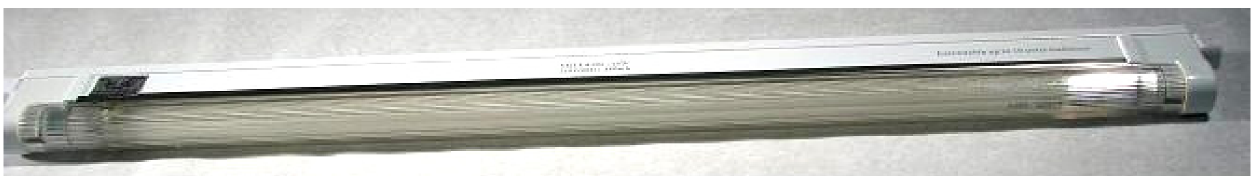
Introduction:

360° Test Labs has been retained to ascertain whether certain circuitry changes to fluorescent lamp electronic ballasts reduce or eliminate an overheating problem whereby a plastic shroud over the lamps melts at the ends of the lamps.

Supplied to 360° Test Labs —

Fluorescent lamp fixtures as follows:

- 10 PN xx50 12W/120V fixtures w/bulbs
- 10 PN xx51 16W/120V fixtures w/bulbs
- 10 PN xx52 12W/220V fixtures w/bulbs
- 10 PN xx53 16W/220V fixtures w/bulbs
- 7 failed fixtures, all 120V: 6x16W, 1x12W, all with at least one melted end on the plastic shroud



Description

Typically, these fixtures are mounted upside down in cabinets, normally with five fixtures daisy-chained together. Each fixture has a male plug on one end and a female plug on the other to facilitate daisy-chaining and creating a long line of fixtures. Each of the four types of fixtures provided utilize an electronic ballast which circuit is a simple AC-to-DC rectifier operating from the AC line input (either 120VAC/50-60 Hz or 220-240VAC/50 Hz).

The fixtures all contain a 1-ampere fuse at the AC inlet. The rectified-filtered high voltage drives a 2-transistor multivibrator at about 45 kHz. The fluorescent lamp's filaments are connected in series. The circuit of both the old, failed, and new fixtures is identical except that a Positive-Temperature-Coefficient resistor was added in series with the filaments on the new fixtures.

This PTC is intended to prevent the multivibrator transistors from being overloaded should a filament short. Previous tests had indicated that a shorted filament would result in destruction of the switching transistors due to overcurrent.

The new PTC is intended to prevent overcurrent by adding resistance in series with the filament circuit; the PTC's cold resistance is about the same as a cold filament. Thus, if a bulb has a shorted filament, the PTC will "substitute" for the shorted filament by adding its own resistance to the circuit, thus preventing overload of the inverter switching transistors.

Experiments discovered that even when one filament is shorted, a bulb will still fire. An open filament, however, prevents the multivibrator from oscillating as the filament and high voltage circuits present a resonant load to the multivibrator which is not "seen" by the multivibrator when a filament is open.

Failed Fixture Examination

Seven failed fixtures were provided to 360° Test Labs. Six are 16 watt fixtures and one is a 12 watt fixture. The shroud on all had melted at one end of the lamp. When the shroud was removed, damage to the bulb's glass envelope was also discovered, as shown below.

At left is fixture 5F (all the failed fixtures were named 1F through 7F to keep lamps, shrouds and fixtures together with their original parts).

Note the appearance of chipped glass; on all bulbs showing this chipped area, this portion of the bulb was in direct contact with the brown, burned spot of the plastic shroud.

At left is fixture 7F, with the same chipped glass appearance but in addition, an obvious crack in the glass envelope.

The plastic shroud was completely melted onto the glass of this bulb and was difficult to remove—and was possibly the catalyst that caused the this crack.

The failed tubes exhibited what appeared to be chipped glass at the areas where the plastic shroud had melted. However, closer examination under the microscope reveals a swirl pattern characteristic of melted glass, as seen in the photo to the right.

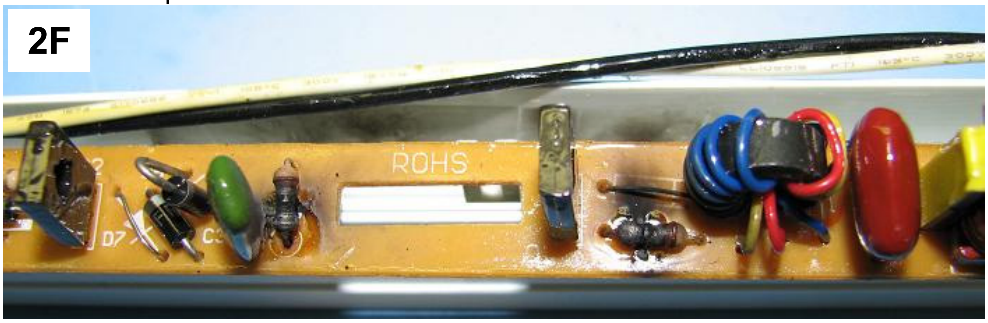
Melting can be seen as the line running from top right-center of the photo, to the middle of the right edge of the photo.

The table below catalogs the observations made of each failed fixture.

Fixture	Bulb Size	Date Code on Fixture	End of Fixture Where Shroud Melted	Filament Resistance of Bulb, Ohms (melted end, far end)	Other Observations
1F	12W	07/06	Female	12.32, open	Good fuse, no burned parts
2F	16W	07/06	Male	8.61, 9.03	R3 & R4 burned, fuse open
3F	16W	07/06	Male	Open, 6.92	Good fuse, no burned parts
4F	16W	08/06	Female	Open, 7.37	Glass chipped, good fuse, no burned parts
5F	16W	12/06	Female	4.5/erratic, 7.03	Severe shroud melting, tube chipped, R3 & R4 burned, fuse open
6F	16W	12/06	Female	Open, 6.71	Severe shroud melting, tube chipped, good fuse, no burned parts; only fixture with white caps on tube (similar to latest new fixtures)
7F	16W	01/07	Male	Open, 7.42	Severe melting of shroud, tube chipped, good fuse, no burned parts; this fixture had been modified with a hardwired PTC installed on the PC board

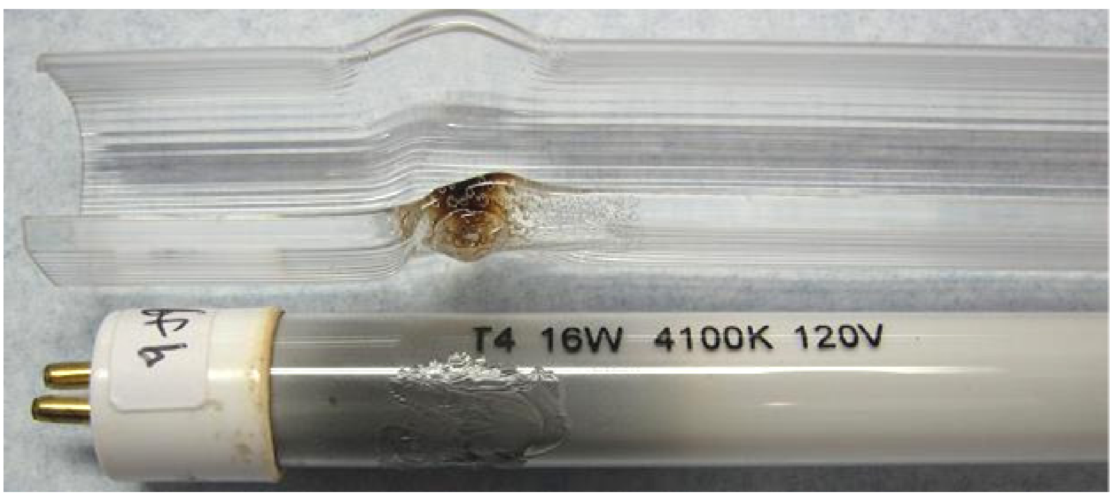
The denotations “female” and “male” above refer to the sex of the AC plug/jack on the end of the fixture; the end into which the power cord plugs is the female side. Note that the failures were evenly distributed on either end of the fixtures.

Two fixtures had burned electronic parts on the PC board, as well as their 1-ampere fuse having been opened, apparently due to overcurrent. The fuses on fixtures with no burned parts were all found good and those fixtures worked again once the tube was replaced. The picture below shows the burned components on fixture 2F.

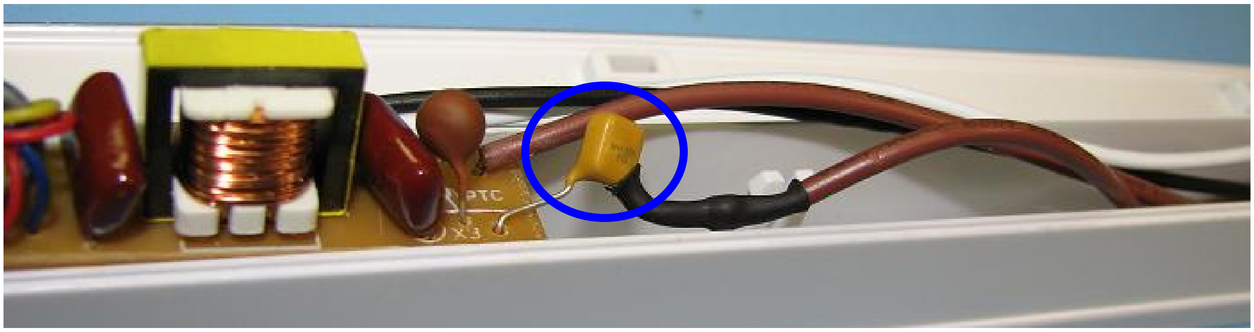


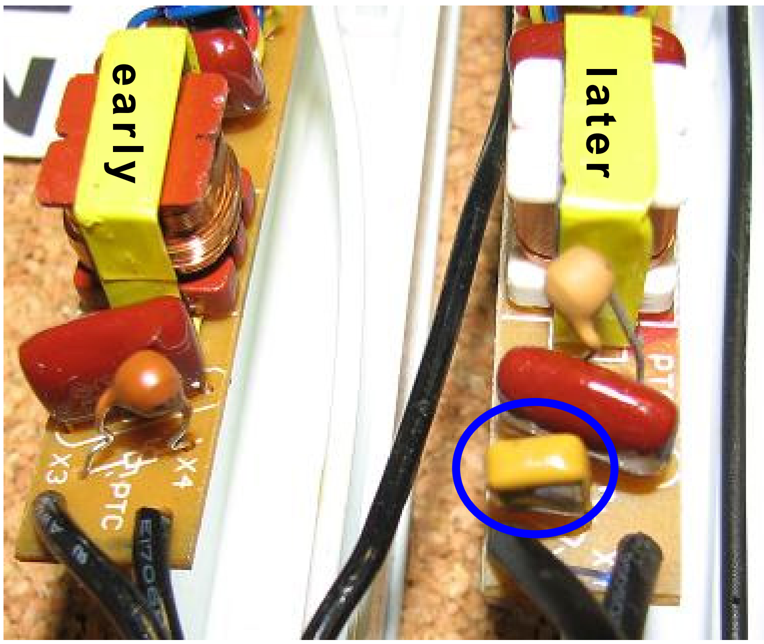
Fixture 5F is shown above; note the smoke smudges on the top cover of the fixture case. The same resistors were burned on this PC board as found on fixture 2F's board.

Fixture 6F was found with a late-type bulb installed – with white end caps; all the bulbs in the other six fixtures had bright aluminum end caps. Besides the different end caps, the light "color" of the white-cap tubes is stamped 4100K on the tubes as seen below, whereas the "color" of the older tubes is 3400K. This white-capped tube, shown in the photo below, exhibits the same chipped-glass failure mechanism as the older aluminum end-cap tubes.



Fixture 7F was found to have been modified at some time by the addition of the same PTC that has been permanently added to all the new fixtures; yet, it's tube still got hot enough to melt the shroud, as seen in the picture above of fixture 7F. The below picture illustrates how the PTC was added to fixture 7F. It is not clear whether this wiring technique is NEC-compliant. However, since the fixtures have plastic cases, there is no danger of this wiring technique shorting.





At left, the photo shows a PC board from an early fixture (left side fixture), with only a high voltage-circuit (HV) PTC. To its right is a late-date code fixture's PC board with both the original HV PTC as well as the added filament PTC. The new PTC is the brownish-orange small rectangular object just above the black wires on the right-hand PC board. The small round brown object above the darker brown oval-shaped capacitor is the high voltage PTC, which is present in all the fixtures. This HV PTC protects the electronic ballast in case the tube will not ignite by increasing its resistance until the multivibrator will stop oscillating.

Filament Resistances

The filament resistance of all new tubes was measured and tabulated in the table below. The resistance of the remaining good filament of the tubes from the failed fixtures is included for comparison.

120V Fluorescent Tube Filament Resistances					
12 Watt Fluorescent Tubes			16 Watt Fluorescent Tubes		
Bulb ID	Filament 1	Filament 2	Bulb ID	Filament 1	Filament 2
1A	13.12	12.88	1B	7.35	7.03
2A	12.50	13.16	2B	7.03	7.13
3A	13.34	12.74	3B	7.42	7.30
4A	12.73	12.86	4B	7.04	7.32
5A	12.81	12.64	5B	7.21	7.21
6A	13.37	12.89	6B (6F)	7.27	Erratic, shorted
7A	12.26	shorted	7B (7F)	7.27	7.52
8A	12.92	12.77	8B (3F)	7.63	7.17
9A	13.13	12.65	9B (4F)	7.52	7.20
10A	12.80	12.53	10B	7.25	7.27
Average:	12.85		Average:	7.27	

Note that the tubes marked as 220V have the same filament resistance range as the 120V-marked tubes. In fact, the 220V tubes operate in the 120V fixtures with no apparent difference in turn-on time or amount of light. It is unknown whether there is a difference in the gas mixture between the 120V and 220V tubes—the filaments appear to be identical—making the tubes essentially interchangeable.

220V Fluorescent Tube Filament Resistances					
12 Watt Fluorescent Tubes			16 Watt Fluorescent Tubes		
1D (220V)	13.04	13.07	1C (220V)	7.53	7.62
2D (220V)	12.71	12.71	2C (220V)	7.54	7.53
3D (220V)	13.40	12.67	3C (220V)	7.47	7.43
4D (220V)	12.90	12.98	4C (220V)	7.46	7.58
5D (220V)	12.43	12.68	5C (220V)	7.39	7.44
Average:	12.86		Average:	7.50	

Filament Resistances of Failed Fixture Fluorescent Tubes					
12 Watt Fluorescent Tubes			16 Watt Fluorescent Tubes		
1F	open	12.32	2F	8.61	9.03
			3F	open	6.92
			4F	7.37	open
			5F	7.03	4.5 to open, erratic
			6F	6.71	open
			7F	open	7.42
Average:	12.32		Average:	8.85	

Functional Tests

In an attempt to duplicate the failure mechanism of the seven failed fixtures, several types of functional tests were conducted on the new sample fixtures:

- Continuous operation
- Power cycling at 45-seconds on, 15-seconds off
- Power cycling at 15-seconds on, 45-seconds off
- Power cycling at 15-seconds on,   4-seconds off

Five each of all four types of new fixtures were set up with a power cycling timer. These types were 12 watt and 16 watt bulbs, and fixtures designed to operate at 120VAC and 220-240VAC. The fixtures were labeled using A for 120V-12W, B for 120V-16W, C for 240V-16W and D for 240V-12W. As earlier noted, the original failed fixtures were labeled using the letter F.

Initially, all twenty fixtures were operated continuously, without power cycling, for 8 hours (pictured at right). The transformer stepped up 120VAC to 240VAC.

The five failed fixtures that did not have burned electronic parts were found to be in good operating order. These were re-tubed using the tubes from the remaining new fixtures that were not being operated in the functional tests, and added to test setup for all further tests. In addition, a 220V, 12W fixture and bulb was operated on 120VAC throughout all regimens.

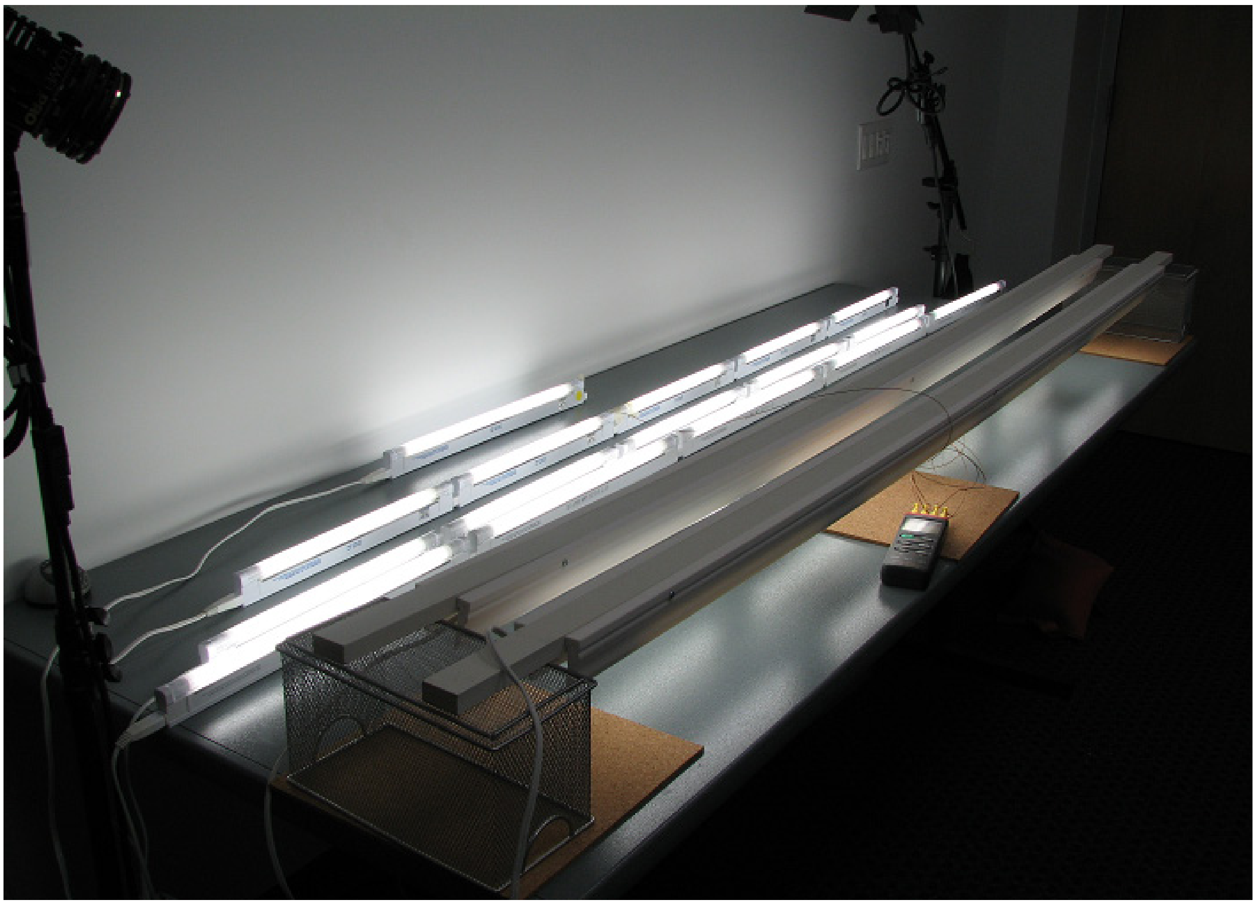
The test setup regimen proceeded as in the list below.

- 8 hours continuous
- 24 hours of power cycling at 45-seconds on, 15-seconds off
- 8 hours at 15-seconds on, 45-seconds off
- 11 days of 10-hour operation at 15-seconds on, 4-seconds off (the same cycle timing used by Client to recreate failures with melted shrouds)
- Following the above, further tests were conducted under conditions of “brownout” and “surge” voltage conditions.

From time to time, the regimen was interrupted or modified in further attempts to induce melted-shroud failures. Initially, as tubes burned out, they were replaced with tubes removed from the fixtures that were not being operated. After the last new 120V tube was used, 240V tubes were installed into the 120V fixtures; no operational difference was found between the 120V and 240V tubes. Because of the perceived danger of a melting/burning shroud starting a fire, the fixtures were only operated while test engineers were present during normal working hours.

During the initial continuous operation test, several fixtures whose shrouds appeared to become warmer than others were set up for temperature monitoring using a Data Logging Thermometer. Thermocouples were mated to shrouds at the same area where the failed fixtures had melted their shrouds. It was found that when operated continuously, shrouds of several fixtures experienced temperatures as high as 155° F. When cycled, the fixtures did not get as hot, the maximum typical temperature being in the 135° F range.

The fixtures were first operated tube-up; thus, the heat of the fluorescent bulbs essentially radiated to the sides or straight up. When installed into appliances such as a salad bar, the fixtures are typically mounted with the tube down inside a metal channel. This allows the bulb heat to rise and surround the fixture itself, heating the whole fixture. After gathering initial temperature data, the test setup was modified with the addition of two custom fabricated “channels” within which fixtures were mounted. These channels were then suspended with the tubes down; see the photo below. It was found that while fixture shroud temperatures did rise when mounted within the channel, the increase was at most several degrees Fahrenheit.



Temperatures were found to vary considerably both between the various fixtures as well as at either end of the shroud on a given fixture. In addition, the fixtures located at the ends of a “string” of fixtures exhibited lower temperatures at the outer end of the fixture. In general, during continuous operation, the cooler fixtures operated around 140° F at one end or the other; some showed nearly the same temperature at both ends. While cycling, the cooler fixtures operated around 115° to 125° F.

Several tests were run whereby a shorted filament was simulated by installing a short across the filament pins. [1] In those cases, that end of the tube always operated 15° to 20° F cooler than the end with a “good” filament. A tube with an open filament, of course, would neither ignite initially nor continue operating after the filament had burned open.

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[1] Such tests were conducted on both re-tubed failed fixtures, and new fixtures. Meaningful differences were not noted between the fixtures under the short condition.

No melting of shrouds, nor ballast failures occurred during the duration of the functional tests.

Tube Life

After 24-hours of both continuous and cycling operation, the 16-watt bulb in one 120V fixture, Nr. 4b, failed to ignite. It was removed and one filament found open. A tube was transferred to the 4b fixture from one of the remaining fixtures not being operated and cycling continued. At the 56-hour point, the filament of a second 16-watt tube in fixture 1b also burned open. Examination of all fixtures did not disclose any noticeable heating damage to any of the plastic fixture shrouds. Two more tubes, one 12W and one 16W, also failed with open filaments after about 56-hours of operation. Throughout the remainder of the tests, tubes continued to fail one after another. By the beginning of brownout-surge voltage tests, only eleven tubes were still operational. It was found that when a tube failed, tapping lightly on the shroud or fixture would sometimes cause the tube to ignite and continue to operate for varying times ranging from several minutes to hours.

Operational tests were conducted for approximately 20 hours of continuous operation (over several days) and over 118 hours of cycling, the last 80 or so using the Client burn-in protocol of 15 seconds on, 4 seconds off. At no time was a shroud found to be melting.

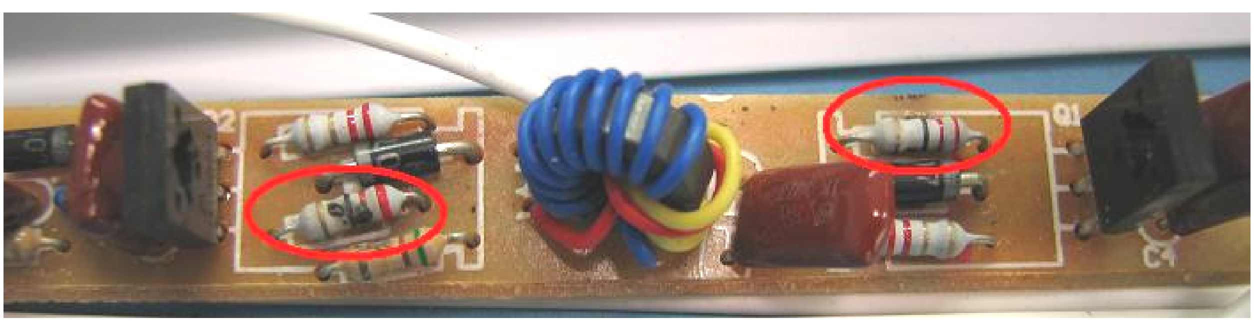
Brownout-Surge Tests

After over 118 hours of cycling, when only 11 fixtures/tubes were still operational, brownout-surge tests were conducted whereby the input AC voltage was adjusted down as low as 80 volts to simulate brownout conditions, and as high as 175 volts (339 VAC for the 240 volt fixtures) to simulate high-voltage surge conditions. Analysis of the ballast electrical design showed that the components of the ballasts should be able to withstand the higher input voltage without exceeding the voltage rating of the components.

Brownout was simulated by reducing the input voltage from the nominal 124VAC to, first, 100, then 90, then 80 VAC, operating all fixtures for at least five minutes at each voltage. In all cases, fixture temperatures dropped as the voltage was lowered. AC input current to the setup remained the same or also dropped slightly, approximately 5%.

“Surge” conditions were simulated by raising the AC input voltage, first to 140 volts, then 150, then 160, and when no failures occurred, finally to 175 VAC. Shroud temperatures rose as the input voltage was raised but never exceeded about 178° F. This peak temperature occurred on the only two adjacent fixtures that were still operating, and on the ends of the two fixtures next to one another. The far ends of both fixtures were much cooler at 155° F.

After approximately 3 hours operating continuously at 175 VAC, one 240 volt fixture failed catastrophically, the first such failure; see the photo below.



In this case, it appears that the two multivibrator transistors either overheated or the high AC input voltage exceeded their voltage ratings. One of the transistors failed internally, causing its associated base current limiting resistor to almost instantaneously burn open, then the other transistor also failed and took out its own base resistor. The two red-circled resistors above show almost no damage other than several small specs of black soot where they instantly burned open. In addition, the edges of each transistor were also sooty, indicating they, too failed almost instantaneously.

The electrical design of the 240 volt ballasts is similar, but not identical, to that of the 120 volt ballasts; one difference is the addition of 0.22 Ohm current limiting resistors at the emitter of each transistor, which can be seen in the photo above (the two devices with the red color bands next to the circled resistors).

The 120 volt ballast design does not contain these emitter current limiting resistors. The failed base resistors shown above perform the same function as R3 and R4 in the 120 volt ballasts, which were the two resistors found severely burned on two of the seven failed fixtures that were provided to 360° Test Labs. However, the similarity of this failure mode between the earlier-failed fixtures and this “surge”-induced failure is likely only that: a similarity.

Note, for example, that the earlier resistor failures evidently occurred over a period of time during which the resistors did not instantly fail, which was the case above where the resistor did not have time to actually burn. In this case, it appears much more likely that the cause of failure was the transistors breaking down due to the high AC input voltage whereas the earlier failures appear to be related to a failure of the fluorescent bulbs, which the multivibrator’s two transistors kept trying to ignite until the transistors overheated and shorted internally.

During the 160 VAC test, it was noticed that several tubes showed a slight blue color at either end, as seen in the photo below:

It is unknown what the bluish color signifies, if anything. When tests were first begun on new fixtures, several bulbs exhibited a similar blue or violet glow near the filament but as the end of the tubes darkened, the glow became less visible.

Electrical Analysis
In an attempt to answer whether the addition of the second PTC resistor will prevent permanent fixture damage when a lamp has reached end of life, 360° Test Labs conducted circuit analysis and tests. To this end, the circuit on the PC board of the 120 volt ballasts was reverse-engineered and analyzed to estimate its behavior under the following possibilities of lamp failure:

- Shorted filament,
- Open filament, or
- Gas release from the tube due to physical damage or leakage.

The ballasts used in the 12W fixtures appear to utilize the exact same circuit and component values, although the PC board layout is slightly different due to the smaller size of the 12W and 16W fixtures.

- **Shorted Filament:** The PTC was evidently added to prevent the electronic ballast's multivibrator from failing due to overcurrent in the event of a filament short. The PTC exhibits the same cold resistance as a bulb filament. The two filaments of a tube are wired in series and so the PTC is also in series with both filaments. Should one filament short, the PTC will substitute its resistance and prevent overcurrent damage of the multivibrator.

  This was tested by purposely shorting one of the PC board's output terminals that are normally wired to one of the bulb filaments. In this circumstance, a lamp will ignite, but not as rapidly as it does with two good filaments. Evidently, the gas pressure inside the tubes is sufficient as to ionize and form a plasma when only one filament is able to be lit. The ballast produces sufficient high voltage as to be able to ignite the tube under this circumstance.

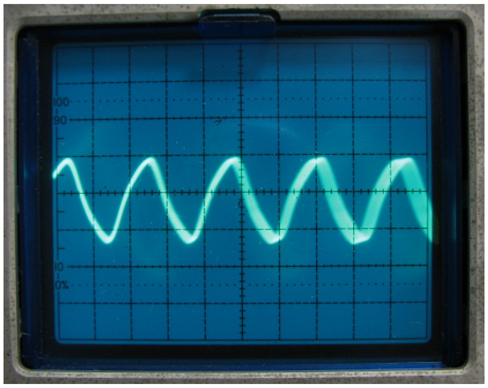
  However, should a second filament short occur (a very unlikely failure mode), the multivibrator will be overloaded and may fail catastrophically as damaged fixtures 2F and 5F did.

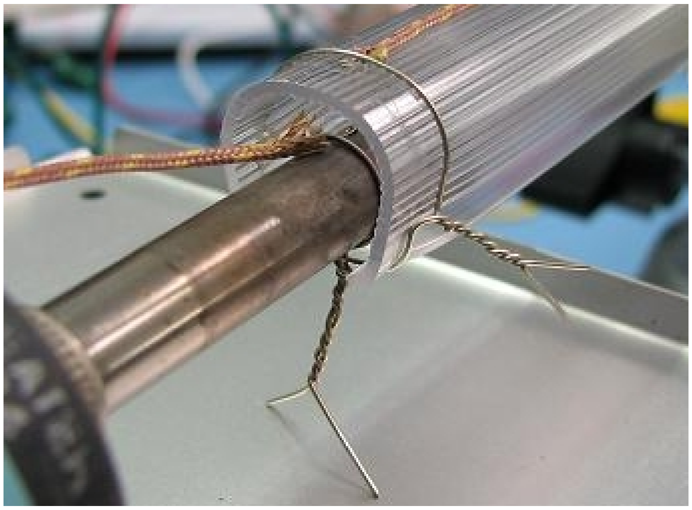
- **Open Filament:** Upon first attempting to fire a tube with an open filament, the lack of filament resistance on the ballast will prevent the ballast from producing high voltage. An open filament occurring during operation will result in the ballast stop producing high voltage, essentially shutting off the fixture.

- **Gas Release:** Release of gas within the glass envelope will result in the filament burning up when the tube is first ignited. A release occurring while the tube is lit will cause the tube to eventually stop producing light. If the ballast then tries to fire the filaments, the filaments will burn open and the ballast will stop operation.

The addition of the new PTC "resistor" does not cause the ballast to explicitly shut down in the event of any type of bulb failure; instead, the PTC helps prevent catastrophic ballast failure when a filament shorts or a new tube with a shorted filament is installed.

An oscilloscope was used to examine the waveform of an operating 120 VAC, 12W ballast. The multivibrator operates at about 45 kHz and produces an almost-triangle wave; see the photo to the right. The amplitude of the high voltage triangle wave applied to a lit 12W tube is approximately 200 volts peak-to-peak (Vpp). As a tube is being ignited, the voltage rises to 700 Vpp (800 Vpp when one filament is shorted). This immediately drops to 200 Vpp after the tube has fired.





Plastic Shroud Melting Temperature

A test jig was set up to simulate an overheating tube to find at what temperature the plastic shroud would soften, blister, and permanently deform; see the photo to the left:

A soldering iron was held steady inside the end of a shroud. One thermocouple monitored the soldering iron's temperature while two more thermocouples were fastened to the shroud in about the location where the filament of a tube would be. The temperature of the iron was then raised while the plastic shroud was observed and the temperatures monitored. The plastic shroud became pliable at about 310° F, began blistering at about 330° F, and softened sufficiently that it could be permanently reshaped at about 333° F.

Summary

The non-failed fixtures received all carry date codes from 08/07 through 10/07, and all contain the filament PTC. The same part found added to the old, failed fixture 6F as a modification.

The electrical design of the newer ballast within these fixtures will:

- in the event of an open filament, cause the ballast to not start up at all
- allow the ballast to start up a shorted filament, but the new PTC will protect the ballast from damage until the tube actually ignites.

The PTC does not cause a fixture to shutoff in the event of any type of bulb failure—the PTC's function is only to protect the ballast. The ballast design will cause a fixture to shutoff except in the event of a shorted filament. In that case, the new PTC should prevent catastrophic damage to the ballast.

If a filament shorts during operation, the ballast will continue producing high voltage and the tube will remain lit, since the filament is not heated by the ballast (except when the tube is not fired). Because the PTC takes the place of the shorted filament, both the tube and ballast should continue to operate normally without any noticeable temperature rise.

During exhaustive functional tests, 360° Test Labs was unable to find a failure mechanism that would produce the melted plastic shrouds found on the new and failed fixture samples, including recreating the method used by Client engineers to recreate the failure in the past. Brownout conditions only resulted in low light emission and slow starting, while higher-than-normal voltage "surge" conditions did not result in noticeable damage until the AC input voltage was raised, and maintained at for several hours, approximately 41% higher than nominal. Even then, only the two remaining 240VAC fixtures failed catastrophically.

While the revised ballast design of the new fixtures may prevent such damage as melting shrouds from occurring, we cannot confirm this possibility. Further, since concurrently operated, re-tubed failed fixtures have performed similarly, the older aluminum capped tubes are in-question. Issues with similar aluminum capped tubes were addressed in past testing by 360° Test Labs.