Product Document

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Application Note

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TSL2521 ALS/Flicker

Settings and Comparison to Legacy ALS Devices

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Content Guide

1 Introduction

TSL2521 offers new ALS and Flicker measurement features on a very small space of 2.0 mm x 1.0 mm x 0.5 mm compared to legacy devices. ALS and flicker are running on the same time base, the FIFO is larger, it has some data compression features, and measurements can be planned in sequences with individual settings. Additionally, a new residual measurement feature offers higher resolution at lower gain.

These new features – especially regarding timing and sequences – require registers different than on legacy ALS devices like TCS3707 – consequently the registers have now different names.

This document explains the settings for ALS measurements compared to legacy ALS devices, e.g. the TCS3707 and shows the new relation between ALS and Flicker measurements.

2 TSL2521 ALS and Flicker Settings

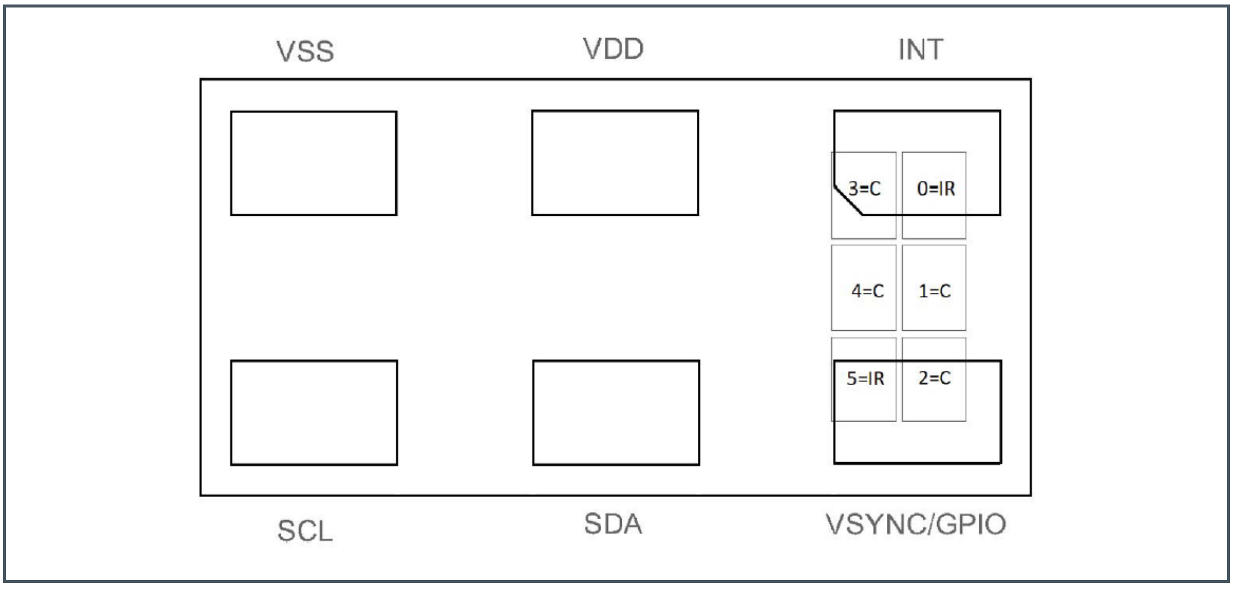
2.1 ALS Channels/Modulators

The datasheets of ALS legacy devices used to name the measurement channels after their filters, e.g. the Clear channel, Red channel, Blue Channel and so on. It was possible on devices like TCS3707 to change the Diode-to-channel connection via a multiplexer, but this was not easy during measurements and therefore not often used.

The TSL2521 has only two ALS channels but it is very easy to change the connection between the individual diodes – no matter which filter is on this diode – and the ALS engine. Consequently, channel related registers are not named after the filter characteristic of the diodes – like Clear (C) and Infrared (IR) – but after the two available ALS modulators: modulator 0 and modulator 1.

Figure 1 shows the number and filter type of the six available photodiodes on TSL2521. The photodiode numbers are used to connect the photodiodes to the modulators in the SMUX registers **MEAS_SEQR_STEP0_MOD_PHDX_SMUX_L** up to **MEAS_SEQR_STEP3_MOD_PHDX_SMUX_H**. The default setting has to be changed since it refers to a different filter layout: modulator 0 should be connected to the four Clear diodes 1, 2, 3, and 4; modulator 1 should be connected to the two IR diodes 0 and 5. There is no separate channel/modulator for the flicker measurements, every modulator can be used for both ALS and Flicker measurements at the same time. On TSL2521 flicker measurements should be done preferred on modulator 0 with the Clear diodes.
The GUI and the drivers provided by ams OSRAM have both mentioned changes implemented.

Figure 1:
Location, Filter Type, and Number of Photodiodes of TSL2521 (top view)



Information

In application cases with high transmissivity glass direct sunlight could cause saturation even at gain setting of 0.5x especially on modulator 0 connected to the Clear diodes. This can be avoided by connecting less than 4 of the Clear diodes to modulator 0 in the SMUX registers of the sequencer.

2.2 Sequencer

TSL2521 has a programmable sequencer for ALS and Flicker measurements built in. There are 4 sequencer steps – step 0 to step 3 – available, but not all need to be used.

In ALS legacy devices like TCS3707 there is no comparable sequencer available, so that would be like using only step 0 of the TSL2521. For a simple two channel ALS/Flicker measurement one step might be enough, therefore the default settings of the TSL2521 only use step 0.

For more flexibility, some settings can be chosen for each sequencer step individually, most of them organized in a 4-bit pattern - each bit of the pattern represents a single step. ALS needs to be enabled in such a pattern in measurement_sequencer_als_pattern in register **MEAS_SEQR_ALS_FD_1** for both modulators, by default ALS with both modulators is enabled for step 0 only.

Flicker measurement can be enabled for each modulator individually, so there are two pattern fields, measurement_sequencer_mod0_fd_pattern and measurement_sequencer_mod1_fd_pattern, both in register **MEAS_SEQR_FD_0**.

The time a sequencer step lasts is defined by the ALS integration time, the Flicker measurement time, or the Wait time – whatever is activated and lasts longer. The same is valid for the whole sequencer cycle if only step 0 is performed.

If in a step there is neither ALS nor Flicker nor Wait time enabled by using the respective patterns then this step will be omitted.

2.3 Residual Measurement

Residual measurement is a new feature on TSL2521 that enables to measure Sub-LSBs on ALS and flicker data at the end of the integration time. Residuals represent fractions of full counts: the integrating ADC – the ALS modulator – like on legacy devices normally counts only a 1 when the capacitor charged by the photocurrent reached a certain voltage. When the integration time is over, normally the remaining charge that did not reach this voltage is discharged. The idea of the Residual measurement is that this remaining charge is measured to get fractions of full counts.

Since the Residual measurement is done with a resolution of max. 4 bits on this device that results in 4 extra resolution bits almost for free. That way it is possible to use lower gains that have a better linearity than higher gains, because the Residual bits provide additional resolution on LSB side.

Nevertheless, that has a limit too, so the Residual measurement resolution is reduced at higher gains – that is why residual measurement is mainly suited to increase the resolution at medium and lower gains.

There are two different gain tables, the default one reduces the evaluated number of residual bits starting at gain 128x upwards by 1 for each gain step. The second gain table is valid up to gain 256x and always uses 4 bits for residuals. It is recommended to use the second gain table and restrict the maximum gain to 256x. Adding the 4 bits Residual resolution results in an effective gain of 4096x in this case – but at the gain non-linearity of 256x, which is rather low.

In order to use the second gain table mod_gain_select has to be set to 3 before starting the measurement, this field can be found in register **MOD_GAIN_H** as shown in Figure 2. The field measurement_sequencer_max_mod_gain has to be set to 9 in register **CFG8** to restrict the modulator gain to 256x.

Figure 2:
MOD_GAIN_H

Addr: 0xED		MOD_GAIN_H		
Bit	**Bit Name**	**Default**	**Access**	**Bit Description**
7:6	Reserved	0		
5:4	MOD_GAIN_SELECT	0	RW	One bit for each channel to select second gain table. This register has to be written before enabling the sequencer!
3:0	Reserved	0		

Figure 3 shows the Number of Residual bits for the gain steps of the two gain tables. If less than 4 Residual bits are used the non-used bits starting from LSB side are set to 0. This leads to higher minimum step sizes of the ALS or Flicker sample results as well.

Figure 3:
Number of Residual Bits Depending on Gain Table Chosen by mod_gain_select

Mod_gainx [gain]	Number of Residual Bits for mod_gain_select = 0	Number of Residual Bits for mod_gain_select = 1
0 [0.5x] – 8 [128x]	4	4
9 [256x]	3	4
10 [512x]	2	Reserved
11 [1024x]	1	Reserved

Mod_gainx [gain]	Number of Residual Bits for mod_gain_select = 0	Number of Residual Bits for mod_gain_select = 1
12 [2048x]	0	Reserved
13 [4096x]	0	Reserved

The additional Residual resolution can be expressed either as decimal places after the full integration counts or – as internally done - with additional bits on LSB side to avoid a floating-point format. Since there are 4 bits added on the LSB side for Residuals – no matter if they are measured or not – the way to get back to the same number space comparable to legacy devices is to divide the results by 16, in this case the decimal places show the residual amount.

The GUI provided by ams OSRAM can show both methods, Figure 4 with the “Integer view box” checked shows the internal integer view with 4-bit Residuals on LSB side like in Figure 5.

Figure 4:
TSL2521 GUI Configuration Tab With Checked “Integer View” Box

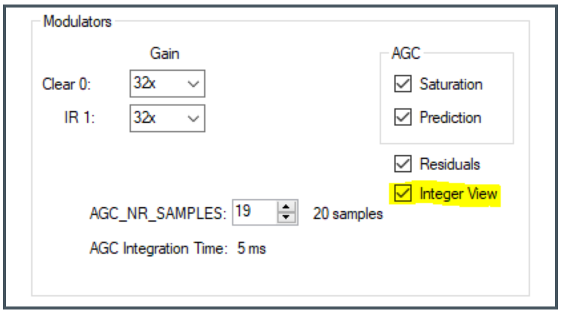
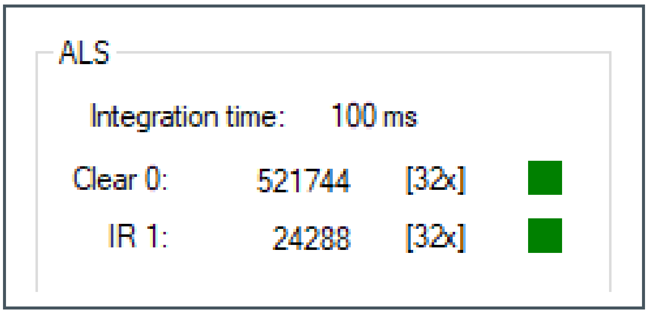


Figure 5:
Internal Integer View With 4-Bit Residuals On LSB Side



In contrast, “Integer View” box unchecked like in Figure 6 does the mentioned division by 16 to show full counts and Residuals as fractions separated by the decimal point like in Figure 7, that way it can be compared to the value of legacy devices e.g. for dark count measurements.

Figure 6:
TSL2521 GUI Configuration Tab With Unchecked "Integer View" Box

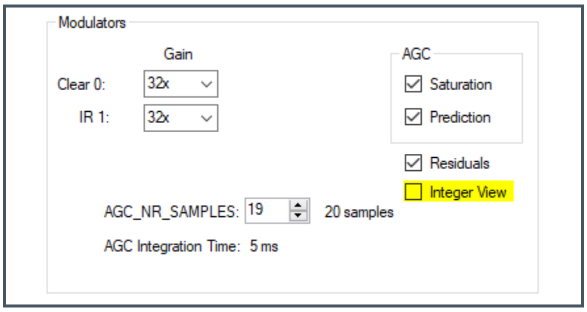
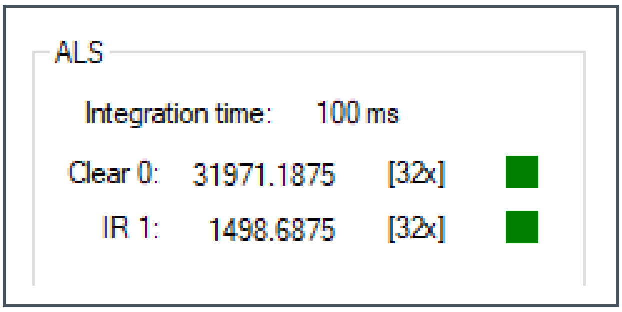


Figure 7:
Residuals Expressed as Fractions of Full Counts



In order to activate the Residual measurement it needs to be enabled per step in measurement_sequencer_mod0_residual_enable_pattern for modulator 0 and in measurement_sequencer_mod1_residual_enable_pattern for modulator 1, both fields are in register **MEAS_SEQR_RESIDUAL_0**.

One difference is that in case of enabled Residual measurement the last sampling time is reduced by the Residual measurement time. This reduces the ALS integration time accordingly but only by a very small amount and in case of no flicker measurement during the same step most times it can be neglected as shown in Equation 1.

Equation 1:

$$ALS\ integration\ time_{with\ Residuals} = ALS\ integration\ time - 1.3889\mu s * (4 + 2\ \hat{}\ (nr\_residual\_bits))$$

In case of flicker measurements within the same step after each flicker sample measurement one residual measurement is done. This reduces the whole ALS integration time more significantly as shown in Equation 2. This needs to be considered when preparing or using a lux equation.

Equation 2:

$$ALS\ integration\ time_{with\ Residuals\ and\ flicker} = ALS\ integration\ time - (ALS\_NR\_OF\_SAMPLES + 1) * 1.3889\mu s * (4 + 2\ \hat{}\ (nr\_residual\_bits))$$

Information

It is recommended to place ALS measurement and Flicker measurement into separate steps of the sequencer in order to avoid noticeable influence of Residual measurement time onto the ALS integration time. This is what the GUI and the drivers provided by ams OSRAM do as well.

2.4 ALS and Flicker Timing

For ALS measurements one of the most important parameters is the ALS integration time. On legacy devices like the TCS3707 that was the product of the modulator clock period at e.g. 2.78 µs, the value in the ASTEP register (+1) and the value in the ATIME register (+1) as shown in Equation 3.

Equation 3:

$$ALS\ integration\ time_{[TCS3707]} = 2.78\mu s * (ASTEP + 1) * (ATIME\ + 1)$$

On TSL2521, it is almost the same but the modulator clock changed to 1.3889 µs and the register/bit field names are different as Equation 4 shows.

Equation 4:

$$ALS\ integration\ time_{[TSL2521]} = 1.3889\mu s * (sample\_time + 1) * (als\_nr\_samples + 1)$$

On TSL2521, the first term – the modulator clock multiplied by sample_time – is the base sampling time both for flicker measurements and for ALS measurements. If Flicker measurement is activated for a modulator within the active sequencer step, every value at the end of the sampling time is pushed to the FIFO – as often as set in fd_nr_samples in registers **FD_NR_SAMPLES0** and **FD_NR_SAMPLES1** - and increases at the same time the ALS result – as often as set in als_nr_samples in registers **ALS_NR_SAMPLES0** and **ALS_NR_SAMPLES1**.

Therefore, the Flicker sampling frequency is the reciprocal of the sampling time set with register SAMPLE_TIME, as shown in Equation 5.

Equation 5:

$$Flicker\ sampling\ frequency = \frac{1}{1.3889 * (sample\_time\ + 1)}$$

The whole flicker measurement time is defined by the mentioned sampling time and the register FD_NR_SAMPLES, see Equation 6.

Equation 6:

$$Flicker\ measurement\ time\ = 1.3889\mu s * (sample\_time + 1) * (fd\_nr\_samples + 1)$$

Note that there is only one new ALS result after the ALS integration time for each modulator 0 and modulator 1 since all single sample values are summed up. In contrast, there are fd_nr_samples flicker results per chosen modulator in the FIFO after the Flicker measurement time of one step. If that number of flicker results is more than the FIFO can handle – 256 values with 16-bit width are normally possible – the FIFO needs to be read out during the flicker measurement time to prevent a FIFO overflow. Figure 8 and Figure 9 show the relation between ALS and flicker measurement within the same step 0 of the sequencer with the chosen settings.

Figure 8:
Step 0 of TSL2521 Sequencer with ALS and Flicker Measurement Activated

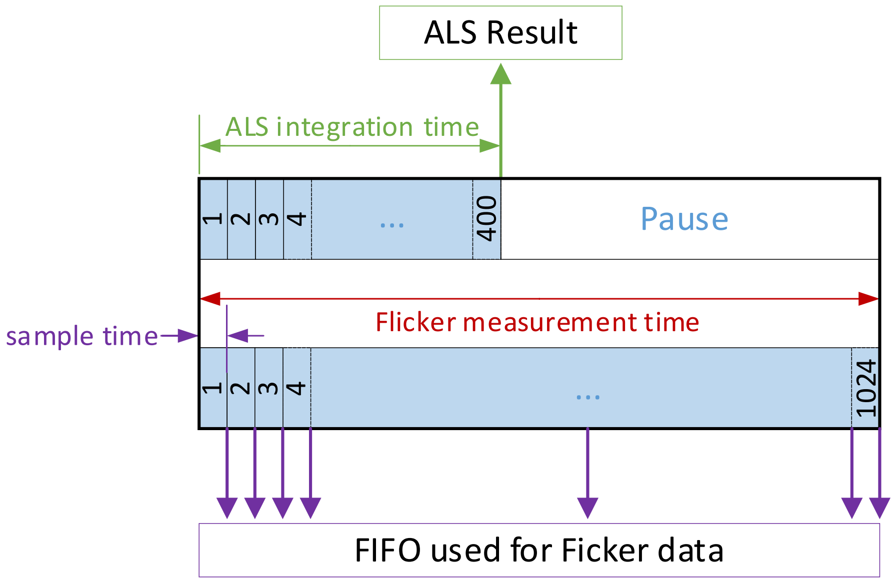


Figure 9:
Example Specification and Proposed Settings

Item	Value [dec.]
Customer Example Specification:	
- **Update interval**	< 0.5 s
- **ALS integraton time**	50 ms
- **Max. flicker frequency**	2 kHz
- **FFT bin size**	10 Hz
Proposal:	
- **Sample time**	125 µs
- **Sample frequency**	8 kHz
- **FFT size**	1024
Settings for Proposal:	
- **sample_time**	89
- **als_nr_samples**	399
- **fd_nr_samples**	1023

2.5 ALS/Flicker Gain and AGC

Another fundamental parameter for ALS measurement is the ALS gain setting. For ALS legacy devices like TCS3707 there was a single AGAIN value. For TSL2521, the gain is set per modulator and even for every sequence individually. The gain for both modulator 0 and modulator 1 for step 0 can be set in register **MEAS_SEQR_STEP0_MOD_GAINX_L**. The modulator gain can range from 0.5x to 4096x and is limited in register **CFG8** by the field measurement_sequencer_max_mod_gain for all modulators and sequencer steps. Please note that in case of enabled Automatic Gain Control (AGC) the modulator gain registers are changed according to the last measurement.

The gain used for the current result set in the **ALS_DATA** registers can be read from the **ALS_STATUS2** register using the bit fields als_data0_gain_status and als_data1_gain_status. This gain information is important for the lux equation, since the AGC – if enabled – might have changed the originally set modulator gain.

There are two Automatic Gain Control (AGC) methods implemented. The legacy one is the saturation AGC that reduces the gain in case of modulator saturation and repeats the measurement until there is no saturated result. This method is easy and – as long as the dynamic range allows it – always leads to a useful result but can take longer time and the time delay caused by this procedure is not deterministic.

The saturation AGC can be enabled in field measurement_sequencer_agc_asat_pattern in register **MEAS_SEQR_STEP1_MOD_PHDX_SMUX_H** individually for each sequencer step. This setting is valid for both modulators.

The second one is the predict AGC, that defines the gain for the next measurement by doing a measurement with reduced gain. The gain reduction can be set in register **CFG8** in the field measurement_mod_gain_reduction; by default it reduces the gain by 4 steps. The advantage of the predict AGC is a shorter and deterministic measurement time, but in case of abrupt changes it can lead to a saturated result that needs to be dropped after checking the saturation signals.

The predict AGC can be enabled in the field measurement_sequencer_agc_predict_pattern in register **MEAS_SEQR_STEP2_MOD_PHDX_SMUX_H** individually for each sequencer step. This setting is valid for both modulators.

The AGC measurement is done by adding an additional ALS sequence round before the actual measurement sequence. Both AGC methods do not need to use the same ALS integration time since AGC has its own dedicated agc_nr_samples fields in registers **AGC_NR_SAMPLE[7:0]** and **AGC_NR_SAMPLES[10:8],** sample_time is the same as for ALS/Flicker. That can help to reduce the whole ALS measurement time by using a shorter integration time for the AGC measurement. Both AGC methods can be used at the same time, in this case the predict AGC firstly sets the gain, but if still analog saturation happens the saturation AGC repeats the measurement with reduced gain. Please note that due to the saturation AGC method the ALS measurement time is not deterministic in this case too.

How often AGC is performed is defined with mod_calib_nth_iteration in register **MOD_CALIB_CFG0**. Additionally, the ACG needs to be linked to mod_calib_nth_iteration by setting the bit mod_calib_nth_iteration_agc_enable in register **MOD_CALIB_CFG2**. Please note that this bit is not enabled by default but has to be enabled to use one or both of the AGC methods.

Information

The same mode_calib_nth_iteration setting is used for the Autozero as well. Since the ALS Autozero procedure can take a longer time it might be necessary to disable the bit mod_calib_nth_iteration_az_enable in register **MOD_CALIB_CFG2** after the first measurement. For this purpose a single measurement can be done after startup either by setting mode_calib_nth_iteration to 1 and setting the bit stop_after_nth_iteration in register **MEAS_MODE0** or just by stopping the measurement after getting the first result. After that Autozero can be disabled by clearing bit mod_calib_nth_iteration_az_enable.

2.6 Wait Time

Related to ALS measurement on legacy ALS devices like TCS3707 was the Wait time that defined the sample rate of the ALS measurement – and therefore had to be higher than the set ALS integration time. The way to activate this WTIME was to set the enable Bit WEN in the ENABLE register.

WTIME is present on TSL2521 as well, but there is no WEN necessary anymore. Instead, there is the additional bit field mod_trigger_timing in register **TRIGGER_MODE** that either switches off the Wait time or defines the time base multiplicator for **WTIME**.

Additionally, the Wait time needs to be activated for each sequencer step individually in bit field measurement_sequencer_wait_pattern in register **MEAS_SEQR_RESIDUAL_1_AND_WAIT**.
As for all sequencer pattern registers on TSL2521 the default value is the right one if only sequence step 0 is used.

Information

Please note that on TSL2521 the Wait time needs to be higher than both the ALS integration time and the Flicker measurement time to have an effect.

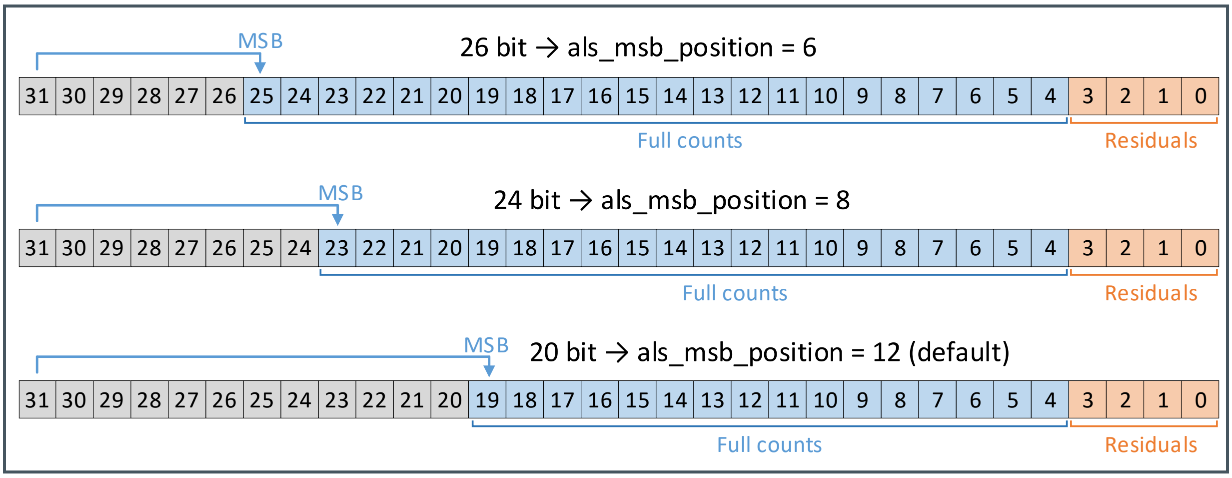
3 ALS Result Data Format

3.1 Internal Data Format

Internally the ALS result is stored in a 32-bit word. The 4 LSB bits are always reserved for residual counts, no matter if they are measured or not – if not, they are set to 0. If there are less Residuals bits chosen or measured than 4 there are still 4 bits reserved in the ALS result format - the ones on the LSB side that are not measured are set to 0.

Since sample_time and als_nr_samples are both 11-bit wide fields the maximum bit width of the full counts is 22-bit, adding 4 bits for Residual counts on LSB side equals a maximum ALS result bit width of 26-bit. The real dynamic range depends mainly on the actual settings of sample_time and als_nr_samples and in most applications it is not that high. The field als_msb_position in register **MEAS_MODE1** moves the MSB inside the 32-bit result register starting from bit 31 to the selected bit. As shown in Figure 10 the maximum result width of 26-bit including 4-bit Residual counts requires als_msb_position to be set to 6. In most applications the second shown format of 24-bit is a good setting since it requires only 3 Bytes on the FIFO per channel and still offers a very large dynamic range.

Figure 10:
Internal ALS Result Format Depending on als_msb_position



The third shown format in Figure 10 with als_msb_position at 12 is the default setting, it results in a 20-bit result containing 4-bit Residual width and 16-bit width for full counts. Apart from the Residual counts this is the same bit width for ALS results as on legacy devices like TCS3707 and with a later described trick it can be transferred over the **ALS_DATA**x registers in case a FIFO transfer is not wanted.

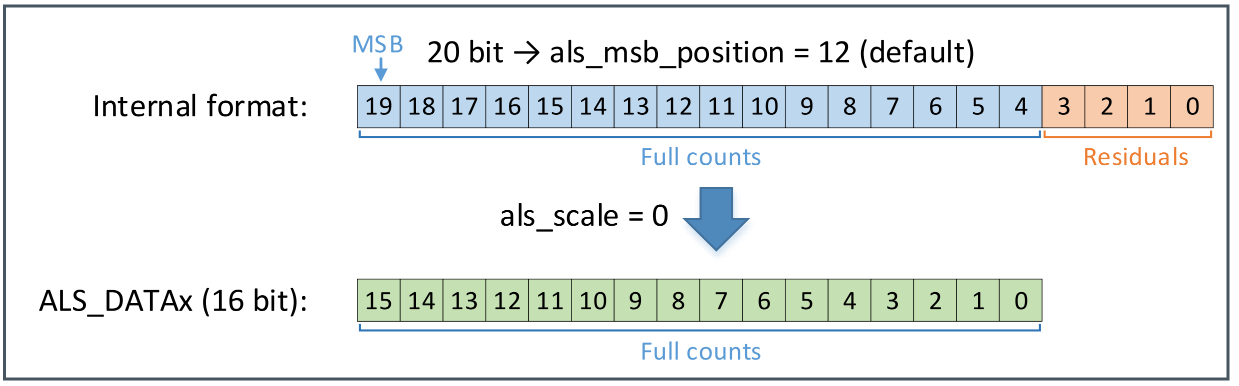
Information

Setting als_msb_position to the right format is necessary to get a valid als_digital_saturation bit.

3.2 16-Bit Data Full Count Results in ALS_DATA Registers

In case the ALS results should be read over the **ALS_STATUS** and **ALS_DATA**x registers the 16-bit full counts can be read out like in legacy devices without using the FIFO – but without the Residual counts, no matter if they are measured or not.
In this case the field als_scale in register **MEAS_MODE0** needs to be set to 0 like shown in Figure 11.

Figure 11:
ALS Results Presented in ALS_DATAx Registers as 16-Bit Word of Full Counts, No Residuals



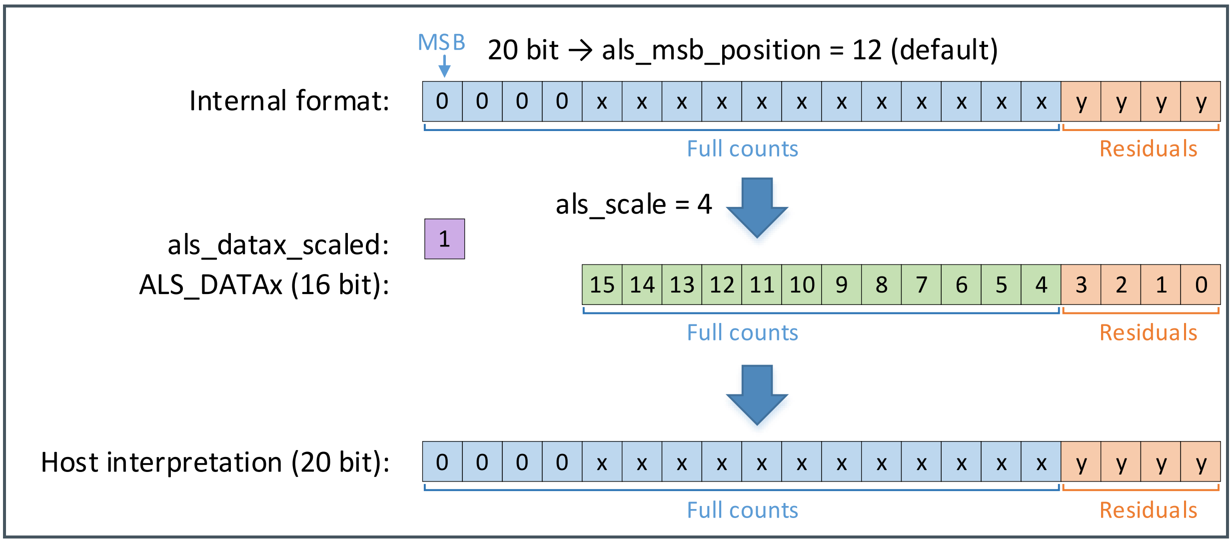
The disadvantage of this method is the loss of the Residual counts and, additionally, it is difficult to change to any method containing Residuals later since the number space is a different one without the 4 bits on LSB side.

3.3 20-Bit Data Result in ALS_DATA Registers Including 4-Bit Residuals

It is possible to transfer the 16-bit full counts over the ALS_DATAx register and, additionally, the Residual counts in case of a lower number of full counts – this makes sense since the additional resolution the Residual counts provide are helpful especially in low light conditions.

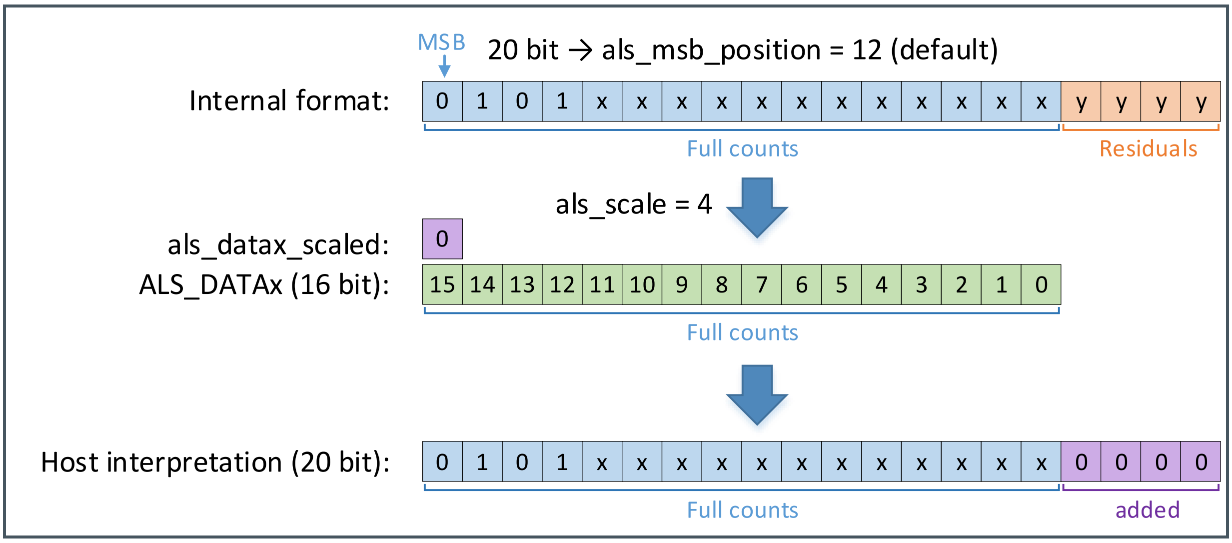
The field als_scale in register MEAS_MODE0 has to be set to the number of full counts MSB that needs to be 0 so that the Residual counts are transferred instead on the LSB side, by default 4 since we have 4 Residual bits. The MSB bits that are 0 are simply left out. To mark such a result as “scaled” the ALS_STATUS register contains a bit als_datax_scaled for every modulator that is set in this case as shown in Figure 12. The host takes the 16-bit number, checks the als_datax_scaled register and – because it is 1 - just adds 4 bits 0 on MSB side to get a 20-bit number.

Figure 12:
Scaled Data Transfer of ALS Data Including Residual Counts



The other case is shown in Figure 13: Not all 4 MSB bits of the 20-bit results are 0 – in this case only the 16-bit full counts are transferred to the 16-bit ALS_DATAx register and als_datax_scaled is cleared. The host reads out both the ALS_STATUS register and the ALS_DATAx registers. Bit als_datax_scaled is checked by the host and since it is 0 the 16-bit full counts result in the ALS_DATAx is shifted by 4 bits to the left or simply multiplied by 16 on host side to keep the data consistent over the whole range and to stay in the same 20-bit number space as in the first case.

Figure 13:
Unscaled Data Transfer of ALS Data without Residual Counts



Using this kind of ALS result format gives both the dynamic range of the ALS legacy devices and the advantage of the residual measurement in lower light situations while keeping the 16-bit register width.

Additionally, it is possible to use this both with Residual measurement enabled or disabled, the number space is consistent in this case. Even changing to 24-bit measurement over the FIFO keeps the data consistency.

Information

For both methods using **ALS_DATA**x registers it is mandatory to read out **ALS_STATUS** firstly and the **ALS_DATA**x registers immediately afterwards. It is recommended to do this in one I^2C block read including the ALS_STATUS2 register since the latter contains the als_datax_gain_status fields that are necessary for the lux equation as well. This way it is guaranteed by design that all **ALS_DATA**x results are from the same integration cycle.

3.4 24-Bit ALS Result Data Transferred Via FIFO

Using a higher dynamic range than 20-bit is only possible using the FIFO transfer of ALS results. Since the FIFO is mainly used for flicker data writing of flicker data takes precedence over the writing of ALS data. Therefore it is – again – recommended, to keep ALS measurement and flicker measurement in different steps of the sequencer. If this is not possible the bit do_als_final_processing in register **CFG1** has to be set. This delays the writing of ALS data until all flicker data is written, after that the ALS data is written to the FIFO.

The format of the ALS data is chosen in field mod_als_fifo_data_format in register **CFG2**. 24-bit format is recommended since it saves one byte per chosen modulator result and gives a high dynamic range, nevertheless, 32-bit format is possible too, whereas 16-bit format uses the same format options as explained in the previous chapters about transferring the results via **ALS_DATA**x.

The fields mod_als_fifo_datax_write_enable in registers **MOD_FIFO_DATA_CFG**x define whether the corresponding ALS modulator result will be pushed to the FIFO or not. The data is pushed in low byte first order starting at the first sequencer step and the lowest chosen modulator number.

Field mod_fifo_als_status_write_enable in register **MEAS_MODE0** needs to be set in order to get the 3 status registers **ALS_STATUS**, **ALS_STATUS2**, and **ALS_STATUS3** (reserved) pushed to the FIFO in that order after the selected ALS modulator results of one sequencer step. These status registers contain analog saturation information as well as gain information and are needed for lux equation calculations.

3.5 Saturation and Maximum Value of ALS Result

There are three conditions that cause an invalid ALS result, two of them can be noticed by dedicated flags and/or result codes, one needs to be handled by host software.

3.5.1 Analog Saturation

Analog saturation means that the signal from the photodiodes amplified by the gain stage is that high that it cannot be checked fast enough by the modulator circuit. It is signaled by the bits als_datax_analog_saturation_status dedicated for each modulator in register **ALS_STATUS**, the result set of all modulators needs to be ignored in this case. The ALS_DATAx register of the affected modulator is forced to the value 0xFFFF additionally, in case of 24-bit FIFO format to 0xFFFFFF, in case of 32-bit FIFO format to 0xFFFFFF. Analog saturation sets the modulator interrupt flag mint in register **STATUS** as well.

In case of manual gain setting the gain needs to be reduced, in case of enabled saturation AGC this is done automatically. If a gain of only 0.5x does not remove the saturation condition the number of used photodiodes for this filter needs to be reduced with the SMUX registers in the sequencer section.

3.5.2 Digital Saturation

The als_digital_saturation flag in register **STATUS2** is set if an internal ALS results cannot be expressed in the data format chosen by als_msb_position in register **MEAS_MODE1**. Additionally, the **ALS_DATA**x register of the affected modulator is forced to the value 0xFFFE, in case of 24-bit FIFO format to 0xFFFFFE. Digital saturation sets the modulator interrupt flag mint in register **STATUS** as well.

Like for analog saturation this can be solved by reducing the gain - if not done by the AGC automatically – or by reducing the number of photodiodes connected to the affected modulator. In contrast to analog saturation a reduction of the ALS integration time has the same effect.

3.5.3 Maximum Value of ALS Result

The maximum value of the ALS result can be important to check because it can be reached, depending on the als_nr_samples and sample_time settings, without getting analog or digital saturation. Nevertheless, measurements beyond this maximum value will always show the same value and are therefore not linear anymore.

This maximum value needs to be checked on host side and in case of occurrence marked as saturation due to maximum value reached, the sensor does not recognize this nonlinearity. Equation 7 shows the calculation for measurements when Residuals are disabled, the factor 16 at the end takes care for the 4 bits reserved for Residuals, it has to be omitted if the 16-bit data results transfer described above is used.

Equation 7:

$$ALS\_max\_value = ((als\_nr\_samples + 1) * (sample\_time + 1) - 2) * 16$$

In case of enabled Residual measurement the calculation is not that easy anymore since the maximum value can change a bit with the Residual measurement time and due to other reasons.
In order to be on the save side the result of the following calculation and every bigger value should be considered as saturation due to maximum value reached.

Equation 8:

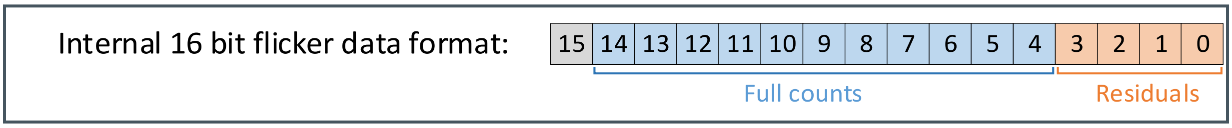
$$ALS\_max\_value\_with\_residuals \geq ((als\_nr\_samples + 1) * (sample\_time + 1) - 22) * 16$$

4 Flicker Result Data Format

4.1 Internal Flicker Data Format

Flicker data is at maximum 15 bits large as shown in Figure 14 – again 4-bit Residuals on LSB side and maximum 11-bit for full counts since the field sample_time is 11-bit wide. Internally these maximum 15 bits are stored in a 16-bit data register.

Figure 14:
16-Bit Flicker Data Format

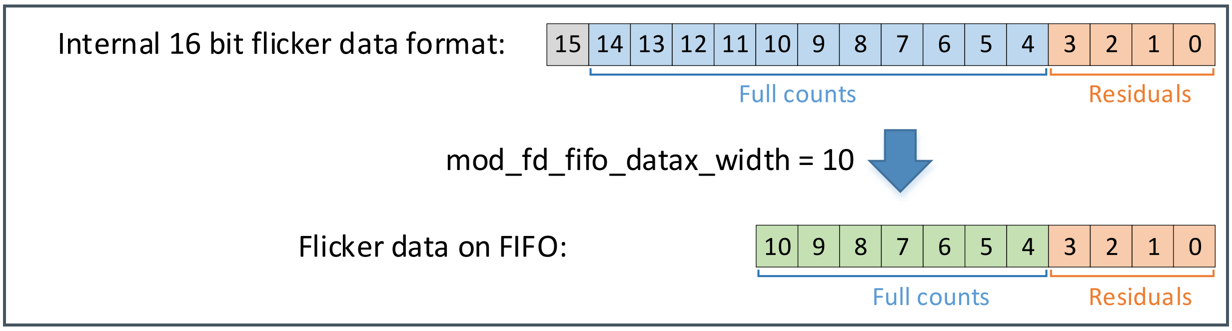


Note that the lower 4 bits are always reserved for Residual bits, no matter, if they are really measured or if the measurement is reduced to a lower number of Residual bits.

4.2 Flicker Data Reduction Options

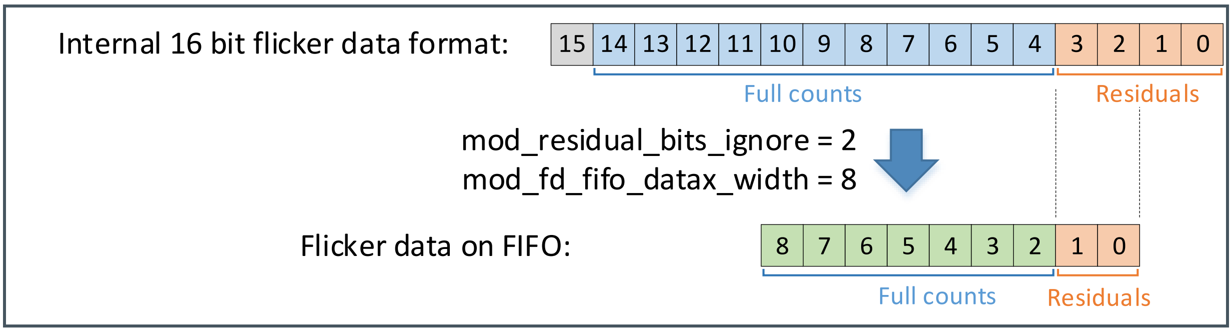
There are several possibilities to reduce the number of transferred flicker data bits in order to reduce I^2C traffic. For high flicker samples rates the dynamic range is lower, so the absolute number of bits of a transferred sample can be set lower. The bit width for flicker data in the FIFO is set by field [3:0] mod_fd_fifo_datax_width of register MOD_FIFO_DATA_CFGx. The default value is 15, which means the full 16-bit wide word shown in Figure 14. Figure 15 shows an example for 11-bit flicker data width, which would be suitable for the requirements of the example specification in Figure 9.

Figure 15:
Flicker Data Format with 11-Bit Width as Example



Additionally, it is possible to remove up to three of the four Residual bits from the flicker data format width by using field[1:0] mod_residual_bits_ignore in register **CFG9** (0xAA), an example is shown in Figure 16.

Figure 16:
Flicker Data Format 9-Bit Width With Only 2 Residual Bits as Example



Nevertheless, such a Residual bit reduction is often not recommended, especially high flicker frequencies do result in a rather small dynamic range, additional Residual bits can improve this situation significantly.

Information

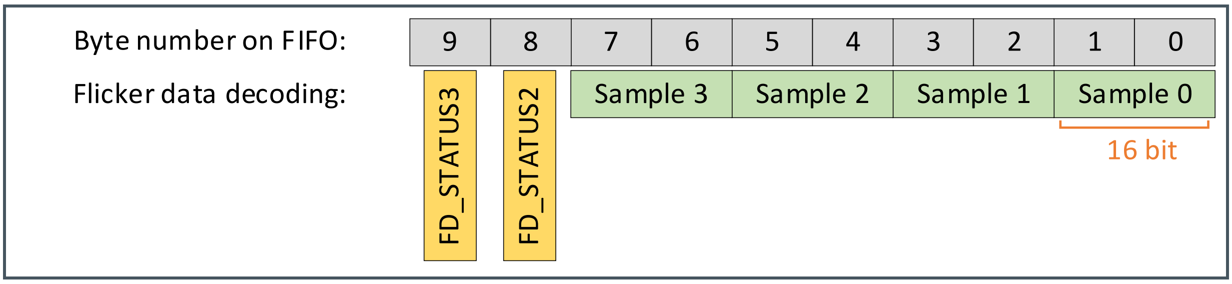
Analog saturation is shown in the flicker data result by forcing all bits to 1. There is no digital saturation flag implemented to signal that the data exceeds a reduced transfer bit width, hence the user must select the flicker data width correctly depending on the sample_time setting.

TSL2521 has a built in non-destructive flicker data compression mode as well that reduces the I^2C traffic significantly, the drivers provided by ams OSRAM show and document the use of these features.

4.3 Flicker Data Transfer Via FIFO

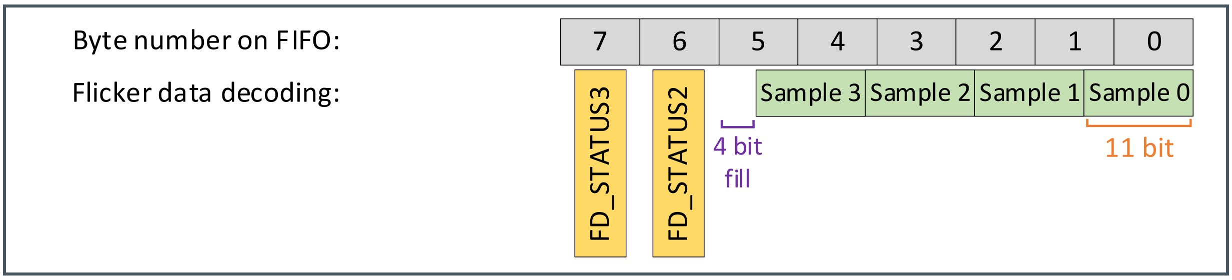
Flicker data is always written to the FIFO if flicker measurement is enabled in a sequencer step starting by the lowest modulator number selected for flicker measurement. Additionally, mod_fifo_fd_gain_write_enable, bit 5 of register MEAS_MODE1, should be enabled to identify the used gain, especially when AGC is enabled. The flicker measurement gain – same as ALS modulator gain if activated in the same step – is written to the FIFO as FD_STATUS2 and FD_STATUS3 (reserved) in the same structure as ALS_STATUS2 and ALS_STATUS3 (reserved), no matter how many channels are enabled for flicker data collection.
Figure 17 shows the FIFO data structure in case of one modulator enabled for flicker measurement with 16-bit flicker data to be transferred. For demonstration reasons fd_nr_samples is set to 3. 16-bit data is transferred with the low byte first.

Figure 17:
FIFO Structure Example for Flicker Measurement Enabled on One Modulator With Flicker Gain Written and 4 Flicker Samples Measured (fd_nr_samples = 3)



In case of reduced Flicker bit width the last FIFO byte containing flicker data gets filled up to full 8-bit on MSB side with 0 before the gain data is pushed to the FIFO. Figure 18 shows such a case for an 11-bit wide flicker data format like shown above in Figure 15.

Figure 18:
FIFO Structure Example With a Reduced Flicker Data Bit Width of 11-Bit and Filled Up FIFO Byte



The flicker data can be read out from register **FIFO_DATA** at any time. The right procedure is to get firstly fifo_lvl by reading **FIFO_LEVEL** (0xFD) and **FIFO_STATUS0** (0xFE) as block read in this order. Checking the fifo_overflow flag in **FIFO_STATUS0** is necessary to judge if the FIFO still has the correct order of bytes. After that the FIFO data can be read from **FIFO_DATA** in a block read with the number of bytes known from fifo_lvl. Reading more bytes than available will return 0 and the fifo_underflow flag will be set in **FIFO_STATUS0**.

5 Revision Information

Changes from previous version to current revision v1-01	Page
Initial version	
Corrected number of preferred modulator for flicker measurements	4

- 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.

6 Legal Information

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