Using RGB Colour Sensors
To Balance The Colour Reproduction of Display Screens

MCS colour sensors are typically used to characterise remitting surfaces that are illuminated with a suitable source (e.g. white LED).

Other applications requiring self-luminous objects to be identified in terms of their colour composition and intensity of the imaged colour position are increasingly coming to the fore. Once an actual value is determined, it provides the input for readjusting to a certain nominal colour.

Among the main applications are display screens, because they feature non-uniformities and are subject to a certain drift. Such effects can be identified through a varying chrominance when test images are displayed on different panel screens.

Manufacturers of technical image processing systems are seeking to achieve the mutual colour fidelity of a master and a duplicate image. The viewer is to be guaranteed that his/her colour impression on contemplating an image is in no way different from the impression when contemplating the master image itself. This requires all involved equipment components, from the recording to the reproduction of an image, to be matched to each other and additional colour information to be provided. The latter can be obtained with the help of MCS colour sensors. Comprehensive testing has been carried out regarding the registration of display screen colours with the help of MCS colour sensors and appropriate signal processing circuitry. As a result, MCS colour sensors have been shown to be suitable for the colour calibration of display screens.

Principle of Colour Generation for Display Screens

With the majority of display screens, colour representation is accomplished by varying the intensity of three defined spectral ranges (red, green, blue) and additive mixing of these spectral ranges (primaries).

Figure 1 shows the three primaries and the colour space that has been obtained using these colour portions in an additive colour mix (u´-v´-colour chart) of a CRT screen.

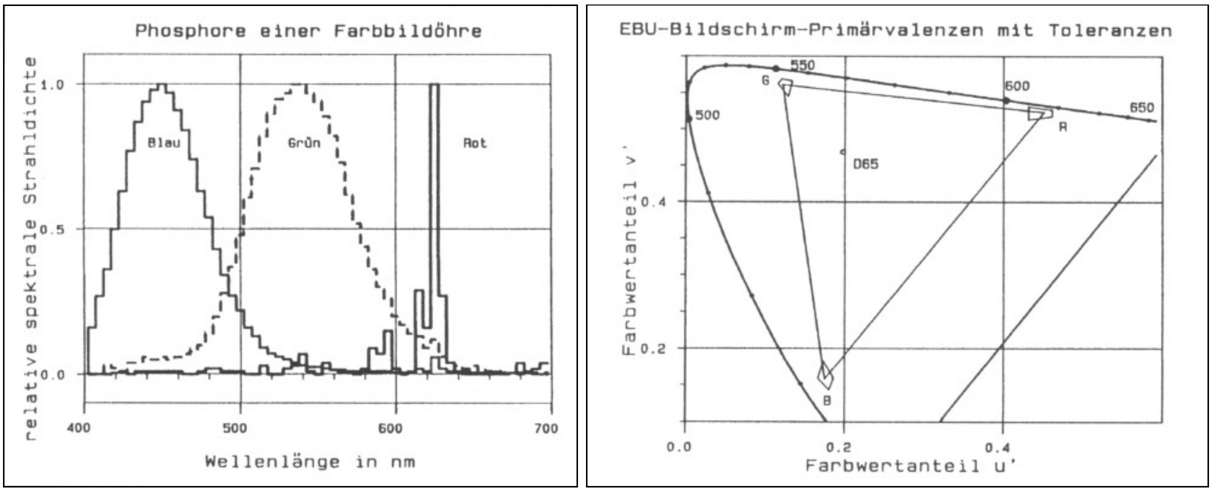
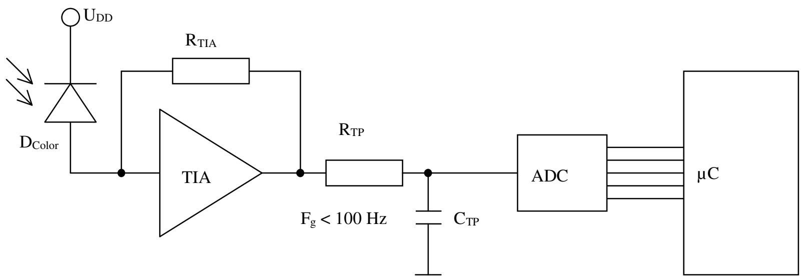


Figure 1 Because the colours are mixed from three defined colour portions (primaries), it is not necessary to use spectral sensitivity sensors for detection of the standard viewing function.

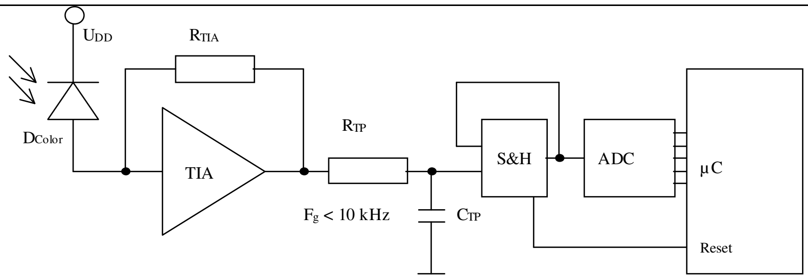
Each MCS colour sensor detects a defined spectral range (blue from 400 nm to 500 nm, green from 500 nm to 600 nm and red > 600 nm). Since MCS sensors operate with predefined spectral functions, there is a direct linear relationship between the RGB values that are detected for a given display screen and the RGB values measured by a sensor (R_{MCS}, G_{MCS}, B_{MCS}).

Circuit Versions For Evaluation of Colour Sensor Signals

To measure colours and evaluate the resulting colour sensor signals, different circuit versions have been analysed. A survey of selected circuit diagrams is provided in .

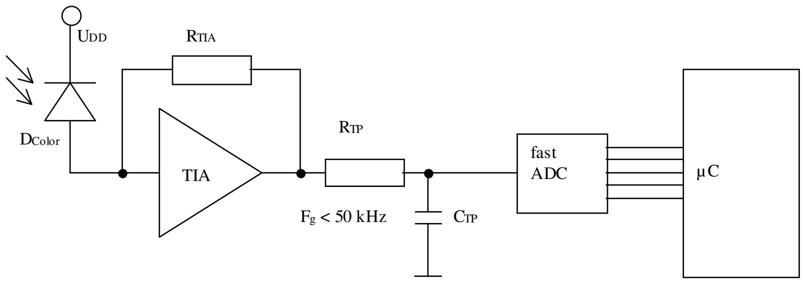
1. Analogue integration by high-grade low-pass filter	
	Once generated, the photocurrents are sent to a transimpedance converter (TIA) to be converted into a voltage. The photocurrents then enter an optimised low-pass filter to be smoothed to a constant DC level. An ADC with low speed requirements performs digitisation.

2. Analogue Max decoder through sample and hold feedback



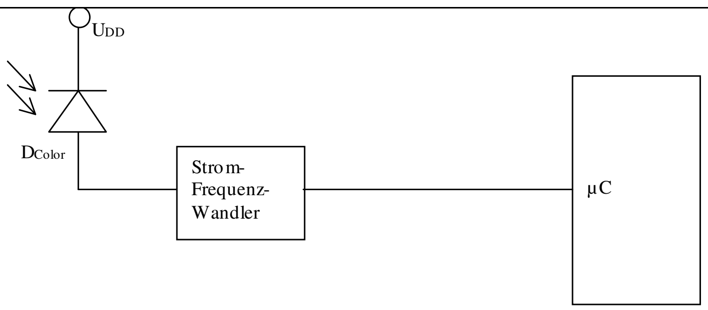
Low-pass filtering to round the line frequency signal follows transimpedance conversion. The resulting signal is representative of the image repetition rate. It is tracked with the help of a sample and hold feedback set-up and provides the ADC with a maximum signal.

3. Analogue/digital integration through low-pass filter and high sampling rate



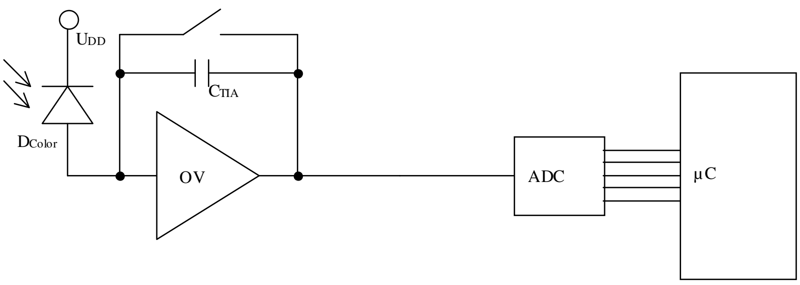
This TIA circuit with low-pass filter relies on an even lower limiting frequency. An ADC with a high sampling rate samples the resulting signal image. Appropriate software algorithms are then used to evaluate the signal diagrams and their residual ripples.

4. Digital integration through current-frequency converter



Current-frequency conversion directly produces countable pulses. These are added up at a digital input point of the μC over a certain period of time.

5. Analogue integration through current-charge conversion



In this circuit version, a generated photocurrent is additively integrated via an amplifier with capacitive feedback. At variable integration times, the charge level can be read off via an ADC. It can also be reset via the μC.

Table 1 Circuit versions for the evaluation of colour signals

The MCS3AS includes an isolating diode (non-filter diode structure to minimise cross-emission of the RGB diodes) that works concurrently to allow the spectral sum signal to be recorded and evaluated.

Using a simple transimpedance amplifier stage with a downline comparator circuit, the sum signal can then be processed as necessary. It is thus possible to monitor the image repetition rate of a CRT display screen. This is achieved by counting the comparator's flanks within a given defined unit of time and provides essential benefits for colour registration, because the colour signals are integrated in analogue mode (circuit version 5 of Table 1) that allows integration via an integer multiple number of the image repetition rate

If an additional pick-up is introduced at the TIA output and monitored with an ADC, it is also possible to distinguish between TFT-type and CRT-type display screens (circuit 2). While an image repetition rate can be counted at the comparator output in the case of a CRT display screen, which also provides the basis for integration time, a TFT screen will generate no flanks at the comparator output. Instead it delivers a DC level that is not equal to zero at the TIA pick-up point.

Figure 2 (lower graph) shows the signal behaviour of a CRT and Figure 3 (lower graph) that of a TFT display screen as output by the transimpedance amplifier stage.

Of the various circuit versions to process colour signals, preference has been given to that for the analogue integration of colour signals (circuit version 5 in Table 1). Figure 2 (upper graph) shows the integration signal of a CRT and Figure 3 (upper graph) that of a TFT display screen. The difference in levels is subject to evaluation, and is obtained for "n" image repeat cycles (CRT monitor), or a pre-defined integration time (TFT screen) at the output of the integrator.

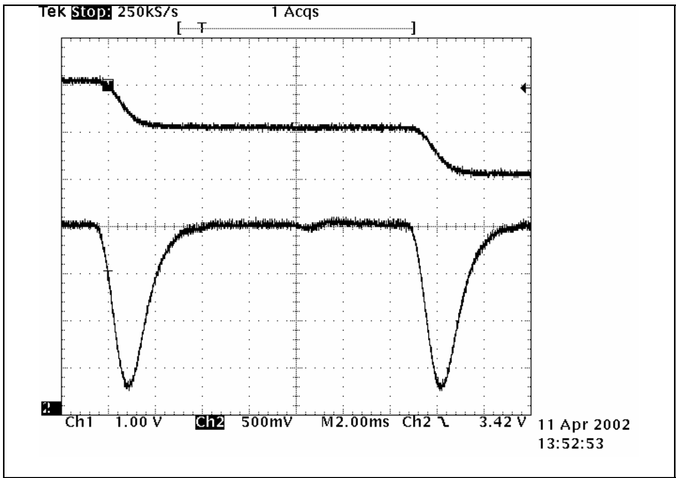


Figure 2 Signal behaviour of a CRT display screen

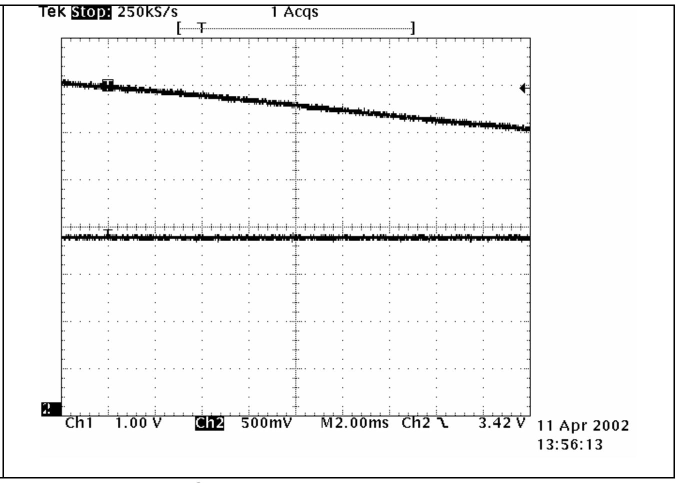


Figure 3 Signal behaviour of a TFT display screen

Linear Correction for Colour Balancing

In order to match various display monitors in terms of their colour profile (linear combination of primaries), it is necessary to determine the respective coefficients (ai;j) for linear combination (Equation 1). This is a necessary precondition for any colour correction that is to achieve a true colour representation on display screens.

For the correction of display colours, the required coefficients (ai;j) are obtained as follows:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{Soll} = \begin{pmatrix} a_{0;0} & a_{0;1} & a_{0;2} \\ a_{1;0} & a_{1;1} & a_{1;2} \\ a_{2;0} & a_{2;1} & a_{2;2} \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{Ist}$$

Equation 1

The RGB_{Ist} values represent the actual screen values of a given display screen that operates with certain inherent colorimetric errors. RGB_{Soll} designates the values that are output to the display screen. These provide the control variable to achieve corrected nominal colours (XYZ standard colour values).

Gauging of the System Measuring Display Screen Calibration

To be able to determine an unequivocal calculation pattern (Equation 2 of coefficient matrix described above) for different display screens, a gauged measuring system is required. A calibrated condition can be obtained, for example, by adjusting the measuring system to a reference (master) screen or using known XYZ standard colour values for mixed colour test charts of a suitable display pattern. For measurement of the XYZ standard colour values of test charts, a colorimeter should be used.

The settings obtained by adjustment to a reference screen (RGB_{Ist}) and the values measured for XYZ standard colours are then used to describe the colorimetric properties of a given sensor in a matrix of coefficients (k) that is specifically allocated to this sensor and store this data in a memory.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{Soll} = \begin{pmatrix} k_{0;0} & k_{0;1} & k_{0;2} \\ k_{1;0} & k_{1;1} & k_{1;2} \\ k_{2;0} & k_{2;1} & k_{2;2} \end{pmatrix}_{MCS} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{MCS}$$

Equation 2

Because the circuit integrates interference filters with long-term stability, the sensor need not be recalibrated.

Assessment of Display Screens

By applying a specific sensor coefficient matrix ($k_{i;j}$) to the values measured for RGB_{MCS}, it is possible to describe the XYZ standard colour values and variances against the nominal XYZ values for a given test chart.

If, on testing a display screen with variances, the same test charts that have been used for matching to a set of nominal RGB_{Soll} values are output as actual RGB_{Ist} values, the currently displayed XYZ standard colour values can be calculated by the sensor system as ($k_{i;j}$)*RGB_{MCS}=XYZ for subsequent determination of the coefficients ($a_{i;j}$) that are required to make appropriate colour corrections. These will then become part of the colour correction (colour management) matrix.

$$\begin{pmatrix} k_{0;0} & k_{0;1} & k_{0;2} \\ k_{1;0} & k_{1;1} & k_{1;2} \\ k_{2;0} & k_{2;1} & k_{2;2} \end{pmatrix}_{MCS} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{MCS} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{Soll} = \begin{pmatrix} a_{0;0} & a_{0;1} & a_{0;2} \\ a_{1;0} & a_{1;1} & a_{1;2} \\ a_{2;0} & a_{2;1} & a_{2;2} \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{Ist}$$

Equation 3

Each further colour output to the screen can thus be linearly corrected for colourfast display using a properly gauged colour correction system that is based on $a_{i;j}$ coefficients.

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