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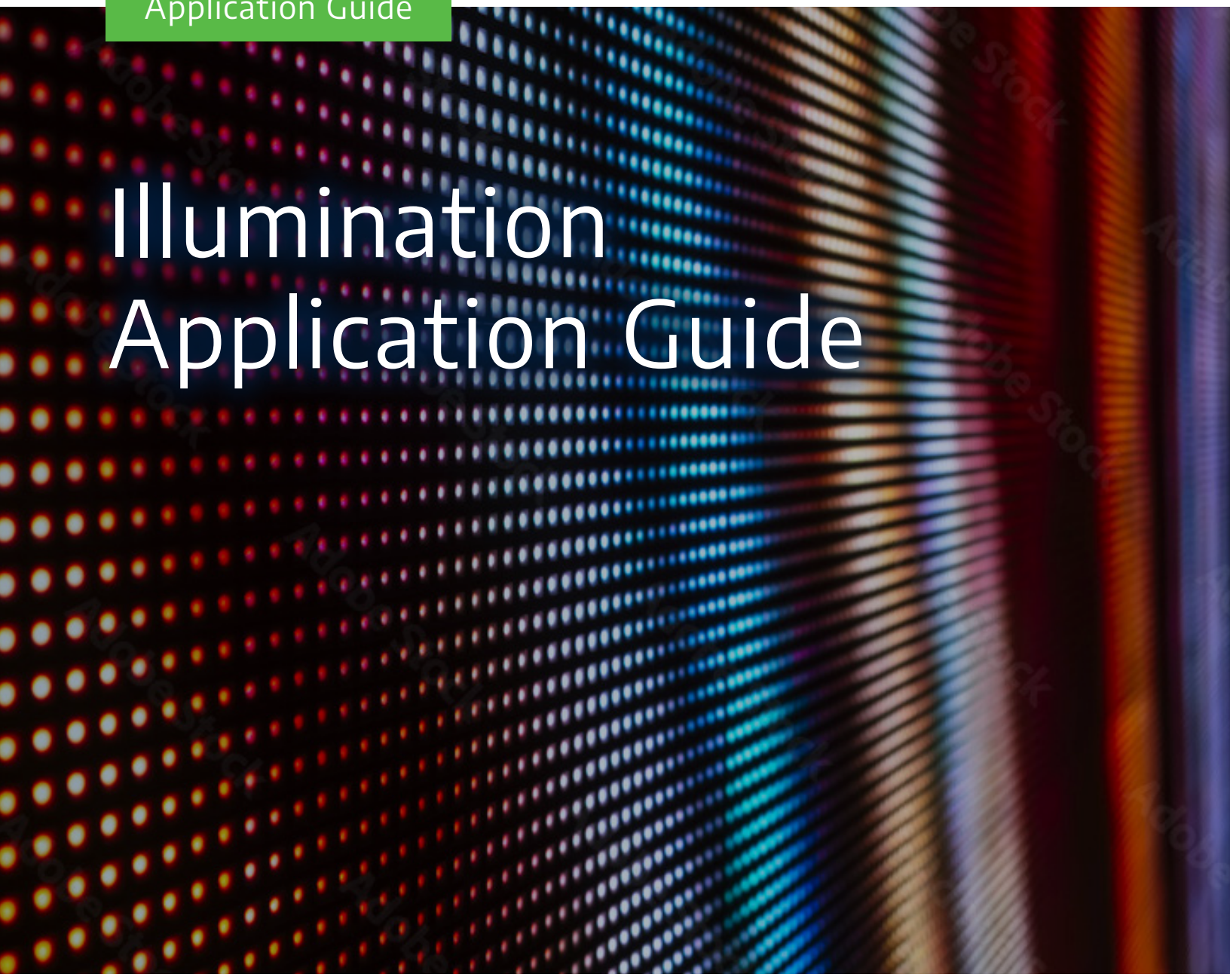
Application Guide



Illumination Application Guide

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Introduction

LEDs for indication and illumination offer OEMs an easy way to boost product function and usability, while improving design. In our era of ever-increasing device functionality, LEDs enhance user interfaces by reporting status, highlighting buttons and screens, and adding visual appeal.

Selecting an LED is just the start, however. The light needs to reach the point of use with sufficient brightness and in the desired distribution. This is where light pipes come into play. Light pipes are optical structures designed to guide the LED output from the source to the user interface. Properly specified, they will yield an effective, easy to use, robust, and attractive product.

Light pipes can reorient light from the source to any other direction in three-dimensional space. They can take uneven, omnidirectional LED output and deliver it as a point source or as an even distribution of diffuse light.

The key to success is to select a light pipe that is compatible with the physical configuration of the device, the form factor of the LED, and the environment, all while minimizing loss.

Matching light pipe to length of travel

Light pipes can be divided into two classes: rigid and flexible.

Rigid

Typically molded from acrylic or polycarbonate, these are rigid structures capable of guiding light along straight paths or straight path segments.

Flexible

Formed of plastic optical fiber, these flexible structures can follow highly complex paths.

Rigid light pipes are best for lengths of about 76 mm or less. Because flexible light pipes are based on optical fiber, their length is theoretically unlimited. In reality, optical loss does introduce some limitations.

Optimizing light pipe for board layout

As the name suggests, rigid light pipes may be rigid, but that doesn't mean they are restricted to only guiding light in straight lines. Straight and right-angle rigid light pipes are widely available as commercial off-the-shelf (COTS) products.

Right-angle light pipes are useful for capturing LED output from a circuit board and redirecting it to a user interface on perpendicular surface, for example the front of a router or modem (see figure 1).

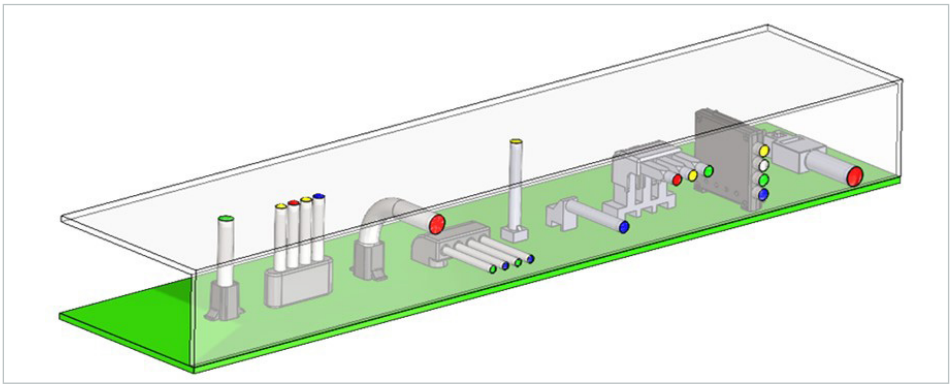

Figure 1: Light pipes carry output from the LED to its point of use, whether that is in a straight line, perpendicular to the LED, or redirected in some other way.

Rigid light pipes with multiple turns and complex paths can be fabricated but there is a penalty in terms of loss. As shown in figure 2, light propagates down a light pipe via total internal reflection from the index mismatch between light pipe material and the ambient air (or between core and cladding in a flexible light pipe).[1] Total internal reflection occurs when the light is incident on the interface at an angle greater than the critical angle θ_c from the normal.

The smaller the angle of incidence θ_i, the lower the percentage of reflected light and the greater the amount lost through transmission through the interface. More turns and sharper turns mean greater loss.

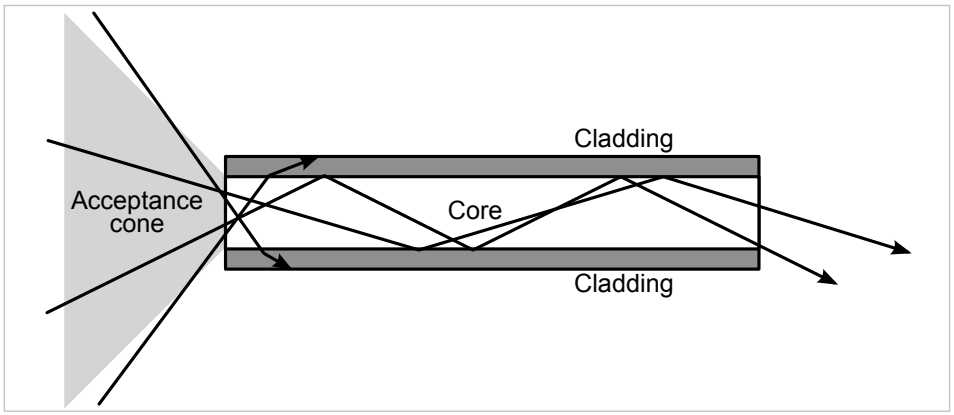

Figure 2: Light propagates down a light pipe via total internal reflection from the refractive index mismatch between the pipe core and ambient air/fiber core and cladding.

The effect can be mitigated somewhat by increasing the angle. One common approach is to use a curved, rather than angled, light pipe (see figure 3). This design increases the angles of incidence for a greater percentage of the light, decreasing loss. Curved light pipes do increase space claim compared to a classic 90° turn, however. The minimum radius of curvature on these light pipes is twice the diameter of the pipe. Lower than that and optical loss becomes unacceptable.

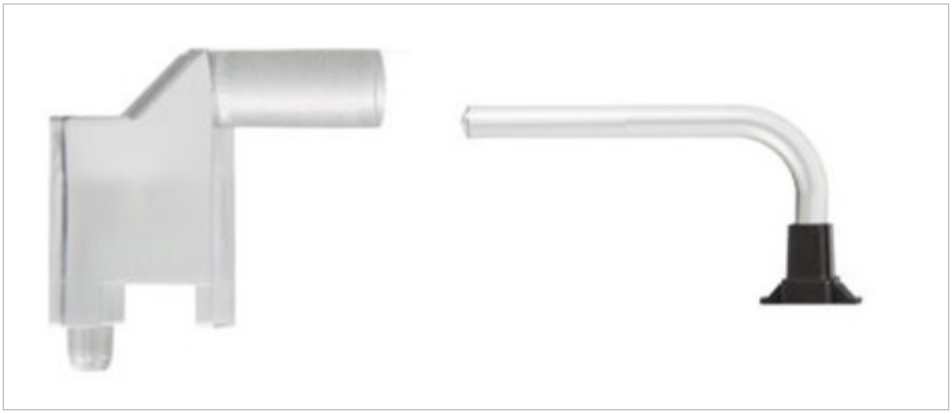

Figure 3: Rigid light pipes can redirect light through specific angles, like this 90° turn (left) or more gradually, as with curved light pipes (right).

Although rigid light pipes can redirect light, they have limitations, particularly when there are obstacles. In such cases, flexible light pipes may be a better solution. Flexible light pipes can make multiple tight turns to circumvent obstacles and transmit the light from the source to some point of use in three-dimensional space.

Flexible light pipes have a minimum bend radius of 10X the fiber diameter; for the thinnest light-pipe diameter of 1 mm, the corresponding minimum bend radius is 1 cm.

Understanding mounting options

Light pipes are available with a variety of mounting options, providing flexibility to address different product form factors, application requirements and environmental constraints. Mounting types can be classed as panel mount or board mount.

Panel-mount

Panel-mount light pipes are mounted to the panel, or housing, of the device. They can be ruggedized for use in harsh environments and are fast and easy to install. They are not physically connected to the board but hover just over the LED, held in position by the panel.

On the upside, this arrangement enables the board to be removed without disturbing the light pipes and panel. On the downside, the separation between LED and light pipe allows light to escape, a condition known as light bleed. Light bleed not only causes optical loss but can also lead to false positives and color mixing in adjacent indication lights (more about this later). The lack of connection to the board can also lead to the light pipe being positioned off-center from the LED, compromising input coupling and increasing optical loss.

Panel-mount light pipes are divided into front-mount and rear-mount designs:

Front-mount light pipes

Front-mount light pipes are installed through the front of the panel. They are built with a flange that seats itself against the panel surface. Front-mount light pipes are good for applications requiring lenses or domed surfaces.

Front-mount light pipes, also known as press-fit light pipes, are available in a variety of styles (see figure 4). The simplest are inserted into the hole in the panel and held in place by friction, typically using a crimped-rib, or crush-rib fastener.

These features make the light pipe slightly larger than the intended hole and deform when it is inserted, exerting a pressure that holds the light pipe in place. Friction-fit light pipes are economical and quick to install, no tools necessary. They work well in controlled environments, such as data centers and laboratories.

Industrial applications like manufacturing, transportation, and warehousing can expose devices to harsh conditions, including shock and vibration and contamination. For these environments, users have more robust options.

Some light pipes incorporate threaded collars that can be combined with locking washers and hex nuts to provide a vibration-resistant fit. With the addition of sealing gaskets, front-mount light pipes can achieve ingress protection ratings as high as IP68 (immersion of up to 1.5 m for 30 minutes). They require tools for installation but are still straightforward to use.

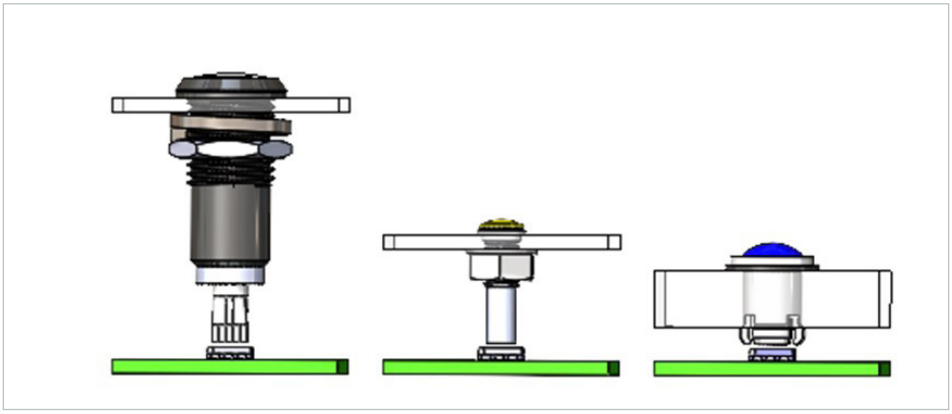

Figure 4: Front-mount, panel-mount light pipe options include (from right) simple friction-fit versions, threaded designs for shock and vibration resistance, or assemblies incorporating gaskets and locking washers for ingress protection.

Rear-mount light pipes

Rear-mount light pipes are installed from the backside of the panel. Some devices incorporate crush-rib features near the lens to help secure the light pipe in the hole. Rear-mount light pipes may include retaining rings to limit how far they project from the housing. They can be fitted with lenses or domes.

Because they don't have any sort of fastener and are not fixed to the circuit board, there's the risk that sufficient external pressure or shock and vibration can cause them to move inward, potentially contacting the LED. Thus, they should be used for indication lights with caution, ideally only when the output face will be slightly recessed from the front of the panel.

Rear-mount light pipes are most commonly used to illuminate panel overlays such as buttons or logos. In these types of designs, the overlay holds the light pipe in place, so its position remains constant.

There is also a hybrid panel mount design that combines a rear-mounted light pipe with a front-mount press-fit lens cap (see figure 5). The light pipe is installed from the back and the lens snaps on from the front. With the addition of a gasket, this particular system can deliver IP-68 contamination protection from a very simple assembly.

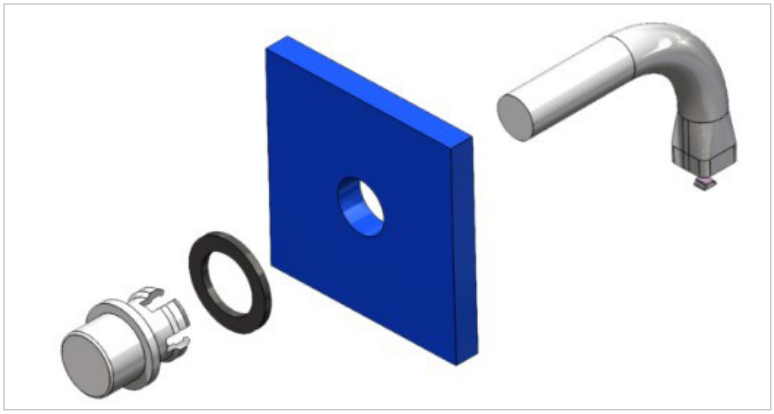

Figure 5: Hybrid panel-mount design combines rear mounted light pipe with a front-mounted press-fitted lens and gaskets to achieve IP68 rating.

Board-mount

In some cases, the light pipe needs to be mounted directly to the board, fixed in position over the LED using a special adapter. Flexible light pipes, for example, can only be board mounted. For cases in which light bleed is a concern, board mounting is typically the better option even for rigid light pipes.

In the assembly process, the adapter is installed on the board and then the light pipe is inserted into the adapter. The adapter includes an internal platform that maintains the appropriate spacing between light pipe and LED (see figure 6). Crush-rib fixtures inside the chimney of the adapter hold the light pipe in place.

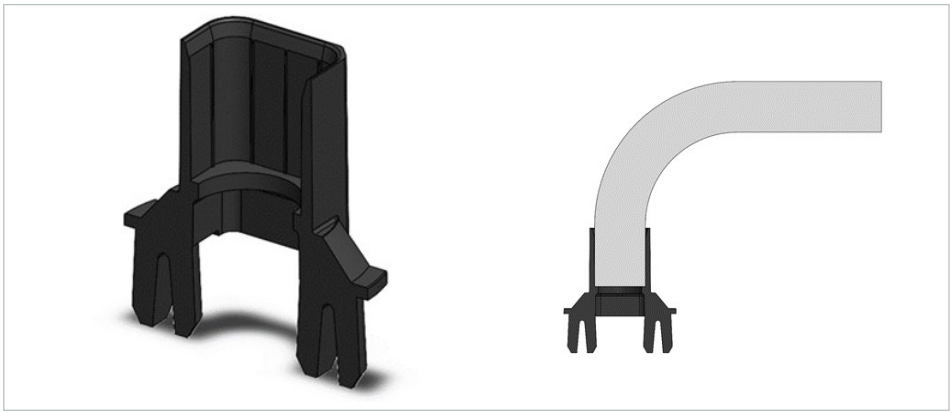

Figure 6: Adapters for board-mounted light pipes (left) include internal collars to prevent contact between light pipe and LED (right). The vertical lines in the chimney are crush ribs that provide a friction-fit for the end of the light pipe.

Board-mount light pipes maximize the amount of light coupled into the light pipe, both because the adapter completely encloses the LED and because it optimizes separation between LED and light pipe. The enclosure of the LED also minimizes light bleed into the device housing. Finally, the adapter maintains the two components in a fixed position, protecting the LED from mechanical damage.

The applications for board-mount light pipes differ depending on the type of light pipe. In the case of rigid light pipes, the output face simply slides through the hole in the front panel, like a rear-mount panel-mount device.

Unlike a rear-mount panel-mount light pipe, the assembly is fixed to the board so that it won't move. The trade-off is that it is still unable to provide ingress protection. These devices are best suited to applications like communications, laboratory instrumentation, and medical devices. They're not appropriate for industrial products unless they will be in climate-controlled enclosures.

In contrast, some board-mount flexible light pipes are specifically designed to offer ingress protection, adding seals and front-mounted lens caps to keep out dust and moisture.

Board-mount light pipes can be divided into press-fit and soldered designs:

Press-fit

In a press-fit board-mount light pipe, the adapter is attached by prongs that are pressed through pre-drilled holes in the circuit board. In the simplest version, the prongs are just round posts. For applications requiring more stability, firm-retention designs—adapters fitted with split prongs similar to those of that secure drywall anchors—provide greater holding power (see figure 7).

Press-fit designs simplify assembly. The process requires holes to be drilled in the PCB but no soldering is required. The actual insertion process is fast and doesn't require any tools.

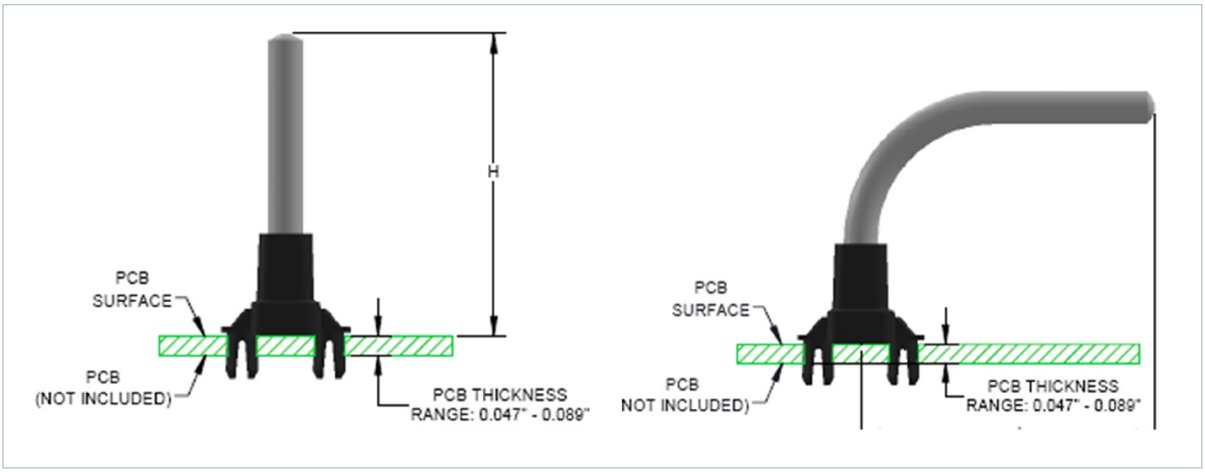

Figure 7: Firm-retention press-fit adapters provide extra stability with ribbed spreading prongs. They can be snapped into the board without tools, speeding assembly.

Solder-on

Solder-on board mount devices integrate LED, adapter, and light pipe in a single unit that just needs to be soldered onto the board. They are available as both surface-mount and through-hole devices, with rigid or flexible light pipes.

The integrated solution simplifies assembly. As with press-fit adapters, the LED is completely enclosed, minimizing light bleed and maximizing coupling. Solder-on board-mount rigid light pipes do not provide ingress protection, so they should be reserved for applications in clean environments, for example a device on a medical cart that would require increased protection against shock and vibration. In contrast, solder-on board-mount flexible light pipes can be designed to provide incursion protection (see figure 8).

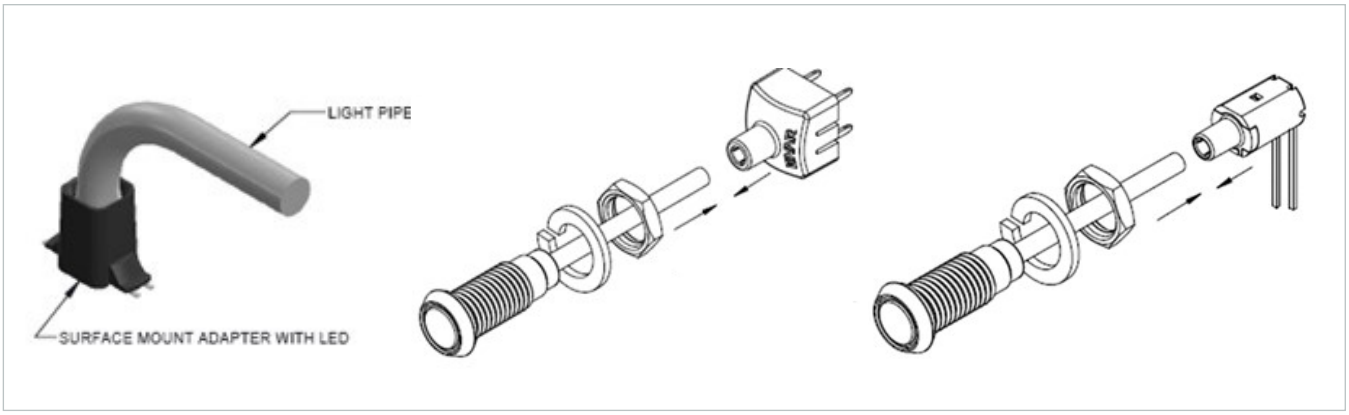

Figure 8: Solder-on, board-mount rigid light pipe (left) slides into the hole in the front panel, providing minimal ingress protection, while flexible light pipe versions (center and right) can be equipped with gaskets and seals.

The final benefit to this mounting style is that the devices are provided as a single unit with a single part number. It simplifies procurement, acceptance testing, and installation. In the manufacturing environment where time is money, these are important benefits.

The drawback to a solder-on mount is that the adapter needs to be soldered onto the board. The LED itself would need to be soldered on the board if it were not part of an integrated assembly, however, so this doesn't really represent an additional step.

Table 1: Comparison of Mounting Types

	Press-Fit Mounting on Panel		Board Mount	
	Front Mount	Rear Mount	Post Mount	Surface Mount
Type of light pipe	Rigid	Rigid	Rigid or Flexible	Rigid or Flexible
IP protection	Yes	No	Yes	Yes
Shock and vibration resistance	High	Low	High	High
Light bleed	Yes	Yes	No	No

Optimizing input and output coupling

The primary goal of light pipe used to capture as much of the LED's output as possible and deliver it to the output face. This requires careful design, starting with the input coupling. LED viewing angles range from 30° to 130°. Without properly matching the light pipe parameters and position relative to the LED, a significant amount of source output can be lost (see figure 9).

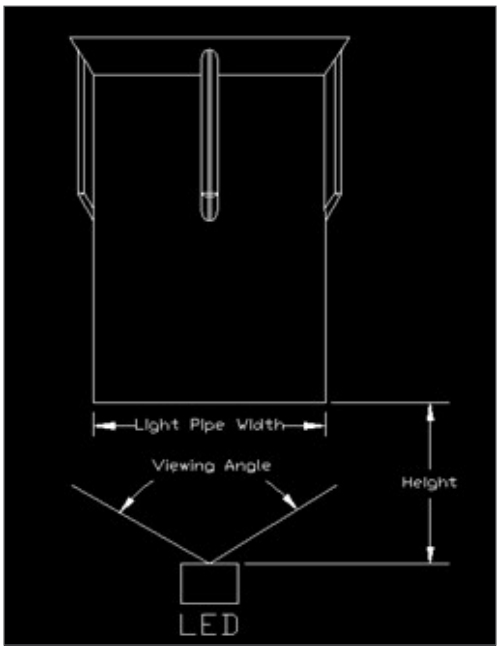

Figure 9: If light pipe is too narrow for the LED viewing angle or the separation between LED and light pipe is too great, significant optical flux will be lost.

In general, the diameter of the light pipe should be wider than that of the LED and the two should be placed as close together as possible while leaving a small gap (around half a millimeter) to protect against mechanical damage. The wider the viewing angle, the wider the light pipe and the closer to the LED it should be (see figure 10).

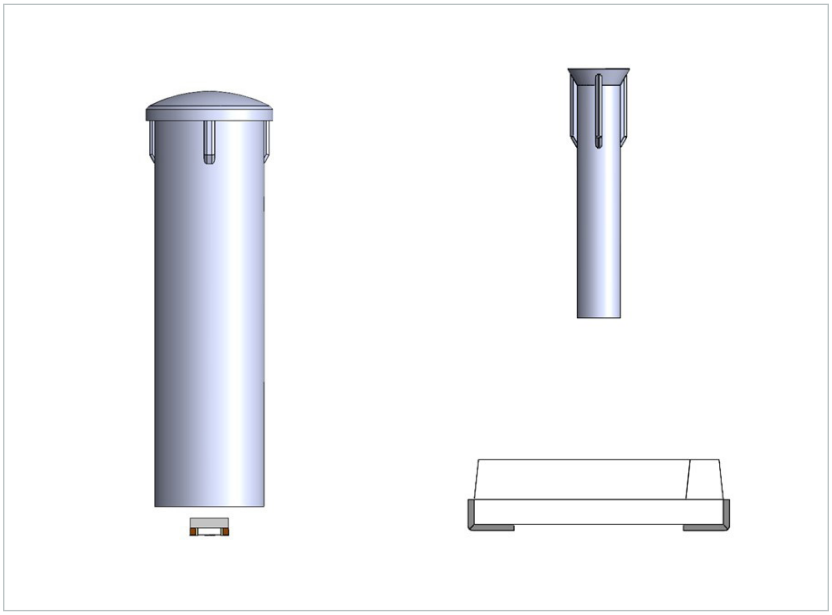

Figure 10: To maximize input coupling, light pipe should be wide compared to the LED in place as close as possible. The example on the left is well-designed, while the one on the right will give substandard results.

Consideration of output is also important. Rigid light pipes can have textured end faces as a result of the molding process, which helps diffuse light output. As light propagates down the pipe, it naturally becomes more diffuse as a result of scattering. The effect is less pronounced in shorter light pipes (below 2 inches). In these cases, it may be desirable to add diffusing particles to the light-pipe material to enhance scattering.

Light pipes are available with a variety of output surfaces, including Fresnel lenses for front viewing, slightly domed output faces for limited side viewing and steeply domed faces for easy side viewing (see figure 11).

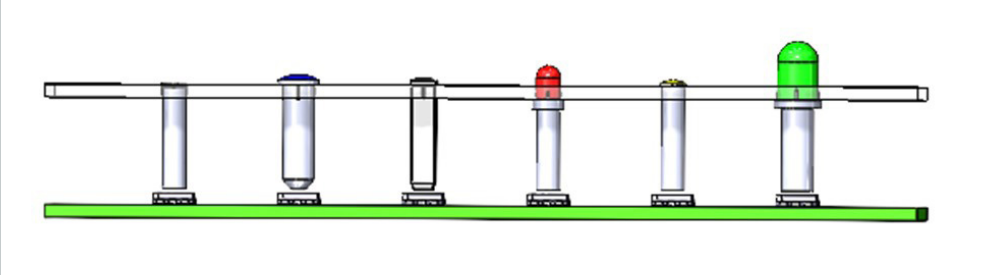

Figure 11: Output face options include Fresnel lenses, slightly domed lenses, and steeply domed lenses.

Many devices, from routers and modems to motor drives, have rows of side-by-side indicator lights. In these types of designs, particularly when the LEDs are of different colors, light bleed is a major issue. As discussed, board-mount devices control light bleed. Sometimes, however, the indicator lights may be too close together to permit separate devices. In these cases, specialized light pipes are available snap over rows of LEDs, encapsulating each one to protect against light bleed (see figure 12).

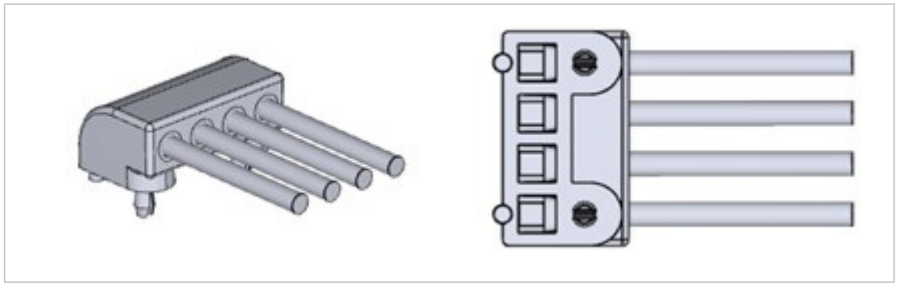

Figure 12: Specialty light pipe snaps over row of closely spaced LEDs to control light bleed.

Table 2: Summary of light pipe characteristics

Parameters	Rigid	Flexible
Distance Requirement	Up to 3 inches	Up to 100 meters
Bending or Shaping Requirement	Vertical, Right Angle	Bend around obstacles
Mounting Options	Panel Press-Fit, Board Mount	Board Mount Adapter
Built-In LED Option	SMD	SMD, Through-Hole
Ingress Protection	Yes	Yes
Side by Side SMD LED Placement	Array, ZeroLightBleed™	ZeroLightBleed™

Conclusion

Light pipes play a crucial role in the effective use of LEDs for indication and illumination applications. The key to successful design is to properly match light pipe characteristics to the requirements of the device. Begin by understanding the requirements for rerouting the LED output.

Choose a mounting style best suited to the layout and environmental needs. Don't forget to take input and output coupling into account to maximize the visibility of the optical signal. Finally, take advantage of the expertise of your vendor. LEDs can dramatically increase the effectiveness, usability, and appearance of your design. Make sure that you've optimized your light pipe design for best results.

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