BY MIKE WOOD

Etendue revisited

Etendue can be considered as the product of the area of the light emitter and the solid angle of the light beam.

ROUGHLY THREE YEARS AGO, I wrote an article in this column that described the optical term etendue, and why it was often not your friend. Etendue is one of those fundamental physical laws that it would be marvelous to be able to break; it always looks like it's possible, but you just can't.

If you remember, etendue can be considered as the product of the area of the light emitter and the solid angle of the light beam. Etendue, sometimes called throughput, represents a measure of the size and angular spread of a beam of light as it passes through an optical system. The larger the beam angle or the larger the source size, the larger the etendue product.

> "Don't they somehow break the law of etendue conservation?"

The law we would love to be able to break when designing an optical system is this: **The etendue of a light beam can never decrease as it passes through an optical system.** It can stay the same, or it can increase due to losses—but it will never, ever decrease. In a perfect optical system, etendue will be conserved, but in a real system, with losses from things like scattering, it will always increase as it passes through the system. Etendue is the optical equivalent of entropy as defined in the second law of thermodynamics. As with entropy, a higher etendue means more disorder, and once things are disordered you can't order them again without using energy. Everything in the universe tends towards disorder, just as light tends to scatter.

I'd like to recap some of the figures from the previous article as a reminder. **Figure 1** shows a simple source and converging lens.

The etendue of the source can be represented by its area times the solid angle of the light beam it emits. As it passes through the lens that etendue is conserved. That means that, as the light beam is converged by the lens and becomes more parallel, the size of the effective source increases accordingly. Both in to and out of the lens, the product of source size and beam angle remains the same and etendue is conserved.

Figure 2 shows the opposite, this time with a large narrow angled light beam and a diverging lens.

After it passes through the lens, the output beam is much wider angled, but also appears to originate from a much smaller source. Again, the product of source size and angle is conserved.

The reason for bringing this up again is that I've been asked more than once in recent years how the current popular narrow beam lights such as the Clay Paky Sharpy, or the Robe Pointe, work. They produce a narrow, almost parallel beam. Don't they somehow break the law of etendue conservation? No, they don't break that law, but it's interesting to see why not and what the optical designers have done to get the result you see.

Let's start with the light source. Just about all the narrow beam projectors on the market use a lamp similar in concept to that shown in **Figure 3**, the Philips MSD Platinum 5R. These are very short arc (1 mm is typical) discharge lamps that are supplied pre-mounted in a glass ellipsoidal reflector. The pre-mounting

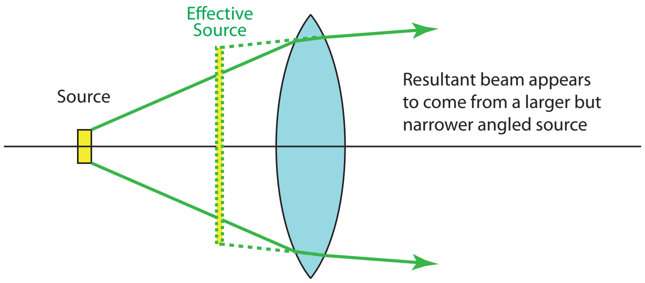

Figure 1 – Etendue conserved

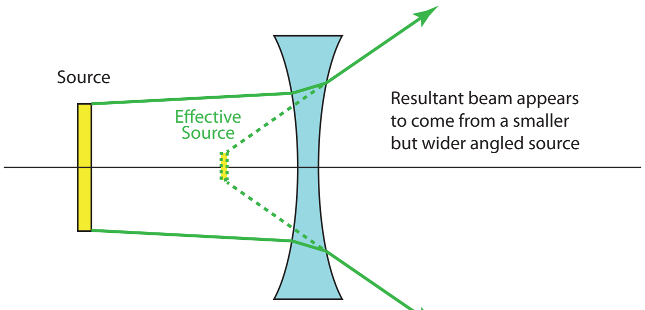

Figure 2 – Etendue conserved

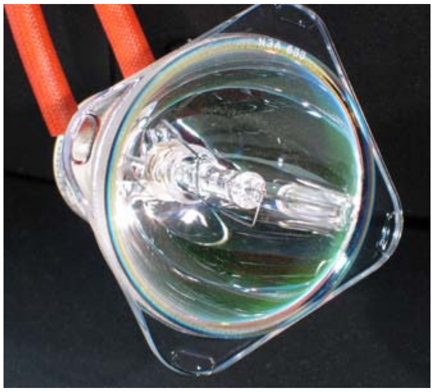

Figure 3 – Short arc HID lamp

ensures they are very accurately positioned within the reflector with the arc at one of the focal points of the ellipsoid. This style of lamp was originally developed by the lamp manufacturers for use in video projection systems. In fact, for a long time, they were exclusively made for that market and weren't available for use by entertainment lighting manufacturers. Recently, the lamp manufacturers relented (or business got tougher) and they were redesigned with different lamp fills and offered to our market.

That's fine, but the market they were designed for, and the length of the arc, means that these lamps work best with a gate or image size that's around 12 – 20 mm in size. This was the typical size of an LCD panel (the majority manufactured by Epson) in a medium power projector.

*Using lamps designed for movie projectors lamps is arguably where the moving light industry started; the Vari*Lite VL1 used a GE MARC 350 lamp, as did the first Coemar Robots. The MARC 350 was designed for 16 mm film projectors, great light output, but horrible lamps with a life of 50 hours, if you were lucky! As with the products under discussion here, the MARC 350 had an integral reflector. This defined the gate size and thus the gobo size used. It had to be similar to a frame of 16 mm film.*

Because the reflector is an integral part of the lamp, we can't change it at all. The gate size is what it is. **Figure 4** shows what a basic system might look like.

The light source on the left within its reflector sends light through an aperture, here shown as the large native 10 – 15 mm aperture, and then on to a converging lens system. As we saw with **Figure 1**, etendue is conserved and the output beam is larger but much more parallel than the beam from the reflector through the aperture.

However, the etendue of the large aperture is high so it still diverges a lot more than we would like for our beam projector. How do we modify this to get that almost parallel shaft of light that has become such a feature of shows in the last few years?

The problem here is that the gate size is way too large for our output lens. To achieve a much tighter beam, we need the lens to be many times larger than the aperture. In this example, the aperture is 15 mm and the lens, at say 225 mm diameter, is perhaps only 15x larger. For minimal beam spread we would like that ratio in size between the lens and source to be 100x, or even more if possible. (Think about wartime searchlights, those huge reflectors made for almost parallel beams.) Clearly there are two ways to do that: either make the lens larger, or make the aperture smaller. A luminaire with a 2 m diameter lens might look impressive, but wouldn't be very practical, so making the aperture smaller is the only practical answer.

Figure 5 shows our modified system, this time with a much smaller aperture with a correspondingly smaller etendue. Perhaps only 1 mm or so in diameter.

“ . . . only 0.5% of the light would get through! ”

Now the lens is over 100x larger than the aperture and we get all the advantages of that conservation of etendue. The tiny (but diverging) input beam is transferred by the lens to a much wider beam that is almost parallel. The 10x reduction in aperture diameter translates to a 100x reduction in area, leading to a corresponding theoretical 100x reduction in beam divergence. Just what we wanted!

So what's the catch? Doesn't it seem as if we've got just what we wanted, a parallel beam from our diverging output lamp? Well, not quite. Conservation of etendue doesn't say that you cannot make a beam small and narrow at the same time, it just says that, if you try and do so, then there will be losses. In this case, we've achieved our desired near-parallel beam, but the losses are significant.

Take a closer look at what's happening at the aperture (**Figure 6**).

The light from the lamp and reflector is still the same 15 mm in diameter when it hits the aperture plate. Only a very small percentage of that light gets through the 1 mm hole and into the rest

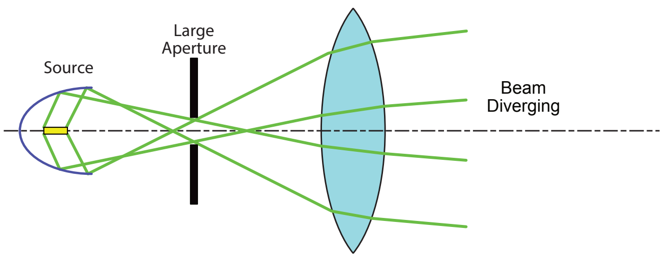

Figure 4 – Basic optical system

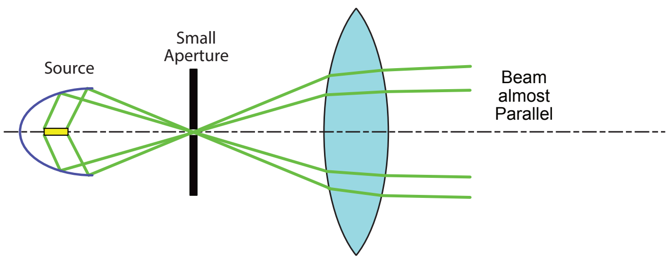

Figure 5 – Beam projector optical system

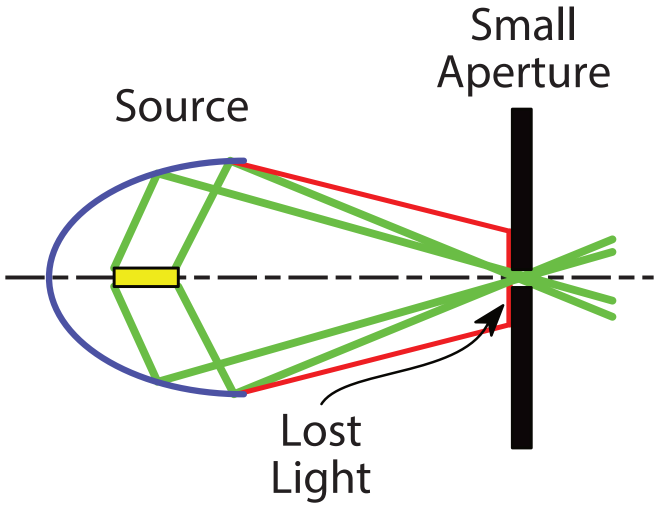

Figure 6 – Losses

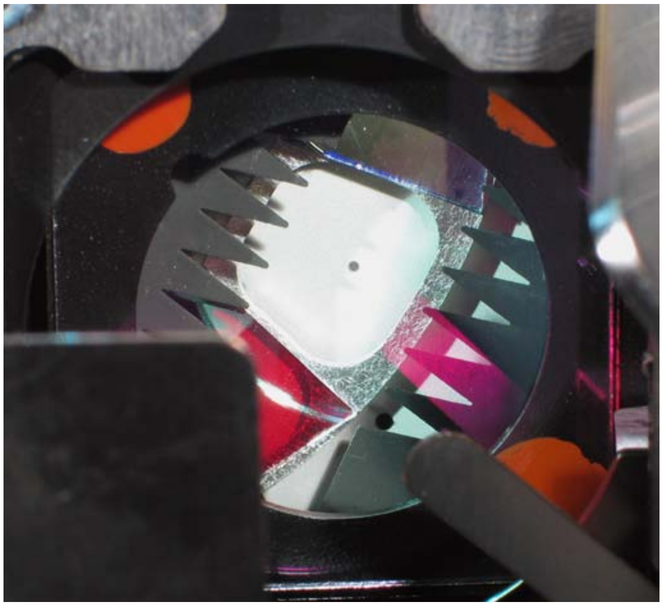

Figure 7 – Real 1 mm aperture

of the system, the remainder (shown in red in the figure) hits the plate and is absorbed or reflected. In fact, if the light were uniformly spread over the 15 mm field, only 0.5% of the light would get through! In reality, we do better than that because the beam isn't flat and we can take advantage of something we normally try and get rid of, the hot spot. The light beam from a simple lamp and ellipsoidal reflector always has a significant hot spot in the center, normally we try and minimize it, but in the case of beam projectors we can take advantage of it. That 1 mm aperture is positioned exactly in the middle of the hot spot so, even though we only allow 0.5% of the area of the light beam to pass through, that area contains a much higher percentage of the total lumen output of the lamp. Perhaps 10% makes it out of the front of the luminaire, still not a huge amount, but a whole lot better than 0.5%! (This is with the narrowest aperture; many of the beam luminaires have gobo wheels providing larger apertures as well, which provide output efficiencies up to 50%, albeit with a corresponding increase in beam divergence.)

Figure 7 shows all this theory put into practice in a real luminaire; this is a view into the gate of a beam luminaire with the smallest gobo aperture in place. You can see the tiny hole in the center of the picture. That hole is only 1 mm in diameter.

As we discussed in the earlier article, it is possible to go from a high etendue light source to a low etendue output, but to do so you must waste light—not *might* waste light, *must* waste light. The Sharpy, Pointe, and others in their class don't break the law of conservation of etendue, instead they exploit the principle and choose to lose some light output in order to get the dramatic effect desired. ■

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