck-boost regulators have the switching transistor between the input and output, which prevents the input voltage from appearing at the output. The negative output boost and the SEPIC converter topologies have a blocking capacitor between the input and output. As with the buck converter, this prevents the input voltage from appearing at the output.

The buck and buck-boost converters using the MIC2179 regulator ICs may be shut down with a logic-low signal applied to the enable input. The LM2574 and MIC4574 ICs can be turned off with a logic-high signal applied to the on/off input. Once the IC is turned off, the circuit will cease to operate and the output voltage will discharge to zero volts. The only current drawn from the input source is the IC's standby quiescent current. This is a maximum of 5µA for the MIC2179 and 200µA for the MIC2574 or MIC4574.

With the exception of the positive boost topology, circuits using the MIC3172 are turned off with a low signal on the enable input of the IC. The IC will draw a maximum of 5µA quiescent current in shutdown mode.

The MIC2570 and MIC2571 switching regulator ICs do not have a shutdown pin. Therefore, positive boost converter circuits using the MIC3172, and any circuit using the MIC2570 or MIC2571, must use external methods of turning off the output. The methods used to turn off the outputs are: increasing the voltage on the feedback pin and blocking the input voltage with a MOSFET.

A high level may be applied to the feedback pin through a switch and resistor (Figure 9). The voltage on the feedback pin will increase over the 0.22V reference level and the IC will stop switching. The output will be a diode drop less than the input. The circuit will draw the 120μA quiescent current of the MIC2570 or MIC2571 plus any current drawn by the output. Resistor R3 is used to prevent excessive current draw from the input through R1. This method of shutting down the converter is good when the input voltage is low and a small voltage on the output is acceptable.
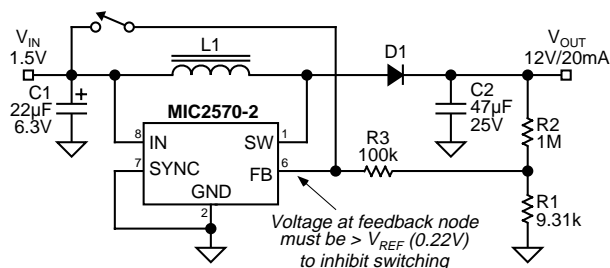
Figure 9. Disabling the MIC2570 ($V_{OUT} \approx V_{IN}$)

If 120μA quiescent current is not acceptable during shutdown, a P-channel MOSFET may be placed in series with the supply input of the MIC2570 or MIC2571, as shown in Figure 10. Pulling the gate of the MOSFET high will remove the input voltage to the IC and eliminate any voltage from appearing on the output (through D1). The disadvantage of this configuration is added cost and reduced operating efficiency due to the MOSFET. Make sure the threshold voltage of the MOSFET is appropriate for the input voltage. A MOSFET with a 4V threshold voltage will not turn on with an input voltage of 1.5V!
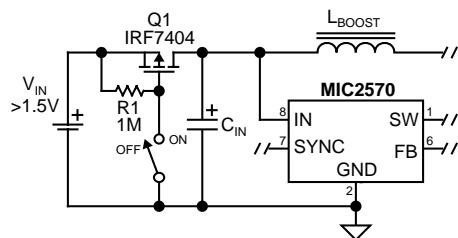

Figure 10. Disabling the MIC2570 ($V_{OUT(off)} = 0V$)

If the losses of the P-channel MOSFET are unacceptable, the switch can be placed in series with the input pin. Figure 11 shows the circuit connections. This configuration will eliminate the 120μA of current drawn into the switch with the advantage of not passing all the input current through the

MOSFET. The result is a more efficient converter. The disadvantage of this configuration is the input voltage (minus the boost-diode drop) appears at the output. For low input voltages and higher output voltages this may not be a problem. The 0.1μF bypass capacitor may be necessary to reduce the voltage ripple on the input of the control chip due to the on-resistance of the MOSFET.
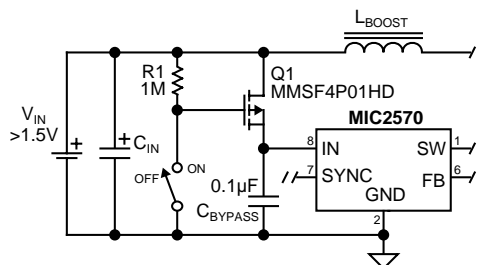

Figure 11. Disabling the MIC2570

Turn-On Time

Some controllers automatically initialize the LCD if the bias voltage rises within a certain period of time. The output ramp-up time of the regulator is determined by the peak current limit of the control chip, the inductor value, output capacitance, and the amount of current drawn by the load. A smaller inductor value, capacitor value, and output current will allow the output voltage to rise faster. A higher IC current limit will also allow quicker output turn-on. This time is generally in the millisecond range. If the output must turn on faster, a MOSFET switch may be placed between the output capacitor and the load. Turn-on times are limited only by the gate drive to the MOSFET. A preload resistor on the output of the converter, before the MOSFET switch, may be necessary to reduce turn-on overshoot. Refer to Figure 12 and 13 for examples with positive and negative output converters.
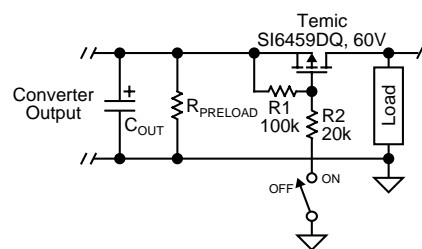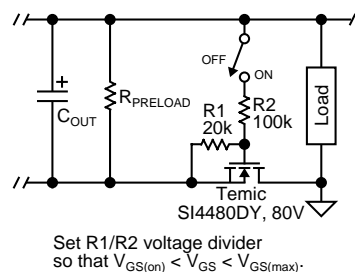

Figure 12. Speeding Turn-On Time (Positive Output)

Set R1/R2 voltage divider so that $V_{GS(on)} < V_{GS} < V_{GS(max)}$.

Figure 13. Speeding Turn-On Time (Negative Output)

Contrast Adjustment

The liquid crystal operating voltage (V_{LC}) affects the LCD contrast and viewing angle. Several methods are used to adjust V_{LC}. Figure 14 shows a method that may be used with low-power, low-cost displays.
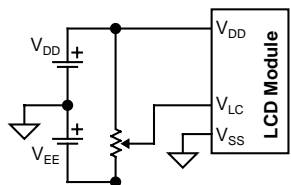
Figure 14. Simple Contrast Adjustment

For higher V_{LC} currents, a buffer is placed between the supply voltages and the LCD module. This circuit is shown in Figure 15. Make sure the buffer can supply the necessary current for the LCD module.

$$V_{contrast(min)} = V_{LC} - 2.5V$$

$$V_{contrast(max)} = \frac{(V_{DD} \cdot R3) - (V_{LC} \cdot R1)}{R1 + R3}$$
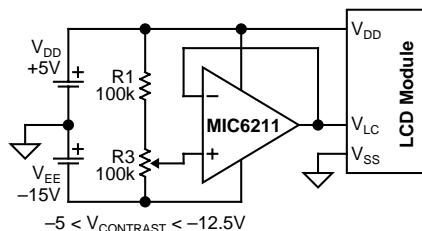
$$-5 < V_{CONTRAST} < -12.5V$$

Figure 15. Buffered Contrast Control (MIC6211)

An op amp buffer can be used with LCD modules with separate V_{LC} and contrast inputs as shown in Figure 16.

$$V_{contrast(max)} = \frac{V_{DD}(R2 + R3) - (V_{LC} \cdot R1)}{R1 + R2 + R3}$$

$$V_{contrast(min)} = \frac{V_{DD} \cdot R2 - V_{LC}(R1 + R3)}{R1 + R2 + R3}$$

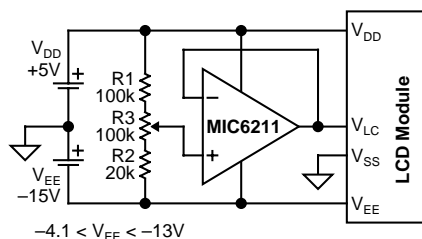$$-4.1 < V_{EE} < -13V$$

**Figure 16. Contrast Control for Separate
$V_{contrast}$ and V_{LC} Inputs**

Instead of using an op amp to control the contrast voltage, the power supply may be varied. Once the voltage adjustment range is known, the value of R1 and R1a can be computed.

$$R1 = \frac{1.24 \cdot R2}{V_{OUT(min)} - 1.24}$$

$$R1a = \frac{1.24 \cdot R2}{\left(V_{OUT(max)} - 1.24\right) - R1}$$

For the example shown in Figure 17, the values of R1 and R1a give an output adjustment range of $V_{OUT(min)} = -11.24V$ and $V_{OUT(max)} = -16.0V$. It is recommended that the adjustment potentiometer R1a be placed as shown in Figure 17. An open circuit is the typical failure mode for potentiometers. If R1a opens, the MIC2574 will stop switching and the output voltage will discharge to zero volts. If the potentiometer is placed in series with R2, and an open-circuit condition occurred, the switching converter would operate at full duty cycle and the output voltage would increase.
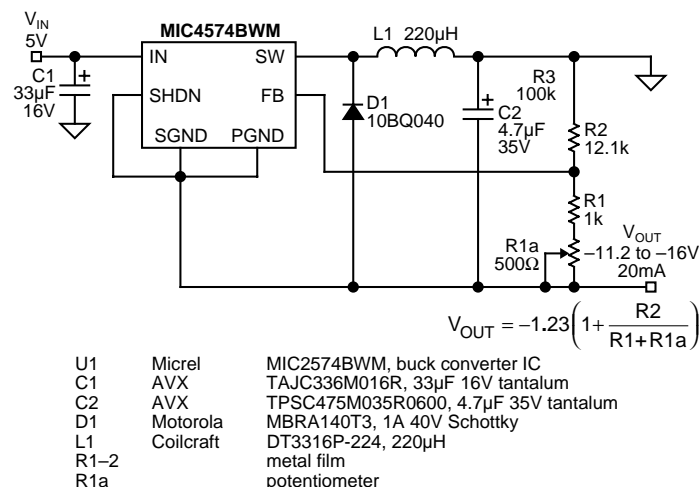
$$V_{OUT} = -1.23\left(1 + \frac{R2}{R1 + R1a}\right)$$

U1	Micrel	MIC2574BWM, buck converter IC
C1	AVX	TAJC336M016R, 33µF 16V tantalum
C2	AVX	TPSC475M035R0600, 4.7µF 35V tantalum
D1	Motorola	MBRA140T3, 1A 40V Schottky
L1	Coilcraft	DT3316P-224, 220µH
R1–2		metal film
R1a		potentiometer

**Figure 17. Contrast Control
Directly From the Power Supply**

Temperature Compensation Circuits

The ambient temperature around the screen affects the display screen contrast and viewing angle. A temperature compensation circuit is used provide a negative temperature coefficient to the V_{LC} voltage to keep the contrast constant. Display manufacturers generally provide either a temperature coefficient for a given display or a list of V_{LC} voltages vs. temperature. From this information, a temperature is calculated for the operating temperature range.

The circuit shown in Figure 18 is a simple solution that uses a negative temperature coefficient (NTC) thermistor to vary the V_{LC} voltage.
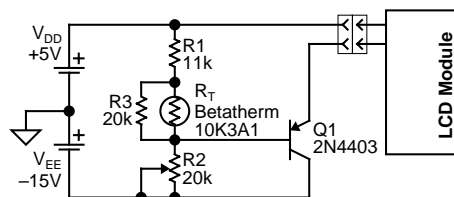
**Figure 18. Temperature Compensation
for Contrast Control**

As the temperature increases, the resistance of the thermistor decreases. This decrease in resistance causes the voltage at the base of Q1 to increase. The emitter voltage of Q1 increases, reducing the voltage across the LCD.

The collector to emitter voltage, V_{CE}, is:

$$V_{CE(Q1)} = \left(V_{CC} - V_{EE}\right)\frac{R2}{R1+R2+R_{T(equiv)}} + V_{BE}$$

The voltage across the LCD module is:

$$V_{OPR} = V_{CC} - V_{CE(Q1)} - V_{EE}$$

where:

$V_{CE(Q1)}$ is the temperature dependent V_{CE} voltage across Q1 in Figure 18.

V_{BE} is the temperature dependent base-to-emitter voltage

$R_{T(equiv)}$ is the parallel combination of R3 and the thermistor.

Resistor R3 is placed across the thermistor in a first-order attempt to linearize its resistance vs. temperature characteristic. The graph in Figure 19 shows a resistance vs. temperature plot of a thermistor (Betatherm, 10K3A1, 10kΩ @ 25°C) with and without a parallel resistor.
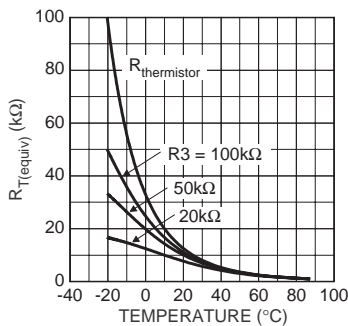

Figure 19. Thermistor Linearization

The temperature coefficient of an LCD is not linear with temperature. It is usually larger at higher temperatures. Some amount of nonlinearity is desired in the thermistor to compensate for the non-linear temperature coefficient of the LCD display. The temperature coefficient of the transistor should also be taken into account. For the 2N4401 it is –1.8mV/°C.

Over the temperature range shown, the graph in Figure 20 compares the operating voltage for a Seiko G1216 LCD (circles) with the calculated results (line) for the circuit in Figure 18. The measured results are also shown in the graph (triangles).
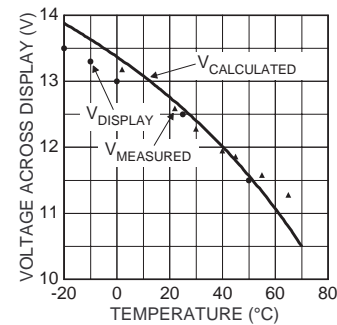

Figure 20. Temperature Compensated Voltage Comparison

Figure 21 shows how the NTC thermistor, R3, can be used to control the output voltage of a switching converter. The thermistor varies the resistance of the voltage feedback loop. An increase in temperature will decrease the resistance of the thermistor. This will cause the output voltage to decrease in magnitude. The potentiometer, R1, is optional and can be used to manually adjust the display contrast. The output voltage is manually adjustable, using the potentiometer, from –6.5V to –7.7V at 25°C. The thermistor will adjust the output voltage over the temperature range of the LCD. Output voltage is calculated as:

$$V_{OUT} = -1.23\frac{1+\left(R4+R3_{equiv}\right)}{R2+R1}$$

$$R3_{equiv} = \frac{R3 \cdot R3a}{R3+R3a}$$

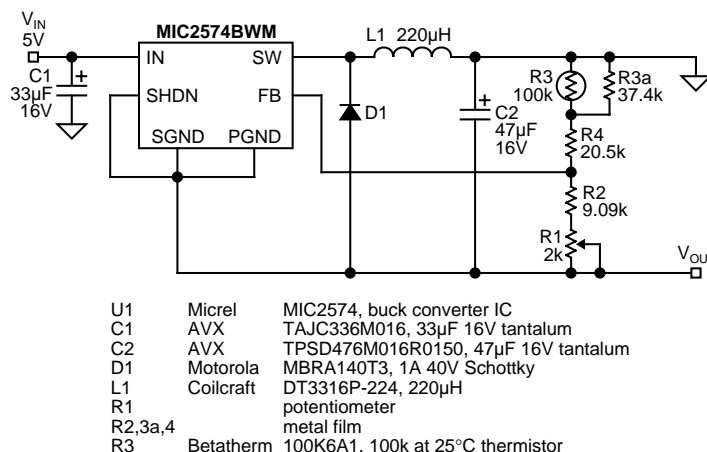| U1 | Micrel | MIC2574, buck converter IC |
C1	AVX	TAJC336M016, 33µF 16V tantalum
C2	AVX	TPSD476M016R0150, 47µF 16V tantalum
D1	Motorola	MBRA140T3, 1A 40V Schottky
L1	Coilcraft	DT3316P-224, 220µH
R1		potentiometer
R2,3a,4		metal film
R3	Betatherm	100K6A1, 100k at 25°C thermistor

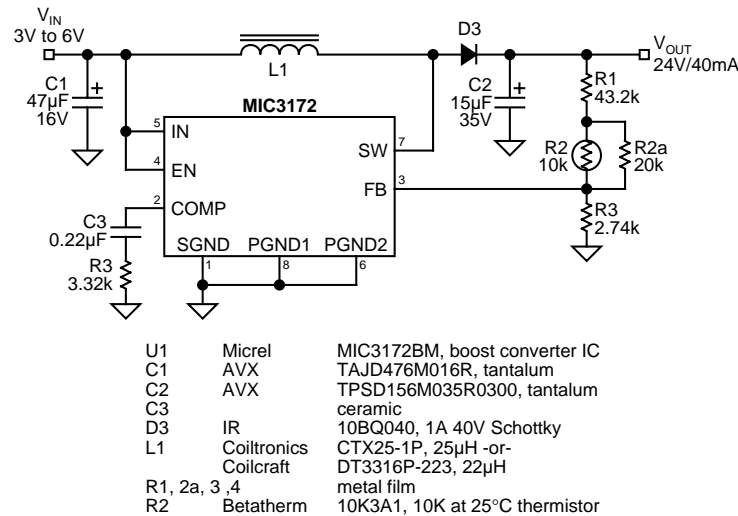**Figure 21. Temperature-Compensated Bias Supply**

Figure 22. Temperature-Compensated Bias Supply

Table 2 shows output behavior for Figure 21 from 0°C to 70°C. The potentiometer set at 1kΩ.

Ambient Temperature	Thermistor Resistance	Output Voltage
0°C	351,017Ω	−7.85V
10°C	207,807Ω	−7.59V
25°C	100,000Ω	−7.05V
40°C	51,058Ω	−6.36V
50°C	33,598Ω	−5.89V
70°C	15,502Ω	−5.07

Table 2. Temperature-Compensated Output

Figure 22 uses an NTC thermistor, R2, to control the output voltage of a positive output boost converter.

An increase in temperature decreases the thermistor resistance. This causes the feedback voltage to increase and the output voltage to decrease. Output voltage is:

$$V_{OUT} = 1.24 \frac{1 + (R1 + R2_{equiv})}{R3}$$

where:

$$R2_{equiv} = \frac{R2 \cdot R2a}{R2 + R2a}$$

Table 3 shows output behavior for Figure 22 from 0°C to 70°C.

Ambient Temperature	Thermistor Resistance	Output Voltage
0°C	32,651Ω	26.4V
10°C	19,904Ω	25.3V
25°C	10,000Ω	23.8V
40°C	5,325Ω	22.7V
50°C	3,601Ω	22.2V
70°C	1,752Ω	21.5V

Table 3. Temperature-Compensated Output

Figure 23 shows an alternate temperature compensation method without using a thermistor. It uses the negative temperature coefficient of the base to emitter voltage of a transistor to provide the temperature compensation to the drive voltage of the LCD display. The variation in output voltage using this topology is more linear than the thermistor method. If the temperature coefficient of the display is linear this method may be preferable.
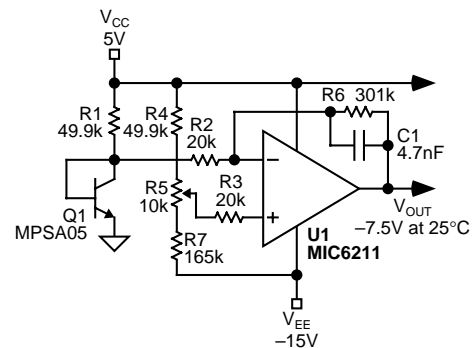
Figure 23. V$_{BE}$ Temperature Compensation

The temperature coefficient of the transistor is −1.8mV/°C. If the desired temperature coefficient of the display is −33mV/°C, a gain of 18.3 is required from the amplifier. If R2 is chosen as 20k, then R6 must be 365k. The V$_{BE}$ of the transistor will be approximately 0.6V with R1 at 49.9k. The output voltage of the op amp will be:

$$V_{OUT} = -gain\left(V_{IN(-)} - V_{IN(+)}\right)$$

If the output is desired to be −7.5V at 25°C, the voltage at the positive input must be:

$$V_{IN(+)} = \frac{V_{OUT}}{gain} + V_{IN(-)}$$

$$V_{IN(+)} = \frac{-7.5V}{18.3} + 0.6$$

$$V_{IN(+)} = 0.19V$$

The potentiometer is adjusted for proper contrast and the variation in V_{BE} will compensate for the negative temperature coefficient of the display.

Figure 24 increases the current drive capability of the temperature compensating circuit by placing a transistor, Q2, at the output. The feedback circuit eliminates any V_{BE} temperature dependence of Q2.
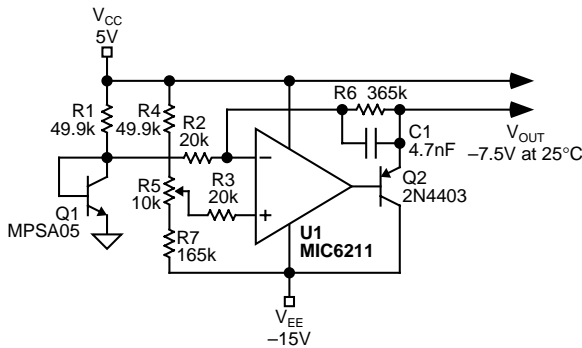

Figure 24. High-Power V_{BE} Temperature Compensation

Backlighting

LED Backlight Supply

LEDs are used in some displays as backlighting. In a typical circuit, the LED is connected to V_{CC} (+5V) through a current limiting resistor. This circuit is sufficient for displays with a narrow temperature range. Extended temperature range LED backlighted displays must have the forward LED current reduced at higher temperatures to prevent damage to the LEDs.
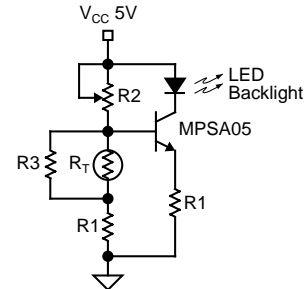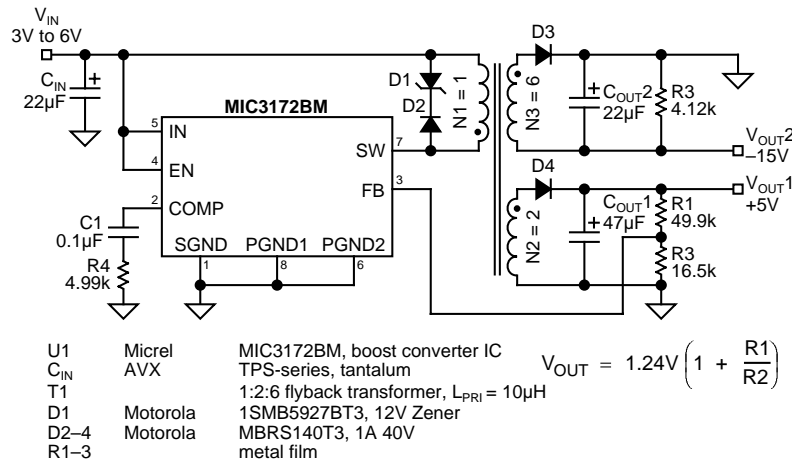

Figure 25. LED Backlight Temperature Compensation

U1	Micrel	MIC3172BM, boost converter IC
C_IN	AVX	TPS-series, tantalum
T1		1:2:6 flyback transformer, L_{PRI} = 10µH
D1	Motorola	1SMB5927BT3, 12V Zener
D2–4	Motorola	MBRS140T3, 1A 40V
R1–3		metal film

$$V_{OUT} = 1.24V \left(1 + \frac{R1}{R2} \right)$$

Figure 26. Multiple-Output Flyback Topology (MIC3172)
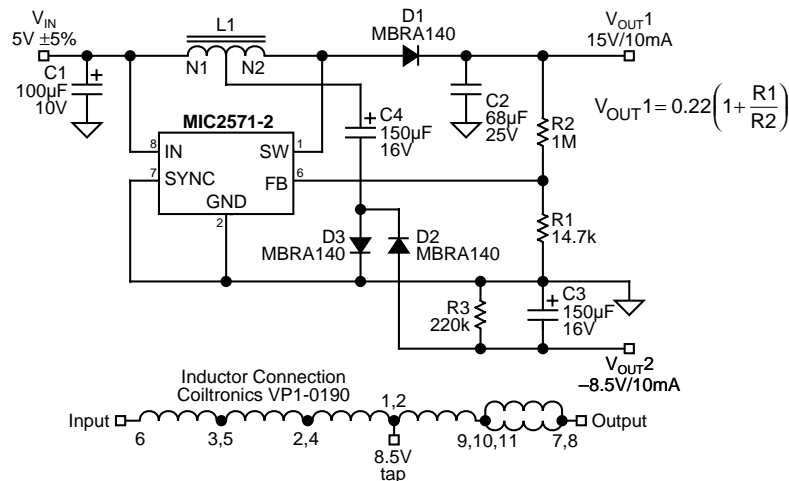

$$V_{OUT}1 = 0.22 \left(1 + \frac{R1}{R2} \right)$$

Figure 27. Multiple-Output Boost Topology (MIC2571)

The forward voltage drop of the LED has a negative temperature coefficient of between −1.8mV/°C and −2.3mV/°C. In a series connected resistor/LED circuit, as the LED voltage decreases, the current through the LED increases. Temperature compensation has the following advantages:

- Prevents the current from exceeding the maximum rating of the LED
- Maintains a constant brightness
- Reduces current at higher temperature to extend battery life

The circuits shown in Figure 25 can be used to regulate the LED current. Set up the thermistor and the voltage divider resistors so the required current flows through the LED at 25°C. The current through the LED is equal to the emitter voltage of Q1 divided by the resistance of R1. As the temperature increases, the required current through the LEDs will decrease. The thermistor resistance will decrease which will decrease the emitter voltage of Q1. The resistor divider (R2 and R4) and the thermistor circuit (R_T and R3) should be set up to adjust the current flow as specified by the LED backlight requirements.

Multiple-Output Power Topologies

It is advantageous in some applications to generate several voltages from the same converter. If both the V_{DD} and V_{LC} voltages need to be generated, a two-output converter has the advantages of fewer parts, lower cost, and less board space than two single-output converters. The advantage of a single-output power supply is better output regulation and no interaction between outputs (cross regulation).

A two-output flyback topology is shown in Figure 26. It uses the MIC3172 as the switching regulator IC and has a V_{DD} output (+5V) and a V_{LC} output (−15V). The output voltage, V_{DD}, is set by the voltage divider and is calculated by the equation:

$$V_{DD} = 1.24\left(1 + \frac{R1}{R2}\right)$$

Output 2, V_{LC}, is set by the transformer turns ratio N2/N3.

If the input voltage does not vary by more than a few percent and the output current is constant, the circuit shown in Figure 27 may be used. It is a boost converter with a tapped inductor. The tap location (ratio of N1/N2) determines the voltage of the negative output. The output voltage is calculated using the equation below:

$$V_{OUT}1 = 0.22\left(1 + \frac{R2}{R1}\right)$$

$$V_{OUT}2 = V_{IN} + \frac{\left(V_{OUT} + V_D - V_{IN}\right)N2}{N1 + N2} - 2V_D$$

Resistor R3 is used as a preload resistor to prevent the output voltage from varying at light load.

Conclusion

Different ICs and topologies have been shown in this application note, which provide the optimum circuitry for powering liquid crystal displays. Temperature compensation circuits are used to keep the display contrast constant under varying temperature conditions. Output disable and turn-on time features are discussed. Multiple-output power topologies are presented and should be used where they are effective.

A summary of the Micrel power supply control ICs is shown in Table 4. It will help to review and select the optimum controller for a given application.

Controller	Input Voltage Range	Maximum Output Votlage	Operating Frequency	Operating Modes	Package	Notes
MIC2570	1.3V to 15V	32V	20kHz	boost, inverting boost	SOIC-8	• Higher efficiency at low power • Skip-mode control • Higher output ripple • Positive and negative output
MIC2571	0.9V to 15V	32V	20kHz	boost, inverting boost	MSOP-8	• Higher efficiency at low power • Skip-mode control • Higher output ripple • Positive or negative output voltage
MIC3172	3V to 40V	65V	100kHz	boost, inverting boost	SOIC-8 DIP-8	• Higher power • PWM-mode control • Lower output ripple • Positive or negative output voltage
MIC4574	4.5V to 24V	1.3V to 18V	200kHz	buck, inverting boost	SOIC-14 DIP-8	• Positive or negative output voltages • Lower output ripple
MIC2574	4V to 40V	1.3V to 37V	52kHz	buck, buck-boost	SOIC-24 TO-263-5 DIP-16 TO-220-5	• Positive or negative output voltage • Lower output ripple
MIC2179	4.5V to 16.5V	1.3V to 16V	200kHz	synchronous buck	SSOP-24	• High-efficiency buck • Lower output ripple

Table 4. Micrel Switching Converter Summary