Overview

Features

- Sensing of up to 100 capacitive touch Sensors
- All sensors individually addressable:

  → Different shapes, arrays and sensor types with a single PE5004 possible;
  Integrate sliders, wheels, buttons and touch matrix arrays with use of one single Chip

- Controllable stimulation for wide spread of suitable sensor capacitance, layout and material
- Highly sensitive, coatings of over 30mm possible
- Very low acquisition time of 10ms for 100 sensors in a matrix
- High resolution of 10bit for each sensor → capacitive changes of less than 5fF detectable
- Standby mode with programmable wake up intervals
- Low operating current : < 3mA for 100 Sensors at 10ms cycle
  < 5µA for 10 Sensors at 1s cycle
- Low-Power Mode for large Sensor shapes
- Very low current during deep sleep (1µA)
- Programmable Number of Sensors for optimal acquisition time and current consumption
- No need for grounding of scanned object
- No need for sampling capacitors or external resistors
- High sensitivity to large parasitic capacitances
- Very robust against noise
- Temperature drift compensation
- Multiple sensor arrays and PE5004 chips controllable with one µC:
  up to 700 sensors through I²C, up to 2000 sensors through SPI (more possible at lower speed)

Applications

- capacitive touch screens
- capacitive sensor arrays
- capacitive keypads/keyboards
- finger/palm print scanner
- capacitive switches, buttons, slider
- fluid control
- size/weight dependent presence detection

General Description

The PE5004 is a high precision capacitive sensing circuit which uses amplitude modulation for very fast stimulating and reading of capacitive sensor arrays and single sensors.
A number of up to 100 sensors per chip can be selected by user, multiple sensor arrays can be cascaded. All Sensors can be addressed individually making it possible to integrate several different types of buttons, sliders, wheels and touch matrix arrays with one single PE5004.
By implementing a controllable sinusoidal generator with a wide range of frequencies and amplitude the spectrum of suitable sensor capacitance is significantly increased for a large range of applications. The implemented DAC with variable reference voltages guaranties proper function over varying environmental conditions and provides digital controlled self calibrating capability. For low power operation the chip can be forced to deep sleep mode with ultra low standby current. Additionally Power consumption of internal Blocks can be programmed to a third of normal if full 10bit-Resolution is not necessary or large Sensor shapes are used. By means of a multi-master I²C interface several detector circuits can be controlled by one MCU.

Table of Contents

1 Revision History

Version	Date	Changes	Page
Initial Version V1.0	03/2009		
V1.1	09/2010	changed conversion time added 10us waiting time Communication	6 21
V1.2	02/2011	added I2C ID information	21; 22
V1.3	03/2011	added I2C R/nW information corrected Table 13	21
V1.4	05/2011	added F_{dig}	6
V2.0	12/2011	added description of power modi	19
V2.1	03/2012	Corrected PCO size	16

2 Package & Pin Description

Package: 32 Pin LQFP

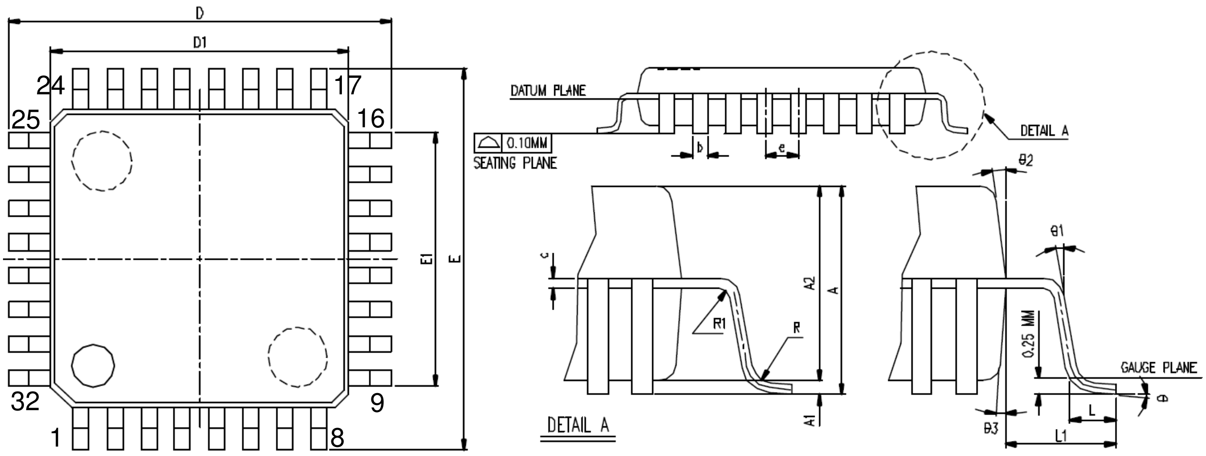


Table 1 – Package Dimensions

Symbol	Dimension in mm			Dimension in inch		
	Min.	NcM.	Max.	Min.	NCM.	Max.
A			1.60			0.063
A1	0.05		0.15	0.001		0.006
A2	1.35	1.40	1.45	0.053	0.055	0.057
b	0.30	0.37	0.45	0.012	0.015	0.018
c	0.09		0.20	0.004		0.008
e	0.80 BASIC			0.031 BASIC		
D	9.00 BASIC			0.354 BASIC		
D1	7.00 BASIC			0.276 BASIC		
E	9.00 BASIC			0.354 BASIC		
E1	7.00 BASIC			0.276 BASIC		
L	0.45	0.60	0.75	0.018	0.024	0.030
L1	1.00 REF.			0.039 REF.		
R1	0.08			0.003		
R	0.08		0.20	0.003		0.008
Θ	0	3.5°	7°	0	3.5°	7°
Θ1	0			0		
Θ2	11°	12°	13°	11°	12°	13°
Θ3	11°	12°	13°	11°	12°	13°
Jedec	MS-026D (BBA)					

Note: Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25mm per side. D1 and E1 are maximum plastic body size dimensions including mold mismatch.

Table 2 - Pin Listing Description

PIN Nr.	Type	Name	Description
1	Output	stim_out_5	Output column 5 stimulus
2	Output	stim_out_4	Output column 4 stimulus
3	Output	stim _out_3	output column 3 stimulus
4	Output	stim _out_2	output column 2 stimulus
5	Output	stim _out_1	output column 1 stimulus
6	Output	stim _out_0	output column 0 stimulus
7	Input	Sens_In_0	row 0 sensor input
8	Power	GND	analog & digital signal ground
9	Input	Sens_In_1	row 1 sensor input
10	Input	Sens_In_2	row 2 sensor input
11	Input	Sens_In_3	row 3 sensor input
12	Input	Sens_In_4	row 4 sensor input
13	Input	Sens_In_5	row 5 sensor input
14	Input	Sens_In_6	row 6 sensor input
15	Input	Sens_In_7	row 7 sensor input
16	Input	Sens_In_8	row 8 sensor input
17	Input	Sens_In_9	row 9 sensor input
18	Input	CE3	chip enable 3
19	Input	CE2	chip enable 2
20	Input	CE1	chip enable 1
21	Output	INT_O	output interrupt
22	Output	SPI_MISO	SPI MISO
23	Bidirectional	SDA/SPI_MOSI	I2C SDA out/in / SPI MOSI in
24	Power	VDDD	digital supply voltage
25	Input	SCL_I/SPI_SCLK	I2C SCL Input / SPI SCLK Input
26	Input	SPI_SEL	SPI select
27			leave open or connect to ground
28	Output	stim _out_9	Output column 9 stimulus
29	Output	stim _out_8	Output column 8 stimulus
30	Output	stim _out_7	Output column 7 stimulus
31	Power	VDDA	analog supply voltage
32	Output	stim _out_6	Output column 6 stimulus

3 Specification

Table 3 - Absolute Maximum Ratings

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Temperature Range	T_{OP}	-40		120	°C	
Supply Voltage	V_{DD}	-0.3		3.6	V	
Input Voltage	V_{IN}	-0.3		3.6	V	
Output Voltage	V_{OUT}	-0.3		3.6	V	
Supply Current	I_{DD}			50	mA	

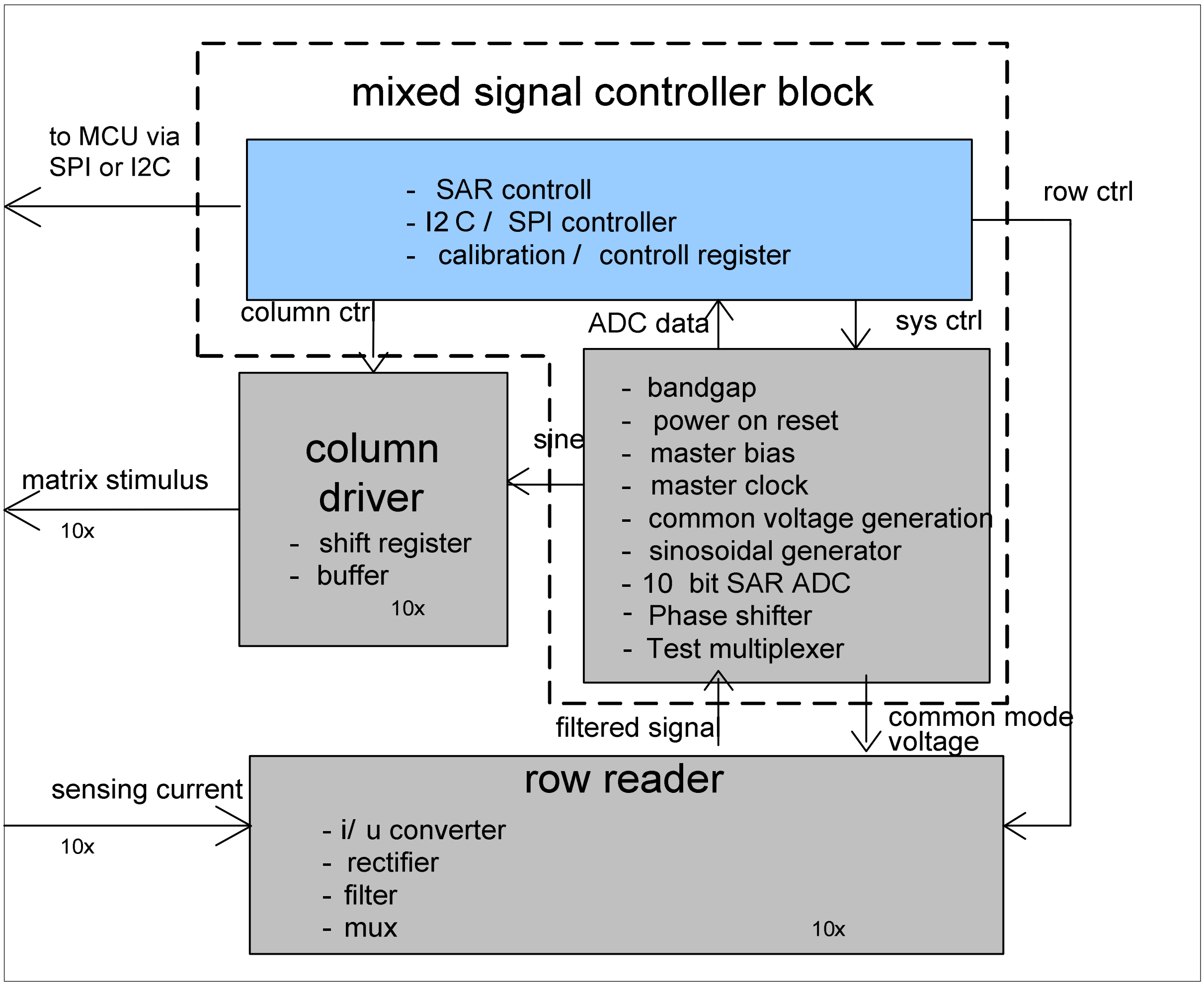
Table 4 - Static Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Condition
Operating Temperature	T_{OP}	-40	27	80	°C	
Supply Voltage	V_{DD}	3	3.3	3.6	V	
Operating Current	I_{DD}	2	2.5	3	mA	max @ PWR 1, max. conversion speed
Standby Current				300	µA	refer to page 19
Deep Sleep Current				1	µA	refer to page 19
Basic Sensor Capacitance	C_{pix}	0.5	5	50	pF	
Input Resistance	R_{in}	70	100	130	kOhm	
oscillator amplitude voltage	V_{Sine}	0.015		1.1	V	6bit tuneable
oscillator clock frequency	F_{stim}	70 83 102 132 177 208 250 314	73 87 106 137 185 217 260 329	78 92 113 146 196 230 276 350	kHz	SINF 000 SINF 001 SINF 010 SINF 011 SINF 100 SINF 101 SINF 110 SINF 111
Gain Vout/Iin	Gain	80		540	kOhm	3bit tuneable
common mode voltage	V_{CM}		1.4		V	
ADC input voltage	V_{DAC_IN}	0		2.6	V	
ADC offset	V_{OFFSET}		2		mV	
ADC Upper reference voltage level	$V_{refhigh}$	0.4875		2.6	V	4bit tuneable, lowest specified value is $3LSB_{dac\_ref}$
DAC reference voltage settling time	$T_{voutset}$			5	µs	
output driver DOUT	I_O	1			mA	

Table 5 - Dynamic Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Condition
conversion time		10	12	16	ms	10x10Matrix
column settling	WAITCOL	50	200	400	us	
row settling	WAITROW	0	10	30	µs	
ADC bit conversion time	t_{BIT}	3	4	5	µs	
serial clock frequency	t_{SER}		1		MHz	I2C (high speed mode 3,4Mhz) SPI
reset delay	t_R			2	ns	after reset edge
filter time constant	T_{FILT}		100		µs	
bandwidth I/U converter	$BW_{I/U}$	300			kHz	
startup time	$T_{startup}$	5	15	33	µs	(depending on sine-frequ, approx 2/f)
Clock frequency digital core	F_{dig}	85	125	170	kHz	

4 Functional Block Overview



The PE5004 consists of 2 analog blocks for stimulating and measuring the sensors and 1 mixed signal block for main controlling and providing the stimuli signals and ADC conversion.

The column driver is responsible for sensor matrix stimulation by connecting the master signal generator to one of the sensor columns and tying all others to ground node.
The switches are controlled by a 10 Bit wide shift register. Each Bit in the register maps to one logical control input of one switch. The register is resettable and serial loadable. Every shift cycle, one Bit is shifted in.

This row circuit is responsible for sensor data acquisition. Signal acquisition is done for every row separately. Thus, every part of the block besides the serial interface is present 10 times according to the number of input channels. The signals are amplified, demodulated and every measured sensor value is mixed to the SAR ADC.

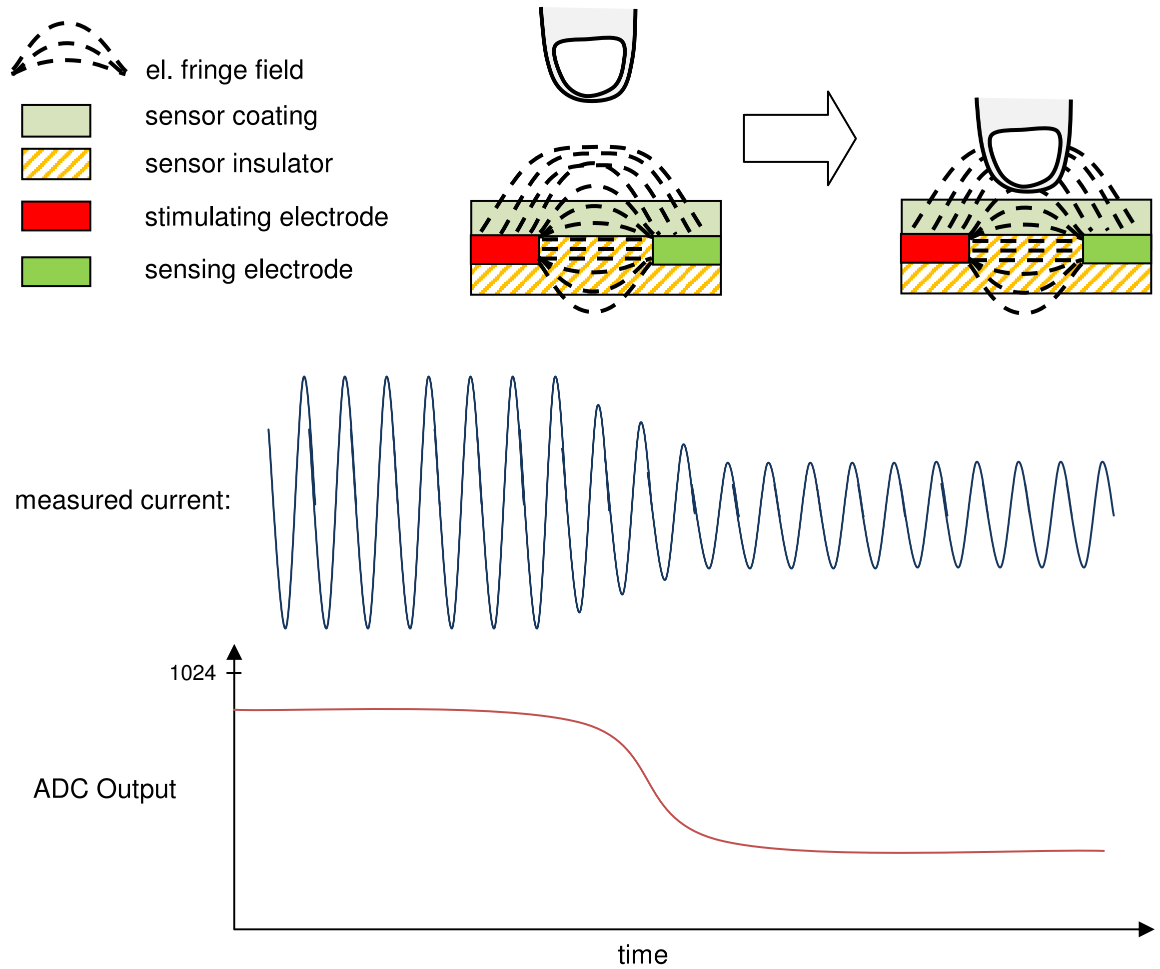
The signal of the actual connected sensor is fed into a comparator whose second input is connected to DAC and converted to 10bit digital word by successive approximation of the DAC output value. The DAC is controlled by digital block and set to a value corresponding to the comparator output. After completion of the analog to digital conversion of one stimulated sensor column, the 10bit value together with row and column address can be read by a MCU while the next column of sensors is measured.

The mixed signal block is controlling the column driver and row reader circuits. It also provides the stimuli Signal for sensor value acquisition, the digital master clock and a temperature compensated reference voltage.

5 Capacitive sensing and sensor design

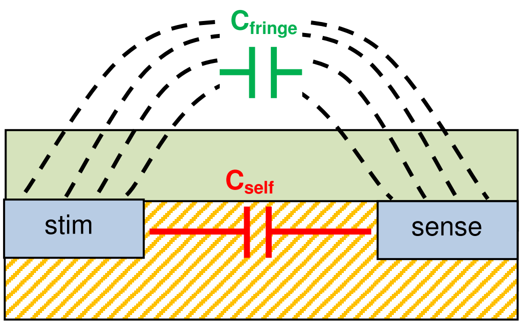
The conversion is done each step one column with all its corresponding row sensors.
Sensing is achieved by amplitude modulation of a current through ac stimulated capacitance of every sensor. The current then is converted into 10bit digital word and send to MCU for reading out sensor capacitance, calibration and drift compensation. While one column is sensed, the residual Sensors are disconnected.

Two plates for stimulating and sensing must be placed near to each other to form an electric fringe field. If an object is brought into the field between both electrodes a change of sensor capacitance could be measured. Depending on the object the electric field is disrupted which leads to a lowering of measured value (typical for human touch). Or the capacity is enhanced which leads to a rise of the measured value (typical for a floating low capacitance object with a dielectric constant much greater than air, e.g. waterdrop).
This sensor method works independent of the potential of the sensed object.

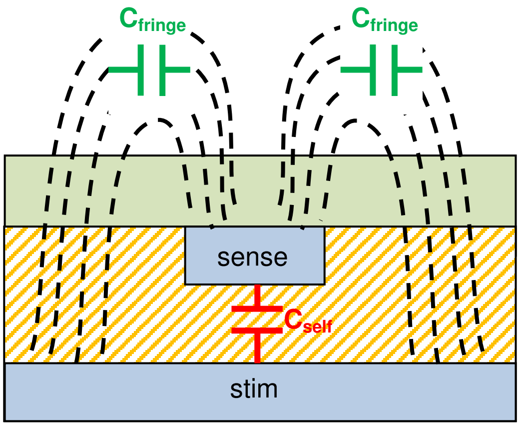


Depending on sensor coating, sensor dielectric and arrangement of stimulating and sensing electrode To each other the sensibility and robustness against noise is effected.

single layer electrode design



double layer electrode design



A high dielectric of the insulator (means the dielectric of the material the sensor is printed on), small gaps between both electrodes and large parallel running electrode planes result in a bigger self capacitance of the sensor. This capacitance is not changed while touching.
A big self capacitance results in a better robustness against noise and a higher base value of the sensed signal.
Due to bonding, pads and internal wiring a small self capacitance of approx 500fF is caused by the chip itself for every sensor.

A high dielectric of the coating, greater distance between both electrodes and non-overlapping electrode structures result in a greater fringe field capacitance. This capacitance is interacting with objects brought into the field and therewith the measured value.
Increasing the electric fringe field capacitance leads to a higher sensitivity.

As the electric fringe field spreads in all directions the touch-sensitive area of one sensor is enlarged with the thickness of the coating. This results in overlapping fields of sensors laying near each other.
Due to high resolution of internal ADC the position of a interacting object can be easily interpolated, leading to a much higher resolution than number of sensors would usually allow.

A physical restriction in ratio between resolution and size of sensor array is the multi-touch ability. When the space between two sensors is bigger than the nearest distance two simultaneous interacting object may have (typical the diameter of a finger), there is no possibility of telling if two weak touch points or one big touch is detected. Both would result in the nearby same changing of the fringe field of the surrounding sensors.

Crossing of Row and Column Wires has to be minimized to avoid unwanted parasitic sensor shapes. Keeping the distance from PE5004 to the sensor matrix as short as possible minimizes parasitic self capacitance. Shielding of wires enhances robustness against noise. When setting up sensor design it always has to be kept in mind that every parasitic capacitance physically acts as a touch sensor.

The Figure below shows the combination of a single layer 6 button slider and a single layer 16 button matrix, both controlled with one PE5004.
The tapered shape of the slider buttons allows a very exact interpolation of the position of the touched object, as the measured signal is increased with the sensor area below the object.
Gap and perimeter of the inner sensing electrodes are nearly equal, this allows to use the same register values for both sensor types.

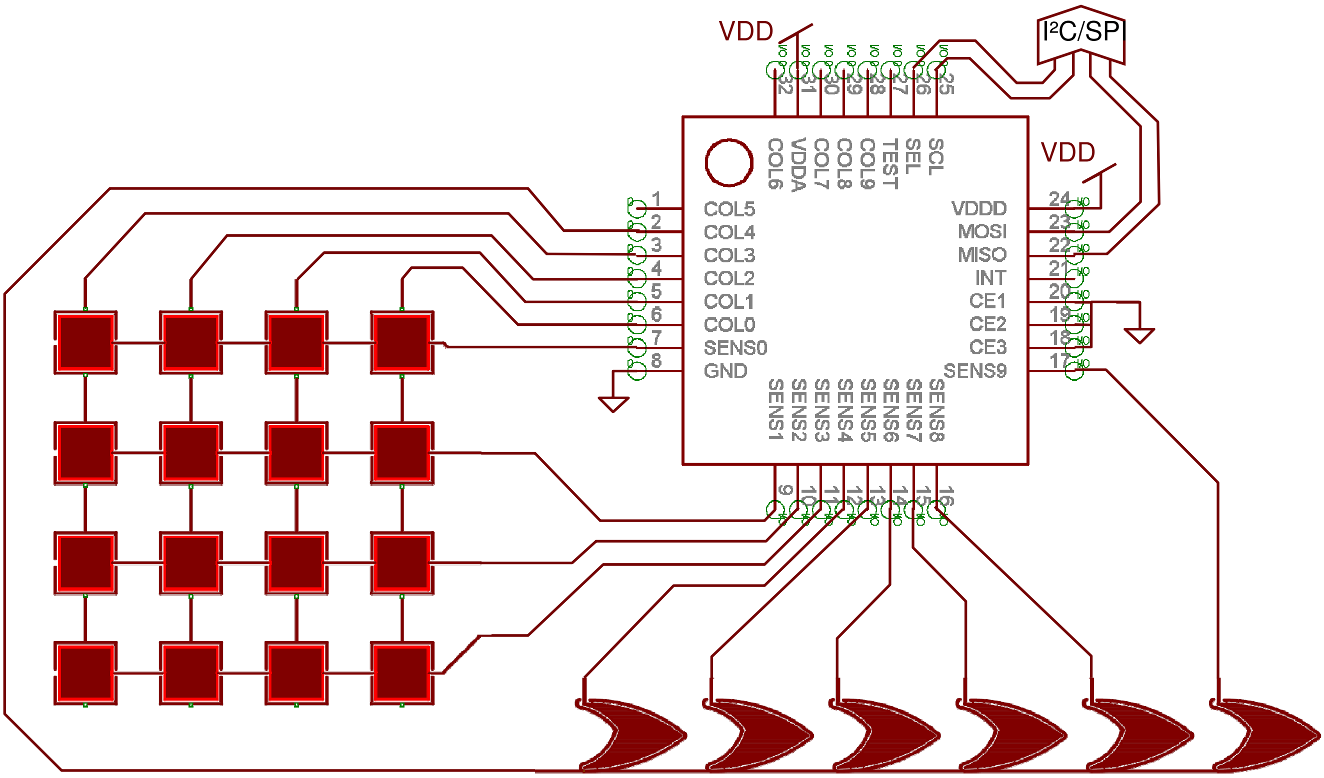


Figure 1 - PE5004 with single layer 4x4 matrix and 6 button slider – matrix 75x75mm, slider 130x12mm

The next Figures show some double Layer Sensor types (blue bottom layer, red top layer).
All Sensors where milled out of 1 mm thick FR4 coated on both sides with 35 µm copper.
These types of Sensors can be kept very simple without loose of accuracy. The most important design rule for these types of sensors is, that the upper electrode must not cover the whole lower electrode, as this would shield the fringe field from the interfering object. The easiest way to follow this rule is making the bottom layer electrode bigger than the top layer electrode.
The polarity whether to connect the stimulating or sensing electrode to the top is not important for the functional principle and depends on the application. In general the sensing electrode should be kept as far away from noise as possible.
Fig. 2 is a simple design consisting of 3 touch buttons. It is recommended to connect the bottom level to the stimulating electrode for better noise performance.

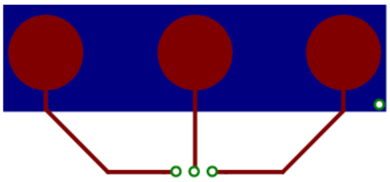


Figure 2 - simple Buttons – sensor diameter and spacing 10mm

Fig. 3 shows a high precision 10x10 sensor array. All stimulating and all sensing pins are connected each with one layer. Every crossing of a bottom and a top layer wire forms a capacitive sensor. The clearance between two sensors is kept small enough to provide multi touch ability for an adult finger over all conditions and allows a resolution of 200dpi (depending on speed of used microcontroller and interpolation algorithm).

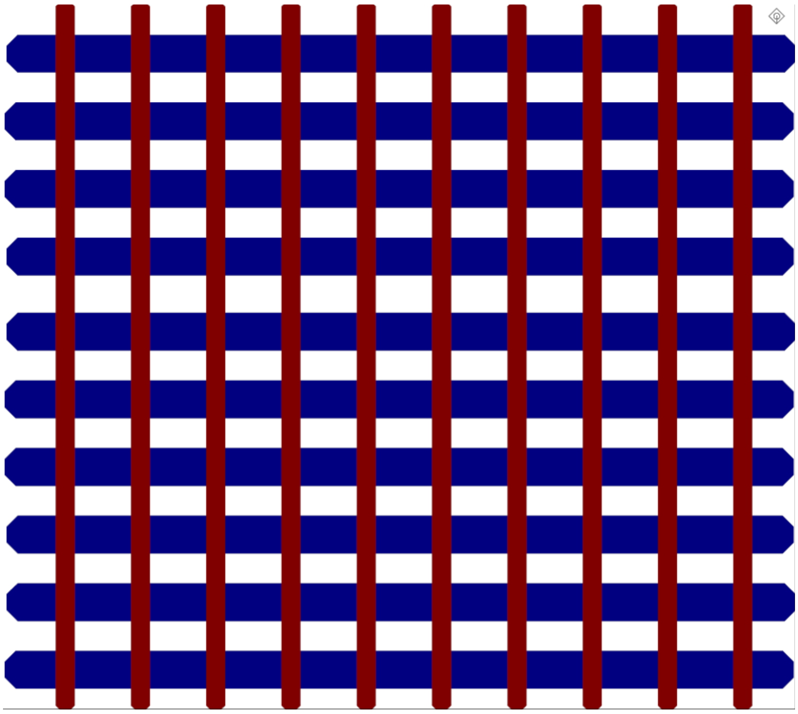


Figure 3 - simple sensor array 10x10 – whole array 105x95mm

In Fig. 4 the upper electrodes where designed in a more complex stile, allowing a bigger self capacitance and interpolation in x and y direction.

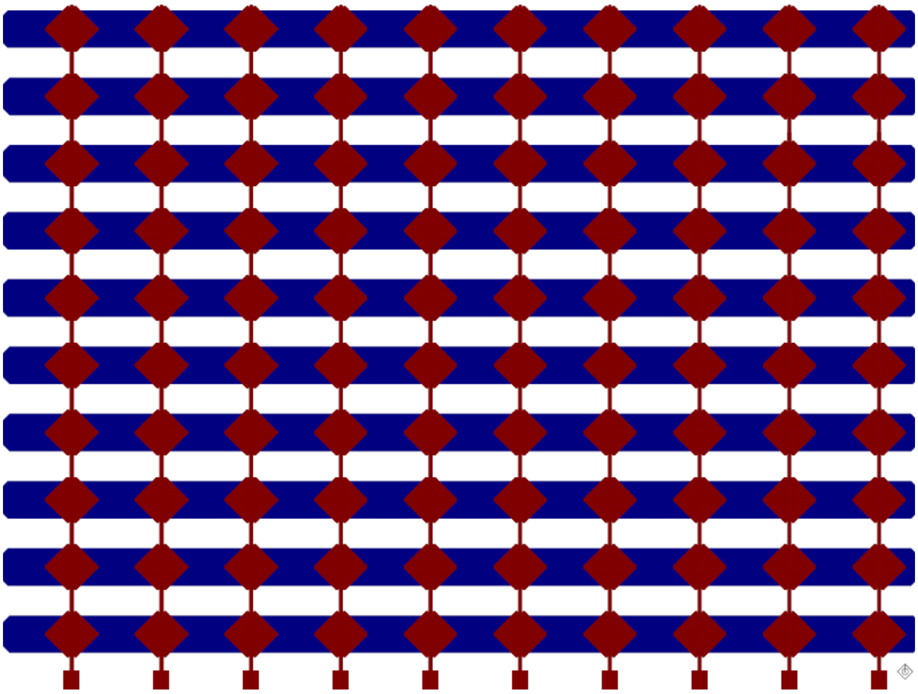


Figure 4 - more complex 10x10 array – whole array 125x95mm

Fig. 5 shows a design where upper and lower electrodes where interleaved in a diamonds style. This results in a very low self and a high fringe capacitance, leading to high sensitivity. This Design is useful in applications where overlaying structures are unwanted because of transparency reasons, like in touch screens where the sensor structures are made of indium tin oxide.

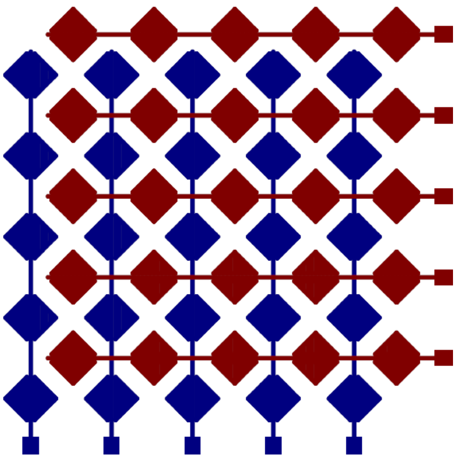
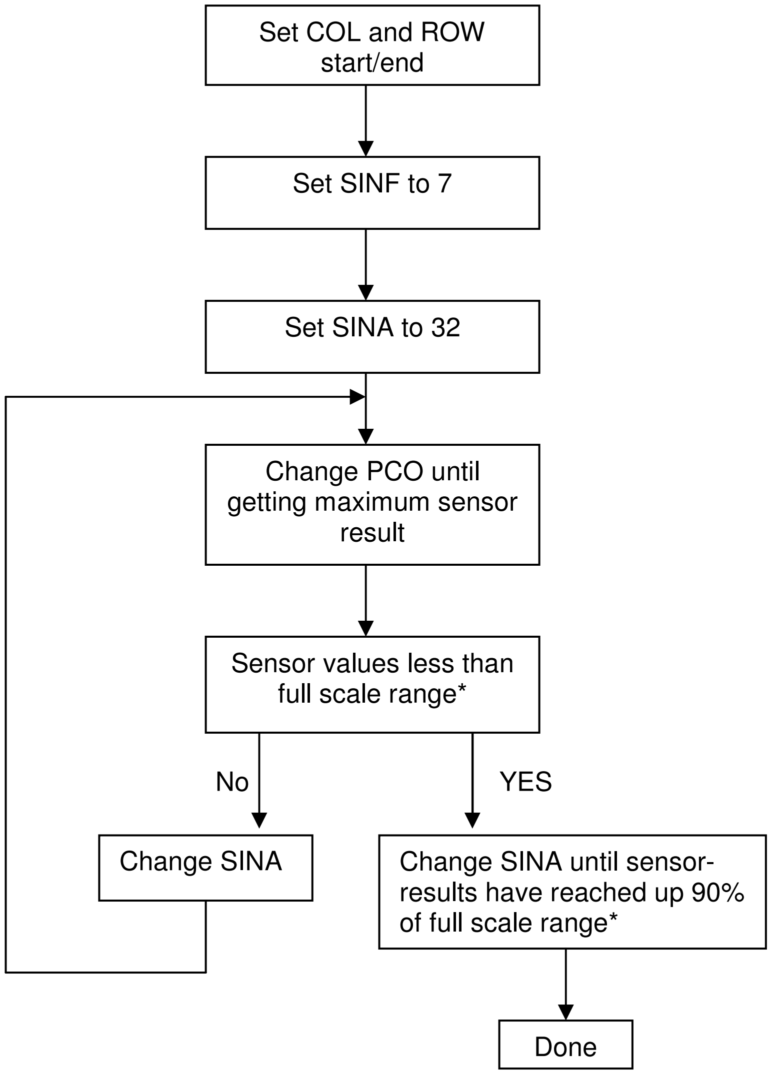


Figure 5 - non overlaying 5x5 matrix - 60x60mm

6 Configuration quick start guide



* The full scale range of 8bit sensor results is 255 and of 10bit sensor results 1023.

Configuration

For optimal customization there are several possibilities to program the internal analog blocks for best fit to the matrix size, desired sensor capacitance and sensitivity.
As sensing accuracy, acquisition time and current consumption depend on each other, the internal parameters can be adjusted to the requirements of the application, consuming not more resources then necessary.

Table 6 – configuration registers

Name	Register	Size [bit]	Data Address [position of LSB]	Description	re-commended value
SARMode	x01	1	1	reading of Mode for sampling '0'= single step, '1'= continuous	user defined
StartSAR	x01	1	0	Start of measure procedure will be set to '0' after internal start	1
COLSTART	x01	4	16	calibration for COL end	user defined
ROWSTART	x01	4	12	calibration for ROW end	user defined
COLEND	x01	4	8	calibration for COL end	user defined
ROWEND	x01	4	4	calibration for ROW end	user defined
WaitCOL	x02	12	12	Wait cycles for COL with WaitCOL x CLK100K	40
WaitROW	x02	12	0	Wait cycles for ROW with WaitROW x CLK100K	1
SINF	x03	3	18	calibration register for sinus frequency 4bit linear 60..400khz	7
SINA	x03	6	12	calibration register for sinus amplitude 6bit linear 0.015..1.1V	31
PWR	x03	1	11	calibration register for bias	3
GCO	x03	3	4	calibration register for gain amplifier 3bit linear 120k…860k	3
DACREF	x03	4	0	calibration register for analog SAR DAC 4bit linear 0.1625…2.6V	15
PCO	x04	10	0	calibration register for phase shift module (MSB 180°)	1024
SelectI2C	x05	1	2	Defines the I2C interface as selected protocol, this flag is only with I2C module settable, this flag deselect the SPI module	user defined
SelectSPI	x05	1	1	Defines the SPI interface as selected protocol, this flag is only with SPI module settable, this flag deselect the I2C module	user defined

6.1 Setting Matrix Size COLSTART/ROWSTART & COLEND/ROWEND

The size of scanned matrix can be set by 4bit **COLSTART**, **ROWSTART**, **COLEND** and **ROWEND** in register *x01*, determining the first and last scanned row and column. Because all rows in a column are sensed at one time, for more than 10 sensors it is recommended to use all rows and reduce not needed columns (e.g. for 16 sensors it is better to build a 2col x 10row matrix and ignore 4 sensors than setting up an 4x4matrix)

6.2 Setting Sinusoidal Generator SINA & SINF

The sinusoidal generator generates the signal which is used to stimulate all sensors in one column.
Frequency, amplitude and sensor capacitance are proportional to the current which is fed into the sensing rows. Setting frequency and amplitude higher enlarges the sensitivity.
Small sensors require a high frequency and amplitude voltage. Large sensors require low frequency and amplitude.

The PE5004 supports both calibration modes in register *x03*:

The frequency can be adjusted in 3bit **SINF** between typical 60khz and 350khz.
The amplitude can be adjusted in 6bit **SINA** between 15mV and 1.1V.

As this leads to two possibilities of calibrating the circuit, the choice which calibration register is preferable depends on the desired application.
For optimal performance the frequency must be always kept as high as possible, doing the fine tune over amplitude. If a low current consumption is more important, sensing at lower frequency and high amplitude is be the best choice (for low power considerations see also 6.6)

6.3 Setting IU-Converter Gain GCO

The UI-Converter converts the ac current trough the sensor in a voltage which can be read by the ADC. If very large or very small sensors are used and calibration analog 3.2 is not sufficient, there is the possibility to lower or higher the sensing gain in register *x03* with the 3bit **GCO** between 80k and 540k.

6.4 Setting ADC Range DACREF

In normal operation full Range from 0 to 2.6V ADC-Range shall be used. For applications with extreme small sensors (<0.5pF) or thick dielectrics the sensitivity can be enhanced by lowering the DAC reference voltage in register *x03* with 4bit **DACREF** (use of values lower then '0011' is leading to large DNL/INL and not recommended)

6.5 Setting Phase Shift Correction PCO

For noise suppression it is required to tune the phase between stimulated and sensed signal. For this purpose a phase shifter with programmable shift angle is implemented. In register *x04* with 10bit **PCO** the first 9bit are for shifting between 0° and 180°. With the MSB the phase is switched 180°.
In normal operation the expected phase shift would be approx. 180°. For Application where huge changes in environmental conditions can appear, it is the best choice to build up a calibration routine based on PCO.

6.6 Setting Power Mode

For most sensor shapes and applications maximum Gain and Frequency is not needed. Also for some applications low power consumption is more important than fast conversion and high resolution.
For this purpose it is possible to control the bias and therefore the overall power consumption of the integrated components in register *x03* with 1bit **PWRI**.
While changing PWRI it has to be kept in mind, that frequency and IU-Gain is lowered with bias.
This means that these other calibration registers must be readjusted.

6.7 Configuring Settling Time WaitCOL & WaitROW

Before AD conversion is done, the analog components need time to provide a stable measurement value.
In register *x02* with 12bit **WaitCOL** the column waiting time as multiple of one system cycle is specified. The digital core is waiting this time before AD conversion of the column sensors starts.
In register *x02* with 12bit **WaitROW** the row waiting time as multiple of one system cycle is specified. The digital core is waiting this time at each sensor before AD conversion starts.

For default the values shall be set to 40 for WaitCOL (400µs) and 1 for WaitROW (10µs).
These values are chosen to meet the specified accuracy under all conditions and lead to overall acquisition time of 15ms for 100 sensors.
Under normal conditions and with a SINF>0 the column waiting time can be decreased down to a value of 15 which leads to improved conversion speed.
For applications where a high resolution is not necessary, the waiting times could also be decreased.

6.8 Setting Conversion Mode SARMode

User can chose between single or continuous conversion in register *x01* with 1bit **SARMode**.
If set to 0, a single conversion is done and after that circuit falls into standby mode. This Mode is preferable for update rates higher than 15ms. Wakeup and measurement initialization must be realized by MCU. If set to 1, the circuit is doing continuous runs until bit SARMode is set to 0.
New register values are overwritten at each start of a new conversion.

6.9 Setting Communication Protocol

The protocol for communication between MCU and PE5004 is set in register *x05* with bits **SelectSPI** or **SelectI2C**. This Register must be set as first. For setting of *x05* either I2C or SPI compatible command sequence can be used. Only the corresponding bit to the used protocol is settable.

7 Starting Measurement and Reading Values

To ensure correct communication with the chip, Register x05 and communication protocol must be written at first (e.g.send x05000002 for SPI).
Before starting the first measurement, the calibration registers shall be set according to application requirements (see "0 Configuration*")*.
Register x01 with SARMode and StartSAR must be written at last.

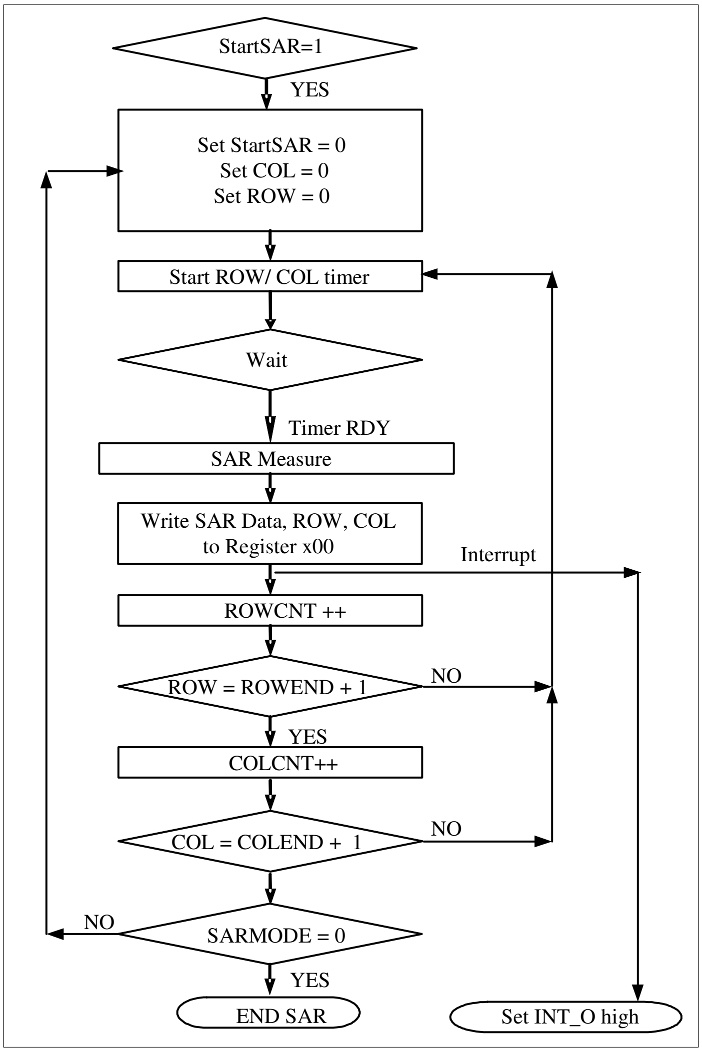


Figure 6 - measurement cycle

The measurement is started by writing register x01 with **StartSAR** set to '1'.

For initialization row, column and StartSAR are internally reset.

After defined wait time, each AD conversion takes 10 system cycles to be completed.

When one conversion is finished, interrupt pin INT_O is set to active high.

The ADC-Value together with the corresponding row and column number of the measured sensor is stored in register x00. The Values are held until the next conversion is finished.

When register x00 is read by MCU, the interrupt pin is reset.

After Sensing of last column and row, depending on SARMode the measurement is repeated (SARMode=1) or the circuit goes to standby until StartSAR is set again (SARMode=0).

The continuous mode can be stopped by sending SARMode = '0'.

8 Power Modes

When connecting to the power supply the internal POR circuit resets the digital core and the PE5004 starts in deep sleep mode (1uA).

After the first “Start conversion” command all analog blocks are enabled and after a startup time of approximately 200µs the conversion has been accomplished.

If a single conversion was started, the chip goes into standby mode after the conversion.
Bandgap and internal clock stay enabled during standby hence reducing the startup time of a following measurement. This consumes max. 300µA of current.

In applications where low power consumption is more important than fast conversion, the chip can be forced into deep sleep. This consumes 1µA of current on cost of a higher startup time before each conversion cycle.
By pulling the VDDA Voltage to ground for minimum 1us, the internal brown out detection will reset all digital blocks and the chip restarts in deep sleep mode.
After deep sleep all configuration registers have to be written again.

The simplest way to implement this in an application is to power the PE5004 out of a microcontroller pin or to control an additional FET switch by the MCU.
(Please refer to the microcontroller manual for checking the driving ability of the MCU IOs. Blocking capacitors on VDDA may increase the needed pull down time.)

9 Register Description

The registers are defined to store various data for sensor function. The main function is to control start and stop the measurement and to transfer measurement date via interrupt to µC. A special function is to store calibration data for a technology parameter specific balancing.
Detailed register definition:

Table 7 - read

Address:	x00																							
SAR_DATA	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	COL				ROW				'0'	'0'	SAR_DATA										'0'	ECOL	EROW	SARMode
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

SARMode reading of Mode for sampling '0'= single step, '1'= continuous sample
EROW reading end marker of ROW
ECOL reading end marker of COL
SAR_DATA reading measured SAR DAC Data
ROW reading ROW number
COL reading COLumn number

Table 8 - read/write

Address:	x01																							
SAR_MODE	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	INT	SL	ST	'0'	COLSTART				ROWSTART				COLEND				ROWEND				'0'	'0'	SARMode	StartSAR
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'1'	'1'	'1'	'1'	'1'	'1'	'1'	'1'	'0'	'0'	'0'	'0'

StartSAR Start of measure procedure will be set to ‘0’ after internal start
SARMode Mode for sampling '0'= single step, '1'= continuous sample
ROWEND calibration for ROW end (for a row < 10, ROW=row-1), (row $\in \mathbb{N}^+$)
COLEND calibration for COL end (for a column < 10, COL=column-1), (column $\in \mathbb{N}^+$)
ROWSTART calibration for ROW start (for a row < rowend, ROW=row-1), (row $\in \mathbb{N}^+$)
COLEND calibration for COL end (for a column < colend, COL=column-1), (column $\in \mathbb{N}^+$)

Table 9 - read/write

Address:	x02																							
WAITCOLROW	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	WaitCOL												WaitROW											
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

WaitROW Wait cycles for ROW with WaitROW x CLK100K
WaitCOL Wait cycles for COL with WaitCOL x CLK100K

Table 10 - read/write

Adresse:	x03																							
GCOSINTRIM	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	SP	'0'	'0'	SINF			SINA						PWRI	'0'	'0'	'0'	'0'	GCO			DACREF			
RESET	'0'	'0'	'0'	'1'	'1'	'1'	'0'	'1'	'1'	'1'	'1'	'1'	'1'	'0'	'0'	'0''	'0'	'0'	'0'	'0'	'1'	'1'	'1'	'1'

PWRI calibration register for IU converter current 1 bit
GCO calibration register for gain amplifier
SINA calibration register for sinus amplitude
SINF calibration register for sinus frequency
DACREF calibration register for analog SAR DAC
SP SIN_PUSH signal to stimulate sinus generator for one SPI/I2C cycle after setting

Table 11 - read/write

Adresse:	x04																							
PCO	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	PCO									
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

PCO calibration register for phase shift module

Table 12 - read/write

Address:	x05																							
SER_MODE	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	SelectI2C	SelectSPI	'0'
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

SelectSPI Defines the SPI interface as selected protocol, this flag is only with SPI module settable, this flag deselect the I2C module
SelectI2C Defines the I2C interface as selected protocol, this flag is only with I2C module settable, this flag deselect the SPI module

10 Serial Interface for µC communication

The serial communication is defined as switch able I2C-Interface with µC fast transfer rates (>= 1MHz) or user defined SPI-Interface (user and µC defined). The design includes an I2C-Interface as multi master interface with project defined static sending format and a software selected SPI-Interface with project defined static sending format. The serial interfaces are defined to start the sensor measurement, calibration purposes (for example white balance, PWR, GCO, DACREF) and reading the sensor results. With every shift data are writing and reading over I2C/SPI from registers. The controller transfers data from/to PC to/from a calibration register, via serial static addressing.
Data shifting to internal registers is synchronized with 100khz clock, when writing multiple registers wait minimum 10us before writing to next register.

The I^2C/SPI registers have the following static structure:

1. reading/writing directions: MSB-first

2. static sending 32 Bit: 8 Bit address
   - Bit 7-0 address - defined in table
   24 Bit data - register width defined

3. Address definition table (Table 13):

Address 7 6 5 4 3 2 1 0	**Function**
S S S 0 0 0 0 0	SAR_DATA Register read only transfer measured data to µC with interrupt
S S S 0 0 0 0 1	SAR_MODE Register to Start and manage Sensor
S S S 0 0 0 1 0	WAITCOLROW time definition between COL and ROW
S S S 0 0 0 1 1	PWRGCOSINDACREF calibration for PWR, GCO, SIN, DACREF
S S S 0 0 1 0 0	Calibration PCO, COLEND, ROWEND
S S S 0 0 1 0 1	Select SPI or I2C
S S S 0 0 1 1 0	RFU

S – for SPI-Protocol and I2C-Protocol select CE3 = Address7, CE2=Address6, CE1=Address5.
CE1, CE2, CE3 are static defined chip enable Pins on PE5004 and must be equal to address definition.

Definition of I^2C protocol

This protocol is implemented as multi master usable slave interface. It has the same function witch is defined in I2C standard with START, STOP condition, I2C address section, R/W, ACK and data. The block diagram shows the general defined function in the sensor.

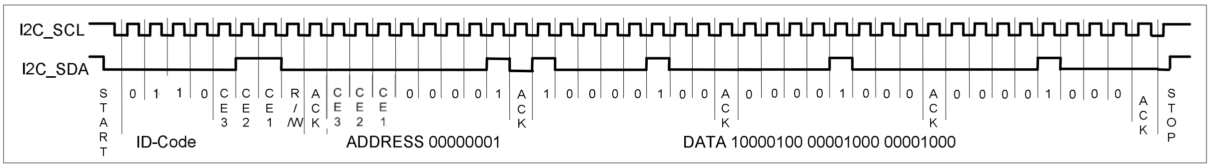


Figure 7 - I2C write cycle with address and data

ID-Code → Bit (6:3) = Customer defined code '0110'; Bit (2:0) = CE3 & CE2 & CE1
R/nW → Read and not write ('1'→read,'0'→write)
ADDRESS → Register address 8 bit (including CE address, see SPI)
DATA → Register data 3 x 8 bit = 24 bit

With this mode it is possible to write 24 bit to address register in sensor.

To set a static address it is possible to write only the address (ID-Code):

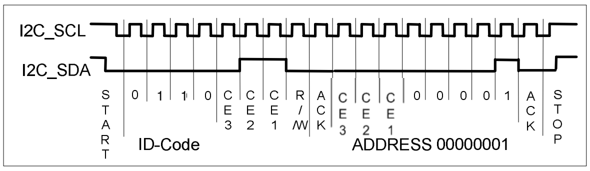


Figure 8 - I2C write address only

Another mode is used to read the information from addressed registers. This mode has two predefined functions. The first function is to write the address off register and start reading with included START-sequence to read the register. The second function is to read data direct from actual address, this is possible for static address (read measure results after interrupt):

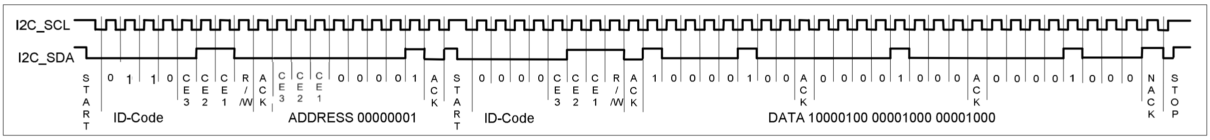


Figure 9 - I2C predicted read modus with included second start sequence

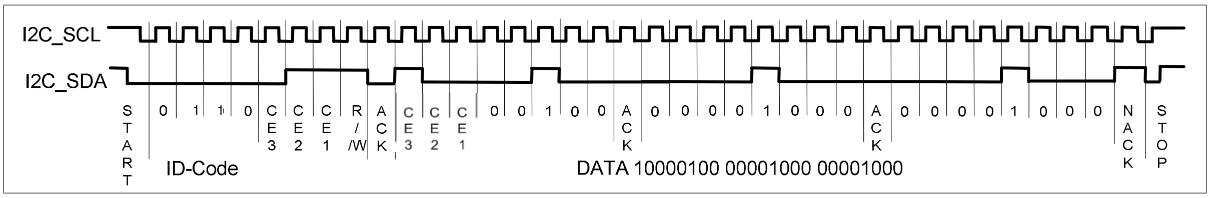


Figure 10 - I2C read modus for predefined static address (defined in write address only)

Block diagram SPI protocol

With user defined sequence on start of µC it is possible to select the SPI-protocol on sensor. This protocol defines a user defined serial interface with n x 7 sensors on n SPI-interfaces on µC with a higher clock rate. In this mode it is possible to read the actual data from register and write (if the register is writeable) the new data to register.

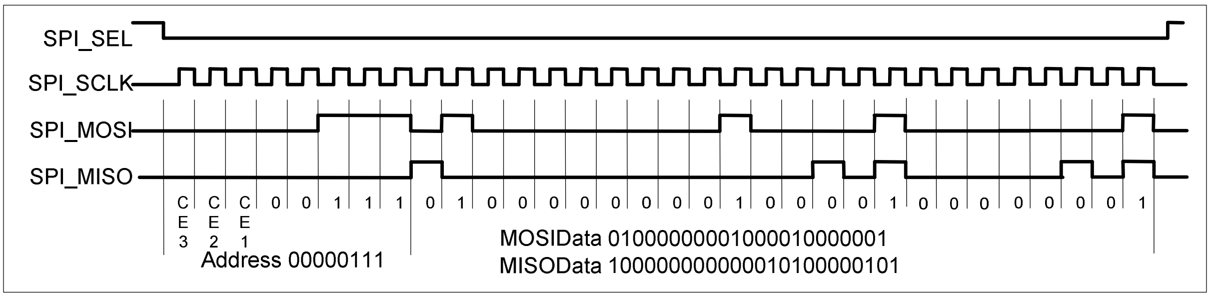


Figure 11 - SPI read/write cycle with address and data

Table 14 - Pin description of communication interface

Interface	I/O	Function	Comment
µC	SPI_SEL	SPI select	
µC	I2C_SCL / SPI_SCLK	I2C clock / SPI clock	
µC	I2C_SDA / SPI_MOSI	I2C serial data inout / SPI serial data input MOSI	Inout for I2C, Input for SPI
µC	SPI_MISO	SPI serial data output MISO	
µC	INT	Interrupt	Interrupt for µC
static	CE1	Address pre definition	Static defined Chip Enable Pin
static	CE2	Address pre definition	Static defined Chip Enable Pin
static	CE3	Address pre definition	Static defined Chip Enable Pin

Attention: The CE3:1 has a defined address room from 0 to 6, the address 7 is reserved for debug functions and can’t be used for normal function.

11 Contact

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