TELEVISION LIGHTING CONSISTENCY INDEX (TLCI-2012)

Alan Roberts © 2015-04-18. Version 2.015e

1 OVERVIEW

This program is intended to be used for the assessment of light sources for use in television lighting.

The program defines a 'standard' camera, and then uses it to analyse a set of test colours when illuminated by a standard source and by the source under test. The colorimetric differences between the two exposure conditions, when viewed on a reference display, is calculated according to the principles espoused by W.N.Sproson and E.W.Taylor of BBC R&D, in:

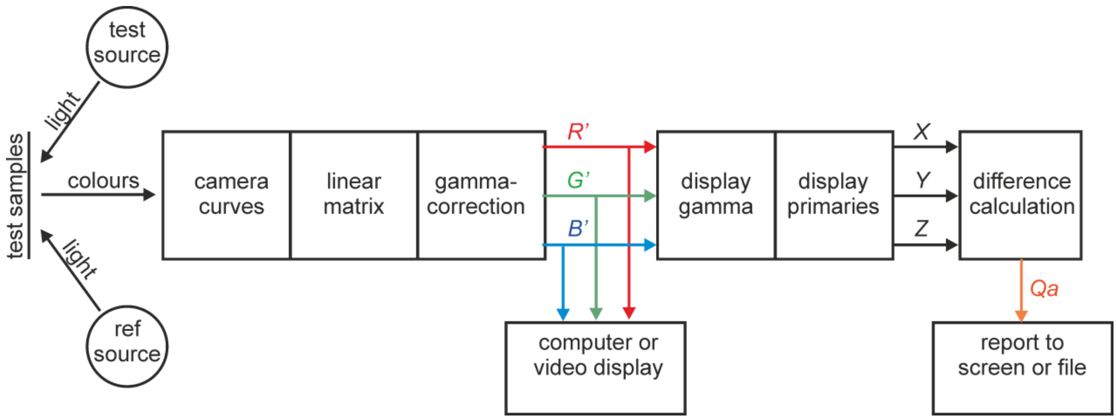
'*A colour television illuminant consistency index*', BBC R&D Report 1971/45

'*Rank order difference analysis applied to tests of the television consistency index*', BBC R&D Report 1982/10

'*The assessment of the colorimetric properties of light sources for use in television scene lighting*', BBC R&D Report 1988/2

The algorithm used in this software is specified in EBU document Tech 3355, with supporting information in Tech 3353 and 3354.

The analysis calculates the video drive signals for each test colour, and can then display them for immediate viewing.



All the relevant properties of the camera and display are set from data within the program.

Each time the program is run, it will create data files it needs for the calculations. They will be created in the same folder as the program software. You can safely delete these when the program exits, if you wish.

Note that, at any time, you can copy the screen contents to the clipboard as graphics with Alt-PrintScreen, or only the text content with Ctrl-Tab. This can then be pasted into any conventional Windows application with Paste or Ctrl-V.

If you have previously used the file conversion program to convert a ASEQ LR1 file for use here, the program will immediately load it and show the report on it using whichever algorithm was last selected.

Menu items which are greyed out are unavailable in User mode, but available in Engineering mode, for which payment is required.

1.1 Warning

This software was written on PCs, starting with Windows XP and then Windows 7 Pro. Although it should work correctly in all versions of Windows, it has not been fully tested on any other versions. So there may be problems as yet undiscovered. For example, running it on a Windows 8 PC appears to set the program window size incorrectly, and I have no idea why.

1.2 Running from the command line

The program can be run from a command line, although I don't expect anyone to do this. However, it means that a filename can be appended to the program name, and this file will be used as a test file immediately the program runs. The file must be a standard *.lum* file created by this program. To enable this process there are things you must do first:

- In Windows Explorer, find an existing file with the .lum extension.
- Right-click on it and select 'Open with' then 'choose default program'.
- Click 'Browse' and navigate to the program file (TLCI-2012.exe) and select it.

- Check the ‘Always use …’ box, and click ‘OK’.

Now, you will find that you can just double-click on any *.lum* file and the program will start and go straight to the TLCI report screen, provided that the file is correctly formatted. You can also simply drag and drop a *.lum* file onto the program file or icon, and the same will happen.

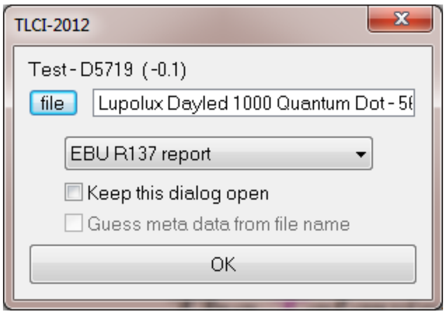
Experimentally, this also works with some spectroradiometer data file formats. Although not fully tested yet, it should handle all the file formats listed in Section 2.1.9, ‘Convert spectroradiometric file’. The file will be converted to the standard .lum format as usual, and then the TLCI report will be shown.

2 PROGRAM MENU STRUCTURE

2.1 File menu

This menu contains the controls for the screen plots, and the generation of standard-format files for later use within the program. Some items are not available in User mode, and will not be described here.

2.1.1 Open illuminant file for TLCI



A dialog opens.Here, you select the test file you wish to analyse. Press *file* (the highlighted button) to select a text file of the spectral data for a luminaire. Although the software uses only correctly formatted files with .lum or .ref extension, you can select other file formats which will be converted for use. The file will be loaded and analysed immediately.

If the CCT measurement shows that the source is too far from the locus of CCTs, you will be told so in the dialog's name, but the calculations can still be done. If the CCT is not numerical (e.g. 'Not found'), then the CCT cannot be found because the luminaire colour is off the end of the Planckian or Daylight locus, and the calculations would not be reliable. The 'OK' button is therefore disabled unless the CCT is satisfactorily found. Calculations are unreliable for CCTs outside the range 2,400 to 10,000, simply because television cameras generally cannot white balance to luminaires outside that range.

If you are processing a lot of files, check the first tick-box to prevent the dialog closing each time.

Select what you want to do, then do it.

- **EBU R137 report**. This is the standard report form for the TLCI.
- **EBU R137 report + save BMP file**. This draws and saves the standard report as a bitmap file. It will be in the same folder as the test file and will have the same name but with *.bmp* appended.

  EBU R137 report + metadata file. This draws and saves the standard report as a bitmap file, and generates a spreadsheet file containing metadata about the measurement. It will automatically fill in the entries it can, and give guidance as to what goes in other cells. Both files will be in the same folder as the test file and will have the same name but with *.bmp* and *.xls* appended. You will be told when the files have been saved, and asked whether you want to open the *.xls* file. Beware that, when creating the *.xls* file, you must make sure that your normal spreadsheet software is able to respond, if that software is running and you are entering or editing a cell, it will be locked up and this program will apparently freeze. There's nothing I can do about this, sorry.

  In this option, you can check the second tick box if it helps. This will attempt to decode the test file name to fill in lines in the metadata file. See Section 2.2.2 for details.

- **Cartwheel, Colourists Advice**. This shows numerical values for the Colourists Advice table around a circle, marked concentrically from -8 to +8 and identifying the colour sector. Values are limited to this range. Note these are continuous values, not quantised: when used in the Colourists Advice Table in the main report display, the values are quantised, so -0.5 to +0.5 scores as zero, +0.5 to +1.5 to +1, -0.5 to -1.5 as -1 and so on. *Lightness* is marked in white or black depending on the background, *Chroma* values are marked in red, *Hue* values are marked in green, Note that all colour differences can be positive or negative.
- **Colour patches as files** shows the performance of the test luminaire and the reference for use in other software. It generates two files in the same folder as the test file, and will have extra extensions added, *.test.bmp* and *.ref.bmp*. The files will have the image dimensions of the program display.

If all is well, then press 'OK' to get the report. The notional camera will be white balanced to the test illuminant, and then compared with the reference illuminant which will be a standard file having the same Correlated Colour Temperature. The CCT of the test file will be shown in the top line of the dialog.

The EBU R137 screen report forms the main output of the software. Note that the software produces optimal-looking output when the window is the default size for the software, 1424x732. If the size or shape is changed, fonts and sizes will be adjusted to try to keep it looking good, but any major departure from the aspect ratio of about 1.95:1 will result in distorted representation of the Colorchecker chart. The colour representation will not be affected, only the shape of the chart and patches.

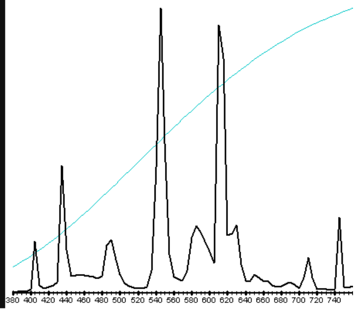
Top left is the verdict, it shows the Test Illuminant file name, its calculated Correlated Colour Temperature (CCT) and the distance from the locus (in multiples of 0.0054 in CIE1960uv chromaticity, as recommended in CIE Tech 15.3), the reference luminaire, and the found TLCI-2012 value for *Qa* on a scale from 0 (no light) to 100 (perfect).

If the distance is greater than +1 it is shown in green, if less than -1 it is shown in magenta, to indicate the direction of the colour shift.

Fluorescent (TV) - CCT : P3270 (+0.2)
TLCI-2012 : 47 (P3270)

Television Lighting Consistency Index

Sector	Lightness	Chroma	Hue
R	++	+	- - -
R/Y	0	- -	- - - - - -
Y	-	- - - -	- - -
Y/G	-	- - - -	-
G	- - -	- - -	+
G/C	0	0	+
C	+	0	-
C/B	++	-	- - - -
B	0	- -	- -
B/M	++++	-	++++++
M	++++	0	+++++
M/R	+++++	0	++++



Top right is the Colourist's Advice Report. This gives advice for the colourist attempting to correct for the colour errors, in 12 hue sectors, with, for each sector, a suggestion for the correction needed in Lightness, Chroma, and Hue. This advice is not, and cannot be, precise or definitive, it is only approximate. A zero value means that the error is probably too small to be visible, a single + or – means the error is very small and the sign tells which way to apply correction), multiple + or - tells that the necessary correction is progressively greater.

Bottom left is Colour Patches. This shows the colours of the Colorchecker card. It is correct for sRGB or television displays only (choose which in 'Setup > General settings', 'Screen coding sRGB (0~255)' or 'Screen coding video (156~235)', this does not affect the TLCI calculations, only the display). Each colour patch is full size for the *Reference* illuminant, with the result for the *Test* illuminant inset centrally.

Bottom right is a plot of the spectral power distribution of the Test (in black) and Reference (in cyan) illuminants. Both spectra are plotted to fill the space allowed.

The formulation for Q_a was constrained to produce a value of 50 for a typical daylight fluorescent tube, and appears to be the watershed separating luminaires into those which are correctable for television use, and those which are not. Based on this intention, the Q_a scale can be labelled in two ways; using the ITU 5-point quality scale, and using opinions derived from a small set of subjective tests conducted by professional colourists.

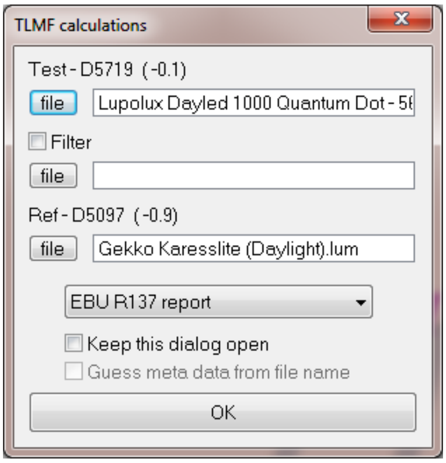
Note that these opinions do not form hard definitions, there is considerable overlap. This has two main causes; the colourists opinions varied slightly, and the chosen colour-difference metric (CIEDE2000) is not perfect.

2.1.2 Open illuminant file for TLMF

A dialog opens.

Here, you select the test file you wish to analyse. Press *file* (the highlighted button) to select a text file of the spectral data for a luminaire. Although the software uses only correctly formatted files with .lum or .ref extension, you can select other file formats which will be converted for use. The file will be loaded and analysed immediately.

The CCT of the test file will be shown in the top line.



You can also opt to include a lighting filter with the test luminaire. Files must be in the correct format: a library of filter data is supplied with the software, derived from data supplied by LEE Lighting. If you have included and enabled a filter file, the CCT of the luminaire, given in the top line, will not be changed, but the CCT of the combination is given next to the filter selection button.

You must also select a reference file for the comparison, which can also be either a .lum or a .ref file. Its CCT is given in the dialog. If a CCT cannot be found in the range 1,000 to 100,000K, a value will not be given and the 'OK' button is disabled. The calculations are unreliable for CCTs outside the range 2,400 to 10,000, simply because television cameras generally cannot white balance to luminaires outside that range.

If you are processing a lot of files, check the 'Keep this dialog open' tick-box to prevent the dialog closing each time.

Select what you want to do, then do it.

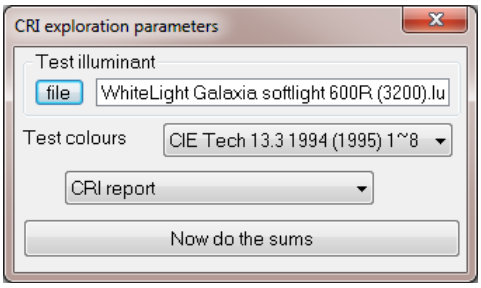
- **EBU R137 report**. This is the standard report form for the TLMF.
- **EBU R137 report + metadata file**. This draws and saves the standard report as a bitmap file, and generates a spreadsheet file containing metadata about the measurement. It will automatically fill in the entries it can, and give guidance as to what goes in other cells. Both files will be in the same folder as the test file and will have the same name but with *.bmp* and *.xls* appended. You will be told when the files have been saved, and asked whether you want to open the *.xls* file. Beware that, when creating the *.xls* file, you must make sure that your normal spreadsheet software is able to respond, if that software is running and you are entering or editing a cell, it will be locked up and this program will apparently freeze. There's nothing I can do about this, sorry.

  In this option, you can check the second tick box if it helps. This will attempt to decode the test file name to fill in lines in the metadata file. See Section 2.2.2 for details.
- **Cartwheel, Colourists Advice**. This shows numerical values for the Colourists Advice table around a circle, marked concentrically from -8 to +8 and identifying the colour sector. Values are limited to this range. Note these are continuous values, not quantised: when used in the Colourists Advice Table in the main report display, the values are quantised, so -0.5 to +0.5 scores as zero, +0.5 to +1.5 to +1, -0.5 to -1.5 as -1 and so on. *Lightness* is marked in white or black depending on the background, *Chroma* values are marked in red, *Hue* values are marked in green, Note that all colour differences can be positive or negative.
- **Colour patches as files** shows the performance of the test luminaire and the reference for use in other software. It generates two files in the same folder as the test file, and will have extra extensions added, *.test.bmp* and *.ref.bmp*. The files will have the image dimensions of the program display.

If all is normal, press 'OK' to get the report. The notional camera will be white balanced to the reference source, and then compared with the test illuminant. Thus you see the result of using the two luminaires in the same scene. The Correlated Colour Temperatures of both files will be shown. If the CCT of the test file is too far from the CCT locus (the number in brackets) then you will be warned, but the calculations can still be done. The calculations are unreliable for CCTs outside the range 2,400 to 10,000, simply because television cameras generally cannot white balance to luminaires outside that range, and this will be reported.

The EBU R137 screen report forms the main output of the software. It is almost identical to that for the TLCI, but is labelled slightly differently. Note that, in the report, the CCT of the combination of test file and filter (if included and enabled) will be given, rather than that of the test luminaire alone.

2.1.3 Open illuminant file for CRI



A dialog opens, for you to select a text file of the spectral data for a luminaire. Although the software uses only correctly formatted files with .lum extension, you can select other file formats which will be converted for use. The file will be loaded and analysed immediately.

Press *file* to select a file.

If the CCT cannot be found, then the 'Now do the sums' button will be disabled. You can also select which colour or sub-set of colours in the test set will be used. Note that if you do not select *1~8*, then the result will be non-standard and you will be told so.

Select what you want to do, then do it.

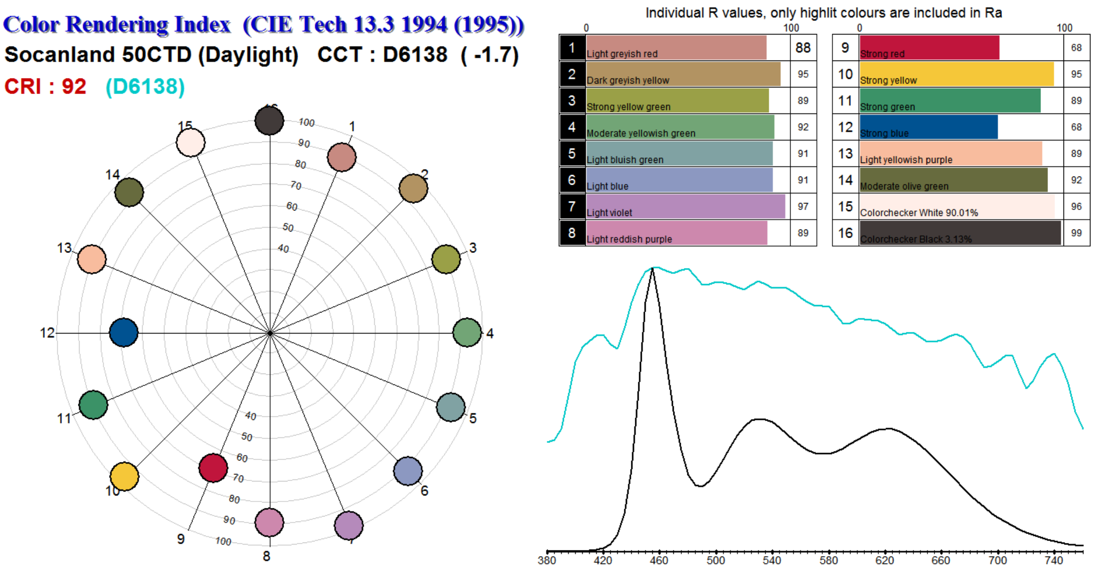
- **CRI report**. This is the standard report form for the CRI in this software.

  Top left is the verdict, it shows the Test Illuminant file name, its calculated Correlated Colour Temperature and the distance from the locus (in multiples of 0.0054 in CIE1960uv chromaticity, as recommended in CIE Tech 15.3), the reference luminaire, and the found TLCI value for *Ra* on a scale from 0 (no light) to 100 (perfect). It also shows the version of the CRI maths used for the report.

  Bottom left is a cartwheel diagram of individual R values. Each colour is represented as it would appear when lit by the white-balance colour set for TLCI calculations, usually D65. Note that colours 15 and 16 are never part of the calculation or Ra, they are included only to show grey scale.

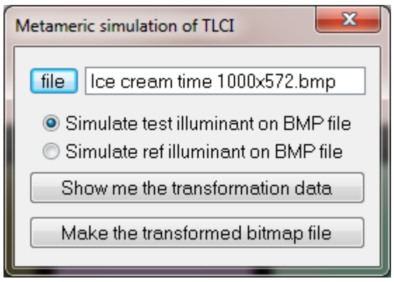
  Top Right shows individual R results for the colours, numbered and named. Only the colours numbered in white-on-black are included in the calculation of Ra.

  Bottom right is a plot of the spectral power distribution of the Test (in black) and Reference (in cyan) illuminants. Both spectra are plotted to fill the space allowed.



- **Cartwheel, Colourists Advice**. This shows numerical values for the Colourists Advice table around a circle, marked concentrically from -8 to +8 and identifying the colour sector. Values are limited to this range. Note these are continuous values, not quantised: when used in the Colourists Advice Table in the main report display, the values are quantised, so -0.5 to +0.5 scores as zero, +0.5 to +1.5 to +1, -0.5 to -1.5 as -1 and so on. *Lightness* is marked in white or black depending on the background, *Chroma* values are marked in red, *Hue* values are marked in green, Note that all colour differences can be positive or negative.

2.1.4 Metameric simulation on BMP file



This is available only if a test illuminant has been analysed for the TLCI, and if a bitmap file has previously been loaded to the screen (and that file still exists). It is not appropriate to the TLMF since that deals with mixed lighting within a shot or scene.

You can change the bitmap file in the usual way, and the program will attempt to simulate the effect that the test illuminant would have had, had it illuminated the scene of the bitmap file. This can happen in either direction, assuming that the chosen bitmap file is the reference or test luminaire performance.

Since only the gamma-corrected *R'G'B'* values are available in the file, the simulation can only be metameric, thus colours will be distorted depending on these signal values, and not on the reflectivities of the original scene colours. The algorithm uses a table of data, derived during the TLCI or TLMF analysis, and interpolates modification factors depending on the hue and chroma of each pixel (press 'Show me …' to see a table of the data values). If any pixels are clipped, you will be told (it makes sense to use a BMP image file in which there is a little headroom for raised signal levels).

Once the file has been generated, it will be flashed alternately with the original bitmap file. You can control the speed of the flashing with the cursor keys; left/down to speed up, right/up to slow down. Press almost any other key to stop, when the screen will stay on the performance of the test illuminant.

The new bitmap file will have been created in the same folder as loaded bitmap file file, and will have the same name with *.test.bmp* appended.

2.1.5 Load .bmp file to screen

A Windows standard dialog appears, for you to select a Windows bitmap file to load. Only files with .bmp extension are allowed. The file will be loaded to the program's window, which will be resized to fit it. If the file is wider or taller than the screen dimensions, then it will be scaled down until it fits. Beware, scaled files may not look good, colours may be wrong.

2.1.6 Save .bmp file of screen

A Windows standard dialog appears, for you to enter a Windows bitmap filename for saving. Only files with .bmp extension are allowed. The saved file will be of the client area of the program's window, everything you see except the menu bar and the outline. This will be a normal, standard bitmap file, 8-bit 3-layer, uncompressed.

2.1.7 Colour bars

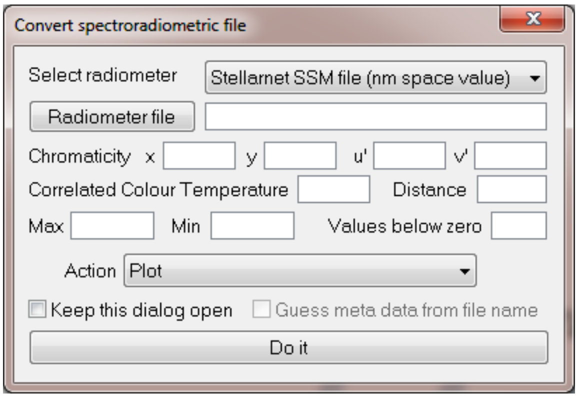
This will clear the screen of all content and draw SMPTE colour bars, including the PLUGE bars for setting black level. If the computer is connected to a television display, then it can be set up correctly using this signal: set the black level such that the -4% vertical bar (bottom centre-right) is just invisible but the +4% bar (to its right) is just visible. Adjust the saturation by turning off red and green signal drives, and adjust until the horizontal partition between the tall and short bars disappears. If the display does not have controls for turning off signal drives, a reasonable compromise is to use a lighting gel filter to stop red and blue emission, use a 'Congo Blue' gel filter (from Lee Lighting, ARRI Media, or Rosco, number 181).

2.1.8 Draw spectrum of test illuminant

If there is a test illuminant file name (first item in the setup dialog), it will be plotted, full screen. The plot is affected by two settings in the 'Setup > General settings' dialog. The background colour can be black or white, and the line can be plotted as a continuous lie or as a histogram, each is filled below the line with an indication of the colour at each wavelength.

There will be a report of the CCT and chromaticity coordinates of the file as well. Also, you can add the camera resonsivities to the plot, which can help to explain why some luminaires are bad and others good. Ths is a toggle.

2.1.9 Convert spectroradiometric file



This is for creating a standard text file from the output of a spectroradiometer or from any other spectral power distribution file. Currently, the only proprietary formats accepted are those from the JETI, UPRTek, Stellarnet, Ocean Optics and Lighting Passport spectroradiometers, but you can select various generic forms as well. All the acceptable formats consist of plain text files only.

If, in the TLCI, TLMF or CRI dialogs, you select a file in any of these formats, the conversion will be done there and then, but here you have other options.

The luminaire file generated by this routine will have an extra extension added to the source file name, thus 'Test file.txt' will cause the generation of a converted file called 'Test file.txt.lum'. You can remove the internal extension if you wish.

In the *Action* selection box, you can decide what to do with the converted file. The list includes all the options in the TLCI and CRI dialog selections, plus plotting the file.

If you are processing a lot of files, check the 'Keep this dialog box open' tick-box to prevent the dialog closing each time.

If, in the ‘Action’ list, you select ‘EBU R137 TLCI report + metadata files’, you can then check the second tick box. This will attempt to decode the file name for lines of data to go in the xls file. See section 2.2.7 for details.

2.1.9.1 Select radiometer

Select the spectroradiometer from the list. The recorded data values need not be at precise 5nm intervals, the program will generate a 5nm listing using data from within ±2.5nm of each output wavelength. Values MUST scan from not more than 380nm to not less than760nm, an error will be reported if there is insufficient data. There can be any number of data values per wavelength, all the values at each wavelength will be averaged to form a single value. Values can be in standard or scientific notation, and the decimal spacer can be a dot (.) or comma (,) in all cases. The program can cope with these formats at present:

- **TLCI/TLMF SPD file (nm TAB value)**

This is a data listing, with an essential header line which the program will use to confirm that the file is of the correct type. Further header lines, all staring with the double slash combination, will be ignored. Data lines are TAB (→ symbol) separated and consist simply of wavelength and value or values:

```
//Spectral Power Distribution file
278.36 0.000464266416
278.53 0.000402887278
278.7  0.000457007576
278.87 0.00049715675
```

The data values must start at or before 380nm and end at or after 760nm, and be monotonic. There is no other limitation, except that the data listing must end with the line:

```
eod
```

… although there can be other lines of data following, which will be ignored.

- **UPRTek MK350 (nm TAB value)**

This has header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are TAB (→) separated and the decimal marker is a dot (.):

```
x = 0.316224
y = 0.339092
u' = 0.196514
v' = 0.474133
CCT = 6257
LumbdaP(nm) = 747.000000
Peak count = 11632.764648
CRI = 97
Lux = 1507
360nm→0.225324
```

Note that the wavelength can be read correctly even though it has ‘nm’ appended to it.

- **JETI Specbos (nm ; value)**

This has header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are semicolon (;) separated and the decimal marker is a comma (,):

```
MODEL;SPECBOS
TYPE;Irradiance
Start Wavelength [nm];350
End Wavelength [nm];1000
Number of points;651
Integration Time [ms];656
Operator;
Memo;
Date;09/21/2012
Time;09:50am

Wavelength;Spectral Irradiance [W/(sqm*nm)]
350;1,494514E-04
```

Note that the values can use a comma as the decimal spacer.

- **Stellarnet SSM file (nm space value)**

This has header lines which are ignored. Beware that this is the ‘scope’ mode of data, i.e. it has not been normalised. The program searches for the first line starting with a number and starts from there. Data lines are space ( ) separated and the decimal marker is a dot (.):

```
" File: Documents\Dokumentfiler\Per Doc's\Stella
" SCOPE->  Wave:634.42nm  Pix:1050  Val:8055.734  Time:519ms  Avg:1  Sm:1  Sg:0  Tc:on
SNAP  Xt:3  Ch:1  Xtrig
 274.00  -1.6755E+001
 274.50  -4.4976E+000
 275.00  1.8847E+000
```

- **Stellarnet IRR file (nm space value)**

This has header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are space ( ) separated and the decimal marker is a dot (.):

```
" File: Users\n14980\Desktop\Socanland YSMG-L322
" RAD->  Wave:634.42nm  Pix:1050  Val: 39.415  Time:285ms  Avg:1  Sm:4  Sg:0  Tc:on  SNAP
Xt:1  Ch:1  Wr:400-700 Xtrig
 274.00  0.0000E+000
 274.50  0.0000E+000
 275.00  0.0000E+000
```

- **Ocean View (nm TAB value)** (Ocean Optics spectroradiometers)

This has header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are TAB (→) separated and the decimal marker is a dot (.):

```
Data from AbsoluteIrradiance Node
Date: Mon Aug 12 13:56:17 PDT 2013
User: alex.yoon
Spectrometer: JAZA1256
Autoset integration time: false
Trigger mode: 0
Integration Time (sec): 1.000000E-1
Scans to average: 1
Electric dark correction enabled: true
Nonlinearity correction enabled: true
Boxcar width: 3
Stray light correction enabled: true
XAxis mode: Wavelengths
Number of Pixels in Spectrum: 2048
>>>>>Begin Spectral Data<<<<<
1.9034E2     -0.000E0
```

- **SpectraSuite JDX file (nm , value)** (Ocean Optics spectroradiometers)

This has header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are comma (,) separated and the decimal marker is a dot (.):

```
##TITLE= SPECTRASUITE EXPORTED SPECTRUM: PROCESSED SPECTRUM
##JCAMP-DX= 5 $$EXPORTED SPECTRASUITE FILE
##DATA TYPE= UV/VIS SPECTRUM
##SAMPLE DESCRIPTION= PROCESSED SPECTRUM
##ORIGIN= OCEANOPTICS EXPORT
##OWNER= alex.yoon
##SPECTROMETER/DATA SYSTEM= OCEANOPTICS EXPORT
##DATA PROCESSING= DARK:No REFERENCE:No
##DATA PROCESSING= BOXCAR:3 ELECTRICAL DARK: false
##.ACQUISITION TIME= 100
##.AVERAGES= 1
##XUNITS= NANOMETERS
##YUNITS= Absolute Irradiance (?W/cm²/nm)
##XFACTOR= 1.0
##YFACTOR= 1.0
##FIRSTX= 190.34
##LASTX= 889.61
##FIRSTY= 1203.704
##MINY= 1203.704
##MAXY= 14635.513
##NPOINTS= 2048
##XYPOINTS= (XY..XY)
190.34, 1203.704
```

- **SpectraSuite TXT file (nm TAB value)** (Ocean Optics spectroradiometers)

This may have header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are TAB (→) separated and the decimal marker is a dot (.):

```
SpectraSuite Data File
++++++++++++++++++++++++++++++++++++
```

```
Date: Mon Aug 12 14:15:22 PDT 2013
User: alex.yoon
Dark Spectrum Present: No
Reference Spectrum Present: No
Number of Sampled Component Spectra: 1
Spectrometers: JAZA1256
Integration Time (usec): 100000 (JAZA1256)
Spectra Averaged: 1 (JAZA1256)
Boxcar Smoothing: 3 (JAZA1256)
Correct for Electrical Dark: No (JAZA1256)
Strobe/Lamp Enabled: No (JAZA1256)
Correct for Detector Non-linearity: No (JAZA1256)
Correct for Stray Light: No (JAZA1256)
Number of Pixels in Processed Spectrum: 2048
>>>>>Begin Processed Spectral Data<<<<<
190.34 0.0000E00
```

- **Lighting Passport CSV file (nm , value ,)** (Asensetek Spectrum genius)

This may have header lines which are ignored. The program searches for the first line starting with a number and starts from there. Data lines are comma (→) separated and the decimal marker is a dot (.). Training commas are an annoyance, but are ignored:

```
Asensetek Spectrum Genius V2.2.0
,1,2,3,4,,
File Name,single-20131204-192918,Source: F7   lux:1000,Source: F2   lux:1000,Source: D55
lux:1000,Max.,
CIE_x,0.3771,0.3129,0.3720,0.3409,0.3771,
CIE_y,0.4181,0.3291,0.3751,0.3554,0.4181,
CCT(K),4337,6494,4225,5171,4337,
CRI(Ra),76,91,65,98,76,
Re(thru R1~R15),68,88,52,98,68,
Illuminance(lx),64,1000,1000,1000,64,
CIE_u',0.2077,0.1979,0.2202,0.2072,0.2077,
CIE_v',0.5181,0.4684,0.4996,0.4859,0.5181,
lp(nm),556.0,435.0,435.0,530.0,556.0,
R1,71.7,89.0,56.6,98.8,71.7,
R2,86.7,93.0,77.2,98.8,86.7,
R3,90.0,93.3,90.6,99.2,90.0,
R4,71.5,90.2,57.6,96.7,71.5,
R5,74.3,90.2,59.8,98.1,74.3,
R6,86.8,90.0,68.1,98.9,86.8,
R7,81.1,94.0,73.8,97.8,81.1,
R8,48.1,86.9,33.5,98.2,48.1,
R9,-39.8,60.7,-82.1,98.4,-39.8,
R10,74.8,81.5,46.8,98.1,74.8,
R11,70.2,87.5,46.9,97.0,70.2,
R12,73.0,87.8,55.9,93.1,73.0,
R13,75.4,90.1,60.8,98.3,75.4,
R14,93.3,96.0,94.3,99.5,93.3,
R15,57.0,87.6,47.6,97.5,57.0,
ld(nm),570.3,78.9,40.5,99.6,570.3,
Purity(%),39.0,88.0,60.0,1E2,39.0,
Spectrum Data
380,0.0197308,
381,0.0234117,
```

- No header (nm TAB value), which is self-explanatory, as are:
- No header (nm , value)
- No header (nm ; value)
- No header (nm : value)

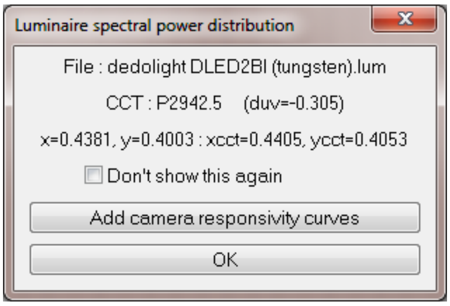
2.1.9.2 RAW responsivity file

Click this to select a file to process, its name will appear in the box, you cannot edit it. The file can contain any number of spectra, provided all the values for each wavelength are held on the same line. If there is more than one set of spectral data, they will all be averaged into the output.

2.1.9.3 Action

Choose what to do after the conversion.

2.1.9.4 Do it



Click this to carry out the action. The conversion takes place. A file will be generated, in the same folder as the RAW file, and with the same file name but with the extra extension '.lum'. The file will be analysed, chromaticity coordinates reported together with the correlated colour temperature. You will also get a Distance value, the distance (in units of CIE1960uv chromaticity) scaled by 0.0054 as used in CRI calculations. The maximum and minimum values in the output file are also reported, together with a count of the number of samples falling below zero (i.e. negative), if any. Any negative values in a file will *not* cause it to be rejected in the CRI and TLCI calculations, and that any such negative values will be *not* be clipped at zero.

You then get whatever choice you made in the Action list.

2.1.10 Run spectroradiometer utility/Run custom utility

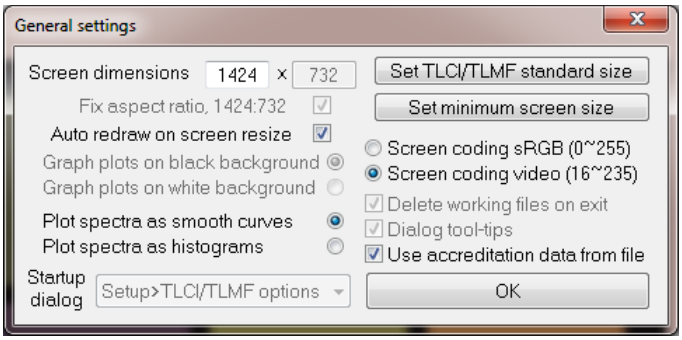
This item is not normally available, it will appear only if one of two utility programs which integrate with this program are found in the same folder. The first ('ASEQ LR1 conversion.exe') has been superseded by a more general utility 'Spectroradiometer conversion.exe'. If either of these is installed in the same folder as this program, it will appear as an option here. The newer program takes precedence. Both perform some functions on data files from the spectroradiometer which may not be essential to the TLCI calculations and are better performed by the proprietary software for the spectroradiometer.

There is a facility for a third utility program, 'Custom utility.exe'. If you have it installed, a menu item will appear from which you can run it. One such program already exists, for decoding data files from the "Lighting Passport" spectroradiometer. It is available only on special request from me at roberts.mugswell@btinternet.com. Other programs to decode other data files may become available in due time, but all will have the same file-name, so you can have only one installed at a time. If you have one of these files, you can run it from this menu item.

2.2 Setup Menu

This menu contains items for colour analysis and control of the screen appearance. Some items are not available in User mode and will not be described here.

2.2.1 General settings



Thus sets several parameters which affect the screen appearance but have no effect on any of the calculations.

- **Screen dimensions**. Set the width and height of the image, you cannot exceed the size of the actual screen. Press OK when done, and the screen size will be changed and cleared to white, unless you have already caused screen output, in which case it will be replaced. Note that the height will be calculated automatically, to keep the aspect ratio to that at which all the displays have been optimised.

BEWARE the software has not been tested on all versions of Windows, and it appears that Windows 8 may introduce some unwanted scaling. At present, there is nothing I can do about that.

- **Set TLCI/TLMF standard size**. The default screen size is 1424 x 732, you cannot change these values. The values were chosen almost by accident, but all the screen output has been designed to look acceptable at this screen size. Enlarging or shrinking the screen, particularly if the aspect ratio is changed, may still be acceptable, but it is up to you to ensure that.

- **Set minimum screen size**. The minimum size allowed is 499x256, which is the ‘thumbnail’ size used on the website of the Guild of Television Cameramen (http://www.gtc.org.uk/tlci-results.aspx). The layout and fonts will be the best I can do at that size.
- **Auto redraw on screen size**. Normally, the program will redraw any screen output whenever you change the screen size, by whatever means. This takes time, because all the calculations will be repeated each time. However, if you uncheck Auto, then, whenever the screen size changes, the previous image will be rescaled rather than recalculated. This is very much faster, but can result in jagged lines, missing pixels and so on. You can always redraw the screen content by going back into the dialog item that originally drew it, when it will be properly fitted to the screen.
- **Screen coding**. Select either sRGB or video coding. sRGB is suitable for graphics displays in which black level is set to 0 and white to 255, while video coding (ITU 601 or 709) is correct for television displays.

  This is relevant only for the on-screen showing of colours, whether colour bars or the results of system analysis. Since the screen, and Windows bitmap files, have only 8-bit coding, only levels 0~255 are available. Broadcast systems accord with ITU recommendations 601 (for SDTV) and 709 (for HDTV) which both specify that black level is set to quantum level 16, and white to 235, i.e. 219 coding levels. Should any colour excurse outside those limits they will not be clipped unless they reach 0 or 255 (i.e. peak white level is 1.091). Use this setting if the computer is feeding a television display, or if a bitmap file is to be saved for further use in a video system.

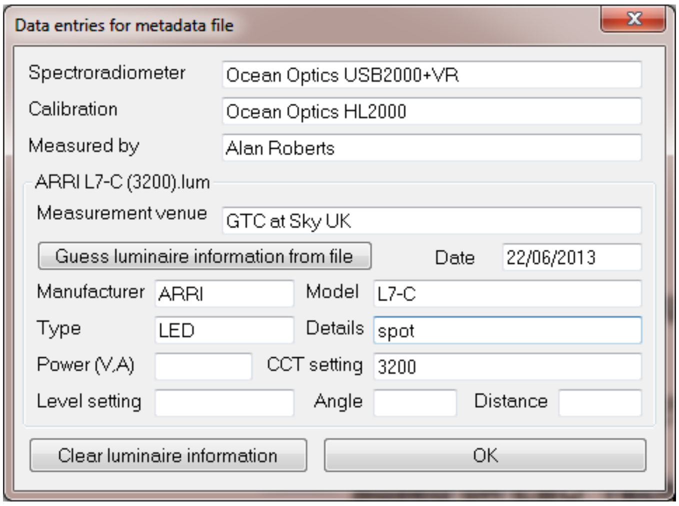
  sRGB is a graphics and multimedia standard, and applies to web video and graphics displays. Use this setting if the computer is feeding only computer displays, and if any saved bitmap will be used in a print or graphics environment.

- **Plot spectra as smooth or histograms**. The software uses sampled spectral data, at 5nm intervals. The most honest way to use this data is to show it as a histogram, with constant energy level across each 5nm band. However it can be more pleasing to show the data as a smooth curve, although very narrow spikes may appear to be misrepresented. It’s your choice. This applies to the report screens and file plot, not to the data plots.
- **Use accreditation data from file**

If you have received the accolade of EBU accreditation for TLCI measurements, you will already know how to exploit this. But there may be occasions where you don’t want t reveal that accreditation, such as when supplying a measurement to a manufacturer for use in promotional material. In that case, uncheck this box to revert to the normal, standard display. This is a toggle, so you can reinstate accreditation by checking the box.

This item is not available if you do not already have EBU accreditation. If you wish to have this accreditation, contact me at roberts.mugswell@btinternet.com to discuss the matter.

2.2.2 Metadata file settings



When you do a TLCI or TLMF calculation, you can opt to generate a metadata file and a BMP image file at the same time. The metadata file is actually a normal text file with TAB separated variables, but has a .xls extension so that you can easily open it in a spreadsheet.

The first 21 rows of the spreadsheet file contain data about the measurement. Some is automatically filled in whatever you do. If you have an EBU accreditation file (details not disclosed here) some data will be extracted from that file.

This dialog allows you to enter or edit all the lines which the program cannot guess for you. You do not have to fill in anything at all, but any entries can be useful for future archaeological excavations of your data archive.

If you press the ‘Guess luminaire …’ button, then the program will immediately attempt to decode the test file name to provide some of the data. I have adopted a standard format for file names, and this decoding assumes that format. The first word (text to the first space) is assumed to be the manufacturer name. Subsequent text, either to the end of the file name, or to the occurrence of an opening bracket, (, is assumed to be the model name. The first word inside the brackets (if there is one) is the CCT setting, any text after a comma within the brackets is the Level setting. Thus, the file name –

De Sisti LED Magis 55W (Daylight, max)

… would yield –

Manufacturer – De

Model – Sisti Magis 55W

CCT setting – Daylight

Level setting – max

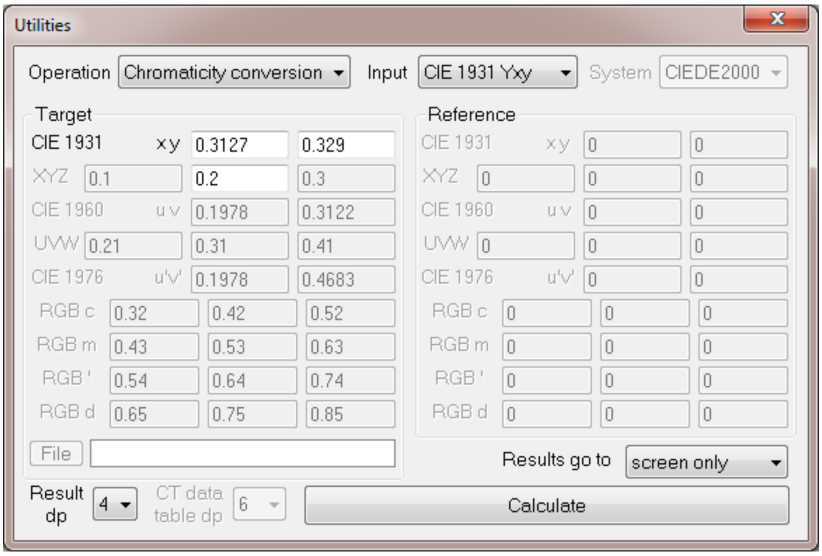
In the example shown, this has obviously failed, because the manufacturer name is two words. So it will not always work properly but you can edit the results here. Note that if the file name does not fit this standard form, then it will not work properly if you check the option in any of the TLCI, TLMF or Convert dialogs.

2.3 Utilities menu

This gives you access to many of the routines in the software, and the stored data. There are two dialogs.

2.3.1 Colorimetric calculator

This dialog lets you use some of the functions and procedures in the software.



Select the *operation* from the drop-down list. For each operation there can be a different selection of input parameters, select from the *input* list. For each combination only the relevant input edit boxes will be available. If you enter parameter values which would cause problems in the calculations, you will be told so, and the calculations will not happen.

Strictly speaking, for chromaticity conversion and finding the correlated colour temperature of a chromaticity pair, you do not need a luminance value, but it is good practice to have one anyway.

If you select the operation to be *colorimetric differences*, then the right-hand panel of parameters is used as well, to provide the reference colour.

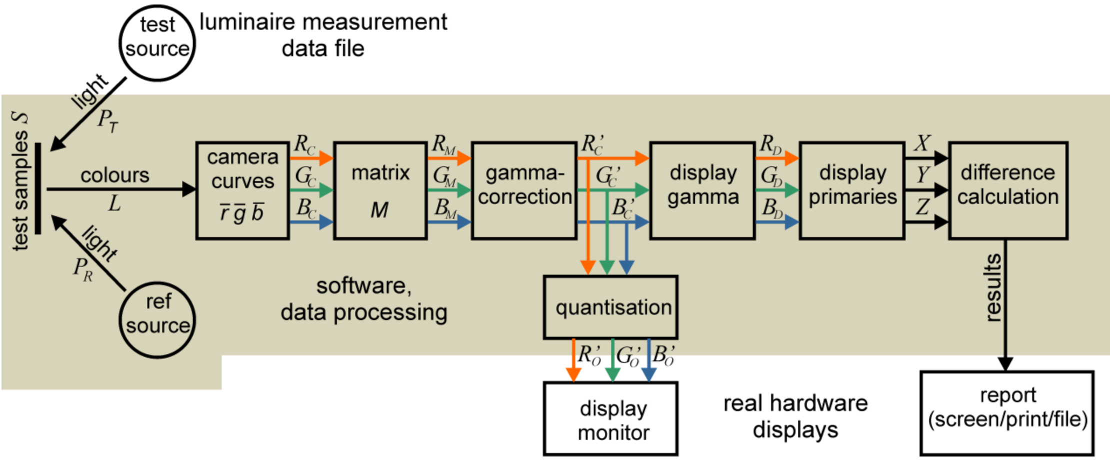
The results will always go to the screen, which will be cleared before use. The screen will scroll vertically if necessary. Results can also go to a text file or to spreadsheet file (xls). However, the spreadsheet file is a simple text file with TAB separated variables but it can be opened directly by a spreadsheet for use. If you have decided to send results to a file, each calculation will be appended to the end of the named file.

Results are generally shown to 9 decimal place precision, but with trailing zeros suppressed. If you select an number of decimal places (*Result dp*) all the results will be reported to that precision. This applies to the screen and text (txt) file, but not to the spreadsheet file, which will have the default 9 decimal places with suppressed training zeros. All the calculations are all done in 64-bit logic which returns about 15 decimal places. Generally, only the first 5 or 6 digits are of use.

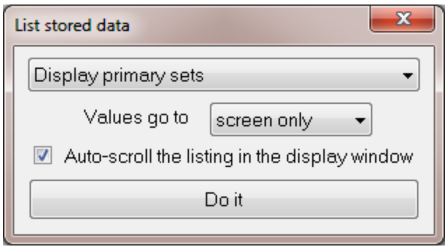
If you select *tristimulus conversion* or *colorimetric differences*, you can enter camera signal levels at various points in the camera chain. These will replace input from earlier in the chain, and the colorimetric calculations will be based on the light output from the display.

The camera and display model is the one used in the TLCI/TLMF calculations, and always uses the default parameters for the TLCI and TLMF.

All correlated colour temperature calculations will use a data table of pre-calculated colour temperatures, and you can control the precision of the data set. The software holds separate data sets for colour temperatures using 4 to 15 decimal places of precision. If you select output to a spreadsheet file, you will get extra data which shows how the calculations work. The same is true for colour-difference calculations.



1.1.1. List stored data



The program holds a large amount of standard data. Some is taken from international standards (usually the CIE), others are gathered from standard practice in television, or from direct measurements made by me. Until now, this data has been available only via EBU Tech.3355, but, for the benefit of those wishing to write their own software, the data is here made freely available.

Select which data you want, and it will be listed to the screen; it can also go to a text file or spreadsheet file as before. Spreadsheet files (xls) are actually plain text using TAB separation so that you can load them directly into a spreadsheet. If you select a text or spreadsheet file, all output will go there until you exit this dialog, or select a different output.

Many of these lists are very long; you can cause the display to pause, presenting a page at a time. If you select this option, all mouse operations will be suspended until the listing completes and the dialog returns. Proceed from page to page by pressing any keyboard key, escape is not allowed, you must complete the listing each time.

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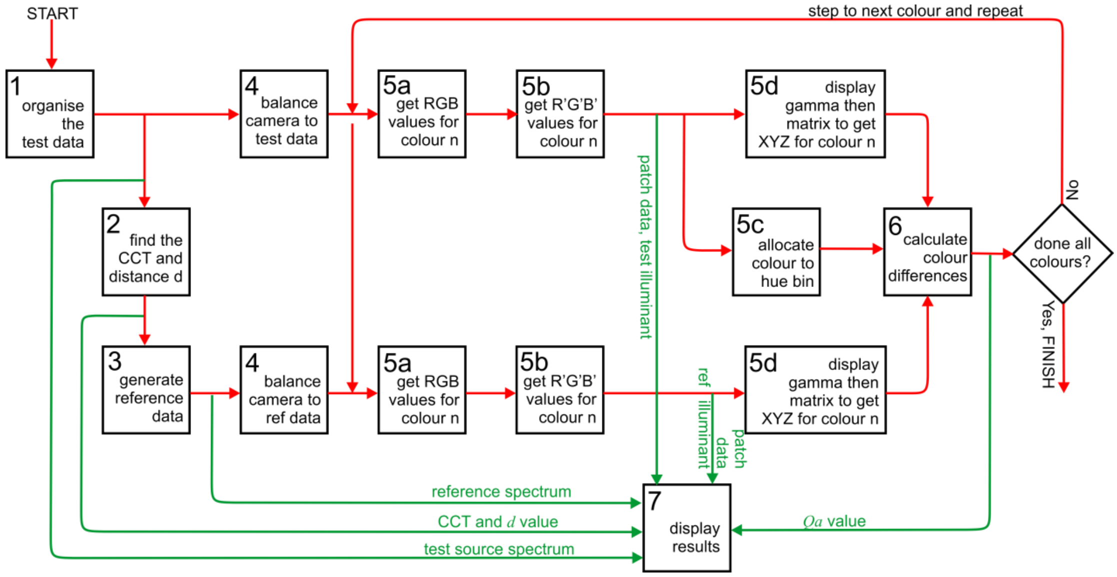
3 THE MATHEMATICS

3.1 Flow diagram of the TLCI processing



3.2 Mathematics of the Standard camera

A notional (or practical, i.e. the performance parameters *could* be those of a real camera) camera which 'sees' the test colours lit by the Test and Reference illuminants and delivers gamma-corrected R'G'B' signals to a practical display and to the analysis process. Its performance parameters are defined by:

- Colorimetric analysis to determine the $R_cG_cB_c$ values for each colour:

$$R_C = \sum_{\lambda=380}^{760} R_\lambda R_\lambda \bar{r}_\lambda \qquad G_C = \sum_{\lambda=380}^{760} R_\lambda R_\lambda \bar{g}_\lambda \qquad B_C = \sum_{\lambda=380}^{760} R_\lambda R_\lambda \bar{g}_\lambda$$

  … where λ is the wavelength of light in nanometers (nm), P_λ is the spectral power distribution of the light source, whether *Test* (supplied in a text file *.lum) or *Reference* (*.ref derived from internal calculations or from a text file *.lum), R_λ is the spectral reflectance of each colour sample in turn (derived from a text file (*.smpl), and $\bar{r}\ \bar{g}\ \bar{b}$ are the responsivity curves for *RGB* respectively (derived from a text file *.cam).

- Followed by balancing. Balancing data (R_b, G_b, B_b) are obtained by colorimetric analysis for a flat colour sample, i.e. with 100% reflectance at all wavelengths.

$$R_{Cb} = R_C R_b\ , \quad G_{Cb} = G_C G_b\ , \quad B_{Cb} = B_C G B_b$$

- Followed by a linear matrix *Mat*() (values are derived either internally, or from a text file *.mat, or by direct numerical entry in Engineering mode) to optimise the colour performance and deliver *RGB* signals:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} Mat(0,0) & Mat(0,1) & Mat(0,2) \\ Mat(1,0) & Mat(1,1) & Mat(1,2) \\ Mat(2,0) & Mat(2,1) & Mat(2,2) \end{bmatrix} \begin{bmatrix} R_{Cb} \\ G_{Cb} \\ B_{Cb} \end{bmatrix}$$

  Note that white balancing is applied after matrix correction but before the application of the saturation control. The saturation control functions as a secondary matrix:

$$\begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix} = \begin{bmatrix} 1-2a & a & a \\ a & 1-2a & a \\ a & a & 1-2a \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

  … where $a = (1 - Saturation/100)/3$.

- Followed by gamma correction (equations are derived from internal data, or from a text file *.gam, or by direct numerical entry in Engineering mode). The equation can accommodate both the BBC formulae (in which an offset is applied to the input) and the alternative formula (in which an offset is applied to the output). The offsets are needed in order to ensure that the join between the power law part of the curve and the linear part below the break point is tangential and smooth. Beware that many of the standard equations are not ideal in that the join is either not tangential, or monotonic, or leaves missing video levels:

$$V' = \begin{cases} slope\ V, & V < break \\ (1+a)\left(\dfrac{V-b}{1-b}\right)^{Law} - a, & V \geq break \end{cases}$$

The output of the 'standard' camera feeds the computer's display directly, so you get to see the real colours (if the display has the correct colorimetric properties). It also feeds the 'standard' display.

3.3 Mathematics of the Standard display

A notional (or practical, i.e. the performance parameters can be those of a real display, entered in Engineering mode) display which delivers light to a colorimetric analysis. Its performance parameters are defined by:

- Applying the non-linear characteristics of the display. Only a pure power law is allowed in this simulation:

  $$R_d = R'^{Gamma} \qquad G_d = G'^{Gamma} \qquad B_d = B'^{Gamma}$$

  … where *Gamma* (derived from internal data or by direct numerical entry in Engineering mode) is assumed to be greater than 1. This does not accommodate any erroneous setting of the display (e.g. mis-set black level or white balance) or non-conformance with a pure power law.

- Followed by colorimetric analysis to derive CIE tristimulus values for each colour as seen on the display:

  $$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} XYZ(0,0) & XYZ(0,1) & XYZ(0,2) \\ XYZ(1,0) & XYZ(1,1) & XYZ(1,2) \\ XYZ(2,0) & XYZ(2,1) & XYZ(2,2) \end{bmatrix} \begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix}$$

  … where the matrix *XYZ*() is derived by analysis of the chromaticity coordinates of the display primaries and white point.

3.4 CIEDE2000 Colour Difference Analysis

This aims to derive a single numerical value (ΔE^*) for the perceptual colour difference between the appearance of each tests sample, when illuminated by the Test and Reference sources.

This is a refinement of CIELAB, intended to improve the correlation between the metric and human vision in the saturated blue and near neutral colour regions.

- Calculate CIELAB values for the Test- and Reference-illuminated colour samples:

$$L^*_{T,i} = 116 f\left(Y_{T,i}/T_w\right) - 16 \qquad L^*_{R,i} = 116 f\left(Y_{R,i}/T_w\right) - 16$$

… where:

$$f(var) = \begin{cases} \dfrac{var}{3}\left(\dfrac{116}{24}\right)^2 + \dfrac{16}{116}, & var < \left(\dfrac{24}{116}\right)^3 \\ var^{1/3}, & var \geq \left(\dfrac{24}{116}\right)^3 \end{cases}$$

$$a^*_{T,i} = 500\left(f\left(\frac{X_{T,i}}{X_w}\right) - f\left(\frac{Y_{T,i}}{Y_w}\right)\right) \qquad a^*_{R,i} = 500\left(f\left(\frac{X_{R,i}}{X_w}\right) - f\left(\frac{Y_{R,i}}{Y_w}\right)\right)$$

$$b^*_{T,i} = 200\left(f\left(\frac{Y_{T,i}}{Y_w}\right) - f\left(\frac{Z_{T,i}}{Z_w}\right)\right) \qquad b^*_{R,i} = 200\left(f\left(\frac{Y_{R,i}}{Y_w}\right) - f\left(\frac{Z_{R,i}}{Z_w}\right)\right)$$

… where the $X_wY_wZ_w$ are the tristimulus values of the display white point.

CIELab Chroma $C^*_{T,i} = \sqrt{a^{*2}_{T,i} + b^{*2}_{T,i}}$ $C^*_{R,i} = \sqrt{a^{*2}_{R,i} + b^{*2}_{R,i}}$

$$\overline{C}^*_i = \left(C^*_{T,i} + C^*_{R,i}\right)/2$$

$$g_i = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{C}^{*7}_i}{\overline{C}^{*7}_i + 25^7}}\right)$$

$$a'_{T,i} = (1 + g_i)a^*_{T,i} \qquad a'_{R,i} = (1 + g_i)a^*_{R,i}$$

$$C'_{T,i} = \sqrt{a'^{\,2}_{T,i} + b^{*2}_{T,i}} \qquad C'_{R,i} = \sqrt{a'^{\,2}_{R,i} + b^{*2}_{R,i}}$$

CIEDE2000 Hue $h_{T,i} = \tan^{-1}\left(b^*_{T,i}/a'_{T,i}\right)$ $h_{R,i} = \tan^{-1}\left(b^*_{R,i}/a'_{R,i}\right)$

Note that the hue, *h*, is measured in degrees, not radians, and that the calculations must correctly take into account the signs of *a*’ and *b** to assign an angle within 0~360 degrees. Next, calculate means:

$$\overline{L}'_i = \left(L^*_{T,i} + L^*_{R,i}\right)/2 \qquad \overline{C}'_i = \left(C'_{T,i} + C^{*\prime}_{R,i}\right)/2 \qquad \overline{h}_i = \left(h_{T,i} + h_{R,i}\right)/2$$

$$\Delta h_i = h_{T,i} - h_{R,i}$$

Note that the hue difference, Δ*h**, is measured in degrees, not radians, and that the difference must lie in the range -180~+180 degrees. If the difference lies outside this range, the 180 must be subtracted from the larger of the two hue angles and the mean and difference recomputed.

- Calculate intermediate values for the actual colour under test.

$$T_i = 1 - 0.17\,cos\left(\overline{h}_i - 30\right) + 0.24\,cos\left(2\overline{h}_i\right) + 0.32\,cos\left(3\overline{h}_i + 6\right) - 0.20\,cos\left(4\overline{h}_i - 63\right)$$

$$S_{L,i} = 1 + \frac{0.015\left(\overline{L}'_i - 50\right)^2}{\sqrt{20 + \left(\overline{L}'_i - 50\right)^2}} \quad S_{C,i} = 1 + 0.045\overline{C}'_i \quad S_{H,i} = 1 + 0.015\overline{C}'_i$$

$$R_{C,i} = 2\sqrt{\frac{\overline{C}'^7_i}{\overline{C}'^7_i + 25^7}} \quad \Delta\theta_{T,i} = 30\,exp\left(-\left(\frac{\overline{h}'_i - 275}{25}\right)^2\right) \quad R_{T,i} = -R_{C,i}\sin(2\Delta\theta)$$

- Calculate the resulting CIEDE2000 difference values:

$$\Delta L_i = L^*_{T,i} - L^*_{R,i} \quad \Delta C_i = C'_{T,i} - C'_{R,i} \quad \Delta H_i = 2\sin\left(\frac{\overline{h}_{T,i} - \overline{h}_{R,i}}{2}\right)\sqrt{C'_{T,i}.C'_{R,i}}$$

- Apply the scalers:

$$\Delta L_i' = \Delta L_i/k_L S_L \quad \Delta C_i' = \Delta C_i/k_C S_C \quad \Delta H_i' = \Delta H_i/k_H S_L$$

- Calculate the resulting difference value:

$$\Delta E_i = \sqrt{(\Delta L_i')^2 + (\Delta C_i')^2 + (\Delta H_i')^2 + R_{T,i}.\Delta C_i'.\Delta H_i'}$$

…where the *k* values are weighting factors, usually unity. They can be varied to customise the metric, affecting lightness, chroma and hue, respectively, and can be separately specified for each test colour on an experimental basis. If they are varied from unity, then their values must be included in the name of the system, e.g. CIEDE2000(2:1:1). For use in the TLCI-2012, all the *k* values are set to unity.

3.5 Derivation of TLCI-2012/TLMF-2013 Qa value

The equation which derives the output *Qa* value from ΔE^* value is:

$$Q = \frac{100}{1 + \left(\frac{\Delta E^*}{k}\right)^p}$$

… which eliminates the possibility of negative values for *Q*, and allows a non-linear, S-shaped curve relating *Q* to ΔE^*. Value for both k and p are chosen to optimise the performance of the metric, *k*=3.16 and *p*=2.4. Note that the ΔE^*values for each test colour are power-averaged, to avoid losing the significance of poorly-performing colours, thus:

$$\Delta E_a^* = \left(\sum_{i=1}^{18} (\Delta E_i^*)^4\right)^{1/4}$$

4 THE MATHEMATICS OF TRANSFORMATION

Simulation of the effect of a test illuminant uses a data table derived from the values of television signals for each of the test and reference illuminants on each of the test colours. The simulation applies data from this table to each pixel in the displayed image.

During the TLCI analysis, each test colour produces a set of gamma-corrected values, for both the reference and test illuminant, R'_r G'_r B'_r and R'_t G'_t B'_t. Each set is coded into television signals, using the coding rules appropriate to ITU R.709 HD):

$$Y' = rR' + gG' + bB' \ \ , \ Cb = u(B' - Y') \text{ and } Cr = v(R' - Y')$$

… where the proportions *r g* and *b* depend on the coding system. Then a *Hue* value is derived from the two chroma signals, using the same mathematics as in the Colorists Advice table:

$$Hue = \begin{cases} 0, & Cb = 0 \\ \tan^{-1}(Cr/Cb), & Cb \neq 0 \end{cases}$$

… and to get the hue into the correct quadrant:

If $Cb < 0$ then add 180 to Hue

If $Cb > 0$ then add s60 to Hue

… and add or subtract t 360 as required to make sure the results always lies between 0 and 360. Then a Chroma magnitude value is calculated:

$$C = \sqrt{{C_b}^2 + {C_r}^2}$$

Finally, the ratio of the individual *R G* and *B* values (linear, not gamma-corrected) are derived:

$$xR = R_t/R_r \ \ , \ xG = G_t/G_r \text{ and } xB = B_t/B_r$$

The table is sorted such that the hue angle increases monotonically.

For the simulation, the bitmap file is read, pixel-by-pixel, producing digital R_d G_d B_d values. These are converted to analogue using the coding rules selected in the *File* menu, e.g.:

$$R'_r = R'_d/255 \text{ or } R'_r = (R'_d - 16)/219 \text{ etc}$$

… for sRGB or Video coding. Then these values are used in the coding equations as above to produce Y'_r C_r and Hue_r values.

The transformation data table is then scanned to find the first *Hue* entry which is less than Hue_t. Then there are two entries in the table, either side of the test pixel, from which data can be interpolated using the proportion *p*:

$$p = \frac{Hue_r - Hue(i)}{Hue(i+1) - Hue(i)}$$

… where the *i*th entry is lower and the (*i*+1)th entry is higher. Then a scaling factor *c* is derived from the Chroma levels:

$$c = \frac{C_r}{C(i)(1-p) + C(i+1)p}$$

Using these, the ratios *xR* *xG* and *xB* are modified:

$$xR_r = 1 + c(xR(i)(1-p) + cR(i+1)p - 1) \text{ etc}$$

If the luminaire analysis was of the TLMF, then another factor is needed, to simulate the offset white balance. This is derived from the *Y* and *RGB* signal levels (linear, not gamma-corrected) resulting from the illumination of a neutral reflector, for the test and reference illuminant:

$$R_{bal} = \frac{Y_{ref}R_{test}}{Y_{test}R_{ref}} \text{ , } G_{bal} = \frac{Y_{ref}G_{test}}{Y_{test}G_{ref}} \text{ and } B_{bal} = \frac{Y_{ref}B_{test}}{Y_{test}B_{ref}}$$

… thus, for the TLMF:

$$xR_r = \frac{Y_{ref}R_{test}}{Y_{test}R_{ref}}(1 + c(xR(i)(1-p) + cR(i+1)p - 1)) \text{ etc}$$

For the processing, the input pixel values are linearised, using the value of Gamma for the system display:

$$R = R'^{Gamma} \text{ , } G = G'^{Gamma} \text{ and } B = B'^{Gamma}$$

The output pixels are then calculated:

$$R_t = R_r xR_r \text{ , } G_t = G_r xG_r \text{ and } B_t = B_r xB_r$$

… or, if the simulation is reversed (i.e. the BMP file is modified to undo the effect of the test illuminant):

$$R_t = R_r / xR_r \text{ , } G_t = G_r / xG_r \text{ and } B_t = B_r / xB_r$$

These values are then gamma corrected using the display power law, and video coded according to the rules selected in the *File* menu:

$$R' = R^{1/Gamma} \text{ , } G' = G^{1/Gamma} \text{ and } B' = B^{1/Gamma}$$

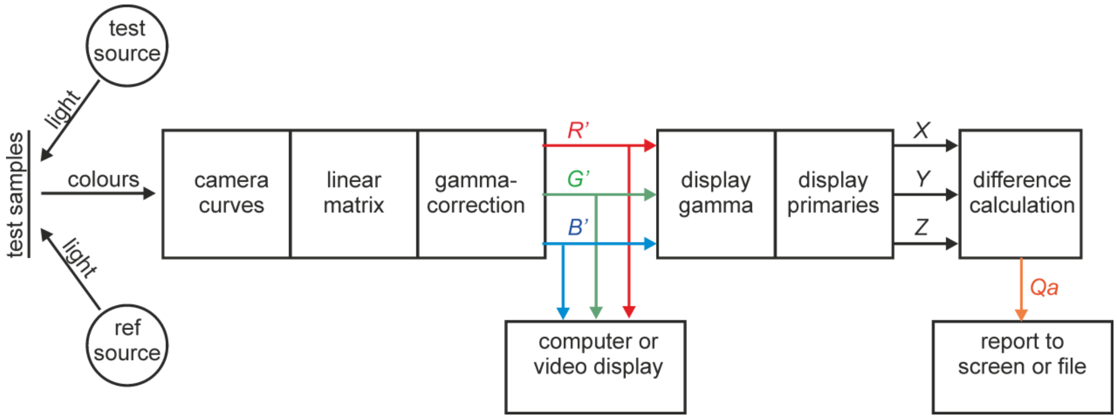
$$R'_d = 255R' \text{ or } R'_d = 16 + 219R' \text{ etc}$$

… and these values are saved in the output bitmap file.

5 SETUP CONDITIONS

Although the software is highly flexible, for general use all the operating parameters have been fixed according to the recommendations in EBU Recommendation 137.

Thus for each operating parameter there is a specified value:



- **Test source**: A measurement file of the spectral power distribution of the test source, measured from 380 to 760nm in steps of 5nm. The file must be plain text, with TAB separated values (nm TAB value) and must have the correct identifying first line:

  ```
  //Illuminant file
  ```

  Note that, for TLMF calculations only, there can also be a lighting filter file. This must be of the same form, but the identifying first line must be:

  ```
  //Filter data file
  ```

  … and it is the convolution of the data contents of these two files which will be used for the calculations.

- **Test samples**: Colorchecker chart, using only the 18 coloured patches for calculation.

- **Reference source**: a standard illuminant on the Planckian or Daylight locus, at the correlated colour temperature (T) of the test illuminant. If T lies between P3400 and D5000, then the program will generate a hypothetical reference using a linear interpolation between Daylight at 5000K and Planckian at 3400K, this ensures that there is no discontinuity in the reference chromaticity locus, and is a reasonable way to deal with mixed lighting.

  Note that, for TLMF calculations, the reference is always a file, whether a measurement (lum) or reference (ref) file. The camera will be white balanced to the reference, and not to the test file, to show the effect os simultaneous use in the same scene.

- **Camera curves**: EBU Standard Camera 2012

- **Linear matrix**: optimised for these curves:

$$\begin{bmatrix} 1.182 & -0.209 & 0.027 \\ 0.107 & 0.890 & 0.003 \\ 0.040 & -0.134 & 1.094 \end{bmatrix}$$

- **Saturation control**: 90%, therefore a=0.0333…:

$$\begin{bmatrix} R_s \\ G_s \\ B_s \end{bmatrix} = \begin{bmatrix} 0.9333\ldots & 0.0333\ldots & 0.0333\ldots \\ 0.0333\ldots & 0.9333\ldots & 0.0333\ldots \\ 0.0333\ldots & 0.0333\ldots & 0.9333\ldots \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- **Gamma correction**: ITU R. BT-709

- **Display gamma**: 2.4

- **Display primaries**: ITU R. BT-709

- **Colour difference metric**: CIEDE2000

- **TLCI formulation**:

$$Q = \frac{100}{1 + \left(\frac{\Delta E^*}{3.16}\right)^4}$$

… where ΔE^* is the value returned by the colour difference metric. k is chosen such that the *Qa* value for a daylight fluorescent tube delivers a value of 50, and p is chosen to compress high and low values and expand the middle, critical, range.

6 LIGHTING FILTERS

The following filters are supplied as spectral data files, from data kindly supplied by LEE Lighting.

002 Rose Pink	134 Golden Amber	217 Blue Diffusion
003 Lavender Tint	135 Deep Golden Amber	218 Eighth CTB
004 Medium Bastard Amber	136 Pale Lavender	219 Lee Fluorescent Green
007 Pale Yellow	137 Special lavender	220 White Frost
008 Dark Salmon	138 Pale Green	221 Blue Frost
009 Pale Amber Gold	139 Primary Green	223 Eighth CTO
010 Medium Yellow	140 Summer Blue	224 Daylight Blue Frost
013 Straw Tint	141 Bright Blue	225 Lee ND Frost
015 Deep Straw	142 Pale Violet	226 Lee UV
017 Surprise Peach	143 Pale Navy Blue	230 Super CTN LCT Yellow
019 Fire	144 No Colour Blue	232 Super WF Green
020 Medium Amber	147 Apricot	236 HMI to Tungsten
021 Gold Amber	148 Bright Rose	237 CID to Tungsten
022 Dark Amber	151 Gold Tint	238 CSI to Tungsten
024 Scarlet	152 Pale Gold	239 Polariser
025 Sunset Red	153 Pale Salmon	241 Lee Fluorescent 5700K
026 Bright Red	154 Pale Rose	242 Lee Fluorescent 4300K
027 Medium Red	156 Chocolate	243 Lee Fluorescent 3600K
029 PLASA Red	157 Pink	244 Lee Plus Green
035 Light Pink	158 Deep Orange	245 Half Plus Green
036 Medium Pink	159 No Colour Straw	246 Quarter Plus Green
039 Pink Carnation	161 Slate Blue	247 Lee Minus Green
046 Dark Magenta	162 Bastard Amber	248 Half Minus Green
048 Rose Purple	164 Flame Red	249 Quarter Minus Green
049 Medium Purple	165 Daylight Blue	250 Half White Diffusion
052 Light Lavender	166 Pale Red	251 Quarter White Diffusion
053 Paler Lavender	169 Lilac Tint	252 Eighth White Diffusion
058 Lavender	170 Deep Lavender	253 Hampshire Frost
061 Mist Blue	172 Lagoon Blue	254 HT New Hampshire Frost
063 Pale Blue	174 Dark Steel Blue	255 Hollywood Frost
068 Sky Blue	176 Loving Amber	256 Half Hants Frost
071 Tokyo Blue	179 Chrome Orange	257 Quarter Hants Frost
075 Evening Blue	180 Dark Lavender	258 Eighth Hants Frost
079 Just Blue	181 Congo Blue	269 Lee Heat Shield
085 Deeper Blue	182 Light Red	278 Eighth Plus Green
088 Lime Green	183 Moonlight Blue	279 Eighth Minus Green
089 Moss Green	184 Cosmetic Peach	281 ThreeQuarter CTB
100 Spring Yellow	185 Cosmetic Burgundy	283 1.5 CTB
101 Yellow	186 Cosmetic Silver Rose	285 ThreeQuarter CTO
102 Light Amber	187 Cosmetic Rouge	286 1.5 CTO
103 Straw	188 Cosmetic Highlight	287 2x CTO
104 Deep Amber	189 Cosmetic Silver Moss	298 0.15 ND
105 Orange	190 Cosmetic Emerald	322 Soft Green
106 Primary Red	191 Cosmetic Aqua Blue	323 Jade
107 Light Rose	192 Flesh Pink	325 Mallard Green
108 English Rose	193 Rosy Amber	327 Forest Green
109 Light Salmon	194 Surprise Pink	328 Follies Pink
110 Middle Rose	195 Zenith Blue	332 Special Rose Pink
111 Dark Pink	197 Alice Blue	341 Plum
113 Magenta	198 Palace Blue	343 Special Med Lavender
115 Peacock Blue	200 Double CTB	344 Violet
116 Medium Blue-Green	201 Full CTB	345 Fuchsia Pink
117 Steel Blue	202 Half CTB	352 Glacier Blue
118 Light Blue	203 Quarter CTB	353 Lighter Blue
119 Dark Blue	204 Full CTO	354 Special Steel Blue
120 Deep Blue	205 Half CTO	363 Special Medium Blue
121 Lee Green	206 Quarter CTO	400 LeeLux
122 Fern Green	207 CTO+0.3ND	410 Opal Frost
124 Dark Green	208 CTO+0.6ND	416 ThreeQuarter White Diffusion
126 Mauve	209 0.3ND	420 Light Opal Frost
127 Smokey Pink	210 0.6ND	441 Full CT Straw
128 Bright Pink	211 0.9ND	442 Half CT Straw
130 Clear	212 LCT Yellow	443 Quarter CT Straw
131 Marine Blue	213 WF Green	444 Eighth CT Straw
132 Medium Blue	216 White Diffusion	450 ThreeEighth White Diffusion

452 Sixteenth White Diffusion	721 Berry Blue	LED 104 Deep Amber
500 Double New Colour Blue	722 Bray Blue	LED 105 Orange
501 New Colour Robertson Blue	723 Virgin Blue	LED 106 Primary Red
502 Half New Colour Blue	724 Ocean Blue	LED 113 Magenta
503 Quarter New Colour Blue	725 Old Steel Blue	LED 115 Peacock Blue

504 Waterfront Green	727 QFD Blue	LED 116 Medium Blue-Breen
505 Sally Green	728 Steel Green	LED 117 Steel Blue
506 Marlene	729 Scuba Blue	LED 118 Light Blue
507 Madge	730 Liberty Green	LED 119 Dark Blue
508 Midnight Maya	731 Dirty Ice Dark Version	LED 126 Mauve
511 Bacon Brown	733 Damp Squib	LED 128 Bright Pink
512 Amber Delight	735 Velvet Green	LED 132 Medium Blue
513 Ice & a Slice	736 Twickenham Green	LED 139 Primary Green
514 Double G & T	738 JAS Green	LED 147 Apricot
525 Argent Blue	741 Mustard Yellow	LED 158 Deep Orange
604 Full CT Eight Five	742 Bram Brown	LED 164 Flame Red
LED 622 One&Eighth Digital CTO	744 Dirty White	LED 180 Dark Lavender
LED 624 Full Digital CTO	746 Brown	LED 181 Congo Blue
LED 626 SevenEighths Digital CTO	747 Easy White	
LED 628 ThreeQuarter Digital CTO	748 Seedy Pink	
642 Half Mustard Yellow	749 Hampshire Rose	
643 Quarter Mustard Yellow	750 Durham Frost	
650 Industry Sodium	763 Wheat	
652 Urban Sodium	764 Sun Colour Straw	
651 HI Sodium	765 Lee Yellow	
700 Perfect Lavender	767 Oklahoma Yellow	
701 Provence	768 Egg Yolk Yellow	
702 Special Pale Lavender	770 Burnt Yellow	
703 Cold Lavender	773 Cardbox Amber	
704 Lily	774 Soft Amber Key 1	
705 Lily Frost	775 Soft Amber Key 2	
706 King Fals Lavender	776 Nectarine	
707 Ultimate Violet	777 Rust	
708 Cool Lavender	778 Millennium Gold	
709 Electric Lilac	779 Bastard Pink	
710 Spir Special Blue	780 AS Golden Amber	
711 Cold Blue	781 Terry Red	
712 Bedford Blue	787 Marius Red	
713 J Winter Blue	789 Blood Red	
714 Elysian Blue	790 Moroccan Pink	
715 Cabana Blue	791 Moroccan Frost	
716 Mikkel Blue	793 Vanity Fair	
717 Shanklin Frost	794 Pretty n Pink	
718 Half Shanklin Frost	795 Magical Magenta	
719 Colour Wash Blue	797 Deep Purple	
720 Durham Daylight Frost	798 Chrysalis Pink	