COLD CATHODE FLUORESCENT LAMPS (CCFLs)

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ABSTRACT

Cold Cathode Fluorescent Lamps (CCFLs) 3.0mm - 6.5mm in diameter are commonly used in a variety of backlight configurations for LCD displays; as light sources for scanners and CCD cameras. CCFLs exhibit unique electrical, photometric, and environmental characteristics, which present a challenge for designers.

Aspects of diameter and length versus voltage, current and luminance are examined. Ambient temperature directly influences CCFL characteristics; lamp performance in relation to temperature is a necessary consideration for many designs. A basic CCFL drive inverter configuration is given with an examination of a vacuum thermocouple current measurement scheme.

INTRODUCTION

Much attention has been given to the development of inverters to power Cold Cathode Fluorescent Lamps (CCFLs) to achieve high efficiency in portable products. CCFLs are found in an array of consumer, commercial, industrial, and military devices.

An understanding of the lamps characteristics are essential for selection of the best CCFL and inverter for a given application. Being a mercury vapor discharge light source CCFLs can present design challenges, especially when low temperature operation is a design criteria. Aspects of temperature performance of the CCFL are examined.

For an understanding of 3.0mm diameter CCFLs, which are increasingly found in LCD display modules, and to aid in the selection of a lamp diameter for a particular application, a comparison of photometric, electrical, and temperature characteristics are given for a 3.0mm and a 6.5mm lamp.

Results of experimentation to enhance low temperature performance by increasing lamp current in relation to reduced lamp temperature are given. The means of lamp voltage and current measurement for the CCFLs tested is outlined.

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PHOTOMETRIC AND ELECTRICAL CHARACTERISTICS

Smaller diameter lamps typically have a higher operating voltage and a higher surface intensity (Cd/m2), when compared to their 6.5mm counterparts. Comparative data for electrical and photometric characteristics are given in Table 1 and 2 for a 3.0mm and a 6.5mm lamp with a typical length of 160mm. The increase in voltage and intensity are consistent with lamp diameters descending from 6.5mm to 3.0mm. Due to the brevity of this paper, a comparison has only been made between these two sizes.

With high efficacy, being a goal in the design of most portable products it would be desirable to select the CCFLs which converts its input power most efficiently into light.

Most discussions to date dealing with lamp and inverter efficiency use the CCFL backlight LCD's surface intensity, Cd/m2 (NITS) to determine efficiency. Efficiency of the lamp is determined by using the lumen output per watt of input power to the lamp expressed as LPW. The lumen measurement of the lamps is the total light output flux as measured in an integrating sphere.

The higher operating voltage of the 3.0mm lamp inherently produces a higher input wattage rating than that of its 6.5mm counterpart at the same 5mA drive level, as shown in Tables 1 and 2. At the 5mA drive level the 3.0mm lamp has a higher LPW rating therefore operating with greater efficiency.

Lamp manufacturers catalog specifications are often approximations calculated from average volt-per-mm of lamp length. For variations in length from the 160mm test lamps, the average voltage change per each 1mm change in length of the 3mm diameter lamp is 1.75 volts/mm. For the 6.5mm lamps, the average voltage change per each 1mm change in length is 1.00 volt/mm.

In Table 1 and 2, data is given for the tested lamps at initial operation and at 168 hour (1 week) intervals to 504 hours, presenting changes in the characteristics over this time period in which the lamps stabilizes. The tests were performed at room ambient temperature of 25° centigrade, using the average of three randomly selected lamps of each type.

The equipment used to obtain the light measurements consisted of a, "Western Photometric", Model 526A mod 3, 14 Inch Integrating Sphere and a "Photo Research", Model PR-704, SpectraRadiometer.

The voltage and current measurement instruments are described later in this paper.

Hours	Vrms	Lumen	LPW	Cd/m2
0	***356.3***	***75.32***	***42.3***	***21837***
168	***351.3***	***74.28***	***42.3***	***22670***
336	***348.7***	***72.94***	***41.8***	***22307***
504	***344.0***	***72.69***	***42.3***	***21960***

Table 1: 3.0mm x 160 mm CCFL @ 5mA

Hours	Vrms	Lumen	LPW	Cd/m2
0	***274.3***	***56.15***	***41.0***	***9330***
168	***273.3***	***54.77***	***40.1***	***9240***
336	***271.7***	***53.64***	***39.6***	***9189***
504	***267.7***	***53.28***	***39.8***	***9170***

Table 2: 6.5mm x160 mm CCFL @ 5mA

LAMP CURRENT MEASURMENT

The high voltage, low current, high frequency characteristics of the quasi-sinusoidal waveform used to drive the CCFL creates some challenges for electrical measurement. The typical Royer CCFL inverter powers the lamp at a frequency of 20-60 kHz with the lamp inherently generating a considerable amount of harmonics often into the low megahertz range. The current and voltage must be measured in a manner, which loads the circuit as little as possible to prevent measurement error.

For voltage measurements a Hewlett-Packard HP3400, voltmeter with a matched Tektronix P6007 probe is used. Current measurements for CCFLs are critical in that the manufacturers photometric specifications are typically established at a given current drive. For evaluation of the lamps photometric and electrical data, lamp current measurements were made using a vacuum thermocouple (VTC) along with a lab quality digital voltmeter.

The VTC converts the rms. (heating value) of the AC current to a proportional DC voltage, regardless of wave form shape and frequency well into the MHz range. The VTC functions by producing a DC millivolt signal from a thermocouple junction that is increased or decreased in temperature in relation to the sample current passing through a heater wire. The VTC thermocouple junction and heater are mounted inside an evacuated glass envelope.

Due to the influence of ambient temperature changes in relation to the VTC's accuracy, a precision current source is used to calibrated and verify the VTC and related circuitry before and after measurements.

The VTC is effected by ambient temperature changes at a rate of .2% per degree Centigrade. A VTC should give results with good accuracy when used in an ambient temperature at or relatively close to the temperature at which it was calibrated. The devices are limited by a rapid decrease in accuracy with currents in excess of their rating. Good accuracy is obtained with currents measured below the devices rating. Typical VTC's used for CCFL testing are rated at 5ma or 10ma.

The VTC used to perform the testing was a 5ma input and 7mv output device, calibrated using a precision current source providing a 1mA and 5mA DC input to the VTC heater. The output was read on a standard lab DVM.

A pictorial view of a VTC, along with a schematic of a typical test set up are provided in Figures 1 and 2.

Please refer to the references for additional information on the utilization of VTC's.

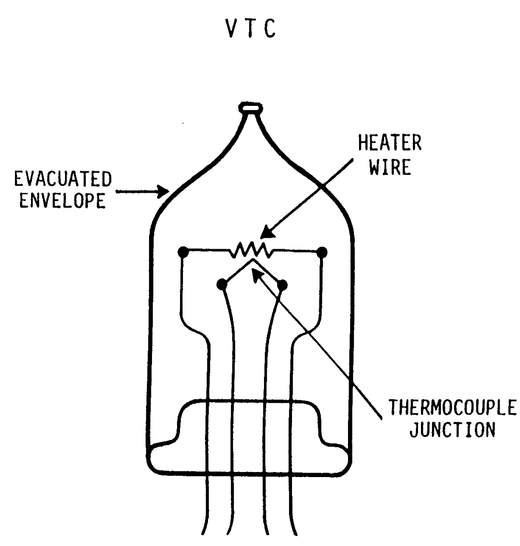

Figure 1

LAMP CURRENT MEASUREMENT (cont)

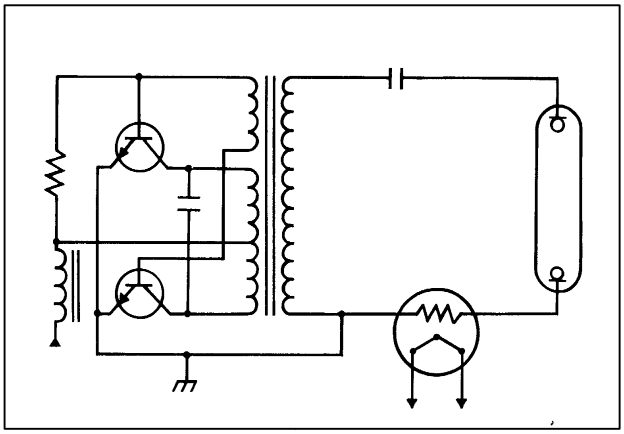

Figure 2

Since the VTC is a square law device one-half of the input current produces one-quarter the output voltage. The formula for calculating the actual input current from the observed output voltage is as follows:

Square Law Formula

E = Output Voltage
I = Input Current
k = Conversion Constant

$$E = kI^2$$

$$\therefore\ I = \sqrt{\frac{E}{k}}$$

Example:
Measured Voltage = $4.91e^{-3}$ Volts
Conversion Constant = 280
(Nom. for VTC used)

$$I = \sqrt{\frac{4.91e^{-3}}{280}}$$

$$I = \sqrt{1.7536e^{-5}}$$

$$I = 4.188e^{-3}\ \text{amps}$$

Note: The accuracy of the measurement may be increased if the value of "k" is calculated for each individual thermocouple at the time of calibration. The following method may be used to accomplish this: apply a known input current through the heater element of the vacuum thermocouple, measure the actual output from the thermocouple junction, and using the following calculate a new value for "k".

Formula to Determine Constant "k"

v = measured output voltage
i = known input current

$$k = \frac{v}{i^2}$$

measured v = $6.93e^{-3}$
known i = $5.00e^{-3}$

$$\therefore\ k = \frac{6.93e^{-3}}{\left(5.00e^{-3}\right)^2}$$

$$k = 277.2$$

substituting the new value of k

$$I = \sqrt{\frac{E}{k}}$$

$$I = \sqrt{\frac{4.91e^{-3}}{277.2}}$$

$$I = \sqrt{1.7713e^{-5}}$$

$$I = 4.209e^{-3}\ \text{amps}$$

LAMP TEMPERATURE COMPENSATION

One of the characteristics of the CCFL is its diminished light output when at low temperatures. As the lamp temperature approaches 0° centigrade a substantial reduction in light output is observed. If the application requires operation at these low temperatures a means of thermal compensation may be required.

To date, most of the low temperature specifications are met by the use of an external heater. Another method of compensating for the reduction in light output is examined here.

If the lamp current drive is increased when the temperature is below nominal, two influences are observed; the first being the increase in self heating of the lamp, and the second being the enhanced stimulation of the mercury arc.

Testing was performed to characterize the affects of increasing the current drive. This testing was performed using a 6.5mm x 160mm lamp. This lamp was placed inside a rectangular acrylic enclosure with a clear window. The enclosure had a volume of approximately six (6) cubic inches.

The enclosure provided a method of preventing convection losses from the airflow inside the temperature test chamber. A thermocouple was attached to the lamp surface. The chamber temperature was maintained at 0° centigrade throughout the test period. The lamp surface temperature, in degrees centigrade, and the lamp surface intensity, in Cd/m2, was recorded at 15 second intervals for a period of 10 minutes. The test was performed on the lamp at a drive current of both 5ma and 10ma.

The results of these tests indicate that a substantial increase in light output can be realized,
when comparing the surface intensity of the lamp with 10ma and 5ma drive current.

Chart 1, below, shows the lamp performance over the 10 minute test period. By comparing the surface intensity after the 10 minute period to the surface intensity at an ambient temperature of 25° centigrade (see Table 2), it can be observed that the 6.5mm lamp reached 27.8% of the 25° C surface intensity at 5ma, and 58.9% at 10ma.

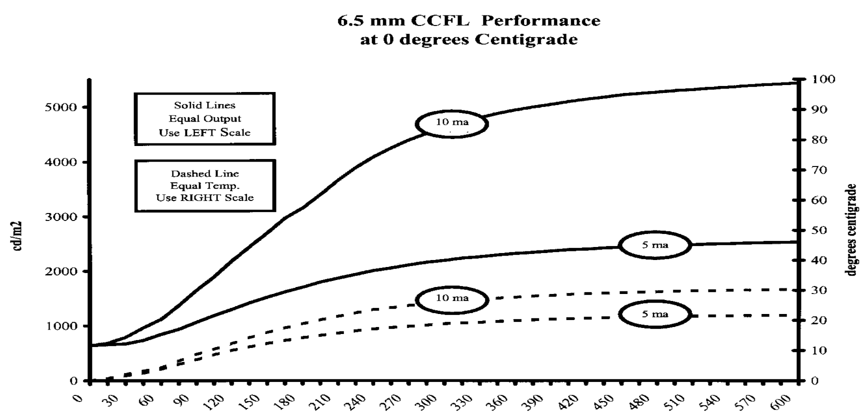

Chart 1

APPLICATION CONSIDERATIONS

Often an application will require a lamp with a particular photometric characteristic. When used to backlight a LCD using a single lamp, with the light gathered and evenly distributed via a light pipe, the 3mm lamp with high surface intensity and compact size is well suited for this type of application.

Other applications, such as digital scanners and CCD camera illuminators, often function best with the total flux of light evenly dispersed at close working distances. For these types of applications the 6.5mm lamp, with inherently lower surface intensities and the total light flux emitted from a larger surface area, might be the lamp of choice.

CONCLUSIONS

The characteristics of CCFLs vary in relationship to size and the environment. The actual application and the level of light required will influence the current necessary for a particular lamp.

To design for best efficiency, the maximum drive current along with the lamp voltage for the chosen lamp diameter should be considered when designing the inverter.

Increasing the lamp's current drive at low temperatures may be a viable method of output compensation for some applications. The increase in output is derived from both the enhanced stimulation of the mercury arc, and the lamp's self heating.

It is entirely possible to utilize a vacuum thermocouple device for accurate current measurement when using the Royer type inverter circuit to provide the lamp drive.

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PRIOR PUBLICATION

This article was previously published in the 'Proceedings of the Fourth Annual Portable by Design Conference' Penton Publishing, March 1997

TYPICAL JKL COLD CATHODE FLUORESCENT LAMPS

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