

## Using RGB Color Sensors To Balance The Color Reproduction of Display Screens

MCS color sensors are typically used to characterize 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 color composition and intensity of the imaged color position are increasingly coming to the fore. Once an actual value is determined, it provides the input for readjusting to a certain nominal color.



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 color fidelity of a master and a duplicate image. The viewer is to be guaranteed that his/her color 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 color information to be provided. The latter can be obtained with the help of MCS color sensors. Comprehensive testing has been carried out regarding the registration of display screen colors with the help of MCS color sensors and appropriate signal processing circuitry. As a result, MCS color sensors have been shown to be suitable for the color calibration of display screens.

### *Principle of Color Generation for Display Screens*

With the majority of display screens, color 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 color space that has been obtained using these color portions in an additive color mix ( $u'-v'$ -color chart) of a CRT screen.

## MCS To Balance The Color Reproduction

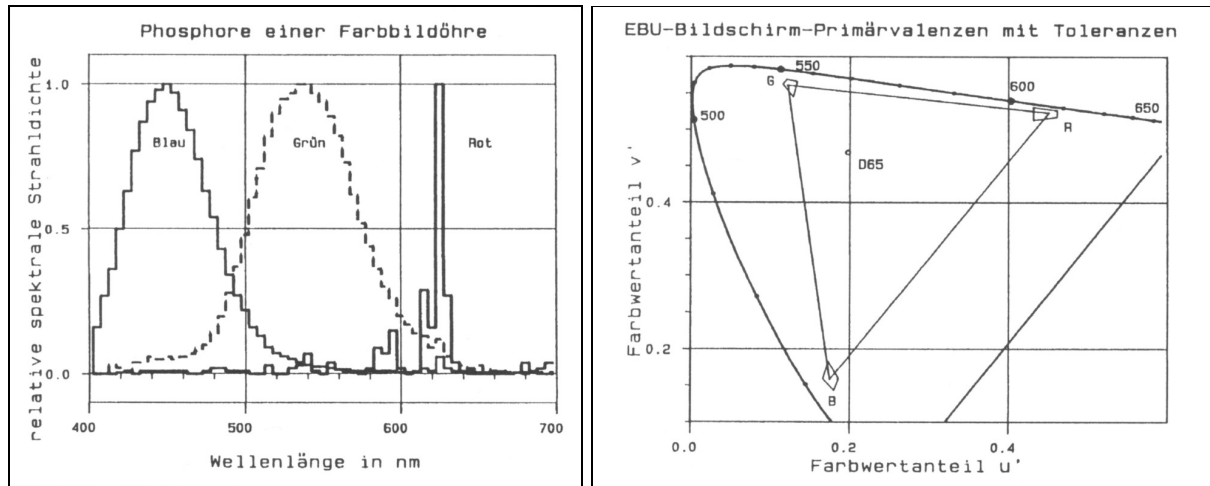


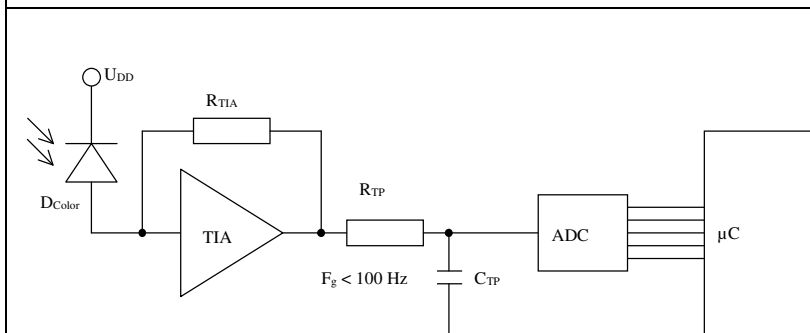
Figure 1 Because the colors are mixed from three defined color portions (primaries), it is not necessary to use spectral sensitivity sensors for detection of the standard viewing function.

Each MCS color 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 Color Sensor Signals

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

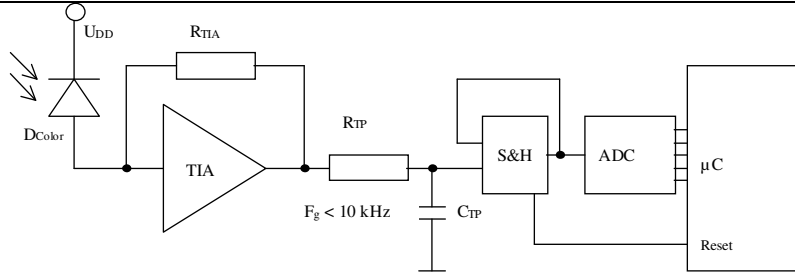
#### 1. Analogue integration by high-grade low-pass filter



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.

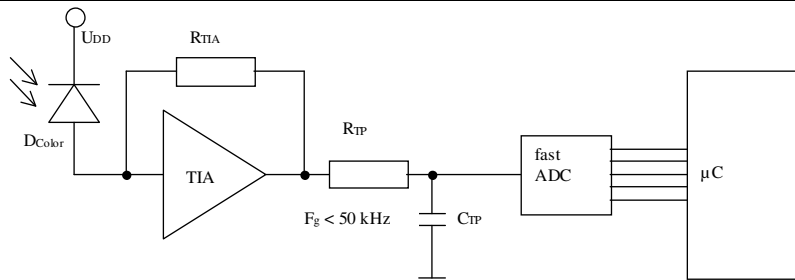
# MCS To Balance The Color Reproduction

## 2. Analogue Max decoder through sample and hold feedback



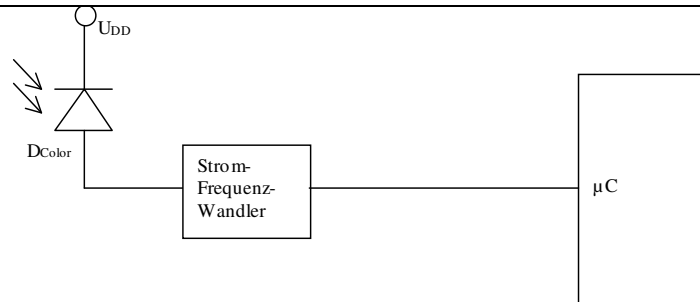
Low-pass filtering to round the line frequency signal follows transimpedance conversion. The resulting signal is representative of the image repetition rate. It is tracked with the help of a sample and hold feedback set-up and provides the ADC with a maximum signal.

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



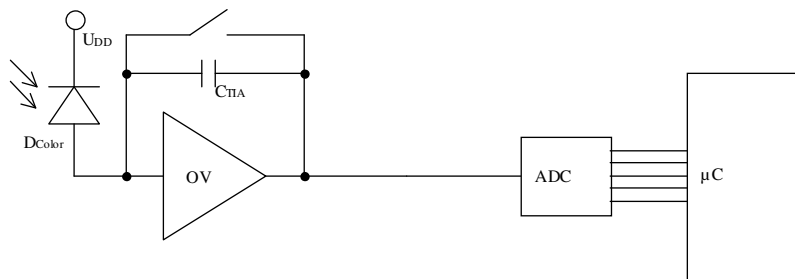
This TIA circuit with low-pass filter relies on an even lower limiting frequency. An ADC with a high sampling rate samples the resulting signal image. Appropriate software algorithms are then used to evaluate the signal diagrams and their residual ripples.

## 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  $\mu C$  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  $\mu C$ .

Table 1 Circuit versions for the evaluation of color signals

## MCS To Balance The Color Reproduction

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 color registration, because the color 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 behavior 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 color signals, preference has been given to that for the analogue integration of color 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.

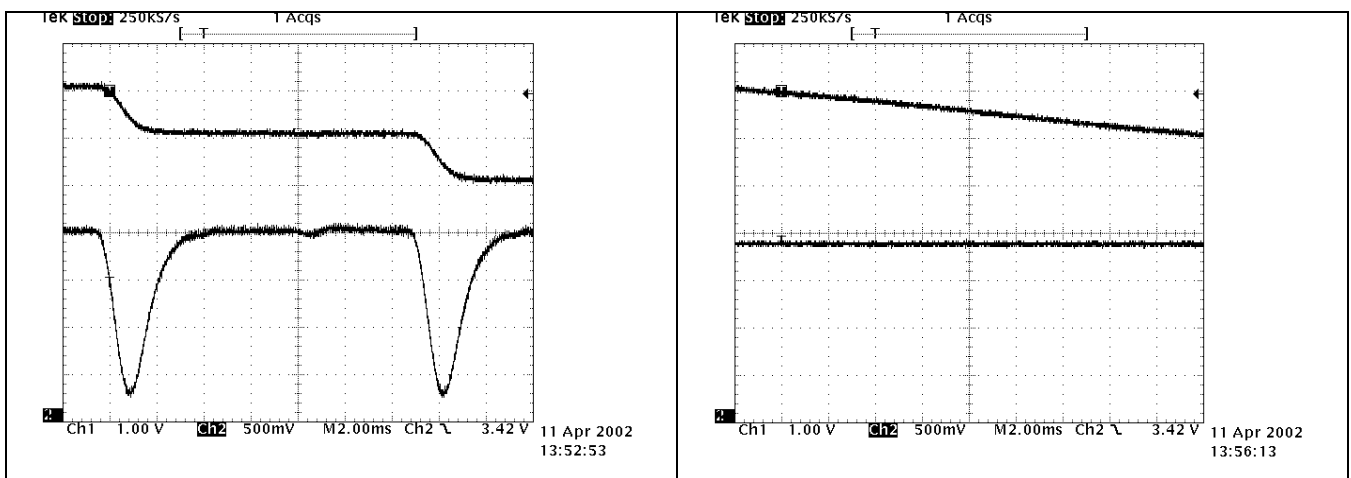


Figure 2 Signal behaviour of a CRT display screen

Figure 3 Signal behaviour of a TFT display screen

## MCS To Balance The Color Reproduction

### Linear Correction for Color Balancing

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

For the correction of display colors, the required coefficients ( $a_{i;j}$ ) 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 colors (XYZ standard color 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 color values for mixed color test charts of a suitable display pattern. For measurement of the XYZ standard color 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 colors 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.

# MCS To Balance The Color Reproduction

## Assessment of Display Screens

By applying a specific sensor coefficient matrix ( $k_{ij}$ ) to the values measured for  $RGB_{MCS}$ , it is possible to describe the XYZ standard color 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 color values can be calculated by the sensor system as  $(k_{ij}) \cdot RGB_{MCS} = XYZ$  for subsequent determination of the coefficients ( $a_{ij}$ ) that are required to make appropriate color corrections. These will then become part of the color correction (color 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 color output to the screen can thus be linearly corrected for colorfast display using a properly gauged color correction system that is based on  $a_{ij}$  coefficients.

## List of Illustrations:

Figure 2 Signal behaviour of a CRT display screen .....	4
Figure 3 Signal behaviour of a TFT display screen .....	4

## List of Tables

Table 1 Circuit versions for the evaluation of color signals .....	3
--	---

## Equations

Equation 1 .....	5
Equation 2 .....	5