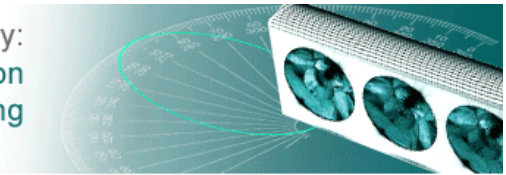




## Goniophotometry: All the angles on Solid State Lighting



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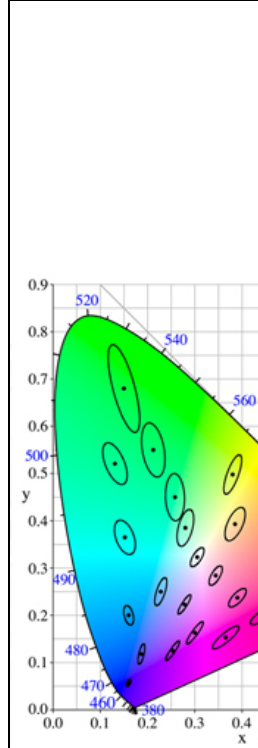
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### LED Colour Difference Metrics: SDCM & MacAdam Ellipses

SDCM is an acronym which stands for Standard Deviation Colour Matching. SDCM has the same meaning as a "MacAdam ellipse". A 1-step MacAdam ellipse defines a zone in the CIE 1931 2 deg (xy) colour space within which the human eye cannot discern colour difference. Most LEDs are binned at the 4-7 step level, in other words you certainly can see colour differences in LEDs that are ostensibly the same colour.



The science behind colour difference specifications was established by Dr David MacAdam in 1942 [MacAdam, D.L., Visual Sensitivities to Colour Differences in Daylight, J.Opt.Soc.Am. 32, 247 (1942)]. MacAdam's experiments relied upon visual observation of the so-called Just Noticeable Colour Difference (JND) between two very similar coloured lights. Just Noticeable Difference is defined as the colour difference where 50% of observers see a difference and 50% of observers do not see a difference. The zones with standard deviations of colour matching (SDCM), were found to be elliptical in the CIE 1931 2 deg observer colour space. The size and orientation of the ellipses varied greatly depending upon the location in the colour space diagram. The zones were observed to be largest in the green and smaller in the red and blue.

Due to the variable nature of the colour produced by white light LEDs, a convenient metric for expressing the extent of the colour difference within a batch (or bin) or LEDs is the number of SDCM (MacAdam) ellipses steps in the CIE colour space that the LEDs fall into. If the chromaticity coordinates of a set of LEDs all fall within 1 SDCM (or a "1-step MacAdam ellipse"), most people would fail to see any difference in colour. If the colour variation is such that the variation in chromaticity extends to a zone that is twice as big (2 SDCM or a 2-step MacAdam ellipse), you will start to see some colour difference. A 2-step MacAdam ellipse is better than a 3-step zone, and so on.

It should be noted that SDCM ellipses are often shown in the CIE colour space diagram at a ten times magnification (see image to left) because they would otherwise be too small to be seen clearly when viewed in the complete CIE diagram.

MacAdam's experiments demonstrated that the size of an SDCM ellipse is quite small, which means that the human vision system is very good at discriminating colour differences when viewing two light sources at the same time. If we consider the size of the 1-step SDCM ellipse at an arbitrary 3,000K colour temperature, the CCT range is  $\pm 30K$ , and the corresponding  $u'v'$  range (the chromaticity coordinates in the 1976 CIE Uniform Colour Space) is  $\pm 0.001$ . In other words, if we view two LEDs with a CCT difference of more than 60K, the chances are that we will see a colour difference. The table below relates the number of SDCM ellipse steps to the range of CCT and chromaticity coordinates for a 3000K colour temperature light source.

SDCM	CCT @ 3000K	$\Delta u'v'$
1x	$\pm 30K$	$\pm 0.0007$
2x	$\pm 60K$	$\pm 0.0010$
4x	$\pm 100K$	$\pm 0.0020$
7-8x	$\pm 175K$	$\pm 0.0060$

Within the lighting industry, reference is often made to the standard IES LM-79-08 "Approved Method of Electrical & Photometric Measurements of Solid State Lighting Products" published by the Illuminating Engineering Society of North America (IESNA). This in turn references the American standard ANSI C78.377-2008 "Specification for the Chromaticity of Solid State Lighting Products" which places white light LEDs used for illumination into standard colour groups which all have the same "nominal" correlated colour temperatures (CCTs). The size of the ANSI C78.377 nominal CCT quadrangle is a 7-step MacAdam ellipse. A 7 to 8-step SDCM is currently representative of the variation in chromaticity of high brightness white LEDs used for illumination.

So when an LED supplier proudly claims to offer you LEDs binned to a 4-step MacAdam ellipse tolerance (or 4xSDCM), keep in mind that this is better than LEDs that are binned to 5-steps but you will still see a colour difference over the range of LEDs supplied to that specification.