High Resolution Detection Specification, Calibration, and Design-In

By Reinhard Schaar

ANALOG REFLECTIVE SENSORS

Reflective sensors utilize an emitter and photodetector - either a phototransistor or a photodiode - to detect the presence of objects. Their detection range is dependent on their construction, the gap between their emitter and detector, the radiant intensity of the emitter, the sensitivity of the detector, and the reflectivity of the object. The smaller the viewing angle, the higher the intensity of the emitter and the sensitivity of the detector. Components without a lens often show viewing angles from 100° to 130°, while the angles are many degrees lower for devices equipped with lenses.

Fig. 1

All reflective sensor share this characteristic:

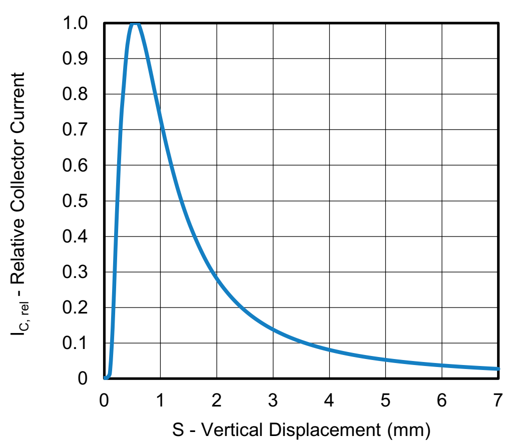

Fig. 2

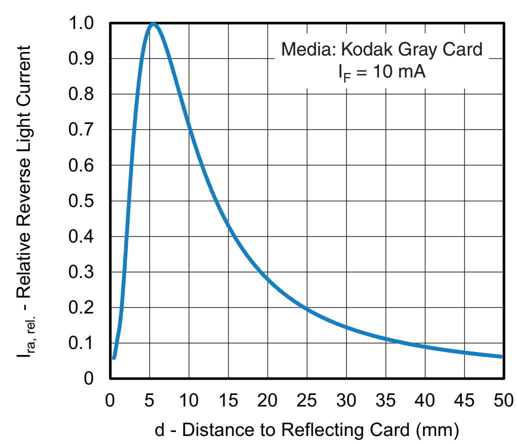

Fig. 3

The peak for the output current of reflective sensors is dependent on their construction and the distance between the emitter and detector. In Fig. 2, the emitter and detector are very close together, with about 1 mm between them. Fig. 3 shows a sensor with about a 4 mm gap between the emitter and detector, so the peak output current is reached at about 5 mm from the sensor. The graphs also show that the output current falls down not linear with increasing distance.

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Many simple reflective sensors use a phototransistor as the detector, which is best for most simple presence detection applications. Requiring high resolution and reproduceable results the high gain tolerances and much stronger temperature behavior of the phototransistors will not allow to take them for a “high resolution” detector.

A photodiode as detector is preferred here, but with these the output current is quite low and will need a very well performing low noise amplification. It is necessary to utilize a proper op-amp for these kind of applications.

Another disadvantage of using analog parts for this task is the additional need for a proper pulse generator. By generating very short pulses with proper sequencing, the emitter can be operated with much higher current than would be possible with DC operation. The short pulse lengths will avoid heating up the emitter chip, which could lead to decreasing intensity and greater temperature dependence.

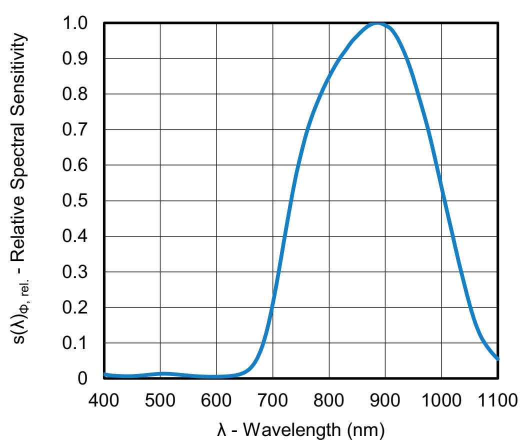

Fig. 4

In addition, any light that reaches the detector will cause unwanted current and falsify the results. Daylight filters are insufficient for applications requiring a high resolution and stable, accurate results.

It is difficult to perform presence detection with discrete analog components given the need for 1) short pulses that are programmable in width to allow for optimal intensity; 2) a photodiode as the detector with an added op-amp; 3) additional circuitry to cancel all disturbing light influence; and 4) a minimum 16-bit A/D converter for achieving high resolution. But a proximity sensor comes with all this functionality.

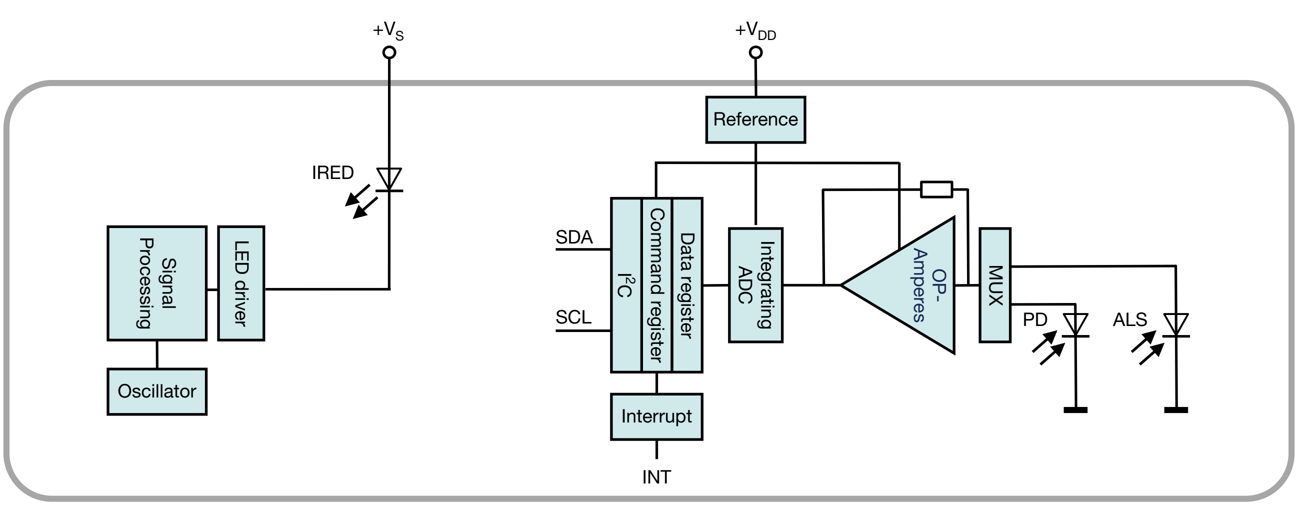

Fig. 5

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DIGITAL REFLECTIVE SENSORS

As shown above, analog reflective sensors offer an output current. This current can be converted to a voltage by adding a load resistor.

A digital sensor operates the same as an analog sensor - an infrared emitter is used with a photodiode. However, the output current is converted to a digital value that is available via an I^{2}C interface. Digital proximity sensors are more commonly used for presence detection.

The detection range for digital sensors also depends on their construction, the gap between the emitter and detector, the intensity of the emitter, the sensitivity of the detector, and the reflectivity of the object. Several sensor types are available. Some feature additional ambient light sensors (ALS), while other are equipped with a lens on their emitter or detector or do not have an embedded emitter.

Fig. 6

The graphs for the output value versus distance for digital sensors look similar to their analog counterparts - the peak depends on the distance between the emitter and detector. The output current, in digital counts, depends on the strength of the emitter's intensity, either due to being equipped with a lens, having higher applied emitter current, or both.

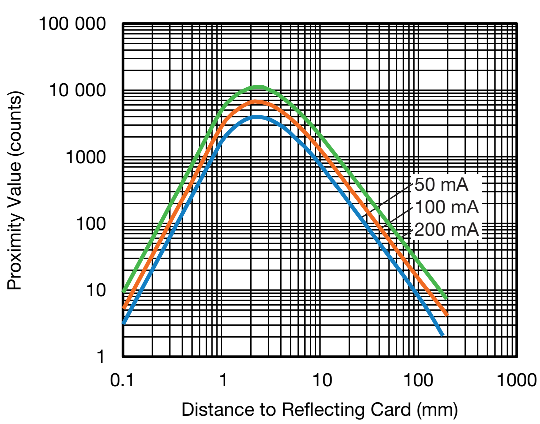

Fig. 7

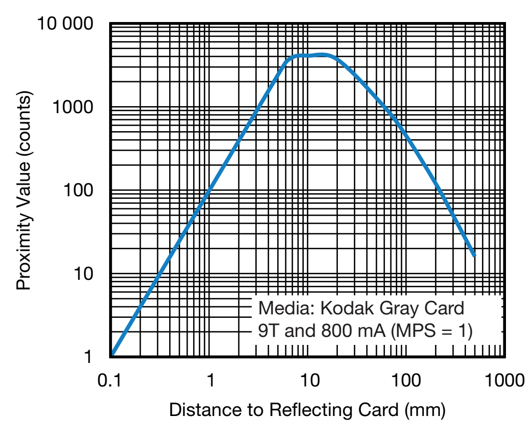

Fig. 8

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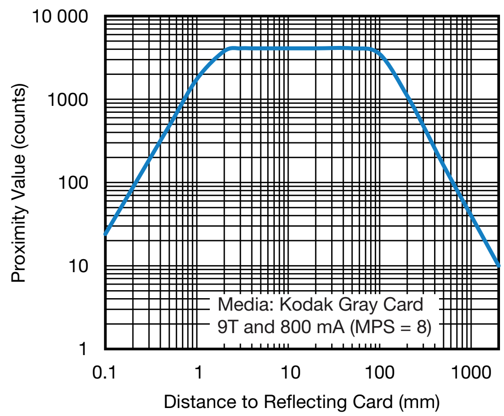

Fig. 9

Fig. 9 shows the saturation for all object distances less than 10 cm, as the target is to detect objects at very wide distances up to 1.5 m. Fig. 8 shows that the peak is reached for object distances of > 5mm to 6 mm, and Fig. 7 shows the peak at about 2 mm. This is seen for such small devices as the VCNL4020, VCNL4020X01, and VCNL4030X01 / VCNL3030X01. The graphs show that more than 10 000 counts can be reached even for this quite low reflecting Kodak Gray card, which offers about 18 % reflectivity. For a mirror or white card, saturation will also be seen for very low distances.

How these counts decrease with distance can be better seen when looking at a linear graph instead of these double-logarithmic ones. The measured values are the same for both.

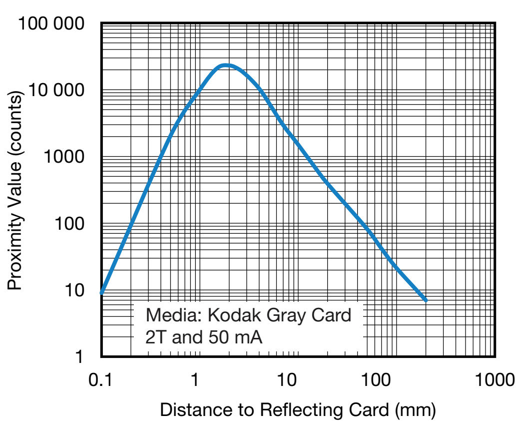

Fig. 10

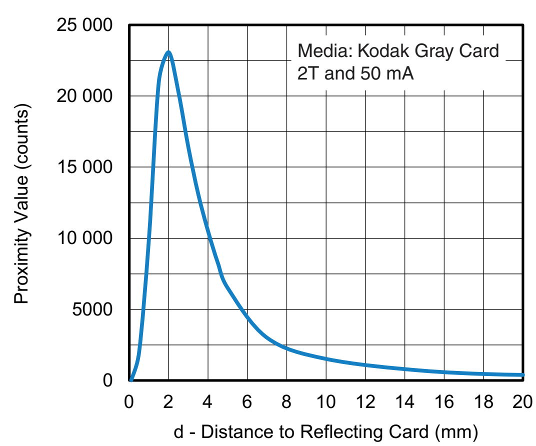

Fig. 11

As shown, the highest change of counts is within a small range, from the peak at about 2 mm to 5 mm, up to 10 mm, depending on the resolution required.

High Resolution Detection
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Between 2 mm and 3 mm there is a delta of several thousand counts, and high enough delta counts are also available at 5 mm to 7 mm. These delta counts are needed due to noise and temperature effects, which will not allow for too small steps to provide reliable detection.

VCNL4030X01, 2T, 50 mA			
DISTANCE	**COUNTS**	**d**	**DELTA CTS**
0.1	9	-	-
0.5	2000	-	-
1.0	10 000	-	-
1.5	21 000	-	-
2.0	23 080	2.0	2830
2.5	20 250	2.5	3850
3.0	16 400	3.0	3280
3.5	13 120	3.5	2620
4.0	10 500	4.0	2240
4.5	8260	4.5	1760
5.0	6500	-	-
7.0	3000	-	-
10	1513	-	-
15	675	-	-
20	390	-	-
50	83.25	-	-
70	42.50	-	-
100	21.50	-	-
200	7.00	-	-

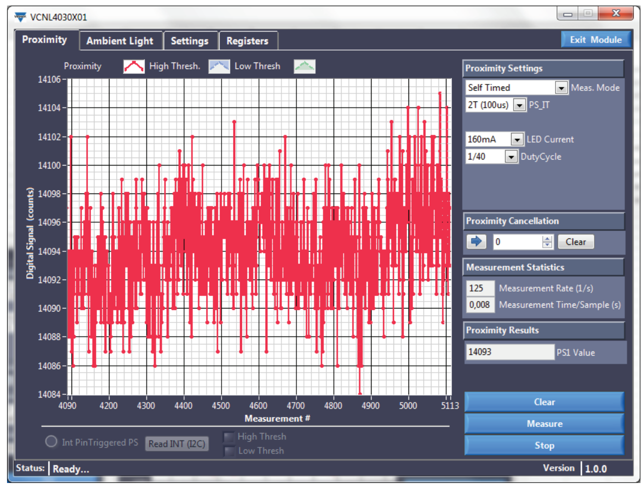

Fig. 12

These noise counts of about ± 20 are not possible to see with steps of several hundred, and are in the range of a few μV - keeping in mind that the whole operating range for the 16-bit ADC is only about 2.2 V. So, 65 535 counts = 2200 mV → V/count = 2200 mV / 65 535 counts = 0.034 mV/count = 34 μV/count. These 20 counts are just 0.68 mV.

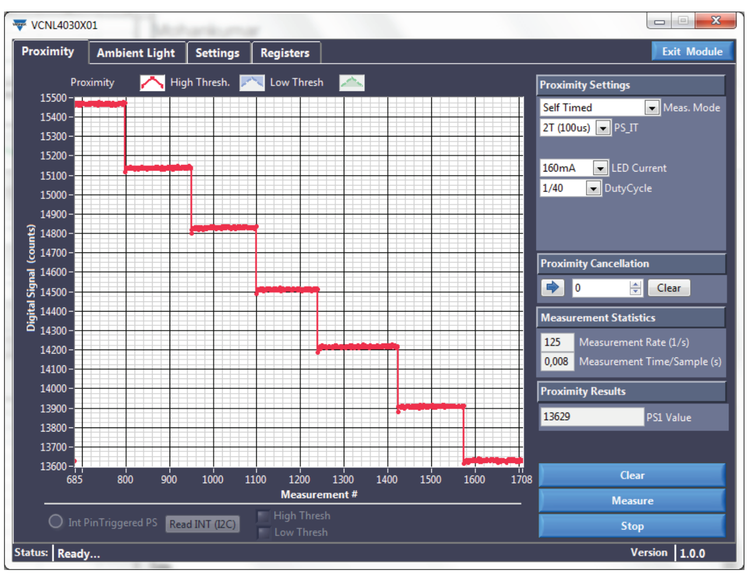

Fig. 13

High Resolution Detection Specification, Calibration, and Design-In

Temperature also affects the results, but within a wide range it is stable. Fig. 14 shows the typical temperature behavior for the VCNL4020. Between 0 °C and 85 °C there is a shift of less than 250 counts.

VCNL4020 COUNTS			
TEMPERATURE (°C)	**COUNTS**		
	d = 5 mm	**d = 10 mm**	**d = 15 mm**
-25	16 810	11 924	10 876
0	17 375	12 008	10 848
25	17 610	12 006	10 800
50	17 640	12 015	10 778
85	17 540	12 200	11 020

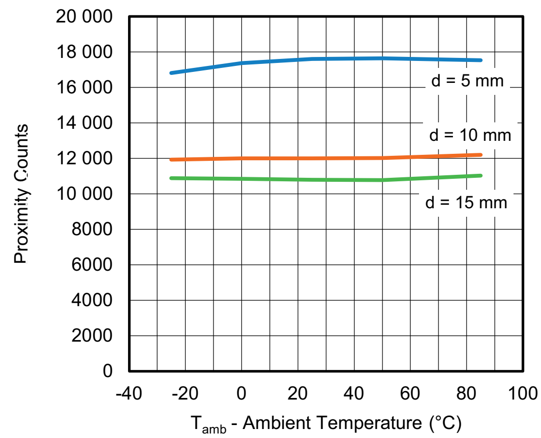

Fig. 14

The temperature behavior for the VCNL4030X01 / VCNL3030X01 is different. It is stable for higher temperatures, but for lower temperatures there is a wider shift.

VCNL4030X01, 4T, 200 mA		
TEMPERATURE (°C)	**COUNTS**	**DELTA CTS**
-25	23 655	0
-10	22 948	707
0	22 978	-30
10	23 211	-233
25	23 740	-529
40	24 264	-524
55	24 765	-501
70	25 126	-361
85	25 305	-179
100	25 235	70

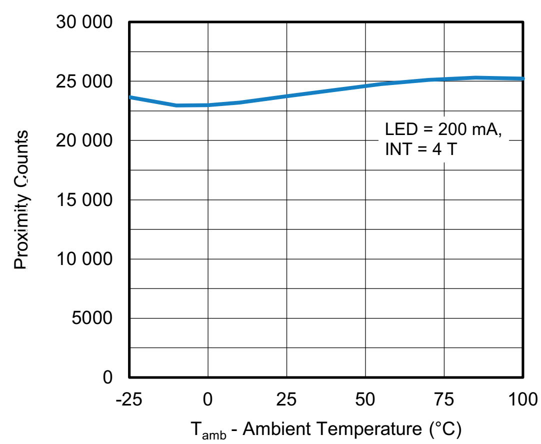

Fig. 15

Both sensors show a temperature dependence of about 250 counts. So, reliable and reproduceable results for defining a small distance change should have > 250 counts as the delta between single steps. Even better would be > 500 counts.

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Results for 100 μm steps for a distance between the sensor and object of about 3 mm to 4 mm will show even > 1000 delta counts.

KODAK GRAY CARD, 40 mA, 390 kHz		
DISTANCE	COUNTS	DELTA CTS
3.0	58 002	0
3.1	56 399	1603
3.2	54 677	1722
3.3	53 062	1615
3.4	51 504	1558
3.5	49 877	1627

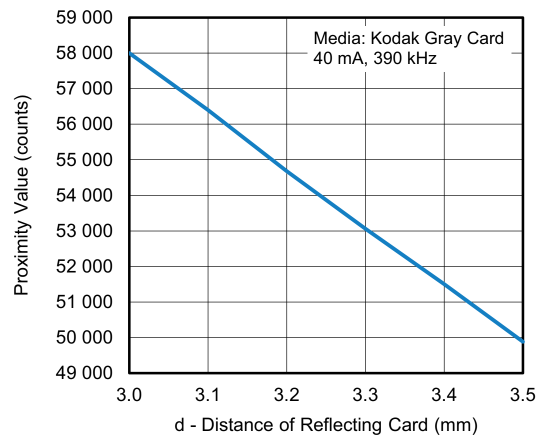

Fig. 16

Measurement results for just a 50 μm distance change for about 3 mm to 3.5 mm (shown below) are about 300 delta counts. However, the emitter current and pulse width are reduced, preventing too high values.

SUPER WHITE CARD, 2T, 16 mA		
50 μM STEPS	COUNTS	DELTA CTS
3.00	16 860	366
3.05	16 494	334
3.10	16 160	370
3.15	15 790	318
3.20	15 472	337
3.25	15 135	298
3.30	14 837	325
3.35	14 512	297
3.40	14 215	302
3.45	13 913	284
3.50	13 629	-

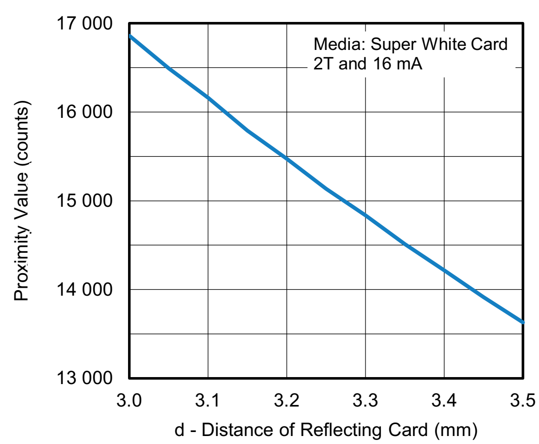

Fig. 17

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Being closer to the peak with a pulse length of 8T and 10 mA results in about 250 counts delta for a 20 μm distance change.

WHITE CARD, 8T, 10 mA		
20 μM STEPS	COUNTS	DELTA CTS
3.00	30 613	260
3.02	30 353	275
3.04	30 078	232
3.06	29 846	256
3.08	29 590	255
3.10	29 335	253
3.12	29 082	254
3.14	28 828	223
3.16	28 605	242
3.18	28 363	261
3.20	28 102	-

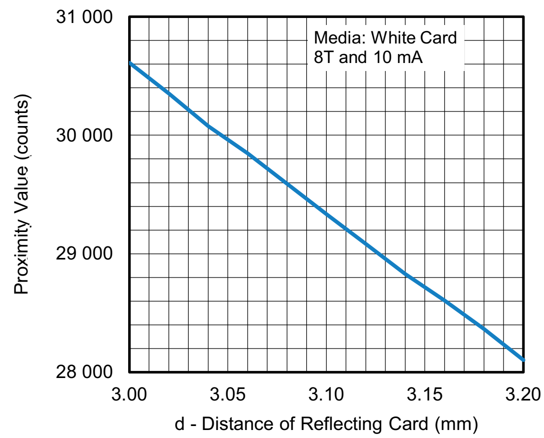

Fig. 18

The measured results do not look very precise, due to a manual change with the help of a micrometer block, and not every step seems to be set precisely.

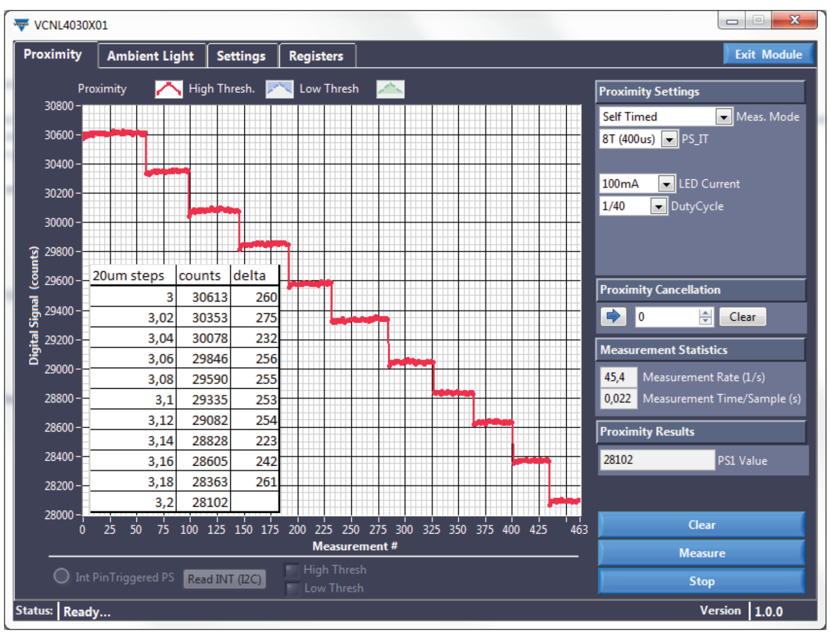

Fig. 19

High Resolution Detection Specification, Calibration, and Design-In

A high resolution will also be possible for higher distances, and also possibly for both quite narrow and quite high distances, but at least one parameter may need to be changed to allow for an optimal range.

A good and stable reflecting object should be used, as any small change or bend could influence the results. The object should also be stable over temperature, so a mirror or metal block would be best.

This object will show saturation for lower distances, at least when applying the highest possible emitter current. Below it can be seen that all distances below 6 mm cannot be shown.

WHITE CARD, 200 mA	
DISTANCE	COUNTS
0.1	915
0.5	35 121
1.0	65 000
1.5	65 535
2.0	65 535
2.5	65 535
3.0	65 535
3.5	65 535
4.0	65 535
4.5	65 535
5.0	65 535
6.0	60 849
7.0	46 917
8.0	37 212
9.0	29 029
9.5	26 519
10	24 368
15	11 852
20	6498
25	4341
30	3093
40	1770
50	1203

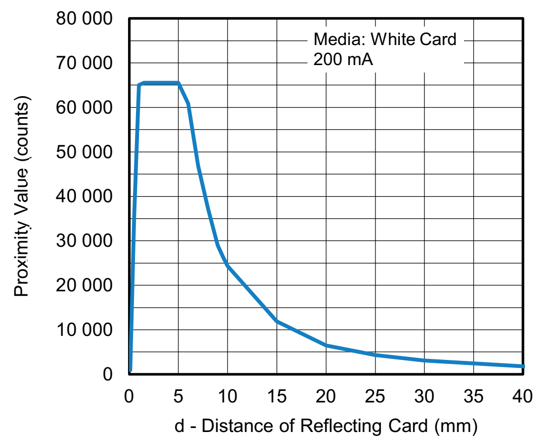

Fig. 20

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But with reduced current, adequate counts are available for higher distances, maybe up to > 10 mm.

WHITE CARD, 80 mA	
DISTANCE	**COUNTS**
0.1	915
0.5	35 121
1.0	65 000
1.5	65 535
2.0	65 535
2.5	61 144
3.0	58 037
3.5	52 363
4.0	43 735
4.5	37 900
5.0	32 783
6.0	24 816
7.0	19 155
8.0	15 106
9.0	12 170
9.5	11 004
10	9997
15	5408
20	3275
25	2072
30	1513
40	963
50	619

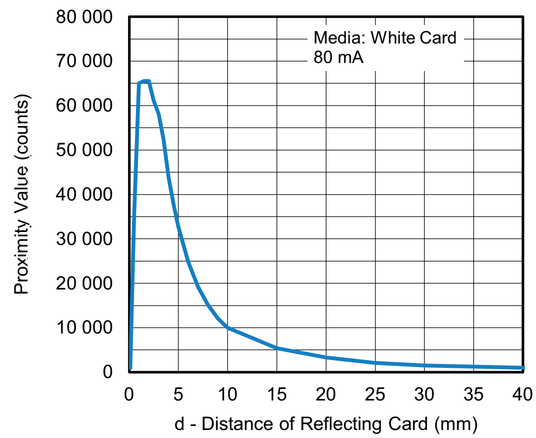

Fig. 21

High Resolution Detection
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Between 3 mm and 3.5 mm, each 100 µm step now shows more than 1000 counts delta.

VCNL4020X01, 80 mA				
DISTANCE	**COUNTS**	**d**	**COUNTS**	**DELTA**
0.1	915	-	-	-
0.5	35 121	-	-	-
1.0	65 000	-	-	-
1.5	65 535	-	-	-
2.0	65 535	-	-	-
2.5	61 144	-	-	-
3.0	58 037	3.0	58 037	0
3.5	52 363	3.1	57 057	980
4.0	43 735	3.2	55 915	1142
4.5	37 900	3.3	54 766	1149
5.0	32 783	3.4	53 566	1200
6.0	24 816	3.5	52 363	1203
7.0	19 155	-	-	-
8.0	15 106	-	-	-
9.0	12 170	-	-	-
9.5	11 004	-	-	-
10	9997	-	-	-
15	5408	-	-	-
20	3275	-	-	-
25	2072	-	-	-
30	1513	-	-	-
40	963	-	-	-
50	619	-	-	-

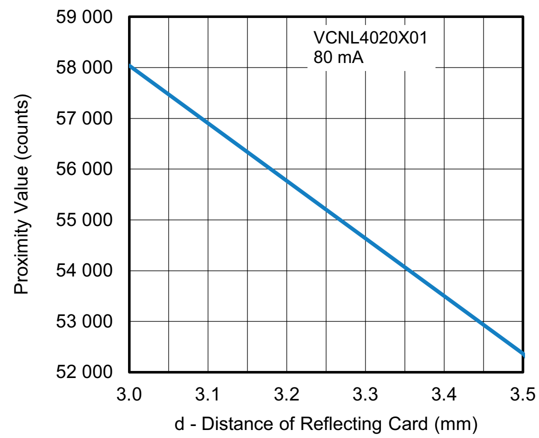

Fig. 22

High Resolution Detection
Specification, Calibration, and Design-In

Up to a distance of 10 mm, 100 μm steps should be reliable enough now that the emitter current is programmed to 200 mA. Now between 9 mm and 10 mm, each 100 μm step shows more than 400 counts delta.

VCNL4020X01, 200 mA				
DISTANCE	COUNTS	d	COUNTS	DELTA
0.1	915	-	-	-
0.5	35 121	-	-	-
1.0	65 000	-	-	-
1.5	65 535	-	-	-
2.0	65 535	-	-	-
2.5	65 535	-	-	-
3.0	65 535	-	-	-
3.5	65 535	-	-	-
4.0	65 535	-	-	-
4.5	65 535	-	-	-
5.0	65 535	-	-	-
6.0	60 849	9.0	29 029	0
7.0	46 917	9.1	28 528	501
8.0	37 212	9.2	27 981	547
9.0	29 029	9.3	27 482	499
9.5	26 519	9.4	26 989	493
10	24 368	9.5	26 519	470
15	11 852	9.6	26 062	457
20	6498	9.7	25 628	434
25	4341	9.8	25 197	431
30	3093	9.9	24 778	419
40	1770	10	24 368	410
50	1203	-	-	-

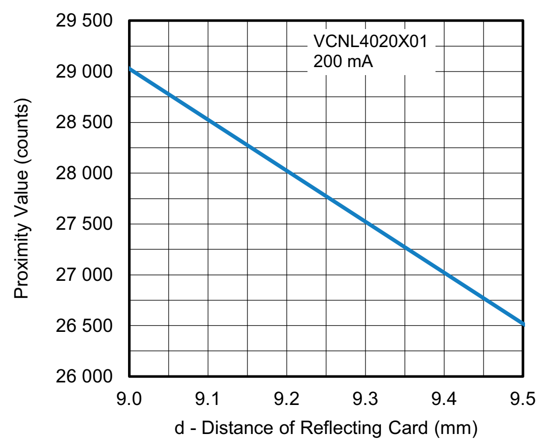

Fig. 23

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Fig. 24

Fig. 25

Both the VCNL4020X01 and VCNL4030X01 / VCNL3030X01 sensors can be used for high resolution detection. The exact operating conditions need to be adapted, as the emitter, detector, and driving pulses are different. But more important will be the wanted / needed distance between the sensor and the object / surface and its reflectivity to define the sensor parameter.

The VCNL4030X01 was developed as a normal proximity + ALS device. The VCNL3030X01 is just a version that comes without the ALS, which isn't needed for a dedicated force feedback sensor.

A further advantage for these two sensors is the LED_I_LOW command:

Command	Bit	Description
LED_I_LOW	7	0 = disabled = normal current, 1 = enabled = 1/10 of normal current, with that the current is accordingly: 5 mA, 7.5 mA, 10 mA, 12 mA, 14 mA, 16 mA, 18 mA, 20 mA

LED_I_LOW allows the emitter drive current to be set down to just 5 mA. This would be necessary if a very good reflecting object is placed very close to the sensor. The advantage of doing so is not only the perfect alignment to operate close to the peak of sensitivity, but also even better stability in terms of temperature effects, as the emitter chip will not heat up at all.

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CALIBRATION FOR FORCE FEEDBACK SOLUTIONS

If the application needs to detect few exact force steps, e.g. every 100 µm step, it is only possible for distances between the sensor and object where high delta values are measured from step to step. This is only given within a small range, shown below as being about 2 mm to 5 mm.

Every single sensor will show part to part tolerances that typically could be as big as those seen for an IRED, e.g. the VSMY1940X01 show below.

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Radiant intensity	I_F = 100 mA, t_p = 20 ms	I_e	9	12	15	mW/sr
	I_F = 1 A, t_p = 100 µs	I_e	-	80	-	mW/sr

The proximity value may also show high variations. However, the application-related tolerances could be even wider, e.g. if the exact positioning and object fixation would be not 100 % the same. So, for any ready-made application, a calibration needs to be done, e.g. for the position without any force applied to the system. The sensor parameter should also not be changed anymore, as this would also influence the measured counts.

Below, two example are shown for the VCNL4030X01 / VCNL3030X01, where either PS_IT = 8T and I_LED is set to 10 mA, or PS_IT = 2T and I_LED = 50 mA.

VCNL4030X01, 8T, 10 mA		
DISTANCE	COUNTS	DELTA COUNTS
1.0	61 696	2236
1.5	59 460	10 323
2.0	49 137	10 112
2.5	39 025	8102
3.0	30 923	6179
3.5	24 744	4646
4.0	20 096	3580
4.5	16 516	2787
5.0	13 729	2166
5.5	11 563	1740
6.0	9823	1418
6.5	8405	1158
7.0	7247	937
7.5	6310	784
8.0	5526	656
8.5	4870	548
9.0	4322	473
9.5	3849	404
10	3445	-

VCNL4030X01, 2T, 50 mA			
DISTANCE	COUNTS	d	DELTA CTS
0.1	9	-	-
0.5	2000	-	-
1.0	10 000	-	-
1.5	21 000	-	-
2.0	23 080	2.0	2830
2.5	20 250	2.5	3850
3.0	16 400	3.0	3280
3.5	13 120	3.5	2620
4.0	10 500	4.0	2240
4.5	8260	4.5	1760
5.0	6500	5.0	-
7.0	3000	-	-
10	1513	-	-
15	675	-	-
20	390	-	-
50	83.25	-	-
70	42.50	-	-
100	21.50	-	-
200	7.00	-	-

High Resolution Detection Specification, Calibration, and Design-In

SOFTWARE ROUTINES FOR FORCE FEEDBACK SOLUTIONS

A way to realize proper force feedback results without dealing with any tolerances and variances would be to check for a fast increase of counts from the current available proximity counts to the next measured ones, maybe with a small average of two to 10 measured samples to eliminate noise spikes.

Below, the counts without any touching of the surface are around 10 700. Just touching the surface where the sensor is mounted results in a change of counts up to about 10 900 or even 11 000. When applying force as one would to press a button, these counts increase up to more than 12 000. This increase of more than 1000 counts is the only value that is taken to confirm that a reliable event has happened.

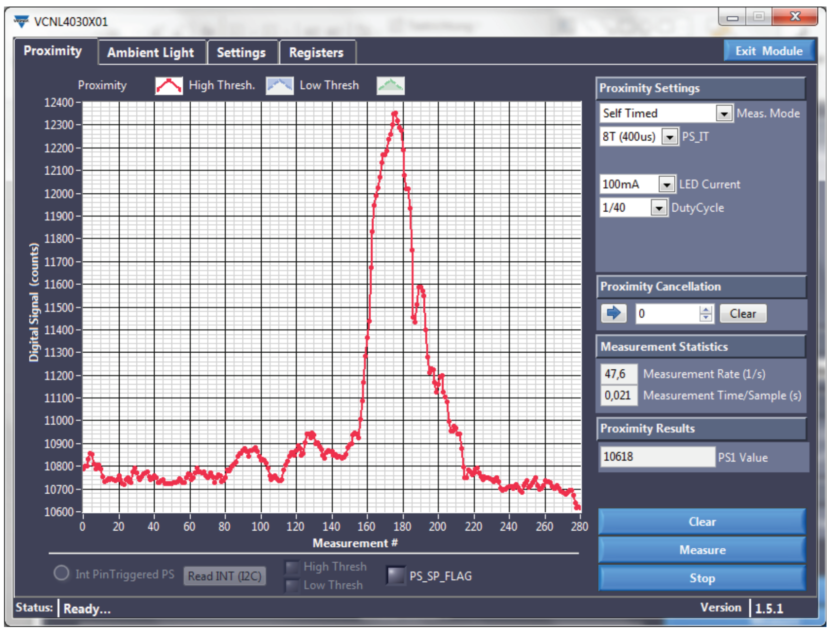

Fig. 26

High Resolution Detection Specification, Calibration, and Design-In

What can also be seen is that these 1000 counts are not present just between one measurement and the next, but needed more than 10 single measurements, as shown in the screenshot below.

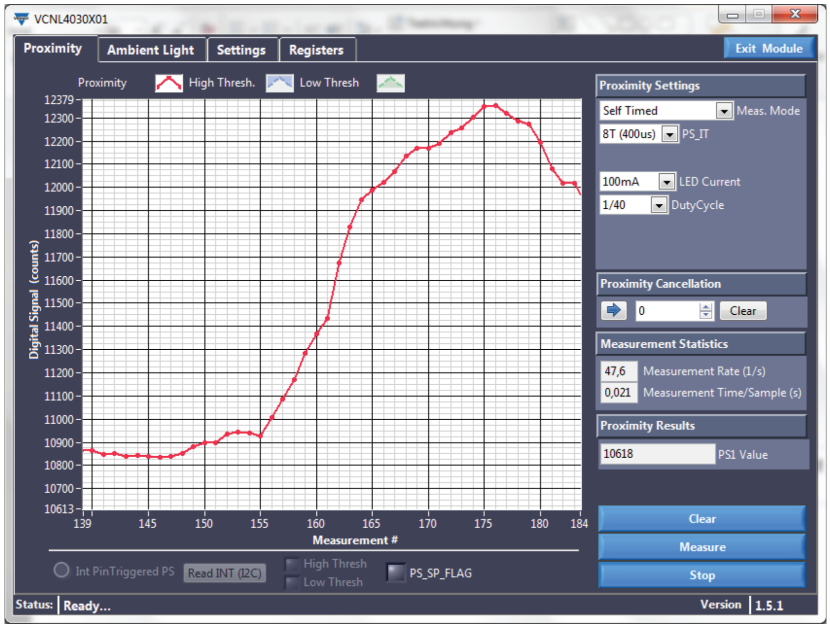

Fig. 27

So, at least 10 measurements should be taken to confirm an event. This is also the reason the measurement speed should not be that low. With an applied duty cycle of 1/40, even with such long proximity pulses as 8T = 400 μs, about 48 measurements are taken per second. For 10 measurements only 0.2 seconds are needed.