

3M Optical Systems Division

3M Uniformity Solutions for LED Lightguides (for Monitors, TVs and Digital Signage)



Create Visions
of Wonder



Contents

- Executive summary3
- LED light mixing challenges.....3
- Changing the uniformity constraint with 3M Uniformity Tape.....4
- Toward entitlement systems.....8
- About 3M9

Executive summary

Manufacturers of LED edge-lit displays are facing an increasingly important problem in the design of monitors, TVs, and digital signage. The fact that LEDs are point light sources and have poor light spreading in lightguide-based displays forces device designers to incorporate bezels (to shield areas in which light is poorly mixed); it also limits their ability to reduce the number of LEDs in a display and makes these systems highly sensitive to LED variations in color and brightness.

Insufficient light mixing in current edge-lit LED backlights has prevented the continuous reduction of LED count that would be expected from the steady increase in LED efficacy. This is critically important since reducing the number of lamps is a traditional cost reduction path for displays.

3M proposes to mitigate this barrier to low-cost systems by introducing a light-mixing tape—3M™ Uniformity Tape—that can be applied directly to the injection edge of a lightguide. This simple solution delivers improved design flexibility, enables a 50 percent reduction in LED count and opens new paths toward entitlement backlights with respect to cost and performance.

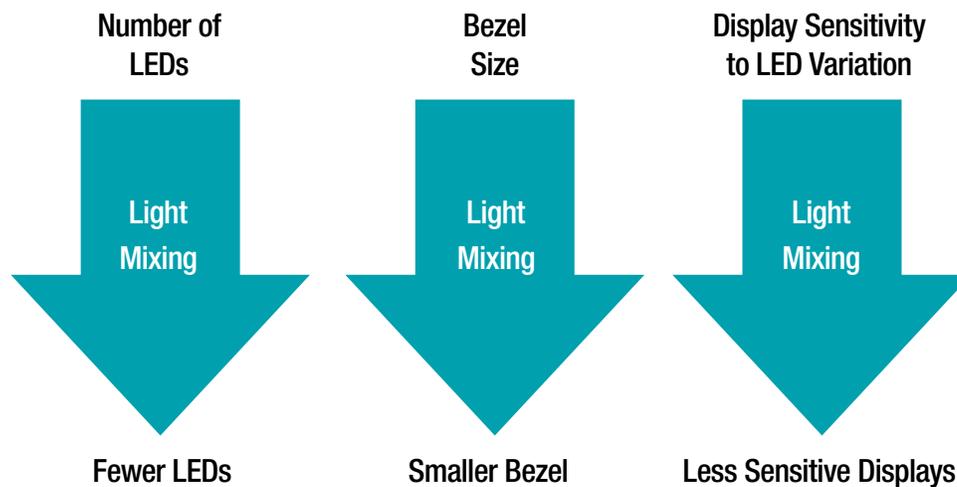


Figure 1. Light Mixing Addresses Several Fundamental Constraints with Edge-lit LED Backlights

LED light mixing challenges

Spreading light efficiently from a few point sources over an extended area requires good light transport and mixing mechanisms. Transporting light by total internal reflection (TIR) using low-loss lightguide materials such as PMMA is common in commercial display systems. Extraction patterns on the surface of the lightguide meter out the light and generate a uniform brightness distribution.

While TIR provides an indispensable confinement mechanism in the thickness direction of the lightguide, it severely limits the amount of mixing that occurs in the plane of the guide, especially in the vicinity of the injection edge. There, the combination of spatially distributed discrete light sources and the refraction-induced injection cone in the solid guide results in dark zones where little or no light is present. This in turn fundamentally limits the maximum LED pitch or space between LEDs (typically between about 9 mm and 11 mm) before non-uniformities become noticeable (Figure 2). We refer to this fundamental limitation as the “uniformity constraint.”

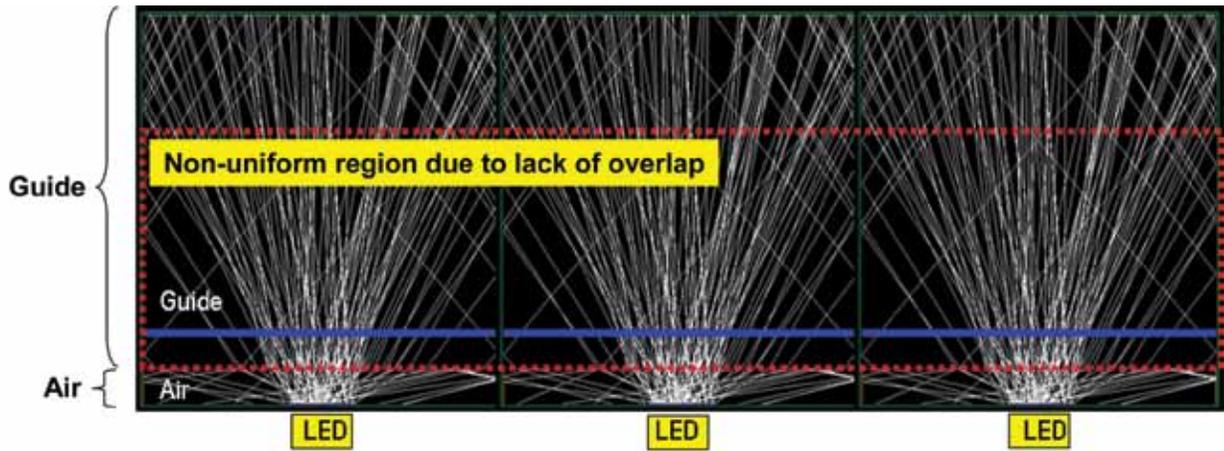


Figure 2. Simulation of Light Injected Into a PMMA Lightguide from Three Nominally Lambertian LEDs

Since their introduction into LCD backlights, LEDs have exhibited a steady increase in efficacy, which has gradually reduced the total number of light sources required to deliver a given brightness level. At first glance, this appears as a potentially significant driver for continuous cost reduction, but the uniformity constraint at the edge of the lightguide has instead forced backlight manufacturers to adopt a discontinuous approach to cost saving. The common industry trend has been to inject light along the four edges of the lightguide, then shift to the two long edges, then to the two short edges and finally a single edge—in each instance using closely packed LEDs.

This approach presents potential drawbacks:

- With each step change, the aspect ratio or the distance the light in the backlight must travel increases significantly making it more difficult to achieve good brightness uniformity.
- The close-packing of the LEDs can present less than ideal thermal management, which can limit overall system efficacy.
- Increased LED spacing beyond the uniformity limit requires increased bezel widths to allow for adequate light mixing.
- Systems at or near the uniformity limit can be sensitive to variations in LED color and brightness (caused by binning or aging).

Changing the uniformity constraint with 3M Uniformity Tape

A solution that addresses the uniformity constraint for LED backlights would be one that increases the TIR-limited injection angle in the plane of the lightguide by allowing high angle light to be coupled into the guide.

One way of doing this would be to optically couple the LEDs to the edge of the lightguide, but this would eliminate the refraction in all directions and result in the non-TIR light leaking from the lightguide near the injection edge. Another solution has been to microstructure the injection edge of injection-molded guides, an approach that is limited in application to smaller displays.

Recently, another approach has been proposed by 3M. We have developed a new microstructured tape, 3M Uniformity Tape, that is attached to the injection edge of the lightguide. Its microstructure greatly reduces dark zones by inducing lateral light spreading in the plane of the guide. This is achieved by selectively allowing light outside of the normal TIR angles to couple into the lightguide while maintaining the TIR condition in the thickness of the guide.

The microstructure consists of linear aspheric prisms (Figure 3) that are aligned perpendicular to the plane of the guide and are translationally invariant with respect to the position of the LEDs. The size of the microstructure is small compared to the size of the LEDs and is typically on the order of 12-50 μm . As a result, no registration of the tape with the LEDs is required.

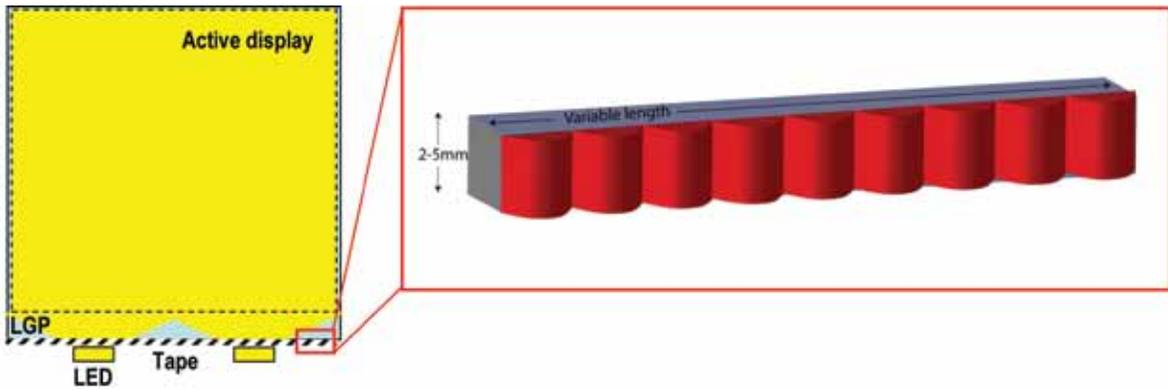


Figure 3. Schematic of Tape on Lightguide and Tape Microstructure

The light-spreading function of the tape can be shown by launching light into the lightguide through the 3M Uniformity Tape. Figure 4a shows two laser pointers injecting light into a conventional PMMA lightguide. The lightguide on the left has the microstructured Uniformity Tape attached to the injection edge; on the right side, the light is injected directly into the bare polished PMMA plate. The photograph clearly shows that the Uniformity Tape creates significant spreading of the light entering the lightguide as opposed to the side without Uniformity Tape, which shows a single collimated beam of light from the laser.

Figure 4b illustrates that Uniformity Tape also allows for the injection of high angle light into the lightguide at angles higher than the TIR angle of the PMMA plate. The lasers are held at roughly a 60 degree angle to the edge of the lightguide. The laser that enters through the Uniformity Tape spreads to angles greater than 70 degrees whereas light from the laser on the right side (without Uniformity Tape) turns within the TIR cone and enters at 35 degrees.

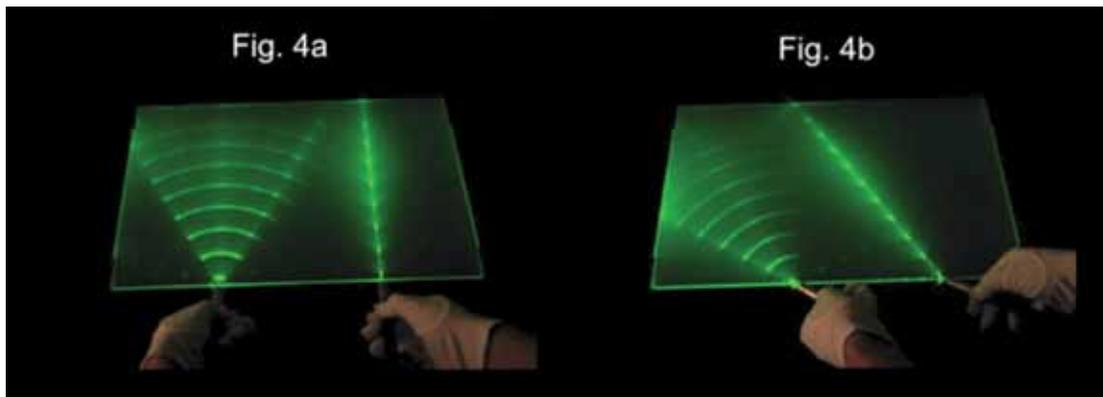


Figure 4. Demonstration of Light-Spreading Function of Uniformity Tape and High Angle Light Injection

The effect of the Uniformity Tape on the injection of LED light from a nominally lambertian LED is shown in Figure 5a-c. The images in Figure 5a show the injection cone angle of the LED into a lightguide under normal TIR conditions (± 42 degrees in a conventional PMMA lightguide with an optically flat entrance face). The right image shows a close-up view of the left image. Figures 5b and 5c (and their details on the right) show variations of the Uniformity Tape with refractive indices equal to 1.57 and 1.65, respectively.

It is easily seen that the Uniformity Tape suppresses the dark zones between the LEDs relative to the normal TIR condition; this permits a dramatic increase in the maximum tolerable spacing between LEDs by a factor 2 or greater as illustrated in Figure 6. The maximum injected angle depends on the refractive index of the tape, with higher indices delivering more spreading power up to ± 70 degrees.

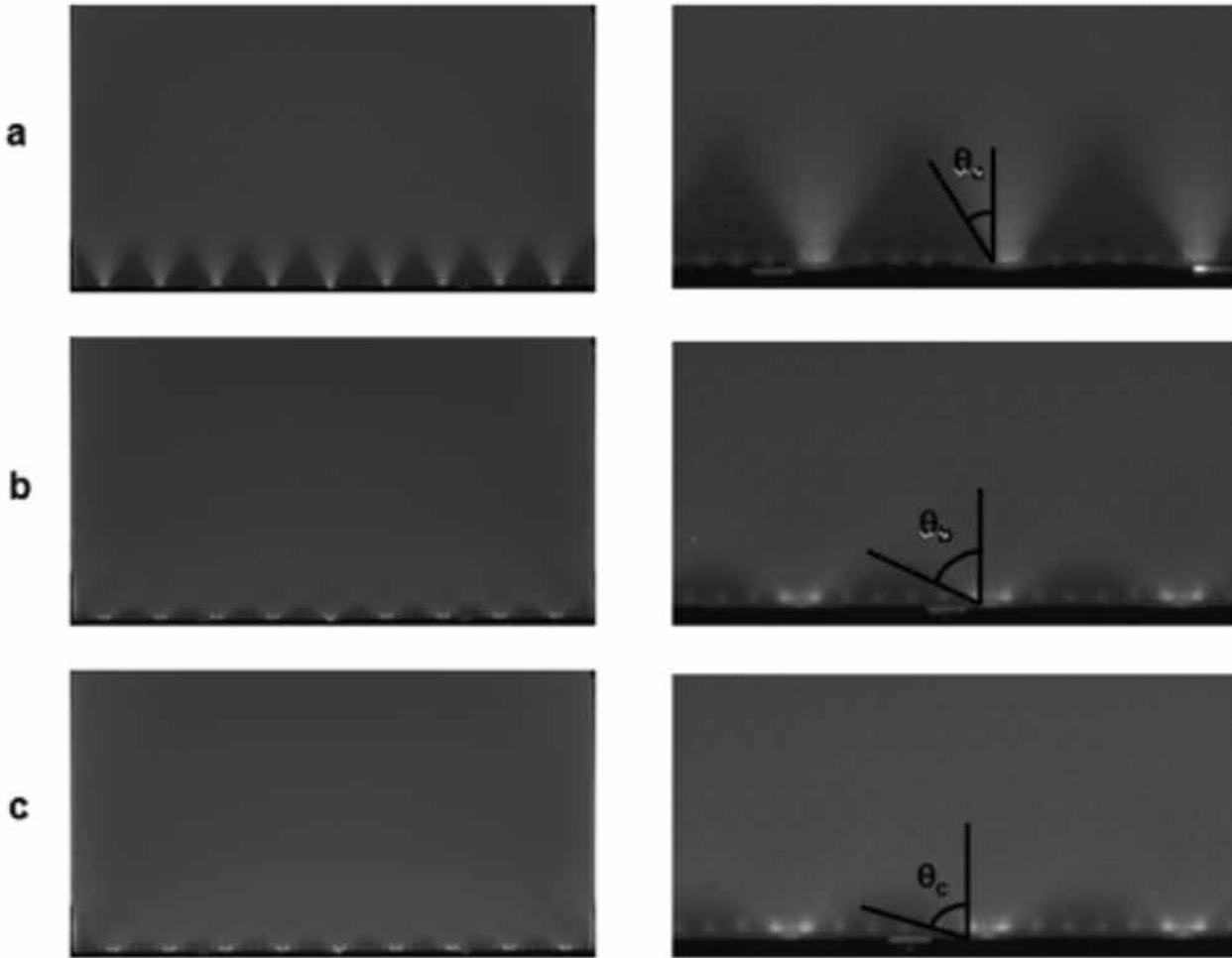


Figure 5. Demonstration of the Light Spreading Enabled by Uniformity Tape

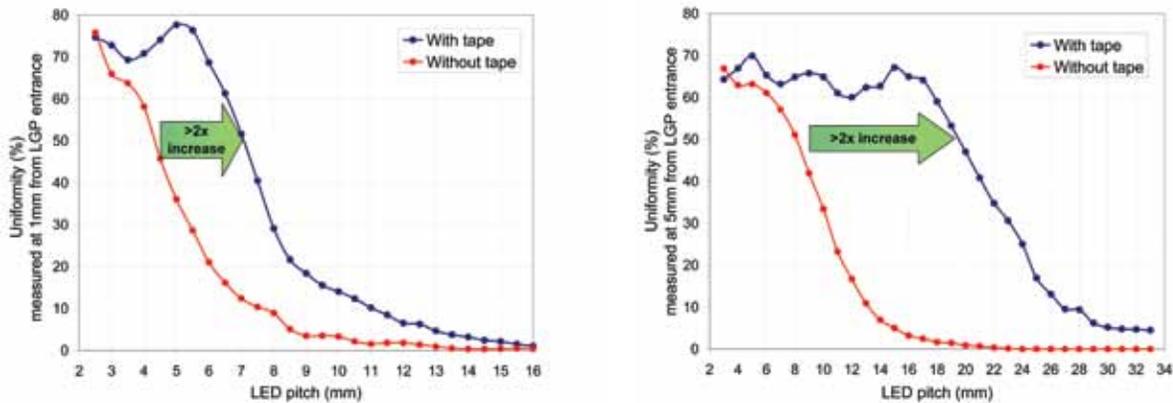


Figure 6. Modeled Increase in LED Spacing for a Given Uniformity* with 1 mm and 5 mm Bezels

*Uniformity is defined as the ratio of minimum brightness over maximum brightness measured across the injection edge.

In order to evaluate the performance of the microreplicated tape in an actual display, a test bed was chosen. The display was a Lenovo ThinkVision L2251xwD 22" diagonal monitor having a 16:9 aspect ratio. The monitor consisted of a backlight cavity having a white reflector, an acrylic lightguide sitting in the backlight cavity with the white reflector behind it, the acrylic lightguide having a white gradient extraction dot pattern printed on its surface, a row of LEDs illuminating the waveguide from the bottom edge of the lightguide/display, a standard stack of brightness enhancing films (including a diffuser film, a prism film and DBEF), an LCD panel and a bezel over the LCD panel.

The display had the following critical dimensions: native LED center-to-center spacing of 9 mm (all LEDs on), a distance from the surface of the LED to edge of lightguide of < 0.25 mm, a distance from the LED to the start of the extraction pattern of ~2 mm, and a distance from the surface of the LED to edge of bezel in the fully assembled display of ~5 mm. The LED light bar consisted of 54 LEDs and allowed for the following configurations; all LEDs on (9mm LED center-to-center spacing), every other LED on (18 mm center-to-center spacing), every third LED on (27 mm center-to-center spacing), and every sixth LED on (54 mm center-to-center spacing).

Uniformity Tape was applied to the input edge of the lightguide by a hand lamination process. When applied, the optically clear adhesive wet out and conformed to the surface roughness of the edge of the lightguide so that the microstructured film was optically coupled to the input edge of the lightguide (i.e., no air was trapped between the adhesive and the edge of the acrylic guide). Because of the thorough wetting out of the Uniformity Tape's adhesive, the PMMA plate's injection edge doesn't require the level of polishing required in a conventional lightguide. We anticipate that this could lead to a reduction in manufacturing steps and lower costs.

Figure 7 below shows images taken of the Lenovo display with LCD panel and bezel in place with (II) and without (I) modification of the input edge of the lightguide at LED center-to-center spacings of 9 mm (a), 18 mm (b), 27 mm (c), and 54 mm (d).

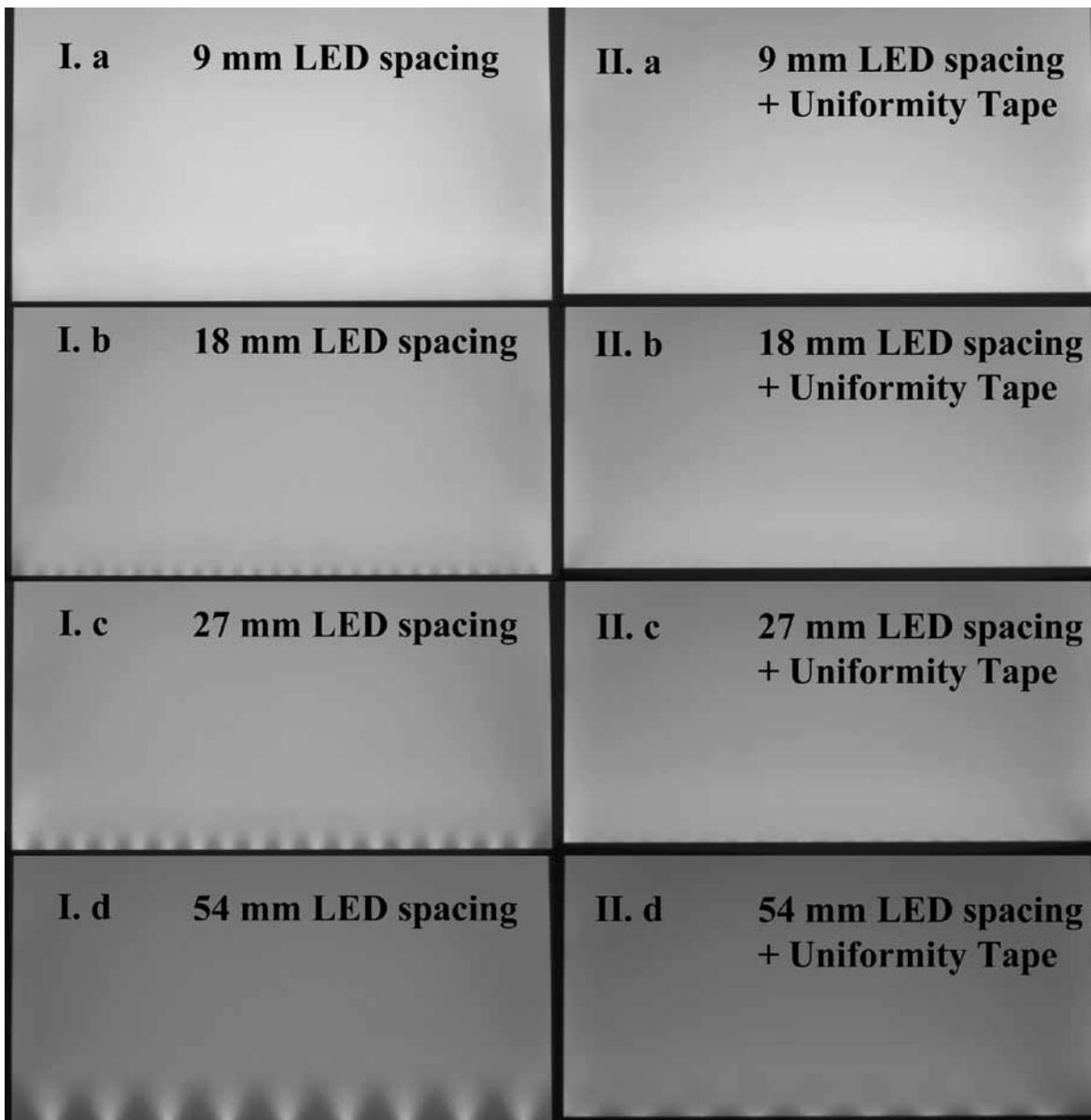


Figure 7. Demonstration of Uniformity Tape and Ability to Address Non-uniformity at the Injection Edge as a Function of LED Spacing

The images show that doubling the spacing of the LEDs to 18 mm results in visible non-uniformity at the edge of the original lightguide. The addition of 3M Uniformity Tape shows a dramatic effect in terms of suppressing non-uniformity at the edge of the lightguide up to 27 mm spacing or three times the original LED spacing. At 54 mm (four times the original spacing) some very slight non-uniformity is visible, which could be eliminated by optimizing the extraction pattern at the edge of the display to match the modified LED light input distribution. The application of Uniformity Tape had little effect on overall system efficiency, with brightness diminished by less than 2 percent.

One important thing to realize is that by broadening the range of angles coupled into the lightguide, the tape increases the average light path inside the guide. As a result, the extraction pattern away from the injection edge of the guide may need to be retuned to reflect this new injection pattern. In addition, since rays are injected past the TIR critical angle, they may leak at the edges of the guide. This can become a noticeable loss mechanism in smaller displays, in which case a high reflectivity tape must be applied to the non-illuminating edges of the guide.

Environmental testing has been conducted to ensure that 3M Uniformity Tape exhibits a long lifetime under LED illumination and standard LCD display reliability test conditions and does not contain harmful elements to the environment.

Toward entitlement systems

The table below summarizes the two approaches previously described:

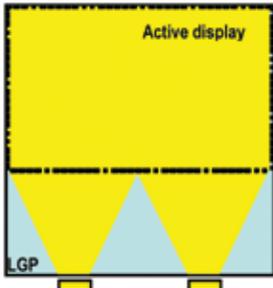
Standard approach	3M Uniformity Tape
 <p data-bbox="553 1142 586 1163">LED</p>	
<p data-bbox="477 1241 808 1423">Light mixing is limited by the refraction that occurs at the air/guide interface. As a result, the minimum bezel size and the maximum spacing between LEDs are limited.</p>	<p data-bbox="818 1213 1148 1457">3M Uniformity Tape injects high-angle light in the plane of the guide while preserving TIR and light transport in the thickness direction. The tape is applied directly to the entrance face of the guide by lamination.</p>

Figure 8. Summary of 3M Uniformity Tape's Attributes

This new uniformity solution offers new opportunities for LED count reduction. We conservatively estimate that the number of LEDs can be reduced by 50 percent from current uniformity-constrained levels while integration of 3M™ Dual Brightness Enhancement Film (DBEF) can help preserve on-axis brightness. Additional redesign of the lightguide extraction pattern could lead to LED reduction approaching two-thirds of current levels. Beyond the obvious cost benefits, this solution can help backlight designers drive toward entitlement systems in terms of performance, form factor, and robustness. In particular, novel architectures can be implemented to deliver the highest performance at the lowest cost:

- Low-cost backlights can be achieved by using LED packages that offer the highest lumens-per-dollar and using LEDs with less restrictive specifications for color and brightness.
- Low-energy backlights can be achieved by optimizing thermal management and maximizing system efficacy using DBEF.

- High-color-gamut backlights can be achieved by periodically inserting even a small number of red LEDs between white LEDs.
- Robust backlights can be designed to remain uniform even under multiple LED failures.
- The light spreading enabled by Uniformity Tape can be used to reduce bezel size.

About 3M

A recognized leader in research and development, 3M produces thousands of innovative products for dozens of diverse markets. 3M's core strength is applying its more than 40 distinct technology platforms – often in combination – to a wide array of customer needs. With \$27 billion in sales, 3M employs 80,000 people worldwide and has operations in more than 65 countries. For more information, visit www.3m.com.



3M Optical Systems Division
3M Center, Building 235-1E-54
St. Paul, MN 55144-1000
U.S.A.

3M is a trademark of 3M company.
© 3M 2011. All rights reserved.
Please recycle.
Printed in USA dez12427



Requester: Morgan Berg
Creator: deZinnia
File Name: dz12427_UTapeWP_OSD.indd
Date: 6/28/11

Printed Colors – Front:

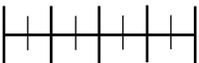


Printed Colors – Back:



Match Colors:



Scale:  1 Inch

This artwork has been created as requested by 3M. 3M is responsible for the artwork AS APPROVED and assumes full responsibility for its correctness.