

Landmark Technology Backlight Inverters

Introduction

An Inverter is an electronic circuit that transforms a DC voltage to an AC voltage. Cold cathode fluorescent lamps (CCFLs) in LCD backlights are most efficient to operate in AC. Consequently, all CCFL powered LCD backlights require inverters.

The typical inverter circuitry for operating a backlight consists of a Royer oscillator and a control circuit. The Royer oscillator converts the DC to AC and the control circuit provides the dimming, On/Off control, and possibly some other functions.

The Royer oscillator circuit in an inverter has a transformer (T) to step up the AC voltage to well beyond 1000 V rms (root mean square value) for lamp ignition. The output voltage is connected to the lamp through a high voltage capacitor (C₂). Typically, the impedance of this capacitor at the inverter oscillating frequency is several times higher than the lamp impedance.

Before ignition, the lamp does not conduct electricity and behaves as an open circuit. As a result, 100% of the output voltage (1000+ V) is applied to the lamp for ignition. After ignition, the lamp current causes a voltage drop across the capacitor C₂. This voltage drop increases as the lamp current increases until an equilibrium is established where the vector sum of this voltage drop and the lamp voltage equals to the output voltage of the transformer. That is, if **I** is the lamp current, **V** is the output voltage of the transformer, **V**_{lamp} is the CCFL operating voltage at the lamp current **I**, then:

$$\mathbf{V} = \mathbf{V}_{\text{lamp}} + \mathbf{I} \times 1/(j2\pi f C_2)$$

where *f* is the oscillating frequency, and $j = (-1)^{1/2}$ which is the base of imaginary numbers.

In the above equation, symbols in boldface are vectors (or complex numbers). Typically, a CCFL behaves very close to a resistance. Therefore, **V**_{lamp} is nearly in phase with **V**

where the second term $\mathbf{I} \times 1/(j2\pi f C_2)$ is -90° out of phase with **V**.

Thus, by selecting the value of the capacitor C₂, we can adjust the final equilibrium condition to provide the recommended operating lamp current.

Backlight Dimming

One of the main functions provided by the control circuit is the lamp dimming. In general, there are two types of dimming methods:

1. Linear dimming (or dimming by reducing lamp current)
2. PWM (pulse width modulation) dimming

In linear dimming, the lamp luminance is adjusted down by reducing the lamp current. Consequently, the lamp stays “ON” all the time but is operating at a lower current. Linear dimming is commonly used in inverters for notebook PCs and desktop monitors where a very limited dimming range of 2 - 5 (i.e., brightness varying from 100% to 50% or 20% respectively) is adequate. With carefully designed inverters and backlights, linear dimming can provide a luminance adjustment range up to about 40 (100% down to 2.5%). Beyond that, linear dimming does not perform too well due to the following reason:

The voltage - current relationship of a CCFL does not follow the Ohm’s law. For the first order approximation, the voltage across a CCFL is nearly independent to the lamp current (in fact, the lamp voltage increases slightly as the lamp current reduces). Consequently, the lamp impedance increases almost inversely with the lamp current. Therefore at low lamp current, the lamp impedance becomes very high. For example, when a lamp is operated at 5% of its normal current to achieve a 20:1 dimming, the lamp impedance increases about 20 times, reaching 1,000K to 3,000KΩ for most of the lamps in Landmark backlights. At this level, the effects due to the stray capacitance (i.e., from the lead wires and the lamps to the

backlight case and to the ground) become significant. As a result, a portion of the current normally going through the lamp leaks away through the stray capacitance. To make it worse, since the stray capacitance associated to each lamp is different, the amount of current leaking away also differs from lamp to lamp. The net effect is that some of the lamps may be operated at a lower current making them dimmer than the others. At the extreme case, certain lamps may even quit where the others are still brightly lit.

In the case of PWM dimming, the lamp current is pulse width modulated at a repetition rate high enough to prevent LCD screen flicker. Within each PWM cycle, the lamps are turned fully "ON" for a fraction of the cycle time. The human eyes, being very slow with respect to the PWM rate, response to the average light produced over the PWM cycle. Consequently, the luminance of the backlight and/or the LCD screen is approximately proportional to the duty cycle of the PWM waveform (Fig. 1).

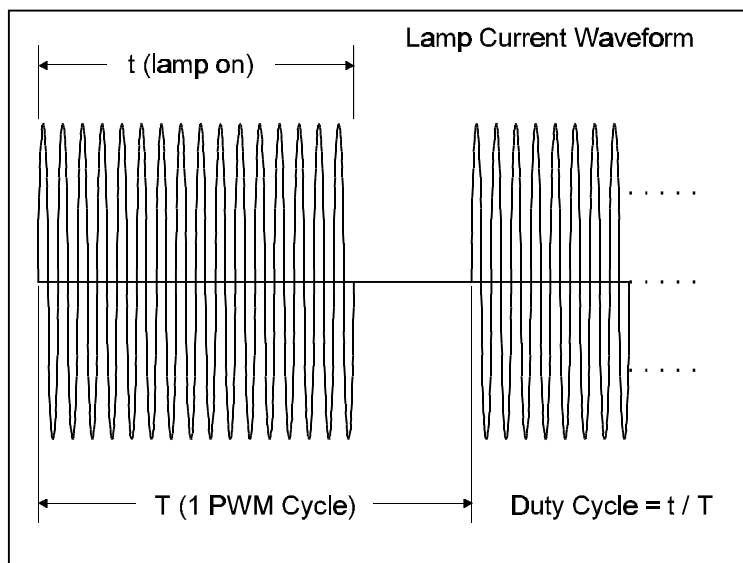


Fig. 1

In general, inverters with PWM dimming have a very wide luminance adjustment range for the following reason. In PWM dimming, the lamp is operated at its full current during the time when the lamp is "ON". So, the lamp impedance is typically in the 50 to 150 K Ω region. Since the lamp

impedance is quite low, the effects due to the stray capacitance are not significant.

With the PWM dimming, some inverters designed for military use can achieve a dimming ratio higher than 2,000:1. That is, the luminance of the backlight can be adjusted from 100% down to less than 0.05%!

Pulse width modulating the lamp current at a high repetition rate can generate a significant amount of noise. Thus, PWM inverters are in general noisier than the linear inverters. However, when the backlight is running at its maximum brightness, the PWM duty cycle is usually at 100%. Consequently, the lamp current waveform is a continuous sine wave which does not generate too much EM interference.

Inverter Open Circuit Output Voltage

The transformer in the inverter steps up the voltage to beyond 1,000 Vrms for lamp ignition. Before ignition, the lamp does not conduct electricity and thus behaves as an open circuit. So, this ignition voltage is frequently called the inverter open circuit output voltage.

The voltage required to ignite a lamp depends on the length of the lamp, the temperature, and the aging of the lamp. For example, the CCFL used in Landmark 10.4" backlight is 220 mm long. Its ignition voltage at 25 °C temperature is about 500 V. However, the lamp used in our 20.1" backlight is 420 mm long and its ignition voltage at the same condition is 830 V. When the temperature drops to 0 °C, the ignition voltage increases by about 40%. Moreover, when the lamp ages, its ignition voltage also increases. For example, after 10,000 hours of operation, the ignition voltage increases by about 20%.

In order to ensure that the lamp will be turned on under the worst condition (i.e. at low temperature and after the lamp is well aged), it is common to design the inverter open circuit output voltage more than twice higher than the minimum ignition voltage of the lamp at 25 °C.

The BI200A PWM Inverter

In early 1998, Landmark Technology introduced the BI200A inverter with 200:1 (100% down to 0.5%) PWM dimming capability. This inverter can drive all Landmark 10.4" and 12.1" backlights and LCD modules. Examples such as the C053G, BK103A, BK106A (10.4") backlights, LM073A, LM121A (10.4"), LM110A, LM114A, LM123 (12.1"). LCD modules.

The BI200A inverter can deliver up to 24 Watts lamp driving power. It is operated at 12V and its efficiency (defined as output lamp power divided by the DC input power at the peak conditions) is about 75%.

The open circuit output voltage of BI200A is about 1,300 V and therefore is suitable for lamps up to about 320 mm long, which is enough to cover backlights and LCD modules up to about 15" size. It is possible to use BI200A to drive longer lamps. However, the low temperature (for example, 0°C or below) performance will not be very satisfactory.

When the BI200A is operated at a dimming ratio near 200:1 or higher, the PWM circuit is running at a very low duty cycle. The Royer oscillator generates a burst oscillation of one or a few cycles and is then forced to stop by the PWM circuit. During this burst, the inverter draws a large transient current that in some cases can pull down the 12 V supply and potentially causes instability of the burst oscillation. When this happens, the backlight flickers. On the other hand, if the power supply has an exceptionally good regulation (such as a lab power supply or a 12V battery), then the BI200A inverter can achieve about 2,000:1 dimming on most Landmark backlights operating at room temperature.

The BI220A PWM Inverter

Landmark Technology introduced the BI220A inverter in late 1998. This inverter is actually a BI200A with a second Royer oscillator power section added. As a result, the inverter output power is increased to about 45 Watts maximum making it suitable to drive the backlights in Landmark 15" LCD modules (LM117, LM120, LM126,

LM128 and LM132 family of LCD modules). The inverter can drive up to 12 lamps at a maximum power output of 45 Watts. The dimming range is specified at 200:1.

The BI320A PWM Inverter

Landmark Technology introduced the BI320A inverter in mid 1999. This inverter is designed to drive long lamps for backlights in Landmark 17" and 18.1" LCD modules. The basic circuitry is similar to those of BI220A. Therefore, it drives up to 12 lamps with a maximum power output of 45 Watts. In addition, the ON/OFF control signal is TTL compatible. That is, ON at 5V, and OFF at 0V. Also, there is a factory installed option to use an external PWM signal for dimming control. The other specifications are virtually identical to those of BI220A.

The BI224A PWM Inverter

The BI224A inverter was introduced in August 2001. It is basically a BI220A inverter re-packed in a BI320A foot print. Therefore, its size may be more suitable than BI220A for certain cases.. In addition, the backlight ON/OFF control signal is TTL compatible. There is also a factory installed option to use an external PWM signal for dimming control.

The BI330A PWM Inverte

The BI330A inverter was introduced in February 2002. The inverter is designed to run large size backlights and LCD modules in the 18.1" to 22" sizes. It can drive up to 18 lamps with a maximum power output of 60 Watts. In addition, the backlight ON/OFF control signal is TTL compatible. There is also a factory installed option to use an external PWM signal for dimming control.

PWM Frequency versus the LCD Frame Rate

Within each PWM cycle, the lamps in the backlight are turned "ON" and "OFF" once. If the PWM frequency is very close to the LCD frame rate (refresh rate), the backlight and the LCD will interfere each other generating a phenomenon call

beating. If the beating frequency (the difference between the PWM frequency and the LCD frame rate) is less than 30 Hz, human eyes can observe this beating effect on the LCD screen as one or more horizontal bars. As time goes by, these gray colored bars may move up then stop and start moving down or vice versa.

There are two ways to solve the beating problem. First, we can synchronize the PWM cycle to the LCD vertical frame rate to completely avoid beating. Second, we can select a PWM frequency that creates a beating frequency beyond what the human eyes can detect and as a result, no annoying moving horizontal bars on the screen.

For the reason of lower cost and simplicity, all Landmark Technology inverters are designed based on the second approach. The PWM frequency is set to avoid the visibility of the beating effect. This has been tested with most of the graphics cards commonly used in PCs.

BI224A, BI320A, and BI330A have a factory installed option to use an external PWM signal for dimming. As a result, the user can generate a PWM signal that synchronizes with the LCD vertical scan rate for dimming control.

In the case that a horizontal moving bar pattern is observed on the LCD screen, please contact Landmark Technology. We can fine tune the PWM frequency to eliminate this problem.

The Dimming Characteristics

Fig. 2 shows the typical LCD screen luminance (brightness) and the inverter current as a function of the dimming voltage. The data was measured from Landmark LM073 sunlight readable LCD module using BI200A inverter.

From Fig. 2, it is obvious that both the luminance and the inverter current curves are quite linear if the dimming voltage Vd in plotted in log scale. Therefore, it is necessary to use a logarithmic dimming voltage generation circuit to achieve a close to linear dimming characteristics.

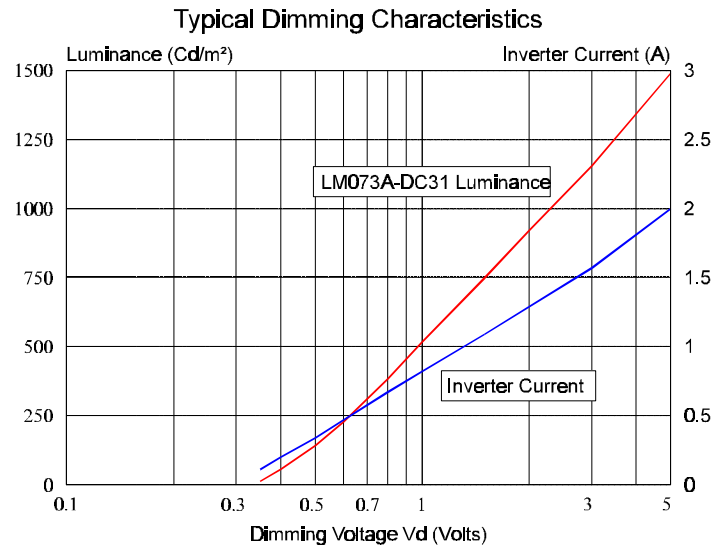


Fig. 2. Dimming curve of BI200A-73 with LM073A-DC31 sunlight readable LCD module plotted in semi-log scale

The total power consumption of the backlight system (including the inverter) equals to the product of the input voltage (12V) and the inverter current (in Ampere). As the LCD screen luminance is dimmed down, the power consumption of the backlight system drops correspondingly. At a typical screen luminance level of a notebook computer LCD, for example, 100 Cd/m², the power consumption of the backlight system drops to about 3 Watts, which is about the same as the power consumption of the backlight system for a notebook computer LCD.

Dimming Control Circuits

The BI200A, BI220A, BI224A, BI320A, and BI330A series inverters require a DC voltage from 0 to +5 V for dimming control. The simplest way to generate this control voltage is to use a potentiometer with some series resistors. A typical circuit for BI200A PWM inverter is as shown in Fig. 3.

BI200A inverter has a +5V regulated supply at pin #1 of the input connector CN1. This supply can be used to power a dimming potentiometer with resistance as low as 2 KΩ. When the potentiometer is set at its maximum resistance, the dimming voltage (Vd) generated is +5V which drives the PWM circuit to 100% duty cycle. At the lowest resistance setting (0 Ω), Vd is the voltage across the resistor R1.

Using the Dimming Control to Limit the Maximum Screen Brightness

When using Landmark Technology backlights and sunlight readable LCD modules in places not subject to strong direct sunlight, it is often possible to operate the LCD at a de-rated screen brightness without sacrificing the display readability. For example, if the display is installed in outdoor open shades, the LCD screen brightness can be reduced to about 1,000 Cd/m². This brightness de-rated operation can reduce the heat generated by the backlight and therefore the thermal related problems. It also increases backlight life since the lamps are operated at a reduced average current.

To cite an example, the maximum specified brightness of LM073-DC31 Sunlight Readable LCD module (10.4") is about 1,500 Cd/m². To operate this LCD module at a de-rated screen brightness of 1,000 Cd/m², the V_d value is 2.4V as those shown in Fig.2. So by limiting the adjustable range of the dimming voltage V_d from 0.32V to 2.4V, the LM073A-DC31 LCD can be operated in a de-rated screen luminance range from 0 to 1,000 Cd/m².

The circuit shown in Fig. 5 can be used to generate the dimming voltage V_d required for this de-rated brightness operation. The R₁ and R₂ values can be calculated by solving the following simultaneous equations:

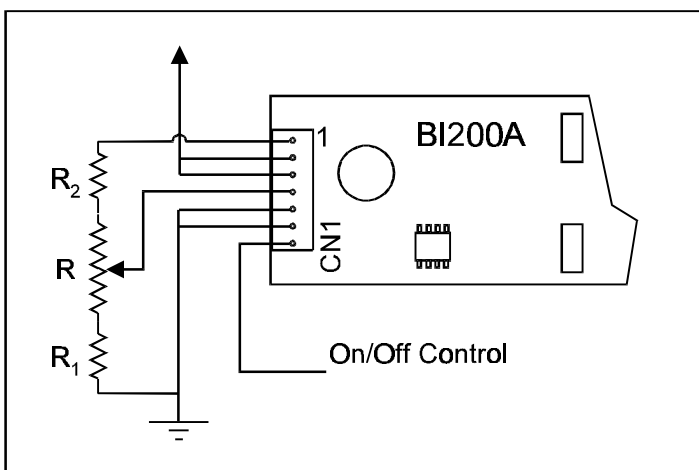


Fig. 5. Using a series resistor R₂ in the dimming circuit for de-rated brightness operation

$$(5 \times R_2) / (R_1 + R + R_2) = 0.32$$

$$[5 \times (R_2 + R)] / (R_1 + R + R_2) = 2.4$$

Again, if R = 10 KΩ, we obtain,

$$R_1 = 11.8 \text{ K}\Omega, \quad R_2 = 1.5 \text{ K}\Omega$$

Using R = 12KΩ and R₂ = 1.5KΩ, we have

$$\text{Maximum } V_d = 2.45\text{V} \quad \text{Minimum } V_d = 0.32\text{V}$$

This gives us a brightness adjustment range from 1,000 Cd/m² to 0.

The On/Off Control

All Landmark Technology inverters have an On/Off control pin on the input connector CN1 for backlight on/off control. To turn off the inverter and the backlight, the On/Off control pin is connected to ground (0V).

For BI200A and BI220A1 inverters, the On/Off control pin should be left floating (not connecting to +5V) in order to turn on the backlight and use the dimming control. If the On/Off pin is connected to +5V, the backlight will be on, however, the dimming voltage V_d is set to +5V all the time and the dimming function is disabled. In this sense, the On/Off control signal for BI200A and BI220A1 inverters is not TTL compatible. If it is necessary to make the ON/Off control TTL compatible, please refer to Tech note TK0500.

On the other hand, the On/Off control signal for BI224A, BI320A, and BI330A inverters is TTL compatible. To turn off the inverter, the On/Off pin is connected to 0V and to turn on the inverter, the pin is connected to +5V. The dimming control functions normally with the On/Off pin connected to +5V.

Backlight Life with PWM Inverters

In Landmark Tech note 801, we briefly described the lamp aging phenomenon due to repeated lamp turn on and turn off cycles. Typically, this type of aging phenomenon seldom occurs in normal LCD backlight applications since it takes

more than half million on/off cycles before serious lamp aging effect can be observed.

However, with a PWM inverter, the lamps in the backlight are turned “ON” and “OFF” more than 100 cycles per second. As a result, it takes only a few thousand seconds (or less than couple of hours) to accumulate a half million cycles. So, how about the life time issue with PWM inverters?

Our lamp scientist tells us that after the lamp is turned off, the gas plasma (a collection of positive and negative ions) in the lamp takes more than 10 msec to die. In general, the PWM On/Off cycle is shorter than that. As a result, the lamp is turned “ON” again before the plasma dies out completely. In this way, there is no “cold lamp start” or “hard lamp start” at each PWM cycle and therefore no life time issue.

Actual life test data on Landmark backlights driven by BI200A prototype PWM inverters over time period of 16,850 hours (about 2 years) show no major lifetime effect due to the lamp on/off cycles associated with the PWM dimming operation. So, the test data support the theory from the lamp scientist that the PWM dimming operation has in-significant impact to the backlight life.

For more detail information on lifetime discussions on Landmark VHB backlights and sunlight readable LCD modules, please refer to Tech Note TK801.