Scope

This application note provides information about how to design systems with the HALIOS®switch E909.01 and gives examples of schematics and appropriate surface materials.

General Description

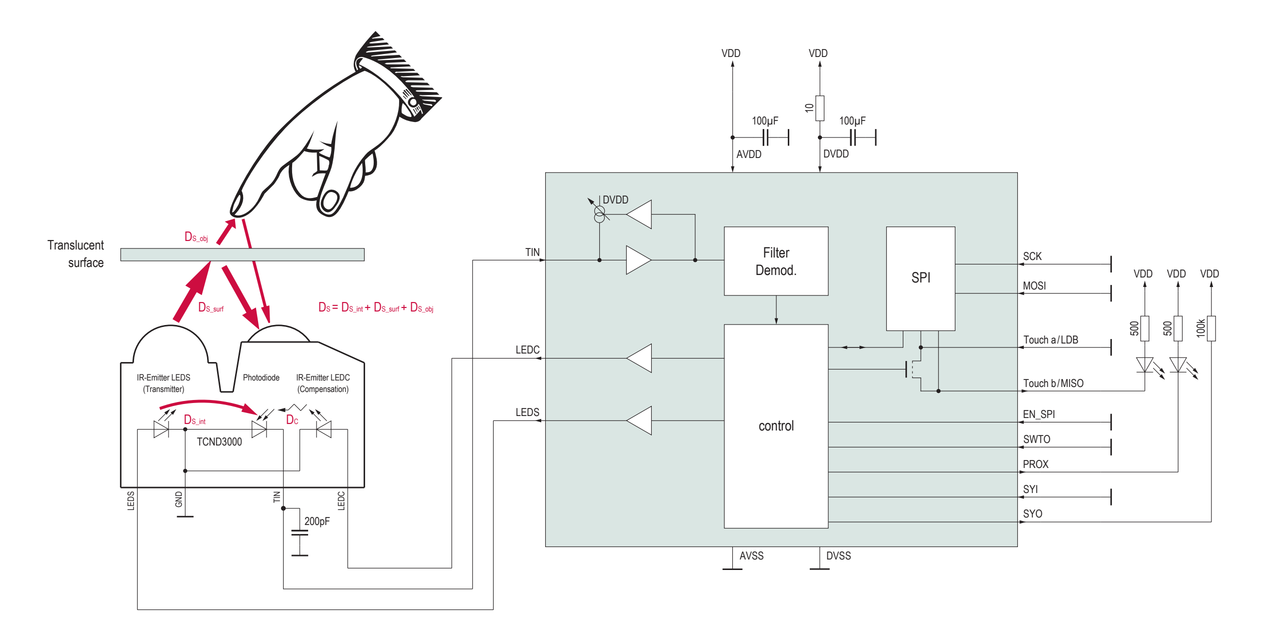
The HALIOS® principle highly improves sensitivity and robustness against disturbances of sensor systems. Therefore it is possible to realize, e.g. touch or approach detection systems based on a capacitive working principle even in metal shielded environment or optical input devices under high ambient light conditions. The E909.01 is an optical switch which is able to suppress the influence of ambient light by using the HALIOS® working principle. The device detects the rapprochement of objects and additionally indicates when the object touches the surface. These functions are available on the device pins PROX and Touch. Further, the corresponding measurement values can be readout via SPI interface. Elmos recommands the integrated optical module TCND3000 for optimized optical sensitivity.

Features

- Two outputs for Proximity and Touch function
- SPI interface for measurement data
- Selfcalibration capability
- Operational up to 200klux ambient light
- Package SOP16 or TSSOP16
- Supply voltage: 3.3V to 5.0V
- – 40°C to +85°C operating temperature

Applications

- Waterproof switches
- Switch for anti-septic environment
- Switch with background lighting function
- Proximity sensing
- Optical key pad array



System Comparison

Parameter	Mechanical	Capacitive	Piezo-electric	Resistive	HALIOS®(optical)
Integration under Solid Surface	no	yes	yes	no	yes
Possible distance between actuator and surface	0 mm Positive fit necessary	Several mm´s	0 mm Positive fit necessary	0 mm Positive fit necessary	0-50mm or more depending on the setup
Possibility to change arrangement of elements (e.g. exchangeability of surface)	Huge effort	Medium effort	Huge effort	Medium effort	Exremely low effort
Printability of surface	yes	yes	yes	restricted	All IR transparent colors and surface possible
Resistance against mechanical wear	no	yes	yes	no	yes
Operation under humid conditions	restricted	no	yes	restricted	yes
Resistance against chemicals and liquids	restricted	Depending on surface	Depending on surface	no	yes
Possibility of far distance detection	no	no	no	no	yes
Possibility to differentiate between certain gestures	no	restricted	no	restricted	yes
Resistance against influences by ageing	no	yes	yes	no	yes
Resistance against influences by temperature changes	yes	yes	yes	Restricted temperature range	yes
Required operation force	Certain force necessary	Touch of surface sufficient	Certain force necessary	Certain force necessary	Light touch of surface, even gesture recognition
Possibility to change functionality via SW	no	no	no	no	yes

SOP16 Package Outline and Description

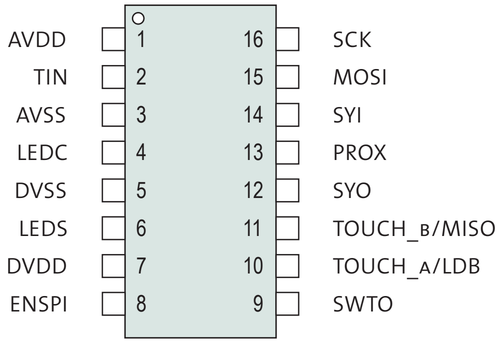


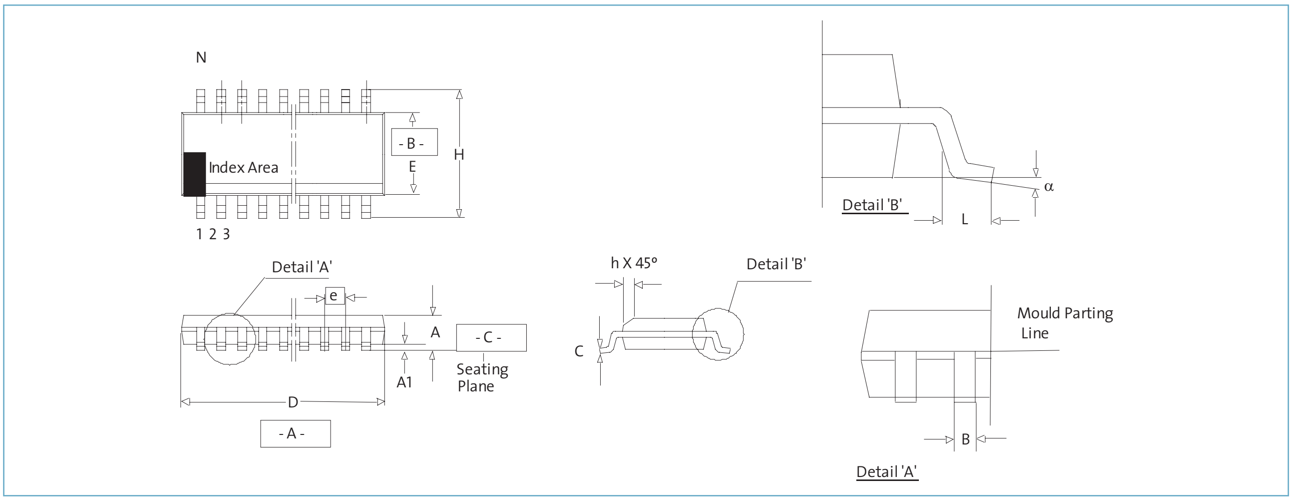
Figure: Pin-Out E909.01

Pin Description

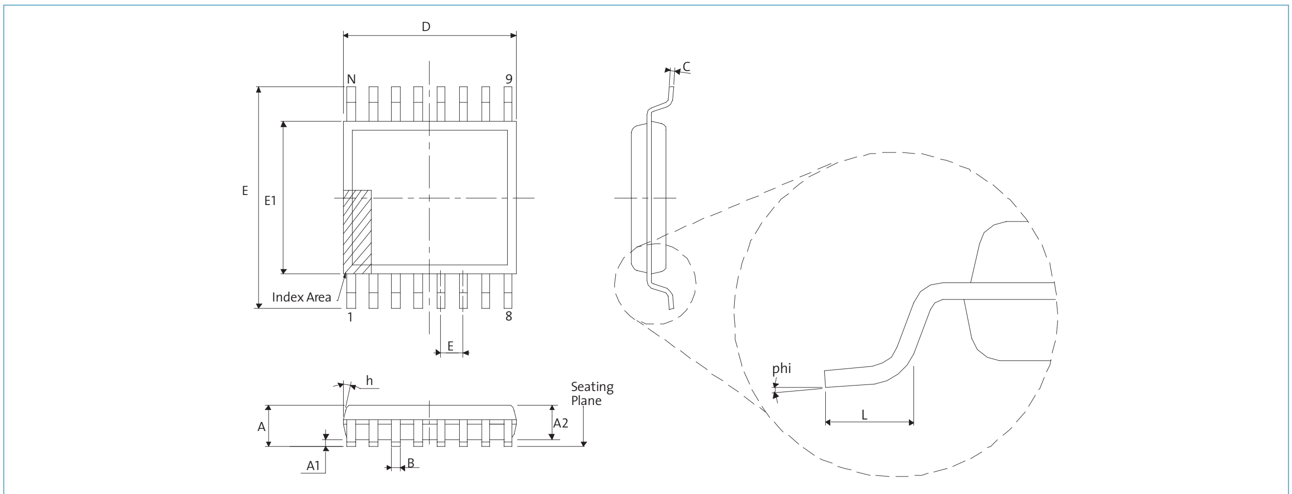
Pin Nr.	Name	Type 1)	Function
1	AVDD	A I	Analogue supply
2	TIN	A I	Transimpedance amplifier input
3	AVSS	A G	Analogue ground
4	LEDC	A O	Output compensation LED
5	DVSS	D G	Digital ground
6	LEDS	A O	Output Sending LED
7	DVDD	A I	Digital supply
8	ENSPI	D I	Enable the SPI Interface
9	SWTO	D I	Select touch or toggle mode
10	TOUCH_A/ LDB	A I/O D I	Output of the “Touch” function with an analogue switch of typically 30Ω between pin 10 and pin 11. In SPI operation mode (ENSPI=HIGH) this pin redefindet to the LDB “chip select” output
11	TOUCH_B/ MISO	A I/O D Z	Output of the “Touch” function with an analogue switch of typically 30Ω between pin 10 and pin 11. In SPI operation mode this pin redefindet to the MISO “master input slave output” output
12	SYO	DZ*	Synchronisation output (*high resistance for a short timer after power on and SPI Reset)
13	PROX	D I	“Proximity” function output (active low)
14	SYI	D I	Synchronisation input
15	MOSI	D I	SPI “master output slave input”
16	SCK	D I	SPI serial clock

1) A = Analog, D = Digital, G = Ground, I = Input, O = Output, I/O = Bidirectional and Z = Tristate Output

SOP16 Package Outline



TSSOP16 Package Outline



1 Optics

1.1 Optical Operation Principle

The HALIOS®-switch is based on the principle of a reflective light barrier. A LED transmits light into the surrounding area. This light is partly reflected by a translucent surface and an approaching finger. The reflected light is then received by a photodiode. Thus the system consists of two optical couplings: one fixed predetermined by the setup, mainly the surface, and one predetermined by an approaching finger. Let's take a closer look at the character of a finger. A finger can be characterised as a reflector with Lambertian characteristics. Figure 1.1 shows some samples of diffuse reflection of human skin (variations due to various reflexion grades).

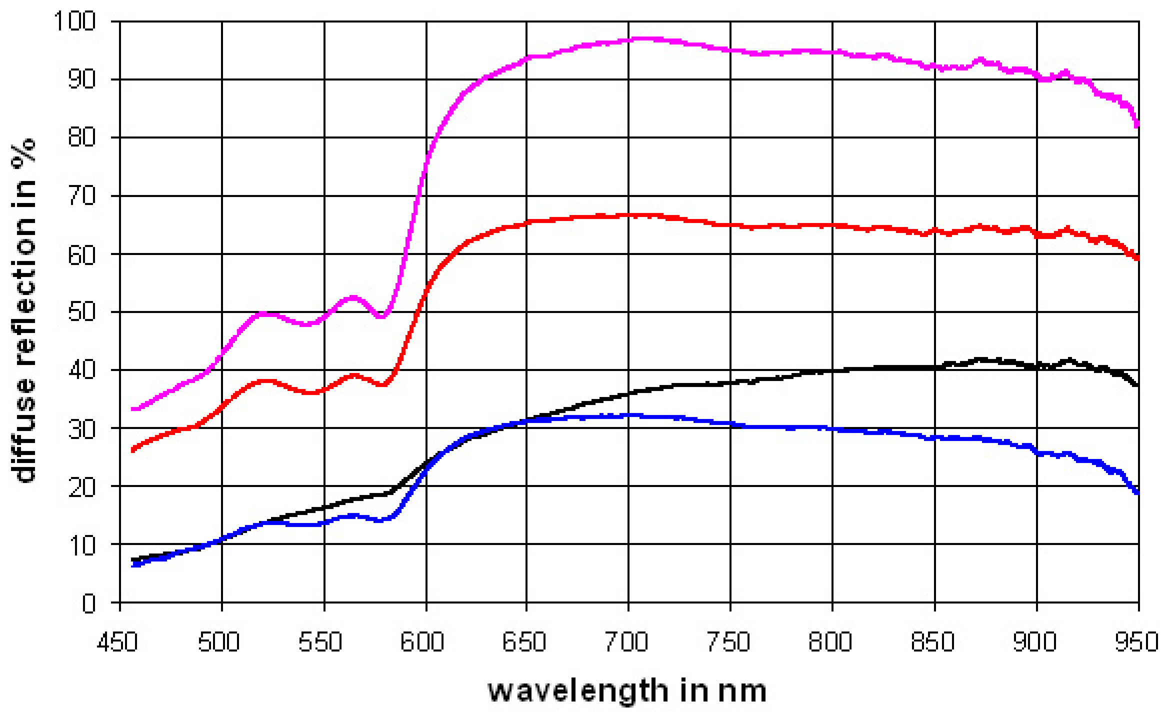


Figure 1.1: *Diffusion of human finger*

The diffusion of the human skin is characterised by an area ranging from blue to green (about 590 nm) with a low diffuse reflection and an area from red to infrared with high diffuse reflection. This characteristic step is generated by the colour of blood and independent of the colour of skin. Consequently the use of red or infrared LEDs for the HALIOS®-switch should be preferred. This spectral range also fits ideally the low priced silicone photodiodes. The TCND 3000 module uses a wavelength of 885 nm. The reflection of clothes in the IR range can not be derived from the visible appearance as shown in Figure 1.2.

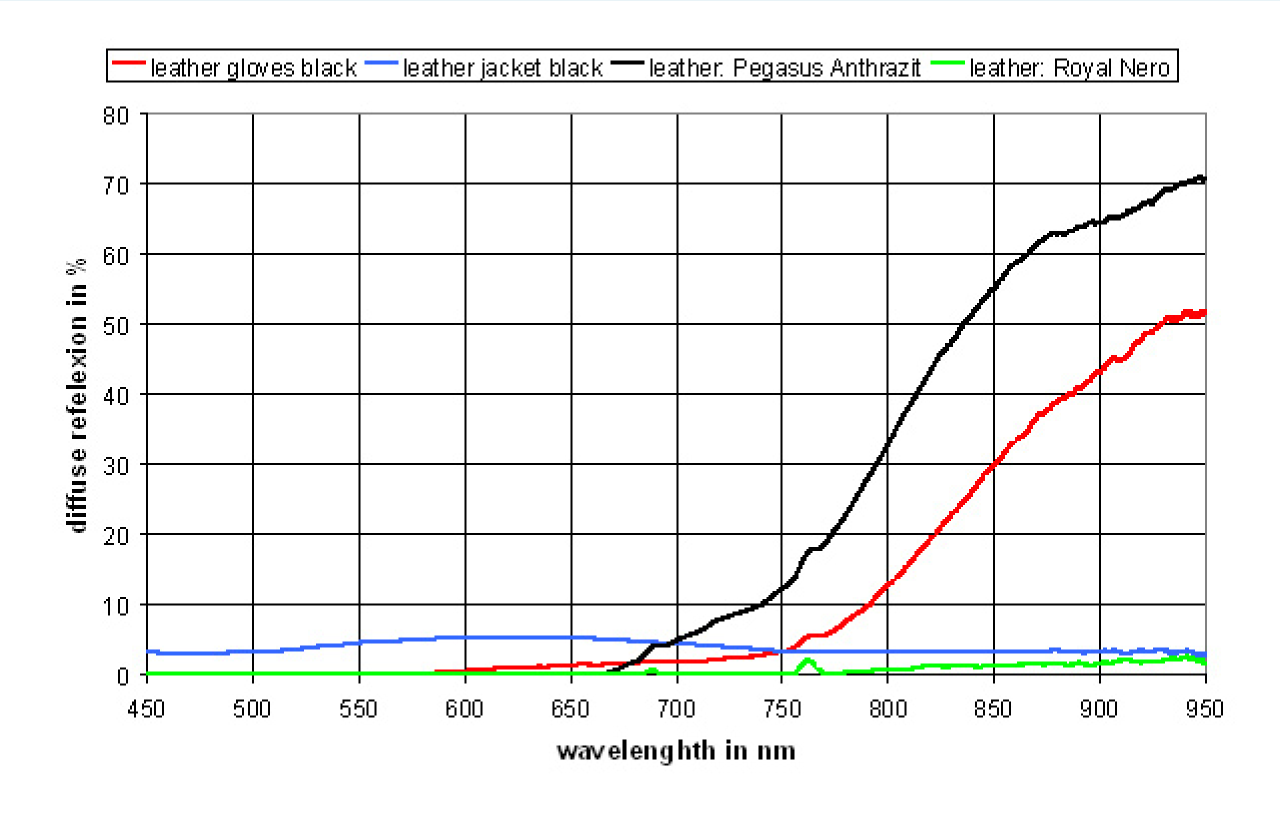


Figure 1.2: Diffusion of some clothes

The area, where the touch is supposed to take place, is illuminated by the transmitting LED and observed by the photodiode. The definition of this area is predetermined by the optical setup, especially the overlapping of radiation and receiving characteristics of the sending LED and photodiode. The sensitivity of the system is specified by a change between the received light resulting from an approaching finger in comparison to the received signal, when no object is near the surface. The setup using the TCND3000 is shown schematically in figure 1.3.

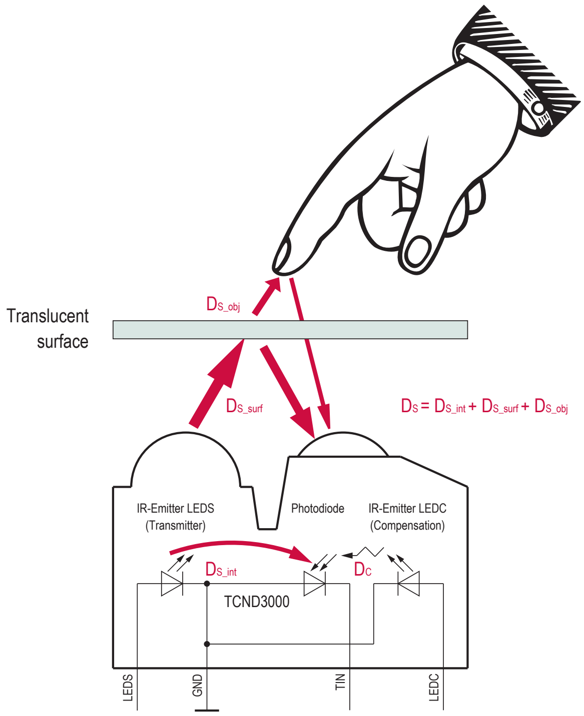


Figure 1.3: Schematic setup with TCND 3000

The light can take three different ways between the transmitting LED to the receiving photodiode. The first way is predetermined by the TCND 3000 module itself (optical coupling D_{S_int}), the second is fixed by the set-up (D_{S_surf}) and the third way is defined by the finger (D_{S_obj}). The internal coupling of the module is designed for stable operation of the IC E909.01. The reflection resulting from an approaching finger, however, should be greater than the one resulting from the internal setup. Please note that every surface gives an additional reflection. The situation can be simulated with ray tracing using a reflector with Lambertian surface characteristics substituting a finger. It is also possible to use an analytical description. The radiation characteristic of a LED or the receiving characteristic of a photodiode is in good approximation given by:

$$\Phi=\Phi_0\cos^{\kappa}(\varphi) \qquad \text{Equation 1.1}$$

The exponent κ is given by the half power angle $\varphi_{0.5}$:

$$\kappa=\frac{\ln(0.5)}{\ln(\cos(\varphi_{0.5}))} \qquad \text{Equation 1.2}$$

The transmitting LED and the receiving LED have both a half angle of 20°, consequently κ is approximately 11. The finger can be characterised as a Lambertian reflector described by the equation 1.1 by setting κ to 1.
To provide a well working system, it is necessary to arrange the optical couplings D_S and D_C (cf. figure 1.3) in a certain ratio and a certain range. The optical coupling is given by the ratio of the received light power compared to the transmitted light power. Especially the ratio of the two parts of D_S should lie within a certain range. For more details, please refer to the next chapter.

1.2 Optical and Geometrical Design

Let’s take a closer look at the HALIOS® - control constraint. The control constraint requires that the photodiode has to “see” the same light intensity from both light sources (LEDs). The ELMOS IC E909.01 controls the current of the LEDs. These currents are then translated into light intensity (k_{LED}). The current produced inside the IC is controlled by a DAC driven from the LOOP-Value n. The transfer factor is 10 or 20 mA (I_{max_s}) nominal full range for the transmitting LED and 1 or 2 mA (I_{max_c}) nominal full range for the compensating LED. It is also possible to choose between two control principles. One controls both LEDs against each other (X-control) and the other determines the intensity of the transmitting LED on a fixed level (Y-control).
The system is described by the following equations:
For X-control

$$I_{max\_S} \frac{n_{max}-n}{n_{max}} k_{LED} D_S = I_{max\_C} \frac{n}{n_{max}} k_{LED} D_C$$

Equation 1.3

For Y-control

$$I_{max\_S} k_{LED} D_S = I_{max\_C} \frac{n}{n_{max}} k_{LED} D_C$$

Equation 1.4

To balance both equations it is necessary to take the ratios of the optical coupling D and the ratio of the current ranges I_{max} into account. The Y-control clips if the ratios are out of balance. The X-control works under any circumstances, but “compresses” the Loop signal to fit into the range from zero to n_{max}. The ratio of the current ranges can be chosen via parameters in three steps:

$$\frac{I_{max\_C}}{I_{max\_S}} = \{0.05, 0.1, 0.2\}$$

Equation 1.5

Consequently the ratio of the optical couplings should fit this range. Normally it is not very easy to adjust the LEDs correctly to meet the specification of D_C and D_S. Using the TCND 3000 one can save oneself the difficult adjusting work, as the development of the module already took this into consideration. The optical couplings are adjusted in such a way, that a finger can be detected in a range of 1 to up to 20 mm`s.
The absolute value of the optical couplings determines the noise and proximity distance. Inside the TCND 3000 the values of the optical couplings are fixed reliable levels.
Using the SPI interface it is possible to read the Loopvalue n. This value contains all information about the system. Here are some hints to qualify the signal:

- noise (difference between min and max-value) without an object: about 2 to 6
- Loopvalue without an object: 100 to 400
- Change of Loopvalue with Object (finger): > 100

Always evaluate the combination of surface material and distance to the module.

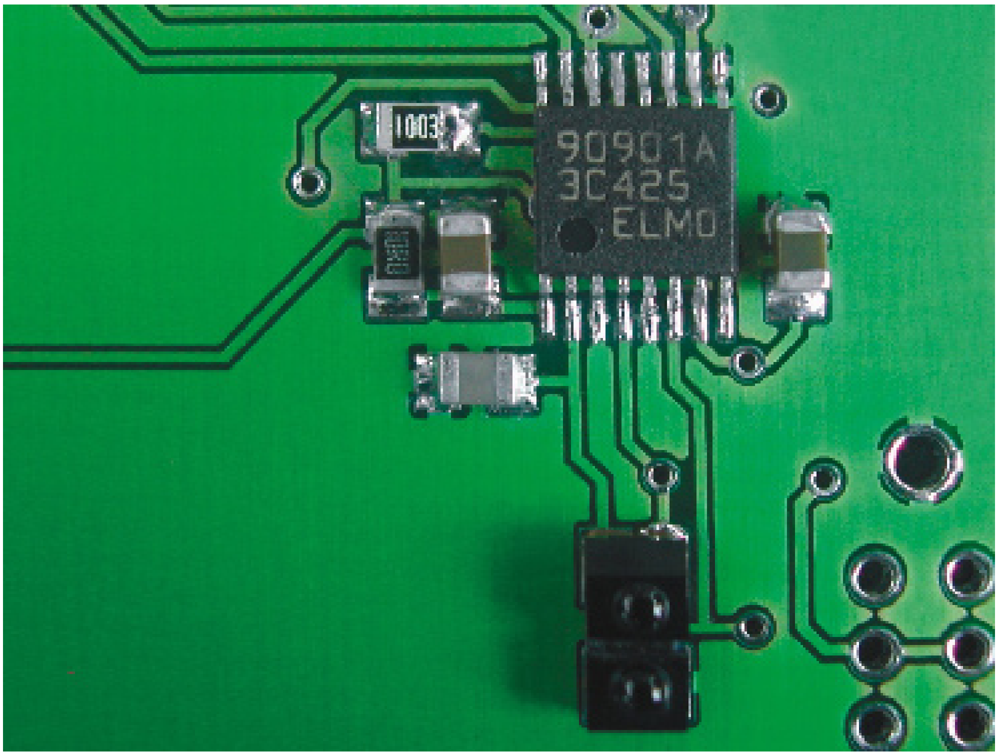


Figure 1.4: Basic arrangement using TCND 3000 module supplied by VISHAY®

The resulting photodiode current depending on the distance of an object (representing a finger) to the TCND 3000 is shown in figure 1.5. Please note that the compensating LED causes a photodiode current of zero to up to 5 µA depending on the loop value.

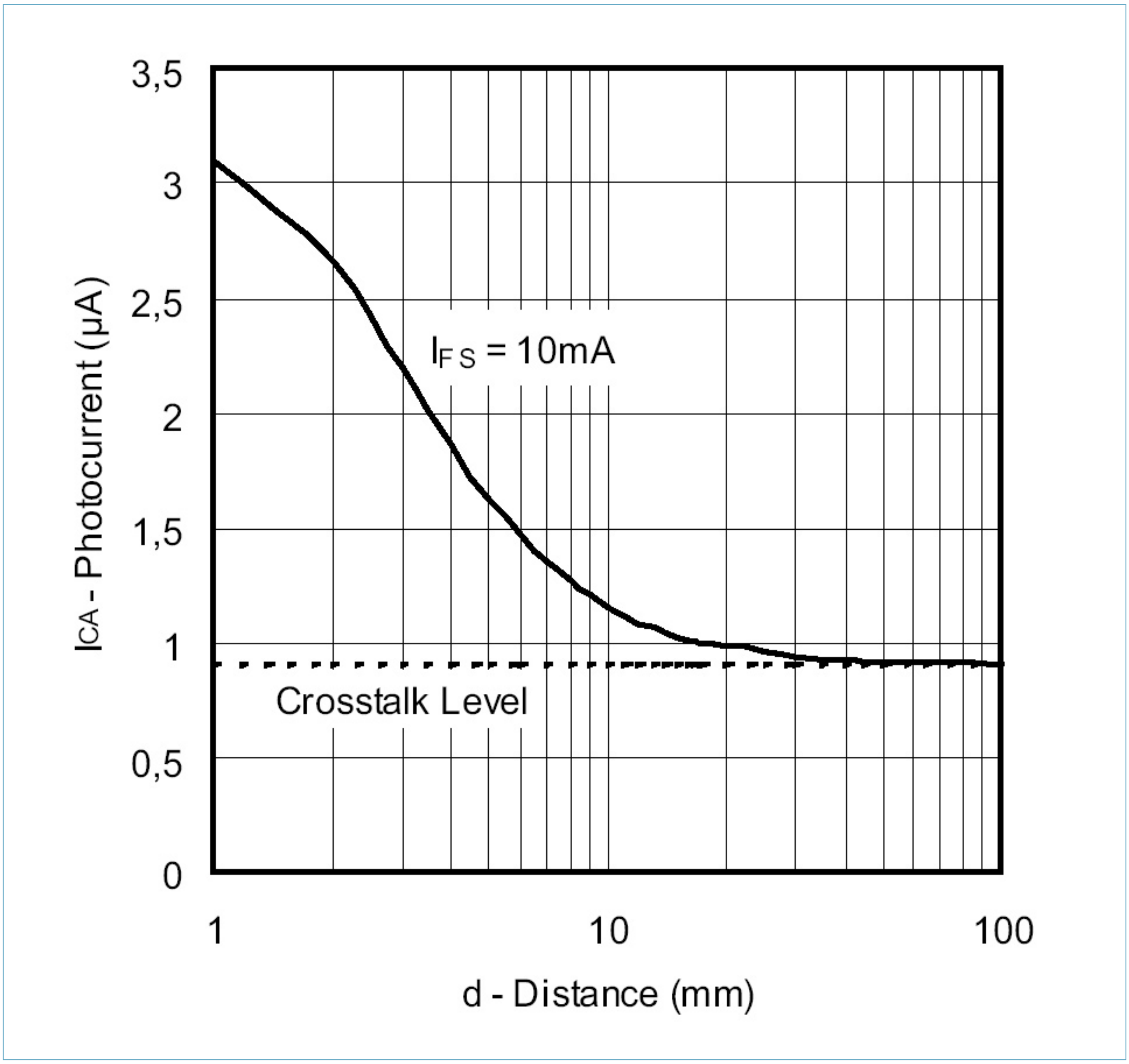


Figure 1.5: Photocurrent caused by reflection vs. distance. (cf. VISHAY® datasheet figure 5)

1.3 Surface materials and mechanical set-up

It is possible to use a wide variety of materials for the surface, however, some constraints have to be taken into account. These constraints can be divided into two groups according to their mechanical or material properties.
Mechanical constraints:

- The surface should not move relative to the optic, otherwise the Touch-Algorithm does not work properly
- The surface should be mechanically stable
- The surface should fit the requirements of mechanical and chemical stability for your application
- The surface should give the user a mechanical orientation, like a dent or a grove.
- This haptic feedback improves the mobility.

Material constraints:
There are three parameters of the material that should not get mixed up. The visible transparency of a material is determined by two effects: the absorption in the volume and the diffusion in the volume. The last material parameter is the diffusion by surface roughness. Nearly all artificial materials are transparent in the visible and near IR range. The transmitted light power is additionally influenced in fully clear materials by the refractive index (Reflexion given by the Fresnell Law). Consequently the transmission can reach a maximum of approximately 92% for PMMA. There are a lot of pigments and colouring dyes. Organic dyes give the visible colour by absorbing some parts of the visible spectral range. They normally do not absorb in the infrared range. Inorganic dyes are enclosed particles and give a diffusion of the material. This diffusion exists also in the infrared range. Especially the colour white is always created by diffuse wavelength independent reflexion. Diffuse surfaces and printing on surfaces gives additional diffusion.
The target is to get as much IR light as possible through the surface and to influence the focusing of the opto-electronic components as little as possible.

Table 1.1 gives a rough overview about materials well suited for switch applications.

Type	Supplier	Colour	Remark
PMMA N6 N7 N8962	Degussa Roehm®	clear	
PMMA white 010	Degussa Roehm®	white	Transmitter with small half power angle and directly mounted to the surface
PMMA white 017	Degussa Roehm®	white	Transmitter with small half power angle and directly mounted to the surface
PMMA 962 (PERSPEX®)	ICI®	black	
PMMA blue 627	Degussa Roehm®	blue	
PMMA 7704 (PERSPEX®)	ICI®	blue	
PMMA red 555	Degussa Roehm®	red	
PMMA 4401 (PERSPEX®)	ICI®	red	
PMMA green 777	Degussa Roehm®	green	
Plexiglas Satinice® clourless	Degussa Roehm®	diffuse	Transmitter with small half power angle and directly mounted to the surface
Macrolon® Ft: 450601	Bayer®	black	

Table 1.1 : Samples of tested materials

1.4 Design Rules

To build up a well working switch please take the following steps:

1. Compile your set-up and read out the Loop-signal

2. Select the kind of surface material, surface roughness and distance in such a way that the Loopsignal ranges between 100 and 400

3. Control the Loopsignal noise (good is 2 to 6 peak to peak)

4. Place your finger on the switch. The Loopsignal should change a minimum of 100 and not go to saturation

5. Repeat step 2.

Here are some hints concerning the selection and adjustment of the components:

- **Diffuse material or a rough surface**
  put the material as close as possible to the TCND 3000 module
- **Signal change by finger too low**
  decrease Loop-value without finger, reduce surface reflexion; change default state of transmitter and compensator currents
- **Proximity distance too small**
  use non diffuse surface material; reduce surface reflexion
- **Noise too high**
  this is caused by a low energy at the photodiode. Increase power of transmitter by increasing the current with a current mirror
- **Proximity-signal without an object**
  this is caused by a top high noise. Also a modulated light source with HALIOS® frequency (125 kHz) can cause this problem
- **A touch is not detected**
  check the amplitude in the LOOP-Signal and the stability of the signal. Check the mechanical stability of the surface.
- **The system is sensitive to ambient light**
  reduce the noise of the LOOP-signal; increase the system power by LED current; check the DC photodiode current (less than 1mA); check for modulated ambient light sources; use photodiode with filter
- **Effect of FIXS configuration**
  by setting the FIXS configuration the touch amplitude is in most cases doubled, but the system is more sensitive to the mechanical adjustment
- **Effects of HICS and HICC**
  enabling or disabling both, gives the same sensitivity except that by enabling both the noise increases. Enabling HICS and disabling HICC gives a sensitive system and disabling HICS while enabling HICC leads to a very stable system

1.5 Advanced configuration

In some special cases it might not be possible to achieve a proper functioning via adjusting the LED currents using the SPI commands or it might not be possible to change the mechanical setup. In such rare cases it could be helpful to adjust the LED currents very precisely. Therefore use a current mirror circuit as shown in figure 1.6. The depicted values are a very good starting point, but should be adjusted to your application.

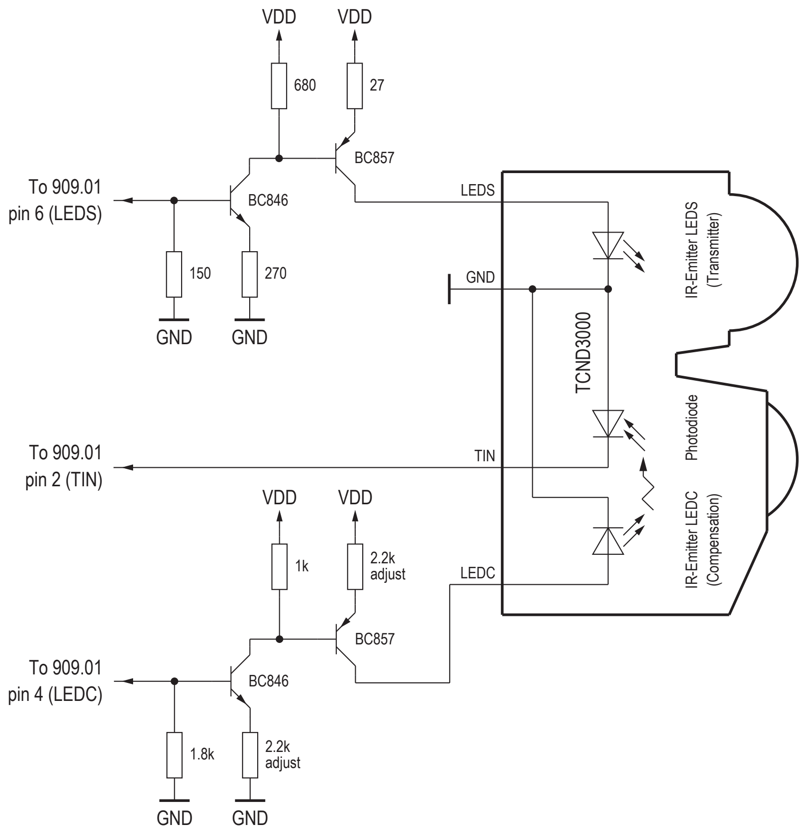


Figure 1.6: Current mirror circuit (shown values are a very good starting point)

In case of a very high backscattering from the surface to the module, adjusting the currents will not solve the problem. In such cases the insertion of an additional shielding between the transmitter and the receiver might be a better solution. This can be reached only by filling the grove in the module between transmitter and receiver by using black epoxy glue (Please make sure that the glue is really IR absorbing), or by introducing a mechanical shielding from the module up to the surface. These two possibilities are shown in figure 1.7. If you use such a set-up please test appropriately and keep the tolerances in mind.

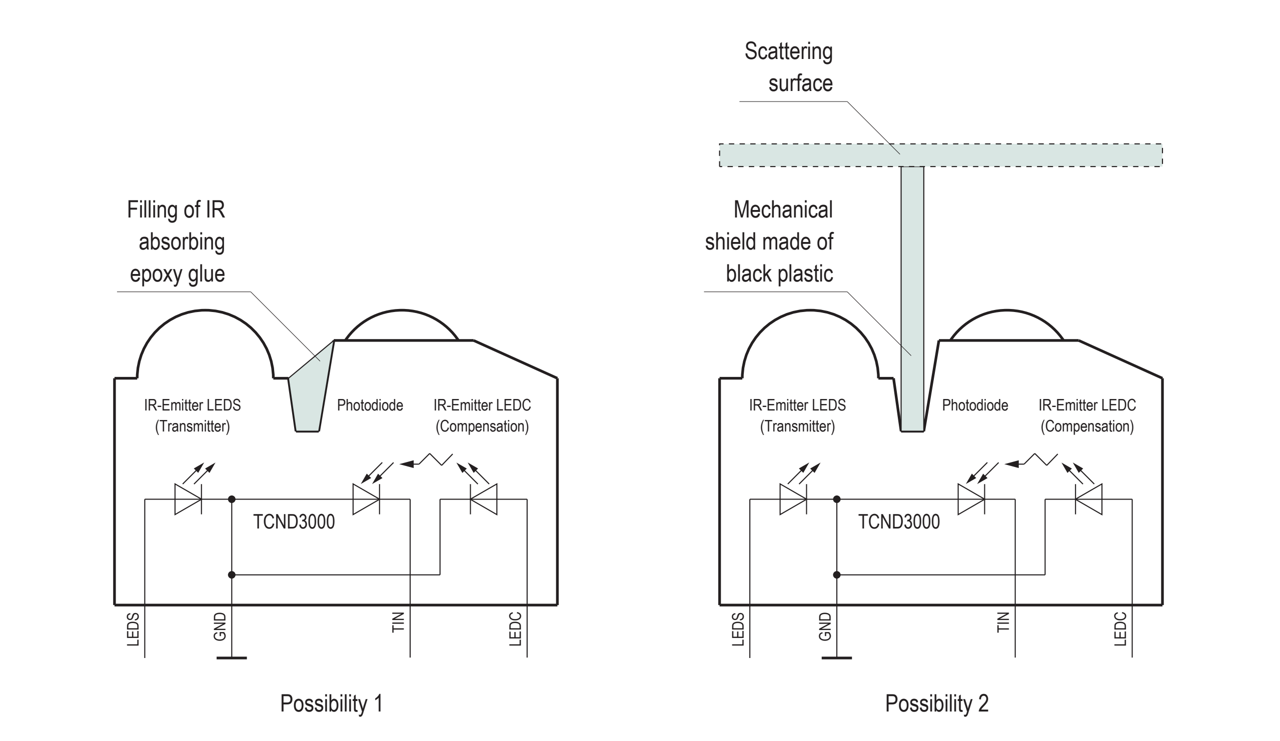


Figure 1.7: Introduction of optical shielding

2 Working Principle ASIC

2.1 Block Diagram

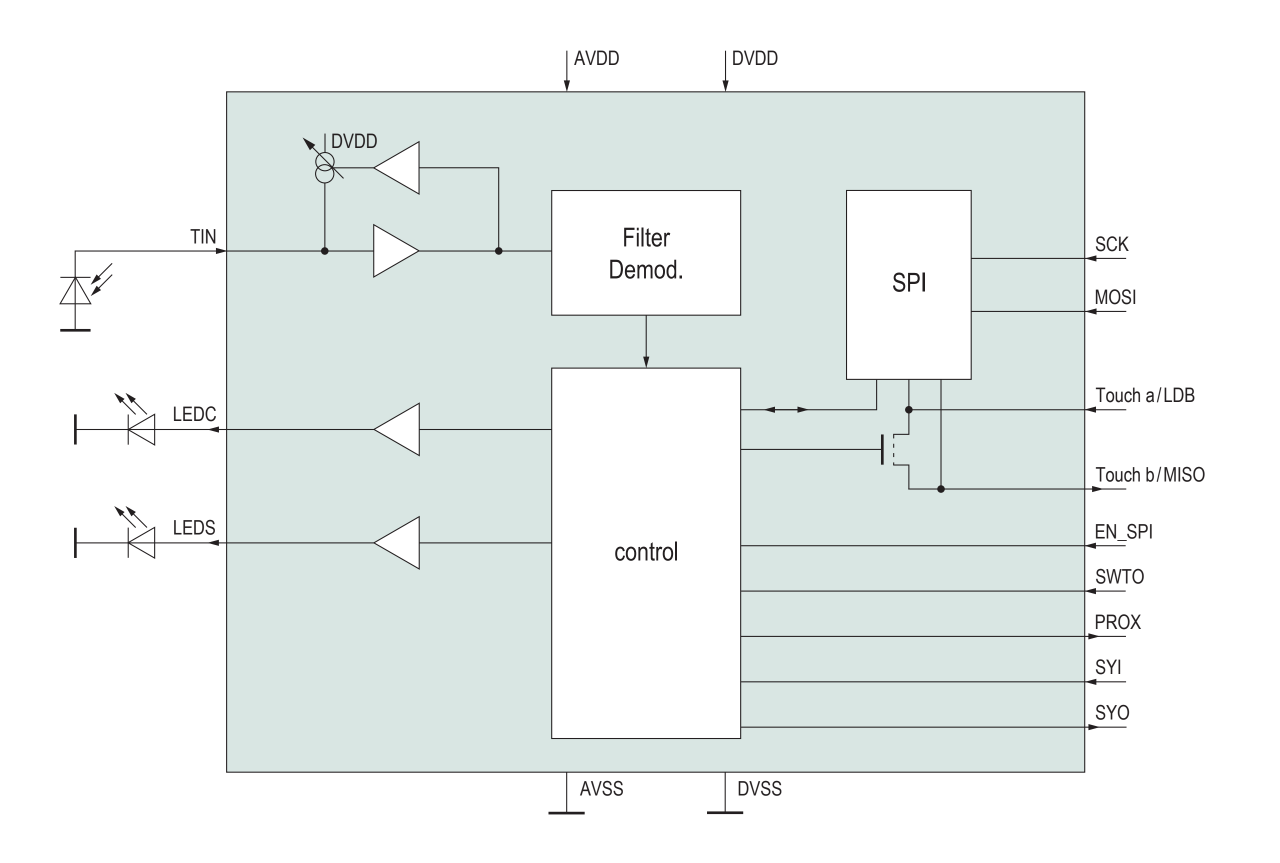


Figure 2.8: Block Diagram E909.01

The high ambient light suppression using the HALIOS® principle is based on two light sources which are clocked by inverted phases. The photo-current receiver amplifies the difference of the received signal in both clock phases and modulates the light source intensity in a negative feedback loop in order to compensate the received signal to zero. Thus the input amplifier is always regulated to its most sensitive operation condition independent of the ambient light conditions.
The receiving path uses a transimpedance amplifier with DC-current control to transfer the photo current into a voltage. The signal is then amplified and filtered to remove disturbing signals and amplifier offsets. The demodulator samples the voltages at the output of the amplifier synchronously to the LED clocks, takes the difference of the signal in phase A and phase B and delivers the sign of this difference to the digital integrator.
The transmitting path produces the signals for the LED modulation by converting the integrator output to an analogue voltage. The output drives the compensation LED (LEDC) as shown in figure 2.1 with a voltage controlled current source of maximum 1.5mA output current. The sending LED (LEDS) is driven by a constant current of 10mA. Both outputs are then clocked synchronously to the demodulator.
The detection algorithm analyses the data sequence of the digital integrator to detect whether an object is simply approaching the sensor or if it is actually touching the surface of the switch.

2.2 Overview Basic Functions

When an object appears in the detection range of the sensor the signal PROX is activated. If a touch occurs on the sensor surface a signal is given by closing an analogue switch of 40 Ohm between the pins TOUCH_a, and TOUCH_b. With a wipe over the sensor surface the detection algorithm is reset.In order to reduce the current consumption the measurement cycle is activated only for a short time $T_{measure}$.
During the passive time $T_{passive}$ the IC is switched to an operation mode with reduced current consumption. When an object is in the detection area of the sensor the proximity signal is activated and the sampling rate is high. If no object is detected the sensor is switched to stand-by mode with reduced sampling rate in order to minimize the mean current consumption.
To change this default configuration a full bidirectional SPI interface consisting of the pins LDB, SCK, MOSI and MISO can be activated with the pin ENSPI. It is possible to adjust several thresholds and time constants which are used for the proximity, touch and wipe function. Additionally it is possible to read back data from the switch to the supervising µ-Controller In this case the output of the digital integrator can be observed directly by the µC and it is possible to implement different algorithms for signal detection.
If several switches are positioned in close range of each other, the measurement phases can be synchronised in order to minimise disturbances between the switches. The synchronisation bus consists of the pins SYI and SYO and connects all switches in a loop.

2.2.1 Synchronisation

The synchronisation is reached by passing a pulse from one switch to the next. The sensor which has activated the measurement cycle switches the output SYO to ‚HIGH'. Then the first switch delays the new cycle until the passive time $T_{passive}$ has passed. The first switch is defined with a pull-up resistor at pin SYO. The synchronisation leads to a reduced noise and improves the ambient light suppression.
If the synchronisation pulse is observed by the µC it is possible to reduce the noise caused by the communication by delaying the SPI commands until the measurement cycles are finished.

2.2.2 Active - and Stand-by - Operation Mode

To reduce the current consumption the measurement phase is only activated for a short time of 25 clock periods (200 µs) and the LEDs are clocked with 125 kHz. Together with a settling time for the amplifiers the total measurement time has a value of $T_{measure}$ = 464 µs. Afterwards during the passive time the measurement is stopped and the LEDs are switched off. When an object (movement) is detected and the proximity signal becomes ‚0' the sensor is in the active operation mode for a minimum of 260 ms (minimum active time). In this case the measurement is activated with a rate of 244 Hz. When no movement is detected during this time the sensor is switched to stand-by mode and the sampling rate is reduced to 15 Hz. If the object is still in the detection area (without a movement) the PROX-output stays active (‚0'), independent of the operation mode (default).
By connecting the PROX output to the interrupt pin of the supervising µC, it is possible to use the proximity event as a wake-up signal for the µC.

2.2.3 Detection Algorithms

The algorithms to detect a switch event are observing the integrator output which is proportional to the modulation current of the compensation LED. If no object is in the detection area of the sensor and the regulation loop has settled, the integrator signal has a static value. If an object approaches the sensor the integrator output changes its value. As soon as a certain threshold value is reached the proximity signal PROX is activated.
To detect a touch event the 1st and 2nd derivatives of the integrator output are used additionally. These values are functions of the object´s velocity and acceleration. A touch is detected if the object is approaching with a minimum velocity, stops on the sensors surface with a minimum of negative acceleration and remains on the surface of the sensor without moving after the touch for a minimum time of 130 ms (can be adjusted with the parameter TOTIM in table 2.2). This time criterion is used to assure that the indented touch is really detected as such.
If the object is removed from the sensor surface the stand-by mode is activated again as soon as the output of the integrator reaches the old value which it had before entering the active mode. If something should fall onto the surface and activate the TOUCH, a time-out function switches back into stand-by mode after global time out (TIMOV – descr. in table 2.2) and the recent static value of the integrator output is used as new reference value for the proximity function.
The TOUCH signal output (on pins 10 and 11 or via SPI) depends on the pin SWTO. When this pin is connected to ground, TOUCH is only active as long as the object touches the surface **(touch-mode)**. When it is connected to supply, it is in **toggle-mode**: A TOUCH event closes the switch and the TOUCH output stays active as long as the next TOUCH event opens the switch.
With a wipe over the sensors surface the detection algorithm is reset. If after a touch some dirt should remain on the sensor, the system will not turn to stand-by mode due to a higher reflection. In this case a wipe stops the time-out and a new reference will be found.

2.3 SPI Interface

16 data bits are sent to the E909.01 via SPI. The first four bits contain the address bits. These four bits tell the E909.01 its general operation. The next four bits contain the Data information. The last eight bits are not used.

The SPI interface consists of 4 pins:

1. MOSI : Master Out Slave In : µC => ASIC

2. SCK : Serial Clock : µC => ASIC

3. LDB : Load (active low): µC => ASIC

4. MISO : Master In Slave Out : ASIC => µC

2.3.1 SPI Transmission

Each transmission starts with a falling edge on LDB and ends with a rising edge. During transmission commands and data are shifted according to the following rules

1. LDB line is active (active ‚LOW')
2. MOSI data are shifted in on the rising SCK edge MSB first and LSB last
3. MOSI data are read on the falling SCK edge.
4. A command is only carried out on the rising edge of LDB when 16 clock cycles are counted during the last transmission.
5. MISO is active when LDB is ‚LOW' and is tristated when LDB is ‚HIGH'.
6. SCK should remain ‚LOW' after the 16th SCK falling edge.

The following diagram shows one data transmission over the SPI-bus. For exact timing please refer to the specification 03SP0277E.

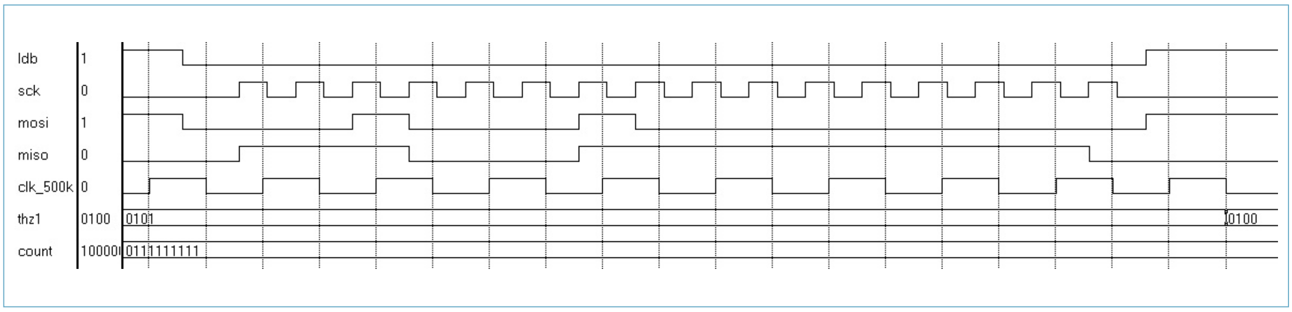


Figure 2.9: Example of a correct data transmission, command h2200

2.3.2 MISO Line

16 bits of Data are returned to the µC on the rising edge of SCK. The returned data contains information concerning the state of the switch and the value of the DAC or the received command. This depends on the parameter RETUR (default ‚LOW').

RETUR	MISO LINE									
	MSB[1]	[2]	[3]	[4]	[5]	[6:13]		[14]	[15]	**LSB**[16]
'LOW'	not STANDBY	MOVEDO	PRETO	TOUCH	WIPE	COUNT[9:0]				TMODE
'HIGH'	not STANDBY	MOVEDO	PRETO	TOUCH	WIPE	ADDR[0:3]	DATA[0:3]	RETUR	TMODE	TMODE

Table 2.2

In the example of figure 2.2 the received bits are: 1110001111111110 (with default parameters).
This means the E909.01 is in **active mode** (internal PROX, here: high active!), the states MOVEDO and PRETO are low active and TOUCH, WIPE are high active. The integrator value is COUNT="0111111111"(511) and the LSB: TMODE (high active) indicates that the E909.01 is not in **test-mode**.

Bit Position	Name	Description	
MSB	MOTION	This bit is activated when an object is moving inside the sensor area. Once the object remains still the signal is deactivated.	
Bit (14)	MoveDown*	This signal is activated when the minimum TOUCH level(THZ2) and the minimum velocity level(THD1) have been reached.	
Bit (13)	PreTouch*	This signal is activated when MoveDown is active and the deceleration remains under the THA level(This parameter is coupled with THD1).	
Bit (12)	TOUCH	If the signal remain in the state PreTouch for the required TouchTime(TOTIM) the Touch signal is activated.	
Bit (11)	WIPE	This signal is activated when an object slides quickly over the sensor surface.	
		RETUR = '0'	RETUR = '1'
Bit (10)	->	COUNT (9)	ADDR (3)
Bit (9)	->	COUNT (8)	ADDR (2)
Bit (8)	->	COUNT (7)	ADDR (1)
Bit (7)	->	COUNT (6)	ADDR (0)
Bit (6)	->	COUNT (5)	DATA (3)
Bit (5)	->	COUNT (4)	DATA (2)
Bit (4)	->	COUNT (3)	DATA (1)
Bit (3)	->	COUNT (2)	DATA (0)
Bit (2)	->	COUNT (1)	NA
Bit (1)	->	COUNT (0)	NA
LSB	TESTMODE	This bit indicates that the ENSPI pin is at half of VDD. It is now possible to conduit the productional tests.	

*Note: Signals marked with * are active low; all others are active high.*
Data is shifted out on the rising SCK edge starting with MSB.

WIPE: This signal RESETs the detection algorithm to it default state. If in TOGGLE mode(set with pin SWTO) an active TOUCH signal will not be RESET unless the SPI cmd. 0X1B** has been sent (RSWIPE).

RETUR: This bit determines the value that is returned over the SPI interface. With the SPI cmd 0X1C** the COUNT value is returned, and with the SPI cmd. 0X1D** the data returned contains the last SPI cmd that was received.

2.3.3 Address decoding

Address	Data	Hex	Default	Signal	Description	
“0000”	“0000”	00**	-	-	-	unused
	“0001”	01**	-	-	-	unused
	“0010”	02**	-	-	-	unused
	“0011”	03**	-	-	-	unused
	“0100”	04**	-	-	-	unused
	“0101”	05**	-	-	-	unused
	“0110”	06**	enabled	G0	disabled	Gain setting 6dB.
	“0111”	07**			enabled	
	“1000”	08**	disabled	G1	disabled	Gain setting 12dB.
	“1001”	09**			enabled	
	“1010”	0A**	enabled	HICC	disabled	High current for compensation LED.
	“1011”	0B**			enabled	
	“1100”	0C**	disabled	HICS	disabled	High current for sending LED.
	“1101”	0D**			enabled	
	“1110”	0E**	disabled	FIXS	disabled	Fixed current for sending LED.
	“1111”	0F**			enabled	

Address	Data	Hex	Default	Signal	Description	
"0001"	"0000"	10**	enabled	ACC_ON	disabled	En/Disabled the counters acceleration (see 4.1). -Enabled -> step size: 1-8 LSD. -Disabled -> step size: 1 LSB.
	"0001"	11**			enabled	
	"0010"	12**	4 LSB	SELACC	4 LSB	Select the maximum integrator step size (see 4.1)
	"0011"	13**			8 LSB	
	"0100" - "0111"	14** - 17**	-	-	-	unused
	"1000"	18**	disabled	SELDE-LAY	disabled	En/Disables an additional touch time , which is depending on the signals dynam-ic. It is used for synchronisation (see 4.4)
	"1001"	19**			enabled	
	"1010"	1A**	disabled	RSWIPE	disabled	Disables the resetcaused by a detected WIPE signal when the switch is in **toggle-mode** (SWTO="1") (see 4.2)
	"1011"	1B**			enabled	
	"1100"	1C**	return counter value	RETUR	return counter value	RETUR switches the data which is send out via MISO, see section 4.1.3
	"1101"	1D**			return com-mand	
	"1110"	1E**	enabled	HOLD-PROX	disabled	If enabled the PROX output is held active (low) as long as an object is inside the detection area.
	"1111"	1F**			enabled	

<table>
<tr><th>Address</th><th>Data</th><th>Hex</th><th>Default</th><th>Signal</th><th colspan="3">Description</th></tr>
<tr><td rowspan="13">“0010”</td><td>“0000”</td><td>10**</td><td rowspan="4">4 LSB</td><td rowspan="4">THZ1</td><td>Sets to 3 LSB</td><td rowspan="2">1st Threshold for proximity</td><td rowspan="2">sensitive</td></tr>
<tr><td>“0001”</td><td>21**</td><td>Sets to 4 LSB</td></tr>
<tr><td>“0010”</td><td>22**</td><td>Sets to 4 LSB</td><td rowspan="2">2nd Threshold for proximity is 2* THZ1</td><td rowspan="2">not sensitive</td></tr>
<tr><td>“0011”</td><td>23**</td><td>Sets to 5 LSB</td></tr>
<tr><td>“0100”
-
“0111”</td><td>24**
-
27**</td><td>-</td><td>-</td><td>-</td><td colspan="2">unused</td></tr>
<tr><td>“1000”</td><td>28**</td><td rowspan="8">32 LSB</td><td rowspan="8">THZ2</td><td>Sets to 8 LSB</td><td rowspan="8">Minimum dynamic for touch detection</td><td rowspan="4">sensitive</td></tr>
<tr><td>“1001”</td><td>29**</td><td>Sets to 16 LSB</td></tr>
<tr><td>“1010”</td><td>2A**</td><td>Sets to 32 LSB</td></tr>
<tr><td>“1011”</td><td>2B**</td><td>Sets to 64 LSB</td></tr>
<tr><td>“1100”</td><td>2C**</td><td>Sets to 128 LSB</td><td rowspan="4">not sensitive</td></tr>
<tr><td>“1101”</td><td>2D**</td><td>Sets to 192 LSB</td></tr>
<tr><td>“1110”</td><td>2E**</td><td>Sets to 256 LSB</td></tr>
<tr><td>“1111”</td><td>2F**</td><td>Sets to 512 LSB</td></tr>
</table>

<table>
<tr><th>Address</th><th>Data</th><th>Hex</th><th>Default</th><th>Signal</th><th colspan="3">Description</th></tr>
<tr><td rowspan="6">“0011”</td><td>“0000”
-
“0111”</td><td>30**
-
37**</td><td>-</td><td>-</td><td>-</td><td colspan="2">unused</td></tr>
<tr><td>“1000”</td><td>38**</td><td rowspan="4">4 LSB/
-4 LSB
(soft)</td><td rowspan="4">THD1/
THA</td><td>4 LSB/
-1LSB</td><td rowspan="4">Velocity and acceleration threshold for touch.</td><td>very soft</td></tr>
<tr><td>“1001”</td><td>39**</td><td>4LSB/
-4LSB</td><td>soft</td></tr>
<tr><td>“1010”</td><td>3A**</td><td>7LSB/
-7LSB</td><td>middle</td></tr>
<tr><td>“1011”</td><td>3B**</td><td>10LSB/
-10LSB</td><td>hard</td></tr>
<tr><td>“1100”
-
“1111”</td><td>3C**
-
3F**</td><td>-</td><td>-</td><td>-</td><td colspan="2">unused</td></tr>
</table>

<table>
<tr><th>Address</th><th>Data</th><th>Hex</th><th>Default</th><th>Signal</th><th colspan="5">Description</th></tr>
<tr><td rowspan="9">“0100”</td><td>“0000”
-
“0111”</td><td>40**
-
47**</td><td>-</td><td>-</td><td>-</td><td colspan="4">unused</td></tr>
<tr><td>“1000”</td><td>48**</td><td rowspan="4">130ms</td><td rowspan="4">TOTIM</td><td>65ms</td><td colspan="4" rowspan="4">Touch time (holdtime),

constant part of Tvalid</td></tr>
<tr><td>“1001”</td><td>49**</td><td>130ms</td></tr>
<tr><td>“1010”</td><td>4A**</td><td>130ms</td></tr>
<tr><td>“1011”</td><td>4B**</td><td>260ms</td></tr>
<tr><td>“1100”</td><td>4C**</td><td rowspan="4">48s</td><td rowspan="4">TIMOV</td><td rowspan="4">TOUCHED</td><td>32s</td><td rowspan="4">PROX</td><td>8min</td><td rowspan="4">Duration of time-out when system sate is TOUCHED or PROX</td></tr>
<tr><td>“1101”</td><td>4D**</td><td>48s</td><td>12,5min</td></tr>
<tr><td>“1110”</td><td>4E**</td><td>60s</td><td>16min</td></tr>
<tr><td>“1111”</td><td>4F**</td><td>No timeout</td><td>No timeout</td></tr>
</table>

Address	Data	Hex	Default	Signal	Description	
"0101"	"0000"	50**	-	-	-	unused
	"0001"	51**	enabled	OSCON	disabled	Switches internal oscillator off
	"0010" - "0100"	52** - 54**	-	-	-	unused
	"0110" - "1111"	56** - 5F**	-	-	-	unused

Address	Data	Hex	Default	Signal	Description	
"0110"	"0000" - "1111"	6***	-	-	-	unused

<table>
<tr><th>Address</th><th>Data</th><th>Hex</th><th>Default</th><th>Signal</th><th colspan="3">Description</th></tr>
<tr><td rowspan="14">“0111”</td><td>“0000”</td><td>70**</td><td rowspan="4">2</td><td rowspan="4">DYNSTEP</td><td>Sets to 0</td><td rowspan="4">Pos./Neg. steps greater than DYNSTEP are counted up in the dynamic counters:

NEGCNT and POSCNT, otherwise they are in reset.</td><td rowspan="2">sensitive</td></tr>
<tr><td>“0001”</td><td>71**</td><td>Sets to 1</td></tr>
<tr><td>“0010”</td><td>72**</td><td>Sets to 2</td><td rowspan="2">not sensitive</td></tr>
<tr><td>“0011”</td><td>73**</td><td>Sets to 3</td></tr>
<tr><td>“0100”</td><td>74**</td><td rowspan="4">2</td><td rowspan="4">PROX-NUM1</td><td>Sets to 0</td><td rowspan="4">If PROXCNT, which counts the number of subsequent samples that pass the 1st threshold THZ1, is greater than PROXNUM1, than proximity is detected.</td><td rowspan="2">sensitive</td></tr>
<tr><td>“0101”</td><td>75**</td><td>Sets to 1</td></tr>
<tr><td>“0110”</td><td>76**</td><td>Sets to 2</td><td rowspan="2">not sensitive</td></tr>
<tr><td>“0111”</td><td>77**</td><td>Sets to 3</td></tr>
<tr><td>“1000”
-
“1001”</td><td>78**
-
79**</td><td>-</td><td>-</td><td>-</td><td>unused</td><td></td></tr>
<tr><td>“1010”</td><td>7A**</td><td rowspan="2">2</td><td rowspan="2">PROX-NUM2</td><td>Sets to 2</td><td rowspan="2">If POSCNT or NEGCNT> PROXNUM2 proximity is detected</td><td>sensitive</td></tr>
<tr><td>“1011”</td><td>7B**</td><td>Sets to 3</td><td>not sensitive</td></tr>
<tr><td>“1100”
-
“1111”</td><td>7C**
-
7F**</td><td>-</td><td>-</td><td>-</td><td>unused</td><td></td></tr>
</table>

Address	Data	Hex	Default	Signal	Description	
“1XXX”	“XXXX”	****	-	-	Test mode com-mands	Don´t use !

Table 2.3: Address decoding

2.3.4 Adjustment of the HALIOS® parameters while using the SPI interface

The parameterization of the IC via SPI by using the parameter commands HICC, HICS, FIXS (see Table 2.3) can lead to a spontaneous activation of the TOUCH-output. This effect is the result of the sudden change of the DAC values caused by the adjustment. The TOUCH-output then will remain active for up to 40 seconds until timeout occurs.
This behaviour only applies to applications that communicate via SPI instead of using the IC stand alone. The necessary procedure to prevent this effect is described below.

In this case the ENSPI pin of the IC has to be connected to an additional digital output from the external controller as shown in schematic Fig. 2.10. The values of the resistor RD1 and RD2 (values are always equal) are dependant on the supply voltage DVDD. It must be ensured that the maximum possible current through ENSPI is limited to 1mA.

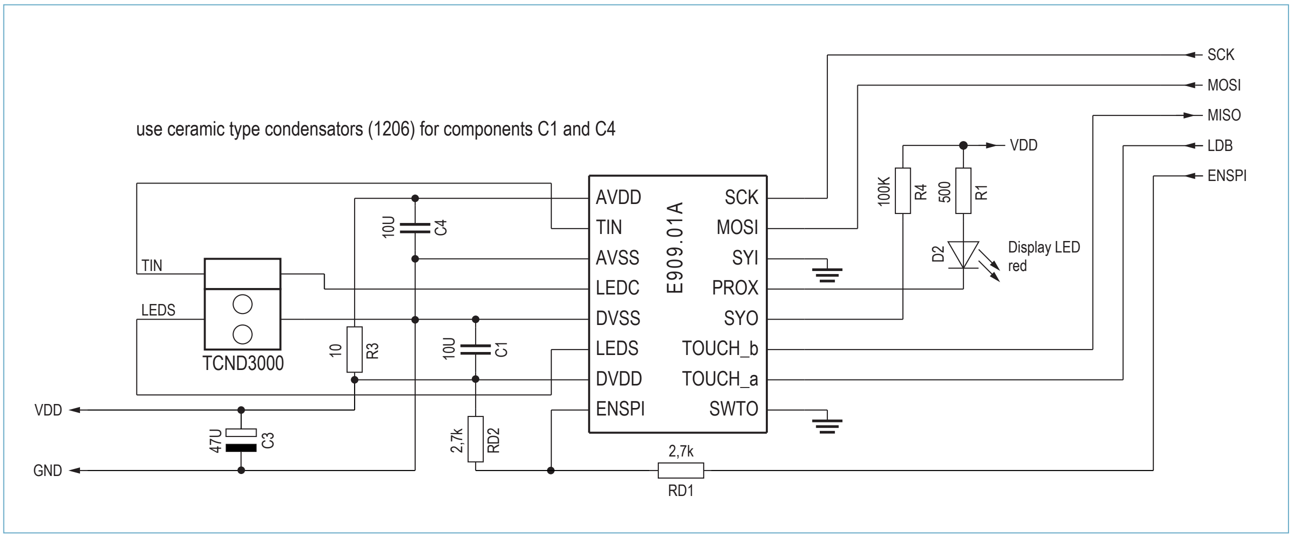


Figure 2.10: Circuit diagram of a freely configurable switch

To parameterize the IC, first, ENSPI must be set low, followed by the two commands 'a5**' and 'a4**'sent via SPI. Then ENSPI has to be released (set high) again and the parameter commands can be transmitted. The required timing for this sequence is described in detail in Fig. 2.11. All shown delay times, except the duration, are meant as minimum values.

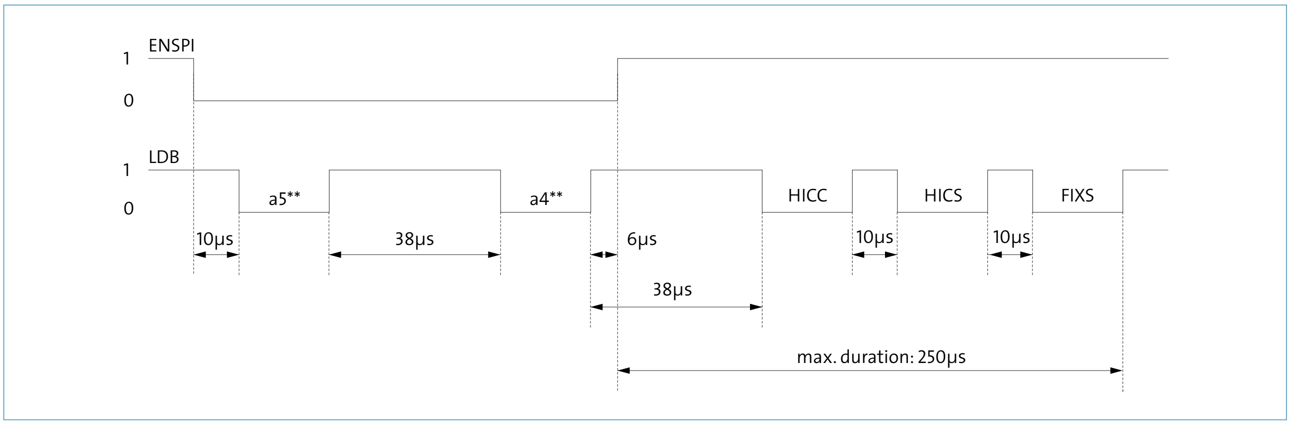


Figure 2.11: Timing diagram of the parameterization sequence

2.4 Synchronisation

The synchronisation is done by passing a pulse from one IC to the next. Each IC has an input SYI and an output SYO. The output SYO is connected to the input SYI of a neighbouring IC E909.01 in a chain of IC E909.01 or connected to its own SYI if there is only one switch. The output SYO is ‚HIGH' when an IC E909.01 is performing a measurement cycle. An E909.01 activates when

1. It is a slave E909.01 and there is a falling edge on the input SYI

2. It is the master E909.01 and the passive time has elapsed.

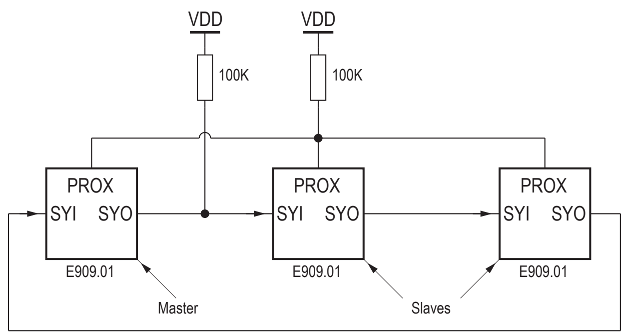


Figure 2.12: Example of synchronisation of three E909.01

2.4.1 Definition of master (via resistance 100k)

In a chain of E909.01 there is only one master E909.01. The decision which one functions as master depends on the output pin SYO. The master E909.01 is defined by a pull-up resistor of 100K on its SYO output. Initially the digital output of this pin is tristated so the value on the pin depends on whether it is connected to a pull-up or not.

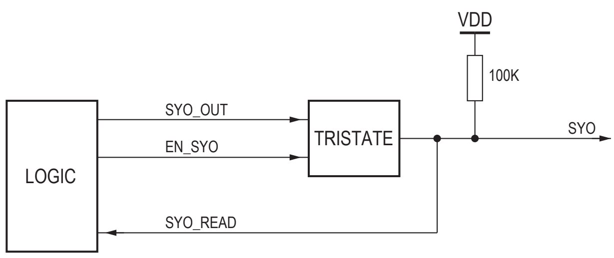


Figure 2.13: Decision of master

After the initial power on or a SPI-reset, each E909.01 checks to see if it functions as master or slave. This decision depends on the value of SYO_READ while EN_SYO is ‚LOW'. The signal EN_SYO controls the tristate buffer, while it is ‚LOW' the pin SYO_OUT is in high resistance state.
The value of EN_SYO is the delayed power-on or SPI reset.

2.4.2 Cancelling a touch signal

The touch algorithm consists of mainly three states. In the state APPROX the algorithm has detected an object and the signal proximity is activated. When the object approaches further with a minimum velocity and stops on the sensor surface with a minimum acceleration the pre TOUCH-STATE is enabled. When the object remains calm on the surface for a certain time the TOUCH-STATE is entered.
To avoid the situation where there occurs a touch by two or more switches at the same time a cancel-pretouch signal is sent over the SYO line to all switches. To ensure that the switch with the highest dynamic responds to the TOUCH event, the additional touch time with SELDELAY (see table 2.2) should be enabled. This means higher dynamic causes less delay.
The first switch detecting a TOUCH sends a cancel-pretouch signal on the SYO line. Each switch in turn cancels its PRETOUCH and sends the cancel-pretouch signal to the next switch. Only the switch that originally detected the touch can stop this pulse, so the pulse is going round at least once until it reaches the switch which detected the switch event in the first place. Afterwards all other switches are able to detect another TOUCH event.
The cancel-pretouch signal is a small pulse which is sent after the measurement cycle is finished and a TOUCH has been detected. To decide whether this signal has been sent or not, the time period is measured in which SYI is zero after a falling SYI event has occurred. If this time is too short then the switch knows that a TOUCH was detected by a neighbouring switch and when it is in state PRETOUCH it will cancel this touch event and change its state to APPROX.

2.4.3 Proximity detection and change of sampling rate

If in a chain of several IC`s E909.01 one of the slaves detects an approaching object it can‘t speed up the sampling rate by itself, as only the master chip is able to do this. Thus all IC`s E909.01 in a synchronised chain are connected parallel to a pull-up resistor and the master chip can read the common PROX signal to change the sampling rate (see figure 2.2). To ensure the appropriate functionality the parameter HOLDPROX (see table 2.2) should be set to ‚0‘ to get the internal PROX = not STANDBY which indicates the sampling rate.

2.5 Analogue parameters

The parameters HICC (High Current Compensation) and HICS (High Current Sender) listed in the address decoding table in paragraph 2.3.3 can be used to set the operating point of the HALIOS® loop. Additionally a self test can be implemented when using SPI interface. By switching the sending current from low to high a touch should be detected. The same effect can be achieved by switching the compensation current from high to low.
With FIXS (table 2.2) the LED driver of the sender can be set to regulated (FIXS=0) or fixed mode (FIXS=1). FIXS=1 means that the sending LED is pulsed with a constant current. By setting FIXS=0 the sending current is inversely controlled to the compensation current. This means that if the compensation current increases, the sending current is decreased by the same relative amount. In this mode the system never saturates and can handle a great variation in optical reflections.
With G0, G1 the gain of the amplifier is set. It should be set to value that the modulator can differ between single one LSB changes of the DAC. The limiting factor here is the noise of the amplifier which is about 2.7nArms referred to the input.
With OSCON=0 (see table 2.2) the system can be set to a sleep mode. If this command is sent during a measurement phase the system waits until the measurement has finished before it stops.

3 Application diagrams

3.1 Application diagram of a switch without SPI

The simplest configuration consists of one switch IC E909.01 as a single switch without SPI interface. The corresponding circuit diagram is shown in figure 3.1. The touch and the proximity signal are indicated with two LEDs. With the pin SWTO one is able to define whether the touch output should be activated only during the time the touch event is detected (touch mode) or if the touch output should toggle its state with each Touch event (toggle mode). The following voltages must be applied to select the corresponding mode:

Touch mode: SWTO = VDD

Toggle mode: SWTO = GND

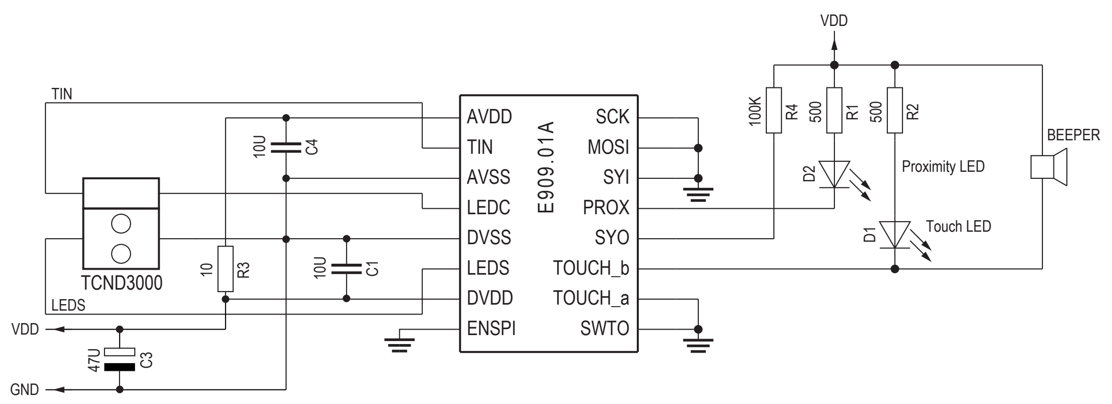


Figure 3.12: Circuit diagram of a single switch without SPI interface

3.2 How to increase the detection range

The sensitivity or the detection range is proportional to the sending current (pin LEDS) and inverse proportional to the compensation current (pin LEDC). The IC E909.01 allows to increase the sensitivity by internally influencing the range of the LED currents with SPI commands. With the SPI command “0D” it is possible to increase the sending current range from 10mA to 20mA. By using the SPI command “0A” the compensation current range is reduced from 2mA to 1mA. The two commands allow to improve the sensitivity of the sensor by a factor of four. With the external drivers shown in Figure 3.2 it is possible to increase the currents to larger values than it is possible with the internal drivers. With the emitter resistor of PNP2 the compensation current can be adjusted and it is possible to adapt the LED current for both channels independently of each other. If the sensitivity is enlarged one must pay attention to avoid saturation of the measurement signal. Should this happen, the stray-light from the sending LED to the photodiode must be reduced by using an optical blocking layer between the translucent surface and the TCND3000. This includes also the air-gap between both lenses of the TCND3000. Please refer to chapter 1.5.

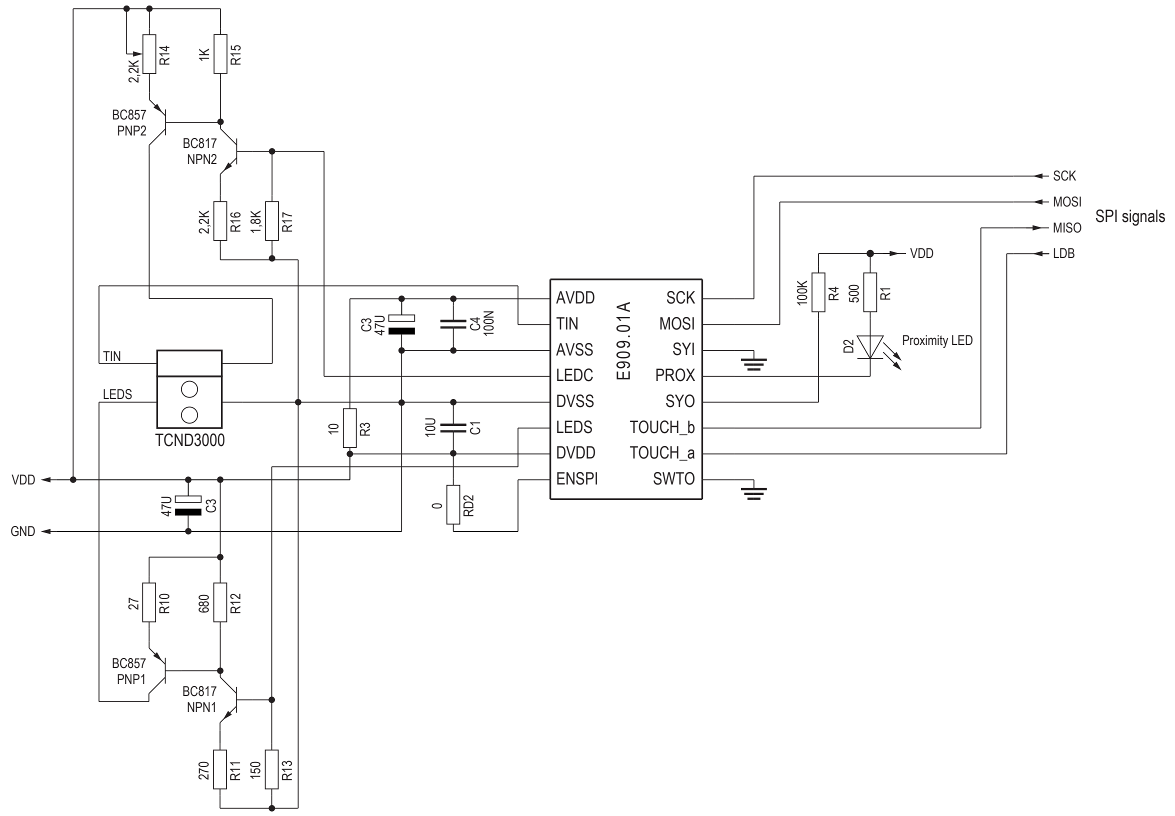


Figure 3.13: Control of the optomodule TCND 3000 with external LED drivers

Another possibility to avoid saturation of the measurement signal is to regulate both the sending current and the compensation current. In normal mode after power up only the compensation current is regulated (FIXS is enabled). By using the SPI command "0E" (FIXS is disabled) the sending LED current is regulated according to the equation

I SEND = I RANGE_SEND * (1 – Loopvalue / 1023)

while the compensation current is regulated according the following equation

I COMP = I RANGE_COMP * Loopvalue / 1023.

In this case, however, the sensitivity is decreased when the measurement signal approaches the limit of the range in order to avoid saturation. Thus the most effective way to avoid saturation in a system with high sensitivity is to reduce the stray light as described above.

3.3 Cascading of optical switches

Several switches can build a group by using the synchronisation bus. This has several advantages.
First, one proximity function for all switches in the group can be realized. This makes it possible to illuminate selected parts of the control panel and define groups of functions. The second advantage is the possibility to avoid unwanted operation by cancelling parasitic touch events. If one switch detects a touch event all other switches are disabled for a short time. A third advantage is that the measurement phase of switches among one group is activated sequentially. This allows switches to be located close together avoiding disturbances if light from one switch is reflected to another switch. The schematic below shows a group of two switches which are connected with the synchronisation bus.

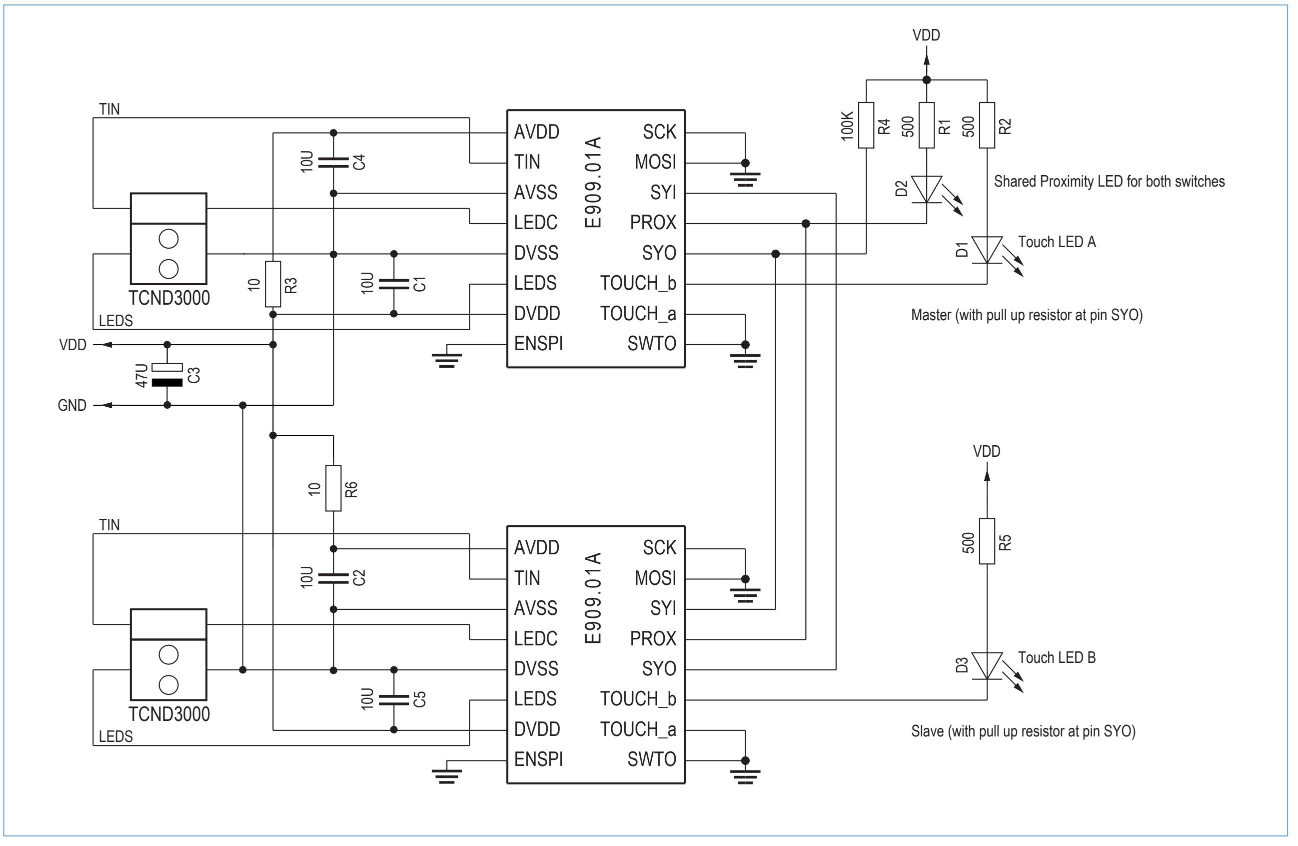


Figure 3.14: Circuit diagram of two synchronised switches

The synchronisation bus is activated by connecting the SYO pin of one switch to the SYI pin of the next switch. The last switch is then connected to the first switch building a closed loop. One switch in this loop is defined as the master by using a pull-up resistor at its SYO pin and connecting all PROX output pins with one pull-up resistor. If one switch in the group detects an approaching object all other switches are switched from standby mode to active mode. The master synchronizes the sampling rate, the “pretouch” time (parameter TOTIM in table 2.2) and the global timeout (parameter TIMOV in table 2.2) of all switches in the group.
Figure 3.4 shows how parasitic touches are cancelled. If several switches are in the “pretouch” phase at the same time the switch that leaves the “pretouch” time first cancels all other “pretouch” phases that are active at this time. This is done by sending a pulse on the synchronisation bus from one switch to the next. If several switches have activated their “pretouch” phase during the same measurement cycle they will leave their “pretouch” phase at the same time. In this case the order in the chain of the synchronisation bus determines which switch will have a valid touch. This means the first switch seen from the front of the chain will accept the touch.

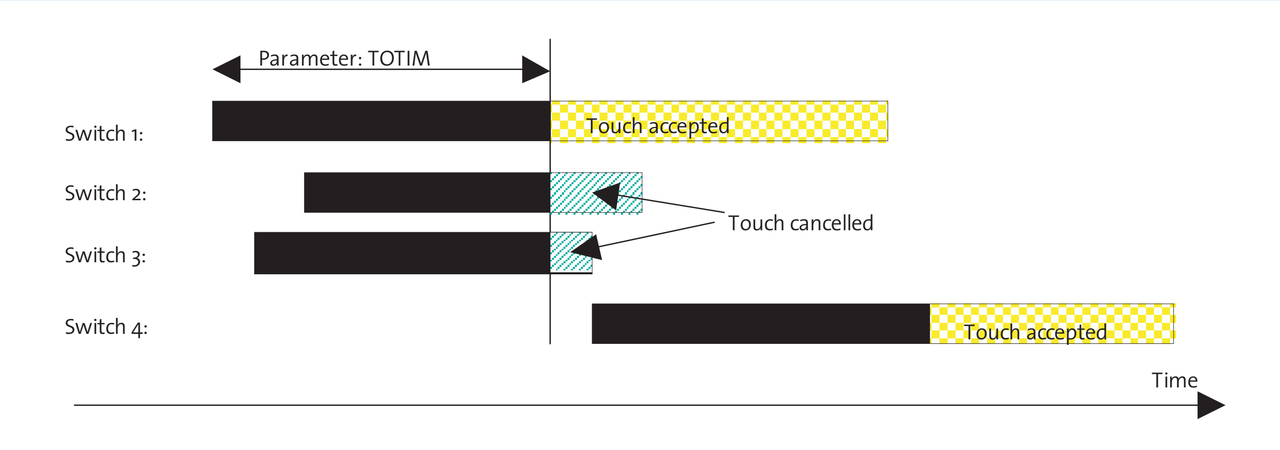


Figure 3.15: Prioritisation of touch events by disabling other touches during the "Pretouch" time

It is also possible to prioritise the switch with the largest signal amplitude to accept the touch. With the parameter SELDELAY (parameter SELDELAY is described in table 2.2) this option can be enabled. In this case the constant "pretouch" time is extended by a variable part, which is proportional to the signal amplitude. If now several switches are entering the "pretouch" phase during the same measurement cycle the switch with the largest signal amplitude will win and activate its touch output.

3.4 Reference Design

The circuit diagram (figure 3.5) below shows an application where the SPI interface is not used in normal operation. It is, however, possible to activate the SPI interface for test purpose by removing the components RD1, RD3, RD4, RD5, RD6 and inserting component RD2. In the case of an activated SPI interface the Touch output is not active any more.
Due to the synchronous demodulation principle of the HALIOS® regulation loop asynchronous disturbances outside the modulation frequency band are not critical and do not disturb the measurement. Only synchronous electrical and optical disturbances can influence the measurement. Thus it is important to avoid electrical coupling of the modulation frequency to the photodiode input and the analogue supply of the E909.01 IC. This can be avoided by shielding the photodiode connection line with analogue ground, which should be designed like a grounded coplanar line. Additionally the analogue supply should be decoupled with a lowpass of first order given in the example by the components R3 and C4.
The ground connection between TCND3000 and E909.01 should be of low resistance type with a ground plane.

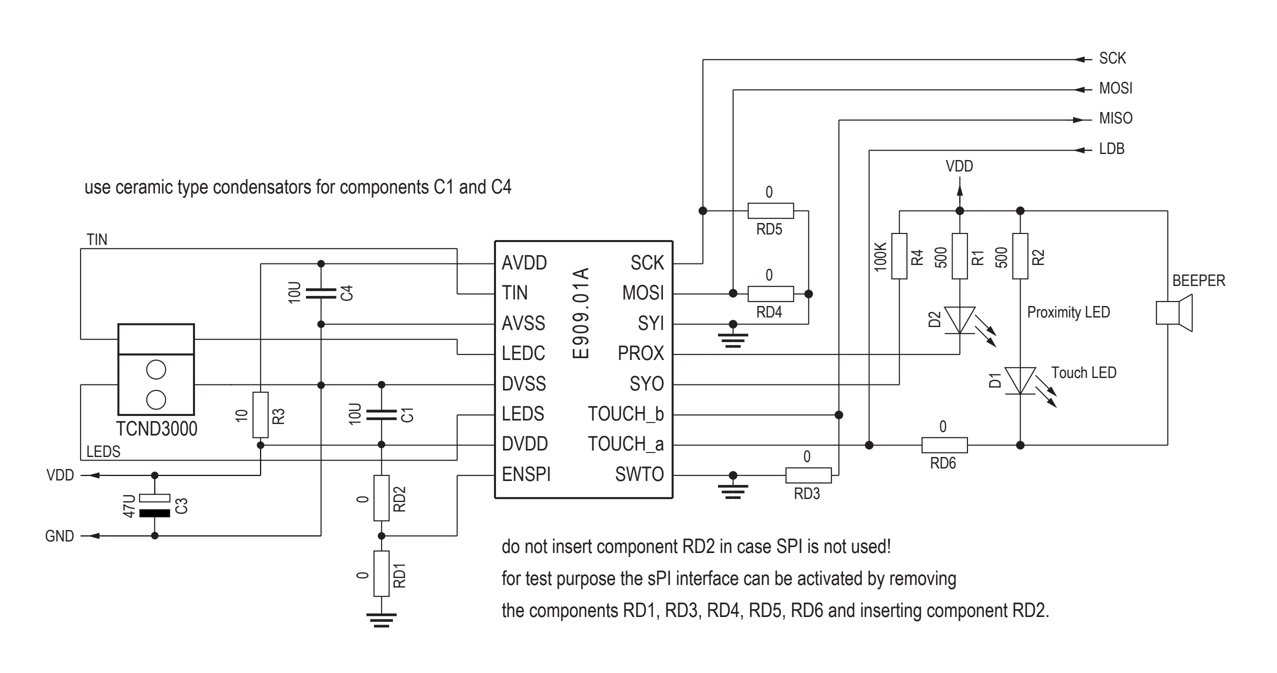


Figure 3.16: Schematic diagram of test circuit with SPI interface

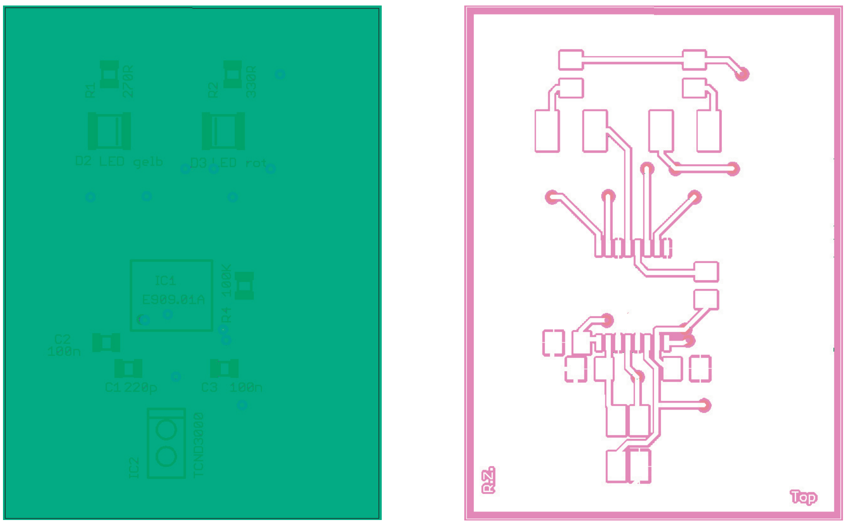


Figure 3.17: PCB Layout of test circuit (top side)

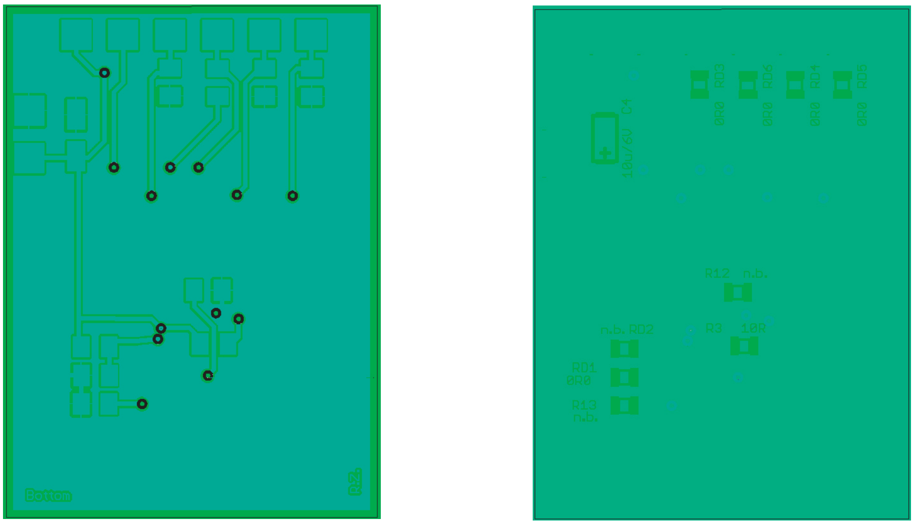


Figure 3.18: PCB Layout of test circuit (bottom side)

4 Related Documents

Dokument-No.: 03SP0277E.XX	Specification E909.01	[1]

5 Record of Revisions

Chapter	Rev.	Change and Reason for Change	Date	Released
3.3	1	Figure 3.14	03.04.2006	RME/ZOE
-	1	page 39 removed - page 5 moved to page 38	03.04.2006	RME/ZOE

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