Out of the Wood

BY **MIKE WOOD**

Mireds or mireks?

I PURCHASED A NEW LIGHT METER RECENTLY, a Sekonic C7000, one of the new breed of meters that recognizes that you need a full spectrometer to correctly measure the output of narrow or discontinuous spectra light sources such as LEDs. Anyone still using a tristimulus color meter of any kind needs to throw it away or sell it on eBay, it's pretty much useless if you are using LEDs. I was reading through the specifications and noticed that the accuracy of the color temperature output was specified in MK^{-1}. What does that mean and why isn't the tolerance of color temperature given in Kelvin, the same unit you actually measure? Well, thereby hangs a tale which you likely know some of, but perhaps not all.

MK^{-1} is the abbreviation for "reciprocal megakelvin" or mirek which is the official SI name for a unit you more likely know as the mired, or micro reciprocal degree. I expect many readers of this column will be familiar with mired used as a measure of color correction filters, particularly in film and television lighting, or as a measure of color temperature itself. It's simply derived as 1,000,000 times the reciprocal of the color temperature of a source expressed in Kelvins. So, for example, 5,000 K is 1,000,000 x (1/5,000) MK^{-1}, or 200 MK^{-1}. Doesn't that seem a strange thing to do though? Why bother taking the reciprocal of the color temperature and multiplying it by a million? Why not just use the color temperature directly?

This all goes back to a topic I've discussed more than once in this column, the sensitivity of the eye to color change, and the concept of a just noticeable difference in color. If you recall, when we look at the standard 1931 CIE color chart, we can represent areas where the human eye perceives no color change by small ellipses, known as MacAdam ellipses after the researcher David MacAdam. He devised an experiment to measure color discrimination using trained observers. They were presented with two different colors at the same luminance level and had to adjust one of them until it matched the other. He then plotted the accuracy with which they were able to make the match. He found that the range of matches from many tests starting from different color points but aimed at the same target fell within a small ellipse on the CIE 1931 chromaticity diagram. These ellipses vary in size and orientation across the chart representing our differing sensitivities to change in various colors. For example, we are relatively insensitive to changes in green, but very sensitive to changes in blue. For this discussion, let's limit the ellipses to just those along the black body line, that is to those colors we perceive as white. From warm color temperatures near red and orange, through mid-whites all the way to the cool whites close to blue and indigo.

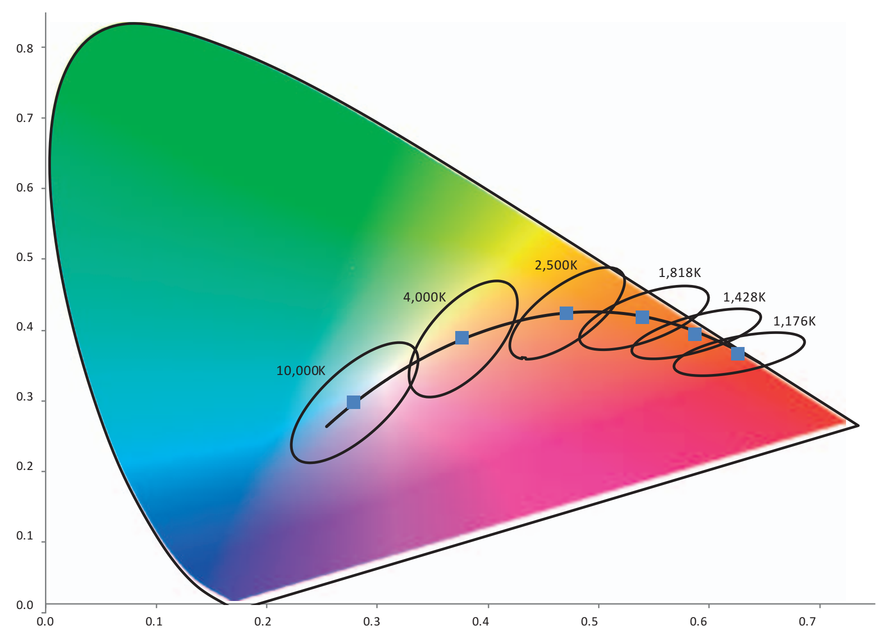

Figure 1 – Equally spaced MacAdam ellipses

Figure 1 shows MacAdam ellipses at a range of color temperatures along the black body line. For clarity, I've drawn each of these ellipses at 24x the size of a single MacAdam ellipse, so each represents 24x the minimum color change you can see. You can see that, roughly, these ellipses touch, with very little overlap, to form a continuous chain along the black body line. In other words, the center point of each of these ellipses represent colors that appear equally spaced to our eyes. Now, if color math were easy, these would fall on equal Kelvin, color temperature, steps. However, color math isn't easy, nor intuitive, so they don't! Look at the values; 1,176 K, 1,428 K, 1,818 K, 2,500 K …. There doesn't seem to be any logic in how these steps progress. The distance between the first two is only 252 K whereas the last two are 6,000 K apart. Does a 6,000 K difference at a high color temperature really look the same to us as a 252 K one at a low color temperature? Well, yes, it does.

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However, what if we take the reciprocals of those color temperatures? Now, we see something that looks much more like a sequence: 0.00085, 0.00070, 0.00055, 0.00040…. These are all separated by the same step, 0.00015. In other words, at least approximately, equal steps in the reciprocal of the color temperature appear as equal steps to our eyes. A change from 1,000 K to 2,000 K is a change in the reciprocal from 1/1,000 to 1/2,000 or 1/2,000. If our theory is correct then this step in color temperature should appear the same to us as the same 1/2,000 step from 5,000 K, which works out to about 14,000 K, and, it does! (The reciprocal of 1/5,000 + 1/2,000 = 7/10,000 or roughly 14,000 K.)

All well and good, but this reciprocal math is messy and not particularly useful or intuitive. This is where the “micro” in mired comes in. To make the numbers easier to comprehend, instead of using just the reciprocal, we multiply that reciprocal by 1 million. Thus our 1,000 K becomes 1,000,000 x 1/1,000 or 1,000 MK^{-1}. Similarly, 2,000 K is 500 MK^{-1}, and 5,000 K is 200 MK^{-1}. Now the math looks simpler, the difference between 1000 MK^{-1} (1,000 K) and 500 MK^{-1} (2,000 K) is simply 500 MK^{-1} and the equivalent step from 200 MK^{-1} is 200 + 500 = 700 MK^{-1}, or the same 14,000 K as we got before.

Now let's look at the steps shown in **Figure 1** again, this time in mireds.

Temperature in Kelvin, K	Temperature in Mired, MK^{-1}
1,000	1,000
1,176	850
1,428	700
1,818	550
2,500	400
4,000	250
10,000	100

This makes a lot more sense now. Each step in color temperature (which I'll remind you are steps that appear the same size to our vision system) are the same 150 mireds apart. Now that we have noticed that equal steps in mired (MK^{-1}) values look similar to the human eye, you can see why it makes sense to specify the accuracy of a color temperature meter in mireds. Specifying accuracy in Kelvin, which seemed logical at first glance, actually makes no sense at all when a difference of 1 Kelvin can look completely different to us at low and high color temperatures. As we've discussed in this column many times before, the science of photometrics is unique and exasperating at the same time because there is no absolute reference. There's no standard lux, foot candle, or lumen in a vault in Paris, nothing in the Smithsonian either. Instead all our master references have to be referred back to the human eye and what a “standard observer” (whoever he or she is) would expect to see. It's the same with color temperature, the concept of color only exists in our eyes and brains, not in the real world, so the only accuracy that matters with a color temperature meter is how it compares to our eye, and by extension and anthropomorphism, a camera. If we can't distinguish two color temperatures with our eyes, then there's little point in the meter being able to either. Giving a tolerance in mired means that the tolerance is in a unit that makes sense to our eye at all points on the black body curve. A one mired error looks the same to us at 1,000 K as it does to us at 10,000 K while the same numerical difference in Kelvin doesn't. Similarly, we are much more sensitive to a 100 K change at 1,000 K than we are at 10,000 K. If we compare mireds back to MacAdam ellipses we can see that a change of three to five mireds roughly approximates the minimum color difference the eye can see.

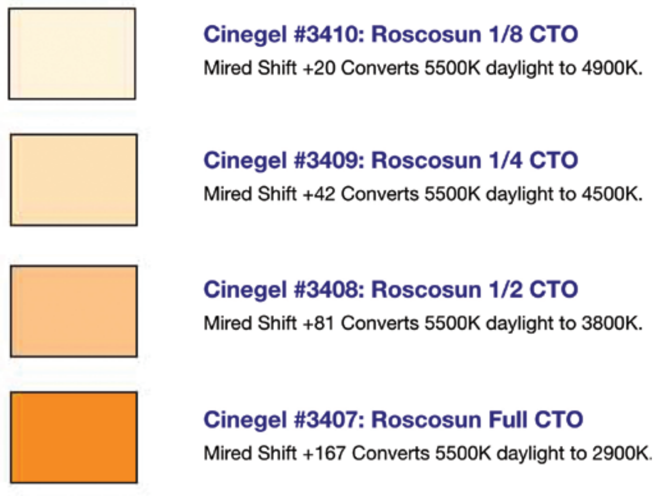
Another really helpful concept that comes out of this, and this is where the video lighting directors will know mired from, is that you can specify a gel that shifts the color temperature of a light source in mireds without having to know the color temperature of the source. CTO and CTB gels can be given a mired value that tells you how far warmer or cooler respectively they will push any given white light source.

> “. . . the science of photometrics is unique and exasperating at the same time because there is no absolute reference.”

For example, a CTO gel that shifts a daylight 5,600 K source down to tungsten 3,200 K has a mired shift of 313 MK^{-1} (the mired value of 3,200 K) minus 179 MK^{-1} (the mired value of 5,600 K) which equals 134 MK^{-1}. All well and good, but what if my source is actually at 4,500 K? How do I work out what the result of that same CTO filter will be now? That's the beauty of mireds. Now we know that this CTO gel has a mired value of 134 MK^{-1}, so we can use that to see what effect the same gel would have on our 4,500 K source. 4,500 K is 222 MK^{-1}, so our corrected temperature with the gel in place will be 222 + 134 = 356 MK^{-1}. This translates back to approximately 2,800 K.

Now get out your Rosco gel book and take a look at the CTO and CTB filters. You'll see that Rosco (and all the other gel manufacturers) have done the hard work for you. Rosco Cinegel 3407, a full CTO designed to shift 5,500 K down to 2,900 K, has a specified mired shift value of +167. That means that you can use the same math as above to work out what that same +167 MK^{-1} filter will do to any other color temperature light. Rosco also tells you on the datasheet that this gel will shift 6,500 K down to 3,200 K, which is the same mired shift of +167. *Note: A positive mired value, such as +167 means that the filter will drop the color temperature; conversely a negative value, such as the -68 of a Rosco 3204 Half CTB filter, means that it will raise the color temperature. It's convention to use the "+" sign with mired values, even if it isn't strictly necessary, just to make that distinction clear.*

This also makes the logic behind ½ CTO and ¼ CTO filters much clearer. In mireds it all makes numerical sense (well, nearly—this is photometrics, after all). A full CTO gel has a mired value of +167, ½ CTO is +81, and ¼ CTO is +42. The math to combine CTO and CTB filters is easy, just add the mired values together. For example, four ¼ CTO gels will add up to 4 x +42 = +168, pretty much the same as a single full CTO at +167.



Cinegel #3410: Roscosun 1/8 CTO
Mired Shift +20 Converts 5500K daylight to 4900K.

Cinegel #3409: Roscosun 1/4 CTO
Mired Shift +42 Converts 5500K daylight to 4500K.

Cinegel #3408: Roscosun 1/2 CTO
Mired Shift +81 Converts 5500K daylight to 3800K.

Cinegel #3407: Roscosun Full CTO
Mired Shift +167 Converts 5500K daylight to 2900K.

Figure 2 – CTO gels

These calculations are often presented as a chart such as that in **Figure 3**. Here the left column represents the color temperature of the source, the center line is the mired shift of the filter, and the right column is the resultant color temperature of the light plus filter. I've drawn a couple of examples on the chart showing how a full CTO of +167 MK^{-1} takes a 5,500 K daylight source down to 2,900 K while that same filter would take a 3,200 K incandescent source way down to around 2,100 K. The other example shows a Half CTB of -68 MK^{-1} converting an incandescent 3,200 K lamp to 4,100 K.

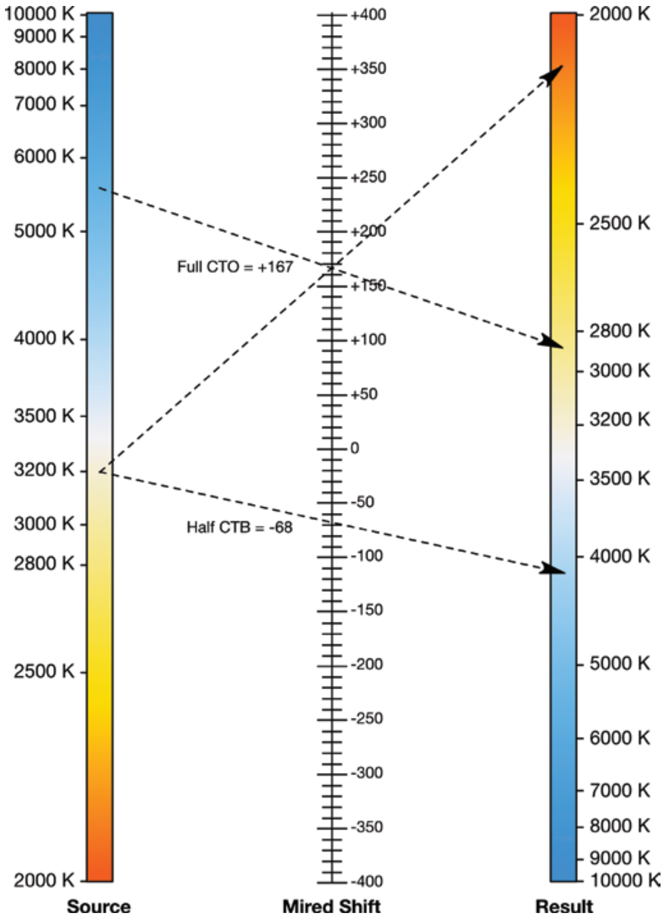


Figure 3 – Mired gel conversion chart

Although I haven't seen it this way yet, it would also be possible to put a mired control in the color picker of a lighting console. That way you could apply a fixed mired shift to a range of lights in various colors to simulate a change in source color temperature. Perhaps put that in the "interesting, but not particularly useful" category.

Oh, and I prefer mireds to either mireks or MK^{-1}. Easier to say even if it's not SI-approved. ■

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 35-year veteran of the entertainment technology industry, Mike is the Immediate Past Chair of the PLASA Governing Body and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.