

LED MR16 LAMPS

Directional lamps are a key component of the focal lighting systems that are often used in retail, hospitality, residential, and museum applications. Halogen MR16 lamps are frequently used for these applications—thanks to their beam control, flexibility, and small size—and the form factor has received considerable attention from the LED industry. However, LED MR16 lamps vary substantially, both in their performance and compatibility with existing infrastructure. Careful consideration and evaluation of operating characteristics is required when converting from conventional sources to LED.

Introduction

Multifaceted reflector (MR) lamps are used in many types of luminaires including track heads, monopoints, and fixed or adjustable recessed downlights. The most common MR-type lamp is the MR16, which has a diameter of 16 eighths of an inch, or 2 inches. MR16 lamps are typically operated at a low voltage (usually 12 V), which introduces an additional level of complexity that must be addressed when considering replacement of halogen sources with LEDs. This is especially important for track lighting systems, where multiple lamps on a single circuit often interact with other electronic components.

Typical halogen MR16 track lighting systems consist of low voltage lamps (commonly 20, 35, or 50 W), luminaires (track heads), optical accessories (e.g., lenses, louvers), one or more electronic or magnetic transformers, and the track itself. A dimming system may also be incorporated. The track—which provides power as well as flexibility for mounting locations—can operate at either line voltage (120 V), requiring low-voltage track heads with integral transformers, or low voltage (12 V), requiring a single remote transformer for several track heads. The majority of currently installed track is line voltage. To date, standards have not been developed for the track lighting market; as a result, track and track heads from different manufacturers typically are not directly interchangeable.

MR16 lamps are unique amongst directional lamps because they are most often operated at low voltage and their design is constrained by the small form factor. Beyond the usual performance characteristics that should be evaluated when comparing LED and conventional products, the interaction of electronic components must also be considered. These compatibility issues are of concern for both retrofit applications and new installations.



LED MR16 lamps are used to wash the wall behind the front desk of the InterContinental Hotel in San Francisco, CA.

Basic Performance Characteristics

Form Factor and Lamp Appearance

Achieving the small MR16 form factor can be a challenge for integrated LED lamps, which must incorporate LED package(s), optics, thermal management, and a driver. Consequently, some LED MR16 lamps may be larger, longer, or have a different shape than the American National Standards Institute (ANSI) specifies,¹ as shown in Figure 1. This can result in the LED lamp not fitting properly into the luminaire or track head, or it may make it harder to use accessories such as lenses, louvers, screens, or filters. Additionally, some lamps have fins used for thermal management that catch on the wire retaining springs used in many MR16 fixtures, making installation and changeout of lamps more difficult.

Most halogen MR16 lamps send some light and heat backwards through the dichroic coating of the reflector; the sparkling and colorful appearance this creates is considered a desirable feature by many specifiers. As of 2012, DOE has been unable to find an LED MR16 lamp that emits substantial backlight; this may change with future designs.

Quantity of Light and Efficacy

According to CALiPER testing to date, the lumen output of most LED MR16 lamps is equivalent to the output of halogen lamps drawing 35 W or less. As of June 2012, the maximum lumen output of an LED MR16 lamp listed by LED Lighting Facts was 550 lumens (see Figure 2). At typically 40 to 60 lm/W—reaching up to 80 lm/W, according to LED Lighting Facts—the efficacy of LED MR16 lamps is much higher than for halogen MR16 lamps, which deliver approximately 5 to 20 lm/W. Notably, MR16 lamps

¹ ANSI standard C78.24-2011, American National Standard for electric lamps: Two-inch (51 mm) Integral-reflector Lamps with Front Covers and GU5.3 or GX5.3 Bases, stipulates dimensions for the most common type of low-voltage MR16 lamp.

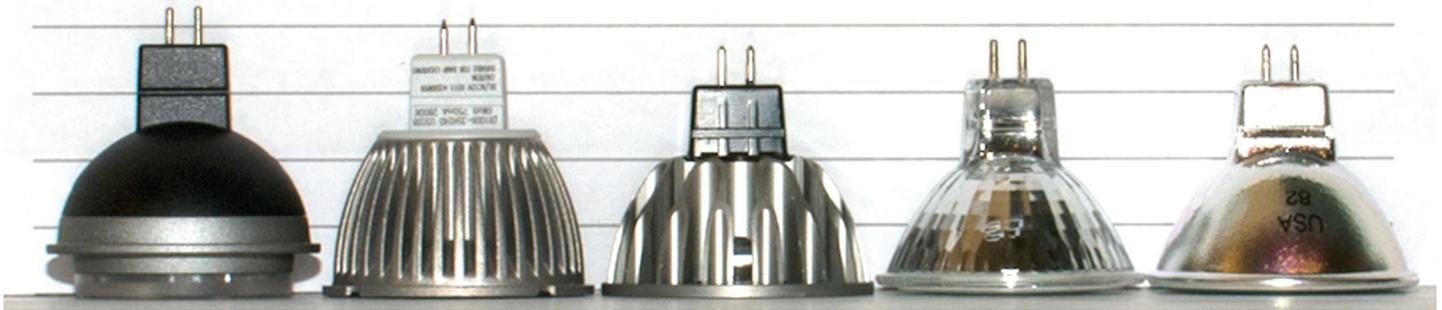


Figure 1. Some LED MR16 lamps (left three) do not match the form factor of conventional halogen MR16 lamps (right two).

are often specified based on luminous intensity distribution characteristics—specifically beam angle and center beam candlepower (CBCP)—rather than lumen output.

Distribution of Light

Halogen MR16 lamps offer a variety of distributions, ranging from narrow pin spots with a beam angle of 7° to wide flood distributions of with a beam angle of 60° or greater. Available distributions for integrated LED lamps are more limited, seldom reaching the extremes of the halogen range (see Figure 3). However, this is not a limitation of the technology, and a greater range of offerings are continually reaching the market.

One potential advantage of LED MR16 lamps is improved uniformity across the beam, with fewer hotspots, no filament images, and no ragged edges. These characteristics may allow the fixture to be operated without supplementary spread or softening lenses which can trap heat and reduce light output.

Color Quality and Spectrum

As with other LED products, LED MR16 lamps are available in a wide range of correlated color temperatures (CCTs). If seeking a visual equivalent to a halogen lamp, products with a CCT of 2700 K to 3000 K are most appropriate.

LED sources can exhibit very good color rendering, with some currently available products having a color rendering index (CRI)

greater than 90 and many options available with a CRI greater than 80. However, this level of performance cannot be assumed and the CRI metric may not perfectly capture human perception. In demanding applications, visual evaluation is the best approach.

A benefit of integrated LED lamps is the substantial reduction of energy radiated in the ultraviolet (UV) and infrared (IR) regions of the electromagnetic spectrum. This is particularly advantageous in museum lighting applications where minimizing material degradation is highly desirable.

Heat Dissipation and Thermal Environment

In general, LED MR16 lamps work best in an open environment, such as with a gimbal ring track head. Unfortunately, many track heads designed for MR16 lamps are compact and enclosed. The effects of different thermal environments on temperatures inside an LED source are dramatic. For example, at the InterContinental Hotel in San Francisco (the site of a GATEWAY demonstration²) relative testing showed that operating a sample LED lamp inside one of the existing enclosed luminaires resulted in a heat sink temperature that was over 18°C higher than when it was operated in open air. In some cases, reduced ability to remove heat can cause LED lamps to discolor—as was the case at the InterContinental Hotel—or suffer degradation in light output and life expectancy. Beyond using enclosed fixtures, adding lenses,

² More information on GATEWAY demonstrations, including the InterContinental Hotel, can be found at http://www.ssl.energy.gov/gatewaydemos_results.html.

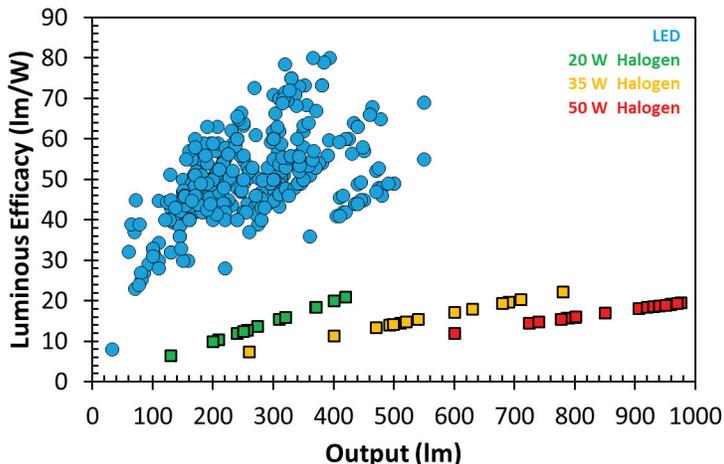


Figure 2. Luminous efficacy versus lumen output for LED MR16 lamps listed by LED Lighting Facts as of June 19, 2012 and selected nominal data for low-voltage halogen MR16 lamps.

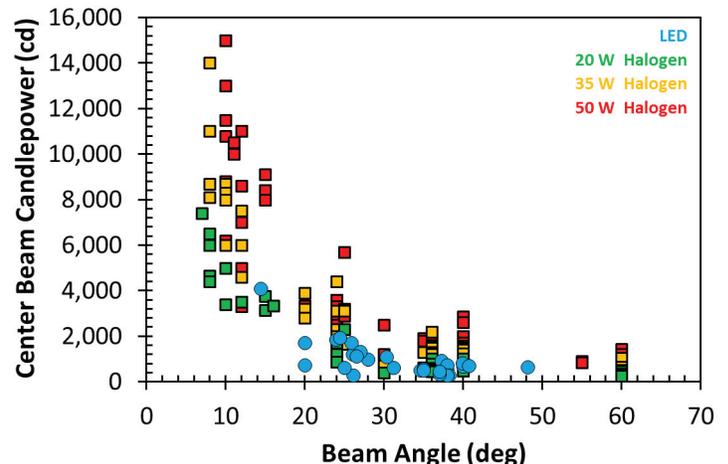


Figure 3. Center beam candlepower (CBCP) versus beam angle for a subset of LED MR16 lamps listed by LED Lighting Facts as of June 19, 2012 and selected nominal data for low-voltage halogen MR16 lamps.

gel filters, or any accessories that compromise airflow should only be done with great caution.

Some LED MR16 lamps utilize active thermal management devices, such as integral fans or vibrating membranes, to aid in cooling. It is critical that the airflow for these devices is not obstructed. Air intake holes should not be blocked (by a glass lens, for example). Some LED sources contain a thermal protector, which in extreme conditions may reduce the light output from the lamp or cease its operation altogether. In this scenario, cycling can result as the lamp turns back on after a sufficient cool down period. Also noteworthy is the additional noise caused by some active thermal management devices, which may be distracting in certain environments, such as a private residence.

Electronic Compatibility Considerations

Electronic compatibility issues arise because MR16 halogen lamps behave electrically like a simple resistor, whereas LED lamps typically require a driver comprised of multiple electronic components that present a more complex electrical interface to other electronic components, such as transformers, dimmers, and other lamps. Not all LED installations experience these problems, but without standardized components, it can be difficult to predict performance without specific compatibility testing.

When considering replacement of a low-voltage lamp, understanding the type of transformer used is an important first step. For some commercially available LED products, magnetic transformers seem to be more robust and exhibit fewer compatibility problems, although they are typically less efficient than electronic transformers. However, greater compatibility is not a fundamental characteristic of magnetic transformers; the observation of fewer problems with some products today may not translate to fewer problems as LED MR16 lamps develop in the future. Installing integrated LED lamps in systems utilizing electronic transformers warrants great care given that they contain their own set of electronic components. Incompatibilities between the electronics in the transformer and the LED driver can lead to poor performance or even premature failure of one or both components. Even minor differences in circuit design of seemingly identical transformers may produce dramatic differences in the performance of seemingly identical LED lamps.

Minimum Transformer Loads

Transformers typically have both minimum and maximum limits for the connected load. Integrated LED lamps draw fewer watts, and therefore may not meet the minimum load requirement of a transformer that was designed for halogen lamps. Depending on the specific design of the LED lamp and transformer, if the minimum load is not met the lamp may shut off completely or flicker. LED lamps can also draw high repetitive peak currents, which effectively stress the electronic components they are connected to (such as those in transformers) more than their wattage rating would suggest. Consequently, the maximum load for a transformer can be lower for LED sources than its rating for halogen sources. For example, a dimmer rated at 600 W for halogen lamps may only support a load of 150 W for a given LED lamp.

Dimming

Regardless of operating voltage, transformer location, or transformer type, compatibility with dimming technology is an important consideration, especially in retrofit applications. Pairing a magnetic low-voltage (MLV) dimmer with a magnetic transformer, or an electronic low-voltage (ELV) dimmer with an electronic transformer does not guarantee compatibility. For example, a transformer's minimum load requirement must be met throughout the dimming range, even as the effective load is continually reduced. One way to address this problem is to use a dimmer with a low-end trim, which can limit dimming to a range where the transformer is stable; below that low-end setpoint, the dimmer simply switches off the lamp.

As is the case with electronic transformers, dimmers contain their own set of electronic components that interact with other equipment on the circuit. For an LED system, dimming performance is dependent on the specific combination of transformer, LED lamp, and dimmer. The consequences of improperly matched components can vary widely but may include flicker, color shift, audible noise, premature failure, very limited or no range of dimming, or failure to light. Including a resistive load, such as a halogen lamp, on the track circuit can improve compatibility and performance, but doing so creates other challenges, such as achieving color consistency across all light sources.

Flicker

Many different approaches may be used to control the current in LEDs. These different methods, which are typically implemented by a driver, lead to wide variation in the periodic modulation of light output from LED sources. The amount and type of modulation, or flicker, present in a given LED source can be more or less than seen in comparable conventional technology sources (see Figure 4). The modulation found in halogen sources is not usually perceptible; however, higher levels of modulation may be perceived as objectionable flicker, which may cause distraction, eyestrain, headaches, or reduced visual task performance in some individuals over time. As is the case for dimming performance, flicker in LED MR16 products is dependent on the specific combination of transformer, lamp, and dimmer (if applicable).

Power Factor

The power factor of an LED MR16 lighting system depends on the design of both the lamp and transformer. In CALiPER testing to date, the power factor for LED MR16 lamps ranged from 0.29 to 0.96 when operated on a reference power supply in a laboratory environment. Additional testing showed that a given LED lamp could exhibit a varying power factor when operated on different magnetic or electronic transformers. It should be noted that tradeoffs between power factor and flicker are typical for LED MR16 lamps because the small form factor limits the incorporation of more sophisticated circuit designs.

Replacement Options

There are several options to consider when the decision has been made to convert from low-voltage halogen MR16 lamps to LED

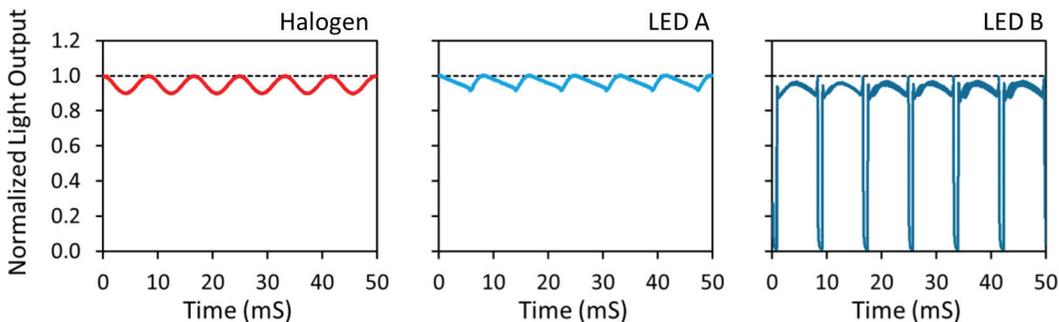


Figure 4. The modulating light output of three different MR16 lamps. The halogen and LED A lamps are not likely to produce objectionable flicker, whereas LED B might.

MR16 lamps. Although every situation is unique, basic considerations are often the same and safety requirements should always be followed. Three options are typically available:

- Replace only the halogen lamp with an integrated LED lamp. In this case, the LED product—combining LED package(s), optics, thermal management, and driver—must both conform to the MR16 form factor and operate in conjunction with the transformer built in to the track head or remotely powering the low-voltage track. Compatibility should be carefully evaluated, and following the recommended practices provided in this fact sheet is strongly encouraged. Dimming presents an added concern; if it can be avoided, finding compatible products may be more straightforward.
- Replace both the halogen lamp and existing transformer with an integrated LED lamp and new transformer—replacing the dimmer, if applicable, may also be necessary. This approach can minimize compatibility issues, but can be more costly. Even if it is physically possible, replacing the integral transformer in a track head can be labor intensive. Replacing the remote transformer powering low-voltage track is less labor intensive, as long as the transformer location is known and easily accessible.
- Replace the entire track head with a dedicated LED track head, which uses an LED array or module instead of an LED MR16 lamp and an integral driver to power the LEDs. A low-voltage LED track head may still experience compatibility issues with the remote transformer. Regardless of voltage, the dimmer may also need to be replaced.

Recommended Practices

While the considerations and potential challenges are significant, LED MR16 lamps can work as promised and as desired given the right combination of system components. Beyond basic equivalency considerations,³ understanding the components of a full lighting system and being aware of their potential limitations are important preliminary steps. Following the recommended

³ See the DOE fact sheet, “Establishing LED Equivalency,” for details (<http://ssl.energy.gov/factsheets.html>).

practices summarized below will help to ensure that expectations are met:

- Seek out compatible product lists from manufacturers. At a minimum, they should include tested combinations of lamps, transformers, and dimmers. They should also specify a minimum and maximum number of lamps (1–4, for example) per dimmed circuit, dimming range (maximum to minimum), and flicker characteristics. As system efficacy and power factor are dependent of the combination of lamp, transformer, and dimmer (if applicable), users who want to achieve specific performance targets should ask for system data rather than individual lamp data.
- Investigate whether any case studies exist that evaluate one or more components of the system under consideration. Evaluating similar installations may not guarantee success, but it can help to identify potential problems.
- Perform an extended duration mock-up of entire circuits (lamps, transformers, and dimmers). Such a mockup can be costly, but it may prevent even larger expenses incurred when dealing with problems once the lamps are installed in great numbers.
- If compatibility lists or case studies do not contain the combination of interest, and a mock-up is not possible, look for lamp manufacturers that are willing to provide a strong warranty and help in diagnosing and correcting any issues that may arise.

Looking to the Future

The best option for the long-term may be complete replacement of conventional luminaires with dedicated LED products, rather than continued use of traditional form-factor lamps, like the MR16. This will allow for the holistic design of line- or low-voltage track and LED track heads with better thermal management and compatible combinations of transformers, drivers, and dimmers. Dedicated LED products may offer more flexibility to control light output, while still maintaining the small profile of luminaires using MR16 lamps.

