Choosing the Right LED Solutions for Your Application

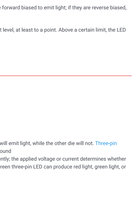
Introduction

From LED modules to LED strip lights and rope lights, to Mini-LED display modules, LED technology is broadly deployed across a wide range of industries and applications. LEDs can seem complex to integrate into products and applications, but advances such as LED solutions with built-in controllers or drivers make the technology simpler than ever to use. The key is to pick the right one. Here, we will review the characteristics and features of modern LEDs to help you choose the best LEDs for your application. We'll discuss major design needs and the LED solutions that can be used to address them. We'll also showcase their use in a range of applications.

Key benefits of LEDs

- High efficiency – minimizing power consumption and energy costs
- Ultracompact – sizes ranging from millimeters to microns, making them good solutions for space-limited applications
- Reliable – lifetimes up to 100,000 hours and failure modes characterized by gradual dimming versus catastrophic failure
- Robust – able to tolerate high shock and vibration

How do LED solutions provide these benefits?



LED lighting solutions basics

How do LEDs work?

LEDs are solid-state devices that spontaneously emit light in a color determined by the semiconductor materials used. They're based on a direct bandgap semiconductor structure known as a PN junction. The admission process is known as electroluminescence. (For more detail, see "Understanding LEDs.")

LEDs have been made from a wide variety of materials. Visible LEDs have been manufactured in all colors. Infrared LEDs and UV LEDs are also broadly available.

Powering LEDs

LEDs are DC devices that require voltage above a certain threshold V_{th} to operate. Because LEDs are diodes, they must be forward biased to emit light, if they are reverse biased, they will remain dark.

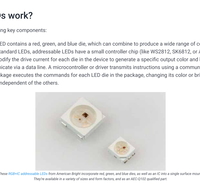
The luminous flux (output level) of an LED is a function of drive current. The higher the drive current, the greater the output level, at least to a point. Above a certain limit, the LED will undergo catastrophic failure. To protect against this, LEDs should be wired with breakdown resistors.

The relationship between current and output has important implications that we will discuss farther down.

Colors/wavelengths

LED lighting solutions are available packaged or unpackaged. Packaged LEDs can be:

- Monochromatic
- Two-color: In a bicolor two-pin LED, two LED dies are co-packaged in a two-pin package. The die that is forward biased will emit light, while the other die will not. Three-pin bicolor LEDs are also available. In these devices, each die has its own positive voltage pin and they share a common ground
- Three color: Two LED dies are co-packaged in a six-pin package. In the six-pin package, each die can be driven independently; the applied voltage or current determines whether the output is exclusively from one die or the other, or mixture of the two that creates a third shade. For example, a red-green three-pin LED can produce red light, green light, or amber light (a mixture of red and green)
- RGB: Co-packaged red, green, and blue dies
- RGBW: Co-packaged red, green, and blue dies with an additional white LED



RGB and RGBW LEDs provide us with more sophisticated options. Physics tells us that mixing precise levels of red, green, and blue light can be used to achieve any color in the color gamut. If we start with a triad of red, green, and blue LEDs (as separate devices or as co-packaged RGB LEDs), we can use current to independently drive the output levels of each LED. The result is an LED that can be tuned across the visible spectrum. RGBW LEDs give users the option of producing pure white light, as well as having greater control over the brightness and saturation of any other color generated.

This color mixing can be controlled by an IC, allowing an LED or group of LEDs to be programmed to produce dynamically changing color displays or small changes to ambient lighting to suit activities and time of day

Infrared LED solutions

IR LEDs are widely used in a variety of sensing and vision applications. They don't create interference like visible or even RF sources would do, and they are robust, efficient, and low-cost.

How does an IR LED work?

As previously mentioned, the semiconductor materials used in an LED determine the output wavelength of the device. In the case of IR LEDs used for non-communications applications, the most common material structure for the PN junction is gallium arsenide (GaAs).

How to use an IR LED

IR LEDs are widely used in sensor and touchless applications:

- Security: motion detectors and security cameras, night vision surveillance
- Industrial: machine vision, proximity and presence/absence sensors, encoders to detect motor movement, and as photo couplers in a variety of electronics
- Retail: self-checkout machines, pill dispensing machines
- Consumer: remote controls, garage door motors, printer paper monitors

UV LEDs

Depending on the bandgap structure, LEDs can be fabricated to emit UVA, UVB, or UVC output. Common applications include material curing and disinfection in areas like water treatment and hard surfaces in operating rooms.

How do white light LEDs work?

White LEDs typically consist of two primary elements: a blue LED die and a yellow phosphor. The phosphor down converts the blue light into yellow light. The mixture of the two is perceived by our eyes as white light. Over time, phosphors have been developed to generate white light in a range of correlated color temperatures (CCTs). White light can also be created from the combination of all colors of light. One method of generating white light with LEDs is to combine equal amounts of red, green, and blue light. Although this can and has been done, it is more complex from a control standpoint and more expensive. Practical white light LEDs take a different approach.

What are addressable LEDs?

Addressable LEDs are RGB LEDs with a built-in IC. This enables them to be individually controlled in brightness and color and programmed for a variety of effects. When used in a group – for example in a strip light or LED display – they can be used to create attention-grabbing shows such as color changing sequences, flashing patterns, color gradations, and even animations like chasing.

Addressable LEDs are available as individual surface-mount devices or packaged as LED strip lights, LED rope lights, or LED modules. Because each LED can be individually controlled, the technology provides a great deal of design freedom. And the built-in IC simplifies design and integration, freeing engineering teams to focus their time on other tasks.

How do addressable LEDs work?

An addressable LED incorporates the following key components:

1. The LED dies: An RGB addressable LED contains a red, green, and blue die, which can combine to produce a wide range of colors (see Figure 1).
2. The integrated controller IC: Unlike standard LEDs, addressable LEDs have a small controller chip (like WS2812, SK6812, or APA102) integrated into each LED unit. This controller receives data signals to modify the drive current for each die in the device to generate a specific output color and brightness.
3. Data I/O: Addressable LEDs communicate via a data line. A microcontroller or driver transmits instructions using a communications protocol such as serial peripheral interface (SPI). The IC in the LED package executes the commands for each LED die in the package, changing its color or brightness accordingly. This allows precise control over the output of each LED independent of the others.

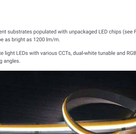


Figure 1: These RGBHC addressable LEDs from American Bright incorporate red, green, and blue dies, as well as an IC into a single surface mount package. They're available in a variety of sizes and form factors, and as an AEC-Q102 qualified part.

What are the benefits of addressable LEDs?

1. Individually Addressable: Each LED die can be controlled independently, meaning you can set different colors, patterns, or brightness levels for each LED in a strip or array. This enables complex animations, fades, and lighting effects.
2. Multiple Colors: American Bright's RGB + IC addressable LEDs offer 256 color levels and 32 brightness levels to deliver any shade in the color gamut. By combining red, green, and blue at different intensities, each LED can produce a wide range of colors (up to 16.7 million, depending on the resolution of the controller). RGBW addressable LEDs provide even more color options, as well as higher contrasts.

How to use addressable LEDs

As far as how to use addressable LEDs, they are excellent for:

- Aircraft interior lighting: wash lighting, cabin illumination, safety lighting
- Architectural lighting and landscape lighting: accent lighting, safety lighting, directional lighting

- Automotive: In automotive interiors, addressable LEDs can deliver animations to welcome the driver, flashes from the dashboard to alert inattentive drivers, and a calm color palette for the drive home at the end of the day
- Entertainment: With animations and programmable light shows, addressable LEDs are taking over casinos, arcades, and bowling alleys. They add excitement and drama to theaters and nightclubs. In concert and sports arenas, an orchestrated change in color can completely alter the appearance and energy of the venue
- EV charging stations: outlining housings, control panels, and shelters
- Marine lighting: Indoor lighting and interior and exterior accent lighting for yachts and other boats

Form factors

LEDs are available in a variety of form factors, making it easy to optimize the LED solution for each application.

Discrete LEDs

Individual packaged LEDs are available in ~~the~~ standard through-hole LEDs with resin cases and various standardized surface-mount devices (SMT, EMC, PLCC, etc.). Diameters range from the conventional 3 to 5 mm diameters to miniature LEDs just 0.65 x 0.35 millimeters.

LED PCB modules

LED PCB modules are built on printed circuit boards. The most common form factors are round, square, and linear, but custom shapes and sizes are typically available for specialty applications (See Figure 2).

Depending upon various applications, these modules can be pre-populated with not just LEDs but IC controllers, breakdown resistors, current regulators, etc. The PCBs can have built-in heat dissipation features, which simplifies thermal management (see Building Board-Level Assemblies for LED Modules). When properly designed and fitted with a diffusing lens, they can generate high luminous flux with no hotspots.

Figure 2: AC LED modules like the American Bright Ingen-AC family of LED light sources incorporate key circuitry like power adapters to speed development and assembly. Available in square, round, and linear form factors, they can also be customized upon request

How to use LED PCB modules

In PCB modules, the electronics are exposed. As a result, the module should be embedded in a lighting product, protected with a diffuser/lens, or used for indirect lighting.

Common applications for LED PCB modules include:

- Aircraft interior lighting: task lighting, overhead lighting
- Architectural and landscape lighting
- Automotive interior and exterior lighting: dome lights, instrument backlighting, foot well lighting, door pockets, adaptive driving beam (ADB) headlights, taillights, safety lights, aesthetic lighting (backlit emblems, etc.)
- General LED lighting solutions: luminaires, task lighting, downlights
- Medical and dental equipment

LED strip lights

LED strip lights consist of surface mount LEDs installed on narrow, flexible linear circuit boards (see Figure 3). They typically include support circuitry like breakdown resistors. LED light strips are encapsulated to protect the components, which can achieve IP ratings of IP20, IP65, and IP68.

LED strip lights are designed for easy splicing, allowing multiple strips to be daisy chained together to fit a variety of needs. Adhesive backing makes them easy to install – just peel off the protective tape and press the strip to the surface.

LED strip lights are available in monochrome colors, white light with a variety of CCTs, RGB, RGBW and addressable RGW and RGBW (see Figure 3):

Figure 3 Flexible light strips are available in a variety of colors and capabilities. American Bright's flexible LED light strips produce line includes 10mm 6mW monochromatic, white light, and individually addressable light strips.

LED rope lights

LED rope lights are a special kind of linear form factor LED that encloses a string of LEDs in a flexible silicone jacket. The protective silicone covering can be clear, revealing the individual LEDs inside, or mixed with diffusers to give a continuous glow. LED rope lighting is offered with monochrome LEDs, white light LEDs with various CCTs, and RGB/RGBW LEDs. They are also available with addressable RGB and RGBW LEDs.

LED rope lighting is available in top emitting or side emitting styles. Both have very tight bending radii, with the side emitting styles most flexible of all. Rope lights are available with IP65 and IP68 ratings.

Because the LEDs and electronics in rope lights are protected by the jacket, they work well for direct lighting applications. Rope lights, particularly IP68 rope lights, are extremely effective for outdoor applications subject to harsh weather.

COB LED light strips

Chip on Board (COB) light strips consist of thermally efficient substrates populated with unpackaged LED chips (see Figure 4). Because the LEDs are unpackaged, COB light strips have much higher packing densities. This allows them to be as bright as 1200 lm/in.

COB light strips are available with monochrome LEDs, white light LEDs with various CCTs, dual-white tunable and RGB/RGBW LEDs. They are also offered with RGB addressable LEDs. The LEDs are typically top emitting with wide viewing angles.

Figure 4: Comparison of unpackaged COB mounted on flexible substrates, COB light strips, like this one from American Bright, offer high brightness output. They're available in monochrome, white light, dual white light and addressable RGB LED formats.

Like LED strip lights, COB light strips are adhesive backed for ease of installation. They are encapsulated during manufacturing, giving them ingress protections as high as IP68, depending on the model.

As with other strip lights, COB LED light strips are highly flexible along the long axis but only moderately flexible for off axis bending or twisting. They should not be sharply bent. Use them to outline slowly varying contours and follow manufacturer guidelines about bending radii carefully.

LED light strips, LED rope lights, and COB light strips can be used in similar types of applications, including:

- Architectural lighting: interior and exterior accent lighting, wash lighting, safety lighting (handrails, stair treads, etc.)
- Automotive interior and exterior lighting: accent lighting to highlight features, functional illumination to assist operators, wash lighting to create ambience
- Backlighting
- Commercial: desks, office pods
- Entertainment: accent lighting, aesthetic lighting, and dynamic lighting effects in theaters, nightclubs, concerts, arenas, arcades, casinos, slot machines, bowling alleys
- EV charging stations: outlining the housings and control panel
- General lighting: commercial buildings such as hotels and hospitals, residential buildings
- Industrial: 3D printers, high-volume medication dispensers, robots
- Landscape lighting: accent lighting, safety lighting, mood lighting
- Marine lighting: indoor and outdoor accent lighting, safety lighting
- Retail: self-checkout machines, display case and window illumination
- Signage

Advanced LED solutions

The unique properties of LEDs have enabled the development of advanced solutions that expand capabilities and simplify design and integration. They include:

- AC LED modules – simplified power design
- Integrated DC LEDs – speed integration into products
- Mini LED display modules – ultra high brightness for outdoor applications

AC modules

LEDs are inherently DC loads. Many applications operate off wall plug power, however. As a result, they either need standalone DC power supplies, which can be bulky and expensive, or the product itself needs to incorporate AC/DC power converter, as some LED fixtures and bulbs do. Both of these solutions add complexity and design work for the OEM and cost for the customer. AC LED modules provide a solution.

An AC LED module features an integrated AC/DC converter (see Figure 5). This eliminates the need for costly external power supplies or time-consuming homegrown solutions. Assuming the AC LED module is compatible with local power (120 VAC in the US), the product incorporating it can operate off wall plug power.

AC LED dimmer modules are also available that are capable of dimming to a warm ambience.

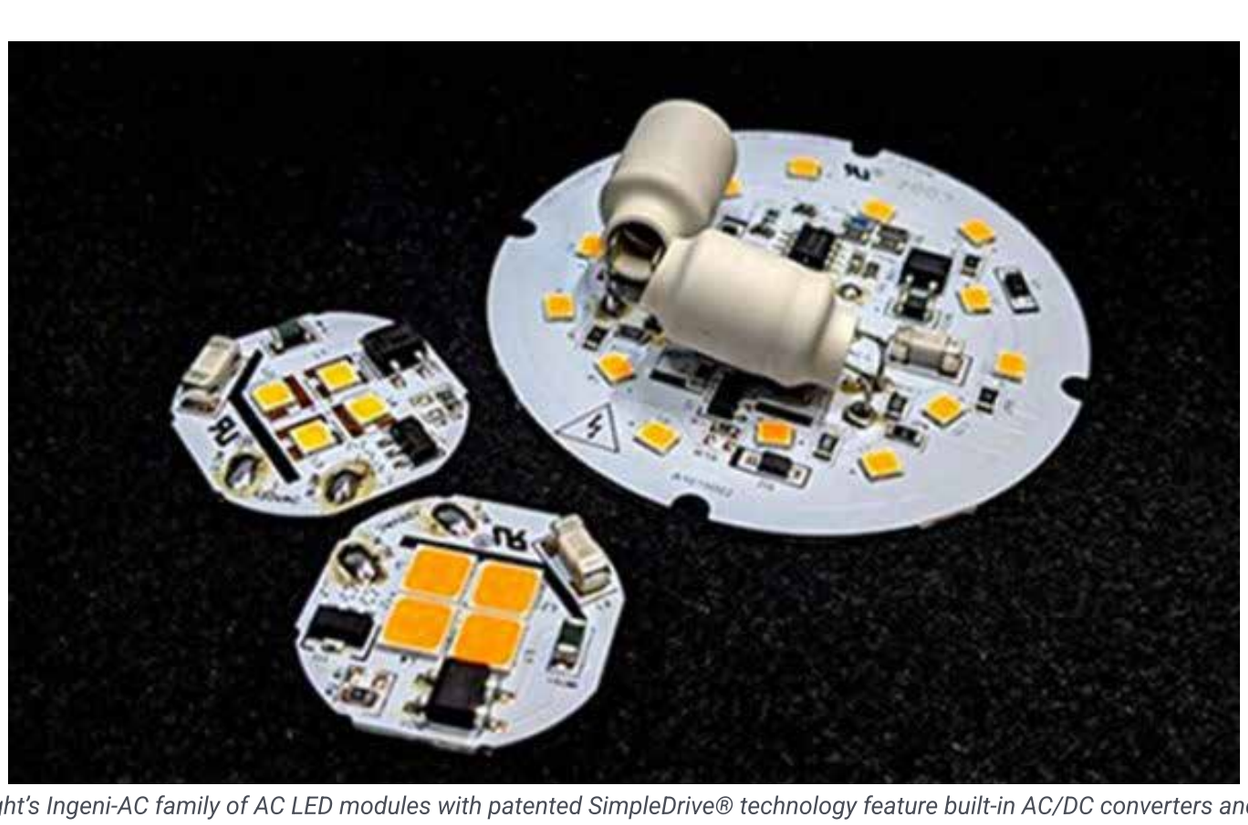


Figure 5: American Bright's Ingeni-AC family of AC LED modules with patented SimpleDrive® technology feature built-in AC/DC converters and dimming capabilities. This allows them to be powered off of 120 VAC wall plug power.

Common applications for AC LED modules include:

Architectural lighting: AC LED modules are ideal for luminaires, making it easy to combine stylish design with LED efficiency and long life. AC LED light dimmer modules bring mood-enhancing atmospheres to environments as varied as living rooms, museums, and restaurants.

Integrated DC LEDs

Integrated DC devices are also available and offer similar benefits. LEDs with integrated ICs simplify design and assembly by removing the need for adding ICs to the board. American Bright's EzyLEDs go one step further, incorporating not just the IC but also passive components like rectifiers (see Figure 6). The result is streamlined design and assembly.

When it comes to drive voltage, EzyLEDs makes life easier for design engineers to integrate into products. The 12 V version operates over a voltage range of either 10.45V < Vin < 24V, while the 24 V version operates 22.5 < Vin < 36V. EzyLEDs feature active thermal management capabilities that prevent them from overheating by decreasing input current.

Figure 6: American Bright's EzyLEDs are available in a variety of colors.

Common applications include

- Automotive interior lights: ambient lighting, dome lighting, glovebox, and functional illumination in cars, vans, trucks, tractor trailers, and buses
- Automotive exterior lights: taillights, license plate illumination, door lights, daytime running lights, door handle lights, etc. in the above vehicles
- Recreational vehicles: ATVs/UTVs, RVs/Camping, off-road truck lighting
- Architectural and landscape lighting: accent lighting, safety lighting

What are Mini-LED display modules?

Mini-LED display modules use miniature LEDs to substantially improve the brightness and contrast ratio of liquid crystal displays. To explain how, we must first review the operation of liquid crystal display modules. The liquid crystal display modules consist of a liquid crystal layer patterned into pixels, and a backlight. The liquid crystal acts as a shutter to pass or block light through each pixel, creating an image. To create color images, the device is augmented with layers of red, green, and blue filters. The liquid crystal is patterned to create an RGB triad for each pixel, enabling each pixel to be color tuned.

Several approaches to back lighting have evolved:

Edge lighting

Rows of LEDs around the edge, on the sides, or just on the bottom of the display backlight the liquid crystal. To boost contrast, displays can use dimming. Global dimming refers to reducing the brightness of the entire LED string for certain frames. Local dimming can be accomplished by using independently addressable LEDs and controlling their brightness. Since most edge lit LCMs either have LEDs on the sides or on the top/bottom, this creates bands of contrast. Some displays further split these bands, creating zones at the top and bottom or left and right.

Direct lighting

A low-resolution array of LEDs back lights the display. These displays have greater brightness but because the LEDs are controlled as a group, these designs do not offer enhanced contrast.

Full array with local dimming (FALD)

FALD uses a much higher resolution array of independently controlled LEDs. This increases the luminous flux of the backlight. It also supports zone dimming for small groups of pixels. Zone dimming significantly increases the contrast for zones of pixels.

This is where Mini-LEDs and Mini-LED display modules come into play. The smaller the LED, the more LEDs that can be packed into the backlighting array and the brighter the display. Even better, smaller LEDs enable much higher resolution dimming. The result is a high contrast display that is bright enough to be easily read even in full sunlight (see figure).

Mini-LED display modules from American Bright, for example, achieve brightness levels of 3000 to 20,000 nits and contrast ratios of 1,000,000:1.

The use of smaller LEDs reduces power consumption and heat generation, which increases lifetime for the LEDs and the display as a whole.

Figure 7: Mini-LED display module at EV charging station shows graphics clearly even in full sunlight.

Common applications for these display modules include

- Vehicles, motorcycles, and marine: Dashboard displays, head-up displays (HUDs), navigation panels, infotainment screens
- Infrastructure: Gas pump and EV charging station control panels
- Commercial: ATMs, ticket machines, retail window displays
- Entertainment: Casino/arcade gaming, outdoor ticket kiosks
- Industrial: Hand-held devices used outdoors, meters

LED Applications

Let's take a look at how the technologies above map to core applications.

Automotive – On road and off-road Vehicles

LEDs are widely applied in automotive interior and exterior lighting due to the combination of small size, low power consumption, reliability, and variety of colors and form factors.

For automotive interior lighting, rope lights and strip lights provide accent lighting in areas like the center console, door pockets, and foot wells. RGB + IC addressable LED light strips enable dynamic programmable displays that enhance the driver experience, from adding ambience to increasing ease of use and improving safety. Look for AEC-Q102 qualified addressable RGB + IC LEDs . Developed by the Automotive Electronics Council, the AEC–Q standard codifies testing automotive optoelectronics to ensure that AEC-Q102 qualified parts will deliver reliable performance even in the case of extreme conditions.

For other automotive interior applications, EzyLEDs are the workhorse technology for use cases like dome lights, glovebox illumination and door handle pocket lighting. As already noted, key design features of EzyLEDs simplify the integration task for engineering teams so that they can focus on the functional and aesthetic aspects of their efforts. Meanwhile, Mini-LED display modules enhance the readability of head up displays, instrument panels, and in-vehicle entertainment.

Automotive exterior lighting applications for LED lights, PCB modules and EzyLEDs include adaptive headlights, taillights, daytime running lights, license plate illumination, and lighting under the door handle. Vehicle designers use rope lights to enhance vehicle styling, sometimes combining it with function, as in the case of independently addressable rope lights that can support animations on horizontal brake lights.

The use of LEDs in the vehicle space goes beyond passenger cars and trucks to encompass buses and Industrial equipment. Mini-LED display modules improve instrument panel visibility in heavy equipment, agricultural harvesters, and even motorcycles (gauges).

LEDs also have a role to play in vehicle infrastructure, livening up gas stations, increasing the usability and styling of charging stations, and even enhancing the function of parking gates and the ticket panel.

Marine

Boats and yachts also take advantage of LED options. High brightness Mini-LED displays make dashboards and gauges visible in direct sunlight. PCB LEDs and white light strip lights support general illumination. Strip lights and rope lights showcase exterior and interior features, adding style and color changing capabilities to enhance aesthetic appeal. Addressable RGB/RGBW strip lights and rope lights can be used to add color changing animations that pulse in time with the music for a festive atmosphere. And because both light strips and rope lights are available with IP65 and IP68 ratings, they are suitable for use in the harsh marine environment.

Entertainment

Entertainment is about excitement. A review of recent trends in entertainment lighting shows that LED modules, rope lights and strip lights are widely used to add excitement and energy to:

- Gaming –slot machines, card tables, payment kiosks
- Arcades & Pinball Machines
- Arenas & nightclubs & bowling alleys

Architecture

LED lighting solutions have transformed architecture. Offering a combination of complete color control and dynamic lighting effects, compact LED solutions set architects and designers free to realize their most creative and playful visions. And LED lighting solutions make those visions practical with a combination of energy efficiency, long lifetimes and ease of use that reduce total cost of ownership. LED accent lighting highlights features on building exteriors, emphasizing the lines of a building or bridge, or illuminating façades. Indoors, LED lighting can add impact to important structural elements like archways. They can be mounted beneath the floor or under the toe kicks of a kitchen or bathroom to create drama. When hidden behind a barrier for indirect illumination, LED lighting solutions can completely alter the mood of a room or draw attention to an architectural ceiling feature. And, of course, LED light bulbs are ubiquitous for task lighting – focused lighting designed to illuminate spaces for specific activities.

Healthcare

LEDs are increasingly popular in healthcare applications, due to a combination of small size and reliability. LED lighting solutions are used for high brightness light fixtures in operating rooms. In a combination of aesthetics and safety, LED lighting can be used for lighting underneath patient transport chairs. They can also be used for accent lighting in both treatment rooms and on large equipment like MRI machines, making them feel more accessible. In the case of wash lighting, the color tuning capabilities of independently addressable LEDs can be applied to shift to tones that minimize eyestrain.

UV LEDs also have a role to play. A high brightness UVC LED lighting solution can sterilize all the hard surfaces of a room in just minutes. Dental equipment uses UVA light for both curing and for bleaching teeth.

Industrial

The industrial sector has no shortage of applications for LEDs. LEDs are widely used for indication lighting in a variety of devices. In 3D printing equipment, for example, LEDs help users monitor the printing process. Industrial vehicles use LED lighting for many of the same interior and exterior applications as automotive lighting. Industrial robots such as manufacturing robots, collaborative robots, and compact autonomous warehouse robots make heavy use of LEDs for indication, navigation, and sensors. They also provide targeted light sources for machine vision.

Away from the factory, LEDs can be found in HVAC units, both as indication lighting and also for illuminating the interior of the housing for service technicians – a long-lasting, reliable replacement for light bulbs. LEDs, particularly in the form of Mini-LED display modules, are also ubiquitous in outdoor meters, gauges, displays, industrial tablets, and many other sunlight readable applications.

Consumer

For the consumer, LEDs are ubiquitous. They simplify the function and add to the appeal of robotic vacuums and enhance the operation of smart devices like thermostats, security and doorbell cameras. They are inside the host of electronic devices ranging from smart watches to tablets and smartphones, to PCs, to autonomous robotic vacuum cleaners

Commercial

The commercial sector takes full advantage of LED lighting solutions. LEDs add aesthetic lighting and functional illumination to a variety of devices, from ATMs to ticket machines to service kiosks. They enhance service robots used to deliver food and drink to restaurant patrons or entire room service meals to hotel guests.

Retail

In retail, LED lighting solutions go beyond architectural lighting applications. Strip lighting and lighting modules are used to light up everything from payment kiosks to lockers for retrieving online purchases. The color changing abilities of addressable LED solutions add extra pizzazz to store window displays. And on a more mundane level, they enhance the appearance and the function of self-checkout equipment.

Conclusion

LEDs offer significant benefits, but design and integration can be challenging. Look for integrated solutions that can dramatically simplify product development. American Bright has a variety of integrated LED solutions. Reach out to one of our team members to learn more.