NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Specifier Reports

Dimming Electronic Ballasts

High-frequency dimming ballasts designed to operate fluorescent lamps

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Introduction

Dimming electronic ballasts for fluorescent lamps can save energy and increase the range of illuminances provided by a lighting system. The ability to dim lamps can enhance the versatility or aesthetics of spaces such as conference rooms, offices, classrooms, and residences. Dimmed lamps require less power so a dimming system saves energy relative to a non-dimming system, assuming the same hours of use. Energy savings, and thus cost savings, can be increased by controlling dimming electronic ballasts with occupancy sensors to dim lamps when no motion is detected in a space, photosensors to dim lamps when daylight is available, or timers or energy management systems (EMS) to dim lamps during peak demand hours or at night.

Dimming electronic ballasts that reduce light output to 20% of maximum are widely available and are suitable for most energy-saving applications. Where a greater dimming range is desired, at least two ballasts are available that dim to less than 1% of maximum light output. Dimming electronic ballasts can dim lamps continuously, with manual slide dimmers, for example, or in steps, with two or more discrete light output settings.

In spaces such as industrial inspection areas or hospital examination rooms, maintaining illuminance is important. Photosensor-controlled dimming electronic ballasts can compensate for reduced light output due to the aging of the lamps and the accumulation of dirt on luminaire surfaces by gradually increasing the power to lamps over their life.

Most dimming electronic ballasts are silent, cause no perceptible flicker, and do not significantly reduce lamp life. Thus they represent a significant improvement over dimming magnetic ballasts, many of which can dim only to 50% light output, emit an audible hum, and may cause dimmed lamps to flicker. Dimming magnetic ballasts may also significantly reduce lamp life.

According to manufacturers surveyed by the National Lighting Product Information Program (NLPIP) in 1994, dimming electronic ballasts designed to operate two 4-foot (ft)[1.2-meter (m)] T8 lamps represent approximately 80% of the dimming electronic ballast market. However, dimming electronic ballasts are also

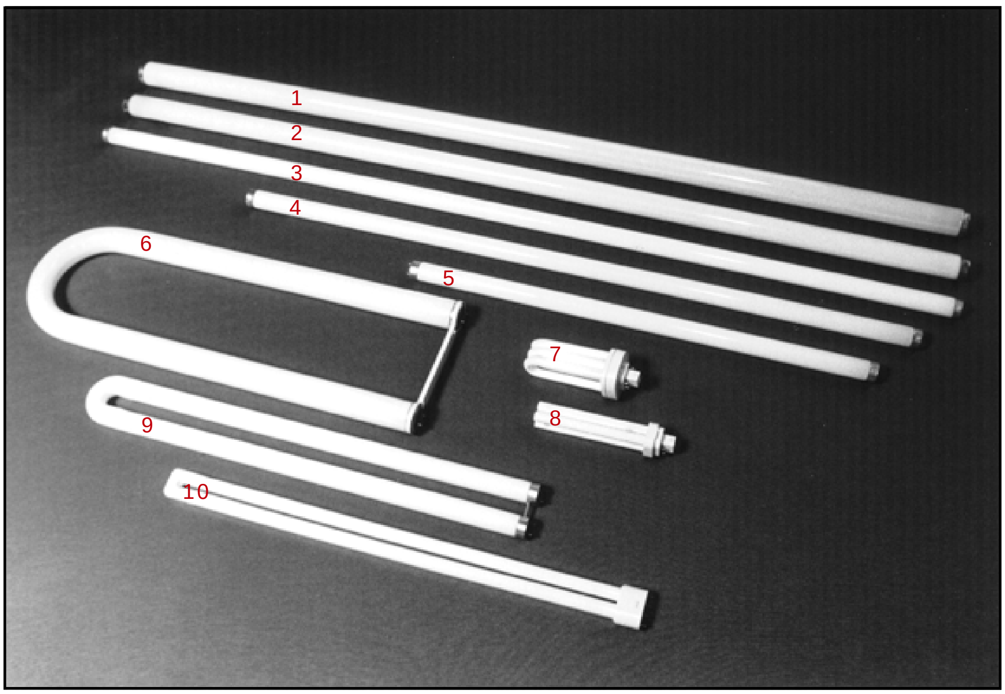
Dimming Energy-Saving Lamps

"Energy-saving" lamps, including 34- and 25-W T12 lamps, use krypton gas to reduce the lamp operating voltage and lamp power. These lamps have a transparent conductive coating on the lamp tube to aid lamp starting and operation. According to the IESNA (1993), these lamps should not be used in dimming systems, unless so recommended by the dimming ballast manufacturer. NLPIP also recommends that these lamps be avoided in dimming systems, because they can be difficult to start, are more prone to flicker, and may have reduced lamp life.

available for most common fluorescent lamp types. Figure 1 shows several fluorescent lamp types for which dimming electronic ballasts are available. For the manufacturers of ballasts that NLPIP tested for this report, Table 1 shows which ones offer ballasts that are compatible with different quantities of T12, T10, T8, and T5 long twin-tube lamps. All manufacturers that are listed offer both 120- and 277-volt (V) versions of these ballasts. Presently, dimming electronic ballasts for 347-V operation (a common operating voltage in Canada) are not available. These manufacturers and others may also offer dimming electronic ballasts for 13-, 18-, and 26-watt (W) four-pin compact fluorescent lamps (CFLs).

This issue of *Specifier Reports* includes manufacturer-provided data for 120-V, continuous dimming electronic ballasts designed to operate two F32T8 lamps, and the results of NLPIP's evaluations of such ballasts from six manufacturers. Dimming electronic ballasts from different manufacturers operate lamps and interpret signals from control devices differently. The compatibility of dimming electronic ballasts with control devices such as manual dimmers, photosensors, occupancy sensors, and EMSs also varies. This issue of *Specifier Reports* explains the performance characteristics of dimming electronic ballasts and describes the differences between ballasts, so that specifiers can more confidently select dimming ballasts for their needs.

Figure 1. Types of Dimmable Fluorescent Lamps



Some of the lamp types for which dimming electronic ballasts are available: 1 F40T12; 2 F40T10; 3 F32T8; 4 F25T8; 5 F17T8; 6 FB40T12; 7 CFM26W; 8 CFQ26W; 9 FB32T8; 10 FT39T5

Table 1. Availability of Dimming Electronic Ballasts for Different Fluorescent Lamp Types

Lamp Type	Number of Lamps	Advance Transformer Co.[a] (708) 390-5000	Electronic Ballast Technology, Inc. (708) 390-5000[b]	ETTA Industries, Inc. (303) 444-2244	Lutron Electronics Co., Inc. (800) 523-9466	Motorola Lighting, Inc. (708) 215-6300	Stocker & Yale[a] (603) 893-8778
F40T12	1	●[c]		●[c]	●		
	2	●[c]		●[c]	●		●
	3	●[c]					●
F30T12	1	●[d]			●		
	2	●[d]			●		
	3	●[d]					
F40T10	1	●		●			
	2	●		●			●
	3	●					●
F40T8	1				●		
	2				●		
F32T8	1	●		●	●		
	2	●	●	●	●	●	●
	3	●		●	●		●
F25T8	1	●		●	●		
	2	●		●	●	●	●
	3	●		●	●		●
F17T8	1				●		
	2				●	●	
	3				●		
FT50T5	1			●	●		
	2			●	●		
FT40T5	1			●	●		
	2	●		●	●		
	3				●		
FT39T5	1	●		●	●		
	2	●		●	●		
	3	●			●		
FT36T5	1	●		●			
	2	●		●			
	3	●					
FT32T5	1			●			
	2			●			
	3			●			
	4			●			

Dimming electronic ballasts are not compatible with instant-start lamps.
NLPIP obtained the information in this table from ballast manufacturers' catalogs, and confirmed it with each manufacturer.
The ● indicates that the product was available as of September 1995. Telephone numbers are accurate as of October 1995.

[a] Manufacturer claims that its ballasts for linear fluorescent lamps also operate equivalent U-shaped lamps.
[b] Electronic Ballast Technology, Inc. merged with Advance Transformer Co. in 1994. Telephone number is for Advance Transformer Co.
[c] Manufacturer claims that this ballast also operates 34-W energy-saving F40T12 lamps.
[d] Manufacturer claims that this ballast also operates 25-W energy-saving F30T12 lamps.

Electrodes: Cathodes and Anodes

Throughout this report, NLPIP uses the term *electrode* to describe both the cathode and the anode. A fluorescent lamp has two electrodes, one at each end of the glass tube. One electrode, called the cathode, emits electrons and the other electrode, called the anode, gathers them. Fluorescent lamps are operated on alternating current, so the two electrodes alternate serving as cathode and anode.

Ballast Technology

A ballast for a fluorescent lamp has two primary functions: it provides a high initial voltage to start the lamp, and it regulates lamp current during operation. Magnetic ballasts typically operate lamps at 60 hertz (Hz). Common electronic ballasts convert 60-Hz line voltage to a much higher frequency, between 19 and 100 kilohertz (kHz). At these frequencies, lamp efficacy (lumens per watt) increases by 10 to 15% relative to 60-Hz operation. High-frequency operation also eliminates the perceptible lamp flicker that is associated with low-frequency ballasts because the lamp phosphors are refreshed more often. Electronic ballasts also operate more quietly and generate less heat than magnetic ballasts.

Starting Methods

Ballasts use one of three starting methods: preheat, rapid, or instant. Preheat starting is not used by electronic ballasts and is used by magnetic ballasts primarily for specialty lamps such as 2-ft fluorescent lamps. Rapid-start ballasts heat the lamp's electrodes with a low voltage for approximately 0.5 seconds (s) before applying a starting voltage of 200 to 300 V. Most rapid-start ballasts continue to heat the electrodes during lamp operation, which adds 2 to 4 W per lamp to the active power of the lamp-ballast system. Cathode-disconnect ballasts (also called heater-cutout, hybrid, or low-frequency electronic ballasts) are a special type of rapid-start ballast that stops heating the electrodes once the lamp starts, which reduces the active power.

Instant-start ballasts do not heat the lamp's electrodes either before or after starting the lamp. Instead, they apply a higher voltage (over 400 V) to start the lamp. The higher voltage increases electrode degradation during starting and can reduce lamp life relative to rapid starting if the lamps are frequently switched on and off, but at longer burning cycles [8 to 12 hours (h) per start] the difference in lamp life between instant-start and rapid-start ballasts may be less.

Once the lamps have started, the heat generated as the arc's electrons strike the electrodes provides the proper electrode operating temperature to maintain light output. However, for rapid-start electronic ballasts for F32T8 lamps, the American National Standards Institute (ANSI) recommends an operating electrode heating voltage of 2.5 to 4.4 V for F32T8 lamps (ANSI 1985); a ballast that does not comply with this standard may shorten lamp life.

Some dimming electronic ballasts use the rapid-start method to start the lamps and some use the instant-start method, but all the ballasts that NLPIP tested provide electrode-heating voltage during lamp operation. Because they dim lamps by reducing the current supplied to the lamps, dimming electronic ballasts must supply electrode-heating voltage or the electrode operating temperature would drop below the temperature necessary to sustain the arc. Instant-start lamps, which are characterized by a total of two, not four, pins, cannot be used with dimming ballasts because they do not have electrode-heating circuits.

See NLPIP's *Specifier Reports: Cathode-Disconnect Ballasts* (1993) and *Specifier Reports: Electronic Ballasts* (1994) for more information.

How Ballasts Respond to Failures of Dimming System Components

A ballast should safely accommodate the failure of system components. Dimming system components that can fail include the ballast, the control device, the lamps, and the wiring that connects the ballast to the other components. Depending on which component fails, a ballast may either simply shut off or begin to overheat. A thermal protection circuit that shuts the ballast off if the ballast case temperature rises above 110°C (230°F) is built into all ballasts listed by Underwriters Laboratories (UL 1992). All six ballasts that NLPIP tested for this report are listed by UL.

If the control device fails, low-voltage control ballasts (see p. 5) operate lamps at maximum light output but high-voltage control ballasts (see p. 5) shut the lamps off. If the wiring to the control device is somehow disconnected or cut, the ballast will respond as though the control device failed.

If a lamp fails, the ballast should recognize the failure and stop sending current. If the lamp failure is not recognized, the ballast may repeatedly send a high starting voltage to the lamp. This can cause electrical arcing within the lamp, especially for lamps with diameters less than 1 inch, creating a potential fire hazard. Disconnecting or severing the lamp wiring should cause the same ballast response as a lamp failure.

NLPIP did not test the responses of ballasts to failures of dimming system components.

Dimming Ballast Control Circuitry

A ballast's compatibility with a control device depends on whether the ballast has low- or high-voltage control circuitry and on whether the control signal is analog or digital.

Low-Voltage Control

Compared with typical non-dimming ballasts, which have eight wires, low-voltage control dimming electronic ballasts have two extra wires, usually one purple and one gray. The ballast supplies either a direct-current (dc) voltage or current [for example, 10 V or 500 microamperes (μA)] to the control device over the purple wire. The control device then sends a dc signal back to the ballast over the gray wire. Typically, the higher the current or voltage from the control device, the lower the light output. If the control device fails, the control circuit's current and voltage are zero, and the lamps operate at maximum light output.

Low-voltage control, continuous dimming ballasts can be operated in a two-level mode (switching between maximum and minimum light output) by connecting a switch, timer, or relay to the control wires. When the circuit closes, the ballast operates the lamps at minimum light output. When the circuit opens, the ballast operates the lamps at maximum light output.

High-Voltage Control

The power for high-voltage control dimming ballasts is provided by either a high-voltage control device or a special interface device that converts control signals from low-voltage control devices into high-voltage control signals. One high-voltage control dimming ballast (the Lutron ballast) has one extra wire: a 120-V (or 277-V) orange wire that connects to the control device or interface. The other high-voltage control ballast (the EBT ballast) has no extra wires; the control device or interface is wired in series with the ballast's input voltage. Unlike control devices for low-voltage control ballasts, when the control device for a high-voltage control ballast fails, the lamps are switched off.

High-voltage control ballasts have greater dimming ranges than low-voltage control ballasts. Both high-voltage control ballasts that NLPIP tested dimmed lamps to less than 1% of maximum light output, whereas the low-voltage control ballast with the greatest dimming range could only dim to 14% of maximum light output.

Wiring

Users should consult product literature from ballast and control device manufacturers for product-specific wiring diagrams. High-voltage wires (such as 120-V wiring) must be within coated sheathing or conduits, according to the National Electrical Code (NEC) in the United States and Canadian Electrical Code in Canada (National Fire Protection Association 1992b; Canadian Standards Association 1994). Low-voltage control wires can be exposed along walls or can be run through the plenum, so access to conduits may be a deciding factor when choosing between high-voltage control and low-voltage control dimming electronic ballasts.

For applications where running even low-voltage wires is impractical, power-line carrier (PLC) transmitters and receivers are available for low-voltage control devices. PLC systems transmit control signals through the existing power distribution system via a high-frequency carrier signal. The transmitter is connected to a low-voltage control device and an unlimited number of receivers can be connected to ballasts throughout an installation. One manual dimmer, photosensor, or EMS computer can simultaneously control several ballasts. High-voltage dimming electronic ballasts that interpret digital control signals use a similar technique; the control device can be located remotely, at a wall switch location, for example, and the digital signal is transmitted over the voltage supply wires.

PLC Transmitters and Electronic Ballasts

Interference from high-frequency electronic ballasts may disrupt some power-line carrier (PLC) signals. Specifiers should consult the manufacturers of both the PLC device and the electronic ballast to assure compatibility. See NLPIP's *Lighting Answers: Electromagnetic Interference Involving Fluorescent Lighting Systems* (1995).

Analog and Digital Control Signals

A control device can send an analog signal, a digital signal, or a combination thereof. Ballasts respond to analog control signals, such as those from a photosensor, based on the amplitude of the current or voltage; they increase or decrease lamp light output in response to changes in the amount of current or voltage they receive from the control device. Digital control signals, such as those from some EMSs, are coded voltage pulses that the ballast interprets to determine light output. Some control devices, such as the high-voltage manual dimmer made by Lutron, send both analog and digital signals. All the ballasts that NLPIP evaluated respond to analog control signals; the two high-voltage control ballasts also respond to digital control signals. Specifiers should consult the manufacturer of the control device for compatibility with specific dimming ballasts.

Most control devices can operate more than one ballast simultaneously. Signal-amplifying devices allow a single control device to operate hundreds of ballasts. Unless otherwise noted, all the control devices listed in this section are directly compatible with low-voltage control ballasts. With an interface device, these control devices may also be used with high-voltage control ballasts. The exceptions are manual dimmers that are designed specifically for high-voltage control ballasts; they do not require interface devices and cannot be used with low-voltage control ballasts. Table 2 shows the compatibility of different control devices with low- and high-voltage control ballasts. Figure 2 shows several control devices.

Table 2. Compatibility of Control Devices with Dimming Electronic Ballasts

Control Device	Low-Voltage Control Ballast	High-Voltage Control Ballast
Manual switch	■	▲
Timer	■	▲
Low-voltage manual dimmer	■	▲
High-voltage manual dimmer	✕	■
Occupancy sensor	■	▲
Photosensor	■	▲
Energy management system (EMS)	■	▲

■ = Ballast and control device are directly compatible.
▲ = Interface device required to use this type of control device with a high-voltage control ballast.
✕ = Not compatible.

Manual Switches and Timers

When continuous dimming capability is not needed, standard wall switches and timers can be used to step-dim ballasts in a two-level mode (either maximum or reduced light output). This is an inexpensive alternative to installing manual dimmers. With timers, dimming electronic ballasts can automatically dim lights at predetermined times of the day in specialized applications. Some manual switches incorporate a timer that can dim the system after a predetermined delay.

Manual Dimmers

Different manual dimmers are required for low- and for high-voltage control ballasts. Most manual dimmers are low-voltage control devices and are designed to replace standard wall switches. They may have a slide or knob controller or push buttons with preset lighting levels. Some manual dimmers comprise a hand-held remote control device and a receiver within the luminaire so that the occupant can adjust the setting remotely. Dimming electronic ballasts generally are not compatible with dimmers designed for use with incandescent lamps; the exception among the ballasts that NLPIP tested is the Stocker & Yale ballast, which, according to the manufacturer, will operate with either incandescent lamp dimmers or low-voltage control dimmers.

Occupancy Sensors

Occupancy sensors are used with dimming electronic ballasts in corridors, warehouses, or security lighting applications to provide automatic two-level control: maximum light output when motion is detected and reduced light output when no motion is detected. Manual dimmers can be used with occupancy sensors to add adjustable dimming to two-level control schemes.

Photosensors

Photosensors are used either for daylight balancing (dimming lamps when daylight is available in a space) or for lumen maintenance control. For both types of applications, the photosensor detects the illuminance in the space and adjusts the control signal to maintain a relatively constant illuminance. NLPIP is preparing a *Specifier Reports* on photosensor controls.

Energy Management Systems (EMS)

An EMS provides a low-voltage control signal that is directly compatible with low-voltage control ballasts and compatible with interface devices for high-voltage control ballasts. An EMS may interpret signals from many sources, including photosensors, occupancy sensors, and timed preset programs, to determine how much low-voltage control current to send to the ballast or interface device. For example, an EMS can dim lamps by 20% during peak demand hours, dim them by 80% when no motion is detected, and turn them off at night.

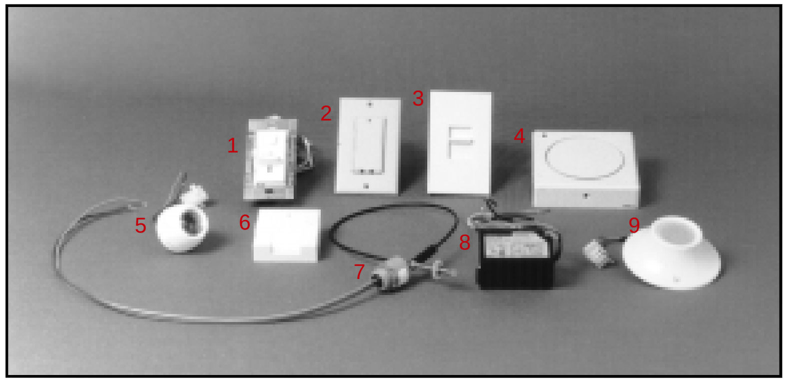
Performance Characteristics

Manufacturers' performance data for dimming electronic ballasts for 4-ft linear lamps are reported in Table 3 on p. 19. NLPIP tested six manufacturers' 120-V ballasts for two 4-ft T8 lamps, measuring performance at 100, 50, and 20% of maximum light output where applicable, and at the ballasts' minimum light output settings. The results of NLPIP's measurements are reported in Table 4 on p. 19. The "Performance Evaluations" section on p. 15 summarizes NLPIP's testing methods.

Light Output Characteristics

The light output characteristics of dimming electronic ballasts include dimming range, ballast factor, ballast efficacy factor, and system efficacy.

Figure 2. Control Devices



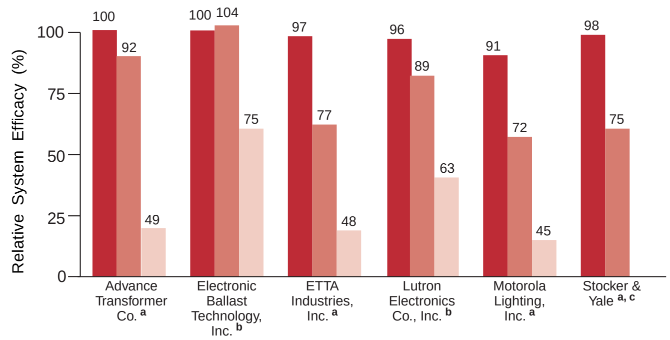
Control devices for dimming electronic ballasts: 1 manual dimmer (high-voltage control); 2 manual switch with built-in timer; 3 manual dimmer (low-voltage control); 4 occupancy sensor; 5, 6, and 7 photosensors; 8 relay for occupancy sensor or photosensor; 9 combination occupancy sensor and photosensor.

Dimming range. The manufacturers of the two high-voltage control ballasts that NLPIP evaluated report a minimum light output setting of 1% of maximum light output. Although NLPIP's evaluations confirmed these claims, some samples caused lamps dimmed to less than 5% of maximum light output to flicker. The manufacturers of the four low-voltage control ballasts that NLPIP evaluated report minimum settings that range from 3 to 40% of maximum light output. In NLPIP's evaluations, minimum light output for these ballasts ranged from 14 to 45% of maximum light output. For many applications, dimming to 20% of maximum light output is sufficient. A wider dimming range may be necessary in specialized architectural applications.

Ballast factor. Ballast factor (BF) is the ratio of the lamp's light output when operated on a commercial ballast to its rated light output. For example, a lamp operated by a ballast with a BF of 0.9 for that lamp type produces 90% of its rated light output. Rated light output is measured on a reference ballast, which is a 60-Hz magnetic ballast, under conditions specified by ANSI (1984).

Lighting designers use BF when calculating how much light a lighting system would actually produce; this information affects how many luminaires are required to illuminate a space. BF varies depending on the number and type

Figure 3. Effect of Dimming on Relative System Efficacy for Dimming Electronic Ballasts Operating Two F32T8 Lamps, as Measured by NLPIP



Maximum light output*

50% of maximum light output

20% of maximum light output

*Highest value for all ballasts set to 100%; see p. 15–16 for methods.

[a] This ballast increases the electrode-heating voltage as lamps are dimmed.

[b] This ballast provides a fixed electrode-heating voltage as lamps are dimmed.

[c] This ballast does not dim to 20% of maximum light output.

of lamps operated, so specifiers should only compare BFs for ballasts that are operating the same number and type of lamps.

Manufacturers of dimming electronic ballasts for two F32T8 lamps reported BFs at maximum light output ranging from 0.87 to 0.92. Using relative light output measurements, NLPIP calculated BF at maximum light output. In NLPIP's results, BF ranged from 0.80 to 0.94.

Ballast efficacy factor. Ballast efficacy factor (BEF) is a measure of how effectively a ballast converts input power into light from the lamps and is used by government agencies to regulate ballast efficiency (U.S. Congress 1988). It is calculated by dividing BF (in %) by active power (system input power in watts). A higher BEF indicates greater efficacy. As with BF, specifiers can only compare the BEFs of two different ballasts if both ballasts are operating the same number and type of lamps. In NLPIP's results, BEF ranged from 1.2 to 1.3 at maximum light output. These BEFs are slightly lower than BEFs for non-dimming electronic ballasts operating two F32T8 lamps, which range from 1.3 to 1.6, according to manufacturers' data (see *Specifier Reports: Electronic Ballasts*, 1994). The power required by the control device and for electrode heating slightly reduces BEF.

System efficacy. Whereas BEF often is used by government regulators, many specifiers are more familiar with system efficacy. System efficacy is the system's total light output (in lumens) divided by its active power (in watts). At maximum light output, most dimming electronic ballasts operating two F32T8 lamps have system efficacies similar to those of other electronic ballasts, ranging from 70 to 80 lumens per watt (LPW).

To dim lamps, dimming electronic ballasts reduce the lamp current flowing between the lamp electrodes, while maintaining enough electrode-heating voltage to prevent the lamp from being extinguished. Some dimming ballasts provide a fixed electrode-heating voltage, whereas some slightly increase electrode-heating voltage as the lamps are dimmed. This electrode-heating voltage does not increase light output, but does increase active power. When NLPIP dimmed the six ballasts to 50% of maximum light output, relative system efficacy (based on relative light output measurements) decreased by an average of 15% (see Figure 3). When dimmed to 20% of maximum light output, relative system efficacy decreased by an average of 44% (for the five ballasts capable of dimming to that level).

Power Quality Characteristics

The power quality characteristics of dimming electronic ballasts include power factor, current total harmonic distortion (THD), and in-rush current. Poor power quality can waste energy and the capacity of an electrical system. It can harm the electrical distribution system and any devices operating on the system. Some dimming electronic ballasts can be part of systems that cause electromagnetic interference (EMI). For more information, see NLPIP's *Lighting Answers: Power Quality* (1995) and *Lighting Answers: Electromagnetic Interference Involving Fluorescent Lighting Systems* (1995).

Power factor. Power factor is a measure of how effectively a device converts energy into useful work. The maximum possible power factor is 1.0; a device with a power factor greater than 0.9 is called a high-power-factor device by the lighting industry. Five of the six ballasts that NLPIP tested had power factors of 0.99 at maximum light output and 0.95 or greater when dimmed to 50 and 20%. The sixth ballast had a power factor of 0.92 at maximum light output, 0.48 when the lamps were dimmed to 50%, and 0.31 when the lamps were dimmed to 20% (see Table 4).

Current THD. Current THD is a measure of the extent to which the current waveform is distorted from a sine wave. Products with high current THD may increase distortion in the line voltage and interfere with the operation of other equipment. The effect of current THD on line-voltage distortion depends on what percentage of the total electrical load a device represents: higher-wattage devices distort voltage more than lower-wattage devices with the same current THD.

NLPIP measured current THD for dimming electronic ballasts at 100, 50 and 20% of maximum light output. At maximum light output, current THD was less than 10% for five of the six ballasts tested. Although current THD increased to as much as 20% for these five ballasts when the lamps were dimmed, the effect of this current THD would be comparable to only 2% current THD at full power because of the power reduction. The sixth ballast had current THD of 35% at maximum light output and 165% when dimmed to 20% of maximum light output. Again, because of the reduction in power, the effect would be comparable to 11% current THD at full power.

In-rush current. In-rush current is a momentary surge in current that occurs when an electrical device, such as a motor or an electronic ballast, starts. Depending on whether the voltage wave is at zero or at a peak when the ballast is switched on, in-rush current of dimming electronic ballasts can range from 0 to 30 amperes (A), compared with 0.5 A during normal operation. The duration of the in-rush current is very brief, typically less than 3 milliseconds (ms), but in-rush current can trip circuit breakers, blow fuses, or overload relays. Occupancy sensor relays, for example, often are rated for 20 A; they can be irreparably damaged by high in-rush current. Some manufacturers of occupancy sensors have addressed this concern by using relays with higher current ratings. High in-rush current also momentarily increases distortion in the supply voltage. Maximum in-rush current for the ballasts that NLPIP tested ranged from 2.7 to 28 A. The duration ranged from 0.2 to 2.8 ms. See the "Performance Evaluations" section for details on the testing methods.

If several ballasts with high in-rush current are connected to the same circuit, the effects can be cumulative. For example, if 20 luminaires with electronic ballasts are simultaneously switched on during a peak in the voltage wave, there can be a momentary current draw as high as 600 A. The duration of the in-rush also increases as more ballasts are added. Such a large current surge could cause a brief voltage drop and create a brief period of extensive voltage distortion that could harm other devices on the supply voltage. ANSI presently does not set limits for in-rush current. At least one manufacturer incorporates a current limiter in its ballast; NLPIP measured an in-rush current of 2.7 A for this ballast (see Table 4).

EMI. All ballasts can produce EMI—unwanted electromagnetic signals that interfere with desirable signals. Interference may either be radiated through the air or conducted through wires. NLPIP is not aware of any North American regulations on radiated EMI. The FCC sets limits for conducted EMI, which all fluorescent lighting systems sold in the United States must meet. The six ballasts listed in Table 4 all meet FCC limits. In Canada, the Department of Communications investigates complaints about EMI, and is developing a regulation.

Factors Affecting Lamp Life

Current crest factor (CCF), starting method, electrode preheat time, glow current, and electrode-heating voltage may affect lamp life (Ji and Davis 1994). Although NLPIP did not conduct lamp life testing for this report, standards related to these parameters exist, and are summarized below.

CCF. CCF is the ratio of the peak lamp current to the root-mean-square (rms) value of the lamp current. If the current

Root-Mean-Square (rms)

The term root-mean-square refers to the effective average value of a periodic waveform, such as voltage or current. Mathematically, it is the square root of the mean of the squared values (volts or amperes) taken over one complete cycle.

waveform is a perfect sine wave, CCF will be 1.41. If the waveform has spikes, as with most electrical devices, CCF is higher. Most lamp manufacturers void their warranties when lamps are operated on ballasts whose lamp CCF values exceed 1.7 as specified in ANSI C82.11.1993 (ANSI and NEMA 1993) because high CCF may reduce lamp life.

At full power, all six ballasts that NLPIP tested met the ANSI standard for lamp CCF. When NLPIP dimmed each ballast to its respective minimum light output, lamp CCF increased to as much as 4.6. However, because of the power reduction, NLPIP expects that the effect on lamp life would be minimal. For example, the largest peak current measured by NLPIP at the minimum light output setting for any ballast was 61 milliamperes (mA), which is less than 25% of the typical rms current of a F32T8 lamp at maximum light output. The lamp CCF results for dimmed operation are reported in greater detail in Buddenberg and Wolsey (1995b).

Starting method. Starting method may also affect lamp life. Most dimming electronic ballasts are rapid start: they are designed to preheat the electrodes prior to starting and supply electrode-heating voltage during lamp operation.

Some dimming electronic ballasts are labeled as rapid start by the manufacturer, but use the instant-start method to start lamps. Once they start the lamps, they operate like rapid-start ballasts, providing heating voltage to the lamp electrodes. These ballasts apply a starting voltage approximately twice as high as that of rapid-start ballasts, without preheating the electrodes. This high starting voltage may reduce lamp life unless the lamps are switched on and off infrequently, such as 8 to 12 hours per start. If lamps are never switched off, for example if they are step-dimmed by an occupancy sensor, lamps may last as much as 80% longer than their rated life, because rated life is based on lamps being switched off every 3 hours.

Electrode preheat time. Rapid-start ballasts can reduce lamp life if they do not sufficiently preheat the electrodes prior to lamp starting. ANSI specifies a minimum preheat time of 0.5 s for rapid-start ballasts. NLPIP's tests found that some rapid-start dimming electronic ballasts did not consistently preheat the electrodes for at least 0.5 s.

Glow current. A concern only for rapid-start ballasts, glow current is the flow of electrons away from the lamp's electrodes during preheating. The higher the glow current, the faster the electrodes' emissive coating degrades; thus high glow current reduces lamp life. ANSI specifies a maximum glow current of 25 mA for rapid-start ballasts (ANSI and NEMA 1993). When starting the lamps at both maximum light output and at 20% of maximum light output, all ballasts that NLPIP tested met the ANSI glow current requirement.

Electrode-heating voltage during operation. During lamp operation, the electrodes should be kept at a temperature between 600°C (1140°F) and 1000°C (1860°F) to maximize lamp life (Verderber et al. 1985). At higher temperatures the emissive coating on the electrodes evaporates, and at lower temperatures the lamp electrode sputters (loses its emissive coating).

Electrode temperature is difficult to measure, so standards-writing organizations address this concern by specifying how much voltage should be applied to heat the electrodes. ANSI specifies an electrode-heating voltage of 2.5 to 4.4 V for non-dimming ballasts operating F32T8 lamps.

NLPIP found that at maximum light output, most dimming electronic ballasts provided electrode-heating voltage within the range specified by ANSI. However, when lamps are dimmed, the electron flow in the arc decreases. To compensate for this decrease, most ballasts exceeded 4.4 V of electrode-heating voltage when operating at the minimum light output setting. This should not severely impact lamp life if the electrode operating temperature is maintained within a normal operating range. There are no electrode-heating voltage standards in North America for dimmed operation of fluorescent lamps.

Dimming Performance

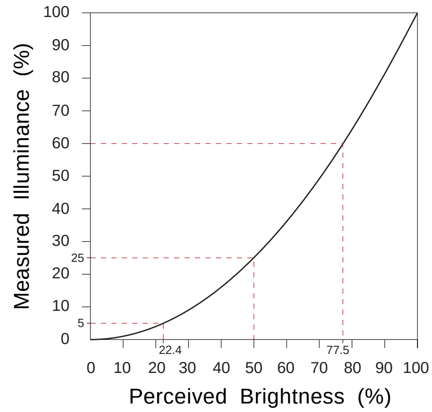
In manufacturers' literature, dimming ranges are described in terms of lamp light output percentages. Dimming ranges can also be described by perceived brightness, which accounts for the adaptability of the human eye when exposed to different amounts of light. For example, a space with a system dimmed to 25% of maximum light output may be perceived as being almost half as bright as the same space with the system at maximum light output. Figure 4 illustrates the theoretical relationship between measured illuminance and perceived brightness.

A continuous dimming electronic ballast should vary lamp light output over the full range of its dimming control circuit to allow the greatest amount of control over the lamp's light output. For example, a low-voltage control ballast with a control circuit range of 0 to 10 V should provide maximum light output at 0 V, minimum light output at 10 V, and a smooth dimming response between these two points.

However, NLPIP found that most ballasts use only part of the dimming control circuit's range. NLPIP uses the term "effective dimming control range" to denote the portion of the control signal's total range over which a ballast responds. For example, a low-voltage control ballast with a reported control signal range of 0 to 10 V may have an effective dimming control range of only 6 to 9 V. A user controlling this ballast with a 10-V manual slide dimmer might not detect any change in light output over more than half of the dimmer's range, which means that all the user's adjustments to light output must occur over less than half the physical sliding limits of the dimmer. Effective dimming control ranges for the other five ballasts were similarly limited and different for every manufacturer. Figure 5, on p. 12, shows the effective dimming control ranges for ballasts tested by NLPIP. Wider ranges provide smoother and more user-responsive control.

Figure 4. "Square Law" Curve: Theoretical Relationship Between Measured Illuminance and Perceived Brightness

Adapted from IES *Lighting Handbook*, 8th Edition (IESNA 1993)



Effective dimming control range is a critical compatibility issue for dimming electronic ballasts used with photosensors. Most photosensors also use only a portion of the full control signal range, so the effective range of a particular photosensor and the effective range of a particular ballast may not overlap. For example, a photosensor with an effective range of 0 to 6 V combined with a ballast with an effective range of 6 to 9 V would not be able to dim lamps. Additionally, the effective range of a photosensor can change depending upon how many ballasts it operates. A photosensor that functions well with one or two ballasts may not work properly with 10 ballasts.

Maximizing Compatibility of Dimming Ballasts and Control Devices

NLPIP recommends that specifiers select dimming electronic ballasts and control devices that are either made by the same manufacturer or listed in manufacturers' literature as being compatible. If a manufacturer-preferred control device is not available for a particular ballast, or if a less-expensive alternative is desired, look for a control device with a control signal range as close as possible to that of the ballast because control signal range is one of the key compatibility issues. For example, some low-voltage ballasts have a control signal range of 1.5 to 9 V; they will work better with dimmers that have a 0 to 10 V range than those with a 0 to 12 V range. A ballast or control device's control signal range typically is listed in the manufacturer's product literature; if it is not, request it from the manufacturer.

Specifiers can use the effective dimming control range information presented in Figure 5, on p. 12, to develop a specification for a control device. The control device's range should be just slightly greater than the ballast's effective dimming control range.

A device with a control signal range that is greater is a better selection than one with a control signal range that does not completely encompass the ballast's effective dimming control range. If the control device's range is too great, much of the device's range may produce no response from the ballast and precise control of light output may be more difficult, but at least the ballast's full dimming range will be usable.

Delayed Light Output Adjustments

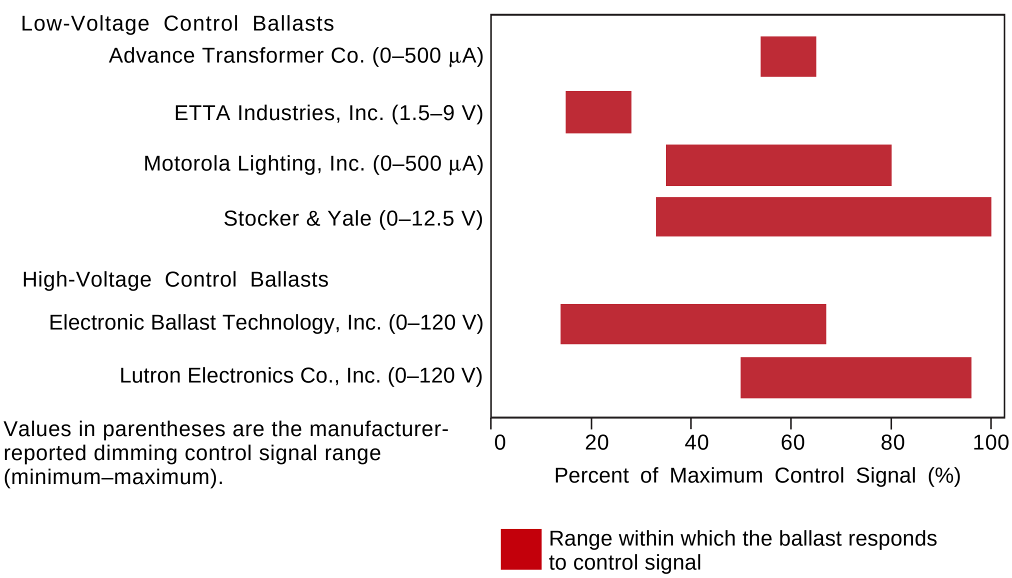
In NLPIP's evaluations, all three Electronic Ballast Technology ballast samples and one of the two Stocker & Yale ballast samples exhibited a time delay in increasing the light output when the setting was changed by sliding a manual dimmer to a new position. NLPIP observed no delay when decreasing the setting. For all four of these ballasts, after sliding the dimmer up to a given setting, light output would gradually increase until it stabilized a few minutes later at the appropriate level. All other ballasts responded to adjustments without perceptible delay.

Specifiers should consult with photosensor manufacturers about the compatibility of their products with specific quantities of specific ballasts.

When installing and programming EMS computers, specifiers should consider the effective dimming control ranges of the ballasts to determine which control signals to program. For systems that use manual dimmers this is a lesser concern because even if the overlap between the control signal and the effective dimming range is limited, the light output can be assessed visually. However, limited overlap will require more dextrous control by users.

NLPIP found only small variations in effective dimming ranges among different samples of the same ballast types. NLPIP did not test ballasts other than those designed for two F32T8 lamps. However, using ballasts from the same manufacturer that are designed to operate different quantities or type of lamps may produce unpredictable results. For example, a single manual dimmer controlling two-lamp ballasts and four-lamp ballasts from the same manufacturer might not produce the same light output with both types of ballasts, if the ballasts' effective dimming control ranges are not similar.

Figure 5. Effective Dimming Control Ranges of Dimming Electronic Ballasts Operating Two F32T8 Lamps, as Measured by NLPIP



Values in parentheses are the manufacturer-reported dimming control signal range (minimum–maximum).

Other Considerations

Costs

Dimming electronic ballasts cost approximately twice as much as non-dimming electronic ballasts. Ballast prices may vary depending on quantity purchased and geographical location. NLPIP surveyed electrical distributors in the Albany, New York, area to find prices for the six ballast models tested (see Table 4). For a quantity of one, prices for five of the six ballasts were between $44 and $53. The sixth ballast cost $100. Control devices are sold separately. Prices for manual dimmers typically range from $15 to $60, photosensors from $30 to $130, and occupancy sensors from $50 to $140.

Specifiers can minimize the costs of a dimming fluorescent lighting system by using ballasts that control several lamps. For example, one dimming electronic ballast designed to operate four T8 lamps can be wired to two adjacent two-lamp luminaires, saving on both ballast costs and active power. Similarly, a single control device can be used with multiple ballasts to reduce the initial investment in controls.

Ballast Life

Life ratings for dimming electronic ballasts range from 10 to 20 years. The products that NLPIP tested carry manufacturers' warranties ranging from three to five years. These warranties are void if the ballasts are operated at temperatures exceeding the manufacturer-specified maximums, which range from 40 to 85°C (104 to 185°F). Electronic ballasts emit less heat than magnetic ballasts. Their case temperatures rarely exceed 60°C (140°F) in typical operating conditions. NLPIP did not test ballast life for this report.

Lamp Flicker

The phosphors of fluorescent lamps emit light when irradiated by ultraviolet (UV) energy generated by ionized mercury within the lamp arc. In a 60-Hz alternating current circuit, lamp phosphors are refreshed 120 times per second. The light produced by the phosphors rapidly decreases between these refreshes, which results in an oscillating light output that some people can perceive as flicker. Flicker is most apparent at the lamp ends, where less UV energy is available to charge the phosphors.

Dimming electronic ballasts operate lamps at high frequencies, typically 20 to 60 kHz. At these frequencies the phosphors are refreshed so often that flicker is imperceptible. Flicker index is the industry-recognized measure for light modulation, and ranges from zero to 1.0. Higher values indicate an increased probability of perceptible flicker. High-frequency ballasts usually have flicker indexes below 0.01.

When lamps are dimmed very low, however, they may flicker if the lamp arc is unstable and begins to rapidly extinguish and reignite. NLPIP researchers sometimes observed flicker when high-voltage control ballasts were set to levels less than 5% of maximum light output, but did not observe flicker at levels of 5% and greater. None of the low-voltage control ballasts dimmed lamps to less than 10% of maximum light output; no flicker was observed for these ballasts.

Susceptibility to Variations in Line Voltage

ANSI specifies that line voltage for commercial customers should be supplied within the range of –13 to +6% of 120 V, or from 104 to 127 V. Key (1978) found that, on average, a building in the United States experiences more than 500 voltage drops or surges that exceed these limits per year, lasting 2 to 60 s each.

Some ballasts adjust lamp current to compensate for voltage drops and surges, so that power and thus light output remains constant. These ballasts draw more current when voltage decreases, and vice versa; if a utility intentionally decreases voltage to conserve power during peak demand, such ballasts will work against the utility's goal. Other ballasts change light output when the voltage changes, which may cause problems in applications that require a consistent illuminance.

NLPIP decreased input voltage by 10% to the six ballasts at three different settings (100, 50, and 20% of maximum light output) and observed light output. Results are summarized in Table 4. Three low-voltage control ballasts held light output constant at all three settings when the voltage was decreased. One high-voltage control ballast held light output constant at the maximum setting, but allowed light output to decrease with voltage at the dimmed settings. Light output with the other two ballasts decreased with voltage at all settings.

Ability to Start Lamps While Dimmed

One potential advantage of dimming electronic ballasts over other ballasts is their ability to start lamps smoothly at a dimmed setting. In a residential application, for example, lights can be turned on at a low output when someone gets up in the middle of the night. If the lamps appear to flicker when starting at a dimmed setting, the electrodes may be sputtering, which reduces lamp life.

The likelihood of sputtering increases as the ambient temperature decreases. Dimming electronic ballast manufacturers specify minimum starting temperatures of 0 to 10° C (32 to 50° F), regardless of the light output setting. Below this temperature, lamps may sputter when starting or may not start at all.

In NLPIP's evaluations, reported in Table 4 and conducted at 25° C ± 2° C (77° F ± 3.6° F), the low-voltage control ballasts all started the lamps immediately and without flicker at their minimum settings. The two high-voltage control ballasts started the lamps immediately but caused the lamps to flicker when starting at their minimum settings; both ballasts started lamps without flicker at 20% of maximum light output.

Circuit Protection

One manufacturer of a low-voltage control ballast claims that its product protects the ballast's dimming circuit from being destroyed if the low-voltage control wires are connected accidentally to a high-voltage power source. All six ballast manufacturers claim that their ballasts are protected against short circuits when the wires from the ballast to the lamp are accidentally connected directly to each other. NLPIP did not test ballasts for any type of circuit protection.

Sound

Vibrations in the laminated magnetic core of a magnetic ballast sometimes produce a humming noise. Electronic ballasts are much quieter because they use solid-state electronics instead of a magnetic core. Ballasts are sound rated from "A" (quietest) to "F" (loudest). All the ballasts NLPIP tested for this report have sound ratings of "A."

Alternative Approaches

One alternative to a continuously dimming electronic ballast is a step-dimming electronic ballast with a built-in switch for selecting preset dim settings. These settings cannot be remotely controlled; the ballast itself must be accessed to change the setting. This can be an advantage where it is not necessary for occupants to control the light output, such as in retail spaces or flexible-use offices.

A second alternative, useful for new construction applications or for extensive lighting renovations, is to wire lamps within luminaires to different control circuits. For example, two of the lamps in a three-lamp luminaire can be wired to a control circuit separate from the third lamp. Depending on which circuits are switched on, one, two, or all three lamps can operate.

Performance Evaluations

NLPIP attempted to identify all manufacturers of dimming electronic ballasts that market products in North America by attending industry trade shows and by reviewing directories in several industry trade magazines. NLPIP invited all six identified manufacturers of ballasts designed to dim two F32T8 lamps to participate. Five manufacturers of such ballasts responded affirmatively, completed data collection sheets, and donated at least two samples of their ballasts for NLPIP to test by June 1994. The sixth manufacturer did not complete NLPIP's data collection sheets. NLPIP acquired two samples of this company's ballast directly from the manufacturer, and lists this ballast in Table 4 (NLPIP-Measured Data) but not in Table 3 (Manufacturer-Supplied Information), on p. 19.

In 1994, Advance Transformer Co. purchased Electronic Ballast Technology, Inc. (EBT) and discontinued the EBT ballast. NLPIP complied with EBT's request not to include their manufacturer-supplied data in this report. However, NLPIP included test results for this ballast because it was still available from distributors at press time.

NLPIP purchased two additional samples each of the EBT and ETTA ballasts through electrical distributors in the Albany, New York, area. The Advance, Lutron, Motorola, and Stocker & Yale ballasts were not immediately available from distributors and could not be acquired within NLPIP's testing time frame. NLPIP performed all ballast testing at the Niagara Mohawk Lighting Research Laboratory in Watervliet, New York, from August 1994 to January 1995. For each round of tests, NLPIP used at least two samples of each manufacturer's ballast (the minimum number of samples acquired for all manufacturers), selected at random from the purchased and donated ballasts.

Electrical and Light Output Testing

Except for in-rush current measurements, which are described below, NLPIP simultaneously performed electrical and light output measurements for each ballast sample. NLPIP tested each ballast sample with two F32T8 lamps from three different manufacturers: GE Lighting, OSRAM SYLVANIA INC., and Philips Lighting. The results reported in Table 4 on p. 19 are the mean values for the two or more samples of each ballast while operating each of the three different manufacturers' lamps.

NLPIP performed all electrical measurements using a conditioned power supply to provide input voltage with voltage THD less than 1%. A computerized data acquisition system electronically captured the electrical data supplied by a series of oscilloscopes and current probes.

NLPIP measured light output by operating the two lamps within a chamber painted matte black. The chamber is illustrated in Figure 6, on p. 16. Two illuminance meters were located inside the chamber directly above slots in a baffle that blocked reflected light. By comparing the illuminances measured for different systems at different settings, NLPIP calculated relative light output from the lamps.

All lamps were seasoned for at least 100 h and, prior to each test round, were warmed up for at least 30 minutes (min). To accurately control light output, NLPIP designed custom dimming controls for the low-voltage control ballasts and used Lutron's high-voltage manual dimmer for the high-voltage control ballasts. To set the systems for the measurements at reduced light output, NLPIP first measured each system's maximum light output. The systems were then dimmed manually until they stabilized at the appropriate percentage (20 or 50%) of maximum light output for at least 5 min.

To calculate relative system efficacy, NLPIP normalized the relative light output data using the highest measured light output for all ballasts operating at maximum light output as the base value (100%). To calculate BF, NLPIP used a calibrated ballast with a known BF (the Advance ballast, which had a measured BF of 0.856). The BF of each tested ballast was calculated as follows:

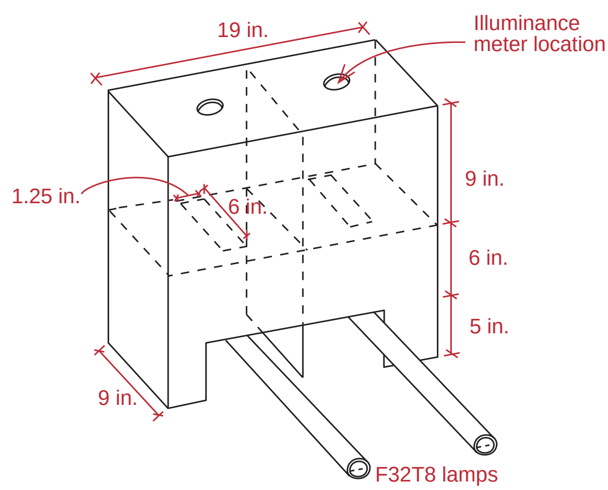
$$BF_{test} = BF_{cal.} \times \frac{RLO_{test}}{RLO_{cal.}}$$

where RLO is NLPIP's measured relative light output value for the indicated ballast (test or calibrated). NLPIP then calculated BEF for each ballast by determining the quotient of the respective BF and active power values.

In-Rush Current Measurements

To measure the in-rush current of dimming electronic ballasts, NLPIP modified a standard power measurement setup by adding a "smart switch" that synchronized power measurements with a peak in the supply voltage. The smart switch used a voltage sensor to identify a peak in the supply voltage wave within a range of ±1 ms. After a brief delay calculated to compensate for the response speed of the relay's switch, the voltage sensor triggered the relay to switch on the ballast exactly one period later at the next voltage peak. The computerized data acquisition system captured the power data supplied by a high-frequency oscilloscope monitoring the ballast current. The methods are reported in full detail in Buddenberg and Wolsey (1995b).

Figure 6. NLPIP's Test Apparatus for Relative Light Output Measurements



All interior surfaces of the light output testing chamber were painted matte black. 1 in. = 2.54 cm

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Data Tables

Table 3 presents product information that was supplied by manufacturers to NLPIP. Table 4 presents data that were collected by NLPIP in the tests described in the “Performance Evaluations” section. Brief definitions of some of the items in the tables follow. Please refer to the text (pages in parentheses) for additional information.

Control signal range: The voltage (V) or current (µA) range within which the ballast responds to control signals (p. 11).

Flicker observed at min. setting: Indicates whether NLPIP observed lamp flicker when ballasts were set to minimum light output. The minimum settings for high-voltage control ballasts are much lower than those for low-voltage control ballasts (p. 13).

Glow current: For rapid-start ballasts, the current that flows away from the electrodes during the electrode-preheat time, at the dim setting indicated. High glow current reduces lamp life (p. 10).

In-rush current duration: The duration of the in-rush current (in milliseconds) as measured by NLPIP for each ballast (p. 9).

Light output varies with input voltage: In Table 4, indicates whether the light output varied when NLPIP decreased input voltage by 10% (p. 13).

Max. in-rush current: In-rush current is a momentary surge in current when an electronic ballast starts. The value in Table 4 is the maximum in-rush current (in amperes) measured by NLPIP (p. 9).

Open-circuit voltage: The voltage that is applied between the electrodes to initiate the discharge during lamp starting. The open-circuit voltage is greater than the operating voltage by a factor of two to three. It should be high enough to start the lamps, but if it is too high, it damages the electrodes and reduces lamp life.

Operating frequency: The frequency (in kilohertz) of the current supplied by the ballast during lamp operation (p. 4).

Peak lamp current at min. light output: The peak current measured by NLPIP when each ballast was dimmed to its respective minimum light output (p. 10).

Rated life: Unless otherwise indicated, the rated life of a ballast is based on 8 operating hours per day.

Relative current THD at 20% of max. light output: Estimates the effect of a dimmed system’s current THD by factoring in the reduction in power compared with the same system at maximum light output (p. 9).

Relative system efficacy: System efficacy is a measure of how efficiently a lighting system converts input power into light, measured in lumens per watt (LPW). NLPIP measured only relative light output (rather than absolute light output); thus relative system efficacy is reported in Table 4, with the highest efficacy measured among all products at maximum light output set equal to 100% (p. 8).

Relative light output range: A ballast’s dimming range relative to the maximum light output for that ballast.

Voltage range for stable light output: The voltage range within which light output is unaffected by line voltage fluctuations (p. 13).

Table 3. Manufacturer-Supplied Information: Dimming Electronic Ballasts Designed for Two F32T8 Lamps

Manufacturer	Trade Name	Catalog Number	List Price ($US)	Listed/ Certified by	Operating Frequency (kHz)	Unit Weight (lb)	Active Power (W) at Max. Light Output	Active Power (W) at 20% of Max. Light Output	Open-Circuit Voltage (V) at Max. Light Output	Open-Circuit Voltage (V) at 20% of Max. Light Output	Power Factor at Max. Light Output	Power Factor at 20% of Max. Light Output	Current THD (%) at Max. Light Output	Current THD (%) at 20% of Max. Light Output	Lamp CCF at 100 and 20% of Max. Light Output	Electrode-Heating Voltage During Operation (V) at Max. Light Output	Electrode-Heating Voltage During Operation (V) at 20% of Max. Light Output	Min. Electrode Preheat Time at 100 and 20% of Max. Light Output (s)	Glow Current at 100 and 20% of Max. Light Output (mA)
Low-Voltage Control Ballasts																			
Advance Transformer Co.	Mark VII	RDC-2S32-TP	50–54	UL/CSA	20–55	1.5	62	20	300	300	0.98	0.93	<5.1	<20	1.3	2.5–4.5	2.5–5.5	0.5	<25
ETTA Industries, Inc.	Series 1100 Sinusoidal	ED2S-120A8AD	>50	UL	20–40	1.5	62	22	<500	<500	0.99	0.92	<5	<10	1.4	2.85–3.15	3.5–4.0	0.5	<10
Motorola Lighting Inc.	Helios[b]	M2-RN-T8-10C-120	45–50	UL/CSA	>22	1.3	65	26	550	550	0.99	0.98	<10	<18	1.5	NA[c]	NA[c]	NA[c]	NA[c]
High-Voltage Control Ballasts																			
Lutron Electronics Co., Inc.	Hi-Lume	FDB-4827-120-2	>75	UL	27	1.4	69	18.6	610	<605	0.99	0.93	<7.3	<10	1.6	4.0–4.2	3.0–3.5	0.8	NS

NA = not applicable
NS = not supplied
°F = (°C x $^{9}/_{5}$) + 32
1 lb = 0.45 kg
All ballasts comply with FCC limits for electromagnetic interference (USFCC 47 CFR 18).
All ballasts are protected from a short circuit of the lamp wires.
All ballasts are rapid start, except where noted.
Data are for 120-V ballasts. Ballasts for 277-V operation are also available; consult manufacturers.

[a] Operating life is based on 12 h per day.
[b] Data supplied for this ballast are for operation at 100 and 10% (not 20%) of maximum light output.
[c] This is an instant-start ballast.
[d] Manufacturer did not supply operating hours per day on which life is based.

Table 4. NLPIP-Measured Data: Performance of 120-V Dimming Electronic Ballasts Operating Two F32T8 Lamps

Manufacturer	Catalog Number	Cost From Electrical Distributor ($US)	Active Power (W) at Max. Light Output	Active Power (W) at 50% of Max. Light Output	Active Power (W) at 20% of Max. Light Output	Relative System Efficacy (%) at Max. Light Output	Relative System Efficacy (%) at 50% of Max. Light Output	Relative System Efficacy (%) at 20% of Max. Light Output	BF at Max. Light Output	BEF at Max. Light Output	Relative Light Output Range (%)	Power Factor at Max. Light Output	Power Factor at 50% of Max. Light Output	Power Factor at 20% of Max. Light Output	Current THD (%) at Max. Light Output	Current THD (%) at 50% of Max. Light Output	Current THD (%) at 20% of Max. Light Output	Relative Current THD at 20% of Max. Light Output[a] (%)	Max. In-Rush Current (A)	In-Rush Current Duration (ms)	Lamp CCF at Max. Light Output	Lamp CCF at Min. Light Output
Low-Voltage Control Ballasts																						
Advance Transformer Co.	RDC-2S32-TP	53	64	40	26	100	92	49	0.86	1.34	17–100	0.99	0.98	0.95	6	8	12	2	28	0.6	1.4	2.1
ETTA Industries, Inc.	ED2S-120A8AD	44	70	44	28	97	77	48	0.91	1.29	16–100	0.99	0.99	0.98	5	7	10	2	2.7	0.9	1.5	2.1
Motorola Lighting, Inc.	M2-RN-T8-10C-120	45	71	45	29	91	72	45	0.87	1.22	14–100	0.99	0.99	0.98	8	11	17	2	15	1.5	1.4	2.3
Stocker & Yale	QSY12DT8DW	45	72	47	NA[c]	98	75	NA[c]	0.94	1.31	45–100	0.99	0.96	NA[c]	9	20	NA[c]	NA[c]	8.0	2.8	1.5	1.9
High-Voltage Control Ballasts																						
Electronic Ballast Technology, Inc.	LCG-120-2/32 RS	44	56	27	15	100	104	75	0.80	1.34	1–100	0.92	0.48	0.31	35	131	165	11	21	0.5	1.4	3.1
Lutron Electronics Co., Inc.	FDB-4827-120-2	100	72	39	22	96	89	63	0.93	1.28	1–100	0.99	0.98	0.95	7	7	13	1	13	0.2	1.7	4.6

NA = not applicable
All ballasts are rapid start, except where noted.

[a] Relative current THD = current THD at dimmed setting × rms line current at dimmed setting ÷ rms line current at full light output.
[b] This is an instant-start ballast.
[c] This product does not dim to 20% relative light output.
[d] NLPIP was unable to collect lamp starting data for this product at the 20% light output setting because the samples for this product did not start the lamps smoothly (several ignition cycles were required).
[e] NLPIP's researchers sometimes observed flicker when lamps were dimmed to or started at less than 5% of maximum light output. No flicker was observed at settings of 5% or greater.

Min. Starting Temperature (˚C)	Control Signal Range	Light Output Characteristics: BF at Max. Light Output	BEF at Max. Light Output	Relative Light Output Range (%)	Light Output Varies With Input Voltage	Voltage Range for Stable Light Output (V)	Life Characteristics: Rated Life (yr)	Max. Case Temp. (°C)	Warranty Period (yr)	Low-Voltage Circuit Protection
10	0–500 µA	0.87	1.40	17–100	no	90–145	20[a]	85	5	no
0	1.5–9.0 V	0.90	1.30	3–100	no	95–140	15	55	5	yes
10	0–500 µA	0.88	1.36	10–100	no	108–132	20[a]	40	5	no
10	0–120 V	0.92	1.33	1–100	no	108–132	10[d]	75	3	NA

Peak Lamp Current at Min. Light Output (mA)	Meets ANSI Preheat Time Requirement: Starting at Max. Light Output	Starting at 20% of Max. Light Output	Meets ANSI Glow Current Requirement: Starting at Max. Light Output	Starting at 20% of Max. Light Output	Electrode-Heating Voltage During Operation (V): At Max. Light Output	At Min. Light Output	Flicker Observed at Min. Setting	Light Output Varies With Input Voltage	Able to Start at Min. Setting Without Flicker
58	yes	yes	yes	yes	4.2	4.7	no	no	yes
61	yes	yes	yes	yes	4.3	5.8	no	no	yes
50	NA[b]	NA[b]	NA[b]	NA[b]	4.5	4.7	no	no	yes
14	NA[b]	NA[b]	NA[b]	NA[b]	3.6	4.5	no	yes	yes
32	no	[d]	yes	[d]	3.4	8.8	yes[e]	yes	no[e]
56	no	no	yes	yes	4.2	3.0	yes[e]	yes	no[e]

NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

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The National Lighting Product Information Program

The National Lighting Product Information Program (NLPIP) was established in 1990 and is administered by the Lighting Research Center at Rensselaer Polytechnic Institute. The Lighting Research Center is a nonprofit educational and research organization dedicated to the advancement of lighting knowledge.

NLPIP's mission is to rapidly provide the best information available on efficient lighting products. We provide complete, current, and valuable manufacturer-specific performance data in useful formats to guide your lighting decisions. Priority is given to information not available now or not easily accessible from other sources.

The National Lighting Product Information Program tests lighting products according to accepted industry procedures. If procedures are not available or applicable, we develop interim tests, focusing on those performance issues that we believe to be important to the lighting specifier and end user. The program does not accept funding from manufacturers.

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