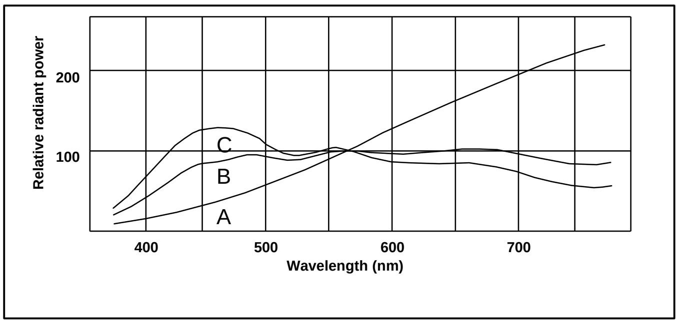
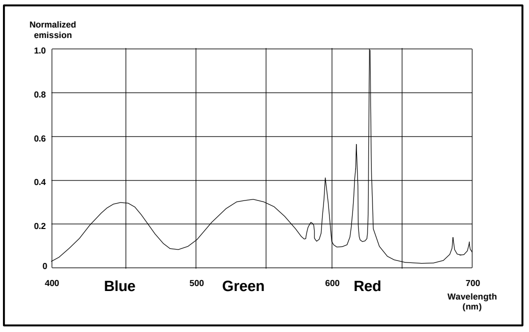
Calibration of Colour Analysers

The use of monitors instead of standard light sources, the use of light from sources generating non-continuous spectra)

Standard colour analysers are calibrated by use of calibrated standard light sources - typically standard light source A or C. These sources have relatively smooth light spectra which are very like the spectrum from a tungsten lamp.



The spectrum from colour monitors is not smooth, it consists of light from three phosphors: red, green and blue. The green and blue phosphors have typically relatively broad and smooth spectra, whereas the red phosphor has a very narrow spectrum typically consisting of one or two lines.



The spectrum from the red phosphor is placed at a frequency where the standard observer red response has declined to a magnitude of about 10%. A minor error on the standard observer filters may give rise to a large measuring error when measuring on a red phosphor with an instrument calibrated on a smooth spectrum. When the instrument is calibrated to a smooth spectrum only the area below the curve needs to be correct, there may exist wavelengths at which large errors are "tolerated". When measuring on very steep spectra the error at a very narrow band can result in large measuring faults. The filter needs to track the specified curve not only in the band with high transmission, but also in the bands with low transmission.

The PM 5639 colour analyser is calibrated by use of calibrated colour monitors. This assures that the calibration is optimized for measurements on colour monitors including the very narrow red phosphor light.

Traceability Of Calibration

- Swedish National Testing and Research Institute (Statens Provningsanstalt, Borås Sweden), traceable to *NIST* (National Institute of Standards and Technology - formerly NBS - in the US): The calibration at the SP Borås was done by use of a Zeiss MM12 double monochromator having a photomultiplier detector. The measurements were taken on the same area as the measuring area used by the PM 5639. The measurements were made with 5 nm wavelength interval throughout 380 to 775 nm. The calibration of the spectroradiometer was done by use of a 1000 W tungsten halogen lamp type F.E.L. irradiating a pressed barium sulphate tablet. The spectral irradiance of the lamp is traceable to NIST, USA by substitution to a group of F.E.L. lamps calibrated by NIST. The measuring results were multiplied and integrated by the CIE 1931 standard observer reference , and curves. Estimated total uncertainty using the BIMP method with a safety factor k=2 is ±0.002 for the white and green colours, ±0.005 for the blue and red colours, and ±2% for the measured luminance.(BIMP: a statistical weighting method)

Errors On Luminance Measurement When Standard Luminance Meters Are Used On Light With Non-Continuous Spectra

The luminance is measured by use of the eye response curve for the Photopic (cone or light-adapted) vision, the V(ë) curve. The V(ë) curve is defined by the CIE 1924 standard observer for photometry and is equal to the CIE 1931 standard observer (ë) (green) response. When the luminance on colour monitors are measured by use of general-purpose luminance meters the obtained accuracy may not be as expected. The explanation is that the luminance meter is calibrated on a continuous light spectrum where also the specifications are given. When used on monitors with discontinuous spectra small deviations from the correct curve can give large measuring errors. (especially for Red)

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Beating between Field and Mains Frequency

TV systems in different parts of the world are operating with different field frequencies. The field frequency is normally the same as the nominal mains frequency, but the two frequencies are not locked together. When the two frequencies are mixed a signal with the difference frequency is generated. When hum is present on the CRT the difference signal may be observed as a slowly vertical rolling "bar" on the CRT. If the hum component is very small it may not be possible to see the bar, but the colour analyser will show the beating. Usually the beating is equal on all tree CRT guns which means that the beating can be observed as a luminance change, if the beating is not equal on the tree colours also chrominance beating occurs.

Beating between the eg. the European 50 Hz mains frequency and the 59.94 Hz NTSC field frequency will be totally removed by the anti-aliasing filters in the PM 5639 colour sensor.

Field Detector - Conventional and HDTV Displays

The line scan is detected and the measuring system is phase-locked to the field scan rate. This makes the measurement independent of the field rate and removes any possibility for beating between the sampling rate and the field frequency. The field detector operates continuously from 40Hz to 120Hz with full accuracy of the measurement. If the field frequency is higher, the measurement resolution will be reduced, but the instrument will continue to work.

Temperature Dependence of Filters

In tri-receptor colour analysers the filters are usually realized with optical glass of different colours. The light is filtered by absorption in the glasses. The absorption transforms the light energy to heat, which gives a temperature rise of the filters. The filter response changes with temperature. The highest change of temperature occurs in the red filter, which unfortunately also is the filter, which is most sensitive to tolerances. To cope with this problem, high-end tri-stimulus colour analysers use an oven for the red filter to keep the temperature and thereby the response constant. In dicroic filters the unwanted light is reflected instead of absorbed and the filter consequently does not get heated. Furthermore the filter response of the dicroic filters are also less sensitive to temperature changes.

Dicroide Filter Design

The objective is to make the total filter response as close to the standard observer response as possible. With the use of dicroide filters it is possible to obtain even the two peak responses of the red filter with good accuracy and repeatability.

In the Standard Observer response defined by CIE in 1931 the red response is a response with two peaks. It is very difficult to generate a filter response with two peaks with traditional absorption filters. The normal solution to this problem is either to use a fraction of the response in the blue filter and add this to the red filter response or to use two red filters. When two red filters are used four filters has to be calibrated together instead of three. The dichroic filters overcomes this problem as it is possible to make two peaks in the response. The filters are designed in a way very common to the design of electrical filters. When light has to be measured at very low level the border is set by the "noise floor" in the sensors and offset drift in the amplifiers. When the standard observer response is simulated with filters built by use of coloured glass the peak red transmittance is about 10%. It is possible with use of dicroic filters to obtain a peak response in excess of 90% for the red filter. The higher amount of light that reaches the light sensors at the same measuring level makes it possible to use the instrument at 10 times less light levels.

The Use of A Standard Colour Analyser as Transfer Device

Colour monitors are not known as very stable elements, so the use of a colour monitor as reference for calibration may give cause for alert. When the monitors even has to be transported between the calibration institute and the factory some special precautinons has to be taken. At DK-Audio we have a "golden" colour analyser and a "golden" RGB window generator which is used as transfer devices in the calibration process.

Additionally we are cross checking this “golden” sensor with two other sensors during the calibartion process.

At the calibration institute the monitor is switched on for two hours before measurement at constant room temperature and mains power. The light from the monitor is then measured first with a newly calibrated spectroradiometer, thereafter with the golden colour analyser and last again with the spectroradiometer to check that neither the golden colour analyser nor the monitor has changed in the measuring time. After the measurement the instruments are brought back to the factory and it is controlled that the monitor and the colour analyser is tracking. If the reading on the colour analyser has changed there has been a change in either the monitor or the colour analyser and a recalibration has to be performed. In this way the calibration is kept traceable to international standards.

The validity of calibration set-up is monitored during every calibration: A reference sensor is used for checking if the monitor has drifted (any discrepancy will be shown).

Use Of Spectroradiometers

[Overload because of time response and spectral lines. Shape of phosphors colour response. Procedures for checking of overload on the colour sensor.]

When measuring on CRT based monitors with photospectroradiometers some precautions has to be taken. The light from the display is pulsed and has a very high magnitude for a short time. In this period the detector, very often a photomultiplier, may be more or less saturated. It is possible to check whether the detector is saturated by placing a mesh with a known attenuation in the light path and then control that the response reflects the attenuation.

Conventional spectroradiometers designed for measuring lamps uses modulating detection systems which are unsatisfactory for the measurement of displays because of beating effects with the display frequency. Some kind of averaging system is needed to remove the beating.

The colours from the CRT's are changed by changing the relative luminances from the tree phosphor "dots". If measurements is to be with an accuracy of 1% at least 100 dots of each phosphor has to be included in the measuring area. This is one of the reasons why the colour sensor of the PM 5639 is as large as it is. If the screen is not uniform also the area and place of the measurement has to be specified.

xy And u'v' Displays (u Prime v Prime Displays).

Chromaticity calculations.

CIE has in 1931 defined the xy chromaticity colour space. This colour space is not a very uniform colour space. The uniformity is usually described by use of the MacAdams ellipses (MacAdam 1942). The ellipses describe how the human perception of colour changes depending upon the direction of the change and the actual colour.

The xy diagram is not very uniform, and to overcome this CIE in 1976 adapted a new colour space, the u'v' UCS (uniform colour space). The MacAdam ellipses in this colour space are more circular and the u'v' space is a more convenient space for human colour perception. The u'v' space is not ideal, but it is a better approximation in the center around the D6500 white reference. One standard exists "in between" namely the CIE 1960 uv colour space, but this is not in widespread use.

Measurement Of Individual Phosphors xy / u'v' Chromaticity Coordinates And Calculation Of Skin Tones

Sensitivity of the eye to colour errors depends upon the manner in which two colours, the original and the reproduced are compared. For example if the two colours are placed side by side the eye becomes very sensitive to any differences. However if the eye comparison is made by memory, the differences has to be much larger to be observed. Furthermore if the colour is one that has not been seen before the colour only has to be accepted by the brain as a colour *plausible* for that object. On the other hand if the object is well known, with a recognized colour, such as flesh tones or a sponsor's packaged product the eye has an established reference and is much more sensitive to reproduction errors.

To check the monitors for their reproduction of skin tones EBU has recommended the following procedure. The individual chromaticity points of the phosphors are measured. It is very important for this measurement that the monitor is adjusted correct so that only one phosphor is emitting light at a time (purity). From the chromaticity coordinates the chromaticity coordinates for the standardized skin tone is calculated. The error is then plotted in a graph and compared to a tolerance circle.

Rear projectors

Rear projectors are constructed by use of three monochrome CRT's (red, green, and blue). The CRT's are optically coupled to a lens system which projects the three pictures on a screen. The screen is usually a fressnell lens having different light output in the vertical and horizontal direction. The less-than-a-semisphere opening angle makes it possible to define a screen gain for a given direction. Gain until 5 is possible but for good picture reproduction a gain much over 1.5 is not recommended. The front of the screen is made with vertical black and clear lines. This construction reduces the ambient light reflected in the screen. When measuring on such screens the measuring head has to have a size that makes the measurement independent of the screen structure. The CRTs used for projectors are in some cases with special phosphors, making a higher light output possible. In normal colour display CRTs only the red phosphor has a line spectrum, in projector tubes also the green phosphor may have a line spectrum. The line spectrum calls for higher accuracy in the filters simulating the standard observer response.

Drift In Colour Reproduction From The CRT - Heating Of The Slot Mask

The test signals for the measurement and calibration of white balance on colour monitors are window signals with an area of about 18%. The video level is 15 % (or 20 %) and 100 %. When the signal is changed between the two levels the CRT may need some time to settle to the new level. The change can include a colour drift lasting for several seconds, which will be observed by the colour analyser. If measurement by some reason is done with full field signal the drift may be much larger and when 100% video are used the slot mask in the CRT gets heated and may twist, creating a large amount of white field non-uniformity.

Colour Temperature And Correlated Colour Temperature

When a black body is heated to a given temperature measured in Kelvin [K] the black body is emitting light. This light is solely specified by the temperature and is said to have this colour temperature. The black body is sometimes called a Plankian radiator. The spectrum of the light from a Plankian radiator is very smooth and much like the spectrum of light from a tungsten lamp as well as the various phases of daylight. If, for example a lamp has a chromaticity point coinciding with the chromaticity of a Plankian radiator at temperature T = 6000 K, the lamp is said to have a "colour temperature of 6000 K". If the chromaticity point of the lamp is not located on the Plankian radiator locus, the temperature giving the chromaticity point which are perceived to be closest to the light from the lamp is chosen to specify the "correlated colour temperature". The nearest chromaticity point is the point which are perceived to give the light which are the best approximation to the light from the lamp. This means that two different light sources may have the same correlated colour temperature but they can look different! The recommended method of calculating the correlated colour temperature is to determine on the uv chromaticity diagram (not the u'v' diagram) the temperature corresponding to the point on the black body curve that is nearest to the point representing actual colour.

White References - Correlated Colour Temperature

For TV production the white reference D6500 with the xy coordinates x = 0.313 and y = 0.329 is used for reference in a majority of the worlds TV systems. The white reference D6500 is placed on the curve in the CIE xy diagram that represents the internationally accepted standard for various daylight. The daylight is not constant but depends upon the time of the day. The daylight curve does not coincide with the black body curve. The curve is in the CIE xy diagram close to a vertical shift of the black body curve (parallel to the black body curve). As the two curves does not coincide the daylight can not be represented correct by a colour temperature, but a Correlated Colour Temperature approximation may be used.

In the film industry 5500 Kelvin correlated colour temperature is often used. It is proposed in some HDTV systems to change to this reference in order to make the TV industry compatible with the film and print industry.

Consumer Sets

The adjustment of consumer sets has in the last decade be according to different white references. The colour reference was in the childhood of colour TV close to D6500 but the evolution has taken the white reference higher until about 9000 K cct (correlated colour temperature) - mainly in order to achieve a higher perceived contrast range. The ability to observe the direction of a desaturated colour afar from neutral (gray) is determined by the of origin. If the colour of gray is about 9000 K cct, the entire picture will be tinted blue - a photographer would call the picture "cold". This bias significantly reduces the colour fidelity of the display. The differences in consumer sets often do not exist in the video signal. It is the blue colour of gray that makes a "warm" scene such as a cozy fireside look wrong.

White Uniformity

In very high-end production facilities monitors may be used for comparison of pictures. When two monitors are beside each other and feed with the same signals, then the two monitors may not look exactly the same even when they are adjusted to the same colour in the center. To get the monitors look alike also the white field uniformity needs to be "equal". It is normally not possible to adjust the white field uniformity but if the user has access to several monitors the monitors may be selected by a uniformity criterion. The white field uniformity is checked by use of a special test pattern. EBU specifies a test pattern with 9 measuring areas. The monitors are adjusted for the best reproduction of D65 100 % video in the middle area, the colour balance is then checked in the other white fields and a selection can be performed.

PM5639 Learn Phosphor Facility.

In the PM 5639 an RGB display is implemented. The display consists of a bar graph display, showing a bar representing each of the three primary colours.

In the standard observer curves there exists a great deal of overlap between the three colour perception curves. The three sensors in the PM 5639 matches these curves, which means that when the green gun is adjusted both the green and red bar should react. This would be very inconvenient when the instrument is used for adjustment of a monitor. To remove this interaction we have included a LEARN PHOSPHOR facility which by mathematics removes the "crosstalk". This means that when the instrument is used on the correct phosphor then adjusting the red gun only changes the red bar.

Unfortunately at the same time a possibility for error has been introduced: if the RGB mode is used with an inappropriate phosphor selected for the adjustment, then the result can be a misadjusted monitor, since the interactions between the present phosphors and the standard observer curves may not be the same as between the erroneously selected phosphors. An easy way to check if the phosphor has been selected correctly is to check that an adjustment of one gun changes the corresponding bar only, or to check the adjustment result itself in the CIE mode.