Product Document

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Application Note

AN000652

Diffuser Effectiveness Testing

TCS3430 Diffuser Testing

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Content Guide

1 Introduction

The **ams** TCS3430 is an X, Y, Z, color sensor that requires the use of a diffuser. The quality of the diffuser will have a dramatic effect on the accuracy of the measurements and the Lux and CCT calculations. The scattering and haze characteristic of a diffuser can be measured by calculating the bidirectional transmittance distribution function (BTDF). This measures the amount of light transmitted through the diffuser relative to the light that hits the diffuser at various angles. The basic equation is:

Equation 1:

$$\text{BTDF}\,(\theta_{in}, \theta_{out}) = \frac{L_{\text{out}}}{E_{\text{in}}}$$

L_{out} is the outgoing radiance from the diffuser while E_{in} is the incident irradiance.

At **ams**, we developed custom equipment using a general instruments CAS140 with a TOP200 optical probe to measure the BTDF. While this approach delivers very accurate measurements of the diffusers, many customers may not have the capability or time to develop this test equipment.

It is possible to use the TCS3430 itself to measure the effectiveness of different diffusers. This can be done by collecting data with the light source set to different incident angles using a custom made angular tester or by collecting data using a fixed light set at a large incident angle while rotating the device under test (DUT). This app note will show how to collect data to measure the diffuser effectiveness as well as show the results from angular testing and rotational data under four different diffusers.

- F301: The current EVM Diffuser provides good diffusion
- GAM1090x1: A single sheet of GAM1090 provides some diffusion, but determined not sufficient.
- GAM1090x2: Two sheets of the GAM1090 diffuser provides good diffusion, but has low transmissivity
- GAM1080: Does not provide acceptable diffusion.

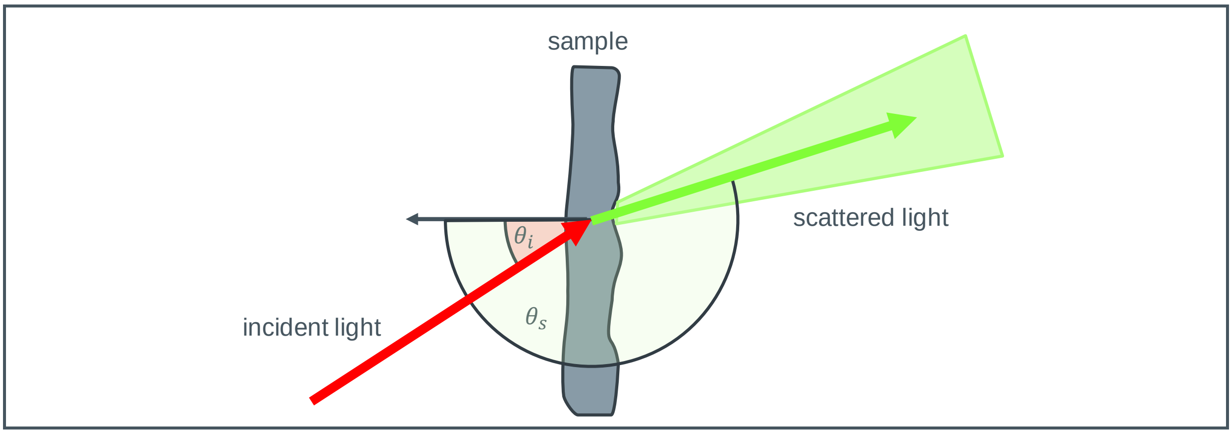
The diffusers used in this app note were chosen to show the effectiveness of the testing and their use or test results should not be considered an endorsement or a recommendation for their use in an application.

The TCS3430 has 4 channels X, Y, Z, and IR1 are multiplied by a color calibration matrix (sometimes called system matrix). The resulting accurate CIE Tristimulus XYZ values can be used to calculate ambient light CCT. The CCT value is dependent on the ratio between the channels. Therefore a critical requirement of a diffuser is to maintain the ratio between the channels over various angles of incidence and rotation. The diffuser testing described in this app note uses raw data which means the diffuser testing can occur prior to generating a system matrix. This will save time since the diffuser quality will affect the matrix coefficient values. In addition, the testing can be performed at any time during product development. There is no need to wait for the optical stack to be finalized and prototyped.

2 BTDF Test Equipment Setup

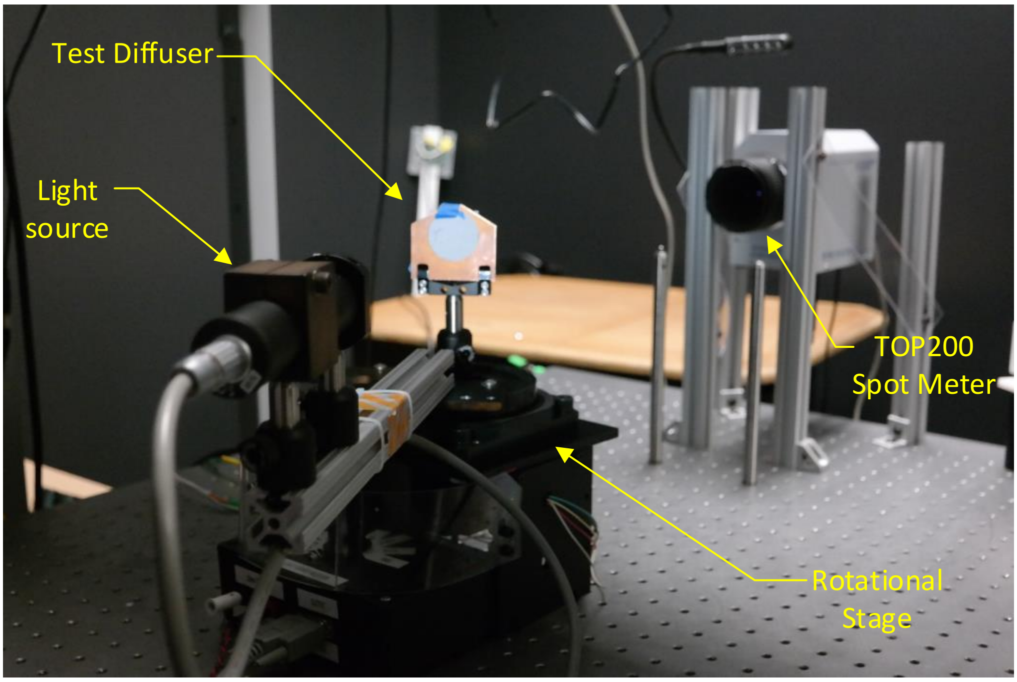
To calculate the BTDF the scattered light that is transmitted through the diffuser is measured as the incident light source is rotated around to various angles.

Figure 1:
BTDF Illustration



The test equipment used at **ams** to measure the BTDF of a diffuser consists of a rotational stage that rotates the light source and the diffuser to vary the incident angle of the light and diffuser relative to the stationary TOP200 spot meter which is connected to the General Instruments CAS140 spectrometer.

Figure 2:
ams Custom BTDF Tester

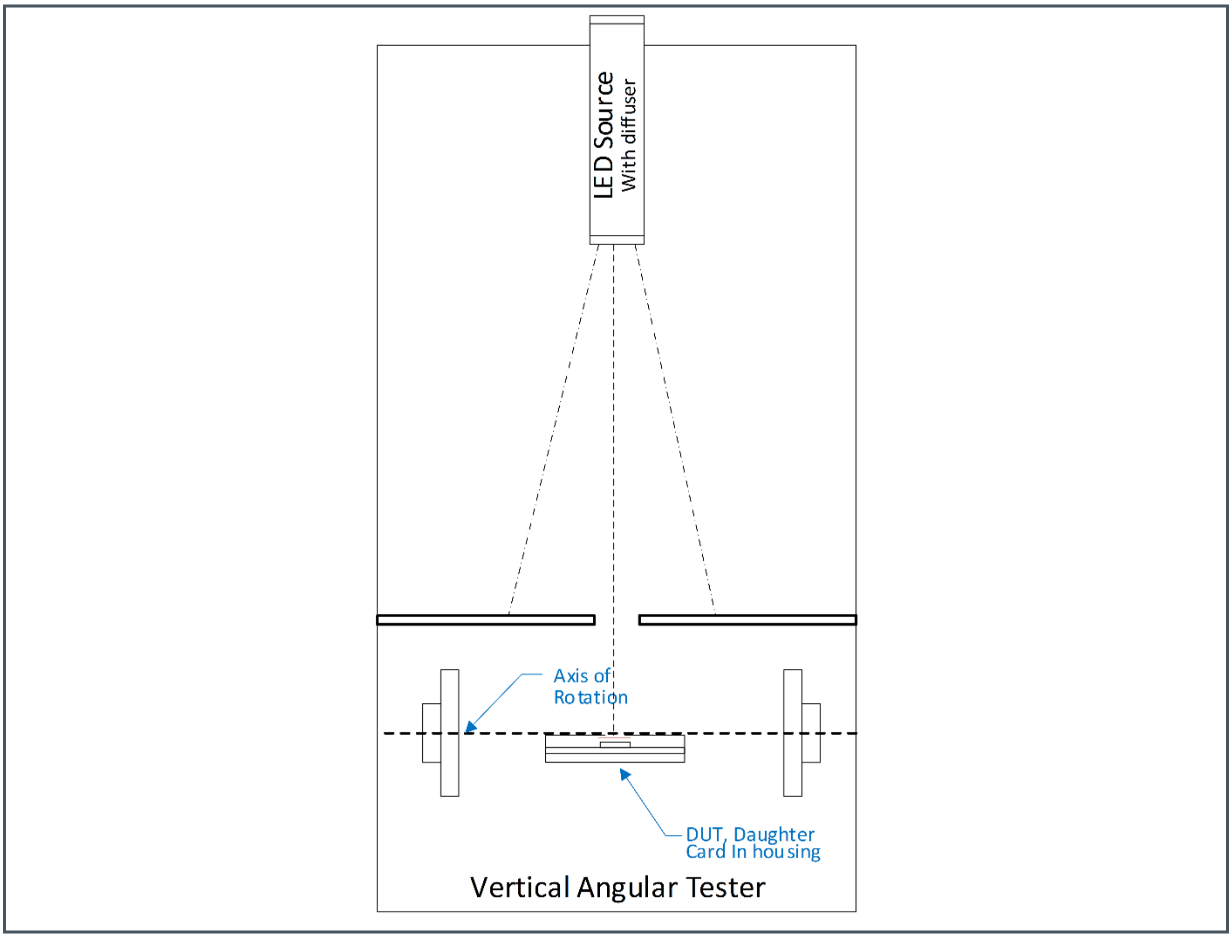


This effectively measures the scattered light and will generate an accurate and objective BTDF measurement of the diffuser. This is useful if you have a predetermined BTDF target you are trying to match for an application. If that is not available, testing the diffuser effectiveness using a TCS3430 may provide a better indicator how the diffuser will work in the application than the BTDF.

3 Testing Angular Performance

3.1 Test Configuration

Figure 3:
Vertical Angular Tester



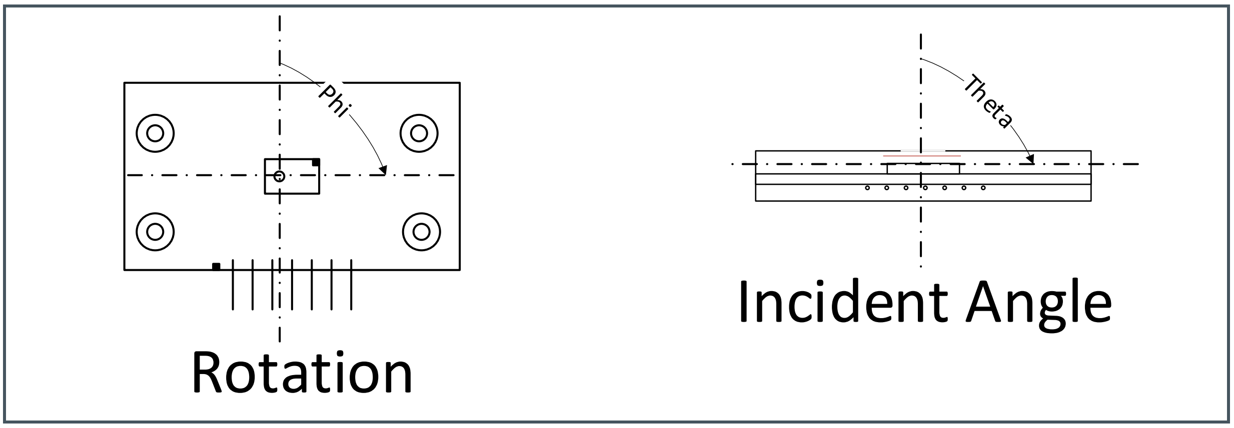
Angular data of the TCS3430 under different diffusers can be collected by having a stationary light source and rotating the DUT about the center line of the diffuser. At **ams** this test is performed with a vertical angle tester. The test consists of varying the incident angle of the DUT from -90° to 90° in 5 or 10 degree steps and collecting data at each step. We generally refer to the incident angle as theta (θ) in the data. The DUT is then rotated 90° and data collection is repeated. The DUT rotation angle is referred to as phi (Φ) in the data.

A key feature of the angular tester is that the axis of rotation is aligned with the top surface of the DUT or aligned with the diffuser. This allows the DUT to be rotated while maintaining the distance to the light source which is critical in maintaining a constant lux level.

As with all light testing the test is performed in the dark and the light source must be given enough warm up time for the light to stabilize. In addition, multiple data points are collected for each step and averaged to remove any temporal noise. For the data used in this app note, ten (10) consecutive samples were collected for each angle and averaged together. The light source is a white LED driven at 100 mA by a current controlled power supply. A current controlled supply is the best way to get consistent lux level with LED light sources.

The ATIME and AGAIN are set such that there is a least 1000 counts for the X and Y channels while the DUT was at 0° to the light source.

Figure 4:
DUT Angles Explained

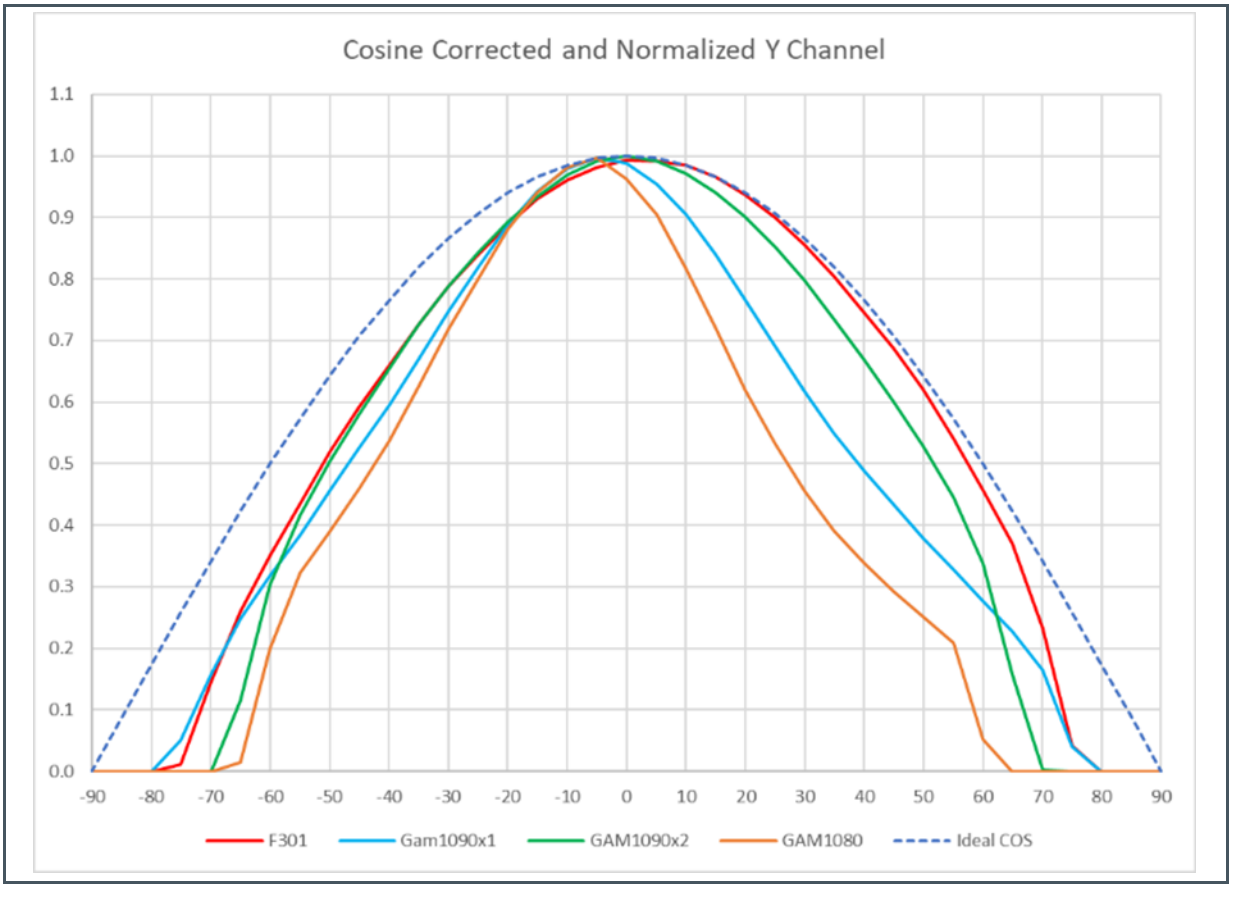


3.2 Test Data

When comparing the data from different diffusers, it is best to look at the cosine corrected normalized Y channel data this will remove differences due to varying transmissivity. As can be seen in the graph below, the two diffusers show a concaved edge on the right ride of the curve indicating too much light transmitting straight through the diffuser and not enough scattering of the light. The percentage of the DUT data to the ideal cosine curve gives a good objective value to compare the performance of various diffusers:

- F301: 88.2%
- GAM1090x1: 76.1%
- GAM1090x2: 81.4%
- GAM1080: 62.9%

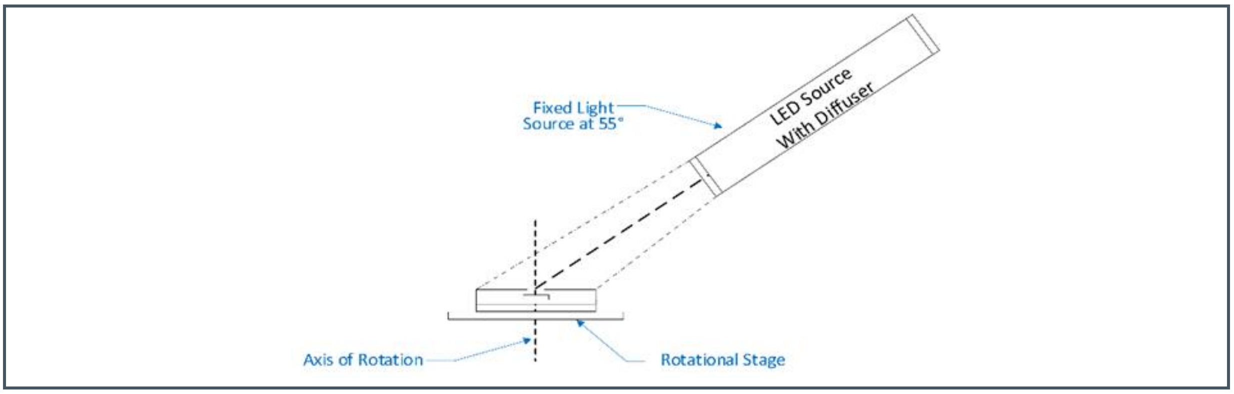
Figure 5:
Diffuser Test Results Graph



4 Testing Rotational Performance

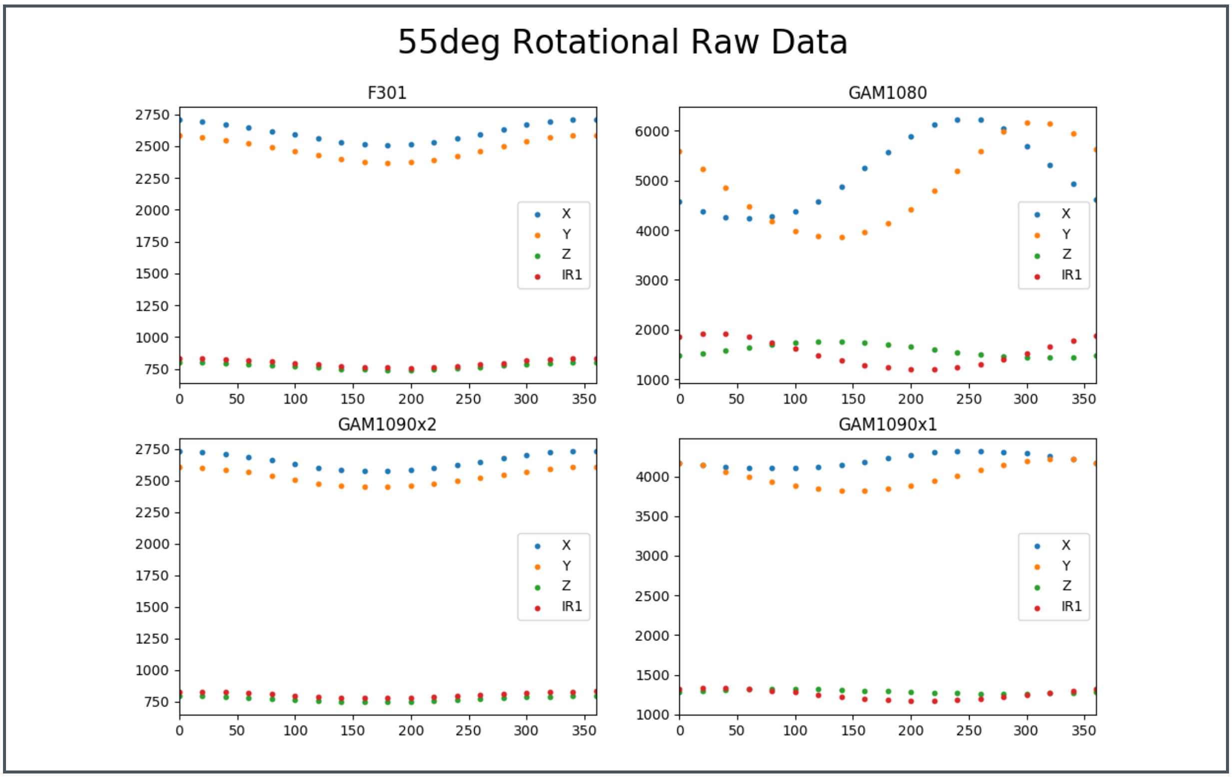
4.1 Raw Data Collection and Analysis

Figure 6:
Rotational Tests Configuration



To collect rotational data the LED light source was held in place at 55° aimed at the center of the TCS3430 daughter card since the TCS3430 is placed on the daughter card so the photo diodes are centered on the board. For the data collected in this app note, the DUT was rotated in 20° steps with data collected at each step. This was repeated for each Diffuser.

Figure 7:
Rotational Data Graphs

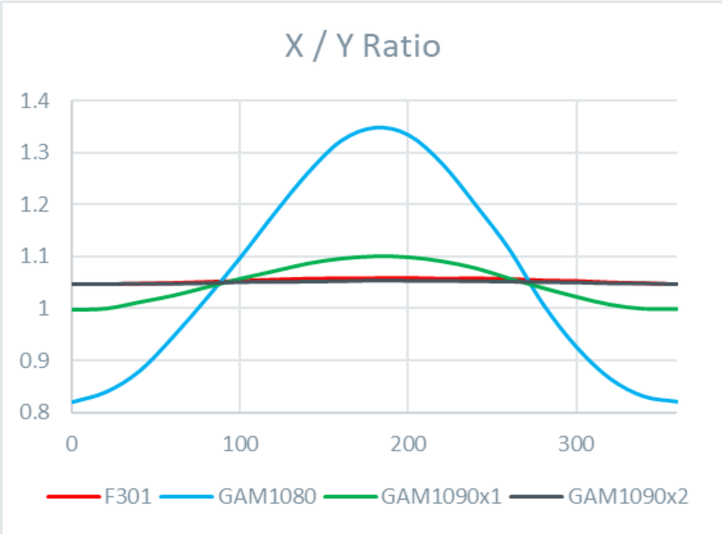


The rotation data graphs show the changing of the raw channel data similar to what was observed with the angular data. In the graphs from the F301 and GAM1090x2, the distance between X and Y remains constant for all angles of rotation even though the value changes. While in the GAM1080 and to a lesser degree GAM1090x1 graphs, the ratio between the four channels are obviously changing. The changing of the ratio between the data channels will cause errors in the CCT calculation. The changing of the X and Y values will affect the lux calculation so a smaller overall variation will provide better lux performance. The GAM1090x2 shows less absolute variation over rotation angle, but at the same time it has a lower transmissivity. These types of engineering tradeoff choices should be application driven and based on the data collected.

4.2 X to Y Channel Ratio

Another way to visualize the effect the diffuser will have on CCT accuracy is to graph the X / Y ratio. In **Figure 8**, the GAM1080 shows significant variation in between X Channel and Y channel data based on the rotation. Although the GAM1090x1 shows less variation it is significantly larger than the other two diffuser samples.

Figure 8:
Changing X/Y Ratio Over Rotation Angle



The X/ Y ratio can also be converted to a percentage of the total variation to the average which can be compared to a minimal acceptance criteria for an application. (ΔY / Avg(Y)):

- F301: 1.01%
- GAM1080: 50.05%
- GAM1090x1: 9.81%
- GAM1090x2: 0.507%

This metric can be used on the other channels as well and it is a good idea to verify all the channels before determining a diffuser is acceptable for an application.

5 Summary

While the Bidirectional Transmittance Distribution Function (BTDF) is an excellent way to measure the scattering properties of a diffuser, there is a huge cost in the equipment required to measure it. The complete BTDF measurement is not necessary to determine if a diffuser is acceptable for use in an application using a TCS3430 or other color sensors.

The effectiveness of a diffuser in an application can be tested using the light sensor device itself by collecting data over various light incident angles. The raw data is then cosine corrected and normalized and compared to the ideal cosine curve to calculate a percentage of how close to an ideal Lambertian diffuser the sample is.

Another way to test the diffuser is to fix the light source at a large incident angle (~55°) and rotate the DUT. This is the easiest way to perform the test since it requires the least amount of equipment. Once the data is collected, it can simply be graphed to see how the ratio between channels change, the X/Y ratio data can be graphed to see how stable it is, or used as a calculated metric of the channel stability over the part rotation.

6 Revision Information

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

- 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.

7 Legal Information

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Headquarters

ams AG

Tobelbader Strasse 30

8141 Premstaetten

Austria, Europe

Tel: +43 (0) 3136 500 0

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