BY **MIKE WOOD**

How bright is bright – Coda #2

This is the second coda article written as a follow up to the "How Bright is Bright" series published in the Summer 2006 through Spring 2007 issues of Protocol. *Coda #1 ran in the Summer 2007* Protocol. *I received a number of questions from readers about this series (most of them complimentary—thank you!) and those questions made it clear I'd left some points uncovered. In particular I didn't always relate everything back to the real world and real lights and explain how to use these concepts. In part that was deliberate as I really wanted to concentrate on the* why *rather than the* what *or* how many. *So treat this current article as a long foot-note to what went before as I attempt to put some reality behind the ideas.*

THE GIST OF THE SERIES OF ARTICLES was that what we perceive with our eyes is often very different from what a light meter or camera sees. I can measure the total lumens and look at a beam profile but what does that tell me about how bright it will look to my eye? Over the last few years I've postulated a theory (with help and suggestions from others, particularly Richard Cadena) on how we can measure this. The reader should understand that what I'm suggesting here is merely an hypothesis and is not rigorously proven. However this is my column and I'll write what I like!

Before we start, it is critical to understand that photometrics is not an absolute science, it's a statistical science based on the averaged response of large numbers of human viewers. If you want absolutes with light then you need radiometric units which represent measures of energy with no regard to the eye. Photometric units, on the other hand, include the response of the human eye and are therefore not easily derivable in terms of absolute scientific units. Instead you have to use that strange and intangible concept of the *average viewer,* whoever he or she is. Photometrics are a lot more useful to us when working with lighting as we are nearly always concerned with how whatever we are lighting is seen—we don't really care about how many watts of light energy is hitting the surface; we care about how many lumens instead. However even those lumens don't tell us the whole story—they tell us what the eye sees, not how the brain/eye combination perceives it. To get to that perception we need to introduce a further level of indirection. I'm going to start using the term ***brightness*** as referring to the final perception of the

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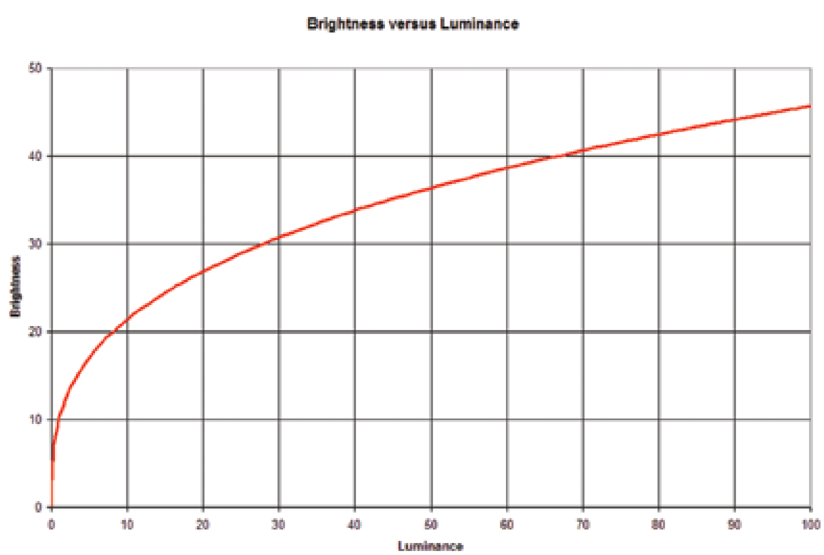


FIGURE 1

illumination level after all the eye and brain processing has gone on. Whenever I talk about brightness that's what I mean. It's not the radiant flux of the light in watts, nor is it the luminous flux in lumens. Instead it's an internal perceptual unit of how bright that light looks to me, right now, in this room with this ambient lighting and this color and with all the other external parameters that affect my vision system. With all these caveats it should be clear that brightness is not a constant.

> **"... it behaves like an unstable equilibrium, which can topple either way depending on how your eye normalizes."**

So, let's start by just considering the brightness of a light in perfect conditions, a dark room and a single projected patch of light of uniform intensity. If we double the light intensity does it look twice as bright? I'm sure you already know that the answer is no. Instead our vision system, like our hearing, perceives light in a logarithmic manner. In fact it's a pretty flat curve. **Figure 1** shows the shape of it. The units on this graph are arbitrary but you can see that to get a doubling of brightness you need something like an 8x increase in luminance. In the mid fifties, while working at Harvard as the founder of their Psycho-Acoustical Laboratory, S.S. Stevens developed a theory now known as Stevens' Law which attempted to evaluate many human perceptions in terms of curves whose form is in general given by the equation:

$$S = kI^a$$

Where I is the intensity of a stimulus, a is a power exponent, k is a scaling constant and S is the resultant Sensation perceived by the observer.

Stevens tabulated these exponents for many different stimuli such as hearing, touch, taste, warmth, and brightness and found that, though the exponents varied considerably, most if not all human responses would fit a curve of this type with appropriate choice of values. If the exponent is less than one it indicates that, like light and sound, our perception of change is desensitized at higher values. Conversely, when the exponent is greater than one it means we are increasingly sensitive to change in that stimulus the higher its value. An example of the latter is our temperature sense—we are more sensitive to changes in temperature the higher the temperature is; we might notice the change from 90°F to 100°F more than we would that same 10° change from 60° to 70° for example.

After experimentation with some more of those *average viewers* Stevens proposed a value of 0.33 for the brightness exponent when the stimulus was a 5° light patch target in a darkened room. The curve plotted in **Figure 1** is Stevens' curve, $S = kI^{0.33}$ and it predicts a doubling of perceived output when the stimulus changes by a factor of 8.2.

So that gives us a start—but what about other factors? As we discussed in previous articles in this series the brightness of a light beam is also strongly affected by its color and by its contrast with its surroundings. How can we factor those in? This is where we get into hypothesis!

I worked on the assumption that Stevens knew a heck of a lot more about this than I did and so I should follow his model for power curve exponents for other factors. Rather than try and factor everything in we can improve the model by considering two more variables which I believe are the next most significant—the color temperature of the light source and the field flatness (which represents the contrast with the surroundings).

It seemed clear, as explained in the second article in this series (Fall 2006 issue of *Protocol*), that a light with a brighter edge than center often appears to have a higher overall brightness. In **Figure 2** of that article, light C appears brighter than either the flat light, B, or the peaky light, A, even though all three are actually the same total lumen value. We can express this as the ratio of the edge to centre illumination and I've called this the ***Flatness Ratio.***

With color temperature, I hope you will agree that a higher color temperature source, or a bluer light, is usually perceived as being brighter than a warmer light of the same output. Let's assume that our eyes are optimized for daylight (a reasonable assumption) and refer our color back to 5600 K. (We could have used 3200 K as our reference and obtained similar results.) We can then express a ***Color Ratio*** as Color Temperature/5600 which expresses as a ratio how much higher or lower than our 5600 K reference we are.

Now we take all these ratios and combine them in a formula using multiple Stevens' power exponents:

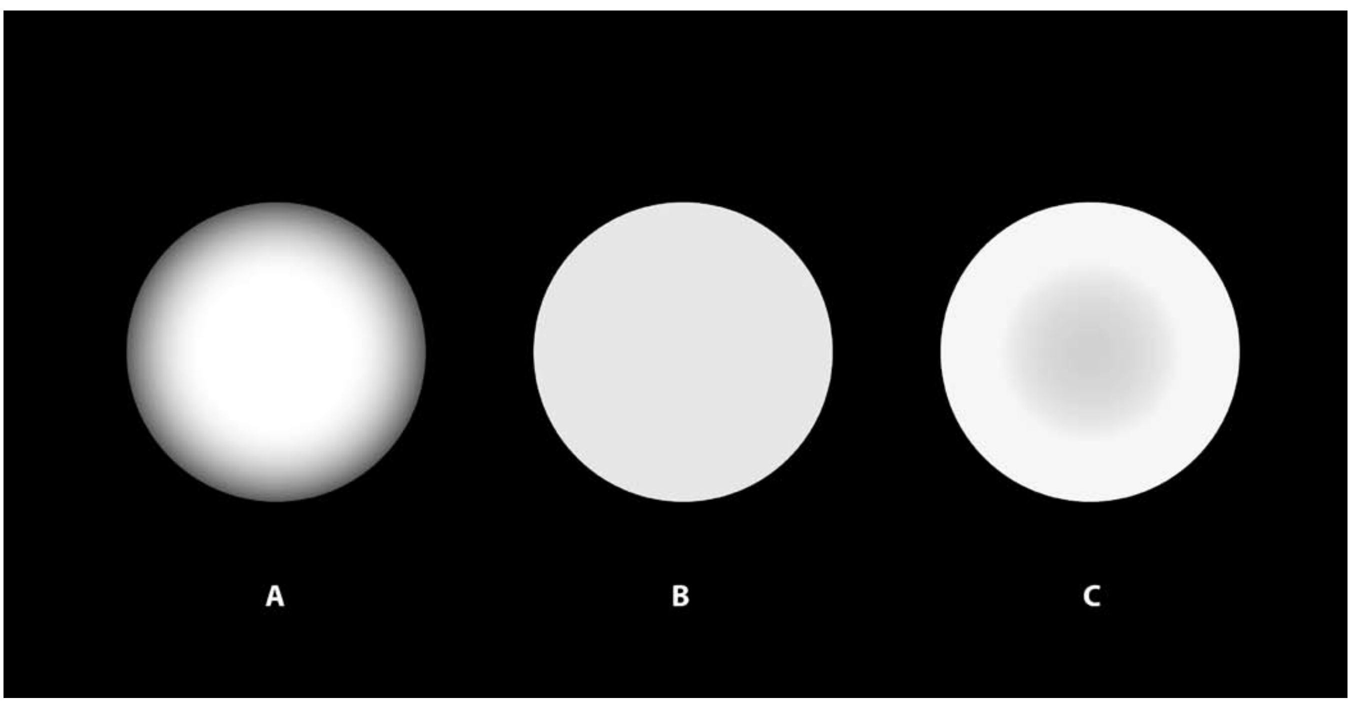
$$\textit{Brightness} = (\textit{Lumen Ratio})^{a} \times (\textit{Flatness Ratio})^{b} \times (\textit{Color}/5600)^{c}$$

After some experimentation and staring at a lot of lights in darkened rooms, I came up with (completely personal and uncorroborated with tests by others) values for b and c of 0.4, so using Steven's value of 0.33 for the Lumens the final formula is:

$$\textit{Brightness} = (\textit{Lumen Ratio})^{0.33} \times (\textit{Flatness Ratio})^{0.4} \times (\textit{Color}/5600)^{0.4}$$

What does this mean? Well we can plug in some values from real lights and get a prediction of how bright those lights would actually look to an observer. As an example, I compared a 250 W discharge ellipsoidal spotlight unit when fitted with two different lamps; a 250 W medium arc lamp with 8500 K color temperature; and a 400 W short arc lamp with 5600 K color temperature. The field lumens were measured at 8500 lumens for the 400 W lamp and 4150 lumens for the 250 W, 49% of the output when fitted with the 400 W. However, once you factor in the edge ratio differences and the higher color temperature of the 250 W lamp, the brightness predicted by the above formula for the 250 W rises to 84% of that of the 400 W. Observation bore this out and, in isolation, the 250 W luminaire did indeed appear almost as

FIGURE 2



bright as the 400 W, even though the 400 W unit produced twice as many lumens! An increase in color temperature and improvement in the field flatness fools the eye into perceiving it's a lot brighter than it really is.

Another example—this time I compared two luminaires identical in every way except that one had a 5600 K lamp and the other a 7200 K lamp. Both luminaires had the same total lumen output and the same edge/center ratio. The equation predicts that the difference in color temperature will make the 7200 K version look 11% brighter. Is that realistic? I think so and my own observations tend to bear this out.

All these tests were done one at a time by switching between units. If you put two units side-by-side in a traditional shoot out arrangement then something else goes on with your perception system that I currently am struggling to quantify. When you view two different fixtures right next to each other your eye/brain tends to normalize to whichever of the two is *brighter* (whatever that means). So, for example, if you put a brighter fixture with a higher (bluer) color temperature next to one which is slightly warmer or redder then you perceive the brighter, bluer, light as the white one and the warmer one looks very red. Increase the output of the warmer light though and, at some point, your vision system flips and you adapt to the warmer fixture so it now looks white and the cooler fixture suddenly looks very blue or even green!

This effect tends to emphasize or increase the initial apparent brightness difference. That is, it behaves like an unstable equilibrium, which can topple either way depending on how your eye normalizes. This is a very usual phenomenon in nature. Chaos theory is written around these kinds of effects where small differences in starting values make big differences in final results.

This effect leads to an interesting possibility. As comparing two lights side-by-side can give a different perceived result than comparing them alternately depending on relative color temperature, flatness and so on, you could envisage that the results of side-by-side comparisons could be non-transitive. In the most extreme case with three lights it is possible that Light A beats Light B, Light B beats Light C, and Light C beats Light A. How would the marketing guys deal with that one? ■

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