

Compatibility of LED Traffic Signals with Existing Traffic Signal Field Equipment
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Background:

Light Emitting Diode or LED vehicle traffic signal heads have become popular in the last four years in the US mainly for their ability to save energy. Currently, their use is more restricted to the red traffic lamp, because the green and yellow are not yet financially feasible. The technology, though not new, became more acceptable in the last few years for several reasons. First, the LED lamps themselves improved, showing less long term light output degradation. This factor is important since the capital cost of installing such signal modules is quite high. This improvement came with the arrival of AlInGaP (Aluminum Indium Gallium Phosphate) lamps. More data on long term degradation furnished by LED manufacturers have provided the foundation to the warranties given by LED traffic signal head manufacturers to user agencies. Second, the design of the units has improved significantly, as the units are more energy efficient, string failure resistant, and moisture resistant. They also have higher power factors and some even have temperature compensation circuitry. A third aspect is that prices of LED modules have come down because of efficient design, even though AlInGaP LEDs are priced higher than the older AlGaS LEDs. This makes the pay back period shorter and more attractive for such investments. A fourth and very important aspect is the acceptance of this device or technology by various public agencies at state, county and municipal levels as practical and useful.

Currently the Manual on Uniform Traffic Control Device does not have any special requirements on LED signal heads. The Institute of Transportation Engineers (ITE) published an Interim Specification in December 1995, which has not been officially endorsed by members for adoptionⁱ. Based on this document and local experiences several agencies have written their own specifications and started installing LED signal modules in their jurisdiction, whereas many have undertaken small scale pilot programs.

While no agency has had an installed base for over seven years to encounter long-term or end of life problems that may be expected, other problems have been noted by various agencies and manufacturers in the field. Two important problems that have been encountered are incompatibility of the LED modules with existing load switches and signal (conflict) monitors. These devices are part and parcel of all traffic signal controllers and are used by all agencies. Many of these devices are seven to ten years old, and are not usually replaced unless there are problems encountered in the field. This presents a unique problem in conjunction with LED traffic signal heads. Incompatibility with signal monitors or load switches can result in malfunctions ranging from signal heads flickering to complete black-outs. Though the occurrence is not very common, a potential for such

a problem is not uncommon, and the consequences to traffic engineering departments may be serious. This article examines these devices, analyzes the problem, and recommends some solutions. It also aims to raise the awareness of this issue among the transportation engineers considering LED traffic signals, or among those who have already installed some in their jurisdiction.

Load Switches and Signal Monitors and their Functions:

Load switches are devices that switch the load current to the appropriate indication or phase red, green or yellow. Each load switch consists of three outputs into the field load bay which connect to a field terminal. These load switches allow a low voltage signal from the Controller Unit to control the delivery of high current and voltage to the traffic signal load. The resulting output voltage across the signal load is measured by the signal monitor.

Conventional load switch circuits contain two triacⁱⁱ switching devices for each output. One triac device has a trigger function while the second triac is the power device. *Trigger current* and *hold current* are two key parameters which must be satisfied to ensure correct load switch operation. The first parameter must be met to trigger the power triac into the conductive state. The hold current parameter must be met to have enough current flowing through the power triac to retain it in a full conductive mode. To ensure that the power triac device is switched to the conductive mode over the full temperature range found in traffic signal applications, an increased trigger current of approximately 100 mA is required. This value is larger at higher temperatures than the minimum specified current at 25°C, due to the temperature dependent characteristics of the triac devices commonly used.

In practice, only part of the total load current contributes to the triggering of the power triac. To reliably trigger the power triac in an actual load switch circuit, a higher load current of 150 mA is required to compensate for internal parasitic currentsⁱⁱⁱ. This ensures that at least 100 mA flows through the trigger triac into the gate of the power triac. Once the power triac is triggered, it carries the full load current.

The power triac will stay conductive as long as the load current is greater than 100 mA. This value is referred to as the *hold current*. Failure to trigger the power triac device may result in permanent damage to the trigger circuit, whereas failure to maintain the minimum hold current may limit the available power delivered to the signal module. Meeting either requirement has not been a problem with existing incandescent traffic signal lamps, where units draw three to ten times greater load currents over the operating range of the signal system.

Signal monitors are devices that detect and respond to conflicting or improper signal indications at the intersection. For example, it ensures that a southbound through green indication and an eastbound through green indication are not active simultaneously at an

intersection. Other improper signal displays include overlapping green, yellow, or red indications. The signal monitor is wired in parallel with the signal load at the field terminal block. It measures the voltage developed across the signal load to determine if the signal is in the “on” or “off” state. If the signal monitor senses there is an active signal during a phase where there should not be, it responds by placing the intersection into a flashing emergency mode. Current National Association of Electrical Manufacturers (NEMA) standards and Type 170 requirements limit the maximum off-state voltage to 15 Vrms.

The Incompatibility Problem:

As mentioned earlier, a main attribute of the LED signal technology is low power consumption and hence energy savings. LED traffic signal heads are devices that consume considerably less power when compared to typical incandescent bulb loads. Additionally, because of internal design characteristics, LED modules present a much higher off-state impedance than higher power incandescent (resistive) loads.

Current standards require that load switches operate correctly with a minimum of 100 mArms of load current. This brings forth problems that have not been expected in the field. LED modules may not draw the necessary load current to meet either the trigger current or hold current requirements of the load switch. This problem is especially critical with extremely low wattage LED units of 15 watts or less. This incompatibility may result in malfunction or permanent failure of the load switch. If incompatible with load switches, two failure modes are possible:

- 1) The load switch trigger circuit may overheat or become permanently damaged if the load current is insufficient to trigger and hold the main power triac, or
- 2) The signal head may flicker or not turn on.

As mentioned earlier, the signal monitor senses the voltage on the various phases to determine whether a signal indication is active. From this signal status, it then determines if there is a conflicting or improper signal condition. Current industry standards specify a maximum off-state voltage of 15 Vrms and a maximum load switch leakage current of 7.1 mArms. This implies the impedance of the signal load must be less than 2120 ohms to limit the off-state voltage to less than 15 Vrms. Otherwise, the signal monitor may incorrectly sense a signal in the off-state as being active. This would force the monitor to respond by placing the intersection into the flashing emergency mode.

While the signal load off-state voltage is the main requirement for signal monitor compatibility, controlling the off-state voltage decay time is also important. Both of these requirements are affected by parameters which vary depending on other cabinet equipment characteristics. The transition from the on-state to the off-state of the LEDs themselves occurs very quickly. However, the off-state load voltage measured by the signal monitor typically decays to its final value somewhere between 100 and 500 milliseconds, depending on the LED signal module design, the load switch leakage current value, and the signal monitor impedance.

Excessive decay time may cause the monitor to sense an inactive signal indication as active and temporarily overlapping the next signal color on that phase. As an example, the voltage measured by the signal monitor on a green field terminal may be sensed as active for 500 ms during the transition from green to yellow on that phase. This may force the monitor to respond by placing the intersection into the flashing emergency mode.

The current version of the ITE *Interim Purchase Specification for VTCSH Part 2: LED Vehicle Traffic Signal Modules* does not address these problems adequately. Its section 5.2.1 requires that the LED traffic signal module be compatible with existing load switches and signal monitors. However, this provision is not effective since there are no methods of defining “load switch and signal monitor compatibility”, or testing for such compatibility. Some engineers have proposed conducting tests to see if the existing load switches and signal monitors in the field are functioning with LED signal heads properly. This would not be practical, since a malfunction may only occur under several worst case conditions not easily duplicated in the laboratory. Compatibility is an issue that should be preempted at the design stage when introducing a new product, rather than leave the user agencies to encounter or correct a field problem.

Under these circumstances, design and test solutions may be applied to satisfy both load switch and signal monitor compatibility.

Design and Test Solutions:

It is clear that both load switch and signal monitor compatibility can be addressed by design and testing of the LED signal module. As discussed previously, the profile of the current introduced into the load switch should be such that the power triac is both triggered and then kept active by the hold current. For low power LED signal modules, an example of a current profile is shown in Figure 1. Within each AC Line (channel 1) half cycle, the load current (channel 2) temporarily exceeds 150 mA, triggering the power triac device. After reaching 150 mA, the current should remain continuously above 100 mA for a time span long enough to ensure that the rms load current during this time span is at least 50% of the total rms load current^{iv}. This would ensure that the main portion of the power is delivered through the power triac and not through the low power trigger circuitry.

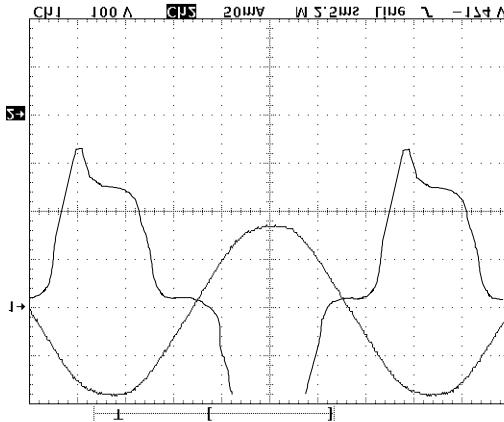


Figure 1

Alternatively, it has been suggested that the load switch could be activated by requiring a minimum load current level, such as 100 mA rms, through the device. The implication of such a design would be to increase the power consumption of the module by a large extent. This would be contrary to the intent of promoting LED technology, i.e. power saving. It also would not ensure that the load switch is triggered properly, unless this current is as high as 150 mA rms. Hence, the load current profile in Figure 1 is the better solution, whereby the total power consumption could still be held at a relatively low level, only affecting total harmonic distortion (THD)^v. Power or utility companies discourage introduction of a large THD on the system mains from field devices, and in many cases specify a minimum THD level. This minimum has varied between 0.2 to 0.4 depending on the agency.

However, with the introduction of the current profile similar to Figure 1, it would be difficult to retain THD at 0.2, especially for very low power units. The lower the power consumption, and thus current draw, the larger the distortion necessary to achieve the current profile of Figure 1, and hence the higher THD value. It has been empirically found that modules consuming 15 watts or higher could retain a maximum THD of 0.2, even with this design change. The newer LED modules have temperature compensated circuits where the current draw increases with temperature to compensate for a decrease in intensity levels. Conversely, current draw decreases with a lowering of temperature. For units consuming less than 15 watts, especially at very low temperatures where current draw is small, introduction of this design change would affect the THD more. Hence for such modules a minimum THD of 0.4 is recommended, instead of the proposed 0.2.

As far as the power or utility companies are concerned, THD of individual modules is not as important as is the total impact on the mains. Allowing a higher minimum THD on low power modules would be preferable than requiring a lower minimum THD and having only high power modules. For example, a 15 watt unit with a 0.4 THD will be preferable to a module consuming 30 watts with a 0.2 THD. Since only the current waveform is being distorted, a lower wattage unit will have less effect on the system mains than a higher wattage unit. The net benefit is that by relaxing the THD for low power modules,

total power consumption can be reduced. Restricting the THD level to 0.2 for all modules will have the effect of restricting the design and manufacturing of low power units that are load switch compatible.

For compatibility with signal monitors, the following test is recommended. An LED signal module would be energized at 135 VAC through a 19.5K ohm resistor. This resistor supplies the maximum allowable leakage current to the signal module, simulating the off-state in the field cabinet. A switch is wired across this resistor. A second high ohm resistor (about 220K ohm) is connected across the signal module to neutral. This provides a small discharge path to neutral as a signal monitor would. To conduct the test, the switch should be closed illuminating the LED module. As shown in Figure 2, when the switch (channel 1) is opened, the voltage across the signal module (channel 2) should be less than 10 Vrms within 100 milliseconds.

If the switch opening is not synchronized with the AC line, the test is to be repeated a sufficient number of times to ensure that the measurement is taken when the switch is opened at the peak of the AC line voltage. The off-state voltage decay time of 100 milliseconds is required to ensure the signal monitor senses the signal off-state before responding to overlapping signal indications. The 10 Vrms level is required as a maximum LED signal off-state voltage which is less than the signal monitor maximum off-state threshold of 15 Vrms.

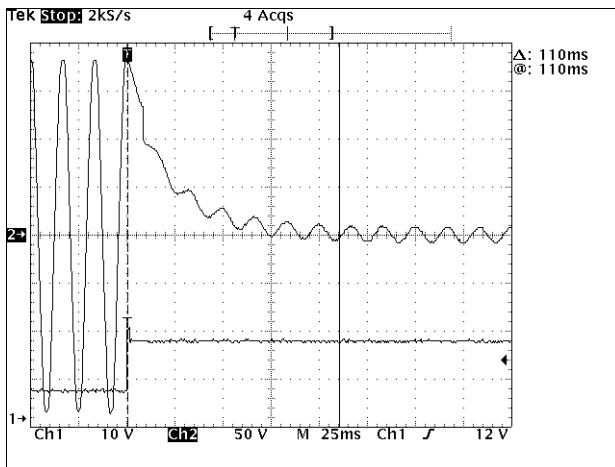


Figure 2

Field Experiences:

LED traffic signal head manufacturers and public agencies have learned about incompatibility problems with their field equipment after the signal heads have been installed. This is because the agencies were not aware of the problems and had not conducted adequate tests in advance. There are instances of such incompatibility with almost all LED manufacturers and in several states, counties and cities. Some such agencies are the City of Sacramento, the State of Minnesota, West Palm Beach County,

Florida, and the State of New York. Some agencies, such as Minnesota, discovered the problem during their pilot testing program and addressed the issue in their subsequent specifications. Some agencies have addressed the problem by requiring a higher AC amperage, which has the detrimental effect of increasing the power consumption.

The agencies involved did not share any documented records of field failures, and hence any detailed information on the number of such cases is not available. However, in all the instances, the agencies involved decided that a direct response to this problem was necessary. It should be noted that many LED signal modules currently being supplied have been designed (or redesigned) to work correctly with existing equipment.

Conclusion:

Both load switches and signal monitors are an inherent part of all traffic signal installations. Most jurisdictions have field equipment that is seven to ten years old that have withstood harsh environmental conditions. Very few jurisdictions have the resources to test and replace such equipment routinely, and do so only when problems occur in the field. The new LED signal modules are being used by more and more agencies in the field, and agencies have been facing incompatibility problems with LED modules and load switches and signal monitors. Such incompatibility problems have lead to black-outs, flickering and triggering the flash mode.

To avoid this problem the LED module can be redesigned easily to ensure proper triggering and holding of the load switches as well as proper voltage sensing by the signal monitor. This would require relaxing the minimum THD level of the LED module from 0.2 to 0.4 to help procure very low power units, without any impact on the system mains. It also requires a circuit to control off-state voltage. Simple tests can be performed on some sample LED modules to test for compatibility with signal monitors and load switches. Once these recommendations are implemented, agencies can reliably use LED signal modules and benefit from power and maintenance cost savings without concerns of field equipment failure.

Notes:

ⁱ This interim specification on LED signal heads may be revised after a NCHRP sponsored focused human factor study on peak traffic signal intensity 5-15) is concluded by mid to late 1998. This is part of a larger study on traffic signal intensity and color on human factors (NCHRP 5-15) which is scheduled to be completed by end of 1999.

ⁱⁱ A *triac* is a three terminal ac semiconductor switch which is triggered into conduction when a low-energy signal is applied to its gate. The triac will conduct current in either direction when turned on. The triac offers the circuit designer an economical and versatile means of accurately controlling ac power.

ⁱⁱⁱ Total load current consists of trigger current plus power triac main terminal current. Before the power triac begins to conduct, trigger current is equal to the total load current (i.e. main terminal current = 0). As the power triac begins to conduct, a small part of the total load current is provided through the main terminal of the power triac. Since trigger current plus main terminal current always equals total load current, this decreases the amount of current available to trigger the triac.

^{iv} This requirement can be verified graphically using an oscilloscope as shown. A test circuit is being developed to facilitate testing this requirement.

^v The Total Harmonic Distortion (THD) is a number which gives the ratio of the rms value of all harmonic components to the rms value of the fundamental (60Hz) current.

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} i_n^2}}{i_1} \text{ (THD of rms current)}$$

The utility company produces electrical energy at the power plant by means of a three phase voltage generator. This energy is transmitted to users via a series of voltage transformers and transmission lines. All these transmission stages have copper losses which are proportional to the square of the current drawn by the end user.

The utility company compensates the phase shift caused by resistive/inductive loads of all end users by connecting large capacitors across the intermediate voltage network. By this method, the voltage and current of the network to the generator are more or less in phase. This ensures the optimum use of the transmission network towards the power plant.

Because these capacitors form a low impedance path for the harmonic frequencies, they lead to increased dissipation within the capacitors.