A whole new way to design backlight inverters for mobile computing applications

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Abstract

In today's mobile computing environment, solutions providing space savings and performance enhancement are key. Backlight inverter applications are particularly sensitive to space and can add unwanted power dissipation in a very confined space with no airflow, as in almost all cases, the backlight inverter is located in the notebook PC screen assembly. Added to this is the demand for larger displays in smaller chassis with more demands on maximum brightness capabilities and the ability to have linear brightness at very low dimming signals across the length of the lamp, with absolutely no flicker. There is a critical demand being placed on the backlight inverter to meet all of these criteria, which makes it extremely challenging for the design engineer.

A new way to design backlight inverters will be discussed, offering reference design solutions to overcome unwanted power dissipation, much improved power design simplicity, achieve much smaller total inverter solution size by up to 50%, and provide best in class display characteristics.

Introduction

The challenge for inverter design in space constrained environments.

In today's mobile computing environment, solutions providing space savings and performance enhancement are key. Backlight inverter applications for the notebook LCD screen are particularly sensitive to space and can add unwanted power dissipation in a very confined space, which has no airflow. As in almost all cases, the backlight inverter is located in the notebook PC screen assembly, where the demands for making larger displays in smaller chassis are increasingly common. This presents a difficult challenge for the power designer, as the real estate left for the backlight inverter is extremely small, and usually in a very awkward form factor. Since the inverter is usually located along the side of the screen assembly, it requires that the overall form factor be very narrow compared to its length. The inverter also needs to have a very low profile to address the demands of ultra-thin notebook PCs. To successfully design a functional backlight inverter in these form factors, approaching 10mm wide and 90mm long, and 7mm profile is one challenge, but to also achieve the best possible performance is yet another challenge. Backlight inverter performance is measured on the ability to attain maximum brightness at the lamp, and to achieve linear brightness across the lamp especially at low dimming signals. It becomes more difficult to achieve linear brightness as the screen size increase, due to the lamp characteristics. Figure 1 shows a simplified schematic of a CCFL lamp assembly in a notebook display.

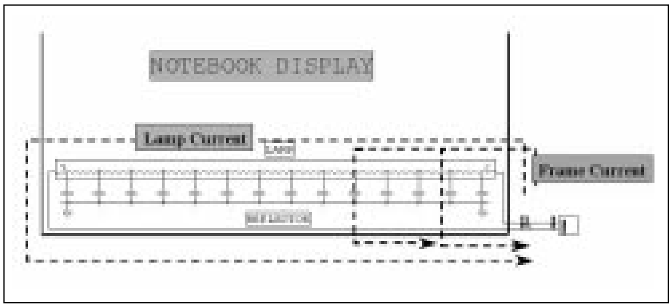

Figure 1 - Simplified schematic of a CCFL lamp assembly

The lamp itself is a rather complex load, made up from a capacitive and resistive network. The equivalent load can be re-drawn as shown in Figure 2.

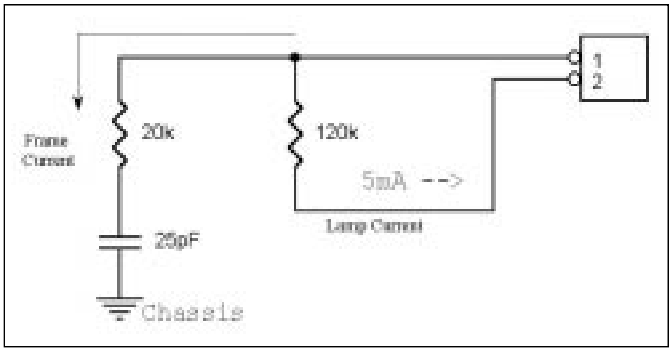

Figure 2 - Simplified schematic for equivalent load for a CCFL lamp

The fluorescent lamp is mounted along the length of the display, and nearly all notebook PCs use a single lamp to illuminate the screen. The lamp is normally wrapped in a reflective material that is conductive and grounded. The lamp itself will also be grounded at one end, and at a relative high voltage potential at the other end. The lamp is a resistive load, but the gap between the lamp and the reflector causes a capacitive coupling effect. Figure 2 shows the two basic paths for current flow. The first is through the length of the lamp, and this can be referred to as “lamp return current”. This is the current that will produce the light across the length of the tube, and the current that we would like to maximize, as the amount of current, and the way this current is controlled will determine the evenness of brightness at various dimming ranges and the maximum brightness of the lamp. The control over these elements will be detailed later in this paper. The second path for current is known as “frame current”. The frame current is the current flowing through the capacitive coupled path, from the lamp to the frame. This current will lead the lamp return current as a phase angle, basically because it will have a shorter path back to the inverter. At the high voltage end of the lamp, the frame current will be highest, which may cause extra illumination of the lamp at one end, if not controlled adequately. All the way across the lamp, the frame current will be present, but to a lesser degree, as the voltage potential decreases, all the way to where the lamp is grounded. The frame current may make the overall appearance of the screen look as though it is brighter at one end versus the other. This is of course an undesirable effect, and to this end, the ultimate goal is to minimize frame current, or frame losses. Any frame current, is taking away from potential lamp return current, and increasing the probability of uneven brightness across the lamp. This becomes even more difficult to control once you reduce the overall brightness of the lamp, if you are trying to extend the battery life. This will also be explained later in this paper.

Overcoming the power design hurdles to enable screen brightness.

There are several ways to design a backlight inverter, using existing topologies. Each has their merits, but there are also disadvantages with each of them. It will be explained how to improve backlight inverter design by implementing several innovative techniques, as follows :

a) PWM dimming control, rather than using adjustable DC level dimming.
b) Taking advantage of the system board power supplies rather than using a two stage power conversion in the screen assembly.
c) Optimizing the output frequency of the inverter.

a) Methods for dimming control of the lamp.

Dimming control is important because some users desire the ability to reduce the brightness of the screen in dark environments such as the cabin of an airplane at night or during a movie. The user does not need the maximum brightness to read the screen in a dark environment, and also it benefits the longevity of battery life whilst working in a portable mode.

Historically the dimming control of the lamp has been done using a DC level adjustment. The DC signal is usually generated on the system board, and is routed to the inverter which is in the screen assembly via wires. These wires are resistive, and will drop some voltage across the length of the wire. The DC voltage generated on the system board is essentially providing a feedback signal to the inverter, so that it can adjust the brightness of the lamp. Due to voltage drop on the wires, the feedback signal received at the inverter, will be distorted, and therefore the inverter will adjust to the wrong brightness level. This reduces the ability to provide very tight control for overall lamp brightness. Also, a DC level adjustment control methodology is quite lossy. The DC level feedback to the inverter causes the inverter to reduce the lamp current by some percentage of the full rated lamp current to adjust the brightness. Unfortunately, since the adjusted lamp current is flowing to the lamp for 100% of the time, it causes the frame current to flow for 100% of the time. Anytime frame current is flowing there is an associated loss. As such, this form of control is in-efficient, and reduces battery life.

PWM dimming control can be implemented to overcome these issues,. This is achieved by taking advantage of various PWM frequencies that are readily available on the system board of the notebook PC, from components such as graphics cards or keyboard controllers. There are usually high and low frequencies available, in the order of 16kHz or 280Hz. For purposes of this example it is assumed that 280Hz is available on the system board. As shown in figure 3, the PWM signal can be modulated to achieve lamp dimming. Operating toward 100% duty cycle will achieve maximum brightness, and down toward 0% duty cycle will achieve minimum brightness, though operating down below 10% is impractical, due to reasons that will be explained.

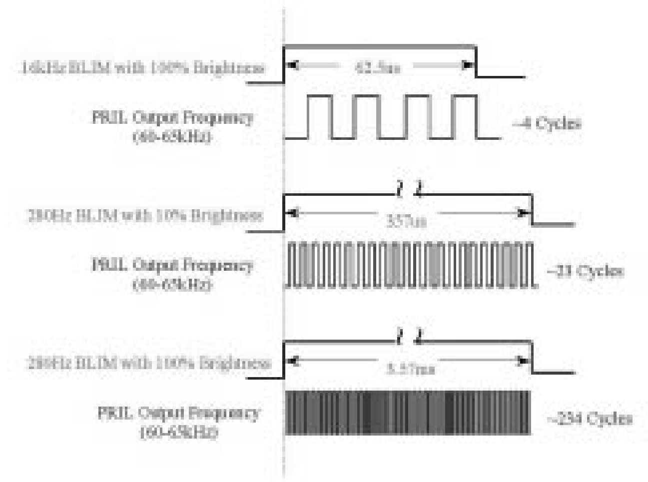

Figure 3 - Diagram to illustrate PWM dimming (PWM signal, with PRIL signal)

The nature of the PWM dimming control does not have any of the inaccuracy issues that DC level control has. The operation of the inverter toggles the primary side of the transformer to deliver an AC current to the lamp. For the PWM controlled system, the dimming signal is modulated, and the transformer is only toggled during the on-time of the modulated dimming signal. The average current to the lamp is then altered, as a factor of the duty cycle that is set by the dimming signal. One benefit of this mode of operation is that the current to the lamp is only flowing during the on-time of the duty cycle, and therefore frame current is not continuously flowing if the dimming signal is reduced below 100%. The benefit becomes even greater as very low dimming signals are approached. If current is not flowing to the lamp continuously, then longer battery life can be realized.

The reason that a minimum 10% duty cycle is recommended is as follows: The lamp needs a certain amount of time to “strike” or to light after the initial current is applied to the lamp. There are two conditions where this applies and the times are different. The first is start-up and the second is at each new dimming signal pulse. At the beginning of each new dimming signal pulse, the transformer begins to toggle and deliver current to the lamp. Frame current will flow almost immediately, but it will take some time for the lamp return current to flow the entire length of the lamp and achieve regulation. The speed at which the lamp can achieve regulation is controlled by the inverter. By using a PWM approach, the lamp current can start flowing within the 2nd toggle of the transformer, and can be in regulation within 50usec. An optimized inverter will have an output frequency, which is the toggle frequency of the transformer, of around 60-65kHz. The time it takes to get the lamp into regulation will limit the minimum dimming signal that can be applied to the inverter. If operation is allowed below a certain dimming signal, then uneven brightness of the lamp or flicker may occur. Figure 4 shows the waveforms for the beginning of a new dimming signal pulse.

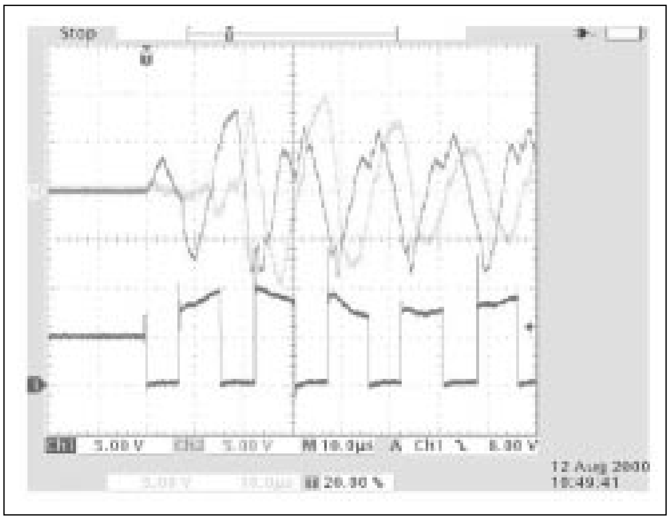

Figure 4 - Waveforms for the beginning of a dimming signal pulse.

If a higher frequency of about 16kHz PWM frequency is the only signal available on the system board, then it is desirable to convert this to a slower dimming signal, like 280Hz, and feed that to the dimming control input of the inverter. The reason is that the 280Hz will allow much more time for dynamic adjustment of brightness. Even if the 280Hz signal is adjusted to 10% duty, then the period of the pulse will be about 357usec, which allows plenty of time for the lamp to become regulated. If the 16kHz signal were used for controlling brightness, then at 10% duty cycle, there would only be about 6usec available to get the lamp into regulation, which is very impractical.

b) Utilize the available power

Notebook PCs have a variable input power source, either obtained from the battery or the AC adapter, and both run at different voltages. Some backlight inverter systems run directly from the input, whereby they need a two stage conversion. The first stage is a current source power supply, so it can provide a constant current to the inverter, and handle the variable input voltage nature of the notebook PC. The second stage is the inverter that converts the power to provide AC to the lamp. The first stage creates unwanted power dissipation in the screen assembly. Since there is typically no airflow present, coupled with the fact that the space is extremely limited, it becomes very difficult to deal with the heat in the screen assembly. By removing the first stage constant current power supply, the overall power consumption in the screen assembly can be reduced by up to 25%, which equates to 4W reduced to 3W.

The more efficient architecture can be implemented by utilizing the 5Vdc system board rail as the first stage. This converter usually has excess capacity, and is generally designed for 5A or more. The backlight inverter needs only a fraction of this available power, typically drawing just 1A rms primary current. Additionally, the system board is much better equipped to handle power dissipation, as it can generally handle in excess of 26W. Also, by using the 5V rail, the input protection circuit of the 5V rail is automatically used, eliminating the requirement for an additional fuse that would have been required if using the constant current power supply directly from the input.

As space is of a premium in the display assembly, the removal of a power stage will allow for better utilization of the actual display area to the screen chassis size.

c) Selecting output frequency.

Lamp specifications have requirements on them for output frequency of the inverter. These requirements can range from <40kHz up to >90kHz. There are trade-offs for designing around each end of the spectrum, see figure 5.

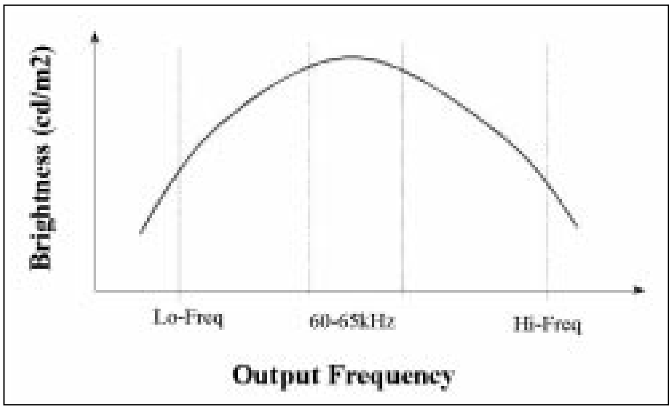

Figure 5 - Output frequency curve (brightness cd/m2 versus frequency)

For the high frequency end, the magnetic components could be reduced in size, but there would be more frame losses. For the lower end of the spectrum the magnetic size would have to be larger, but the frame losses would be reduced. For each end of the spectrum the lamp brightness would be lower than that of the mid-point of the spectrum. The optimum area is at the mid-point, around the 60-65kHz range, where frame losses, magnetic size and lamp brightness are all beneficial.

Solutions that can enable easy, efficient, small backlight inverter designs.

International Rectifier's new iPOWIRTM Technology provides an example of a product that can offer all of these benefits for backlight inverter applications, eliminating extra power conversion in the display assembly and utilizing motherboard power, using a PWM dimming control scheme and optimizing output frequency for the best brightness. Housed in a BGA package this solution offers an extremely simple building block approach to power design, saving board space and design time and effort. The only elements needed to complete the backlight inverter circuit are the filter and bulk capacitors, the transformer, and two connectors. Most backlight inverters require a very complex discrete component design, that takes a large amount of power design expertise to complete, and achieve the best performance. The overall inverter solution is shown in figure 6, compared to a traditional discrete solution.

Figure 6 clearly shows the overall simplicity and space savings of implementing an integrated BGA style solution. The merits to this approach are that solutions can be brought to market much faster, since the overall design can be done quicker by simplifying the power design greatly. The space savings also allow the continued reduction in overall display chassis size.

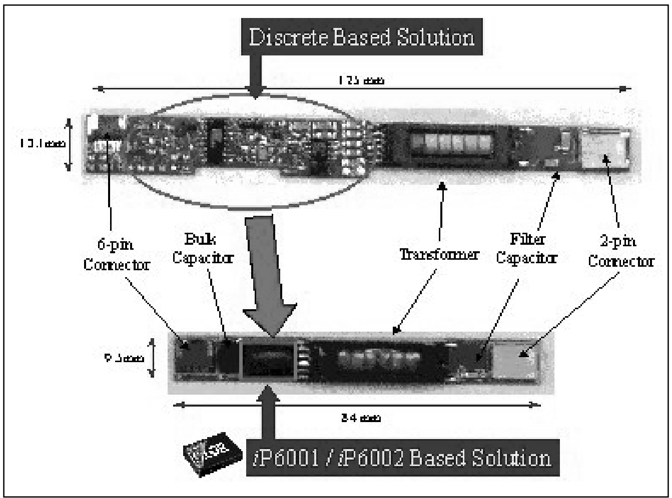

Figure 6 - Photo of the iP6000 series backlight inverter assembly versus a discrete based solution.

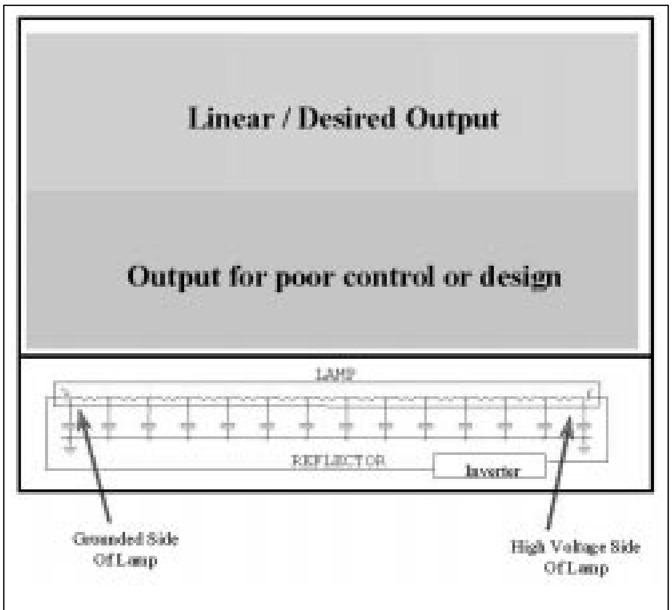

Figure 7 - Graphical representation of a notebook display

An extended dimming range can be brought down to 10%, saving battery life, and maintaining linear even brightness on the display with this solution as shown if Figure 7.

Able to operate in many end system environments, the PWM dimming feature relies on the PWM clock frequencies available in the end system, and can be configured to use the most common PWM frequencies available. The iP6001 is optimized for 280Hz dimming frequency, and operates in a direct drive mode, i.e. the input PWM signal, is directly translated to the output. The iP6002 is optimized for high frequency input dimming frequencies, but the output is translated to a lower 280Hz dimming frequency. The input frequency can be either 15.6kHz, 18.6kHz or 23.4kHz, and the iP6002 is easily configured via select pins to operate at each of these frequencies. For any given system there will be one or all of these frequencies available from components such as graphics cards or keyboard controllers, all that is needed is for the iP6001 or iP6002 to be selected based upon which frequency is available.

Similarly, the lamp current can also be configured via select pins, and is set depending on the requirements of the lamp. These solutions can be easily configured for 4mA, 5mA or 6mA lamp current.

Safety requirements are always important to address, especially with the nature of a high voltage output of the inverter. These solutions both offer overload protection, i.e. in the event of a foreign object, like a finger, being applied to the output terminals of the inverter. The system will shutdown once this is detected, and will allow enough time for the foreign object to be removed before attempting to strike the lamp again. Also, in the event of an open lamp condition, the inverter will attempt to strike the lamp for a short period of time before shutting down, if there is no lamp present

By implementing some of the ideas in this paper, it is possible to obtain higher levels and better control of display brightness, whilst improving overall system efficiency and enabling much faster design cycles for next generation notebook systems.

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Introduction

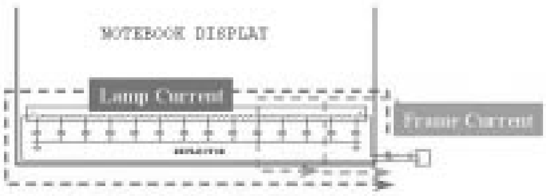
The challenge for backlight inverter designs

- Power dissipation in confined space with no air flow
- Larger screens with less space for inverter assembly
- Awkward form factor requires narrow and low profile assembly
- Size approaching 10mm x 90mm x 7mm

Inverter performance expectations

- Maximum lamp brightness
- Linear brightness across screen even at low dimming range
- Efficient power conversion

Lamp Characteristics

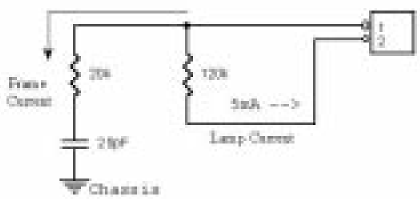


- Complex capacitive and resistive network
- Normally single lamp for notebook computers
- Lamp surrounded by reflective material that is conductive and grounded
- Grounded on one end with high voltage at the other end
- Lamp is resistive, but gap between lamp and reflector is capacitive

Two Current paths

Lamp return current

- Produces light across length of lamp
- Control will determine evenness of brightness



Frame Current

- Undesired
- Capacitive coupled
- Current is greatest at high voltage end of lamp
- Less current flows at grounded end of lamp
- Could cause uneven brightness across lamp
- Starts to flow immediately after power is applied

Overcoming the Design Challenges

This paper will explain the benefits of:

- Implementing PWM dimming control instead of DC level dimming
- Taking advantage of system board power instead of direct two stage conversion
- Optimizing the output frequency of inverter

Dimming Control

Traditional Method

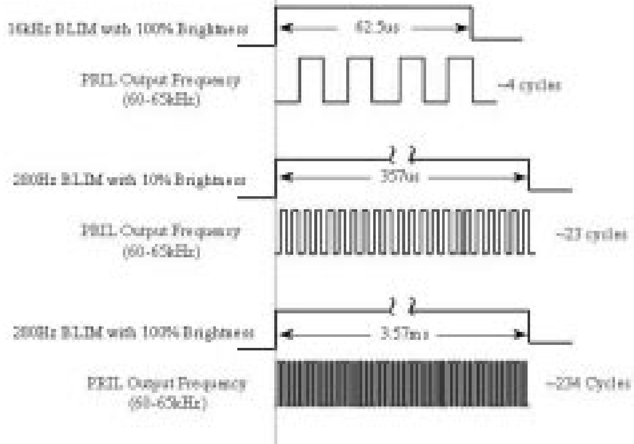
- DC level adjustment
- DC Signal usually generated on system board
- Voltage drop on wires distort signal
- In-efficient because lamp current and frame current flow 100% of the time

PWM Method

- Use existing PWM frequencies from graphics cards or keyboard controllers
- Signals can be modulated to achieve lamp dimming
- Reduces frame losses when operating at <100% brightness

Optimized Output Frequency

- Not much opportunity to dim signal below 100% brightness and achieve regulation & linear brightness.
- Better to convert to lower frequency



PWM Dimming Control

Explanation

- Inverter toggles primary of transformer to deliver AC current
- Transformer is only toggled during the on-time of dimming signal
- Average lamp current is altered as factor of duty cycle
- Frame current only flows during on-time
- No distortion in dimming signal

Limitations

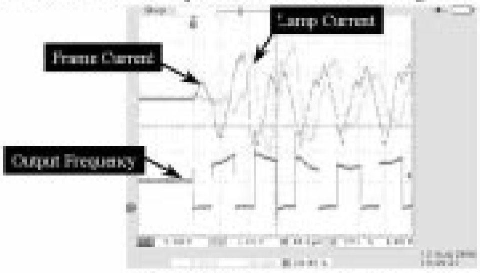
- Need time to "strike" lamp after initial current is applied

  Two conditions where this applies

  - Start-up (also occurs with DC level dimming)
  - Each new dimming signal pulse

PWM Waveforms

- At each new dimming signal the transformer toggles and begins delivering current to lamp
- Frame current begins flowing almost immediately, followed by lamp current
- Takes time for lamp current to flow entire length of lamp and achieve regulation

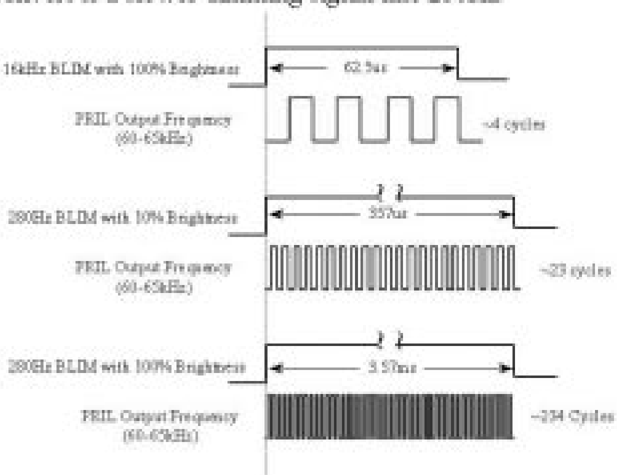


Waveforms showing PRIL (CH1), frame current (CH2) and lamp current (CHMath)

- With PWM, lamp current can start by second toggle
- Achieve Regulation within 50us
- Near sinusoidal frame current

Optimized Output Frequency

- Regulation time will limit minimum dimming signal
- If the only BLIM signal available is high freq., then it is desirable to convert to a slower dimming signal like 280Hz



Input Power Choices

Two stage conversion direct from battery

- Some inverters run directly from variable input
- Require two stage conversion
- First stage - constant current source
- Second stage - converts power to provide AC to lamp
- First stage creates unwanted power dissipation it the screen assembly
- Difficult to remove heat since no airflow and very limited space

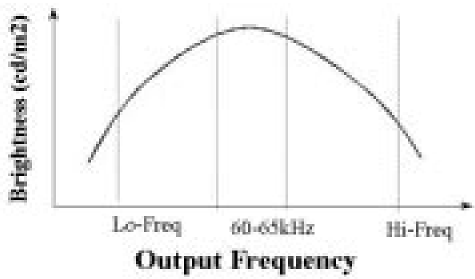
Single stage conversion from 5V rail

- Most systems have excess capacity at this rail
- Can reduces power dissipation from screen assembly by up to 25% (~1W)
- System board is better equipped to handle the heat (≥26W)
- 5V rail already has protection circuit built in (i.e. fuse)

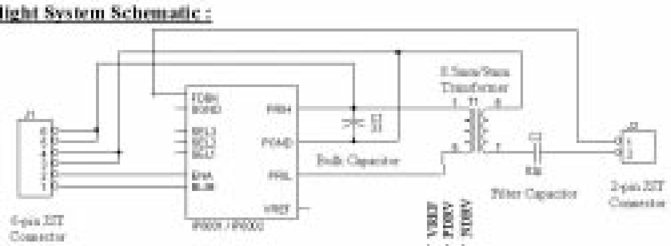
Output Frequency Selection

Requirements range from about 40kHz to 90kHz

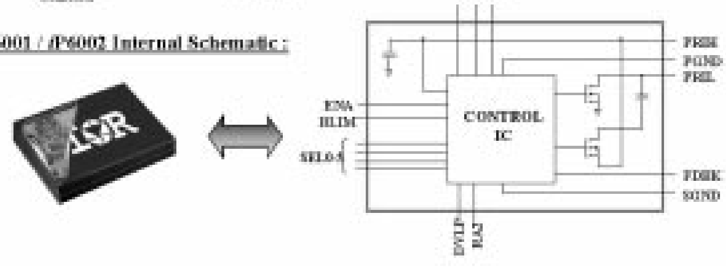
- At high end magnetics and filters could be smaller
- At low end frame losses are lowest
- At mid point lamp brightness is optimum



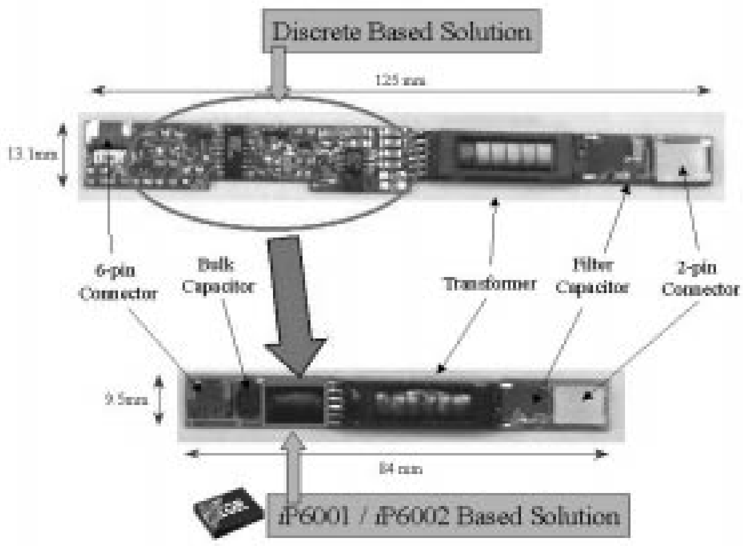
Backlight System Schematic :



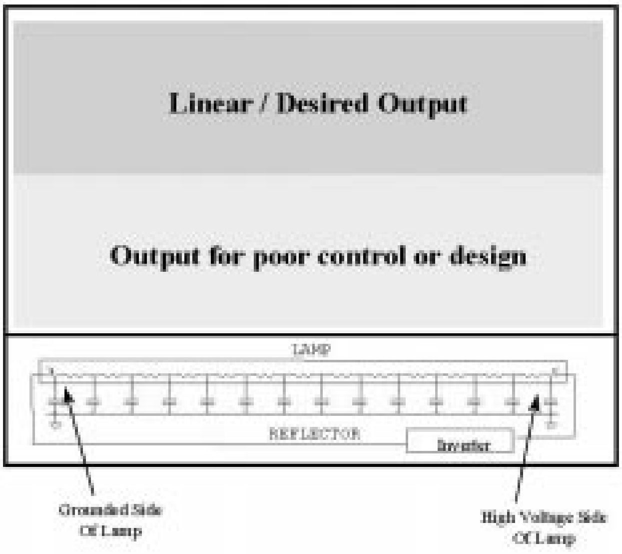
iP6001 / iP6002 Internal Schematic :



Solution Comparison



Graphical representation of notebook display



Specifications :

	Min	Typ	Max
Input Voltage	-	5V	7V
BLIM Frequency - iP6001	280Hz		
BLIM Frequency - iP6002	15.6kHz, 18.6kHz or 23.4kHz		
Output Frequency	60kHz	62.5kHz	65kHz
Output Dimming Frequency	270Hz	280Hz	290Hz
Primary RMS Current	-	-	1.5A
Input Power	-	-	6W
Operating Temperature T_{PCB}	0°C	-	90°C

iP6001 / iP6002
MOSFETs
+ Control IC + Passives

Features :

- 4, 5 and 6mA selectable lamp current
- Overload protection
- Open lamp shut-down
- 15:1 Dimming Range*
- Linear brightness, at low dimming signal (selectable BLIM)*.
- Development pin (DVLP) allows easy design of external transformer
- Layout non-critical

Conclusion

- PWM Dimming provides best control and less power consumption
- Using 5V system power for input reduces power dissipation at screen assembly
- The iP6001 & iP6002 provide solutions that:
  - Minimize space requirement
  - Minimize design complexity
  - Provide linear brightness
  - Provide efficient power conversion