*The advance of technology continues on, sometimes with unintended consequences. In the last several decades, we have seen a superior insulating material (asbestos) be banned because it was a carcinogen. Poly Chlorinated Biphenyls (PCBs) brought about excellent heat transfer characteristics to transformers, but now are an anathema. Aluminum wiring was thought to be a panacea, but we now know about the severity of aluminum oxide formation, cold flow (creep), and differences in thermal expansion coefficients. A gasoline additive known as MTBE was thought to improve the nation's air quality, but is now known to pollute the water supply. Ironically, each of these products was once revered because of their superior design qualities; now, each is better known for the manner in which they bring harm. It is with this backdrop that we examine the attributes of the electronic ballast, and why it is a product that fire investigators should pay attention to …*

# Electronic Ballast Fires

**Mark Goodson PE** **Mark Hergenrether PE** **Aaron Stateson**

## BACKGROUND

Fluorescent lamps are widely used in commercial and residential applications as a more efficient alternative to their incandescent counterparts. At the heart of a fluorescent fixture is the ballast. The ballast works to excite and regulate electrons from the gas inside the fluorescent lamp. The electrons form a plasma which releases photons that strike the phosphorescent coating on the inside of the lamp, thus producing visible light. Ballasts now come in two forms, "magnetic" which are formed much like a traditional copper/ferrous transformer, and "electronic" which are formed using solid state devices and fly-back circuitry.

For many decades, the magnetic ballast was the accepted way of energizing a fluorescent bulb. In a conventional fluorescent fixture (2X4' troffer), two magnetic ballasts allow the operation of four 40 watt (nominal) lamps. Figure 1 shows the schematic of a magnetic ballast wound for 2 lamp operation. This ballast is known as a Rapid Start ballast, and it is capable of firing the two lamps. Each lamp has two pins at each end, with an internal filament between the two pins often made of tungsten. These filaments are used to help start the lamp, and are rated at about 4 volts. Each filament consumes about 1.4 watts such that for a 4X4 (4 bulbs) troffer this is approximately 11 watts.

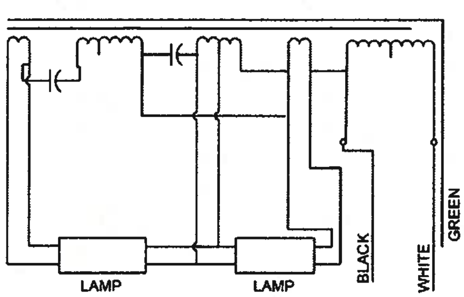


**FIGURE 1**

One design characteristic of a magnetic ballast is that it emits a humming sound as a result of line frequency (60 Hz). In a large office, where there can be many fixtures, this hum could be overwhelming. To reduce the hum level, the ballast is commonly potted with a mixture of sand and asphalt. This mass serves to dampen vibrations and quiet the ballast. As a downside, the asphalt can be ignited under the right conditions. To help prevent ballast fires, magnetic ballasts are thermally protected and are designated as Class P ballasts. Typically the thermal protectors are switches that open at ~ 105° C. The intent of the thermal protector is to prevent the ballast from reaching dangerous temperatures; however, the protection scheme does not always ensure the ballast can not start a fire. The ambitious reader will refer to a case styled *Truck v Magnetek* for a very good description of how a magnetic ballast is alleged to have started a fire.[1] This seminal case also addressed the issue of 'pyrophoric carbon', and was reported in a previous edition of *Fire and Arson Investigator*.[2]

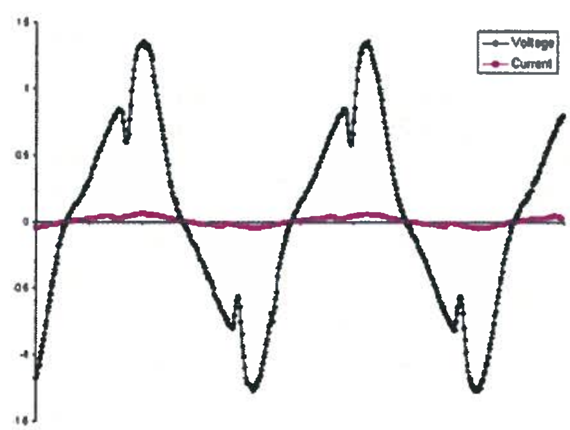


**FIGURE 2**

The introduction of the electronic ballast is an attempt to improve the overall efficacy of fluorescent lighting. In common parlance, efficacy is measured in Lumens per Watt where a lumen is light flux from the lamp and a watt is the power to the lamp. It is obvious that the electronic ballast is more efficient than is the magnetic ballast, because the former has no filaments that need to be powered. Internally, the electronic ballast converts single phase line voltage (120 or 277 VAC, 60 Hz) to a waveform that approaches 700 volts open circuit at a frequency between 25 and 40 KHz. Figure 2 shows an oscilloscope trace of the waveform to a type T8 lamp; the upper trace depicts voltage and the lower trace depicts current. Lamps driven by an electronic ballast do not require heated filaments in order to illuminate. The initial voltage is high enough to break down the gas and start and an arc inside the lamp. This mode of operation (without heater filaments) is known as 'instant start', as opposed to the aforementioned 'rapid start'.

In addition to a lighting system that does not need to make use of heating filaments, the electronic ballast uses a much higher frequency. This difference allows for a fixture to use much smaller electronic components (specifically the inductors) and one which does not require the fixture to be grounded for proper operation. (Note - per the NEC, the fixture is grounded for reasons of shock prevention. In comparison, the magnetic ballast also relies on the ground on the fixture to act as a capacitor plate to induce starting. The grounding is not necessary for starting of the bulbs driven by electronic ballasts.)

So far, the electronic ballast looks very promising in our analysis. It has greater efficiency, weighs less, and (due to a lack of heat production) should last longer than a conventional magnetic ballast. Furthermore, the electronic ballast requires much less potting compound (asphalt) and as such would appear to be much less of a fire risk.

## THE HIDDEN DANGER:

The electronic ballast has one characteristic that we feel is important for the fire investigation community to be aware of. In our view, the ballast can bring on fires by means of poor electrical contact; this is of course no great revelation, in that electrical energy can often cause fires when there are voltage drops across poor contacts. What is different about the electronic ballast is that it can continue to illuminate the bulb properly while at the same time allowing a destructive arcing process to take place at the lampholder/pin interface. It is this ability to keep the bulb fully illuminated while a poor contact and arcing exists that is different from the conventional magnetic ballast. With a conventional magnetic ballast, should the pin(s) be misaligned, the bulb usually will not illuminate and often the second bulb will not illuminate, either. If the bulb is not illuminated, the user knows to climb a ladder and rotate the bulb such that good contact is established.

Unlike the rapid start feature of the magnetic ballast, the electronic ballast does not use the heater filaments. Instead it increases the start voltage to about 700 volts momentarily, so as to cause the bulb to start. Once the bulb has started, the ballast serves as a true 'ballast,' in that voltage drops and a relatively stable current level is maintained. Herein lies the first part of the hidden danger. When the ballast senses that the lamp has gone OFF such as if the bulb is misaligned, the ballast increases the voltage again in order to restart the lamp. Often this voltage is sufficient to allow arcing to occur between the lampholder's contacts and the lamp pin. If the voltage 'jumps' the gap, the bulb will illuminate.

A second factor in this scenario is related to the use of high frequency. For conventional AC line frequency (60 Hz), the arc extinguishes (quenches) 120 times per second, each time there is a zero crossing. As zero is crossed, the arc temporarily extinguishes and begins to cool. With the electronic ballast, however, the transition through zero is so quick (due to the high frequency) that the arc does not extinguish. In fact, the high frequency serves to stabilize the arc, allowing a continuous plasma. This characteristic of the electronic ballast helps sustain arcing between lamp pins and lampholder contacts. Figure 3 shows a 2 x 4 troffer, with the inner 2 bulbs illuminated.

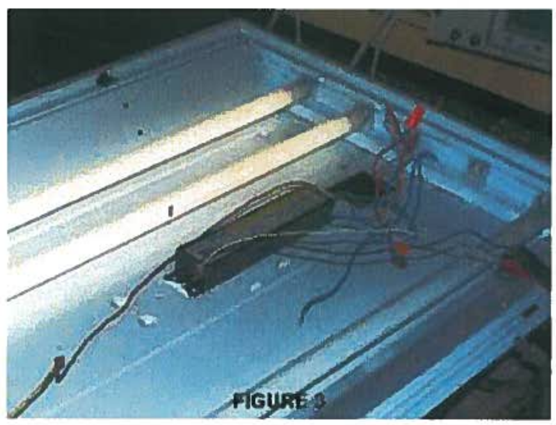
FIGURE 3

## LITERATURE SEARCH

A literature search was conducted, and the authors found a document authored by NEMA (National Electrical Manufacturer's Association) and published in 1998, entitled *Application Note: Wiring Equipment for T-8 lamps with Instant-Start Ballasts.*[3] The document recommended that BOTH pins be connected at each end of the lamp, even though both pins will be at the same potential. The document also proposed that as an alternative, a shunted lampholder be used. A shunted fluorescent lampholder has an internal connection that ensures that at each pin, the ballast fires both pins, rather than just one at each end. The document further recommends that contacts be repaired or replaced if pitting has occurred.

The electrical industry heeded the advice given in the above NEMA reference, and has produced bi-pin lampholders. As an example, Leviton literature lists a model 13653 for use with fluorescent lamps. However, if the lamp is to be driven by an electronic ballast, the correct part number is 23653, which states that it has internal shunt for connection to electronic ballasts.[4]

## TESTING

In order to examine the potential for electronic ballast to start fires testing was performed. For the setup, the authors purchased 2 x 4' fluorescent troffers with universal electronic ballasts, capable of operating on both 120 and 277 VAC. The troffers were suspended, and the bulbs intentionally misaligned by slight manual rotation of the bulb. The arcing that occurred was immediately noticed. At times, the arcing would continue for several minutes, and at other times the arcing would cease until the bulb was again misaligned. The most fearful set of circumstances was brought on when the arcing had ceased for several hours, and then would begin again without manual intervention. Examination of the lampholders showed that they had been severely degraded by the arcing process. Figures 4 and 5 show the resultant lampholders.

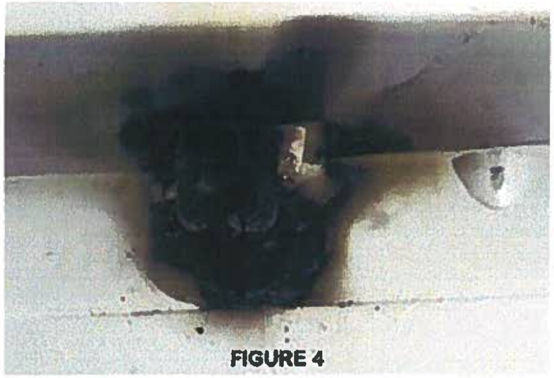

FIGURE 4

FIGURE 5

## "DAUBERT" CRITERION

Many of the readers of this article will certainly ask the question, 'Is this theory readily accepted, and has it been tested?' The answer to both questions is, 'Yes.' These questions (and their answers) help to meet the *Daubert* criterion, which includes several questions.[5] For our purposes, the following two *Daubert* points are referenced:

- Peer Review and Publication
- General Acceptance.

In a recent legal matter, subpoenas for the production of documents were served on two non-parties, Underwriter's Laboratories (UL) and NEMA. Both UL and NEMA begrudgingly produced responsive documents regarding electronic ballasts and fires. These entities also desired that the documents not be publicly distributed. However, their existence and content were aired in legal proceedings styled *Greenville ISD v Humphrey et al.*[6]

By way of background, there had been complaints made that caused UL to examine the issue of electronic ballasts *vis a vis* fire causation. NEMA, through its Lighting Section Task Force on Ballast / Luminaire Compatibility, contracted with UL to perform testing of ballasts and lampholders to determine if and what risk existed. In the past, UL had addressed similar issues in the development of UL 471, *Standard for Safety for Commercial Refrigerators and Freezers*. UL gave 3 options available to address the commercial refrigerator problem; as follows:

1. Use of a ballast with a circuit that shuts down should arcing occur, known as a type CC ballast
2. Provide independent support of the lamp so that it would not rely on the lampholder to secure it, or
3. Use lampholders that comply with IEC 60400.

Pursuant to the NEMA contract, UL performed a series of tests, and reported their findings to NEMA. The test methodologies were similar to those conducted by the authors in their own research. The background material and resultant testing are fully described in a report published by UL on August 25, 2005.

## UL TESTING

Testimony in the *Greenville* case revealed that UL has extensively researched the problem at hand. The UL document produced to the jury describes the exact theoretical scenario as we have given: when a poor contact occurs, the voltage is increased to start the lamp, with resultant arcing between the lamp pin and the lampholder contacts.

UL tested 22 different types of lampholders, using 4 samples of each type, for a total of 88 different tests. The same ballast was used for each test. UL pre conditioned some of the lampholders for 168 hours at a temperature of 100° C, and the remainders were tested 'as received.'

UL personnel manually rotated the lamps while they were illuminated in order to induce arcing. The arcing was induced for ~ 5 minutes on each sample. Placed 12" below each lampholder was a bed of cotton.

Some of the more important results from the testing are as follows:

- Preconditioning had no discernible effect of production of fire
- Arcing caused charring, outgassing, and ignition of the lampholder
- Approximately 80% of samples had ignition within 2 minutes, some as early as 10 seconds
- Every sample had flaming ignition sufficient to ignite tissue paper placed above the lampholder.

The UL report states that their testing was severe, but displayed the arcing that may occur as a result of vibration, loose contacts, jarring, or corrosion.[7]

## DISCUSSION

Although the testing we have carried out was some what rigid, the UL and NEMA documents, makes it clear that there is a issue with electronic ballasts and T8 lamps. The authors reiterate that a loose and overheating contact pair can often be considered a competent ignition source, depending on the resistance and the amount of current; however, there are salient differences between a 'normal' overheating contact and the lamp pin/lampholder interface associated with the electronic ballast. Described here are three characteristics of the electronic ballast circuitry which (as a group) bring about operating conditions that are much different than that of the magnetic ballast:

1. Voltage is ramped up in an Open Circuit (OC) condition enabling gaps created by loose connection to be jumped via arcing.
2. The high frequency (tens of KHz) helps to stabilize the arcing process
3. The lamp continues normal operation, unlike what would happen in a magnetic ballast

The latter of the aforementioned design characteristics also becomes a human factors issue. We are all familiar with poorly seated bulbs in troffers with magnetic ballasts. When a 'normal' bulb fails to ignite due to such a poor contact, we instinctively know of the problem and rectify it by rotating the lamp in order to restore the connection. With a lamp that stays illuminated it can be difficult to spot the signs of a poor connection.

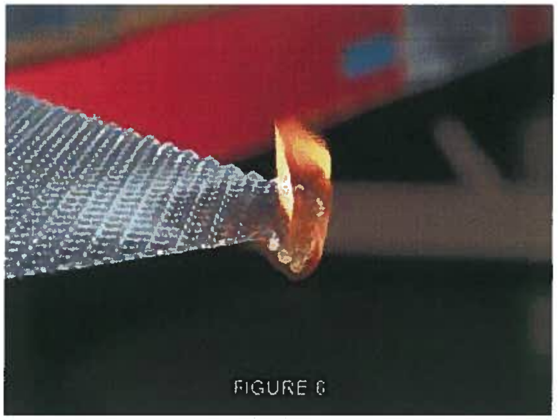

FIGURE 6

A very pertinent question to all this examination relates to the first material ignited. The diffuser (lens cover) that is present on many lamp fixtures has no UL 94 rating. Testing of the diffuser shows that it both sustains combustion and drips molten (and flaming) plastic. Figure 6 shows combustion taking place on such an acrylic diffuser. Our own testing was done without a diffuser, and it achieved ignition of the lampholder on numerous occasions. We can easily envision a scenario where the ignition of the lampholder ignites the lens diffuser.

In our preparation of this article, we learned that there has been FAA Airworthiness Directives (AD) issued for essentially the same problem.[8] To wit, some Saab jets were using electronic ballasts to drive fluorescent lamps. The AD stated that cabins were receiving smoke and arcing was occurring between the lamp pins and lampholders. We think this scenario exemplifies the same problem that UL has been addressing, except with an airframe providing an environment that included vibration insult instead of a more conventional environment such as the air handler on an HVAC unit.

Based upon our own testing, the UL work, and the FAA's AD and underlying work, we feel that the lampholder/pin interface for fluorescent lighting systems with electronic ballasts can form a viable ignition source. Perhaps the more disturbing issue is that the lighting industry is well aware of the phenomenon, but has not seen fit to warn anyone that the danger exists.

## INVESTIGATION

The investigator who is at a fire scene and who is suspect of this type of event should make every effort to find the lampholders and pins. If located, they should be carefully examined both visually and microscopically. Further examination via SEM (Scanning Electron Microscope) with EDX capabilities (Energy Dispersive X-ray) might be relevant to ensure the investigator that the phenomenon seen is truly some form of arcing, and not a result of binary eutectic melting (sometimes referred to as 'alloying').

Finding arced pins and contacts after a fire can be a challenging task, based on their size. Moreover, there has been very little written in the fire investigation community on this exact phenomenon. Two articles that come to mind include one published in *Fire Findings* and one that was authored by Dr. Zicherman.[9, 10]

## DESIGN CHANGES

While the rigors of proper engineering design to prevent these fires are outside the scope of this paper, we will state that there are several avenues that need to be pursued. They include:

1. Using type CC ballast circuitry on all fixtures
2. Using lampholders fabricated from porcelain
3. Adding fire retardants to the lens diffuser
4. Using lampholders that use the pins for electrical contact only, while supporting the lamp tube independent of the electrical contacts.

## SUMMATION

Indeed electronic fluorescent ballasts do have a hidden danger and we are of the opinion that this danger can lead to fire causation. Certainly, the seasoned investigator is aware of overheating contacts that can cause fires. Society's own practical experience has taught that if a fluorescent bulb is not lit, then try to re-seat it in its contacts. The operation of the electronic ballast is unusual in that it will continue to effectively illuminate a bulb while at the same time force arcing through poor contacts and cause overheating. As the progression of technology continues on, we cannot help but think back at the asbestos, PCB's, and MTBE's investigations of yesteryear and be reminded about what the philosopher Santayana once said: "He who ignores history is doomed to repeat it".[11] ●

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### ABOUT THE AUTHORS

**MARK GOODSON** is a Professional Engineer in ten states, and is licensed in both EE and ME. He received his EE degree from Texas A&M in 1979, and then went to UT Southwestern where he studied forensic medicine. He is the principal of Goodson Engineering in Denton, Texas. His practice involves electrical and mechanical failure analysis, CO deaths, and electrical injuries. He is a fellow in the AAFS. He has published over 25 papers on electrical investigations and fires. He holds two patents, with two more pending, on inventions related to fire safety. He is a consultant to numerous medical examiner's offices.

**MARK HERGENRETHER** holds a BS an MS in Mechanical Engineering, both received from Oklahoma State University. He practices failure analysis, and was formerly with both Sandia Labs and Goodson Engineering. He is a licensed as a Professional Engineer in multiple states.

**AARON STATESON** is an engineering student at Texas A&M, and a former intern with Goodson Engineering.

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