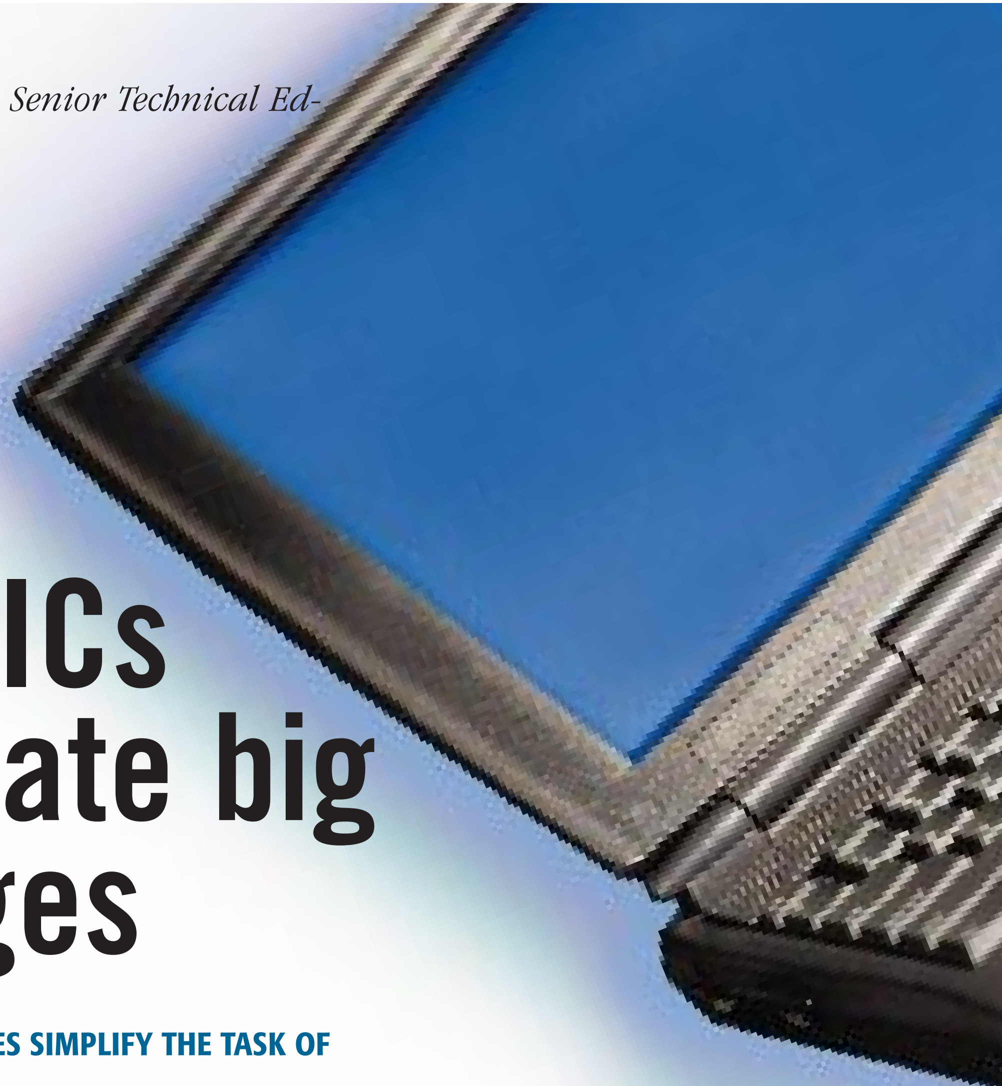
 By Bill Travis, Senior Technical Ed-



Little ICs generate big voltages

ICs AND SMALL MODULES SIMPLIFY THE TASK OF GENERATING THE HIGH VOLTAGES FOR DISPLAYS AND THEIR ASSOCIATED BACKLIGHTS.

When you turn on your notebook computer or personal digital assistant, a highly readable screen with a pleasant glow in the background greets you. It's in striking contrast (no pun intended) with the old days (remember the Radio Shack 100?) of LCD screens, when you had to orient the screen just so to read the characters. Today's high readability stems from both the thin-film-transistor-LCD technology and the backlighting. Most LCDs use cold-cathode fluorescent lamps (CCFL) for backlighting. These miniature fluorescent tubes are tricky to drive; they're particular in their striking- and operating-voltage requirements. It's difficult to dim them in such a way that the brightness remains uniform across the length of the tube. A recent generation of ICs and small modules makes it easier to configure a drive system for CCFLs and gives you a great deal of flexibility in controlling the lamps' performance.

Jim Williams of Linear Technology has published a comprehensive treatment of CCFL drive (**references 1** and **2**). Williams delves into the vagaries and idiosyncrasies of CCFLs. For example, the lamps work best with a sinusoidal ac voltage applied. Operating voltage can range from 200 to 500V rms, and the lamps require 1000V or higher striking voltage. It's best to eliminate any dc component in the drive voltage; otherwise, migration effects can have a detrimental effect on the lamps' lifetime. **Figure 1** shows some characteristics of a typical CCFL. **Figure 1a** shows that the lamp's intensity is a direct function of the lamp current, and the lamp "saturates" at currents above its maximum rating; any increase in current produces no further increase in intensity. **Figure 1b** shows the CCFL's negative-resistance characteristic; lamp current is inversely proportional to the operating voltage. In his development efforts in **Reference 1**, Williams describes how he borrows from classic high-voltage circuitry in Tektronix oscilloscopes and adopts the Royer oscillator as the basis for CCFL-drive circuitry.

Linear Technology uses the Royer topology in its LT1182/1183/1184 family of display-driver ICs. **Figure 2** shows a recommended connection. The Royer circuit at the top of the diagram provides the drive for the lamp via a high-turns-ratio transformer. With the component values shown, the switching frequency of the circuit is approximately 200 kHz. The LT1182 and LT1183 provide CCFL drive and LCD contrast control; the LT1184 provides CCFL drive only. The ICs can control the current of grounded or floating CCFLs. In a grounded configuration, the IC senses half the CCFL current; a feedback loop provides current control. In a floating configuration, the IC controls the current provided to the primary side of the Royer circuit. The floating configuration is recommended, because it's not susceptible to "thermometer" effects—uneven lamp intensity along the length of the tube, stemming from parasitic lamp-to-frame capacitance. Speaking of current control, Williams also discusses dimming techniques for CCFLs (**Reference 3**).

Linear Technology claims its CCFL-drive ICs improve on traditional feedback-control methods. These methods use an error amplifier in the control loop to regulate lamp current. This approach converts an rms voltage to a dc voltage at the input of the error amplifier. The method requires several time constants to provide stable loop compensation, resulting in a relatively slow loop. The LT1182/1183/1184 ICs replace the error amplifier with a lamp-current programming block. The control loop exhibits the response of a single-pole system and virtually eliminates the overshoot inherent in multipole systems. CCFL drive can be tricky, as the ICs' data sheet explains. The best electrical efficiency, approximately 90% for the LTC ICs, occurs just as the Royer transformer's drive waveforms begin to exhibit artifacts of higher order harmonics reflected back from the secondary winding. Maximizing electrical efficiency entails using smaller values for the primary-side resonating capacitor and larger values for the secondary-side ballast capacitor. The best optical efficiency occurs with larger primary-side capacitance and smaller secondary-side capacitance. LTC opted for a point between the optimum electrical and optical efficiencies. The LT1182/1183 also provides LCD-negative- or positive-contrast control in the form of a variable output current as high as 625 mA.

AT A GLANCE

▷ Best electrical efficiency in a cold-cathode-fluorescent-lamp (CCFL) driver does not coincide with best optical efficiency.

▷ Stray capacitances in a CCFL-driver layout can compromise efficiency.

▷ A sinusoidal waveform for CCFL drive yields the best conversion efficiency.

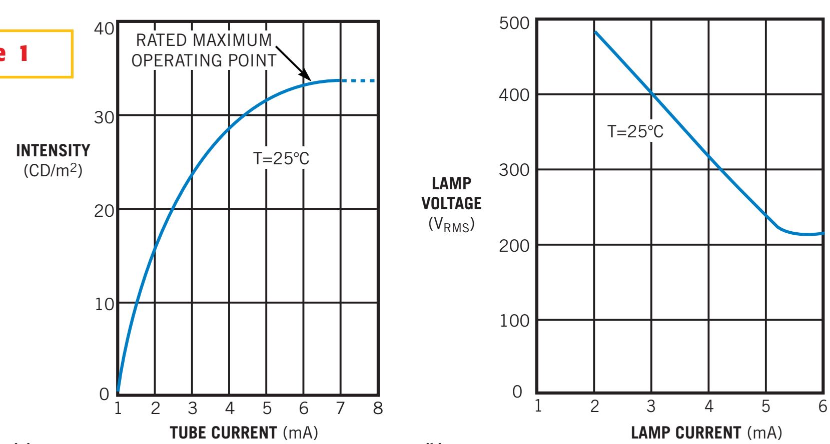
As you can see in the copious notes in **Figure 2**, you must carefully choose the external components to obtain optimal performance from the LT1182/1183/1184 CCFL drivers. For the primary-side capacitor, C_1, you should select an aluminum electrolytic type with ESR≥0.5Ω to prevent damage to the IC's high-side sense resistor from surge currents during turn-on. You should choose high-quality tantalum types for the rest of the polarized capacitors. And C_2 must be a low-loss type to optimize efficiency in the resonant circuit.

CIRCUIT PROVIDES DIGITAL CCFL CONTROL

Linear Technology's LT1186 uses the same Royer-topology output configuration as the LT1182/1183/1184 ICs, but also offers digital control of CCFL current. The IC contains an 8-bit DAC that provides a current output of 0 to 50 μA with a resolution of 256 steps. The DAC accepts inputs in SPI or pulse mode. On power-up, the DAC counter resets to half-scale, and the DAC configures itself to SPI or pulse mode, depending on an IC-pin setting. In SPI mode, the system μP serially transfers the current 8-bit data and reads back the previous 8-bit data. In pulse mode, the upper 6 bits of the DAC configure as increment-only (one-wire interface) or increment/decrement (two-wire interface), depending on an IC-pin setting. An internal gain-of-five current amplifier converts the DAC's 0- to 50-μA output to a 0- to 250-μA level for programming the CCFL current in the Royer circuit. Note that measurements of efficiency and other parameters can pose tricky problems. **Reference 4** describes effective measurement techniques.

Maxim's MAX1610/1611 also offers

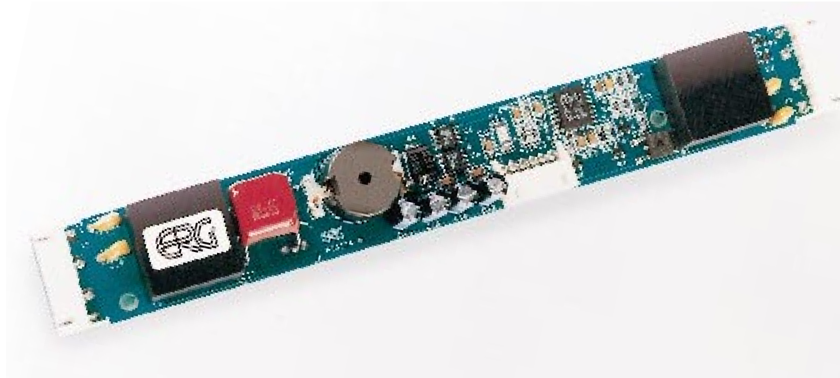
Figure 1



A CCFL saturates at its maximum operating current (a) and exhibits a negative-resistance characteristic (b).

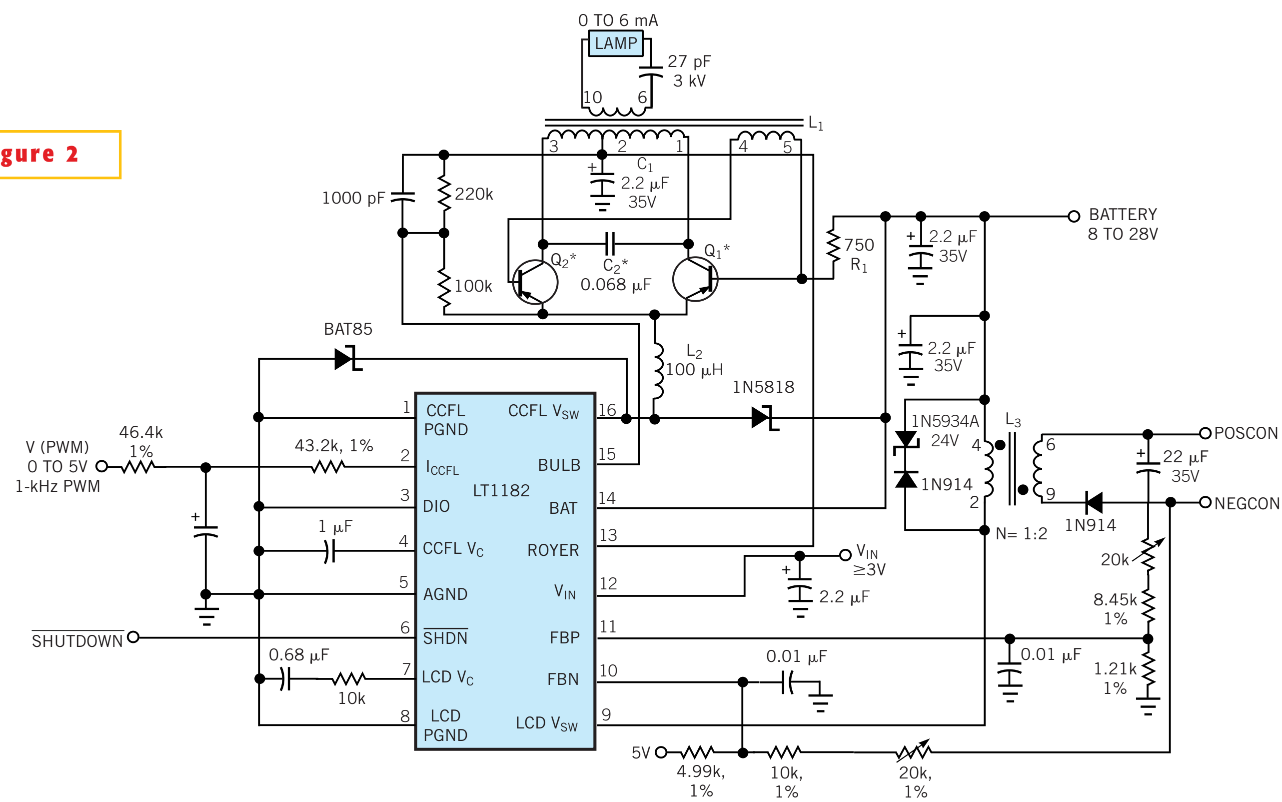
digital control of CCFL current in the form of a 5-bit counter connected to a five-bit DAC (**Figure 3**). The IC uses an SMBus two-wire serial interface to control CCFL current and, therefore, brightness, in 32 steps. The digital brightness setting remains active during shutdown. An on-chip 26V, 0.7Ω power MOSFET drives the Royer circuit. You have two choices for adjusting brightness: You can either program the CCFL current or operate with a fixed lamp current and chop the CCFL on and off at a rate faster than the eye can detect. The MAX1610/1611 regulates CCFL current by controlling the current delivered to the primary winding in the Royer circuit. You could also directly regulate the CCFL current by adding some sensing components to the secondary side. However, as the Maxim data sheet explains, this technique increases the likelihood of encountering the thermometer effect, in which one end of the tube is brighter than the other.

Texas Instruments/Unitrode offers a large family of CCFL drivers. The UCC-3927/3973 also uses the Royer resonant



A minuscule module in Endicott Research Group's DMB Series powers four CCFLs.

Figure 2

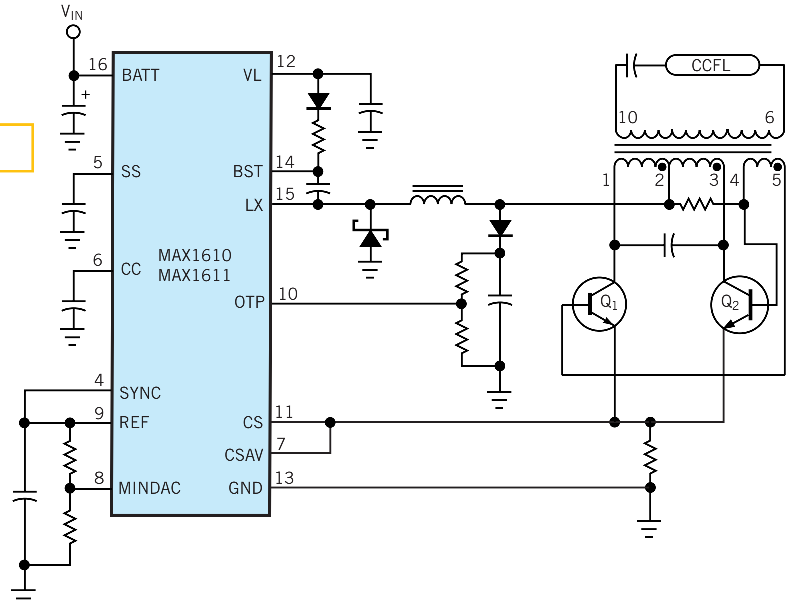


NOTES:
ALUMINUM ELECTROLYTIC IS RECOMMENDED FOR C_1 WITH AN ESR≥0.5Ω TO PREVENT DAMAGE TO THE LT1182 HIGH-SIDE SENSE RESISTOR DUE TO SURGE CURRENTS AT TURN-ON.
*DO NOT SUBSTITUTE COMPONENTS.
C_2 MUST BE A LOW-LOSS CAPACITOR; C_2=WIMA MKP-20.
Q_1, Q_2=ZETEX ZTX849 OR ROHM 2SC5001.
L_1= COILTRONICS CTX210605.
L_2= COILTRONICS CTX100-4.
L3= COILTRONICS CTX02-12403.
0- TO 45-µA ICCFL CURRENT GIVES 0- TO 6-mA BULB CURRENT. THIS CURRENT IS EQUAL TO 0 TO 90% DUTY CYCLE FOR THE PWM SIGNAL.
EITHER NEGCON OR POSCON MUST BE GROUNDED. GROUNDING NEGCON GIVES VARIABLE POSITIVE CONTRAST FROM 10 TO 30V.
GROUNDING POSCON GIVES VARIABLE NEGATIVE CONTRAST FROM −10 TO −30V.

You can drive CCFLs and control LCD contrast at the same time with LTC's ICs.

oscillator to drive the CCFL (**Figure 4**). The IC derives feedback for controlling CCFL current from the secondary side of the transformer. The diode and resistors connected to ground provide a sensing signal on each half-cycle to the feedback pin on the IC. Negative-feedback servo control maintains the average voltage on the sensing point at 1.5V. The IC maintains control by setting the duty cycle of the power MOSFET in the buck-type regulator. The resonant frequency of the Royer circuit is approximately 50 kHz; the buck regulator synchronizes to the Royer frequency. In the circuit in **Figure 4**, the CCFL receives a strike voltage of approximately 1000V with the minimum input voltage; operating voltage is approximately 375V rms. The higher strike voltage happens automatically. Before a CCFL turns on (strikes), its impedance is much higher than that of the ballast capacitor; therefore, the lamp receives the bulk of the secondary voltage. In fact, the starting voltage can reach 5000V and more with the maximum input voltage applied and perhaps cause a breakdown in the transformer. TI's data sheet describes a simple external clamp you can add to the circuit to prevent such a scenario.

Figure 3



Maxim's CCFL-drive ICs control floating lamps by adjusting the primary current.

The UCC3972/3973 offers two analog methods for CCFL dimming (**Figure 4**). One method is to simply adjust the potentiometer in the bottom leg of the CCFL. The voltage on the sense node is a half-wave-rectified waveform whose voltage is proportional to the lamp current. The feedback loop sets the duty cycle of the PWM stage to control the current in the CCFL. You can also achieve analog dimming by applying a digital pulse stream (or a dc control voltage) to the feedback pin. For this technique, the sense resistor is fixed, and the IC averages the feedback-node voltage against the digital pulse stream. You can obtain a 10-to-1 dimming range using these analog techniques. Beyond this range, the lamp may exhibit the thermometer effect with resulting uneven illumination. You can obtain dimming beyond a 10-to-1 range by operating the lamp at rated current and gating the lamp on and off at a low frequency. To do this task, you inject a PWM signal into the feedback pin to turn the lamp on and off. The repetition rate should be greater than 120 Hz to avoid visible flicker.

In a backlight design, the spacing can be tight between the lamp and the high-voltage secondary winding with respect to the foil reflector and the LCD frame. With this restricted spacing, the lamp circuit develops unavoidable stray capacitances (**Figure 5**). The stray capacitances give rise to leakage currents from the high-voltage secondary winding to ground. Although these stray currents don't directly cause losses, the extra current through the transformer, primary resonant tank, and switching devices does contribute to losses. A poor layout with excessive stray capacitance can reduce circuit efficiency by tens of percentage points. High-frequency harmonics in the secondary-voltage waveform further compromise efficiency, because the stray capacitive reactance decreases as frequency increases. For this reason, a pure sinusoid gives the best electrical-to-optical efficiency: no harmonic losses. However, as noted, sinusoidal waveforms require more circulating current in the resonant tank, thereby

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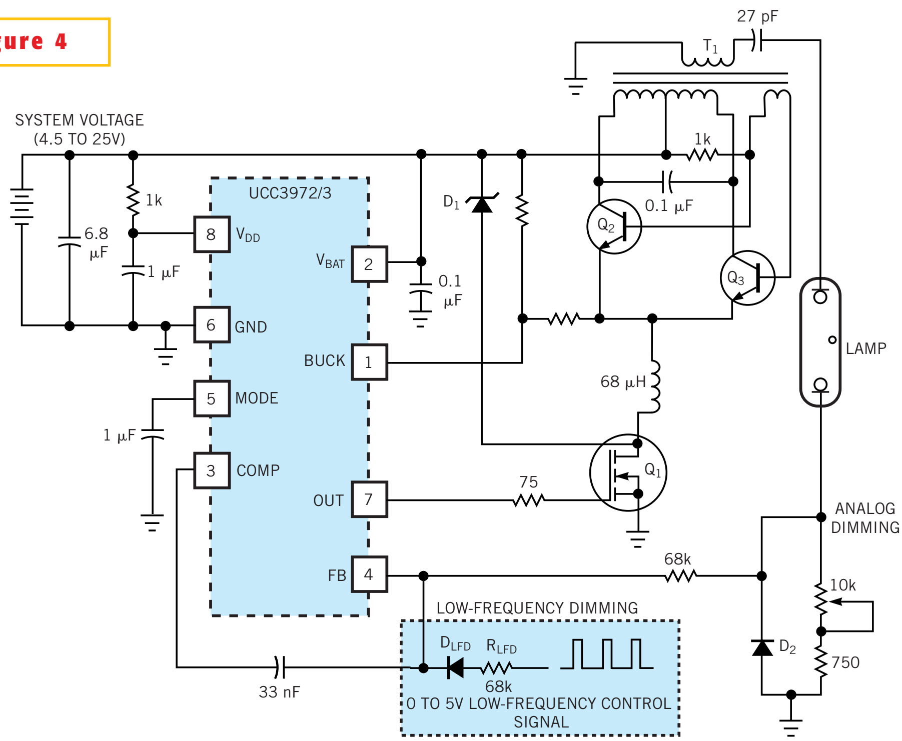
lowering the purely electrical efficiency of the inverter.

Linfinity also offers CCFL-driver ICs. The LX1686 includes a lamp-current burst circuit that can provide a 100-to-1 or greater dimming range from a 0 to 2.5V input. You can synchronize the burst rate with the panel's frame rate to prevent interference from optical beat frequencies. The IC uses a high-voltage feedback loop to control maximum open-lamp and minimum and maximum strike voltages. This feature protects the transformer from breakdown damage and overheating during lamp striking. The LX1686 operates from 3.3 or 5V power supplies. The IC offers a choice of operating frequencies, so you can choose the frequency that matches the lamp's most efficient operating point.

Figure 4

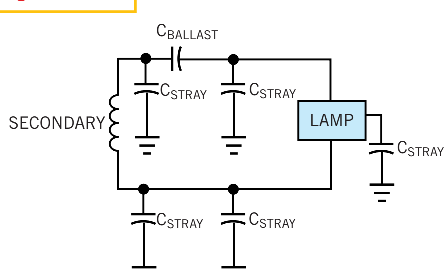


TI's CCFL drivers use analog or low-frequency dimming techniques.

MODULES MAKE IT EASY

So far, we've discussed the ICs you can use to configure dc/ac inverters to power CCFLs. Several manufacturers offer small, complete modules to fulfill that function. Endicott Research Group, for example, offers a large family of modules that drive multiple lamps. Its recent DMB Series of closed-loop inverters drives as many as four CCFLs. Power efficiency reaches a notable 90%. Most roll-your-own circuits operate with efficiencies in the mid-80% range. It's a given that power-conversion (or, in this case, inversion) efficiency is crucial in battery-operated systems. Assume that you're providing 4W to a CCFL from an 80%-efficient inverter. With 80% efficiency, you must provide 5W to the input of the inverter, which equates to 1W wasted. Now, assume a 3V battery supply and a 90%-efficient dc/dc converter to supply the inverter's required rail voltage. The 1W wasted in the inverter equates to 0.11W wasted in the dc/dc converter. So, the 3V battery supply must supply 1.11W more for the dissipation in the converter and inverter. That's 370 mA of additional battery drain lost to inefficiency. Note that Endicott Research Group has recently introduced the 8MD series of CCFL inverters, a low-profile (8- versus 13-mm-high) version of the DMB series.

Figure 5



Stray capacitance in CCFL mounting can reduce efficiency.

The company has taken measures to combat the thermometer effect; you can control brightness without incurring flicker throughout the dimming range. You can use either dc voltage or a PWM digital stream to control brightness. The DMB Series has an optimized form factor for use with 17- and 18-in. flat-panel displays. Another Endicott family, the MC Series, provides even more power for driving CCFLs. It can drive as many as 10 tubes and provide as much as 40W output power. It also accepts dc or PWM signals for dimming.

A series of CCFL-drive modules is also available from Linfinity. The LXM1641 Series is a four-lamp driver that uses a digital dimming technique. The technique yields a dimming ratio greater than 1000-to-1 without flicker. You control the digital dimming circuitry with an external potentiometer or a dc signal. The digital circuitry uses burst-mode operation to effect dimming. You can synchronize the burst rate with the panel's frame rate to avoid optical beat-frequency effects. The LX1641 contains a fail-safe feature that keeps a display operating at or near normal brightness in the event that a lamp fails. The display can thus remain online until lamp replacement is convenient. The family of modules does not use the classic Royer resonant-circuit topology but rather a direct-drive technique (**Figure 6**). It thus eliminates a number of inductors and capacitors, allowing for smaller modules. The module measures 161×32×8.6 mm.

Taiyo Yuden's SIPF-200 CCFL-driver module accepts input voltages of 8.5 to 20V. The single-tube driver provides 6-mA, 4W drive to the CCFL. You can achieve dimming by gating the CCFL on and off with a control terminal that uses logic-level signals. The module uses a CCFL operating frequency of 50 kHz. The SIPF-200 also uses low-profile packaging; the module measures 96×22.7×7.3 mm. A line of modules from TDK drives single or dual CCFLs. The CXA Series boasts low noise, thanks to a sinusoidal output from its push-pull resonator circuit. The family does not offer a dimming-control input. The module measures 56×29×17 mm.

You have a variety of options in driving CCFLs. You could design your own circuit. However, it's probably a better idea to choose an IC from a number of sources to configure a driver circuit. All the IC makers provide abundant applications information in their data sheets. Alternatively, you can select a ready-made module that entirely eliminates the design task. Your choice depends on cost considerations and space constraints.□

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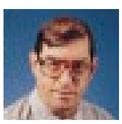
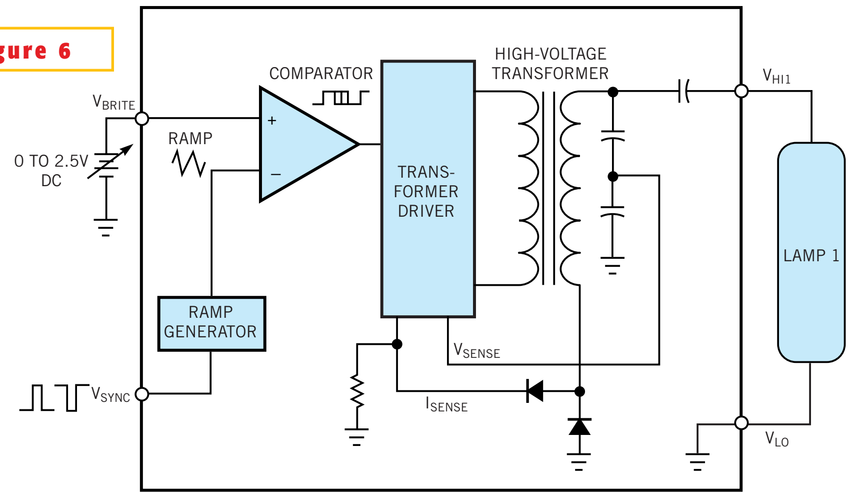


Figure 6



CCFL-drive modules from Linfinity use a direct-drive technique.

REFERENCES

1. Williams, Jim, "Techniques illuminate backlit LCDs with high efficiency," *EDN,* Jan 6, 1994, pg 89.

2. Williams, Jim, *The Art and Science of Analog Circuit Design*, Butterworth-Heinemann 1995, pg 139.

3. Williams, Jim, "Avoid pitfalls in dimming and shutting CCFL back-lighting for LCDs," *EDN*, March 4, 1996, pg 103.

4. Williams, Jim, "Measurements on CCFL-driver circuits pose tricky problems," *EDN*, May 9, 1996, pg 175.