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Application Note

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Spectral Sensor Calibration Methods

AS7343/AS7352 Evaluation Kit

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Content Guide

1 General Description

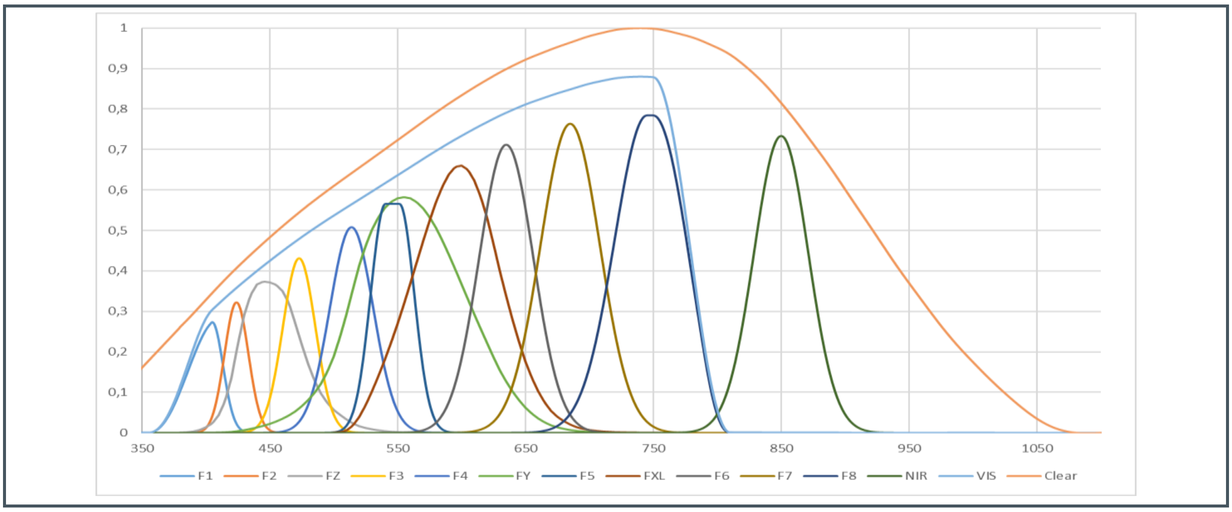
This Application Note describes how to implement correction and calibration methods by considering different effects based on the Spectral Sensor (and derivatives) Evaluation Kits (EVKs). It shows various steps, procedures, and approaches used for alternative methods of spectral and multi-spectral sensors. Everything is explained using the AS7343 (identical in construction with the AS7352) example. Other spectral sensors are similar in spectral technique, differing in the number of filters and peaks, but not in the algorithm and spectral sensor correction functions shown here. Therefore, the details shown here for the AS7343 example can also be used for all other similar spectral sensors with adaptation.

The following chapters show why and how to correct sensor results in general. Other documents describe it in more detail or give practical examples for the Evaluation Kits (EVKs) and their calibration (see [1], [2], and [3]). These methods can also be used for customer series calibrations, but must be tested and verified beforehand.

1.1 Filter Correction

The AS7343 is a 14-channel sensor for spectral identification and color matching applications. The spectral response has a wavelength from approximately 300 nm to 1000 nm. Eight optical channels cover the visible spectrum. One channel can be used to measure near-infrared light. The “Clear” channel is a photodiode without a filter (clear) for monitoring tasks, and the “Flicker” channel is prepared for flicker measurements.

Figure 1:
Typical Spectral Behavior of Each Channel in the AS7343



The spectral filters, in combination with the diodes and electronics, provide details about the measured spectrum of light on the sensor. The sensor results are dependent on the sensor arrangement and other direct effects such as series-related disturbances and deviations, as well as effects in the measuring process itself. Therefore, in a final system setup, a correction of the raw sensor values is necessary to eliminate the unavoidable disturbance effects and deviations. Furthermore, the conversion of the sensor results as raw digital values into physical parameters (the application) is necessary after the correction of the influences, and can be part of the correction and calibration.

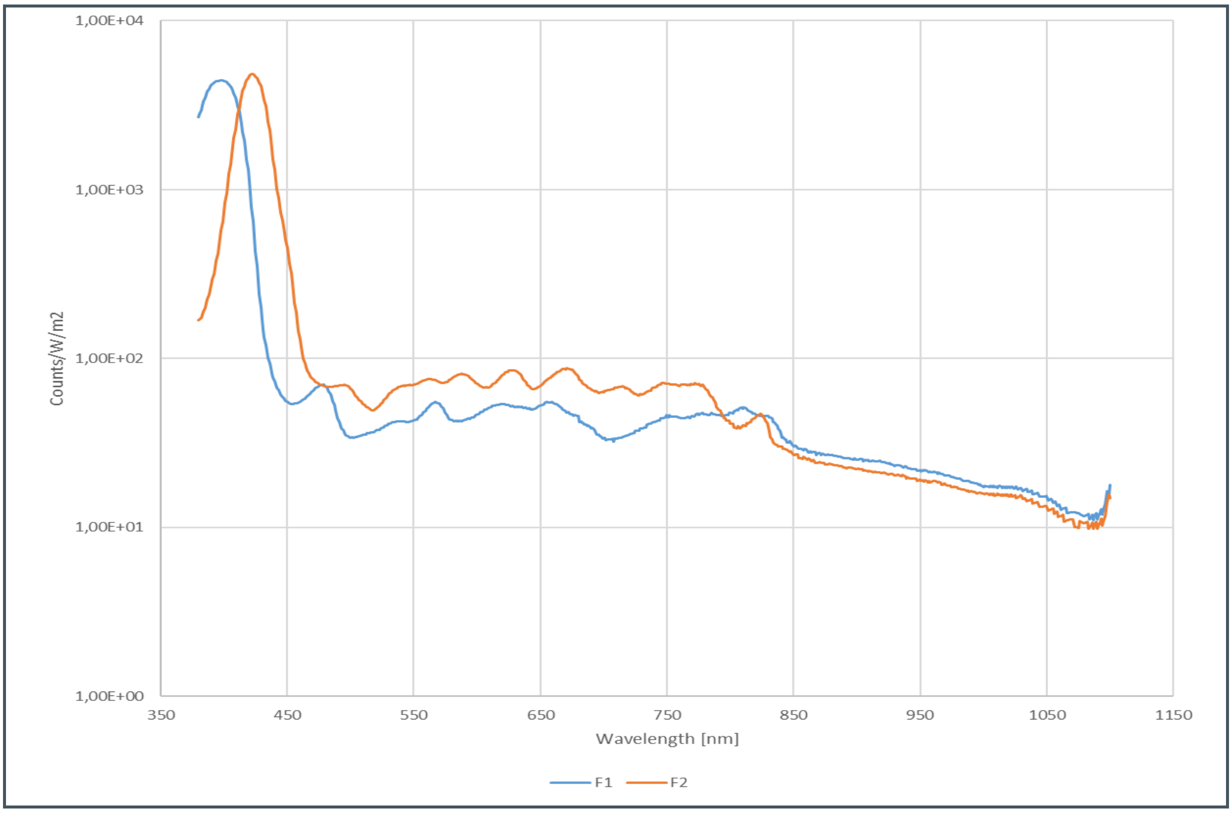
Theoretically, a narrow band filter in spectral sensors should only allow a unique light frequency that matches the filter spectrum in transmission to pass through (like a spectrometer).

In practice, and for the AS7343 sensor specifically, the transmission range and blocking outside of it is not ideal, resulting in optical interference. Secondly, the filters and sensitivity are not in ideal form. They are sometimes different in wavelength and vary slightly in the series in the specimens and lots.

Figure 2 shows the sensor-specific spectral response of filters 1 and 2 with filter overlapping (doubled active filter in transmission). The spectral values of the channels are not limited to the exact band wavelength (transmission and filter function), instead, it has an out-of-band spectral value in VIS and NIR (rest transmission in blocked wavelength). This is due to the opening of the optical channel band filters, which affects the sensor results.

For other sensors, it looks similar but different. Scaling factors, matrices, or special algorithms during the calibration and correction process will reduce such effects.

Figure 2:
AS7343 Channel F1 + F2 Spectral Response (logarithmic y-axis) with Rest Transmission



1.2 Diffuser Compensation

The photodiodes within the AS7343, or other spectral sensors, have a near cosine response to incoming light. Typical spectral filters used for channel separation are specially designed interference filter stacks on top of the photodiodes. Due to physical influences in the filter stacks, the interference filter technology is limited to an incidence angle range (AOI) and expects a Lambertian power distribution. The maximum angle of incidence to the photodiodes is limited to the design requirements of the filter stack by the aperture/pinhole of the package. The rays with the most obtuse angle hit the edges of the photodiodes from the opposite edge of the aperture. It is necessary to get a diffused light on the sensor to meet these requirements of power distribution. In the case of a non-diffuse application, the use of an achromatic diffuser is required, which emits light with Lambertian characteristics to the sensor, regardless of the angle of incidence. If the diffuser is very close to or directly on the sensor package, then its structure has to be very fine to get the same distribution to each photodiode of the detector array. On the other side, the diffuser also changes the spectral response and transmission of the sensor system because they always have their specific transmission curve, which is greater than zero and not constant. Therefore, a correction of the diffuser transmission may be required as one part of the calibration. The manuals and guides [1] to [3] list more details for the diffusers and EVKs.

1.3 Deviations and Disturbances

Disturbances influence the sensor results statically or dynamically. A verification and optimization process must correct or eliminate all these negative effects to obtain optimum results. The following list includes some examples, which can affect the accuracy depending on the application.

- Basic noise (e.g. dark current)
- Non-linearity Integration Time
- Gain Error
- Temperature and ageing effects from sensor and luminary (e.g. LEDs)
- Ambient Light
- Reflections inside the sensor system

Due to these different causes, there are differences between the expected and necessary behavior of a sensor and the actual real sensor responses. These must be measured for correction. It can be done by application-specific measurements using a target (e.g. color spectra that define the application) or by measuring the complete sensor behavior by scanning its response using pulses over the sensor dynamics (e.g. using a monochromator over the entire wavelength range of interest). For both methods, it is important that the measurements (a) fully represent the later application, (b) run under conditions of the intended application, and (c) remove all interference beforehand or consider the interference as individual or typical. It is not useful and practically worthless to measure the real sensor behavior for correction differently than it occurs in practice, which subsequently makes a correction senseless with the wrong results.

1.4 Measurement Setup

For sensor applications, the measurement setup and optical stability play a crucial role in accuracy and calibration. For calibration, the most stable and reliable measurement setup is selected.

Monochromatic test systems, spectrometers, or other reference devices are required to prove the test setup, measure the target pattern, and/or scan the sensor response. Furthermore, they are important to verify the sensor results and their corrections/calibrations. Reference devices depend on the sensor's dynamic range and should be active for the AS7343 from VIS (UV) to NIR, with a spectral range from 350 nm to 1000 nm. The highest accuracy for a reference device is essential when high accuracy for the sensor is expected. The reference instrument should be at least ten times more accurate or higher than the sensor requires.

The test setup with the sensor and reference device should be stable and free of any disturbances and drifts. They must be checked individually and systematically for each application, possibly after adding modules, to obtain typical applications or device-specific correction values. Use the sensor EVK for feasibility projects. The hardware, software, and adapters have been designed to be stable and ensure high accuracy for standard applications. However, the EVKs consist of bare hardware and are not shielded against any environmental conditions. They also only supply digits and raw values. Therefore, the customer has to adjust the EVKs + results and the calibration + corrections for their specific application. For more details, please refer to [2], [3], and other application notes on correction and calibration.

2 Methods of General Correction

2.1 Calculations with BasicCounts

Sensor results depend on a sensor-specific setup - the selected parameters for Gain (AGAIN) and Integration Time (TINT). However, changing these parameters under constant conditions in measurement should not change the real sensor response – RawSensorValues. Alternatively, ADC results are directly dependent on and approximately proportional to Gain and TINT[1]. The higher the Gain and TINT, the better the ratio between the signal and noise. Raw_Counts (= Raw Sensor Values) from the ADC must be transformed into a result, which is not dependent on the parameter setup but should achieve as maximum as possible. All sensor calculations are based on BasicCounts, which is defined in Equation 1.

Equation 1:

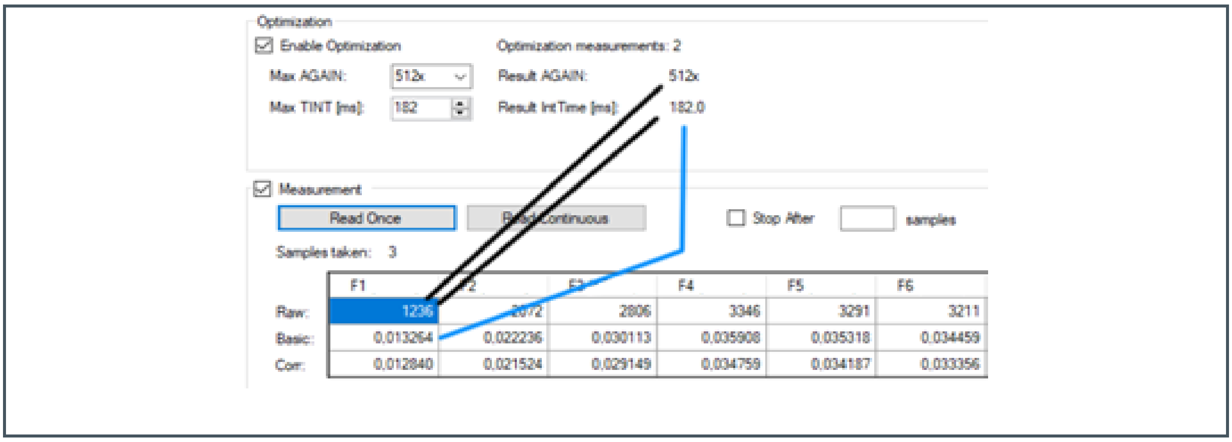
$$BasicCounts = \frac{Raw\_Counts}{(Gain \times Integration\,Time)}$$

Figure 3 shows an example from a protocol file with Setup, Raw_Counts, and BasicCounts. The BasicCounts in this example for F1 are calculated by:

Equation 2:

$$0.013264 = \frac{1236}{(512 \times 182)}$$

Figure 3:
Example of BasicCounts



[1] TINT (Integration time) selection can affect the counter for the sensor results. It means TINT directly determines the Full-Scale Range and saturation.

For all corrections and calibrations, always use BasicCounts or other calculated values without dependence on the setup and parameters, especially for dynamic gain and the like.

2.2 Offset

Here, offset is defined as a constant interference signal that continuously affects a sensor via the measuring process, for example, dark values, ambient lighting, or overcrossing. Each sensor channel has its offset characteristics. Therefore, consider offsets individually per channel.

The first step of the correction is to measure the offset. This often requires a special device setup. It is also recommended to check more than one sensor to see their individual, lot, and series deviations. Averaging can be a method to get an approximated and typical value for correction or to use the individual offsets as part of a single device calibration.

The second step is to calculate or define correction values based on the offset measurements (and averaging). These offset correction values will reduce the raw sensor values in the sensing process by a simple subtraction:

Equation 3:

$$SensorCorrectedValueOffset = BasicCounts - BasicCountOffset$$

The offset can be set in the GUI initialization and calibration files, as shown in the following example. It is important to always use BasicCounts for offset correction.

Figure 4:
Example of Calibration Files with Specified Offset and Factors for Corrections in the EVK

```
//OffSet values decreases Basic values - example Pen
OffSet=0.009906;0.027358;0.013936;0.04078;0.046826;0.05566;0.042624;0.03289

// Correction factor of Raw values
CorrectionFactor=0.55500034;0.454630147;0.485751323;0.511139519;0.482990316;0.531305638;0.53409503

//Correction factor for gain error
//0.5x.1x.2x.4x.8x.16x.32x.64x.128x.256x.512x
CorrectionGain=1.0240;1.0240;1.0240;1.0400;1.0000;1.0000;1.0000;1.0000;1.0000;0.9875;0.968

//correction factor to correct Y as Lux from CIE1931 Y
corr_lx = 683
```

2.3 Gain Correction

Gain, like TINT, is one of the parameters of the ADC that affects the size of the Raw_Counts. The higher the gain, the higher the counts as long as the sensor does not go into saturation (affected by TINT), which sets the length of the counter for the counts (FSR = Full-Scale Range = 16-bit = 65335 counts).

Gain is largely linear, i.e. increasing gain by a factor of two results in almost double counts. However, there is a small deviation in the fine range, which is called gain error or gain non-linearity. The deviation is individually different per sensor and in each gain and sensor channel, and can be corrected depending on the degree of accuracy. In the datasheet, the gain error is defined as an average value with min/max, and usually found in the chapter “Optical Characteristics”. It is better to measure the gain error in the system and form correction values. These correction values are multiplied by the basic counts if the application needs gain correction. This is always interesting when measuring with changing gains in an application and the non-linearity affects the results. If an application measures with only one gain, gain error has no effect. When applying automatic gain settings, note that BasicCounts are used in the process and must be corrected if necessary, including offset correction.

Figure 5:
Result of Gain Test with Gain = 128 Normalization, Min/Max and Deviation in Percent

Gain	Basic F1 (405nm)	Basic F2 (424nm)	Basic FZ (440nm)	Basic F3 (473nm)	Basic F4 (514nm)	Basic FY (546nm)	Basic F5 (546nm)	Basic FXL (596nm)	Basic F6 (635nm)	Basic F7 (670nm)	Basic F8 (710nm)	Basic Clear	Basic NIR	Fain/b= 128	min	max	dif
0,5	1,02	1,02	1,01	1,02	1,01	1,02	1,02	1,01	1,02	1,02	1,01	1,02	1,02	1,02	1,01	1,02	1,8%
1	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	0,7%
2	1,02	1,02	1,02	1,03	1,02	1,02	1,02	1,02	1,03	1,02	1,02	1,02	1,02	1,02	1,02	1,03	0,6%
4	1,03	1,02	1,02	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,02	1,03	1,03	1,02	1,03	0,5%
8	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	1,00	0,99	0,99	0,99	1,00	0,99	0,99	1,00	0,8%
16	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,99	1,00	0,99	0,98	0,97	1,00	0,99	0,97	1,00	3,0%
32	1,00	1,00	1,00	1,00	1,00	1,01	1,00	1,00	1,00	0,99	1,00	1,00	1,01	1,00	0,99	1,01	1,3%
64	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,01	1,00	1,01	1,01	1,00	1,01	1,4%
128	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	1,00	1,00	1,00	0,0%
256	**1,02**	**1,02**	**1,02**	**1,02**	**1,02**	**1,02**	**1,02**	**1,02**	**1,02**	**1,01**	**1,02**	**1,02**	**1,02**	1,02	1,01	1,02	0,6%
512	**1,05**	**1,05**	**1,05**	**1,05**	**1,04**	**1,05**	**1,05**	**1,04**	**1,04**	**1,04**	**1,05**	**1,05**	**1,05**	1,05	1,04	1,05	1,0%
1024	**1,02**	**1,02**	**1,02**	**1,00**	**1,02**	**1,00**	**1,02**	**1,02**	**1,00**	**1,02**	**1,02**	**1,02**	**1,02**	1,02	1,00	1,02	2,7%
2048	**1,02**	**1,03**	**1,03**	**0,98**	**1,02**	**0,99**	**1,03**	**1,03**	**0,98**	**1,02**	**1,03**	**1,02**	**1,03**	1,02	0,98	1,03	5,4%

Figure 6:
Results of Gain Test from Figure 5 as a Diagram (y-axis In logarithm form)

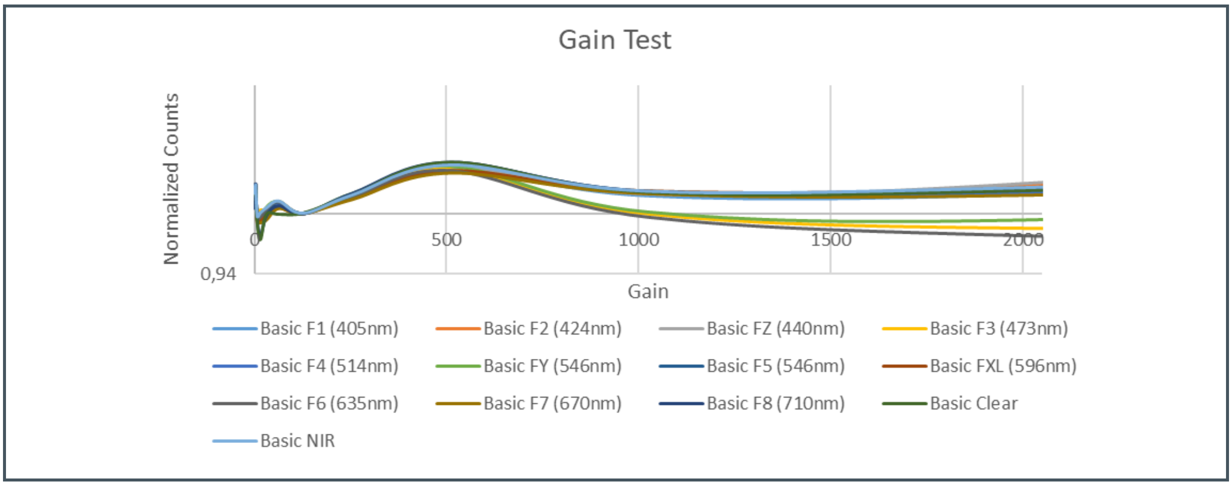


Figure 5 shows the results from a series of measurements in which a light source was measured at all gain levels with one sensor. The results were then normalized to a gain and the deviation was calculated. It can be seen that up to a gain of 512, the gain error is <1% and possibly negligible. Other sensors of the same type would give similar but not identical results. All gains greater than 512 are "not corrected" and lead to larger errors, which must be individually corrected.

Equation 4:

$$SensorCorrectedGainValue = BasicCounts \times GainCorrectionMatrix[Filter; UsedGainStage]$$

Figure 7 shows the gain correction values of the AS7352 EVK in the initialization file as a matrix. The red values should be created individually, while the black values can be used globally as an approximation.

Figure 7:
Recommend Gain Correction for the AS7352 EVK

Gain Matrix	0,5	1	2	4	8	16	32	64	128	256	512	1024	2048
F1	1	1	1	1	1	1	1	1	1	1	1	1	1
F2	1	1	1	1	1	1	1	1	1	1	1	1	1
FZ	1	1	1	1	1	1	1	1	1	1	1	1	1
F3	1	1	1	1	1	1	1	1	1	1	1	1	1
F4	1	1	1	1	1	1	1	1	1	1	1	1	1
FY	1	1	1	1	1	1	1	1	1	1	1	1	1
F5	1	1	1	1	1	1	1	1	1	1	1	1	1
FXL	1,05011	1,04866	1,04796	1,05040	1,05224	1,05001	1,05001	1,05268	1,05321	1,04719	1,05179	1,05025	1,04809
F6	1,04749	1,04746	1,04710	1,04951	1,05201	1,04988	1,04988	1,05226	1,05256	1,04729	1,05129	1,04992	1,04965
F7	1,03034	1,03032	1,03053	1,03250	1,03417	1,03295	1,03295	1,03440	1,03462	1,03119	1,03342	1,03242	1,03249
F8	1	1	1	1	1	1	1	1	1	1	1	1	1
NIR	1,03330	1,03476	1,02986	1,03691	0,98815	1,02900	1,02900	0,98762	1,02171	1,04011	0,98742	1,01948	0,98727
VIS	0,98686	0,98088	0,94698	0,98554	0,92624	0,95981	0,95981	0,94269	1,00763	1,02546	0,92870	1,00130	1,04128

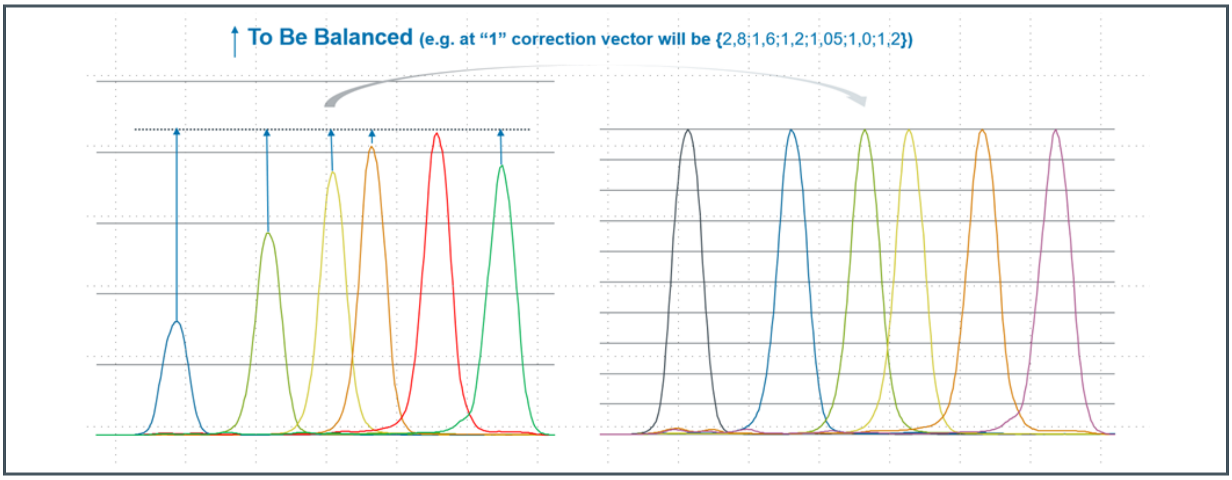
Device (Individual) Calibration

This method is the most complex but has the highest accuracy. The targets must be measured separately with and for all the sensors. Then, the data of each sensor is compared with the reference data to get a device-specific and individual calibration matrix. It is necessary if there are deviations between the individual sensor systems or devices.

2.4 Normalization/Scale

Scale procedures are corrections when the sensor results show a percentage error compared to the reference values. Such values can be the results of targets measured by the reference. In general, the correction factor for each channel is the result of balancing reference values and sensor readings. The result of the scaling is a correction vector, which includes correction factors for each sensor channel. All the values are BasicCounts.

Figure 8:
Typical Spectral Channels Before and After "1"-Scale (or Balance)



Scaling procedures are often used to adjust the behavior of sensors for one defined reference point, e.g. the minimum, maximum, or any other point from the series test (see Figure 8).

According to the objectives, a one-point correction or two-point correction is applied. A typical formula for such a scaling using one reference point is:

Equation 5:

$$SensorCorrectedValueScaled = \frac{ReferenceValue}{SensorCorrectedValueOffset}$$

One-point correction means the sensor response of all sensors in an application will be calculated to be scaled at one-point (e.g. Minimum (min), Maximum (max), or somewhere between min and max). The title of this method is "White or Black Scale".

If the sensor results are normalized between two-points (e.g. Dynamic Scale or Black/White Scale), then these two-points will be used in the formula:

Equation 6:

$$SensorCorrectedValueScaled = \frac{(X - X_{min})}{(X_{max} - X_{min})}$$

Where,

- X is the $SensorCorrectedValueOffset$
- X_{min}/X_{max} are the two min/max reference Values

Figure 9 to Figure 13 show an example of scaling in a light application.

The example describes the light detection via the spectral sensor and inserts the spectrometer target data (Figure 9), the sensor results as raw sensor values, and the corrected sensor results after scaling (Figure 11).

The correction uses scaled “Sensor values to spectrometer targets” for one defined light source – daylight is used here. The result of scaling is the correction vector, which includes, for each channel, a value representing the deviation sensor RAW to a spectrometer (Figure 10). These correction values are useful to correct sensor results and also for other light sources. In the example, a daylight source and its results and target show the accuracy of the scale procedure.

The results in the diagram(s) are good for such a primitive correction method but can be better using matrices. The difference between scale and matric methods is the number of used targets. A higher number of reference targets can dramatically increase accuracy for calibration.

Figure 9:
Comparison of Spectrometer Results and Sensor RAW Data for Daylight

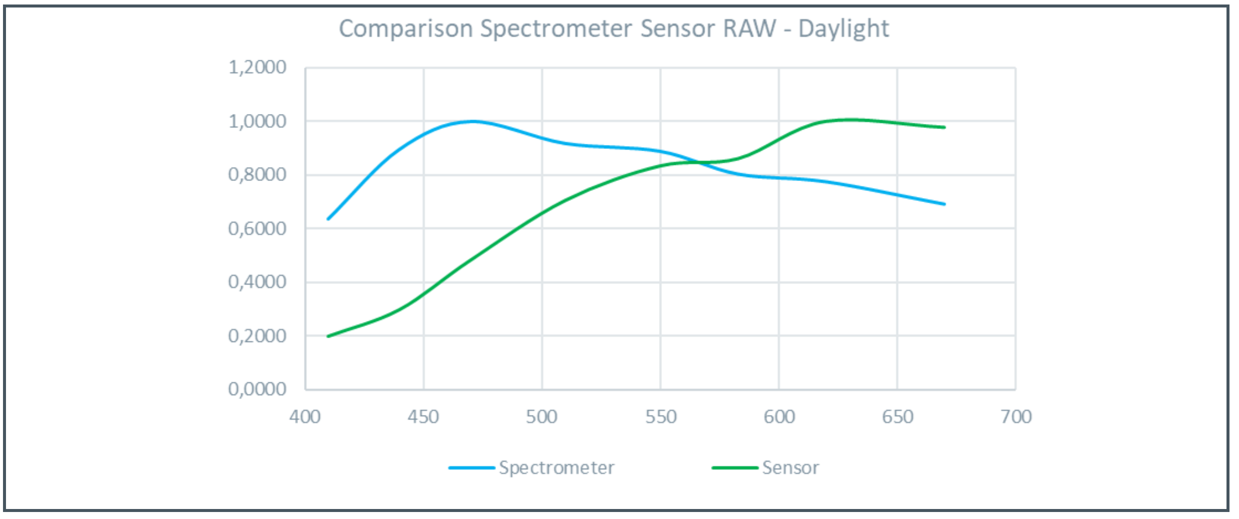
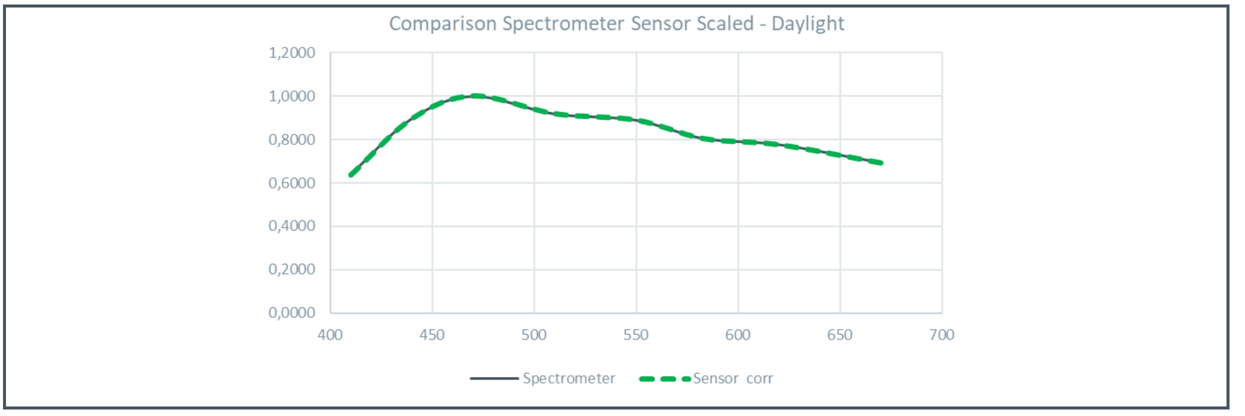


Figure 10:
Correction Factors Based on Daylight Scale (Spectrometer values/Sensor Raw-Data)

	F1	F2	F3	F4	F5	F6	F7	F8 …
CorrFact	3.20	3.00	2.07	1.30	1.07	0.93	0.78	0.71

Figure 11:
Comparison of Spectrometer Results and Sensor Corrected Data for Daylight (1)



(1) Curves lie on top of each other.

Figure 12:
Comparison of Spectrometer, Sensor RAW, and Sensor Corrected Data for LED Light

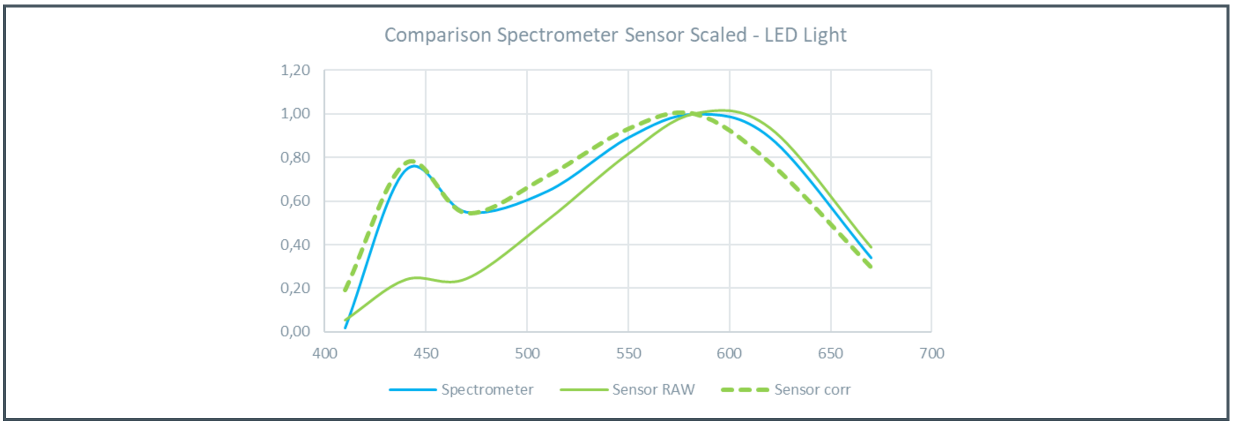
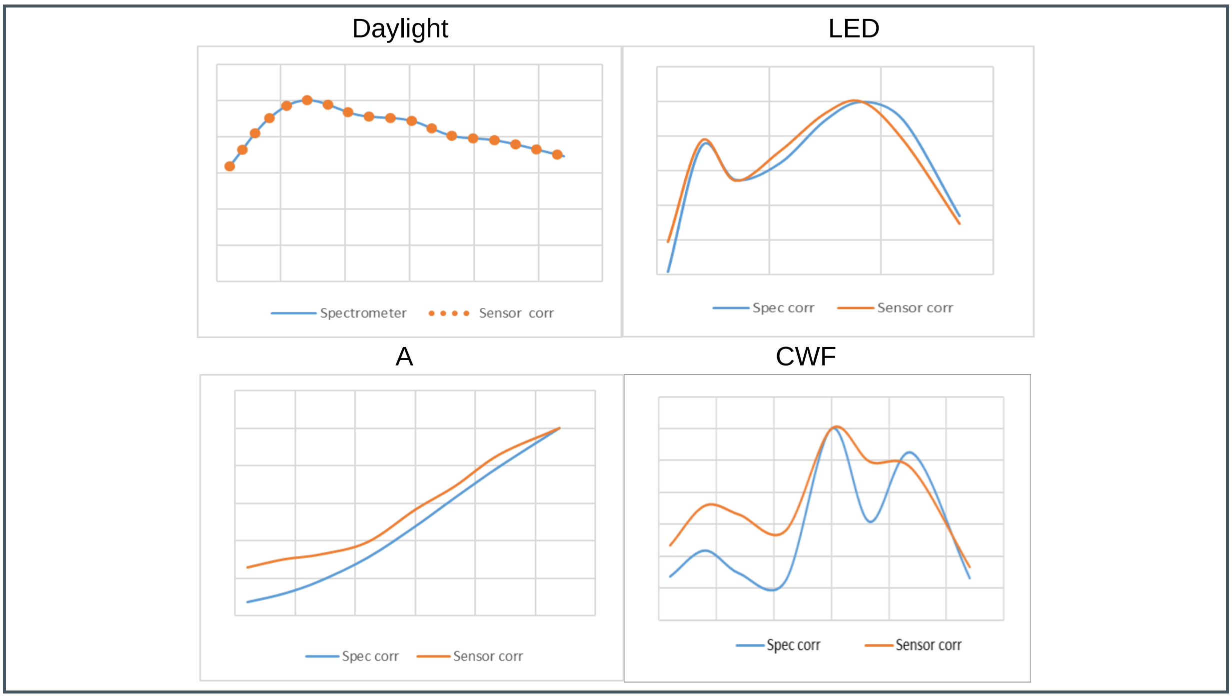


Figure 12 shows a comparison between the results of a spectrometer, sensor RAW, and corrected data for an LED Light under the condition of using daylight for calibration. The sensor corrected results (broken green line) are much closer to the spectrometer results than the unscaled results (green line). The accuracy after correction for LED lighting is lower than for daylight because, for both corrections, a scaling based on daylight was used.

Figure 13:
Comparison of Spectrometer Results (blue), Sensor Corrected Results (based on daylight scaling) for Daylight, LED, A, CWF (red)



Often the correction via a correction reference does not lead to the desired result (e.g. daylight in Figure 13). Then, it can also be tested if several references and their correction vectors, used as an average in one, leads to a better result. Thus, different ways may have to be tested for success.

2.5 Referencing Via Matrix-Based Methods

Alternative calibration methods are used if there are more than one or two reference values (white and/or black balance), which affect each other. Such an algorithm considers a relationship between n reference values = n targets T, measured with a reference device, and the sensor results = values S (individual or typical) of the identical target. This relationship between T and S is described in a Calibration Matrix K - which represents a correction function that corrects and matches the sensor results into the application-specific values measured with the reference device. It means such a method is corrected and matched in one-step. The target data determine the dynamics of the measuring range that is not only a three-dimensional color space but also a reconstructed spectrum or something else. Therefore, the matrix dimensions of the target and the algorithm must be matched.

2.5.1 Global/Local Calibration

If the target represents the entire dynamic range of the application, we are referring to a global target (e.g. the entire color space of natural colors) and a “Global Correction” matrix. If the target represents only a small part of the application (e.g. only red colors as part of the entire color space), we refer to a

"Local Correction" and local correction matrix. However, a localized correction also only produces corrected results for this part of the target and is therefore only applicable to this smaller part. However, it can lead to better results under certain conditions, since the correction function has to consider fewer targets. Therefore, a two-step calibration can be advantageous if the global correction only determines the subspace in which one is located, then the local corrections are applied to this smaller part of the target. For example, a global color correction in the CIE1931 space is used to define an approximate position in the color space. Then, for example, a local matrix defined as a "red-oriented matrix" can be used, which corrects "red' more precisely (but does not take green as a color location into account). Figure 14 shows for a color x (dark skin of the color checker), the comparison of the targets and the results for the global and local correction, if the target was reduced from 24 colors to 12, to the colors which have the smallest color distance Delta E around color x. The error in Delta ab can thus be reduced from 1.3 to 0.4 (or Delta E from 1.7 to 1.4) for the correction for this color x (dark skin).

The error here is always the deviation of the sensor values corrected by the matrix from the reference value (measured with a spectrometer). It is important to make all measurements with the sensor and reference device under identical conditions close to the application. Each deviation from calibration and application decreases the accuracy.

The method of "Linear Regression"[2] is often an algorithm, where the calibration matrix values are determined from S and T. The following formulas of linear regression with transposed and inversed matrix calculations define calibration matrix K by using S and T:

Equation 7:

$$K = (T * S^T) * (S * S^T)^{-1}$$

Where,

- S = Sensor values as a matrix (including offset correction and based on BasicCounts),
- T = Reference values as a matrix and Target measurement from a spectrometer, and
- K is the Calibration Matrix (CM) that can be used to correct and match the sensor results.

[2] An alternative to "Wiener Inverse".

Figure 14:
Comparison Results and Targets for "Dark Skin" Global (Left) and Local Correction (Right)

Delta Global Correction	
Delta ab	1,31426
Delta E	1,71191

Delta Local Correction	
Delta ab	0,37337
Delta E	1,42966

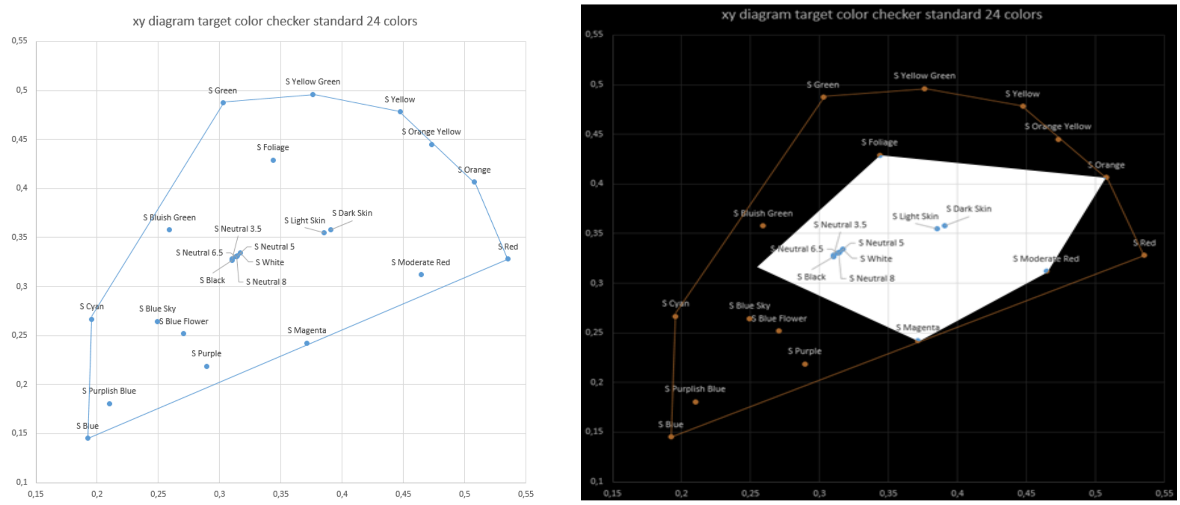


Figure 15 shows the general flow in the generation of the calculation of the matrix. From the point of view of calibration, the sensor accuracy, as a result of calibration, is dependent on the calibration procedure, used targets (number, quality, relationship), as well as from the generation and validness of the relationship of the Target (T) and Sensor results (S).

The algorithm and target must be adapted to the application and required accuracy and conditions of the sensing process. The number and quality of targets must represent the application-specific product. Targets can be optimized to get a minimum deviation per target (as a "typical, min or max error" or averaged over all the targets), compared with the reference device.

2.5.2 Device/Batch/Type-Oriented Calibration

A calibration matrix can refer to a device-specific calibration, a GD[3]-batch calibration, or a GD-type calibration. It depends on which sensor data are used for calibration.

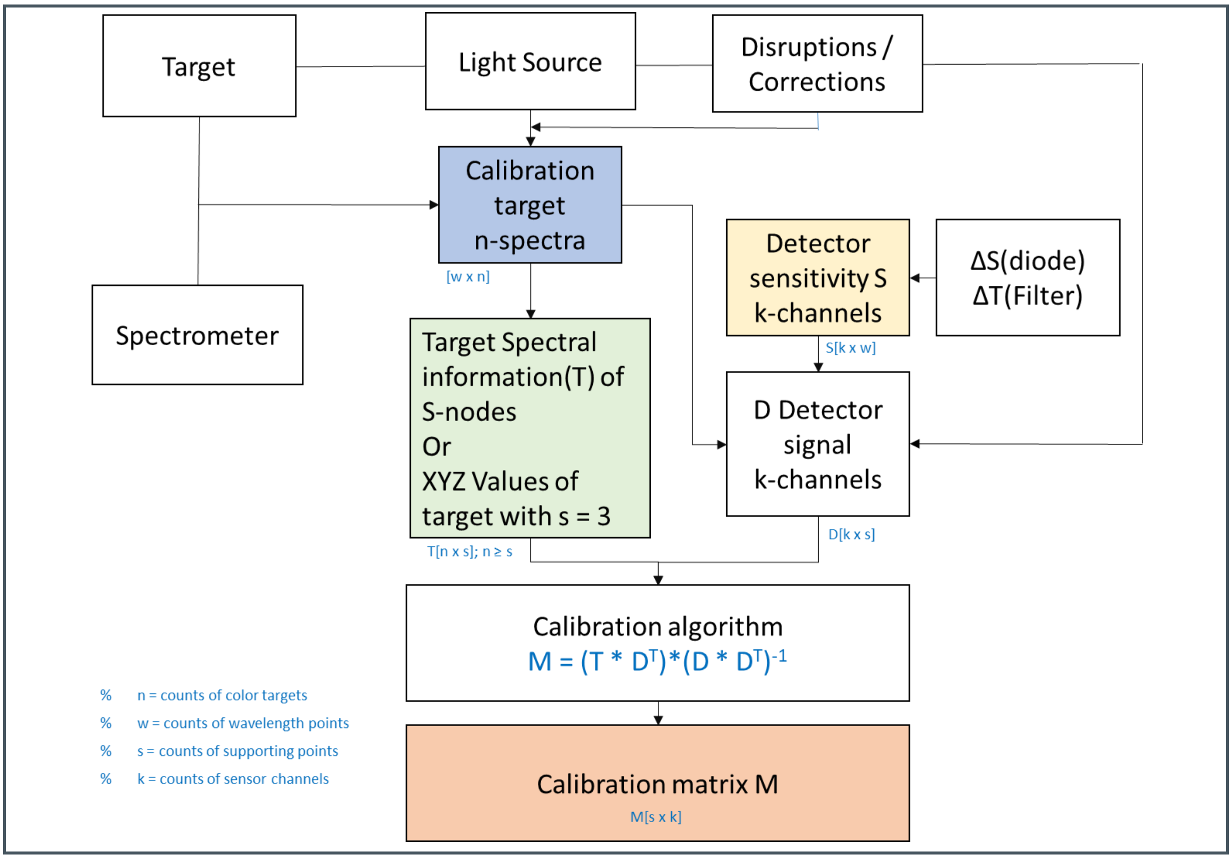
Batch Calibration

Here, the targets are captured with one sensor from a batch and calculated with the reference data. The result is typical for all sensors in a batch. Therefore, this method is less complex, but does not

[3] GD = Golden Device

consider the individual deviations of the sensors. This is recommended if there are very small deviations between the individual sensor systems in the batch.

Figure 15:
Parts and Effects During the Calculation Process of the Calibration Matrix



Type Calibration

Here, the targets are captured with a sensor as a prototype and calculated with the reference data. The resulting calibration matrix is for all sensors of this type, without consideration of the individual deviations or changes over time and all the batches. This method has the smallest effort but produces the worst results. Use this method in combination with a scaling where the individual deviations are corrected. In this case, the advantages can be used – the low effort of a Device-to-type calibration by a simple scaling to correct individual issues.

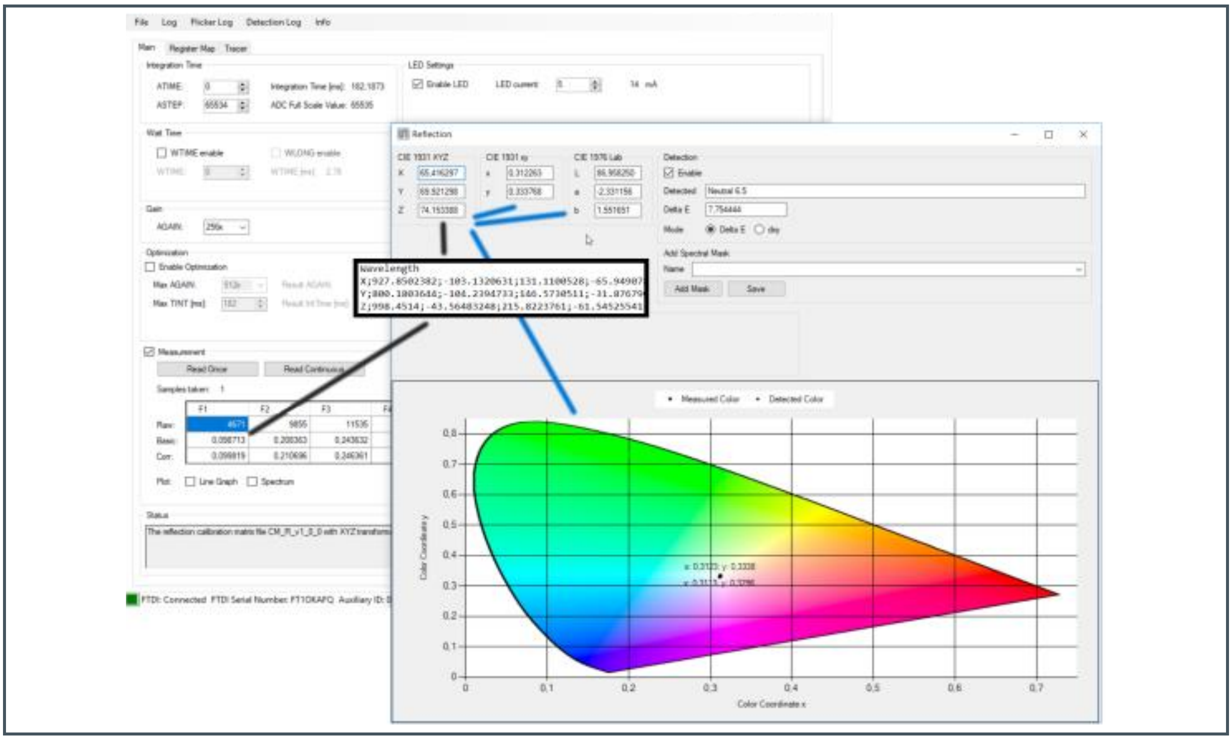
2.5.3 Calibrations in the AS7343 EVK GUI

The GUI from the AS7343 EVK was prepared to measure, correct, and map the sensor's data from light sources directly = luminary mode[4] (light in emission and transmission) or in reflected mode[5] (reflected light from objects).

For the luminary mode, two alternative calibration matrices were prepared. The first matrix corrects the sensor spectral values directly into CIE1931 XYZ values (Figure 16); the second generates a reconstructed spectrum with a step size of 1 nm (Figure 17). A spectrum evaluates itself, allows a spectral fingerprint, or works with CIE1931 XYZ quantities after mapping it with an XYZ standard observe function.

The following figures show the AS7343 GUI for both modes, from BasicCounts to the corrected values via offset, scaling, and calibration by matrices. Depending on the mode and the deposited calibration matrix (see marked the black boxes in Figure 16 and Figure 17), Raw_Counts are transformed by the calibration into a spectrum (then spectrum into XYZ) or directly into XYZ values.

Figure 16:
BasicCounts to XYZ Values Based on XYZ Calibration (1)

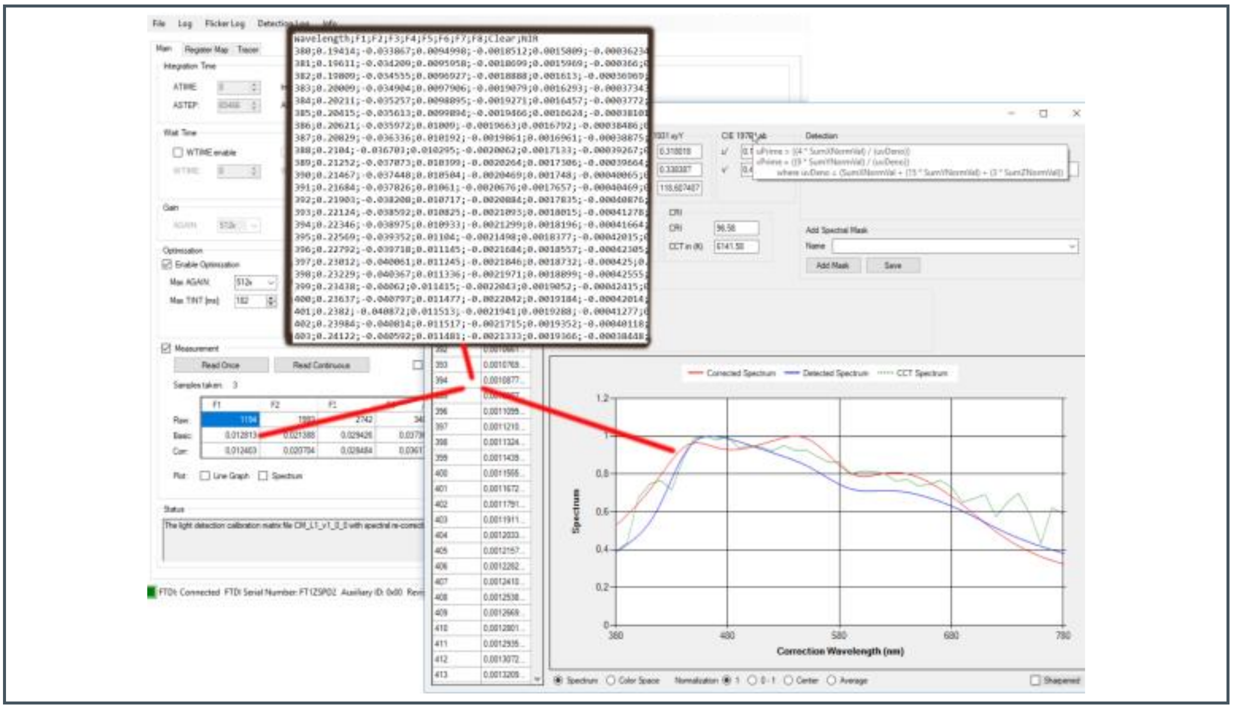


(1) Filter names in the GUI and initialization files can vary based on different GUI versions.

---

[4] **Filter calibration:** Using a general calibration matrix that was created from filter spectra (Golden Device measured with monochromator) and Wiener Inverse Algorithm.
[5] **Target calibration:** Using a general calibration matrix based on 24 Color target calibration (Color Checker Large from Co. XRite) measured with a golden device and an individual offset corrected and white balanced.

Figure 17:
BasicCounts to XYZ Values Based on Spectral Calibration (1)



(1) Table for Calibration matrix interrupted. See the original spectral CM file after the EVK installation.

In the following subchapters, some examples show typical processes for calculating and using calibration matrices. The algorithm and data are identical to the AS7343 GUI, whose matrix usage is described above in chapter 2.5.1.

Light Detection Example

In the ALS Excel sheet, all steps from the ADC sensor values to the photometric results in light detection are shown based on two alternative calibration methods – “reconstructed spectrum” and “direct XYZ matching”. Both methods are also part of the GUI.

In spectral reconstruction, the calibration matrix (CM) for light detection is a spectral matrix with a step size of 1 nm, within the wavelength 400 nm to 1000 nm. The calibration then yields a reconstructed spectrum in the given wavelength, which can be used for an XYZ calculation by multiplying the reconstructed spectrum and the CIE1931 standard observer function XYZ. If XYZ calibration is used, the target must be a reference between the sensor ADCs and the reference values measured with a spectrometer. The results after calibration are direct XYZ values for the actual measurement. The calibration matrices for both variants were created with a Golden Device (GD) sensor selected with a typical sensitivity. The sensor was stimulated with typical light sources and referenced with the spectrometer results to the calibration matrices representing device-to-type calibrations. Since all the sensors have deviations from this GD, all the sensors must be adapted or scaled to the GD. A scaling to daylight or another homogeneous light spectrum can do this. The results of the calibration for light detection are XYZ photometric values that can be used to calculate Lu'v', CCT, and Lux. The use of spectral calibration also allows typical calculations based on spectral values such as CRI or advanced functions (e.g. light source detection by Spectral Mask Compare).

Figure 18:
Alternative Calibration Process for Light Detection

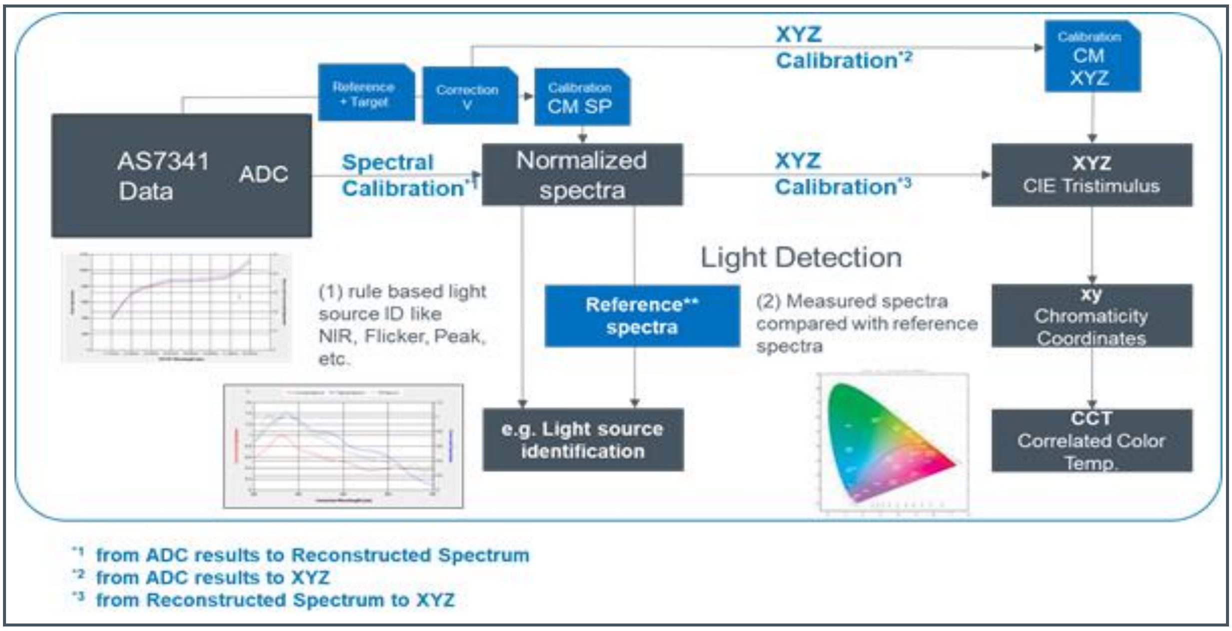


Figure 19 up to Figure 21 show a part of an excel sheet with a calibration procedure based on the algorithms “spectral calibration” and “XYZ calibration”. The excel sheets explain all the steps for both algorithms - from spectral ADC calculated BasicCounts, corrections, calibration, and XYZ calculations to get the photometric results. All formulas can be checked over the full algorithm systematically or it should be helpful to benchmark your software.

Figure 19 shows the sensor data from the ADC as BasicCounts, before/after corrections, and lists all correction values that can also be used directly in the EVK GUI’s ALS initialization and calibration files. For more details, see [3]. Figure 18 shows the process from the reconstructed spectrum[6] to the photometric results, and the results based on the spectral calibration are shown in Figure 20.

Figure 21 contains the photometric result of the direct XYZ calibration. The minor differences between both photometric results is due to the different algorithms and calibration matrices despite the identical sensor and reference targets in the calibration process.

Regardless of the minor differences, both algorithms differ, not only in the algorithms but also in the effort required to correct them. Depending on which filters are included in the calibration, the XYZ matrix for direct calibration has a dimension of [3 x 8…11]. The spectral reconstruction requires a

[6] Based on a calibration file inserted in another sheet. The calibration file is based on a General Calibration described in chapter 2.5.3 of this document.

matrix dimension of [400 x 8…11]. Since the matrices have to be stored and used in the microcontroller, this should be taken into account when selecting the method. On the other side, spectral reconstruction also offers greater flexibility and contains more information. Spectral results, such as CRI and spectral comparisons of light sources and perturbations, can be calculated via the spectrum, which is not possible via color coordinates. Thus, each application has to be adjusted and optimized regarding its necessary functions, accuracies, and effort in calibration.

Figure 19:
Sensor Data with Corrections are the Basis for Calibrations

Measured Sensor's Channel Data's					
AS7352 Channel	Channel Wavelength (WV)	Basic Counts from protocol file	Basic Counts Gain Corrected	Corr Sensor Factor	Corrected Sensor Data's
F1	400	0.020503	0.020503	1.055464	0.021640
F2	424	0.024782	0.024782	1.043510	0.025860
FZ	450	0.029999	0.029999	1.029576	0.030886
F3	473	0.042570	0.042570	1.017505	0.043316
F4	514	0.058553	0.058553	1.004419	0.058811
FY	555	0.099731	0.099731	0.987356	0.098470
F5	547	0.026050	0.026050	0.957597	0.024945
FXL	595	0.113507	0.113507	0.995863	0.113038
F6	635	0.166035	0.166035	1.014629	0.168464
F7	685	0.238866	0.238866	0.996501	0.238030
F8	745	0.151498	0.151498	0.933073	0.141359
NIR	850	0.590086	0.590086	1.052236	0.620910

Figure 20:
Reconstructed Spectrum (1) and Photometric Results After Spectral Reconstruction

Spectral Reconstruction based on Channel data's			Matching Spectrum into XYZ				CIE1931 based on Golden Unit Spectral Calibration Matrix		
WV	Reconstructed Sensor Spec	Reconstructed Sensor Spec Normalized	WV	X	Y	Z			
380	0.000809	0.042	380	0.000001	0.000000	0.000005	X	0.5582	
381	0.000815	0.042	381	0.000001	0.000000	0.000006	Y	0.5009	
382	0.000822	0.042	382	0.000001	0.000000	0.000006	Z	0.1929	
383	0.000831	0.043	383	0.000001	0.000000	0.000007	x	0.4458	
384	0.000841	0.043	384	0.000002	0.000000	0.000008	y	0.4001	
385	0.000854	0.044	385	0.000002	0.000000	0.000009	z	0.1541	
386	0.000868	0.045	386	0.000002	0.000000	0.000010			
387	0.000885	0.045	387	0.000003	0.000000	0.000012	Lx	342	lx
388	0.000903	0.046	388	0.000003	0.000000	0.000014	L	4.52	
389	0.000924	0.048	389	0.000003	0.000000	0.000016	u'	0.2581	***
390	0.000947	0.049	390	0.000004	0.000000	0.000019	v'	0.5211	***
391	0.000973	0.050	391	0.000005	0.000000	0.000022			
392	0.001000	0.051	392	0.000005	0.000000	0.000025	CCT	2823	K

(1) Tables were interrupted; see the full tables in the original MS Excel File “AS7352 Template Spectral to Spectral to XYZ sensor calibration ALS”.

Figure 21:
Photometric Results After XYZ Calibration

CIE1931 based on Golden Unit XYZ Calibration Matrix		
X	0.5645	
Y	0.5038	
Z	0.2067	
x	0.4427	
y	0.3952	
z	0.1621	
Lx	344	lx
L	4,55	
u'	0.2583	***
v'	0.5187	***
CCT	2831	K

Calibration is therefore dependent on the method, target, disturbances, sensor settings, and results. If necessary, several methods may have to be applied, one after the other. Figure 22 shows general sensor results after the calibration of different light sources for matrix-based methods.

- For (A), a general calibration matrix based on the design data of the filters,
- For (B), a general calibration matrix based on the measurement data from a typical sensor (golden device), and
- For (C), a general calibration matrix based on the measurement data from a typical sensor (golden device) with additional adjustment by scaling.

Figure 22:
Typical Results for Alternative Calibration Methods of Spectral Sensors for ALS

		D65 Sensor		U30 Sensor		TL84 Sensor		CWF Sensor		IND A Sensor		HZ Sensor	
		Target	Measured	Target	Measured	Target	Measured	Target	Measured	Target	Measured	Target	Measured
(A) General Calibration	Spectral Compare	D65		U30		TL84		CWF		Ind A		HZ	
	CCT absolute	6514	7068	2898	3329	3922	4539	4040	4379	2884	3519	2365	3488
	Error abs and %	**554**	**9%**	**431**	**15%**	**617**	**16%**	**339**	**8%**	**635**	**22%**	**1123**	**47%**
	Lux absolute	1083	1057	1568	1550	1485	1175	1146	937	1802	1900	1124	1343
	Error abs and %	**26**	**2%**	**18**	**1%**	**310**	**21%**	**209**	**18%**	**98**	**5%**	**219**	**19%**
(B) Golden Device Calibrated	Spectral Compare	D65		U30		TL84		CWF		Ind A		HZ	
	CCT absolute	6514	7056	2898	3225	3922	4311	4040	4227	2884	2880	2365	2296
	Error abs and %	**542**	**8%**	**327**	**11%**	**389**	**10%**	**187**	**5%**	**4**	**0,14%**	**69**	**3%**
	Lux absolute	1083	1039	1568	1260	1485	1185	1146	963	1802	1710	1124	1050
	Error abs and %	**44**	**4%**	**308**	**20%**	**300**	**20%**	**183**	**16%**	**92**	**5%**	**74**	**7%**
(C) Golden Device Calibrated plus Balance	Spectral Compare	D65		U30		TL84		CWF		Ind A		HZ(CT	
	CCT absolute	6514	6787	2898	2835	3922	3836	4040	4180	2884	2837	2365	2238
	Error abs and %	**273**	**4%**	**63**	**2%**	**86**	**2%**	**140**	**3%**	**47**	**2%**	**127**	**5%**
	Lux absolute	1083	1072	1568	1445	1485	1365	1146	1041	1802	1752	1124	1035
	Error abs and %	**11**	**1%**	**123**	**8%**	**120**	**8%**	**105**	**9%**	**50**	**3%**	**89**	**8%**

Display Measurement Example

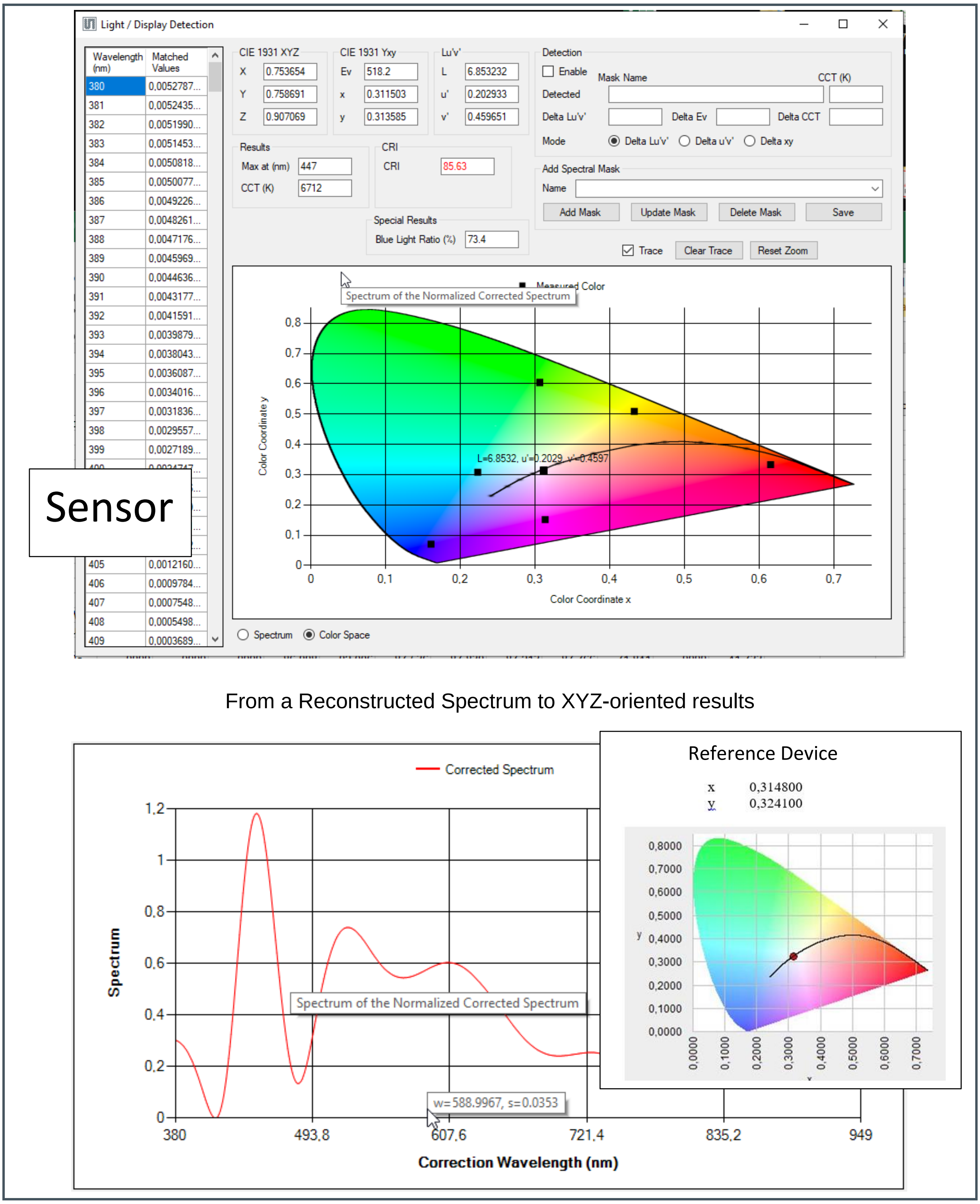
In the display measurement application, the ALS correction matrix should produce logically correct results as a reconstructed spectrum or in the CIE1931 color space.

In these cases and regarding GUI tests, no other correction matrix than the standard installed matrix should be used. When using a golden matrix (lot or type calibration), a correction vector to adapt sensor Raw_Counts to a golden device or a white balance can be helpful to increase accuracy.

Another way is using a direct spectral to XYZ correction matrix based on targets that are measured on display with the sensor and reference device. It is the same procedure as described in the next chapter “Reflection Mode Example” but using another target. ams OSRAM provides excel templates where calibration and correction are shown as examples.

Be attentive to the number of linearly independent targets, which must be greater than or equal to the number of filters used in the sensor to obtain a stable matrix.

Figure 23:
Display of Test Results in a White Color Diagram Using Trace Mode for the Measured RGBWCMY



Reflection Mode Example

In the excel sheet[7] Reflection mode is an example of an individual calibration. It shows the calculation and usage of a spectral to XYZ-based global calibration matrix[8]. The matrix calculation considers twenty-four measured reference targets from the color checker[9], measured with the sensor (raw spectral values) and reference device (in XYZ values). The data used was not collected for accuracy, but are standard values. Therefore, the results do not reflect the performance of the sensor system.

Figure 24 shows a part of the excel sheet where the reference values (Target T) from a spectrometer are listed as XYZ, and the sensor values (S) and offset are listed as corrected BasicCounts per channel in rows. In the table, 24 columns include the 24 color targets.

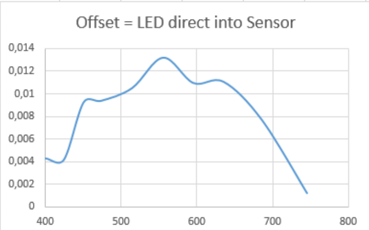
Figure 24:
Part of the Excel Sheet (1) with Target, Sensor Values, and Sensor Offset (2)

TARGET DATA T

Reference values	1	2	3	4	5	6	7	8
	Dark Skin	Light Skin	Blue Sky	Foliage	ue Flower	ish Green	ge Yellow	ow Green
X	11,55	38	18,02	10,72	24,65	30,3	45,84	34,38
Y	10,57	35,03	19,12	13,4	22,96	41,93	43,05	45,2
Z	7,55	25,66	35,01	7,18	43,02	44,77	8,07	11,62

Offset Sensor

	adc offset	AS7352
F1	400	0,004247
F2	424	0,004134
FZ	450	0,009214
F3	473	0,009345
F4	514	0,010471
FY	555	0,013168
F5	546	0,003974
FXL	595	0,010924
F6	635	0,011024
F7	685	0,007691
F8	745	0,001174
VIS	700	0,018154
NIR	850	0,000493



Sensor Matrix S

	1	2	3	4	5	6	7	8
	Dark Skin	Light Skir	Blue Sky	Foliage	Blue Flow	Bluish Gr	Orange Y	Yellow Gr
400	0,07106	0,16588	0,25598	0,06611	0,31499	0,26210	0,08530	0,07559
424	0,06910	0,17729	0,25875	0,06485	0,32981	0,28788	0,09658	0,08629
450	0,15860	0,49436	0,62471	0,16252	0,76774	0,89702	0,19525	0,27442
473	0,15123	0,54285	0,56189	0,15322	0,67198	0,95896	0,18328	0,31492
514	0,22290	0,71617	0,56679	0,38968	0,61255	1,34883	0,61936	1,06285
555	0,37117	1,05944	0,57256	0,44628	0,70590	1,26383	1,41366	1,30361
546	0,09480	0,23760	0,16823	0,14913	0,19090	0,41663	0,40505	0,43798
595	0,38925	1,15003	0,40787	0,33385	0,59478	0,75739	1,51812	0,99210
635	0,52568	1,63927	0,44231	0,36006	0,81396	0,58766	1,81305	0,90554
685	0,38160	1,34255	0,30558	0,24731	0,63024	0,44979	1,27461	0,70848
745	0,07888	0,20865	0,08382	0,04163	0,12205	0,07212	0,17616	0,11010

(1) The tables were interrupted. See the full tables in the original MS Excel File “AS7352 Reflection target calibration XYZ”.
(2) Filter names in the spreadsheets and other sensor files can vary based on the development status.

[7] Ask the ams OSRAM support team for the original XLS file “*#Template Spectral to TCS Sensor calibration Refl.xlsx*” to check the data and formulas of the AS73XX.
[8] Example of a local calibration on request.
[9] https://www.xrite.com/categories/calibration-profiling/colorchecker-targets

Figure 25:
Used Target (Global) in the CIE1931 Color Space From the Color Checker for Calibration in the XY-diagram

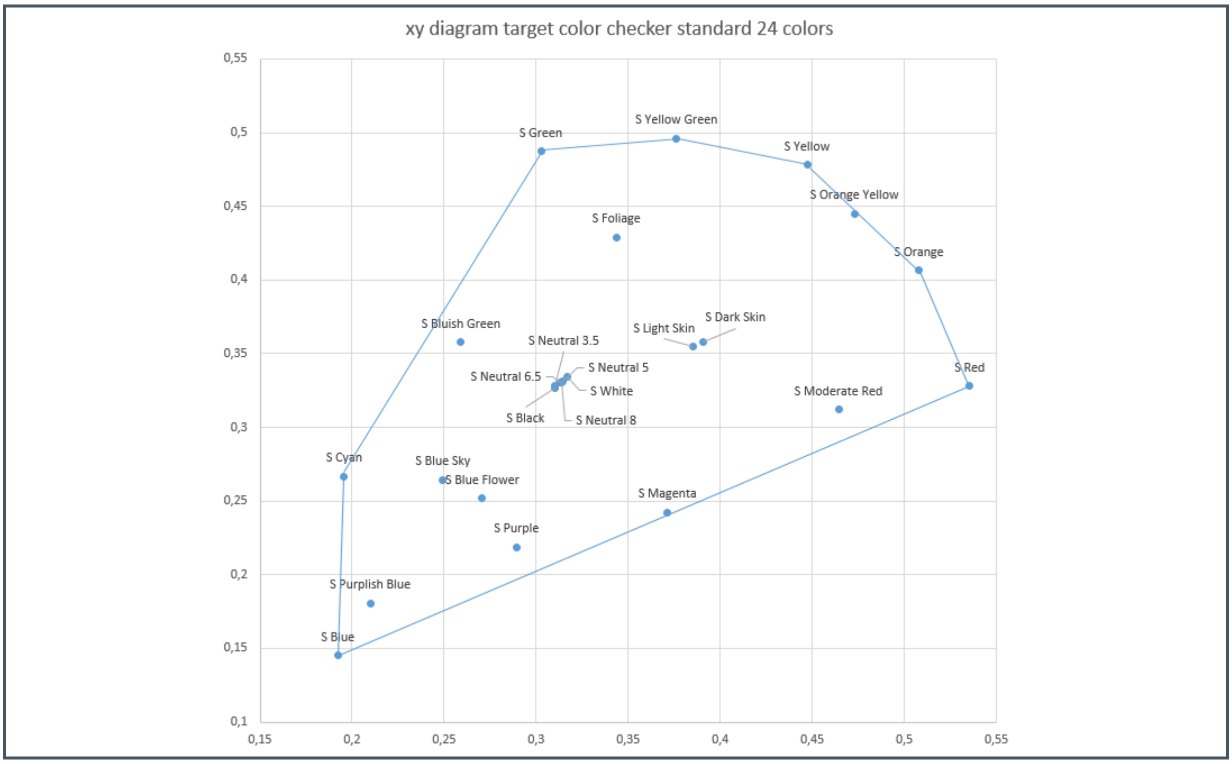


Figure 25 shows the used reference target “Color Checker” (24 colors) in an XY diagram and represents the dynamic range of the sensor target. This means that all colors at an imaginary outer boundary line form in their sum, the color space, which is realized later by this correction. All colors in the color space can thus be included in the measuring range of the sensor. Colors outside the measuring range are not, or incorrectly, corrected. Fewer or more colors in the measuring range can increase/decrease the dynamic range of the sensor if the color location changes the boundary lines. A change in the number of colors in the target usually leads to changed accuracies, both positive and negative.

The target determines not only the accuracy and dynamics of calibration but also the form of output values. Using XYZ-based targets will result in XYZ sensor values after calibration. If the target reference values are in spectral form, e.g. 1 nm step size, then the result is also a spectrum with a step size of 1 nm.

The following example in XLS shows the calculation of a correction matrix K, using a linear regression algorithm based on a 24 x target (dark skin, light skin, etc. - see the columns in the first lines of Figure 26). The reference values of this target were measured with a spectrometer and the sensor values with a multi-channel spectral sensor in RAW values of S. The correction matrix is calculated using matrix multiplications (inverse and transposed) of the sensor and reference matrix. Customers can systematically verify the algorithms for calculating the calibration matrix in the XLS sheet to insert the algorithm into their software.

Figure 26:
Part of the Calculation of the Direct XYZ Matrix Based on the Reference and Sensor Data (1)

		1	2	3	4	5	6	7	8	9	10	11
Sensor Matrix S		**Dark Skin**	**ight Skin**	**Blue Sky**	**Foliage**	**e Flower**	**sh Green**	**e Yellow**	**w Green**	**Purple**	**rate Red**	**lish Blue**
	400	0,07106	0,16588	0,25598	0,06611	0,31499	0,26210	0,08530	0,07559	0,16423	0,14061	0,25313
	424	0,06910	0,17729	0,25875	0,06485	0,32981	0,28788	0,09658	0,08629	0,14872	0,13466	0,30326
	450	0,15860	0,49436	0,62471	0,16252	0,76774	0,89702	0,19525	0,27442	0,27359	0,27561	0,76358
	473	0,15123	0,54285	0,56189	0,15322	0,67198	0,95896	0,18328	0,31492	0,21319	0,25128	0,65321
	514	0,22290	0,71617	0,56679	0,38968	0,61255	1,34883	0,61936	1,06285	0,17621	0,26275	0,38660
	555	0,37117	1,05944	0,57256	0,44628	0,70590	1,26383	1,41366	1,30361	0,24884	0,70430	0,38372
	546	0,09480	0,23760	0,16823	0,14913	0,19090	0,41663	0,40505	0,43798	0,06146	0,10448	0,10050
	595	0,38925	1,15003	0,40787	0,33385	0,59478	0,75739	1,51812	0,99210	0,27186	1,02436	0,27394
	635	0,52568	1,63927	0,44231	0,36006	0,81396	0,58766	1,81305	0,90554	0,54430	1,65233	0,34743
	685	0,38160	1,34255	0,30558	0,24731	0,63024	0,44979	1,27461	0,70848	0,75107	1,13617	0,49952
	745	0,07888	0,20865	0,08382	0,04163	0,12205	0,07212	0,17616	0,11010	0,16917	0,15355	0,14986

Sensor Matrix corr offset		**Dark Skin**	**ight Skin**	**Blue Sky**	**Foliage**	**e Flower**	**sh Green**	**e Yellow**	**w Green**	**Purple**	**rate Red**	**lish Blue**
	400	**0,06681**	**0,16163**	**0,25173**	**0,06186**	**0,31074**	**0,25785**	**0,08105**	**0,07134**	**0,15999**	**0,13636**	**0,24888**
S' = S - offset	424	**0,06496**	**0,17315**	**0,25462**	**0,06072**	**0,32567**	**0,28375**	**0,09244**	**0,08215**	**0,14459**	**0,13053**	**0,29913**
	450	**0,14939**	**0,48514**	**0,61550**	**0,15331**	**0,75853**	**0,88780**	**0,18604**	**0,26521**	**0,26438**	**0,26639**	**0,75436**
	473	**0,14188**	**0,53350**	**0,55254**	**0,14388**	**0,66263**	**0,94961**	**0,17394**	**0,30557**	**0,20385**	**0,24194**	**0,64386**
	514	**0,21243**	**0,70570**	**0,55632**	**0,37921**	**0,60208**	**1,33836**	**0,60889**	**1,05238**	**0,16574**	**0,25228**	**0,37613**
	555	**0,35800**	**1,04627**	**0,55940**	**0,43311**	**0,69273**	**1,25067**	**1,40049**	**1,29044**	**0,23567**	**0,69113**	**0,37055**
	546	**0,09083**	**0,23362**	**0,16426**	**0,14515**	**0,18693**	**0,41266**	**0,40107**	**0,43401**	**0,05748**	**0,10050**	**0,09653**
	595	**0,37833**	**1,13910**	**0,39694**	**0,32292**	**0,58385**	**0,74646**	**1,50719**	**0,98118**	**0,26093**	**1,01344**	**0,26302**
	635	**0,51466**	**1,62825**	**0,43129**	**0,34904**	**0,80293**	**0,57664**	**1,80203**	**0,89451**	**0,53328**	**1,64131**	**0,33640**
	685	**0,37391**	**1,33486**	**0,29789**	**0,23962**	**0,62255**	**0,44210**	**1,26692**	**0,70079**	**0,74338**	**1,12848**	**0,49183**
	745	**0,07770**	**0,20748**	**0,08264**	**0,04046**	**0,12088**	**0,07095**	**0,17498**	**0,10893**	**0,16799**	**0,15237**	**0,14868**

		400	424	450	473	514	555	546	595	635	685	745
calculation: **matrix for linear transformation CM**	**A = T * S'_trans**	142,5177	163,2143	410,4609	393,1663	582,4636	816,665	228,9099	754,7851	904,3754	654,5415	96,84877
		145,4349	167,4864	428,822	414,3827	626,9071	849,2707	243,5794	759,0558	878,2706	633,4448	93,86426
		167,2429	190,8926	487,152	460,3641	561,9948	690,0651	195,8271	585,1666	681,2461	501,3504	79,75564
		180,7118	-428,668	215,3315	-114,861	-24,0697	39,44455	-16,4092	-20,7301	-8,0364	29,74944	-104,46
		-428,668	2303,911	-1688,91	1061,428	140,0555	-623,681	683,0566	400,4745	-12,9371	-171,942	563,9014
		215,3315	-1688,91	1414,982	-963,108	-61,9822	534,7456	-727,251	-317,341	-3,80139	149,0717	-475,202
		-114,861	1061,428	-963,108	720,7381	120,0141	-811,723	1035,097	497,766	-33,7553	-100,283	326,8643
		-24,0697	140,0555	-61,9822	120,0141	572,3402	-2134,85	2050,233	1465,131	-239,393	10,86543	32,35221
	B = [S' * S'_trans]^-1	39,44455	-623,681	534,7456	-811,723	-2134,85	8558,352	-8652,76	-5772,34	901,0318	-11,8476	-201,845
		-16,4092	683,0566	-727,251	1035,097	2050,233	-8652,76	9077,549	5744,224	-855,915	-15,9823	263,6993
		-20,7301	400,4745	-317,341	497,766	1465,131	-5772,34	5744,224	3926,663	-630,175	20,46656	110,2934
		-8,0364	-12,9371	-3,80139	-33,7553	-239,393	901,0318	-855,915	-630,175	119,8456	-30,6599	50,97516
		29,74944	-171,942	149,0717	-100,283	10,86543	-11,8476	-15,9823	20,46656	-30,6599	55,35498	-153,697
		-104,46	563,9014	-475,202	326,8643	32,35221	-201,845	263,6993	110,2934	50,97516	-153,697	477,841
	CM = A * B	**-106,763**	**264,0092**	**-112,898**	**60,23206**	**6,208266**	**0,828751**	**-8,7215**	**33,75812**	**-5,37536**	**-1,99021**	**3,154893**
	==> Device Calibration	**-113,08**	**267,1864**	**-123,162**	**65,94365**	**27,52857**	**-32,685**	**47,6374**	**46,19491**	**-11,6796**	**0,537424**	**-1,25876**
		-128,412	**388,3724**	**-146,35**	**109,2606**	**12,3867**	**-37,8635**	**28,47036**	**25,13567**	**-2,49406**	**-8,66411**	**11,79338**

(1) The tables are interrupted. See the original Excel sheet for the full table.

The result of this sheet is the calibration matrix K, marked in green in Figure 26, which can be used to match the sensor results after measuring the RAW data. This method of linear regression by using these data is only one example to get a correction matrix. Other algorithms are known and must be tested to get optimized sensor results.

Another method, shown earlier in this document, is to use a multi-stage matrix-based calibration concept, by mixing the methods consecutively. For example, use a complete (global) color target (e.g. 24 colors) for calibration as a first step to get a local position in the CIE1931 color space, and then a local calibration around this color position, with a reduced color (selected 12 colors) target but higher accuracy.

A device-specific calibration uses a specific calibration matrix separately for each sensor. If the matrix is used for an alternative sensor from the same batch/for this specific product, then it is a batch-/type calibration. The calibration method, algorithm, and target must be harmonized with the application and its requirements.

The offset from Figure 24 and the calibration matrix from Figure 26 should be used as input data for the AS7343 GUI and reflection mode. For more details, see [1].

Figure 28 shows the usage of the calibration matrix in comparison with the reference values. The formula can be checked systematically. It considers the calculation of the XYZ Tristimulus result for the sensor, XY coordinates, and the actual La*b* (D65 illumination, 2° observer). Deviations are given by comparison with the reference values.

In Figure 27, all the results are shown in one diagram. It can be seen that each color has its accuracy after the calibration. Therefore, the minimum, maximum, and average (typical) deviation of the color target is always interesting. Accordingly, calibration can be optimized to minimize color variations or min/max/typ. for a range of colors.

Figure 27 :
Delta E and Delta ab After Correction, Using Direct XYZ Device Calibration

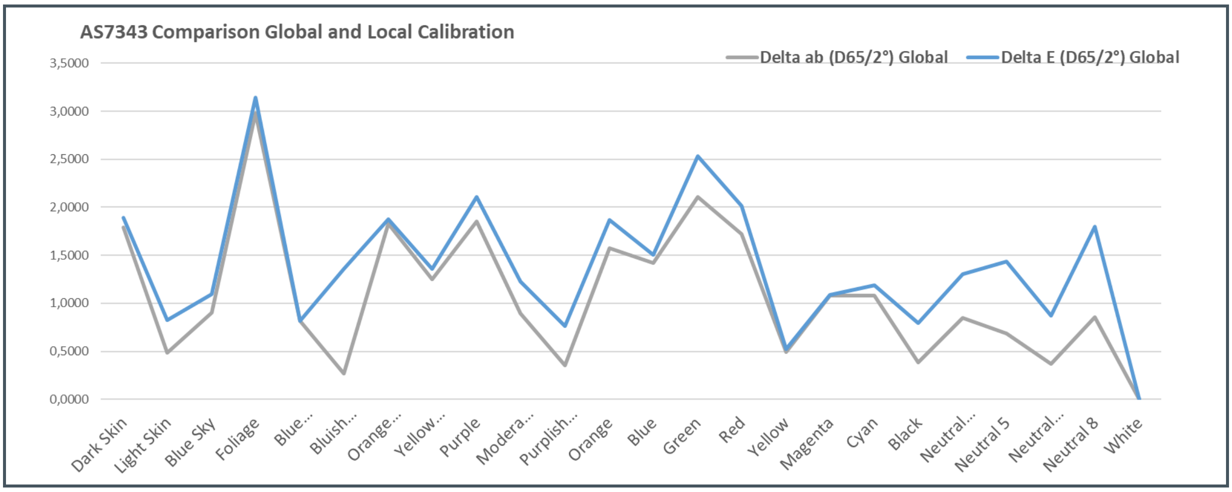


Figure 28:
Using 24 Targets(1) to Correct Sensor Results and Comparison with References

Reference values	1	2	3	4	5	6	7	8	9	10	11
	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
X	11,55	38	18,02	10,72	24,65	30,3	45,84	34,38	8,82	28,72	14,08
Y	10,57	35,03	19,12	13,4	22,96	41,93	43,05	45,2	6,67	19,27	12,16
Z	7,55	25,66	35,01	7,18	43,02	44,77	8,07	11,62	14,92	13,74	40,48
S	S Dark Skin	Light Skin	S Blue Sky	S Foliage	lue Flower	uish Green	nge Yellow	llow Green	S Purple	derate Red	rplish Blue
x	0,3893	0,3850	0,2498	0,3425	0,2720	0,2590	0,4728	0,3770	0,2900	0,4653	0,2110
y	0,3563	0,3549	0,2650	0,4281	0,2533	0,3584	0,4440	0,4956	0,2193	0,3122	0,1823
z	0,2545	0,2600	0,4852	0,2294	0,4747	0,3826	0,0832	0,1274	0,4906	0,2226	0,6067
	1	2	3	4	5	6	7	8	9	10	11
Corrected counts	Dark Skin	Light Skin	Blue Sky	Foliage	Blue Flowe	Bluish Gree	Orange Yel	Yellow Gre	Purple	Moderate R	Purplish Bl
400	0,0668	0,1616	0,2517	0,0619	0,3107	0,2578	0,0811	0,0713	0,1600	0,1364	0,2489
424	0,0650	0,1732	0,2546	0,0607	0,3257	0,2837	0,0924	0,0822	0,1446	0,1305	0,2991
450	0,1494	0,4851	0,6155	0,1533	0,7585	0,8878	0,1860	0,2652	0,2644	0,2664	0,7544
473	0,1419	0,5335	0,5525	0,1439	0,6626	0,9496	0,1739	0,3056	0,2038	0,2419	0,6439
514	0,2124	0,7057	0,5563	0,3792	0,6021	1,3384	0,6089	1,0524	0,1657	0,2523	0,3761
555	0,3580	1,0463	0,5594	0,4331	0,6927	1,2507	1,4005	1,2904	0,2357	0,6911	0,3706
546	0,0908	0,2336	0,1643	0,1452	0,1869	0,4127	0,4011	0,4340	0,0575	0,1005	0,0965
595	0,3783	1,1391	0,3969	0,3229	0,5839	0,7465	1,5072	0,9812	0,2609	1,0134	0,2630
635	0,5147	1,6282	0,4313	0,3490	0,8029	0,5766	1,8020	0,8945	0,5333	1,6413	0,3364
685	0,3739	1,3349	0,2979	0,2396	0,6226	0,4421	1,2669	0,7008	0,7434	1,1285	0,4918
745	0,0777	0,2075	0,0826	0,0405	0,1209	0,0709	0,1750	0,1089	0,1680	0,1524	0,1487
	1	2	3	4	5	6	7	8	9	10	11
Calibrated Results	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
X	12,03	36,73	17,37	10,91	24,30	31,54	45,89	33,62	9,24	29,29	14,38
Y	10,80	33,83	18,41	13,95	22,77	43,45	43,22	43,95	7,03	19,80	12,47
Z	7,85	25,01	34,54	7,00	43,22	46,22	7,68	11,49	14,73	13,85	40,80
Deviation in %	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
XSP-XS	-4%	3%	4%	-2%	1%	-4%	0%	2%	-5%	-2%	-2%
YSP-XS	-2%	3%	4%	-4%	1%	-4%	0%	3%	-5%	-3%	-3%
ZSP-XS	-4%	3%	1%	3%	0%	-3%	5%	1%	1%	-1%	-1%
After WB	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
Xwb	12,16	37,13	17,56	11,03	24,57	31,89	46,40	33,99	9,34	29,61	14,54
Ywb	10,91	34,18	18,59	14,09	23,00	43,89	43,66	44,40	7,10	20,01	12,60
	7,93	25,25	34,86	7,06	43,63	46,65	7,76	11,60	14,86	13,98	41,19
Deviation in %	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
Xwb-XS	-5%	2%	3%	-3%	0%	-5%	-1%	1%	-6%	-3%	-3%
Ywb-XS	-3%	2%	3%	-5%	0%	-5%	-1%	2%	-7%	-4%	-4%
Zwb-XS	-5%	2%	0%	2%	-1%	-4%	4%	0%	0%	-2%	-2%
AWB Results	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
x	0,3922	0,3846	0,2473	0,3426	0,2694	0,2604	0,4743	0,3777	0,2983	0,4656	0,2128
y	0,3520	0,3540	0,2618	0,4379	0,2522	0,3585	0,4464	0,4934	0,2269	0,3146	0,1844
z	0,2558	0,2615	0,4909	0,2195	0,4784	0,3810	0,0793	0,1289	0,4748	0,2198	0,6029
AWB Results	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
dxy	0,0052	0,0011	0,0040	0,0098	0,0029	0,0015	0,0028	0,0023	0,0112	0,0025	0,0027
Average dxy	0,00365										
min dxy	0,00000										
max dxy	0,01122										
Spektrometer	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
L (D65/2°)	38,85	65,77	50,83	43,36	55,03	70,82	71,59	73,02	31,04	51,00	41,47
a (D65/2°)	11,25	15,88	-0,81	-14,28	12,69	-32,67	14,57	-27,47	23,59	46,72	16,85
b (D65/2°)	12,40	17,45	-21,80	21,54	-24,29	0,97	67,00	58,62	-22,00	15,20	-44,73
Sensor	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
L (D65/2°)	39,43	65,10	50,21	44,36	55,07	72,16	72,00	72,50	32,04	51,84	42,15
a (D65/2°)	13,01	15,93	-0,59	-16,33	12,16	-32,57	14,37	-26,56	23,64	46,51	16,75
b (D65/2°)	12,05	16,96	-22,67	23,71	-24,92	1,22	68,82	57,76	-20,15	16,08	-44,39
Global Correction	Dark Skin	Light Skin	Blue Sky	Foliage	lue Flower	uish Green	nge Yellow	llow Green	Purple	derate Red	rplish Blue
Delta ab (D65/2°) Global	1,7951	0,4888	0,9001	2,9827	0,8181	0,2666	1,8297	1,2515	1,8534	0,8984	0,3513
Delta E (D65/2°) Global	1,8880	0,8279	1,0920	3,1472	0,8189	1,3614	1,8758	1,3582	2,1064	1,2308	0,7642

(1) The tables were interrupted. See the full tables in the original MS Excel File.

3 Revision Information

Changes from previous version to current revision v1-00	Page
Initial version	all

- Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
- Correction of typographical errors is not explicitly mentioned.

4 Additional Documents

The following list includes a selection of additional documents with more technical details for the sensor AS7343 and its Evaluation Kit. This list is not fixed and it is constantly changing. Ask us for new details.

For further information, please refer to the following documents:

1. ams-OSRAM AG, *Reference EVK for Spectral Sensor Calibration (AN001038)*, Application Note.
2. ams-OSRAM AG, *AS7341 Eval Kit Spectral Balance and Calibration (QG000139)*, Quickstart Guide.
3. ams-OSRAM AG, *AS7343 14-Channel Multi-Spectral Sensor for Spectral and Color Measurement (UG001009)*, User Guide.

5 Legal Information

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