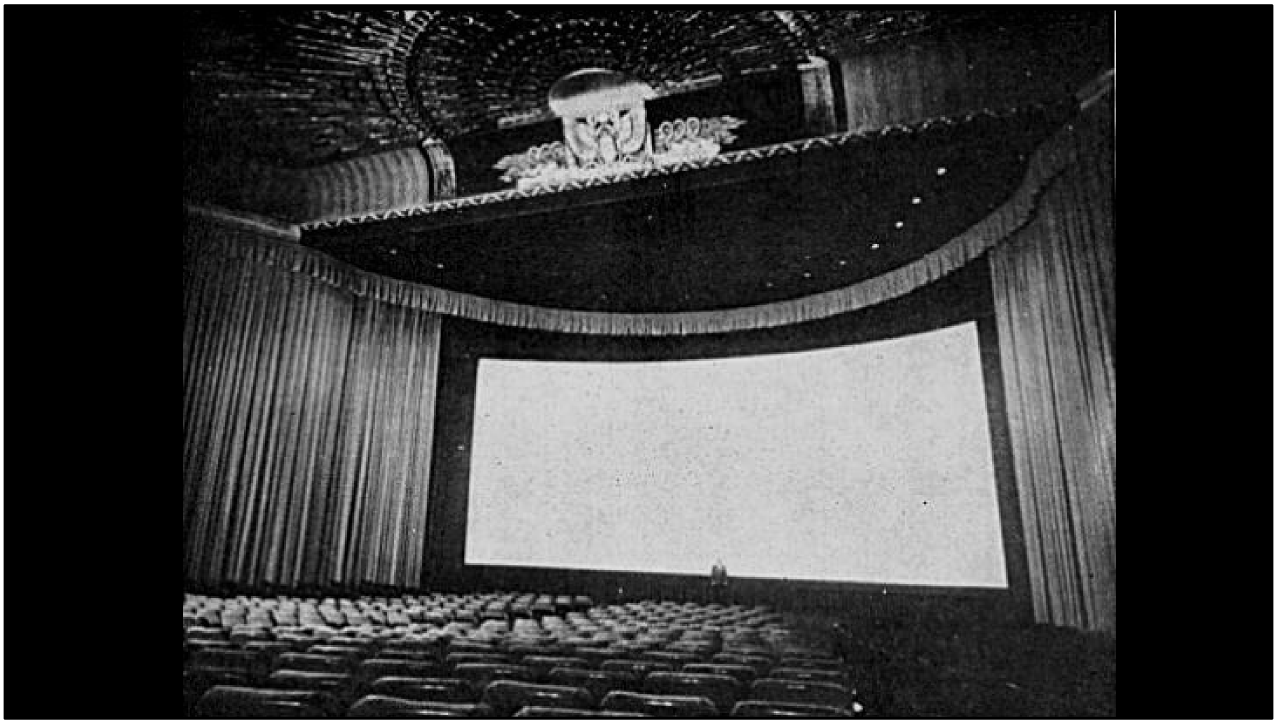
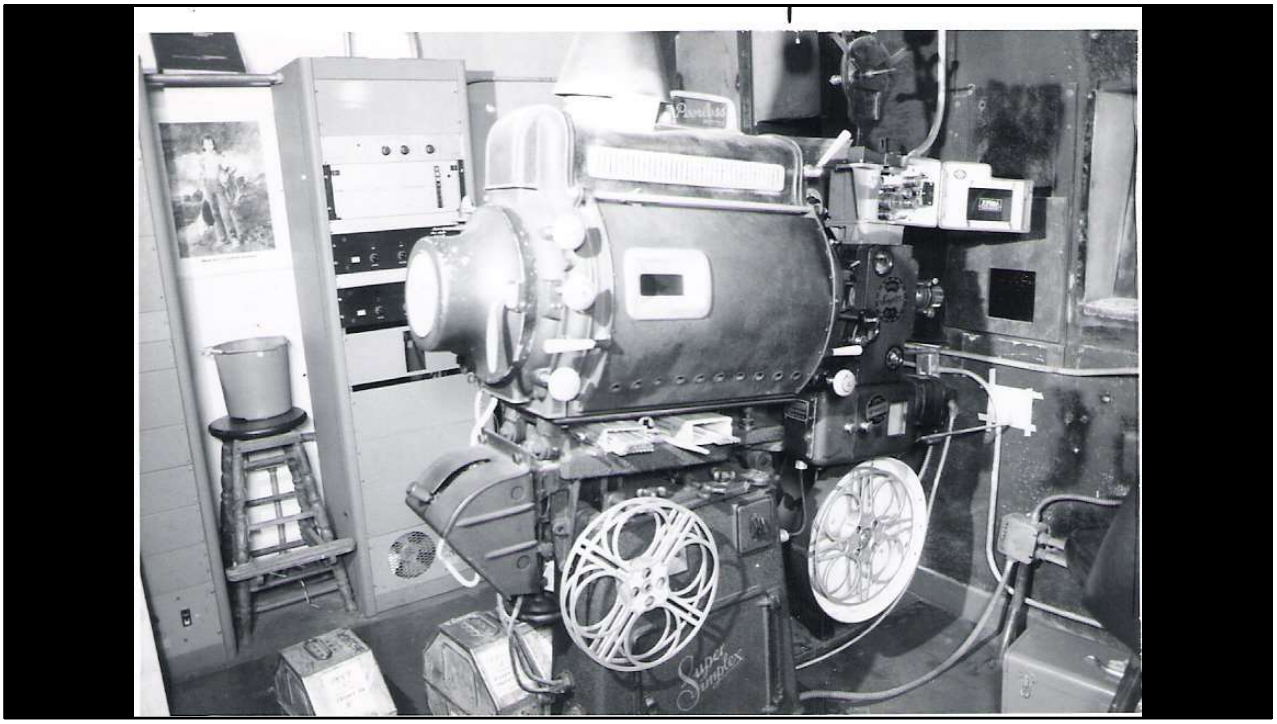
Spoiler alert:

LED screens for cinema are amazing – but they are unlikely to replace projectors any time soon. I’ll explain the promise and the challenges.



For the past 120 years, going to the cinema has meant watching a large, reflective projection screen…

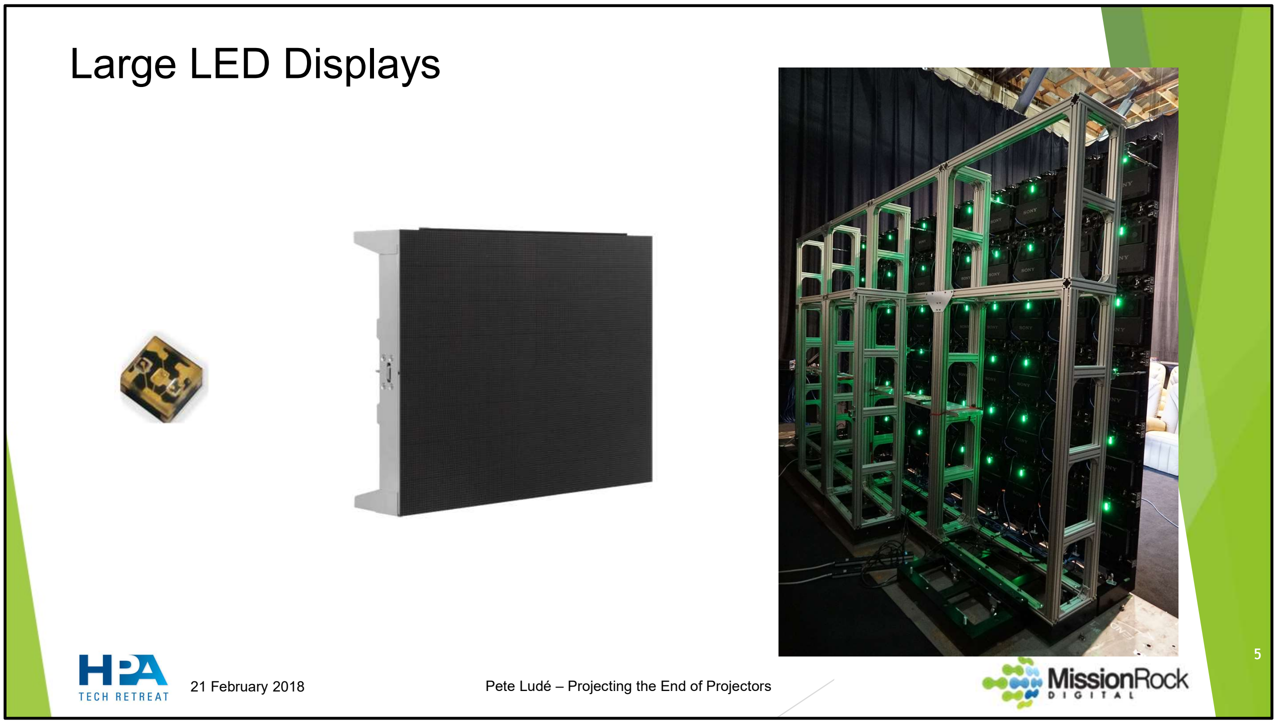


…that was displayed an image generated by a projector.   The first illumination source used was the carbon arc, which was replaced in the 1950’s with the xenon arc-lamp. Today, modern projectors are using solid state laser illumination.

Movies were originally distributed as a photochemical emulsions, arranged in a sequence of frames on a strip of film. Over the past 15 years ago, the transition to a fully-digital projection system has been completed. But what’s next?

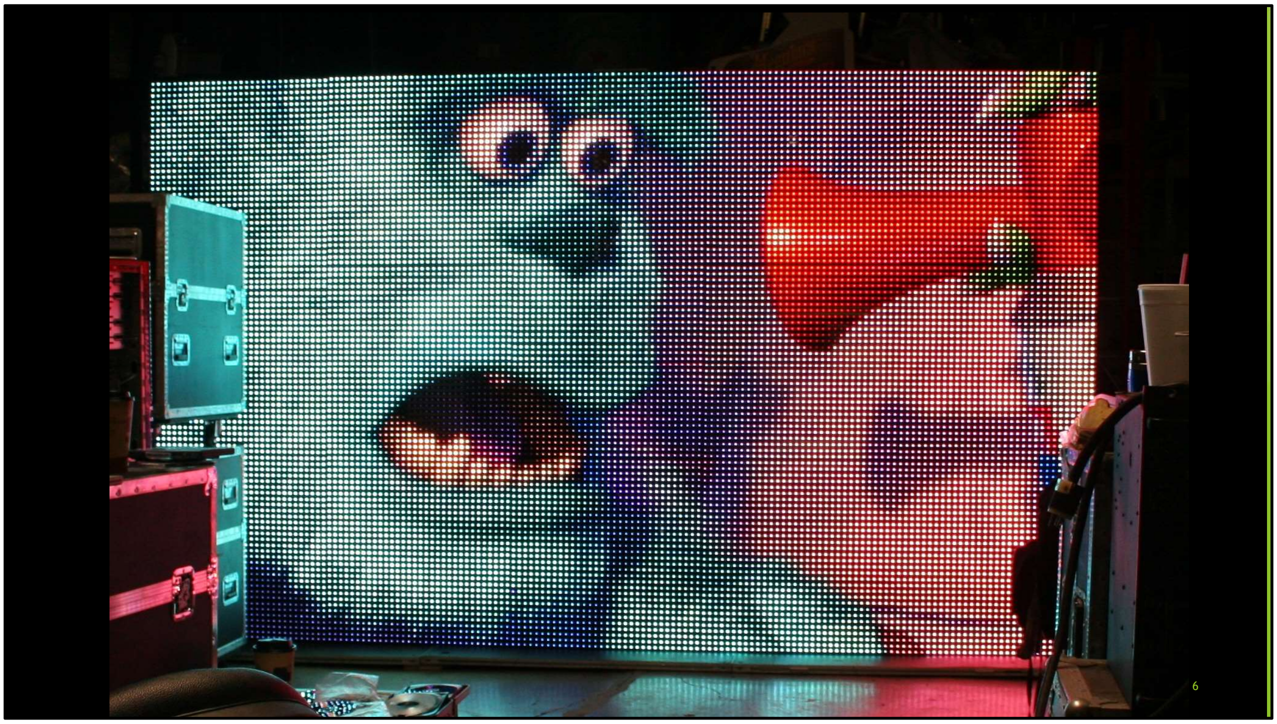
25 years ago, if you wanted a high-quality home theater system, you would use a projection television system. But today you would not consider that, since large, high-quality direct view displays – such as LED-backlit LCD and OLED – are available at a reasonable cost.

Might the same thing happen for movie theaters?



Large LED “Video Wall” displays have been around for many years. The concept is quite simple: LED pixels with red, green and blue light sources are built into modules, and these modules are stacked into a frame to create the desired image size.

These displays have been used for outdoor signage, and indoor applications such as retail, restaurant menus, control rooms, corporate lobbies, trade shows, broadcast stage sets and many other uses.



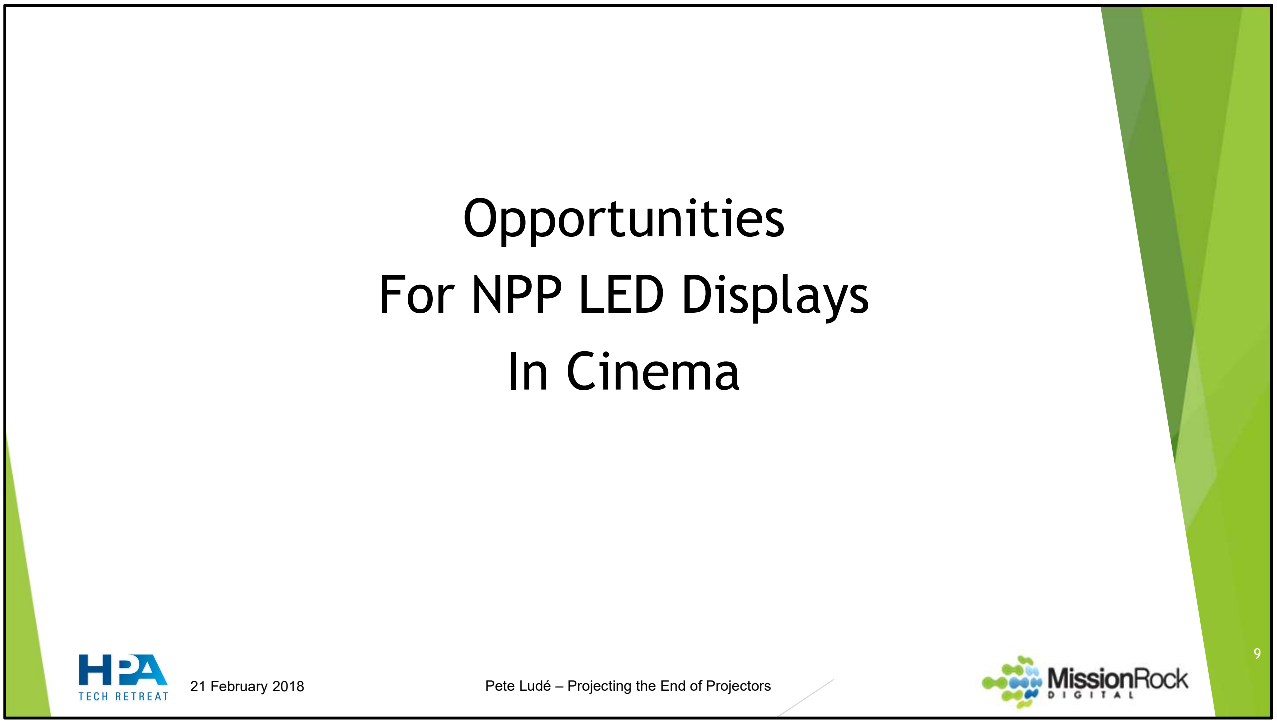
Many of you are probably thinking of LED displays from a few years back – which were fine for outdoor signs, but lacking the quality we need for movies.

That is no longer the case. Anyone who has viewed the latest technology in LED displays from Sony, Samsung, Nanolumens, SiliconCore, Leyard or many others has been dazzled with the amazing picture quality.

So – how do get these into cinema?

Just last year, the first LED display intended for cinema use was introduced. Is this the beginning of a major trend? Or a niche product suitable for only special cases? There are already 10 installations of LED Cinema screens worldwide – will this continues?

That is the topic for our session today.



Let’s start by considering the opportunities – why might an emissive direct-view display be preferable over projection technology?

Why LED Cinema?

- **Dramatically improved HDR**
  - Blacker blacks
  - Very high peak luminance (for spectral highlights)
  - Very low surface reflection (no backscatter light)

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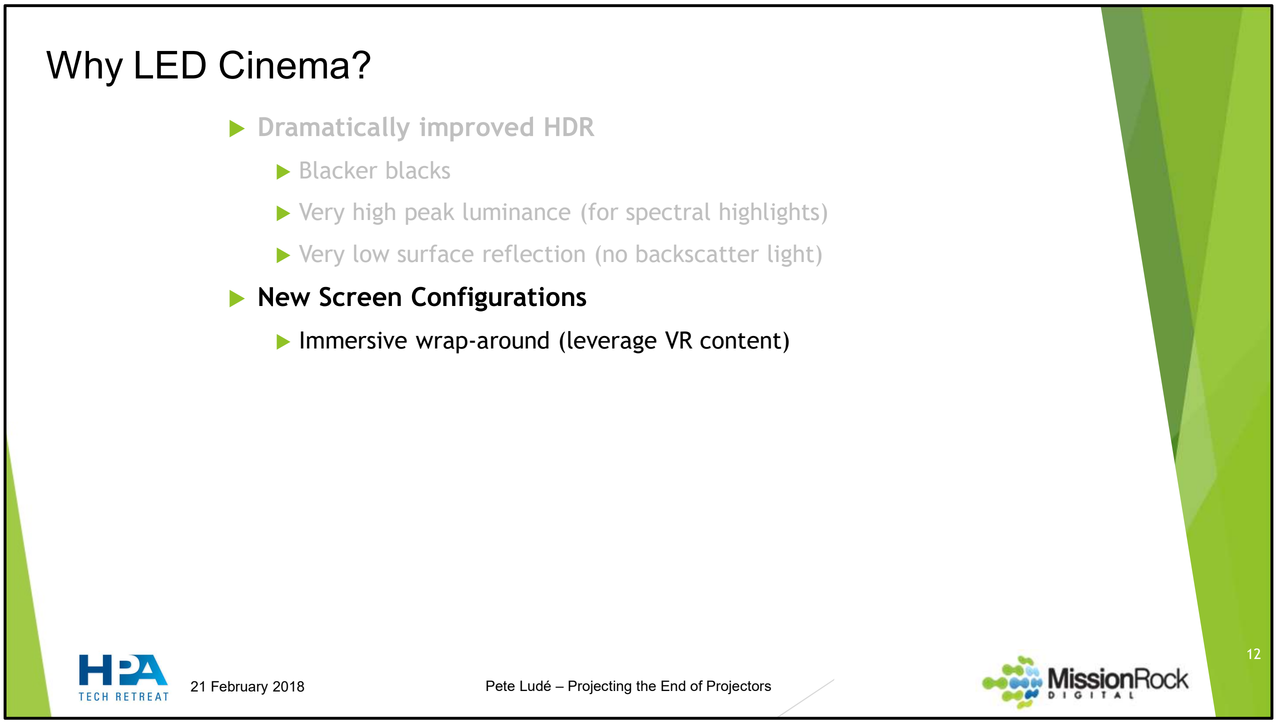
LED emissive displays hold the promise for dramatically improved high dynamic range since – unlike projectors – blacks are truly black. And high brightness can far exceed anything a projector can accomplish, pixel by pixel.

For example, in this scene, the deep shadows can be faithfully reproduced with no light emitting from the screen.

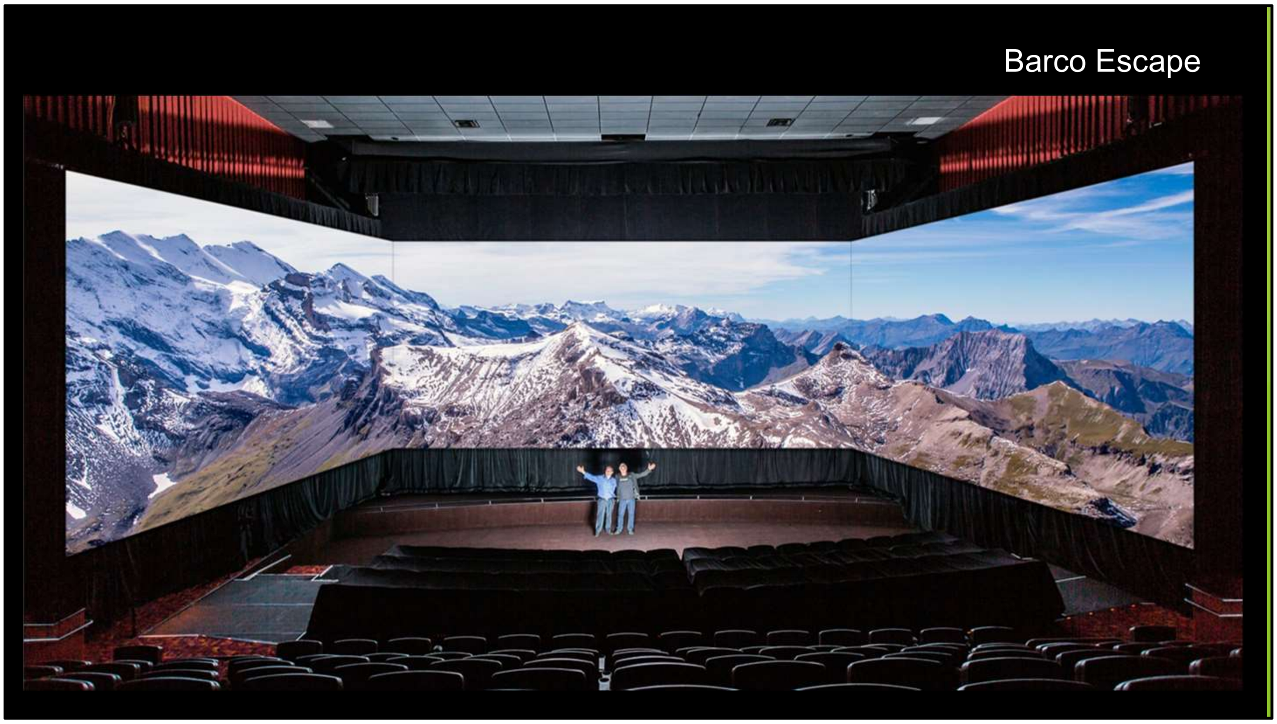
The "normal" white level of the haze would be displayed roughly the same as today's rpojectors – or maybe a bit brighter, such as 20 or 24 ftL (say: 100 nits). This is all that's needed for most scenes in the dark environment of the cinema.

But to punch out the direct light and spectral highlights, we can fire up the pixel to potentially achieve dramatic hightlights – perhaps 500 or 1,000 nits.

This results in a stunning image, simply not possible with projection technology.



LED screens can also facilitate new screen configurations.



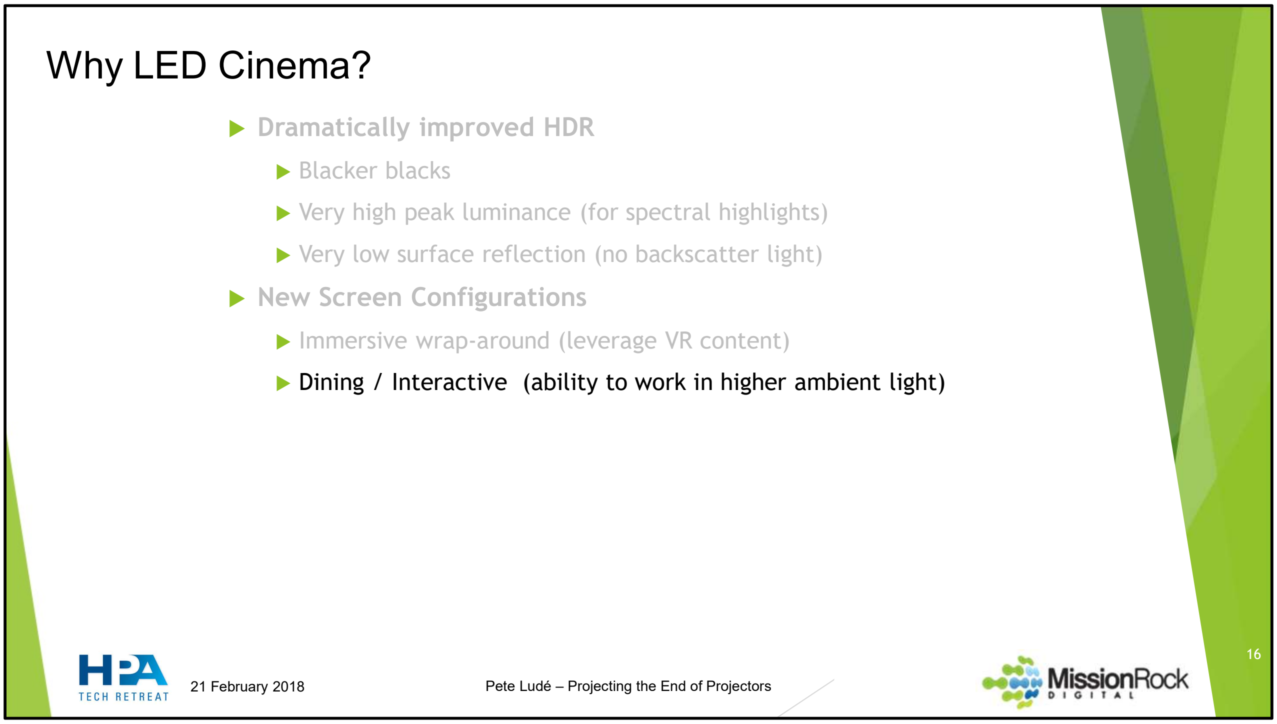
Suppose you want to enjoy the immersive experience of a movie image that surrounds you – like this Barco Escape system.

With projectors, these immersive theaters suffer from the challenge of light bouncing off one screen to degrade the contrast of the others. The result is often a lack of deep black levels.

Now – image such an auditorium configured with an emissive direct-view display. Now, there are now seams between projected images. The screen can be curved in whatever radius is desired. And there is no reflected light from one area of the screen to the other.

The result is stunning contrast and bright images throughout your peripheral vision.

…and perhaps the opportunity to leverage immersive content already being produced for virtual reality, but enjoyed in a social environment with your friends rather then an isolating he-mounted display.



There are also applications for dining theaters, that benefit from such screens providing great images. This could be a great application for LED emissive screens.

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Cinema Restaurants – need ambient lighting

STUDIO MOVIE GRILL

200 screens in 9 states

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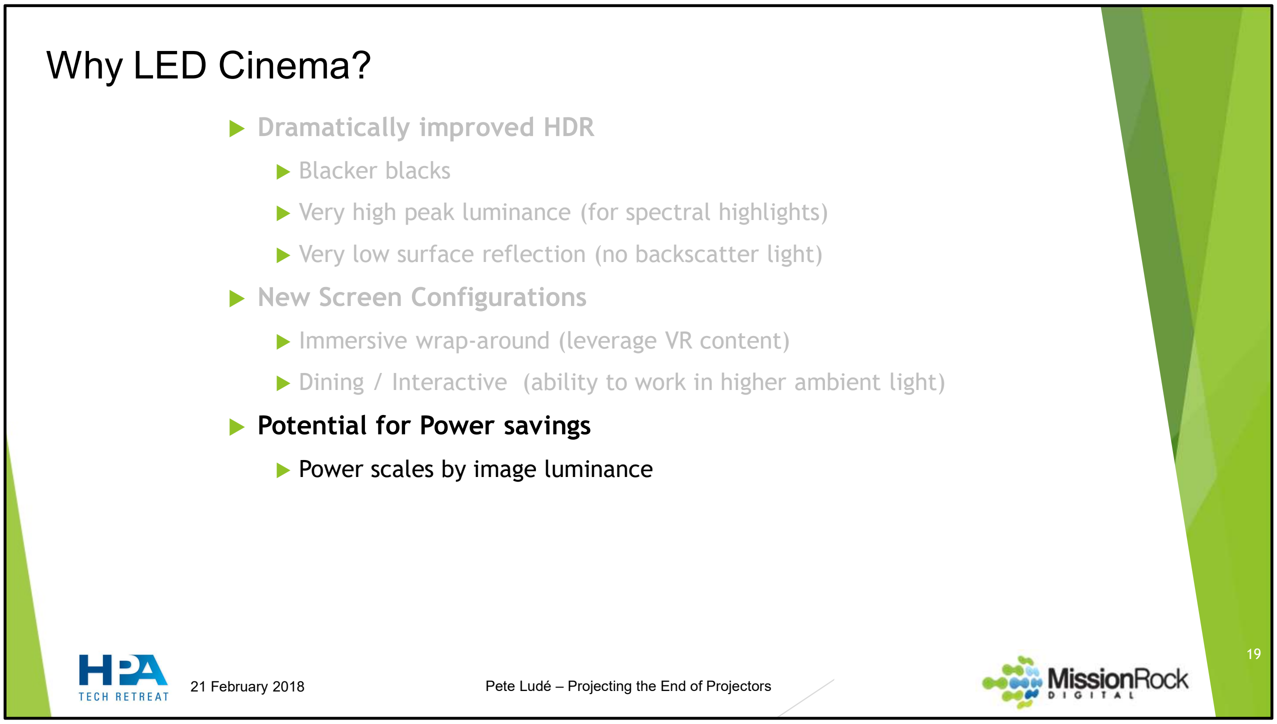
Dining cinema restaurants are becoming popular in some regions. There are over 2,000 dining cinemas in the US now.

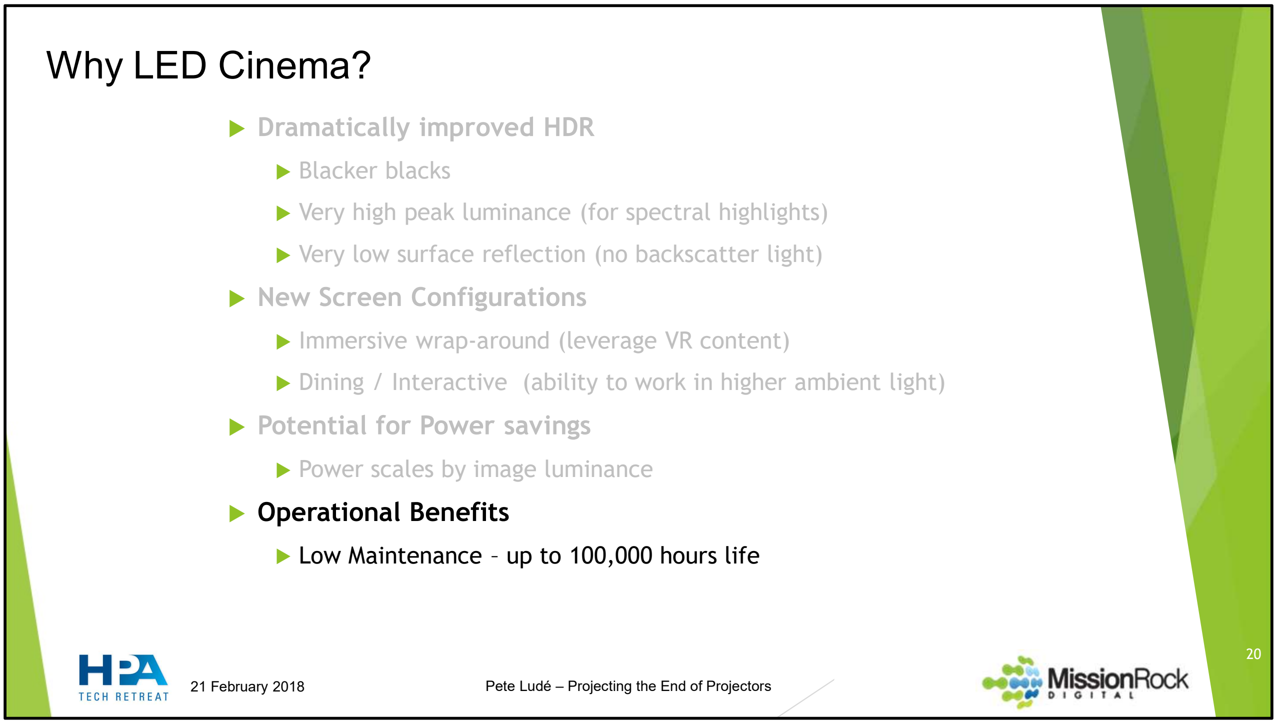
With a direct view display, it is possible to enjoy a stunning picture, even with ambient light needed to read your menu.

Imagine a dining theater optimized for enjoying both the movie and your meal!

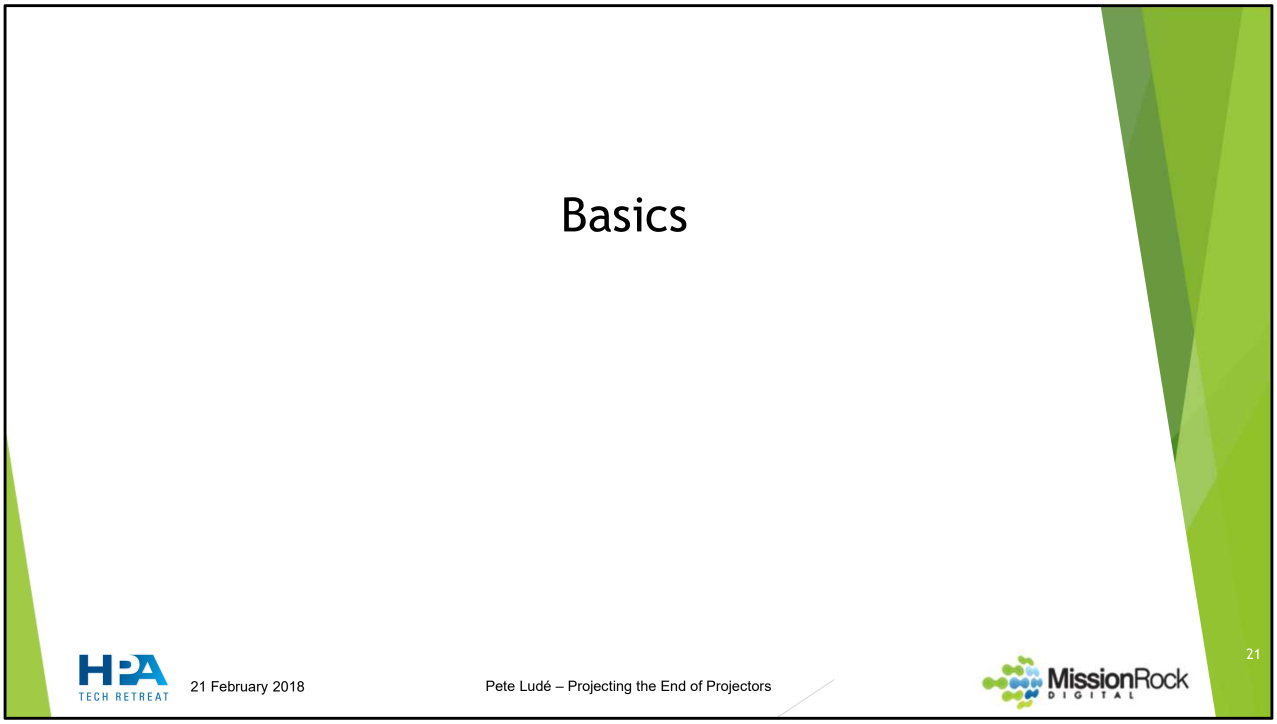
Pete@MissionRockDigital.com



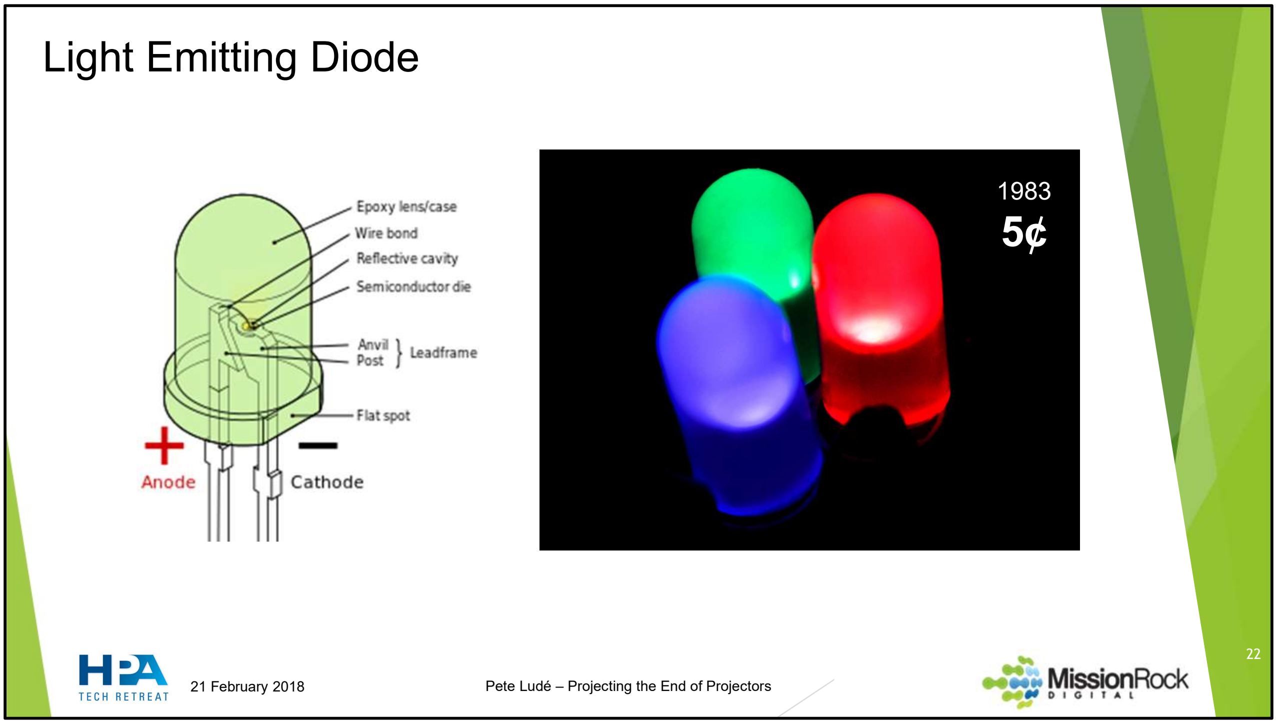
LED screens could also provide power savings. Projectors have a constant power draw, based on their xenon lamp – consuming 2kW to 6kW – or laser system with somewhat lower draw. LED's will consume very little power when the picture is near black, but will consume much more electricity when all pixels are lit up. Since most movies have average luminance of less than 10%, it is likely that power savings would be possible.



In addition, LED cinema will provide substantial advantages in operations, such as minimal maintenance, and long life.

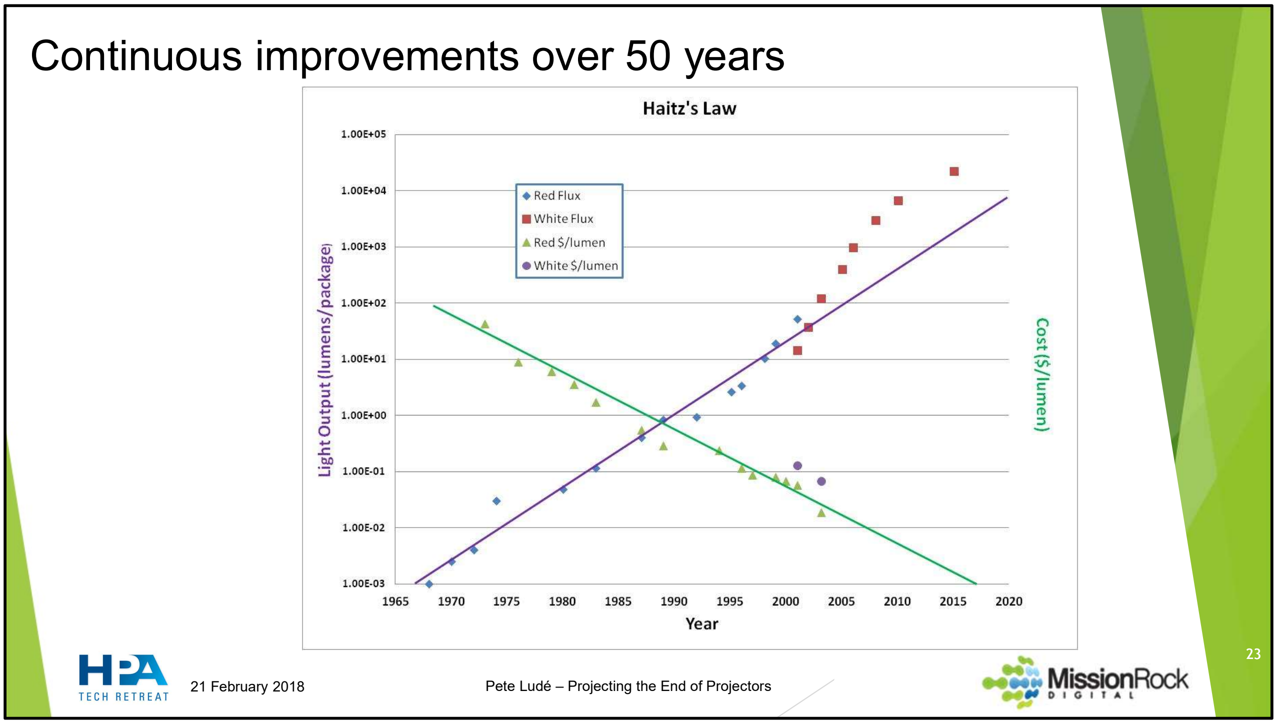


First, a few basics.



Light emitting diodes were first developed in the 1950's. By using semiconductor technology, LED's proved an efficient way to convert electrical energy into photons.

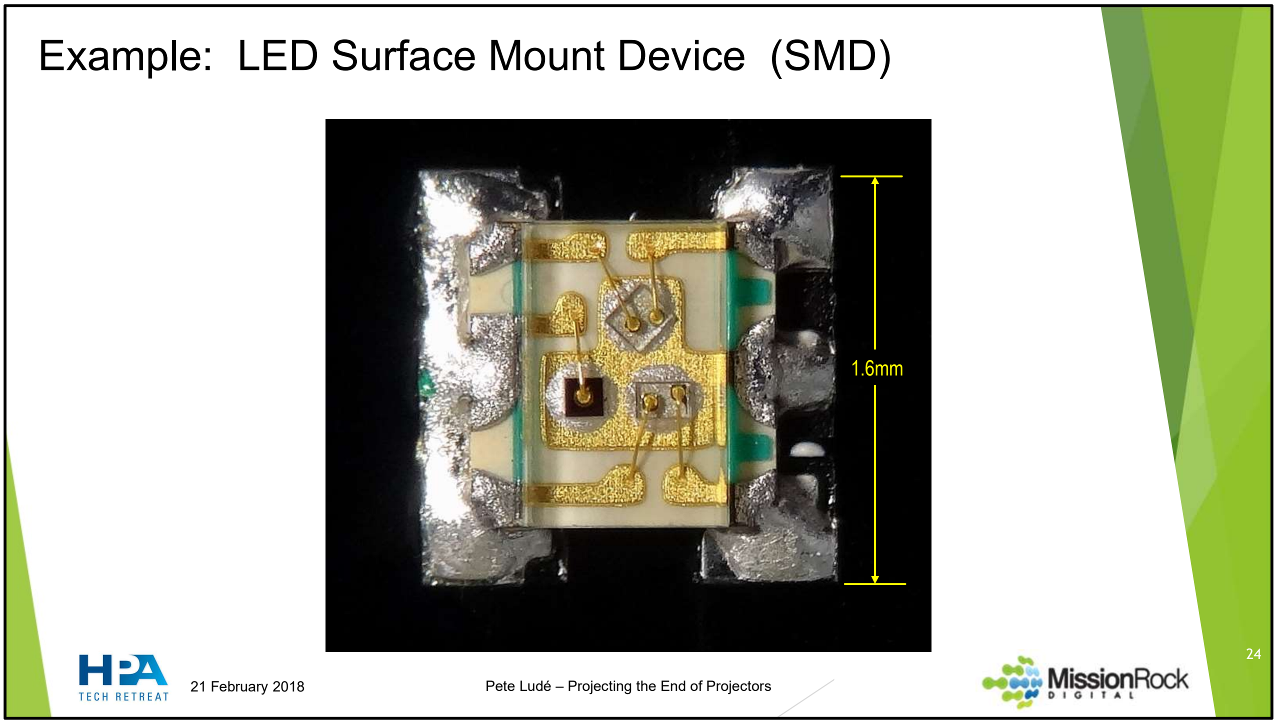
LED's did not become cost effective until the early 1980's when new epitaxies and manufacturing processing allowed mass production, at a cost as low as 5 cents (US). But only red emitters were available at first.



Over the years, LED's continued to improve. Much like Moore's law described advancements in microprocessors, Haitz's law tracked the similar progress in LED development. Here, the purple line represents lumens per diode , which has been advancing continuously.

The green line shows the cost reduction in lumens per dollar over the same period.

Most experts expect these general trends in higher brightness and lower cost to continue – potentially making LED display affordable for many new applications.



Here's a typical example. This configuration is called a Surface Mount Device – or SMD. The three diodes are affixed to a mount, gold conductive leads are attached and a plastic frame and epoxy seal are added.

This example of an SMD pixel is 1.6mm square, so would be ideal for a display with a 2 mm pixel pitch. Each LED is driven independently by specialize chips called drivers.

Total LED Cinema Display cost

Based on **Pixel Count:** *4K: 4,096 x 2,160 = 8,847,360 pixels*

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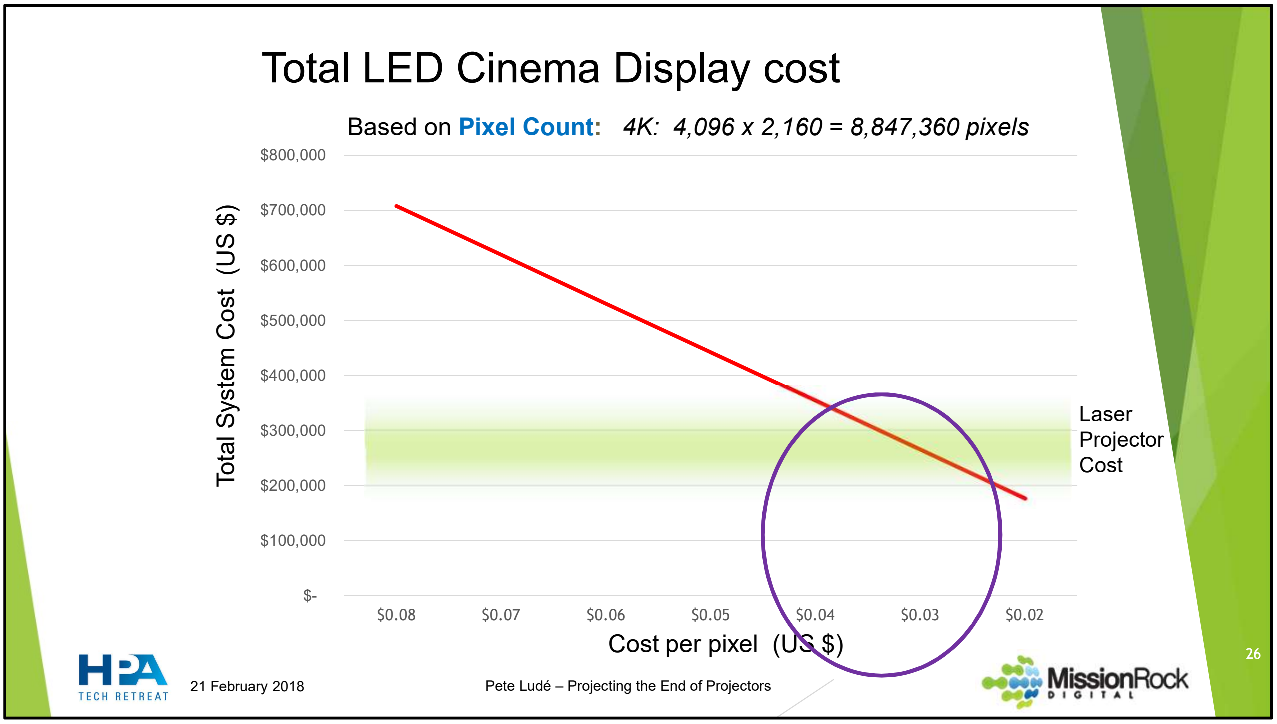
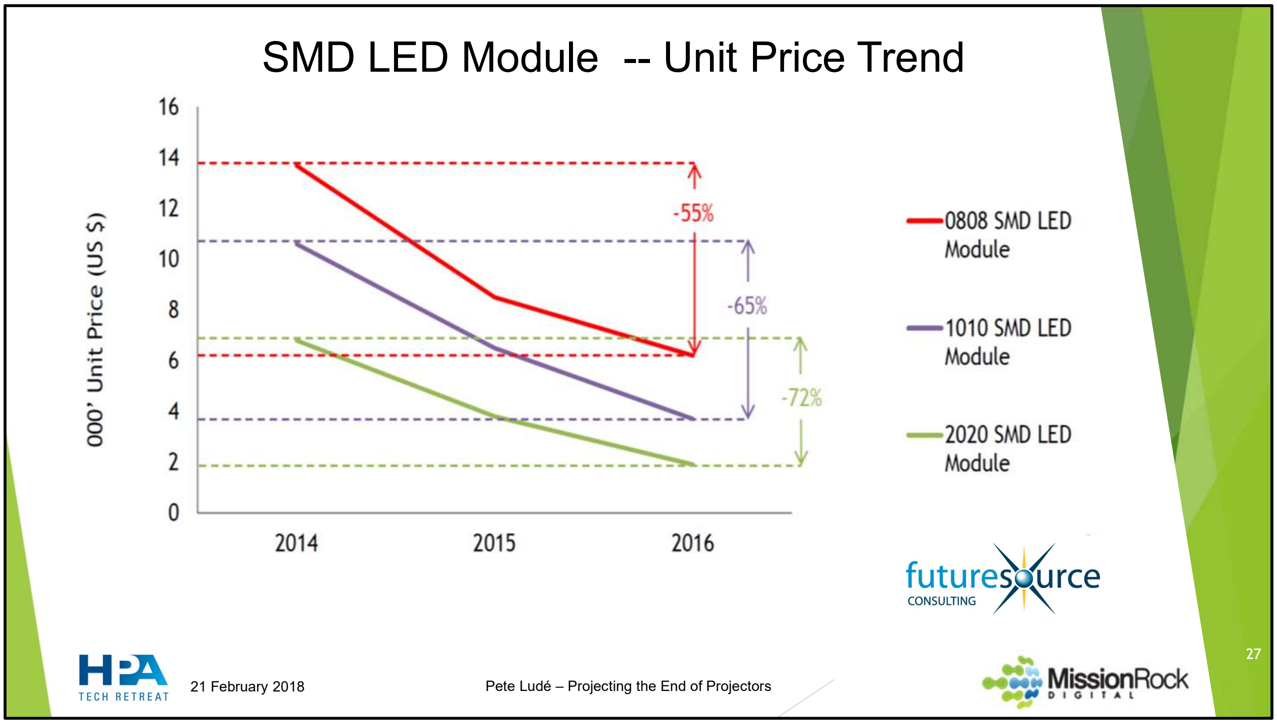
Well…. One way to calculate this is by considering the cost per pixel. After all, a 4K cinema screen will need the same number of picels whether it's in a 5 meter screen or 20 meter screen. An image of 4,096 by 2,160 requires about 8.8 million RGB pixels.



If each pixel cost 8 cents (including all associated parts), that would imply a screen cost of $700 thousand. But as the pixel cost drops, the screen becomes more affordable.

Let's compare this to the cost of a current top-end laser projector. I've shown this as a fuzzy line, since there are variations in projector designs and cost.

But you can see that as the per-pixel cost approaches 3 or 4 cents, the LED display starts to look competitive. Are we there yet?

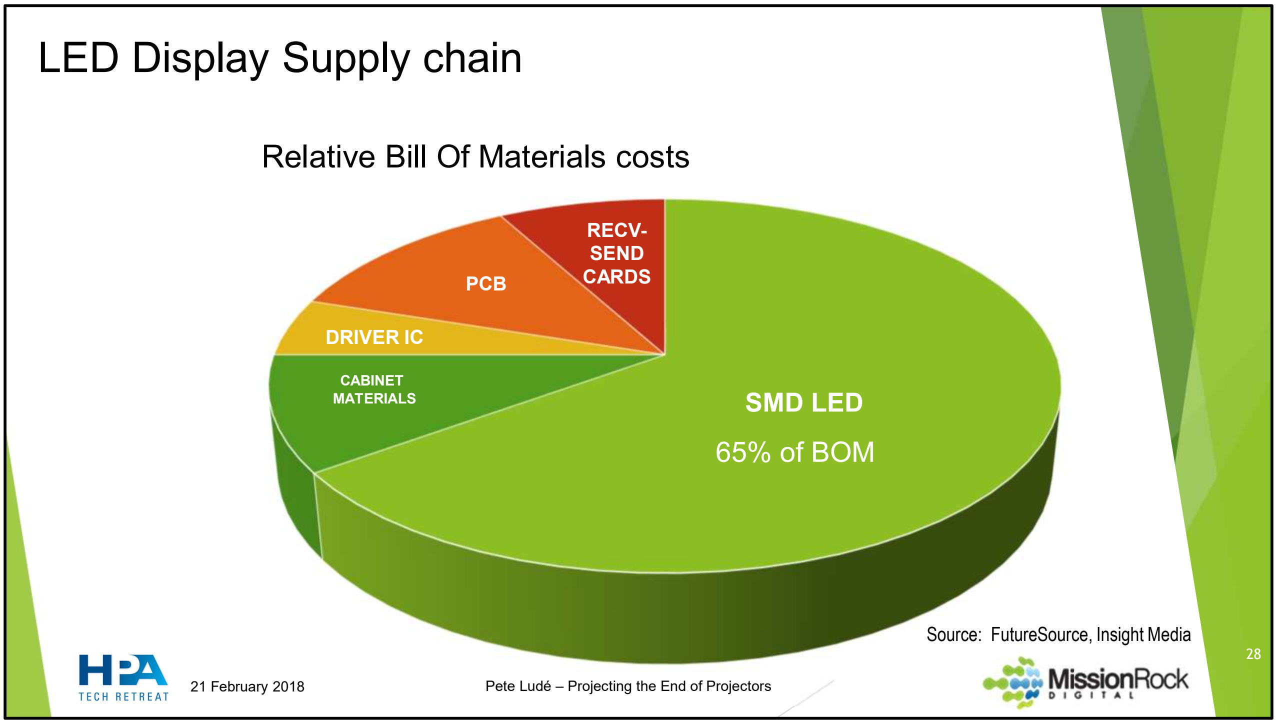


FutureSource Consulting has analyzed the cost-down trend for LED display modules using these SMD packages.

The red line show a 55% drop in the cost of the 0808 package – which is .8mm square. The purple line is for a 1mm square package and the green is 2mm .

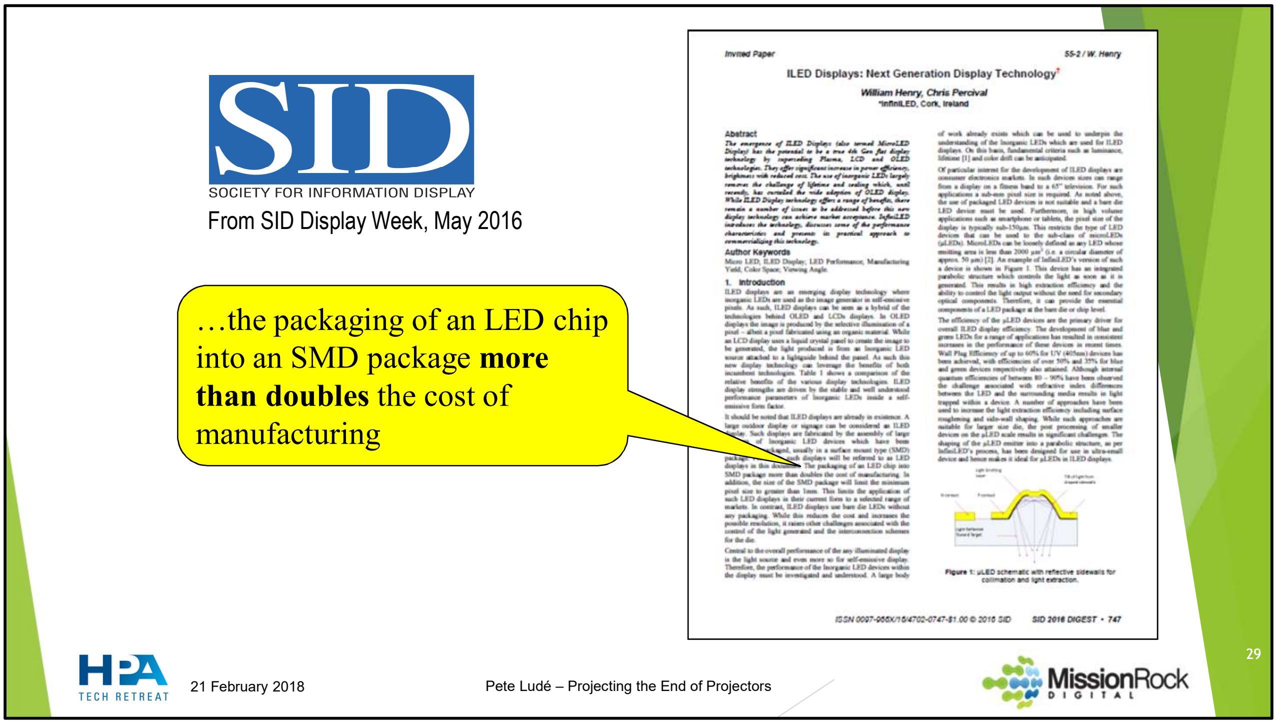
It is expected that these costs will continue to decrease over the next few years.

But how does this translate to the final cost of an LED cinema screen?



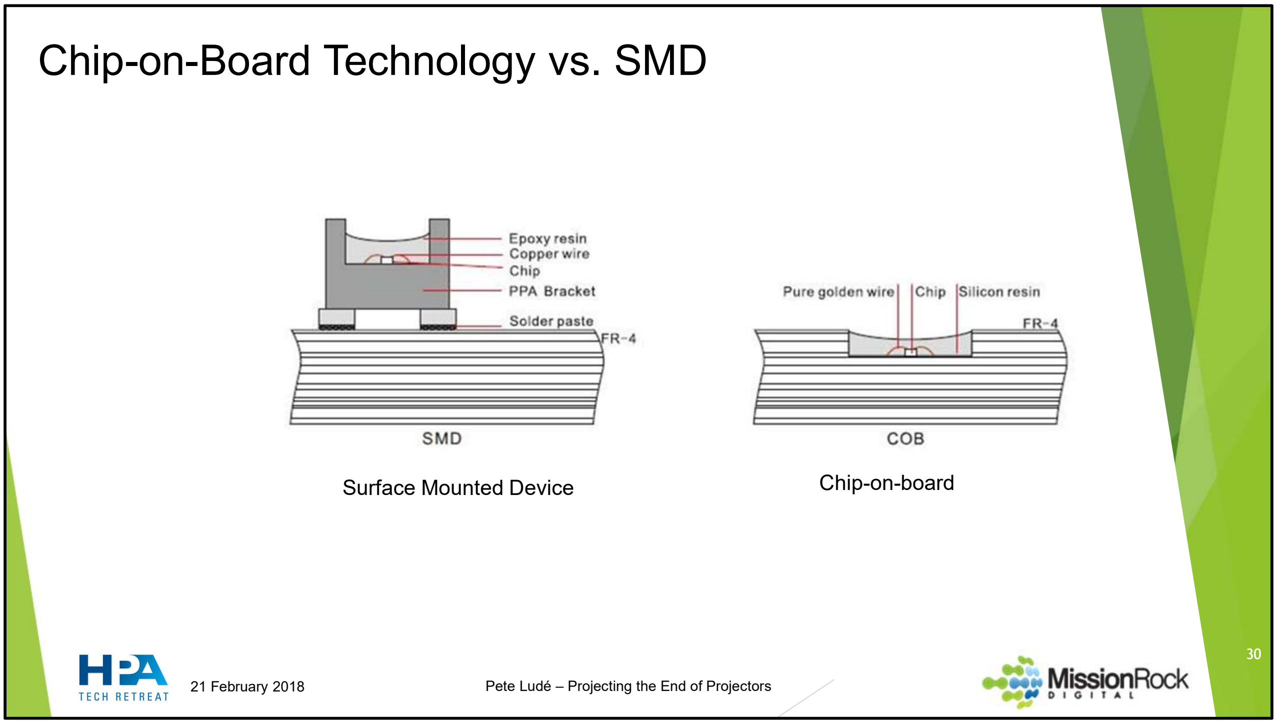
How can we get the cost down? Let's start by looking at the estimated breakdown of the Bill of Material --- or BOM – costs for a typical LED display. You can see that there is the cabinet material, driver IC's and Printed Circuit Board costs – which are not likely to reduce much over time.

But the Surface Mount Device LED is about two-thirds of the expense. We already saw that these SMD cost are expected to reduce over time – remember Haitz's law? But there's also another interesting trend…



Some clues as to how LED display costs might be driven down were revealed at the SID conference last year. This paper points out that packaging of an LED chip in an SMD package more than doubles the cost of manufacturing.

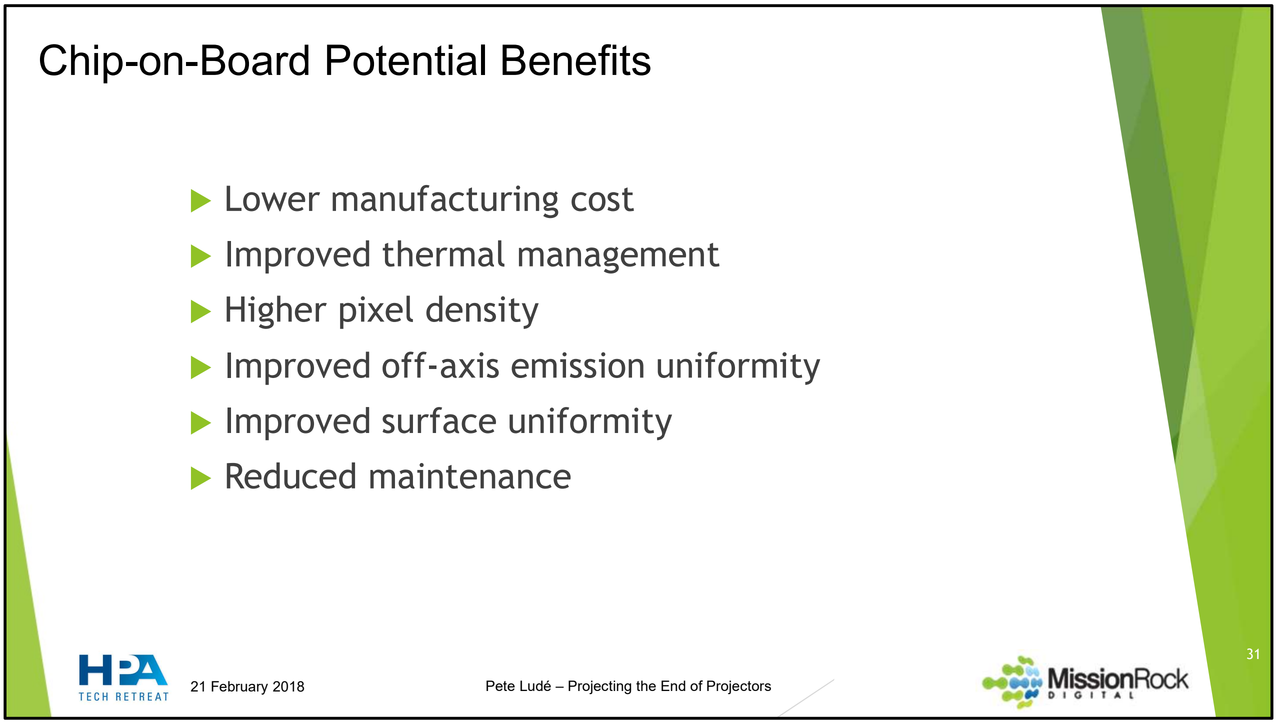
Is it possible to simplify this packaging?



Yes – it is possible to simplify packaging. The “Chip on Board” configuration.

Instead of the SMD technique, where the LED chip mounted in a frame with separate leads, mounts and epoxy lens, the chip is placed directly on the PC board, with short gold leads bonded directly to the board. An epoxy layer is then added over the entire board.

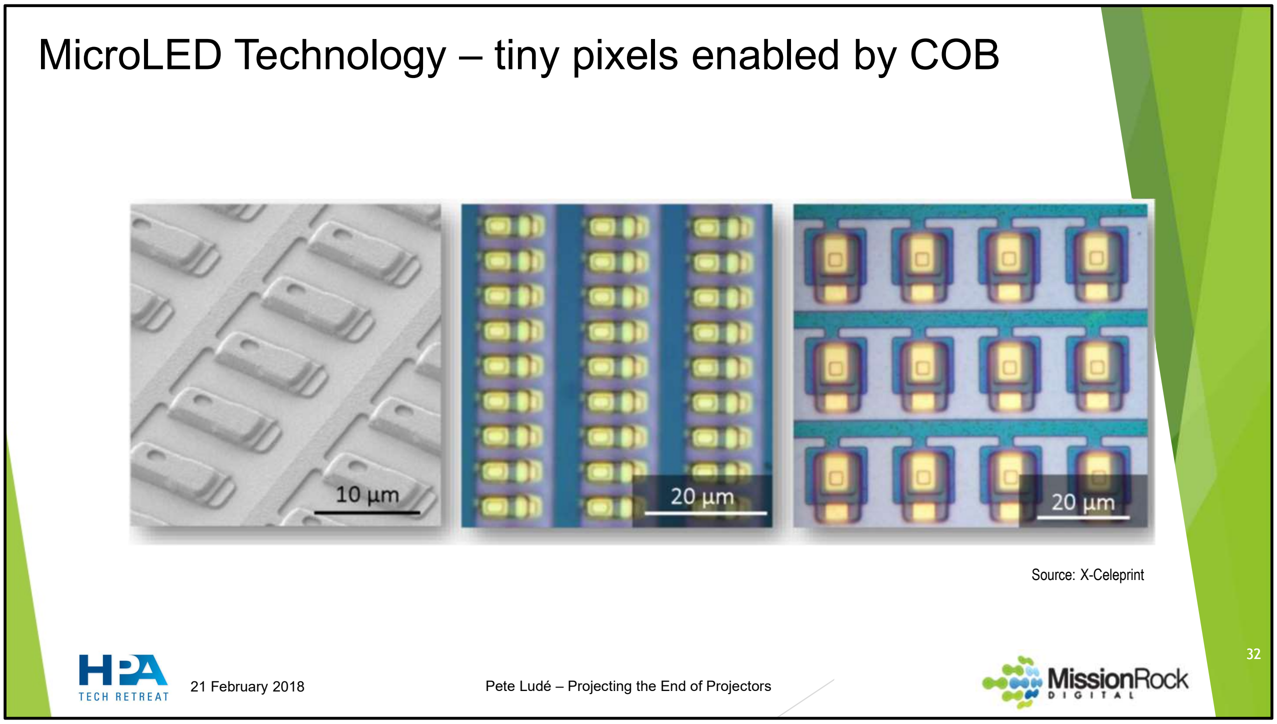
This COB process is expected to be much cheaper to implement – once the bugs are worked out. COB is already very common for LED’s used in lighting fixtures, and at least five manufacturers have started to introduce COB LED displays – but it’s still very early.



COB modules are expected to have notably lower manufacturing cost. They also provide opportunities for improved thermal management, facilitation higher luminance LED dies. Because there is no external package, the pixel density could be much higher, and the light emissions patterns more uniform – being better off-axis viewing.

The surface of the display panels is monolithic, and therefore more uniform then with individual LED components in the SMD configuration. And maintenance should be simplified, since the parts are mechanically bonded in one PCB assembly.

Consider the third bullet here – higher pixel density. SMD LED packages have shrunk from 10mm to 5mm and now down to .6mm…



…ut with COB, you can use LED dies down to .1mm or even .01mm – 10 microns. This new technology called Inorganic LED (ILED – to distinguish it from OLED) or MicroLED technology. In these displays, the same basic type of LED chip is used as we're talking about for Cinema-scale displays. But instead of several millimeters in size, they are in the range of 5 to 300 microns.

Sony was a pioneer -- showing the Crystal LED TV prototype at CES five years ago.

Currently, there the major players include companies like LuxVue, InfiniLED (in Ireland) and eLux (in Portland, US).

Notably, LuxVue was bought up by Apple in 2014. Rumors are that MicroLED will replace the OLED displays in the Series 4 iWatch, to be released in 2018. Prototypes are rumored to enter production later this year.

InfiniLED was acquired by Oculus a year ago – presumably for future VR applications.

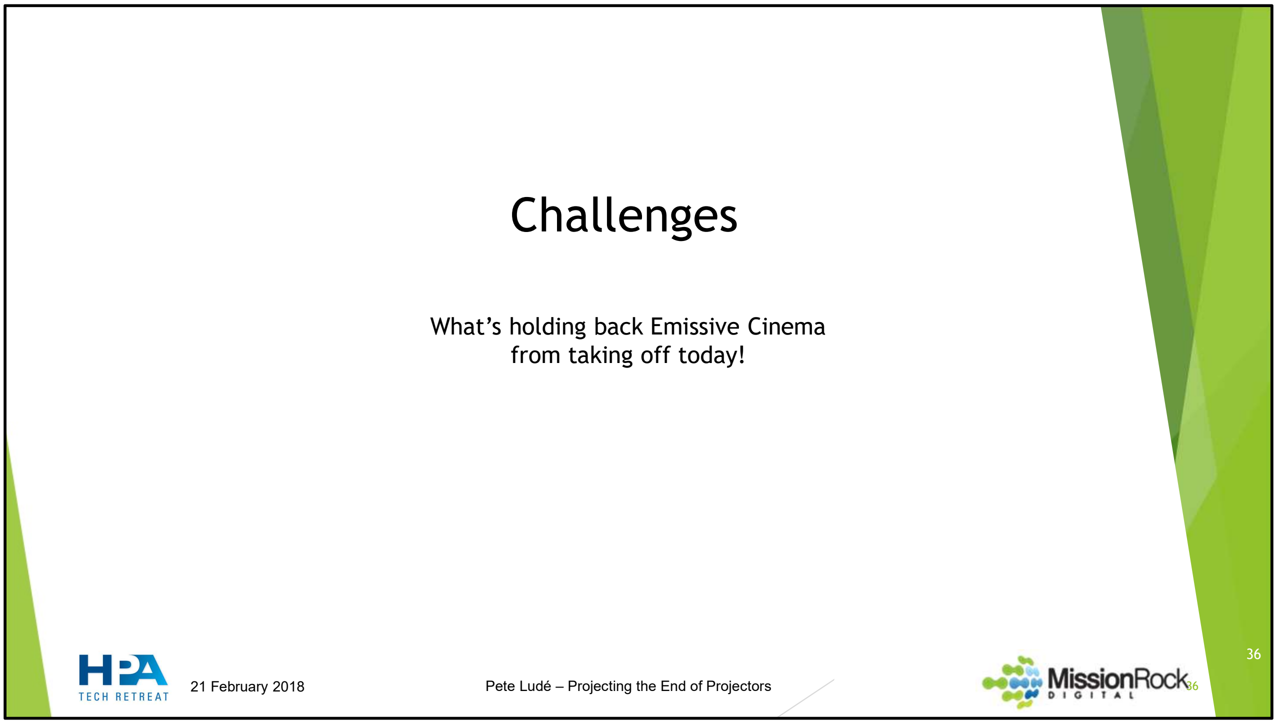
And eLux wil be part of FoxConn-Sharp as of next month.l

And last week, there was news that Google made a substantial investment in glo, based in Sweden and Silicon Valley.

It seems quite a few smart people are betting on MicroLED as a future display solution. If you can build a high-resolution LED display for $40 to go in a phone, might it be possible to build an affordable LED cinema display?

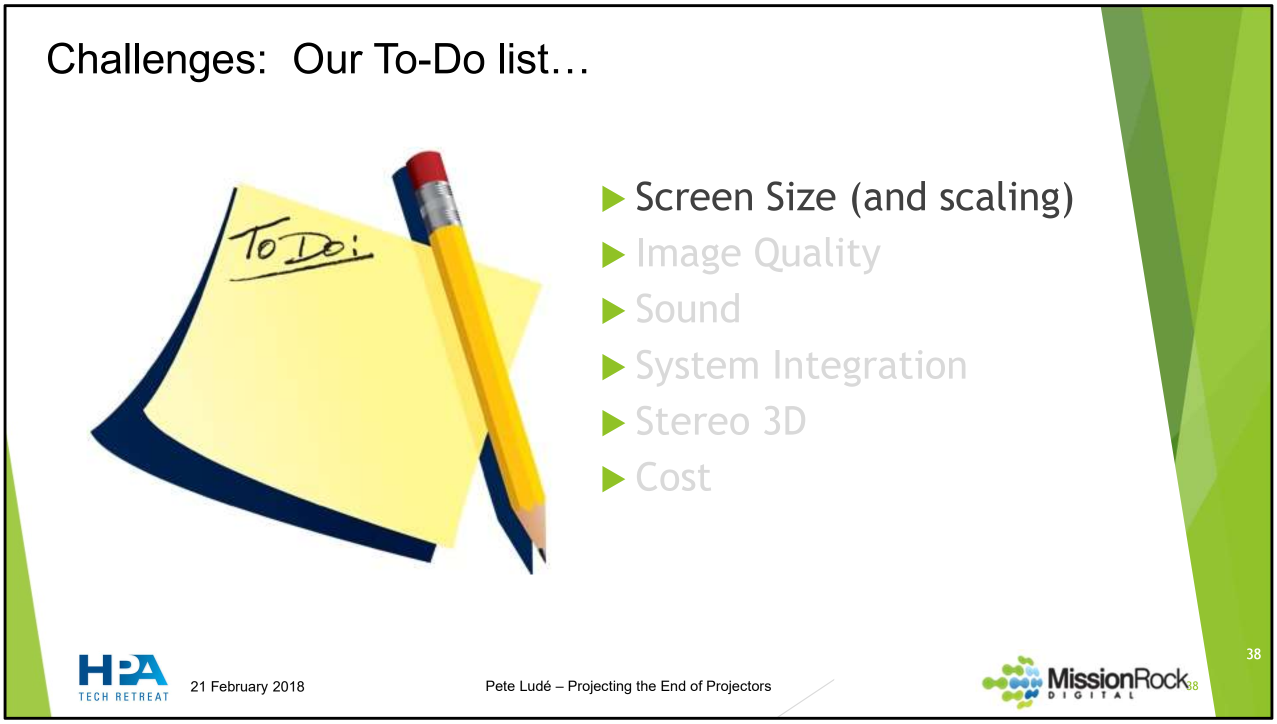
Last month at CES, Samsung introduced an LED consumer display – at 146-inch

Here's a development that had less publicity – Plessey semiconductor showed a MicroLED prototype that used 30 micron displays, with 100,000 nits.



So if the picture is so bright – what could to wrong?

Here are a few of the challenges in getting LED cinema to market.



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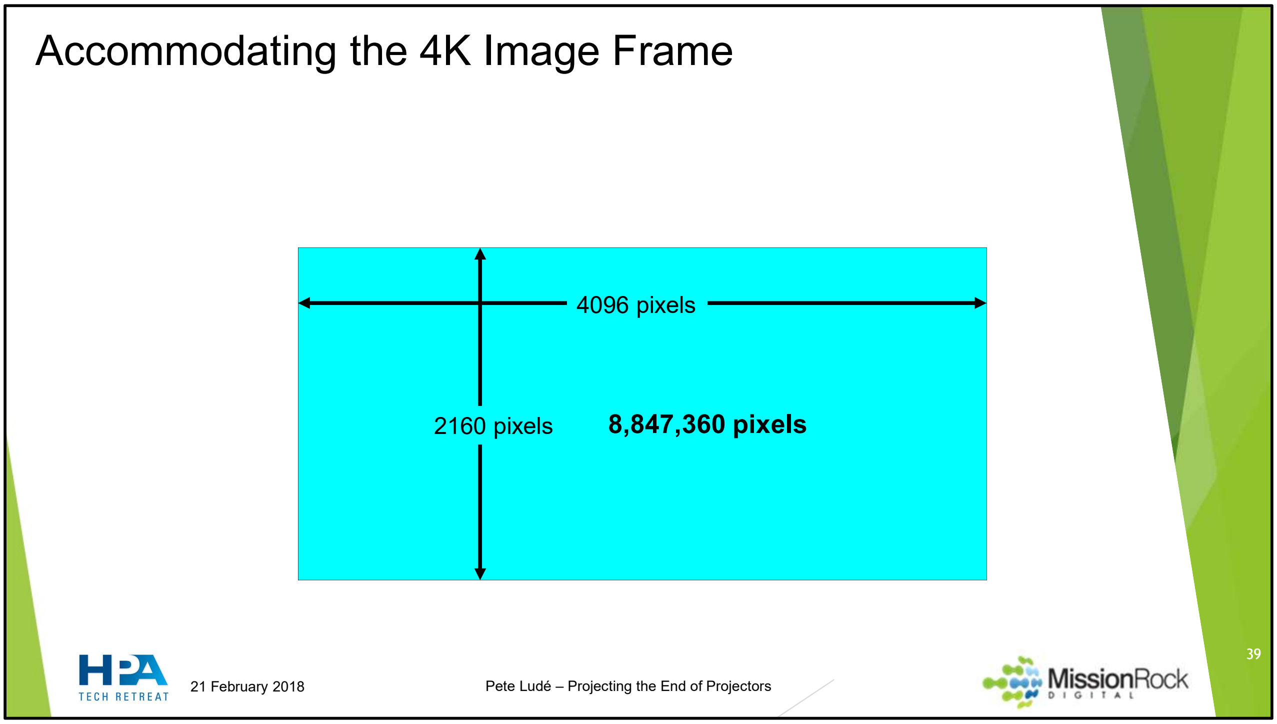

In my view, it makes since to focus on 4K – not 2K – cinema. That means we need almost 9 million RGB pixels, or about 27 million individual red, green and blue chips.

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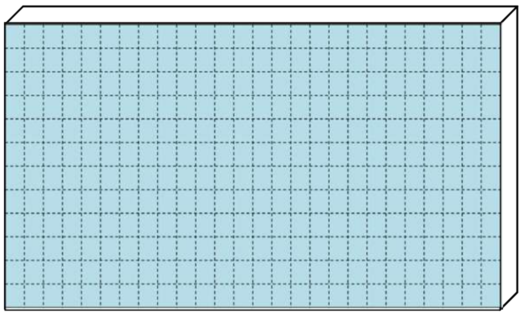
Screen size scales with pixel pitch

Fun Fact:
Digital Cinema "Projector Pixels" are typically 3 - 5 mm



...assuming 4K (4,096 pixels)

Pixel Pitch	Screen Width	
(mm)	*Meter*	*Feet*
1.9	7.8	25.5
2.5	10.2	33.6
4.0	16.4	53.8
5.0	20.5	67.2
6.0	24.6	80.6

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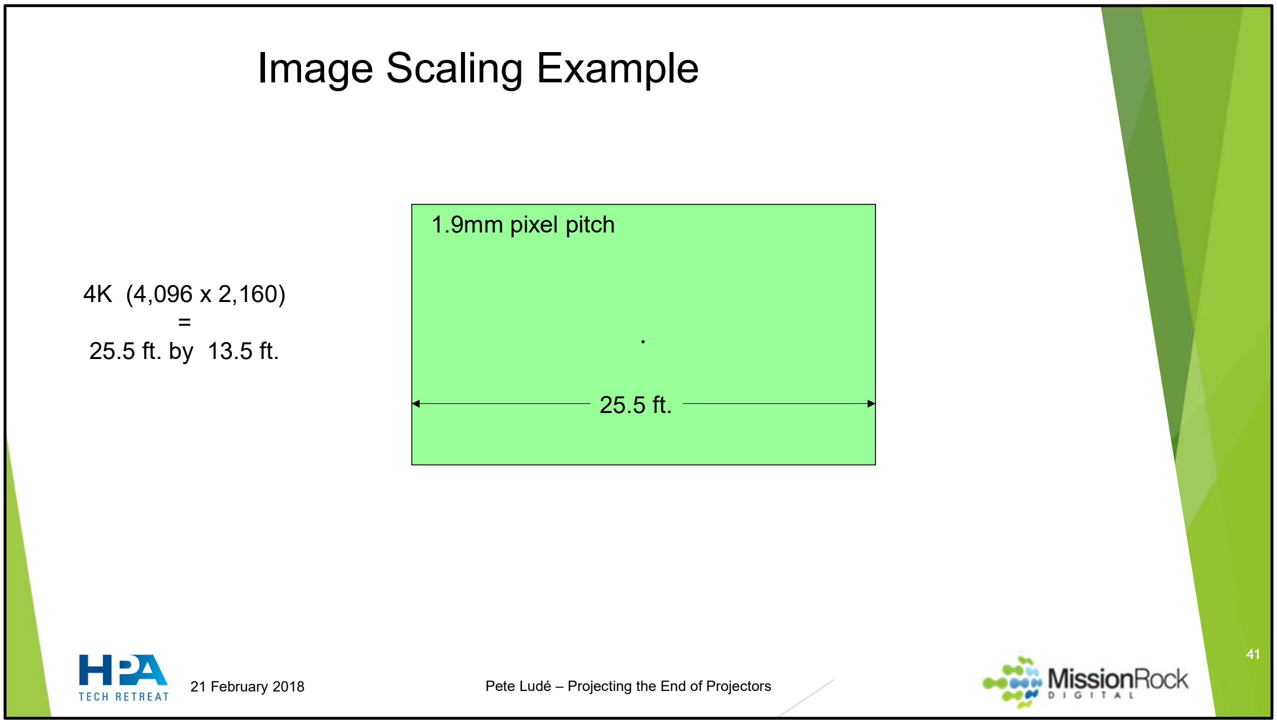
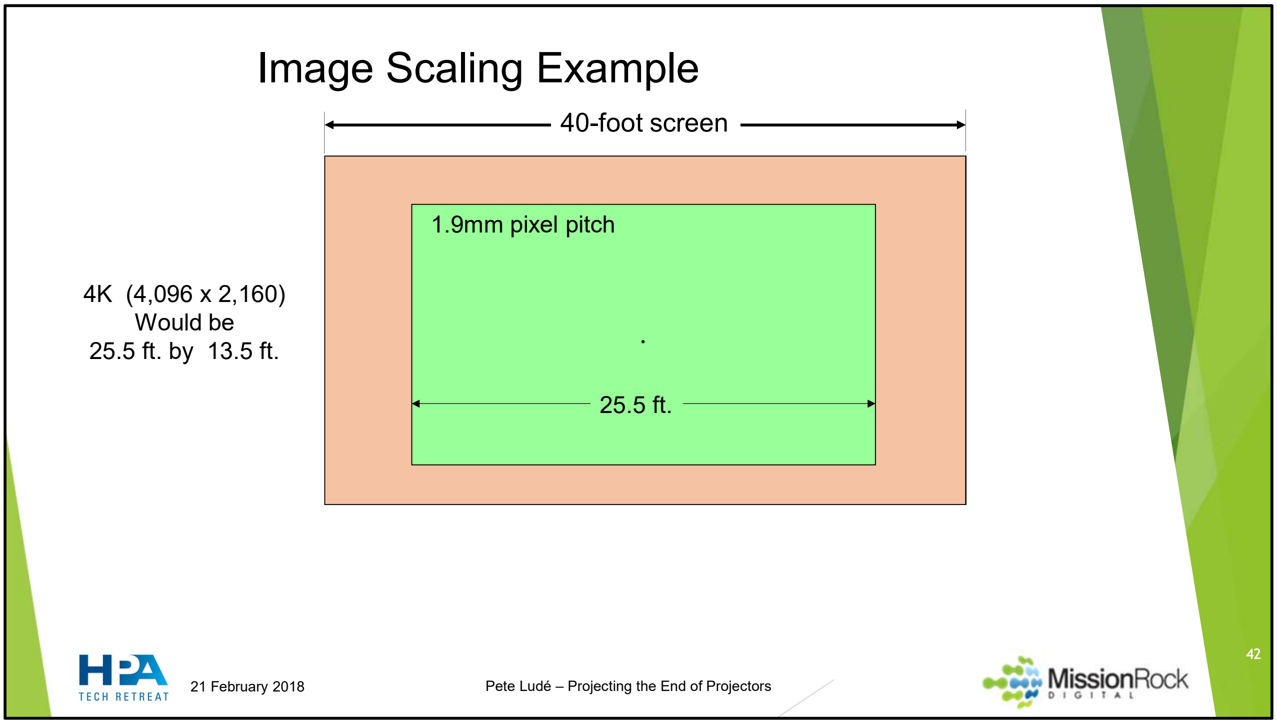
You may not realize that pixels projected on a cinema screen are rather large – in the range of 3 to 5 mm even in a 4K projector.

So for example, if we wanted to use 4mm pixels, in a 4,096 raster configuration, that would result in a 16.4 m – or 53 foot – screen.

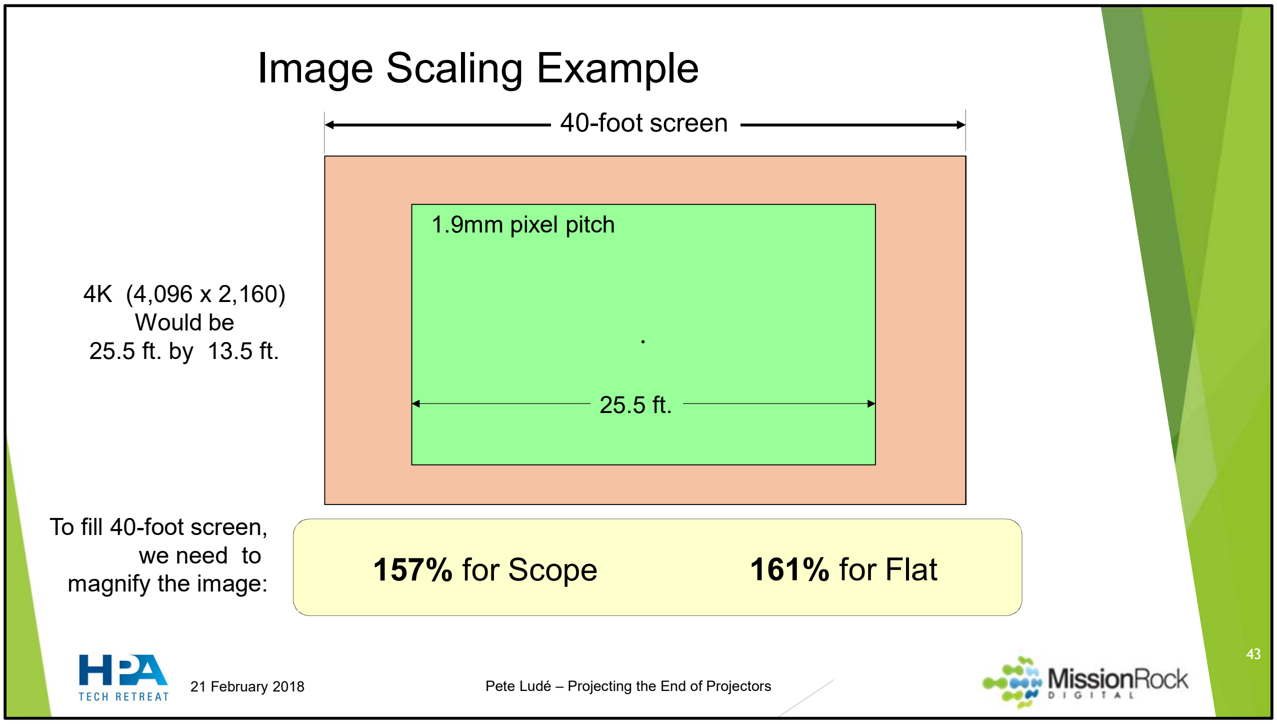
However, due to the "screen door effect" it may be desirable to actually use smaller pixels than the 4K image – depending on viewing distance and LED emitter optical properties. This is one of the factors that needs careful consideration.



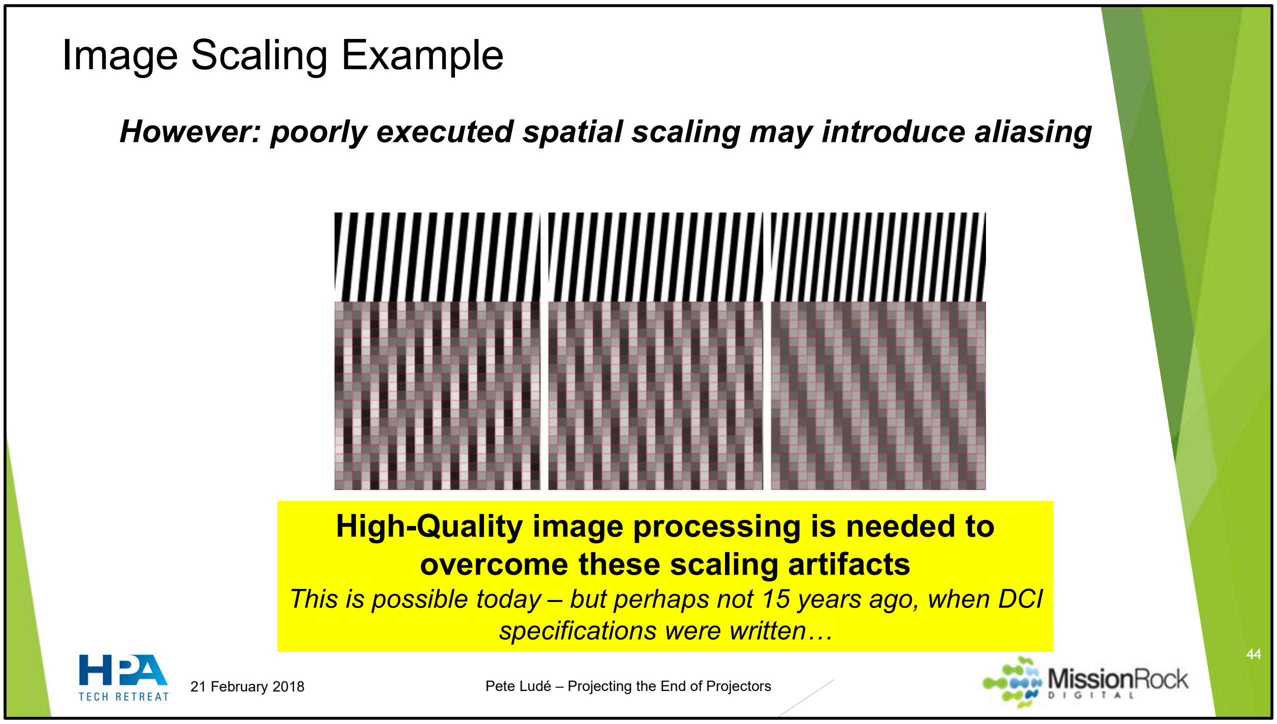
If our screen size is fully dependent on the LED pixel, it could be a problem. Suppose you intended to use a 1.9mm pixel pitch – a common LED configuration with beautiful image quality. 4,096 pixels times 1.9mm resuls in a 25.5 ft – or 7.7 meter – screen.



But suppose my auditorium needed a 40 foot screen?



Using the same 1.9mm pixels, I would need to enlarge the picture by 157% to fill the full 40-foot screen; or by 161% in Flat aspect ratio.

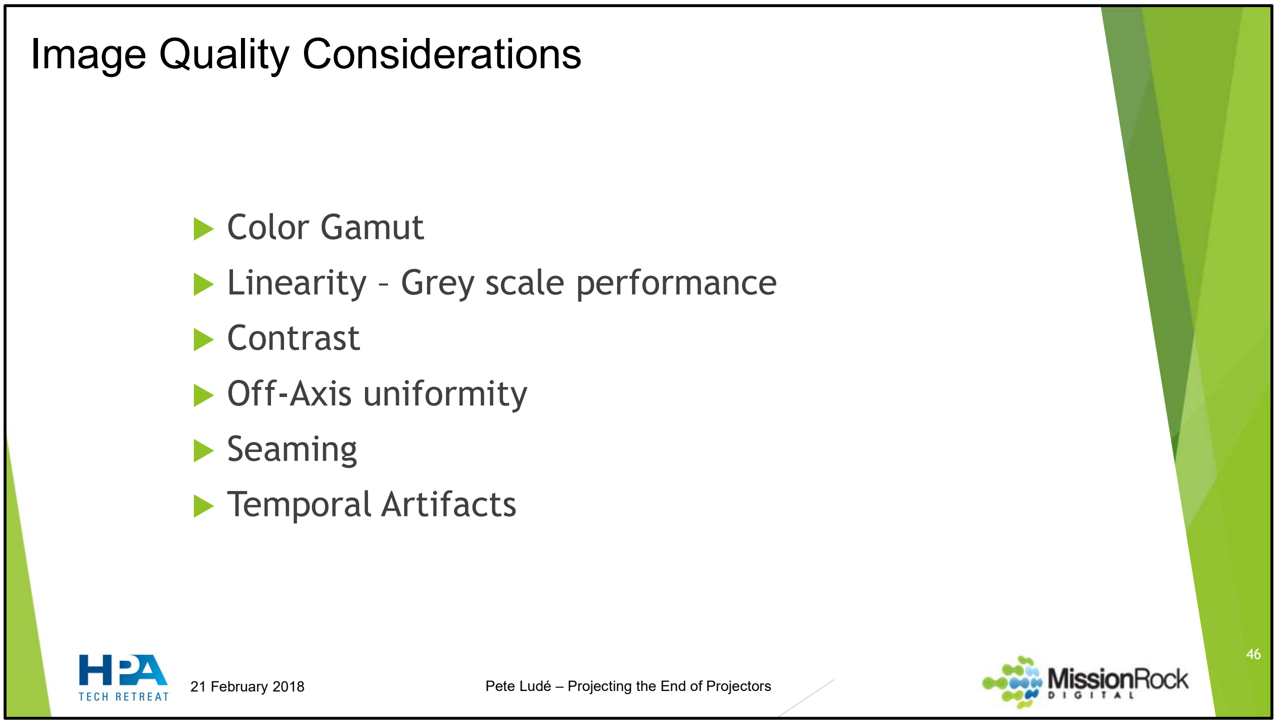


For you image scientists out there, you know that if you're scaling the image to less than two times the source image, aliasing could occur.

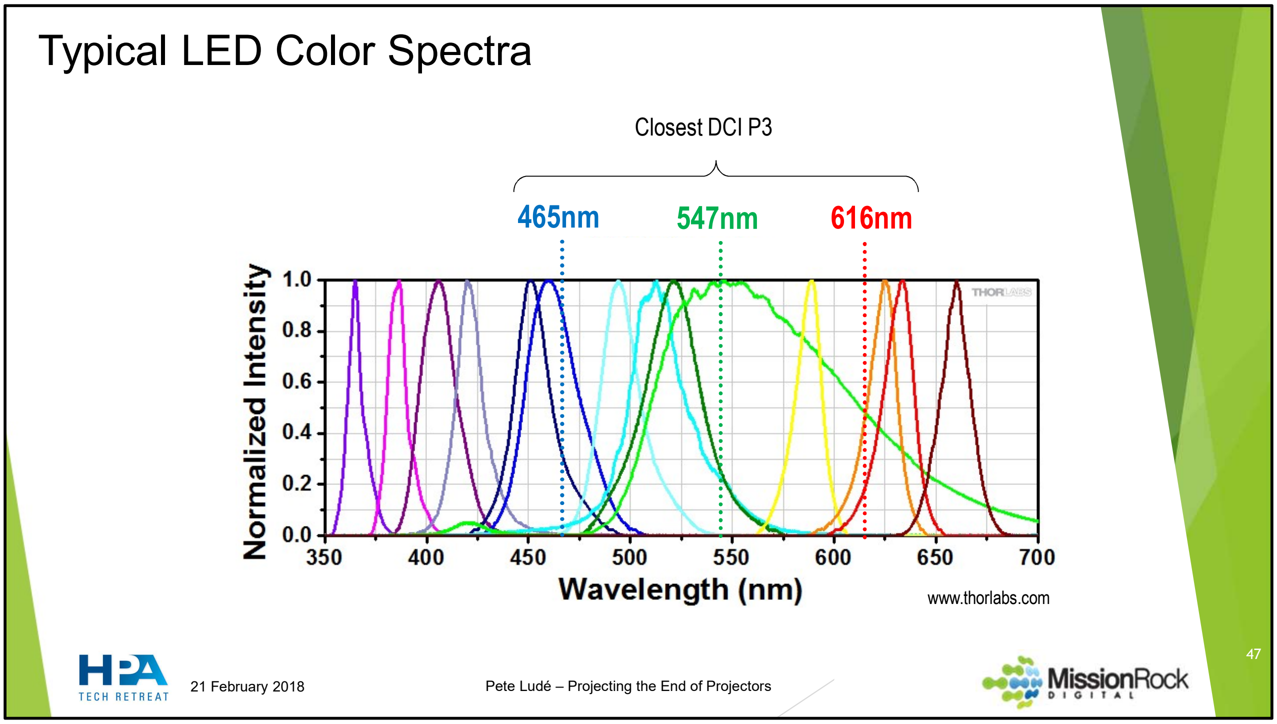
Fortunately, igh quality scaling algorithms are now practical to implement, which would result in a very high image quality and no visible aliasing artifacts. But this needs to be carefully done.

DCI – the Hollywood studios – have frowned upon scaling images in projector systems, but in my view, this must be re-visited for the new world of direct-view cinema displays.

Here are a few of the challenges in getting LED cinema to market.



Here are a few of the key factors that must be considered to ensure appropriate image quality in LED displays.



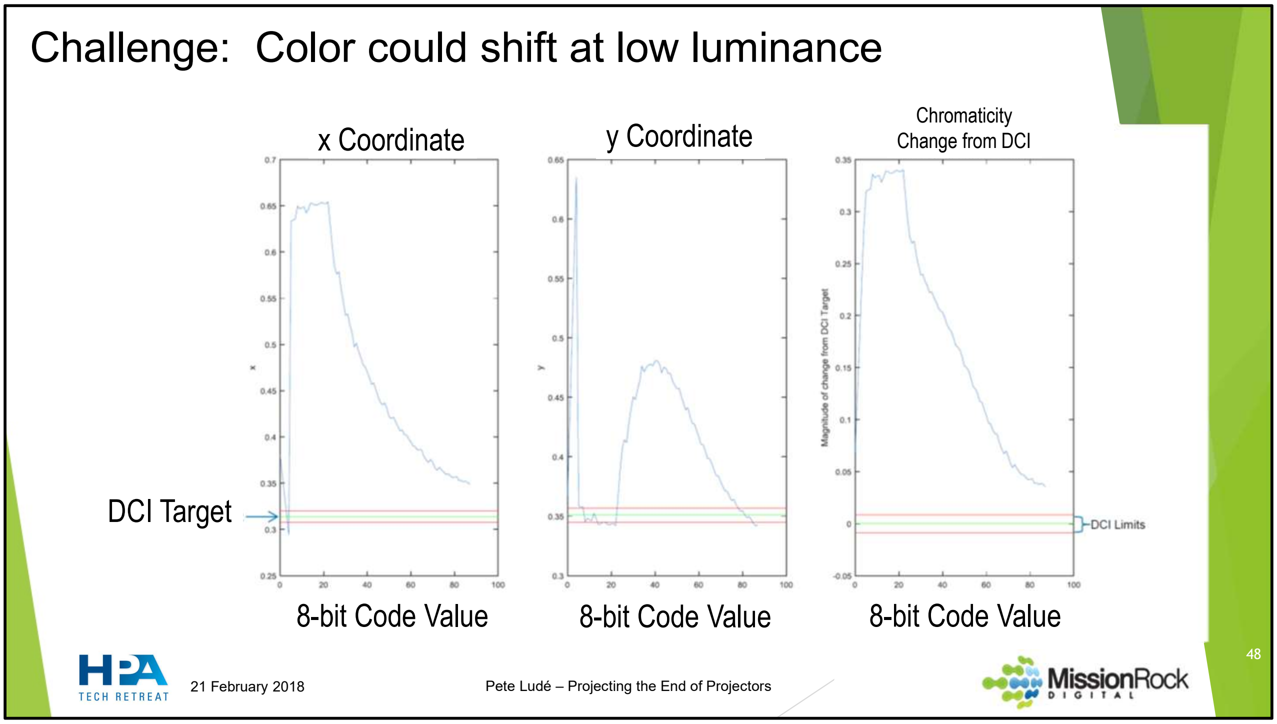
The full DCI color gamut needs to be supported. This graph shows the chromaticity spectra of commonly available LED chips.

And here are dominant wavelength that will conveniently support the DCI P3 color gamut. As you see, it would appear that green if not to difficult, but blue and red are bit off from where we'd like them.

The system engineer has several choices: You can still support P3 with these spectra, but with reduced brightness efficacy.

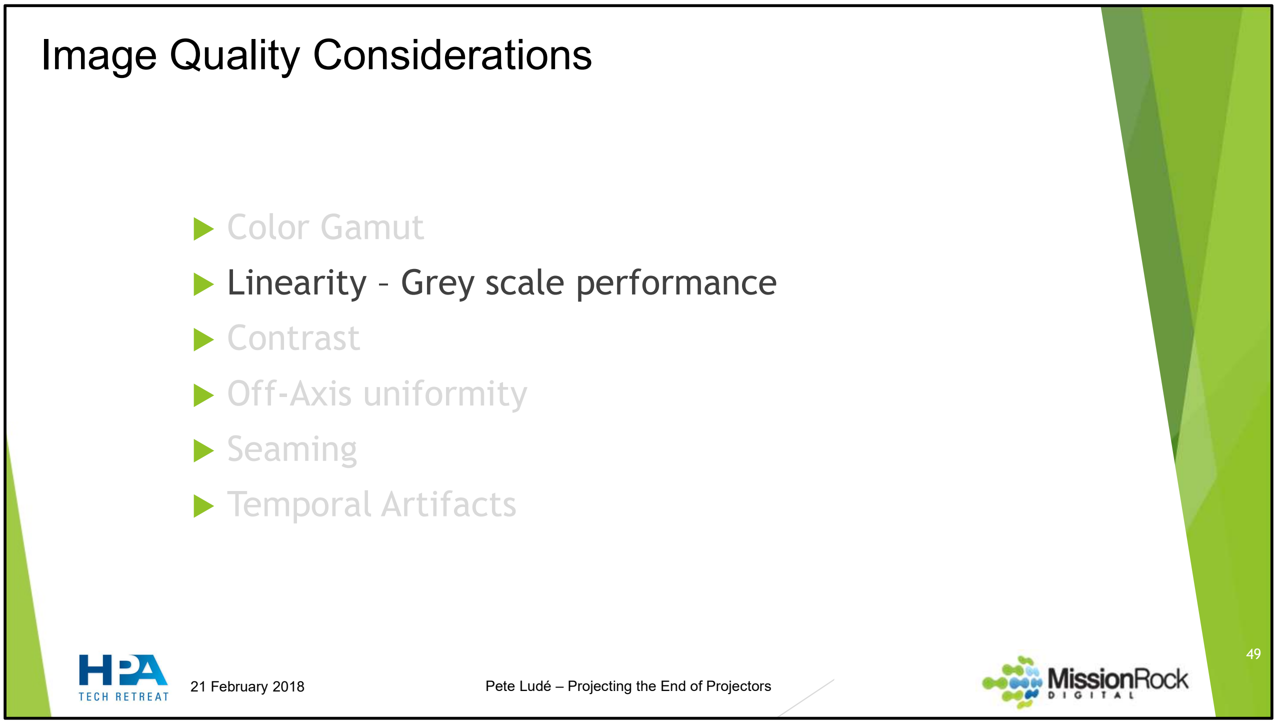
Or, since LED's vary from one to another, you can use a "binning" process to cherry-pick just the ones that match your required wavelength.

Or – you can work with the LED foundry to develop a modified chip to exactly match your needs. All of these three options are possible, but none are particularly trivial or inexpensive.

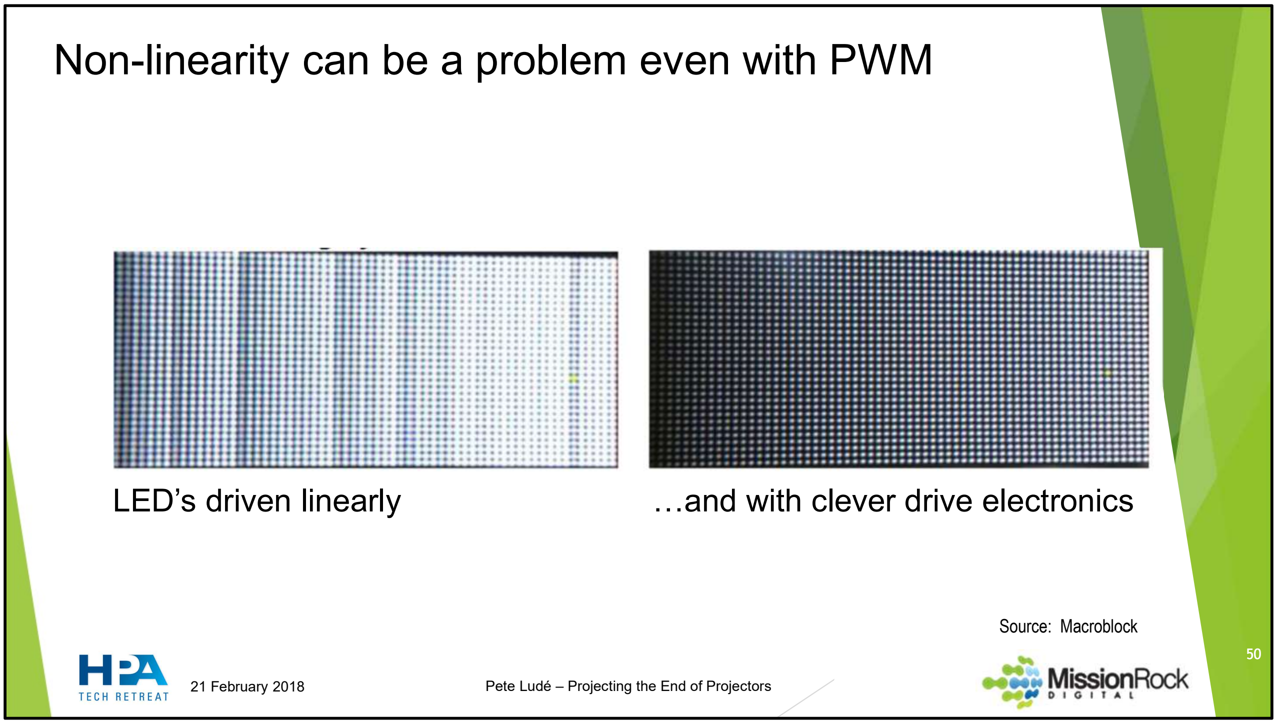


Another issue with color reproduction is consistency at low light levels. Here's an example of what happens to the x and y chromaticity coordinates as you range through zero to 100 8-bit code values. There is quite a bit of variation. The DCI target is shown as the faint green line near the bottom, and the DCI color tolerance limits are shown in red.

As you can see, garden-variety – normal – LED chips and drivers might be acceptable for advertising or control room applications, but there is some work to do to achieve cinema quality.



Next on our list is linearity at low grey levels

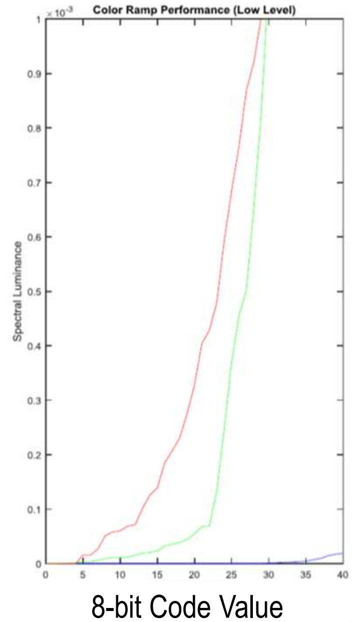


Even then, a poorly implemented PWM system will result in inconsistent grey-level reproduction. The pulse width controller must be very well designed to achieve proper grey-scale reproduction.

It is particularly tricky at very dark areas – low code values – due to slight variations in the way LED's fire, capacitance in the wire bonding and other factors.

Linearity

LED's don't always fire at the same time



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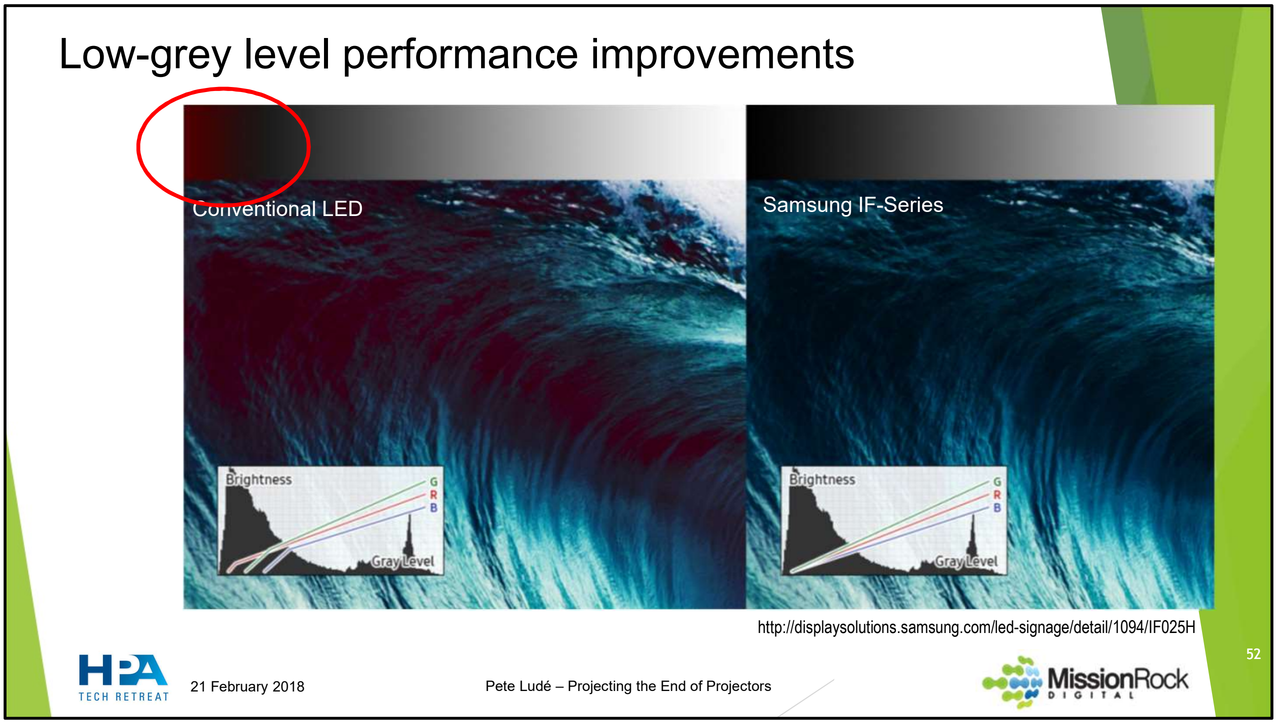
This graph shows that due to differing epitaxies in the LED die, the red, green and blue may turn on at different code vales, when ramping up slowly from black.

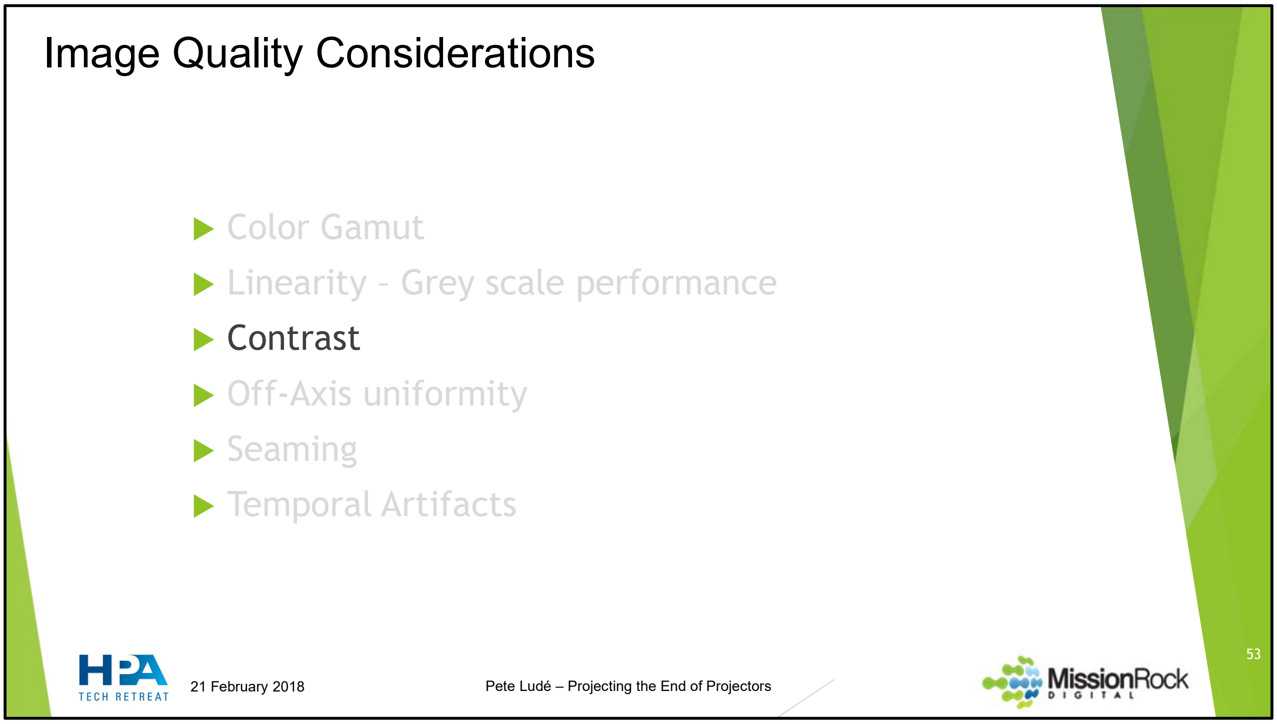


Here's a good example of the problem being addressed. This is from the Samsung web site – not the Samsung cinema LED display, but what they call their IF series.

On the left is a conventional LED.. You can see in the small graph the red, green and blue LED luminance varying at low levels. On the right is the properly aligned system, with uniform linearity for red, green and blue.

Here in the upper left you might be able to see the symptom – a shift to red in the deep black segments.

This is an issue that must be addressed for proper cinema quality.



Next on our list -- Contrast

Optimizing contrast by LED SMD design

Source: Osram TopLED

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Typical LED displays – as shown on the left, have a light-colored, reflective LED die and substrate.

To achieve superior image contrast, this needs to be fixed by using dark tinted epoxies or other means to reduce reflected light. You can see the fix on the right.

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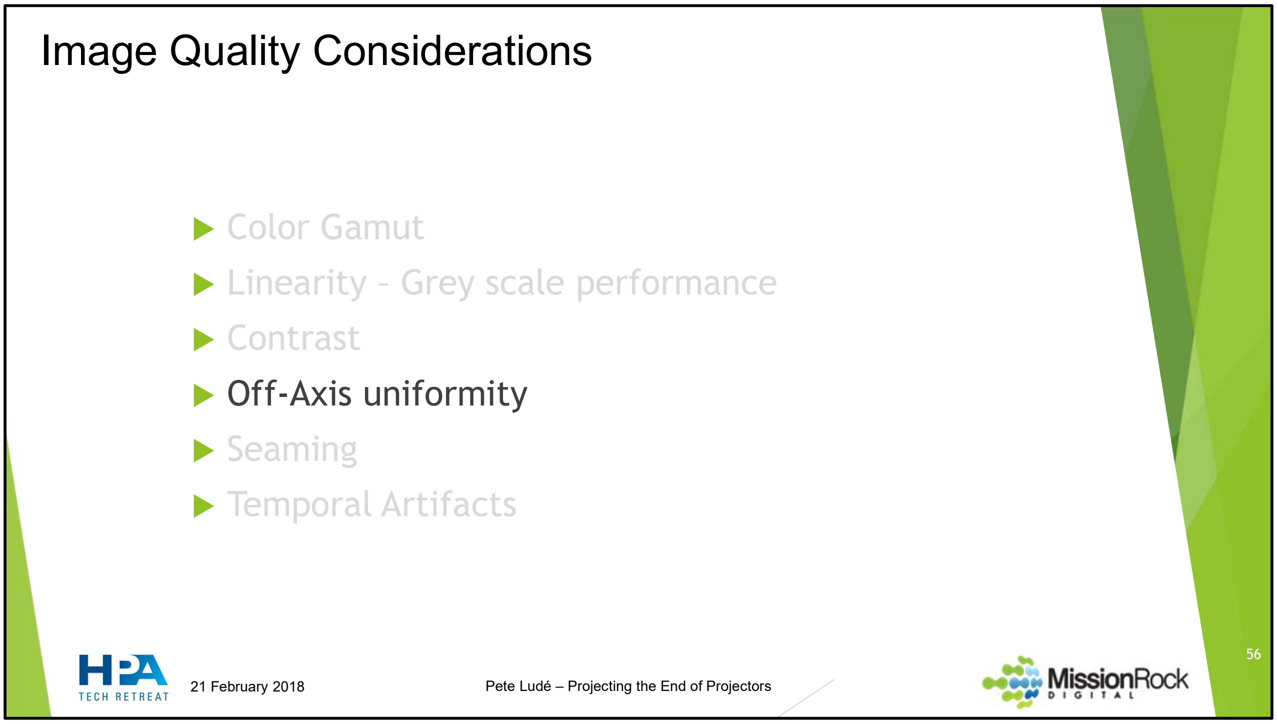
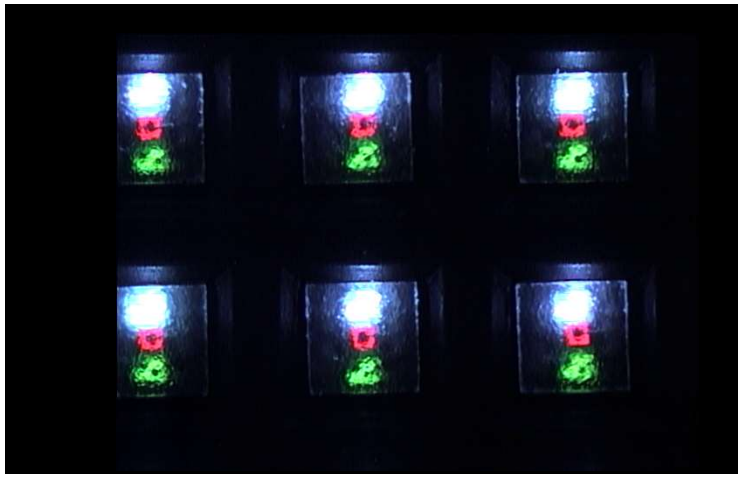
Manufacturers are aware of this requirement, and have some good solutions. Here is a new LED SMD package just introduced by Cree. IT's designed specifically for high-quality LED displays, including improved contrast.



Another factor is uniformity of the image when viewed from the side rather than straight on from the front.

Pixels may look good from directly in front, but…



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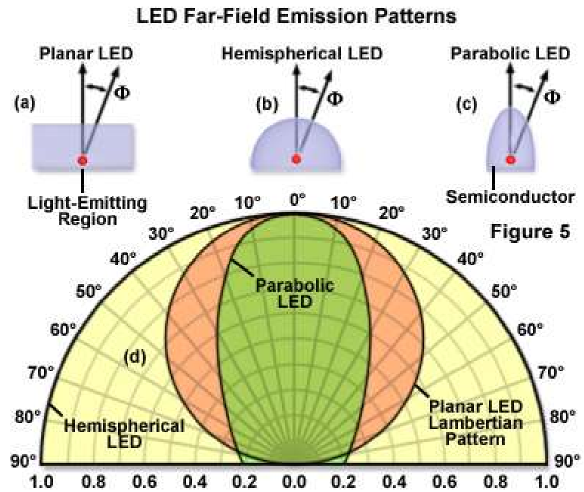
Due to the optical design of these RGB pixels, you may have excellent picture uniformity when viewed from the front, but when viewed off-axis, you might see substantial variation in color and luminance uniformity

Emission patterns vary according to optical package



http://zeiss-campus.magnet.fsu.edu/print/lightsources/leds-print.html

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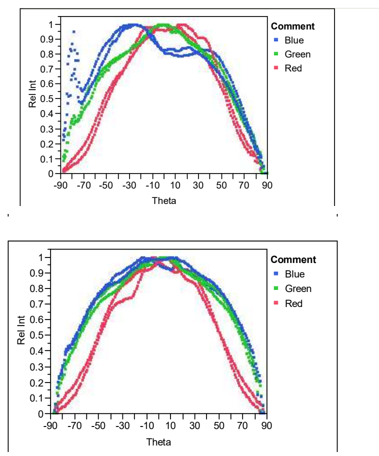
This is due to the emission patterns of the LED chips in their package, including the variation from the position of the red, green and blue in the same package.

Many configurations are available, including planar, hemispherical and parabolic, but for LED displays, we're looking for a high level of consistency in brightness over a wide horizontal and vertical viewing angle.

Improvements in Radiation Pattern

Vertical

Horizontal



Typical SMD 1010 Package

Source: Cree

Again – this is an issue well-understood by the chip manufacturers, and it's being addressed in new specialized devices. Here's and example of plotting the relative luminance of the red green and blue chips as you move your viewing distance from left to right (on the bottom) and from top to bottom (in the upper chart).

You can see that there is a good deal of variation as you viewing position moves.

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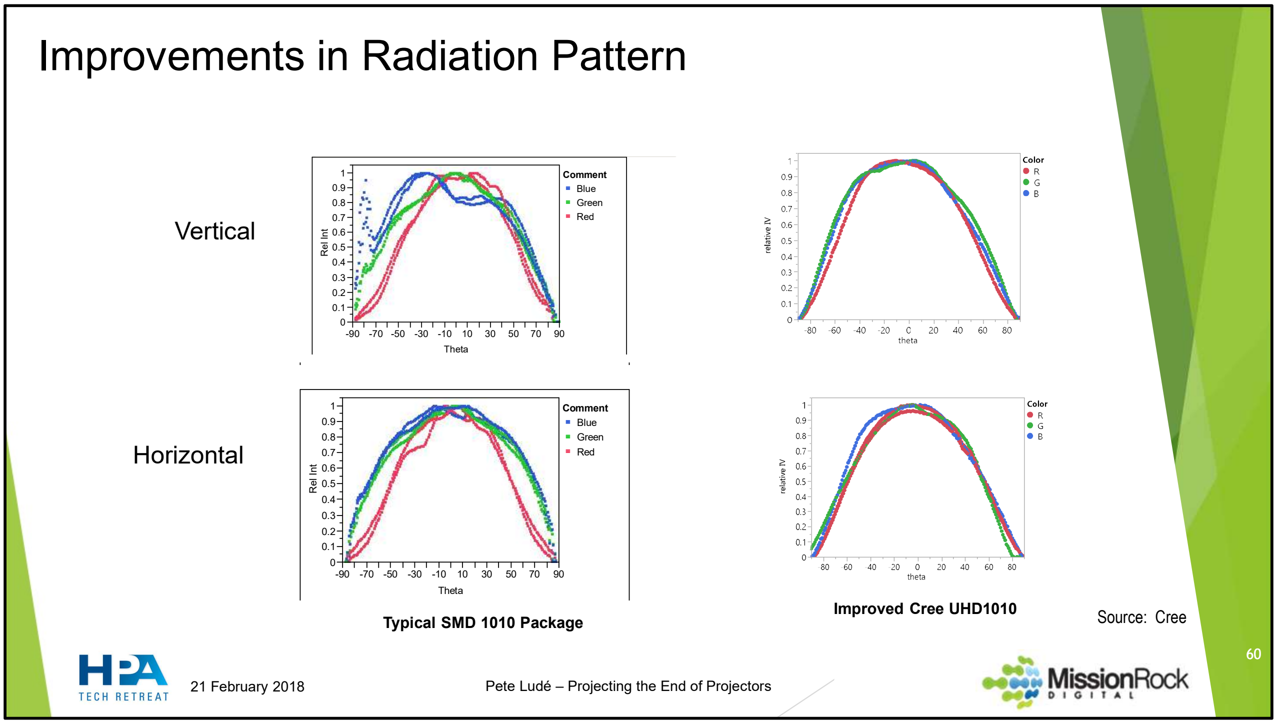
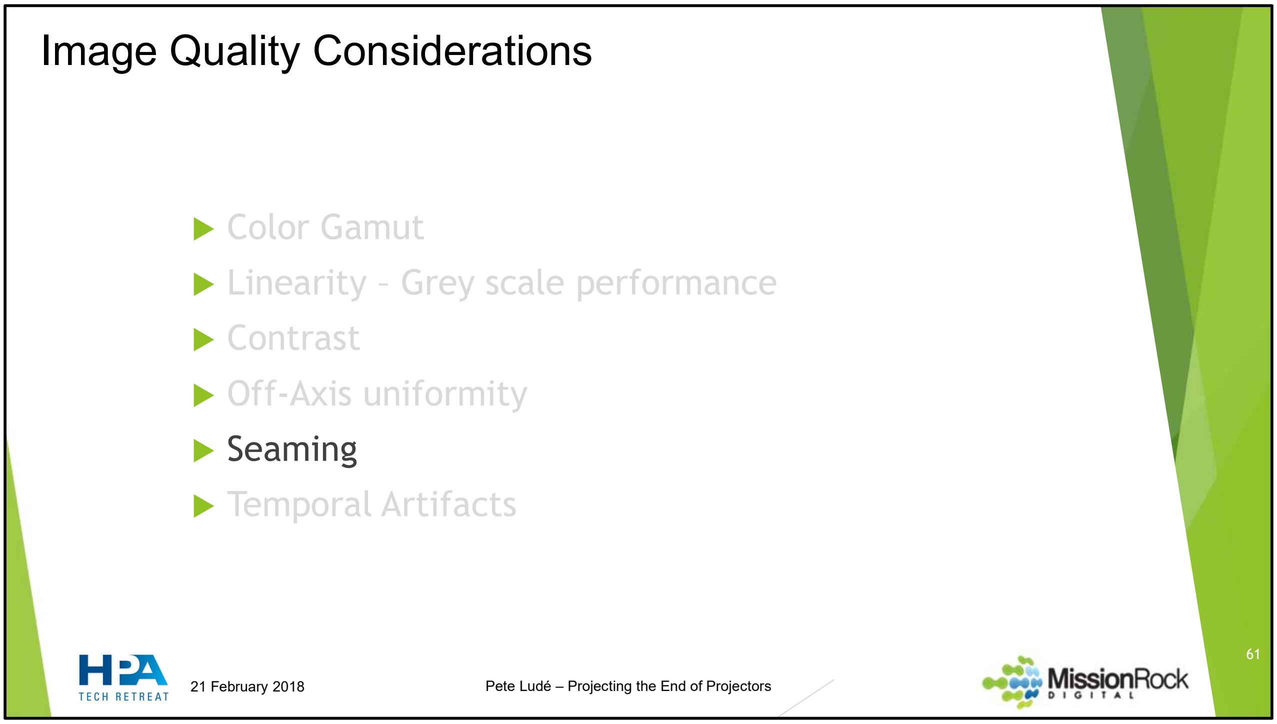


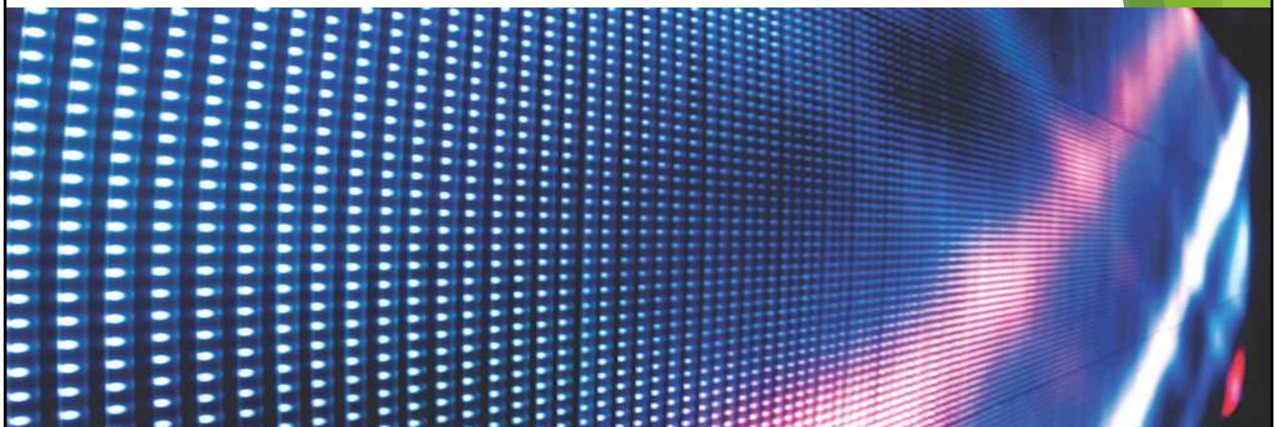
But on the right is the much-more consistent implementation. This is also from the latest package released by Cree.

This is the sort of performance required to achieve DCI quality cinema displays.



This next one is easy to understand

Modules must be precisely aligned



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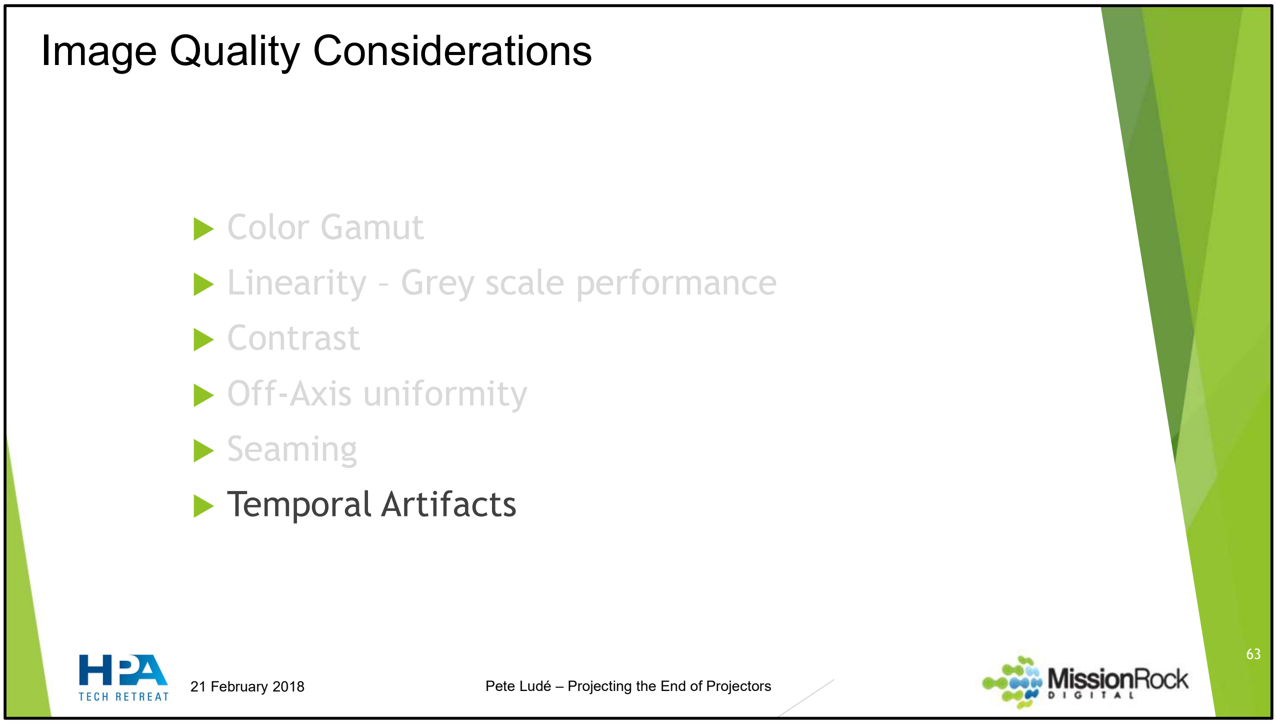
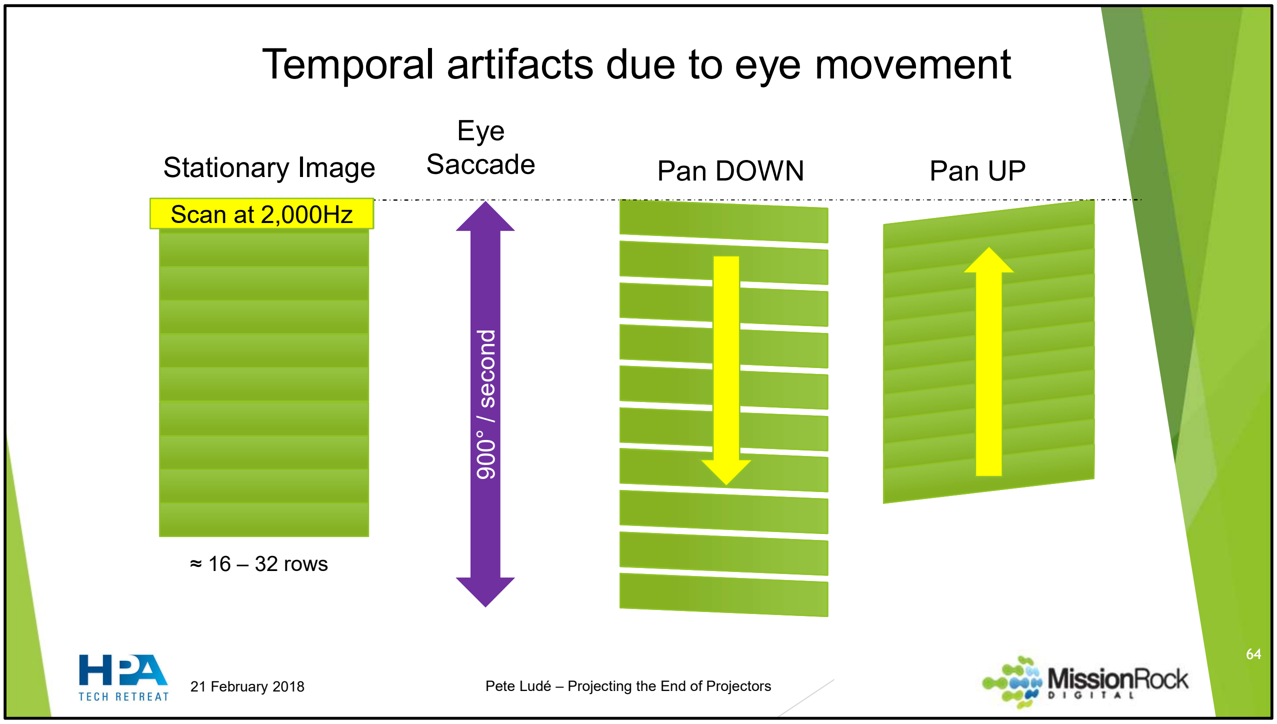
Since the LED display is made up of hundreds of cabinets mounted adjacent to each other, great care must be taken to align them, otherwise visible seams will result. This is somewhat of a mechanical engineering challenge – but a number of quality manufacturers have developed excellent mounts and alignment procedures to ensure invisible joints between the modules.

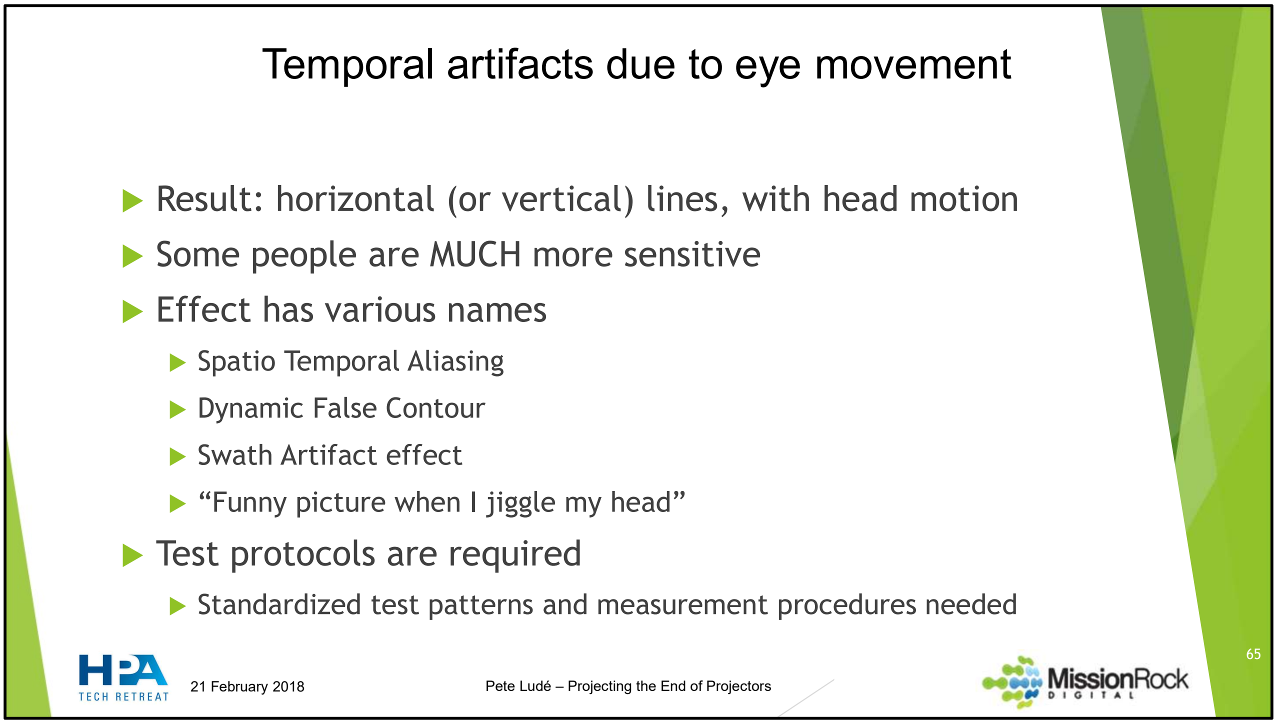


Due to the way the LED's are scanned, there is the prospect for some undesirable temporal artifacts that we need to look at.



Typically, an LED display is scanned so that every 32nd – or perhaps every 16th row of pixels -- is addressed at the same time, from left to right. Then, the next row down, and the one below that until the fully image is "painted" on the screen. The scan rate is typically in the 2 to 4 kHz range.

When you view the image, you eye is also moving. This might be you moving your head, or simply the eye saccades, where your retina is naturally moving at up to 900 degrees-per-second. The result is that if your eye pans in one direction, the scanned rows will appear to be separated, whereas if you pan in the opposite direction, the pixel rows could appear to overlap..



The result is brief but annoying bars or lines in the image. These can appear horizontal or vertical, depending on the scanning configuration.

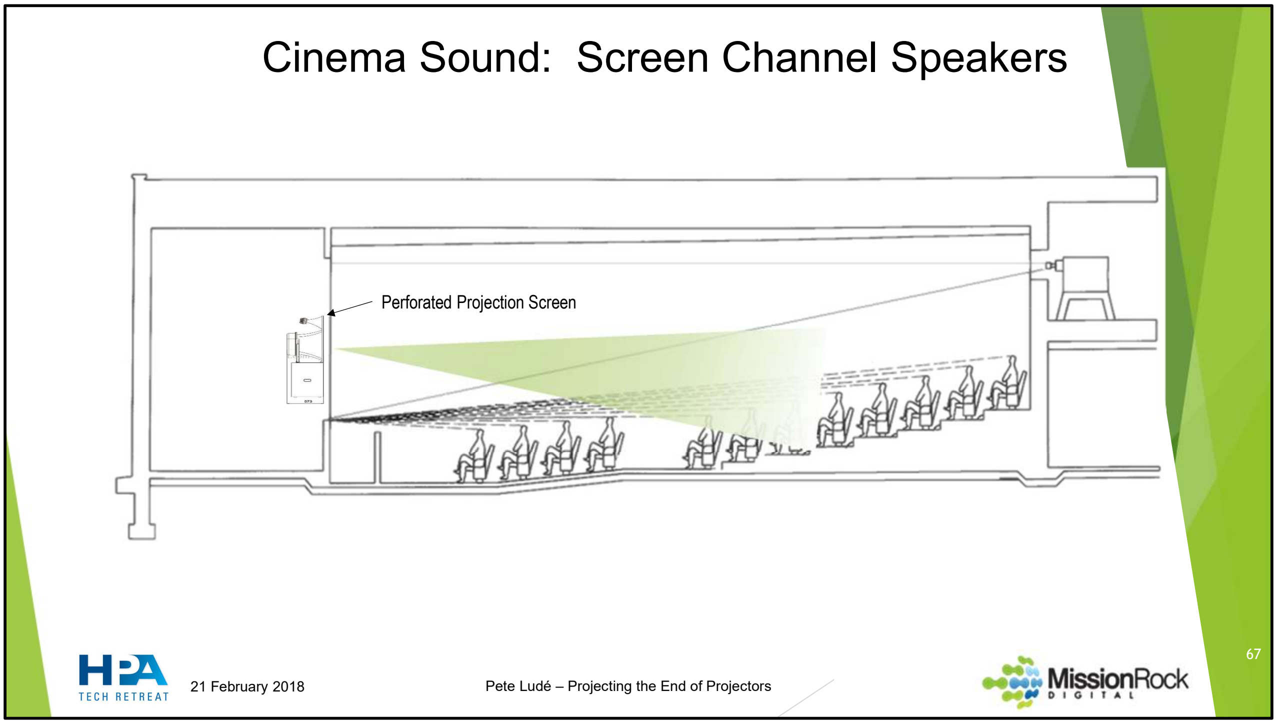
If you have ten people in the room, some will see it, and some won't. Visibility of this phenomena varies greatly by observer.

The effect is widely known, but I haven't found a consistant terminology for it. It has the same cause as what we used to call the "color wheel effect" on single-chip home rear-screen projectors, in which some viewers saw distracting color fringes.

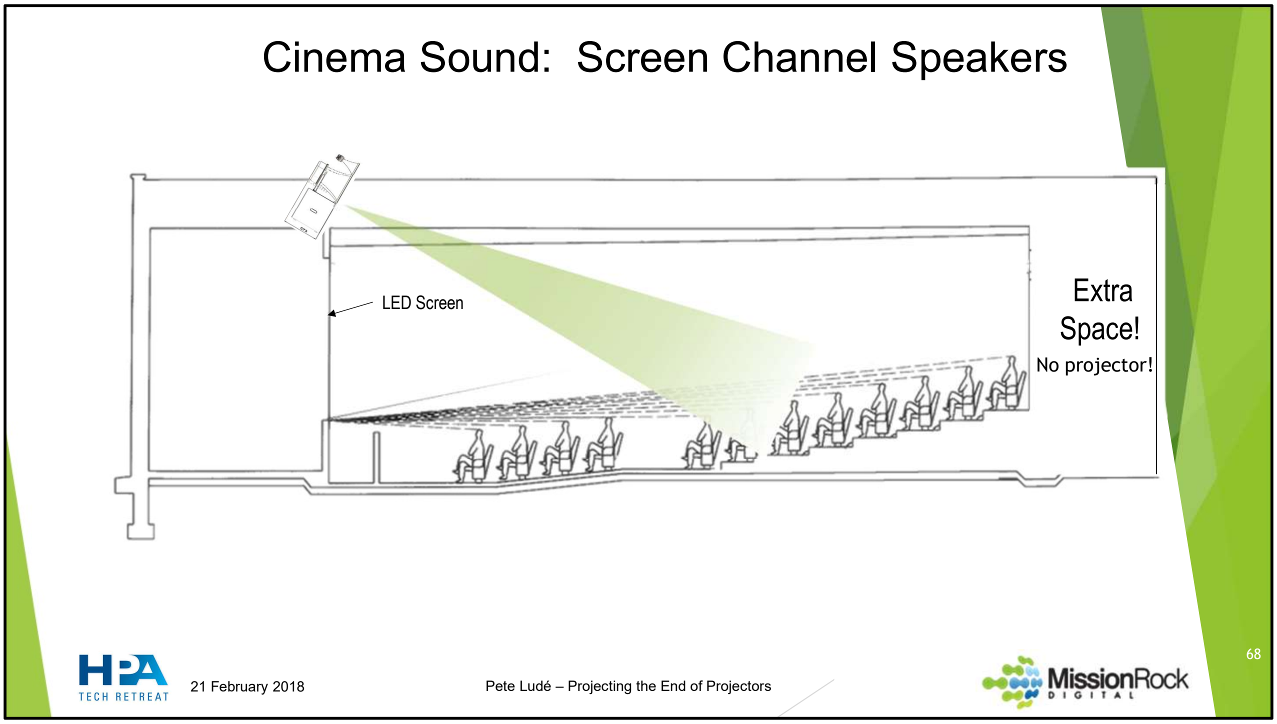
I think we'll need to find some consistent and repeatable test patterns and measurement protocols for this effect, so we can ensure it's never bothersome to anyone in the theater.

Engineering who worked on the development of the DLP chit for projectors have a lot of experience and insight into this.

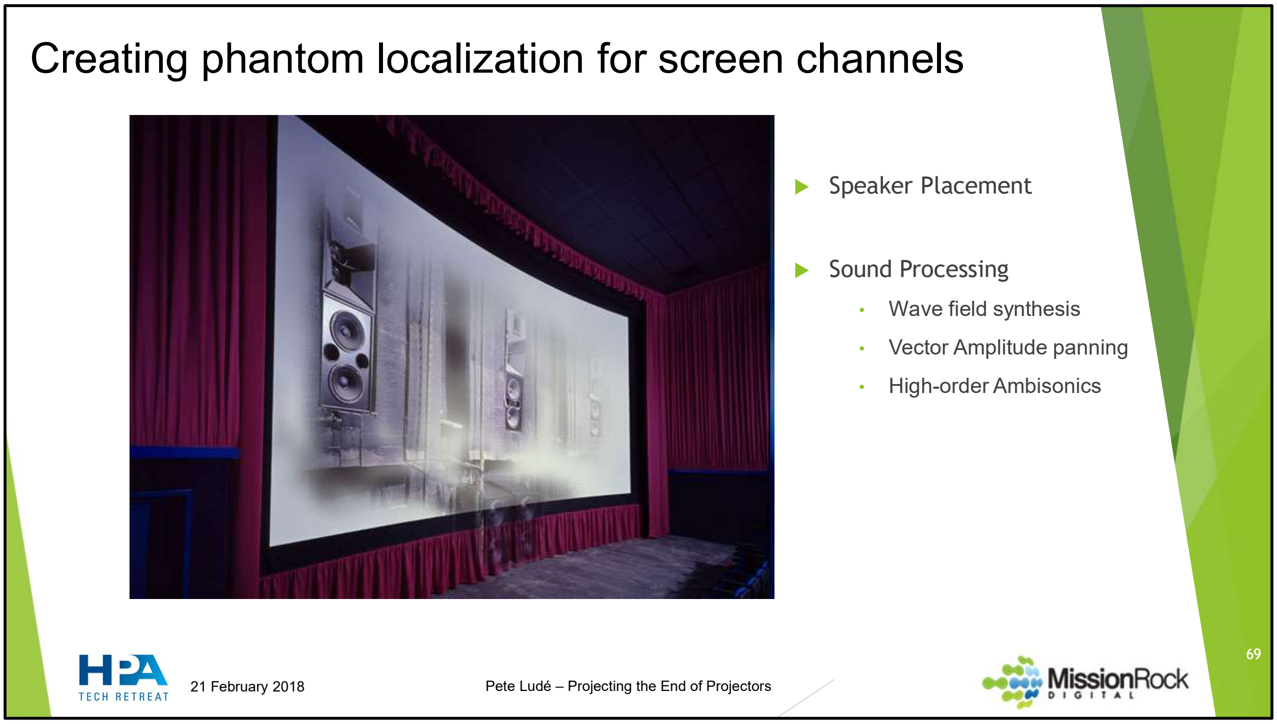
Here are a few of the challenges in getting LED cinema to market.



The issue here is that in a typical cinema system, screen-channel sound comes from speakers mounted behind the projection screen. The screen is perforated so that it's acoustically transparent, and it sounds like the dialog is coming from the mouths of the actors being projected onto the screen.

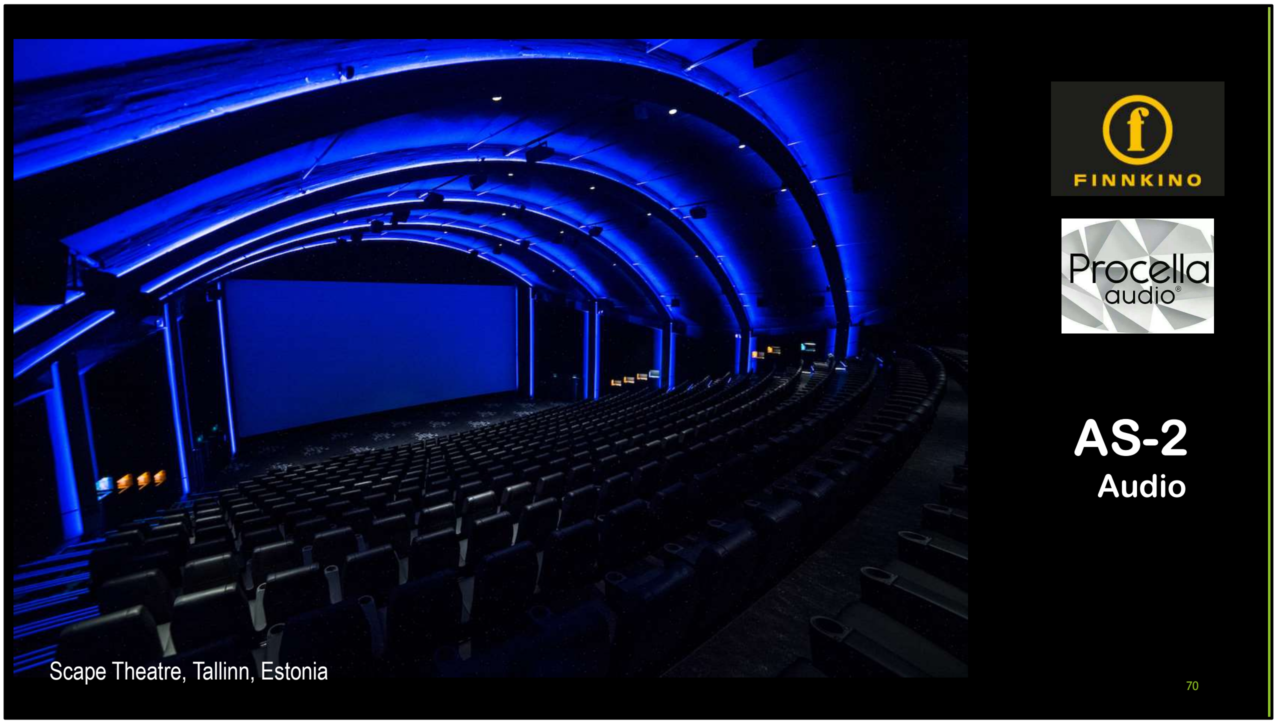


But the LED display is probably not acoustically transparent, so we have to move the speakers to somewhere that allows them to be audible. In doing so, I have lost my sound localization – so this needs to be addressed.



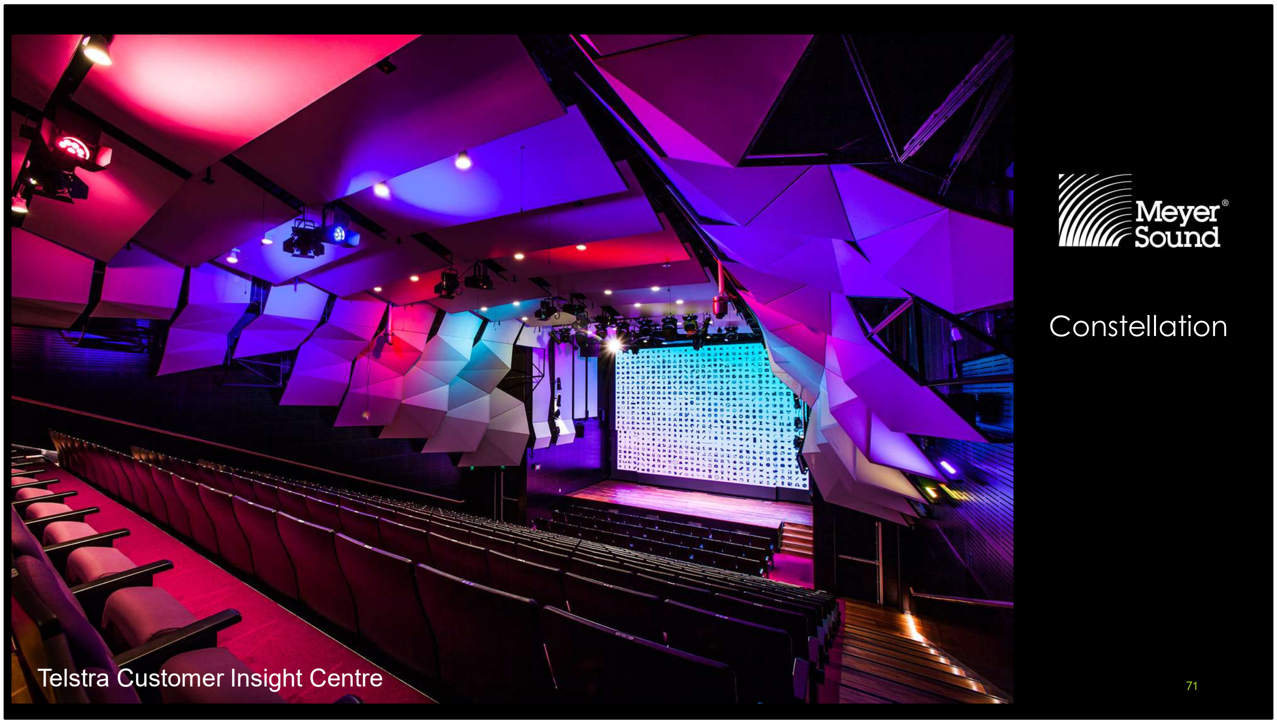
The solutions here generally involve some combination of clever speaker placement, and advanced signal processing, in order to make the perceived source of sound at the proper location on the screen.

Let's look at a few examples of how this has been attempted so far:

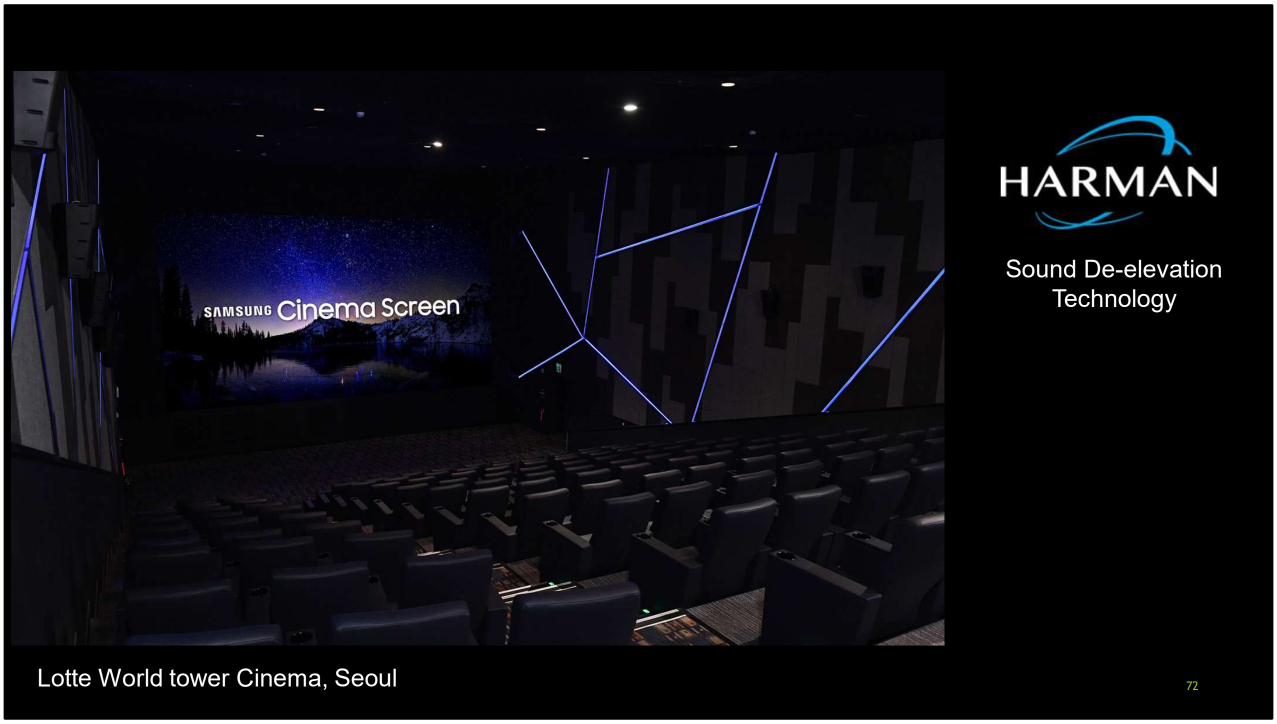


The AS-2 Audio system was specifically developed by Finnkino so that they can use a non-perforated projection screen. Specially designed speakers are placed above the screen. The speakers and drive configuration were developed by Procella audio, and this system has been installed now in dozens of theaters, with good results.

They've even implemented it with the full Dolby Atmos object-based sound system.



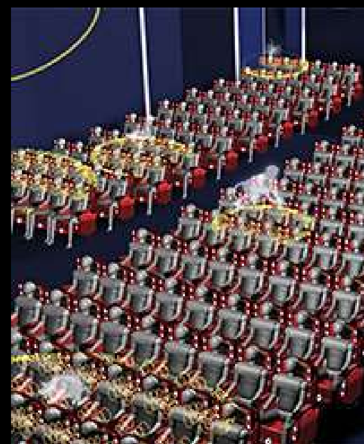
Another case study is at the Telstra Customer Center in Sydney. Here, they are using a giant 4K LED display screen accompanied by the Meyer Sound Constellation System, which uses advanced digital signal processing and speakers located throughout the auditorium to reproduce the intended soundfield.



A third example is the implementation of the Samsung Cinema LED Screen. They report using a system developed by Samsung and Harman, using what they're calling de-elevation technology to move the apparent sound source from the speakers mounted above the be screen to sounding like they're behind the screen.

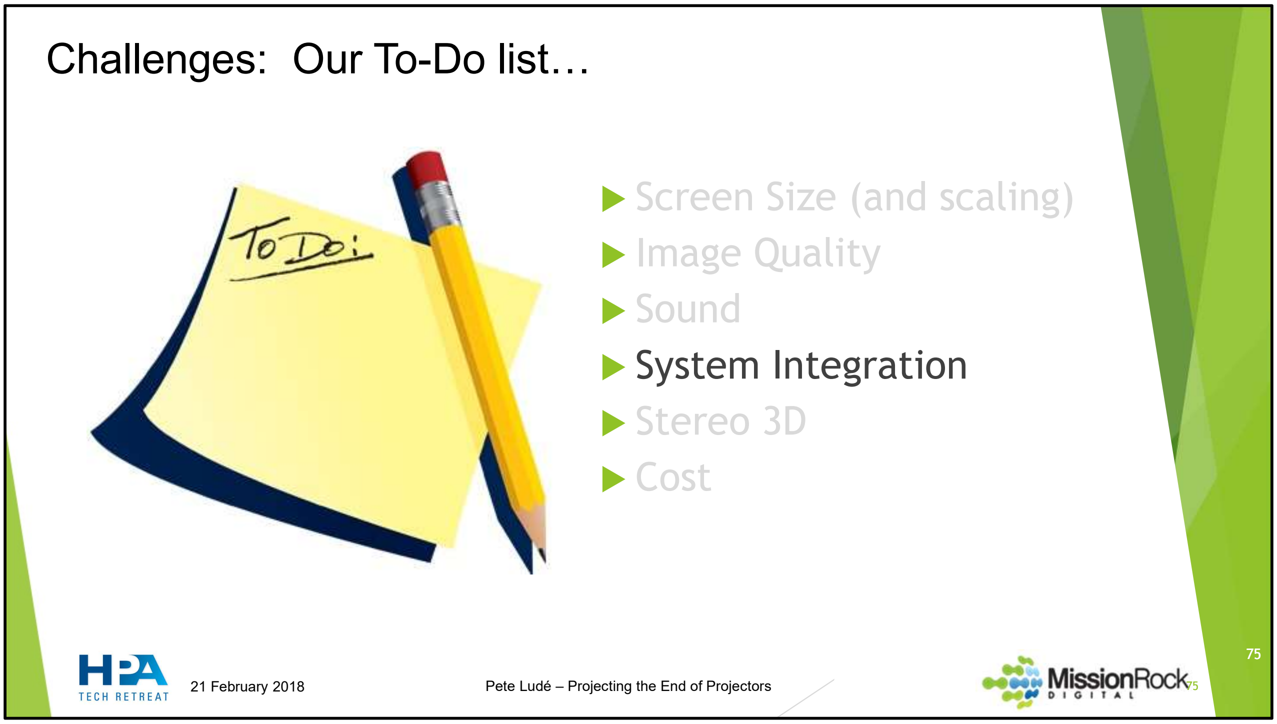
And another example can be found at the Great America Theme Park in California, where the Mass Effects attraction uses a huge 60-foot 3D LED display screen. Here, they reportedly used a combination of near-field supplemental monitors, and speakers directed at the screen surface, to bounce back sound to the listener.

So, while not simple, it seems that we have several options available to solve the sound problem.



Yalos Stream – Concept drawing

Yalos Stream, a company based in Moscow, is proposing cinema seats with multiple speakers, which might be used to replicated screen-channel speakers from a distributed display.



Here are a few of the challenges in getting LED cinema to market.

System Integration

Requires DCI-compliant IMB
and content security provisions

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This is a big one, but in brief summary, it is necessary to meet the DCI requirements for security and operations – which are not simple. The DCI security approach, intended to thwart piracy of valuable movie content, was designed for a projector, not a direct view display. Therefore, some interpretation and creativity is needed.

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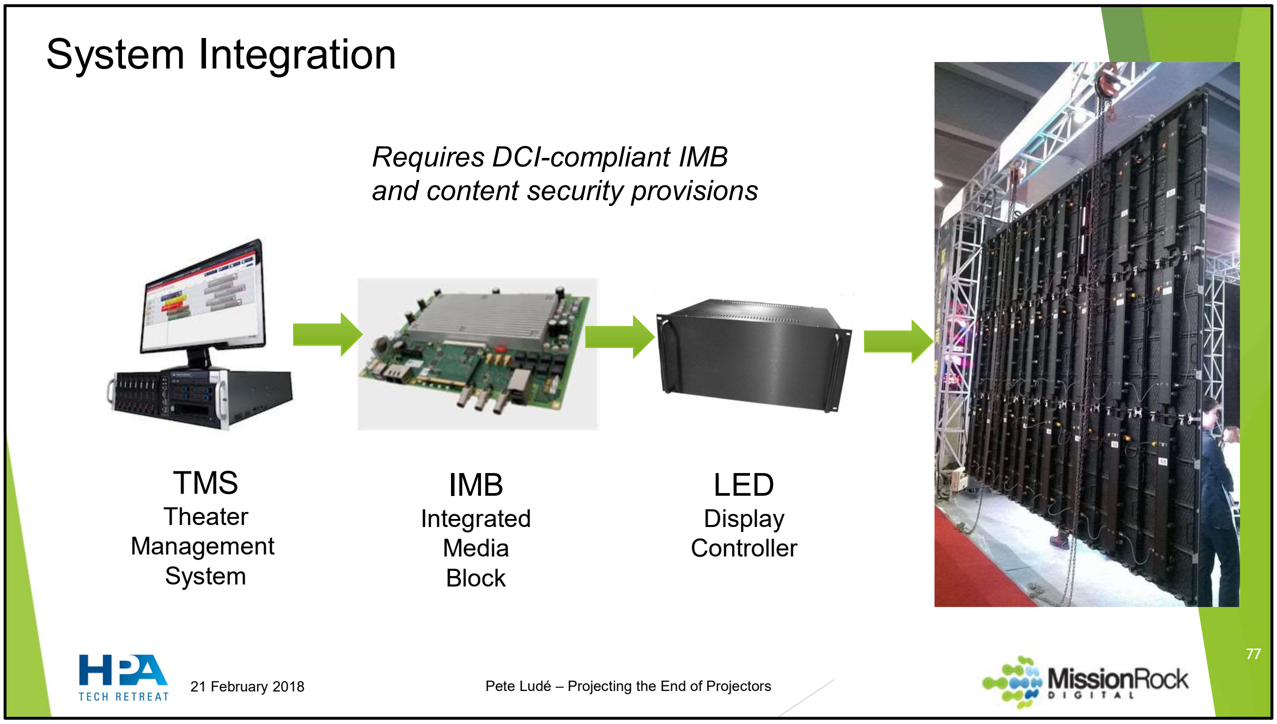
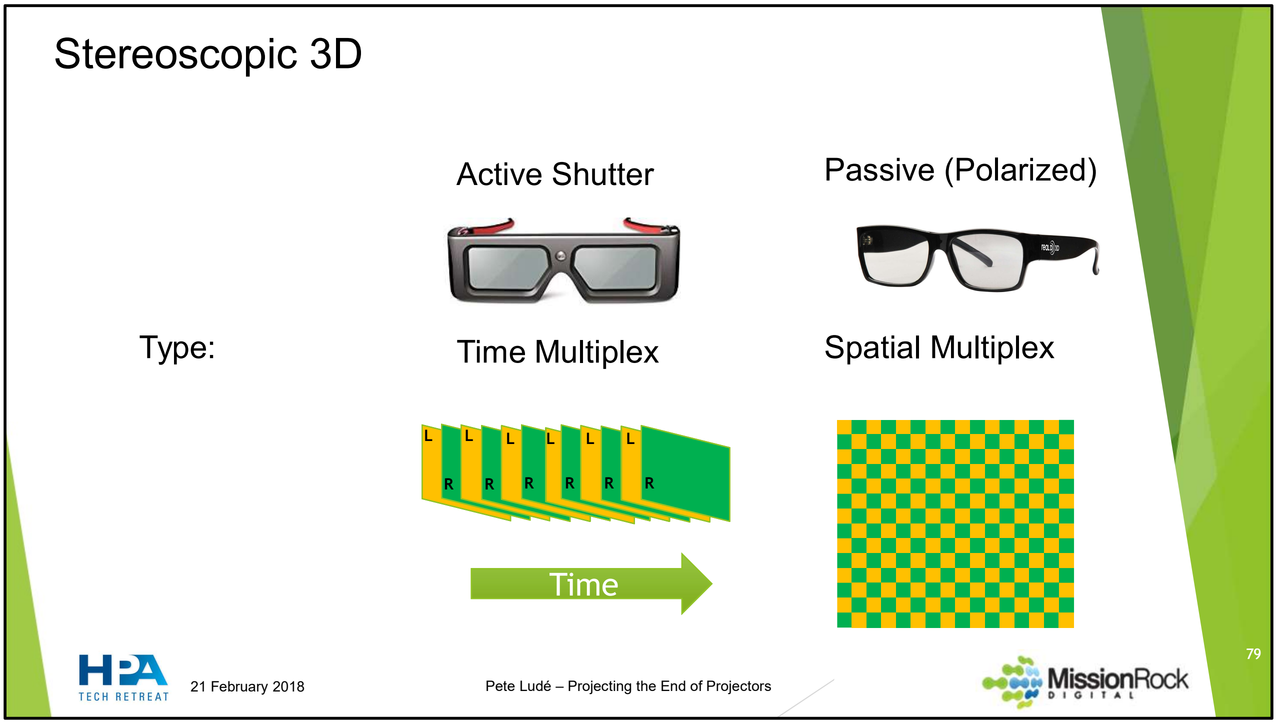


We need to integrated the LED display wall with a DCI-compliant media block to play back files, and with the TMS and SMS systems typically used by cinema operators. While this isn't necessarily rocket science, it requires a good deal of work for a full implementation.

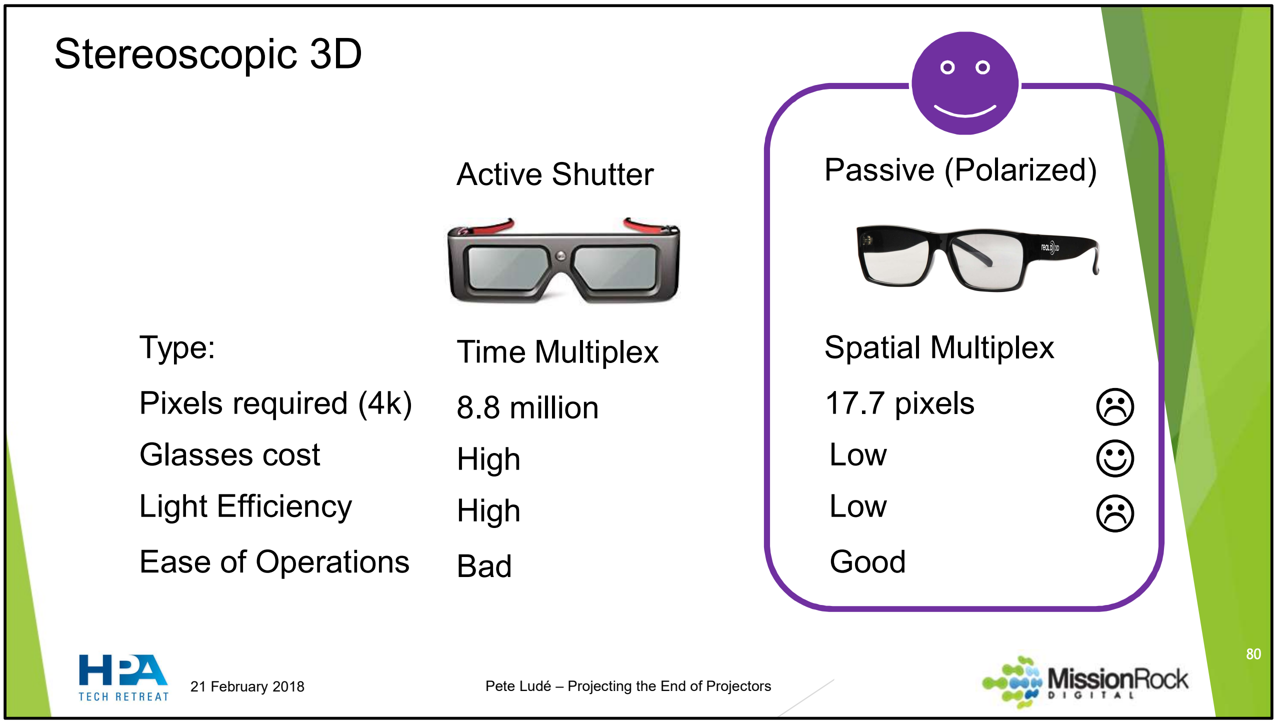
Here are a few of the challenges in getting LED cinema to market.



There are two basic approaches: Active shutter glasses, or passive polarized glasses.

The active shutter variety uses time multiplexing – that is, the left and right eye images take turns being displayed on the screen, and the glasses use precisely synchronized shutters so the viewer sees one image at a time, in the correct eye.

The passive glasses solution uses spatial multiplexing. Both left and right eye images are displayed on the screen at the same time, but with polarizing filters installed so that the correct image makes it to the viewer through the polarized glasses.

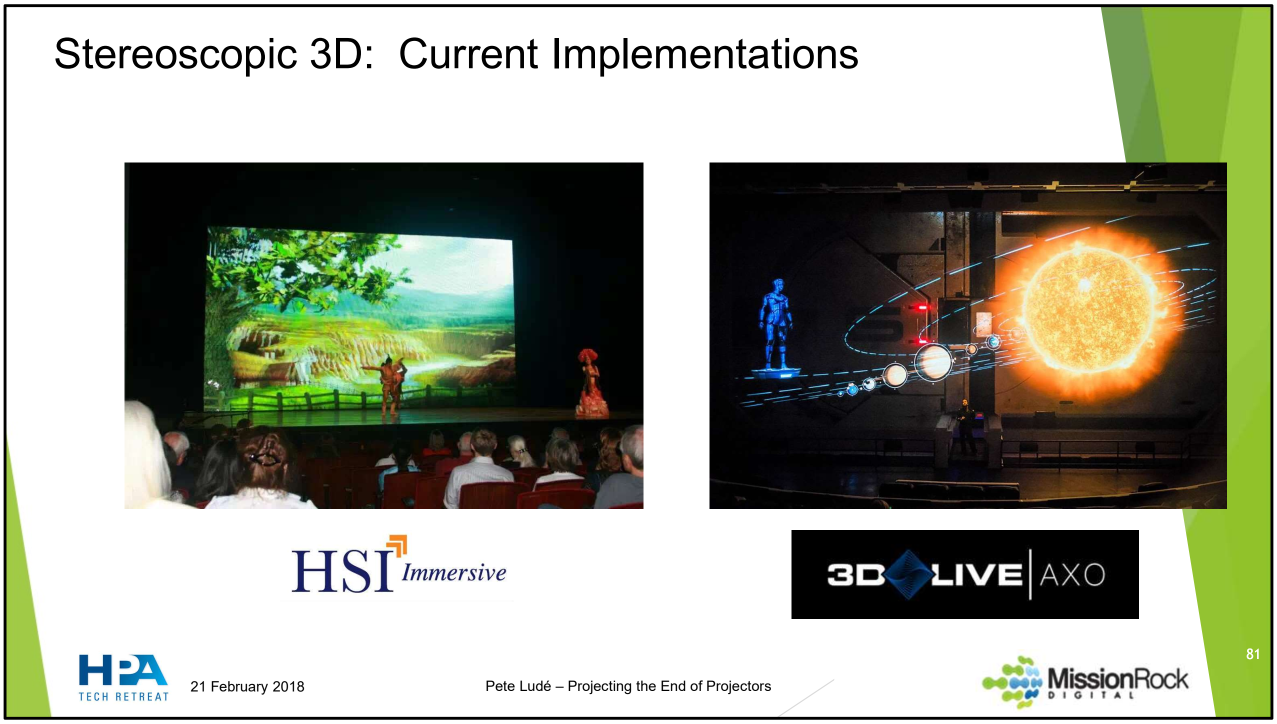


Of course, this means that you need to have twice as many pixels in the polarized solution, so that I can simultaneously have a left and right eye version of each image pixel. That’s a downside.

On the other hand, the shuttered glasses are quite expensive, and require battery changes, maintenance and cleaning. The polarized glasses are very inexpensive, so they’re single-use. A big advantage.

In terms of light efficiency, the polarization optics suck up more light, so they are less efficient that using shuttered glasses. However, LED’s tend to have excess luminance available – they’re capable of being very bright, so maybe this isn’t problem.

A big difference in operations. The expense shutter glasses need to be recovered after each show, and cleaned before re-use. Batteries need to be charged, and defective units found and fixed. Polarized 3D glasses require none of this. In the past, these have proven to be unreasonable requirements for most cinema operation's, so I think the passive 3D solutions is likely to be the best fit.

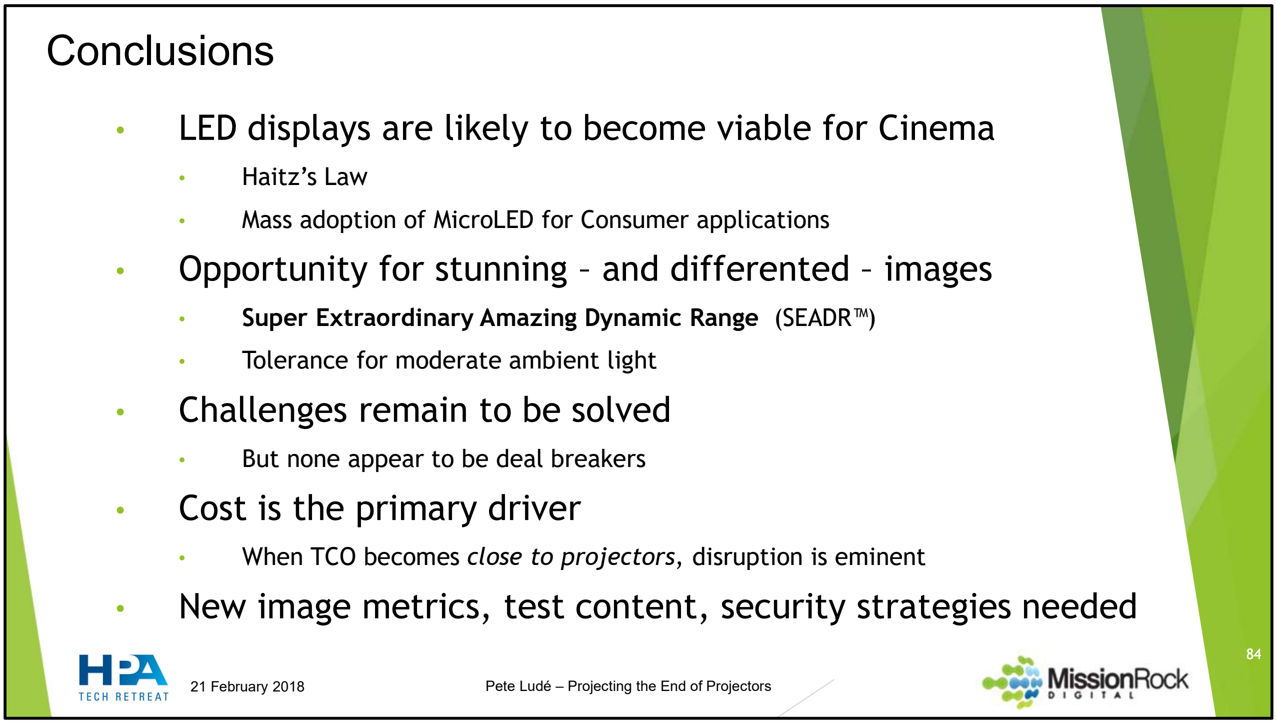


There are a few examples of 3D LED screens already out there. HSI Immersive markets a polarized 3d LED display originally developed by CCDL in China. They have a few systems installed, including one at a University in Denver.

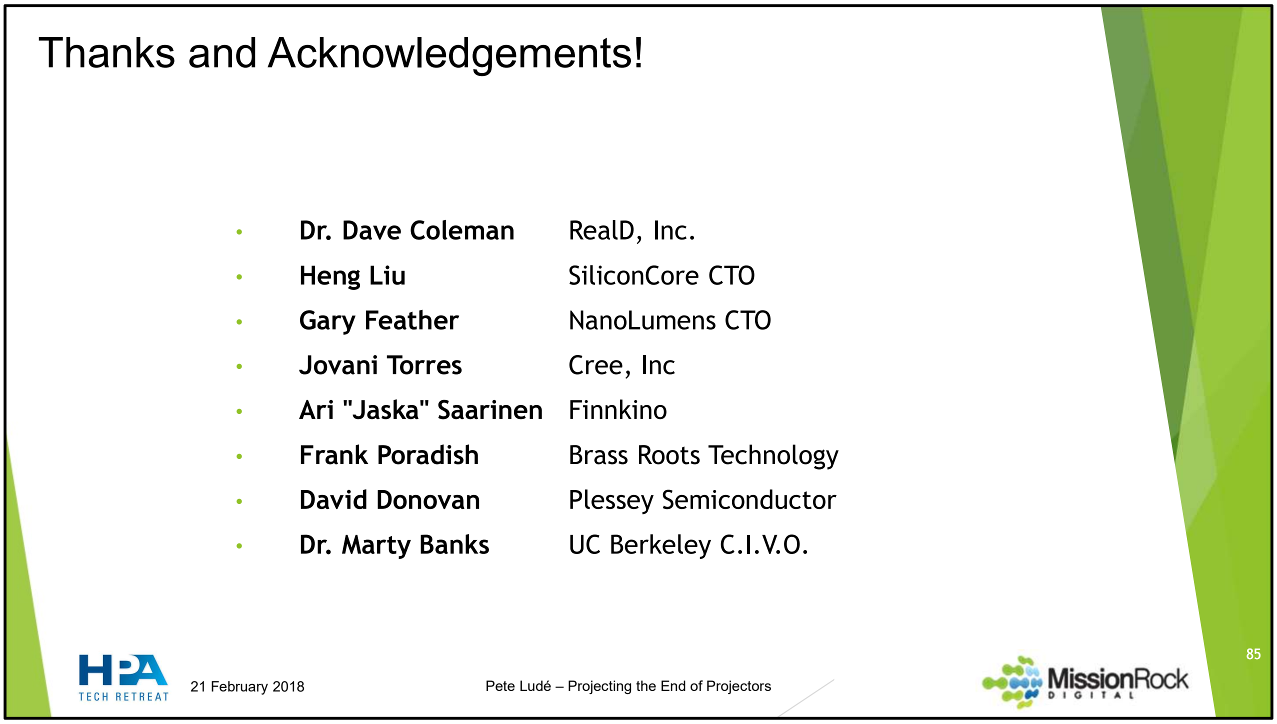
3D Live is the company that built the 3D LED display for Mass Effects a the theme park in California. They also use polarization optics.

Just three weeks ago, Samsung introduced a 3D version of their LED cinema screen. This one uses shuttered glasses.

Here are a few of the challenges in getting LED cinema to market.



So in conclusion…



I am indebted to many experts that aided in the data presented here. I’d particularly like to acknowledge these contributors for their generous time and deep expertise.


THANKS!
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