Wayside LED Signals – Why it's Harder than it Looks

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It seems like it should be so simple. All you have to do is replace a light bulb with an array of LED's and you're off and running. Unfortunately, nothing is ever as simple as it seems. In this article, we'll talk about both the benefits of wayside LED signals and highlight some of the areas we need to be aware of. AREMA Committee 37 (Signal Systems) is presently working on a Manual Part to address some of these issues so that railroads will be able to specify a wayside LED signal and feel comfortable that manufacturers are building the wayside LED signals to a common standard.

The benefits of wayside LED signals are improved visibility, higher reliability and lower power consumption. The basic purpose of a wayside signal is to display the proper aspect to an engineer. Anything that provides better visibility with less maintenance is a good thing, providing enhanced safety for both operating and maintenance personnel, as well as reducing train delays due to downgraded or dark signals. LEDs produce light more efficiently than incandescent bulbs, so that less power can produce equivalent light, thereby reducing operating costs. This benefit is somewhat elusive though, as existing systems require a minimum amount of power to be used in order to operate with the existing interface. Most of the benefits are self-evident so I won't spend most of this article simply reciting them.

It's the unintended or unexpected consequences of applying the wayside LED signals that need to be considered in more depth so that railroads can make intelligent decisions regarding the application of this technology. These areas include

- Unexpected Visibility Issues
- Interface with existing equipment installed in the field
- Safety-Critical Design issues
- Lifecycle cost issues

Unexpected Visibility Issues

The unexpected visibility issue is probably not a major issue, but should be understood. Existing wayside signals are focused so that their on-axis light beam is extremely bright when you are within the light beam, and substantially less so as you move off-axis. LED signals are generally not focused (or at least less so than incandescent bulbs) so they are viewable over a wider angle. In many cases, this wider angle is preferable as the signal provides enhanced brightness over a wider viewing range, and is less susceptible to focusing adjustments. However, there are situations where tighter focusing is desirable.

These include focusing the signal around a curve for better visibility, focusing along a single track in multiple track territory to improve the engineers ability to determine which aspect is intended for the track being occupied, and for long straight track in open areas (typically in western states) where an engineer would be able to see wayside signals beyond the signal being approached.

Interface with existing equipment installed in the field

Interfacing with existing equipment in the field is a major issue for LED signals. Wayside signals are lit from either vital relay-based systems or vital processor-based systems that are available from a wide variety of manufacturers. The two basic types of systems have different interface characteristics, and interface characteristics vary substantially within the various processor-based systems.

The primary goal for a replacement wayside LED signal is to have a module that can be installed in the signal head itself without modifying either the existing signal head wiring or the control circuitry located in the wayside bungalow or case. Another goal is to have only one type (or at least a very small number) of replacement LED signal units to minimize the required spares inventory and to minimize potential safety hazards of installing the wrong replacement unit at any given location.

Part of the interfacing issue includes the hot-button topics of hot and cold filament checking. This subject always leads to substantial discussion and argument. While the terms relate to incandescent bulbs, the underlying concepts apply equally well to LED signals. Hot-filament checking implies verifying that sufficient visible light is being emitted when the appropriate input is provided to the signal head. This is a safety function, but provides operational advantages also. A dark aspect that is part of a multi-aspect signal has the potential of having the overall aspect misinterpreted by the locomotive engineer. This is covered in FRA Rule 236.23(f). Equivalently, a dark aspect for a multi-track location could cause the engineer to misinterpret the aspect from an adjacent track as the controlling aspect. From an operating perspective, determining that an aspect is not being correctly lit allows a degraded (less permissive) aspect to be displayed avoiding a stop and proceed, or an absolute stop. Cold filament checking is similar, but is a check done when the aspect is not illuminated. This provides advance knowledge of a lamp or LED failure so that the preceding aspects can be downgraded in advance, thus preventing a sudden unexpected downgrade. While the “hot filament” check is clearly a safety-critical function, it can be argued that the “cold filament” check does not necessarily have to be implemented in a fail-safe manner. Performing cold filament checks on LEDs is very difficult since they respond to the short pulses used by processor-based systems and could generate visible light during them, especially under failure modes of the drive circuitry. An argument can be made that existing filaments are far more likely to fail when power is initially applied, leaving the value of a cold filament check questionable. Perhaps it is more useful to think of a “cold filament check” as verifying the integrity of the wires up to the signal head, rather than an actual broken filament.

With incandescent bulbs, it is generally accepted that no current flow through the bulb is an indication that no visible light is being emitted. While there are cases of this not being true (e.g. corroded sockets), their occurrences are sufficiently rare as to be considered an acceptable safety risk. With LED signals, this is not necessarily the case. First, there is limited information available to indicate that individual LED's will always emit light if they are drawing current. Certain LED technologies have embedded protection diodes as part of the LED itself that have the potential of shorting and allowing current to flow while bypassing the light generating portion of the LED. Some people have suggested that the published reliability numbers of LED's are so high as to make this step unnecessary, relying on complete unit replacement every few years instead of verifying light output. However, these published Mean Time Between Failure (MTBF) numbers are based on averages and neglect issues arising from manufacturing anomalies (e.g. solder connections), production anomalies and failures due to the environment (e.g. lightning transients). Relying on these numbers also means that the safety must be re-evaluated every time an LED manufacturing process and/or technology change occurs. A second area to consider is that, unlike incandescent bulbs, LED signals generally have electronic components in the signal head to provide a regulated, constant supply current to the individual LED's. Failures in these electronic components also have the effect of allowing the signal head to draw current even though no light is being generated. These electronic components may now become a higher risk for overall reliability, including the failure mode of having all the LED's go dark simultaneously. Another factor to consider is the number of independent LED strings within the light. In some cases, a single LED failure will cause several other LEDs to stop working. In other cases, the single LED failure causes the other LEDS to glow more brightly, but by overstressing them and reducing their future lifetime.

As if this wasn't complicated enough, relay-based systems and processor-based systems perform these hot and cold filament tests in substantially different ways. Relay-based systems measure one value of continuous current when the aspect is lit, and a second continuous value when the aspect is dark. This first value requires that LED replacement signals draw at least this minimum value of current when lit, thereby negating potential power saving advantages. In addition, they must draw at least a minimum value of current when the aspect is not lit while making sure that this minimum current does not allow any light to be generated from the LED's.

Some processor-based systems operate similarly to relay-based systems, but many others use a brief output pulse (of full power) to the signal head to verify that current is being drawn. This output pulse is typically only a few milliseconds and occurs approximately once per second. This pulse width is not long enough for an incandescent bulb to respond to, but could easily cause an LED to turn on to full brightness for a few milliseconds. Some people argue that this brief flash is not sufficient to be interpreted as a signal aspect. This may be true under normal viewing conditions, but viewing in dense fog, snowstorms, or rainstorms could easily allow such a flash to be interpreted as a continuous aspect.

While this brief flash is being discussed, it's important to note that many processor-based systems incorporate a similar output pulse as part of their safety-critical checks on output status. Similarly, they incorporate their version of hot-filament checks into their systems regardless of whether or not it is used in the application. In other words, these interface considerations are important even if hot and cold filament checking are not used as part of the application logic.

These interface design issues are critical to the operation and safety (see following paragraph) of wayside LED signals. It is important that the unit be designed as part of an overall safety system, and that it is not just "tricking" the interface into thinking everything is OK.

Safety-Critical Design issues

Signal aspects governing train movements are an inherent part of safety-critical (vital) train control systems. Substituting technologies for a component within a system is an everyday and perfectly valid occurrence. However, we must make sure that we are not inadvertently introducing new hazards into the overall system. LED wayside signals must have the same comprehensive safety analysis that any other electronic system used in safety-critical applications has. This includes hazard analyses, fault tree analyses and Failure Mode Analysis in line with AREMA Manual Part 17. Incandescent bulbs have directly accepted failure characteristics that are part of the safety analysis of existing systems. LED wayside signals can be designed to provide the same characteristics, but they must be specifically designed to do so. Within AREMA Committee 37, we identified the following basic hazards that must be mitigated.

- Wayside signal must not flash (at any rate or for any duration) at any input voltage from zero to maximum rated input voltage (unless responding to a flashing input voltage).
- Wayside signal must not flash (at any rate or for any duration) in response to processor-based output check signals or processor-based cold filament check pulses.
- Where light-out detection is used, wayside signal must not indicate that light is being generated when less than 50% of the rated light output is being generated.
- Where multi-color aspects are used, the proper color aspect must be the only one lit.
- Wayside Signal must not generate light output unless proper rated input voltage is present.

These hazards must be mitigated both under normal operating conditions (e.g. environment, rated voltages, etc) and under failure conditions (including all credible single point failures as generally accepted in the industry). AREMA Practices specify the technology independent principle that no single point component failure can produce a potentially unsafe condition. It is further specified that single point failures that are not self-revealing (e.g. immediately obvious to a competent user so that corrections can be made prior to follow-on failures occurring), secondary failures must be considered in combination with the initial failure. As new technologies are introduced, manufacturers have developed techniques to maintain compliance with these technology independent principles. LED signal manufacturers from other industries should be encouraged to provide products for the rail industry, but the users must verify that these basic principles, which have served the industry extremely well, are maintained. Otherwise, users will be ill served when they discover that a single failed component causes the signal to operate in a potentially unsafe manner and they have to do a massive modification or change-out of all the LED wayside signals in the field.

Lifecycle cost issues

Finally, there is one last area to be thrown out for consideration by the user. Certainly for the foreseeable future LED wayside signals are going to have higher initial costs that wayside signals with incandescent bulbs. It's anticipated that this will be offset by enhanced safety, reduced maintenance, and reduced train delays. One factor that needs to be included in this calculation is the operating lifetime of an LED Wayside signal unit. Mean Time Between Failure (MTBF) numbers for LED's of 50 to 100,000 hours (5 to 10 years) are not uncommon. This number represents the average time to complete failure of an individual LED and not necessarily the time over which the LED will maintain the required minimum luminous intensity. LED luminous intensity degrades with age and temperature so the Average Life Expectancy (ALE) is different than the MTBF. Some designs compensate for this by increasing the current through the LED's, but this has the undesirable effect of further stressing the LED and shortening its life. Users need to work with the manufacturers to understand what this time is for guaranteed minimum luminous intensity and not wait to replace LED wayside signal units only in the event of catastrophic failure. Users also need to understand this useful lifetime so they can budget capital replacement costs for the units.

Conclusions

LED Wayside signals have a bright future (pun intended). This article identified some of the additional factors that need to be considered in the procurement and application of the units so that users can fully understand both the benefits and the risks associated with their use. The article also identified some of the efforts presently being done by AREMA Committee 37 to help the process along.