SERMA
PRODUCTIVITY ENGINEERING

Datasheet

PE5010

Table of Content

1 Revision History

Version	Date	Changes	Page
Initial Version V1.0	09/2010		
Version 1.1	10/2010	Important notice for measure results	9
Version 2.0	10/2011	- deleted notice on measure results - updated general description - added description of differential mode - added description of single ended mode - added detailed register description - changed measurement sequence - added offset cancelation routine	9 11 12 13 14-17 18 19

2 Introduction

PE5010 is a capacitive to digital converter (CDC) with an integrated SPI slave.
Main features are:

- 12Bit sigma delta converter
- two channels
- each channel has the possibility for differential or singled-ended measurements
- Implemented calibration routine for both channels
- Internal offset capacitance
- SPI slave
- Low conversation time
- possibility for external excitation frequency input
- TSSOP16 package

3 PE5010 Overview

The PE5010 is an integrated circuit for sensor signal conditioning for capacitive sensors.
The circuit offers two channels, both supporting single-ended or differential measurement mode.
The PE5010 has to be used in connection with a micro controller, to provide data storage or data conditioning.
It contains the following main functional blocks:

- 12Bit Sigma-Delta converter
- Internal adjustable capacitance
- Control unit for Sigma-Delta converter and SPI
- SPI for external communication

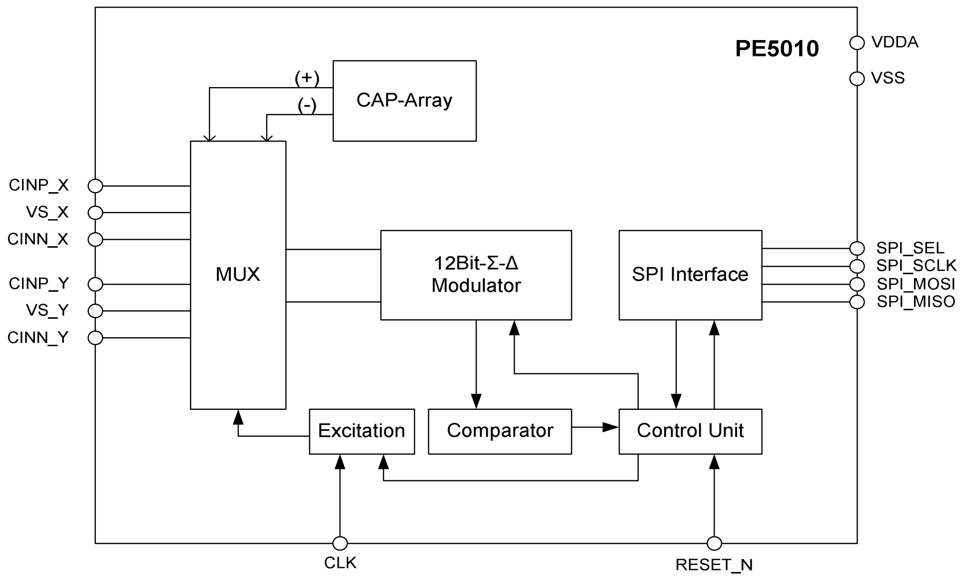

Figure 1 – PE5010 block diagram

4 Typical Application

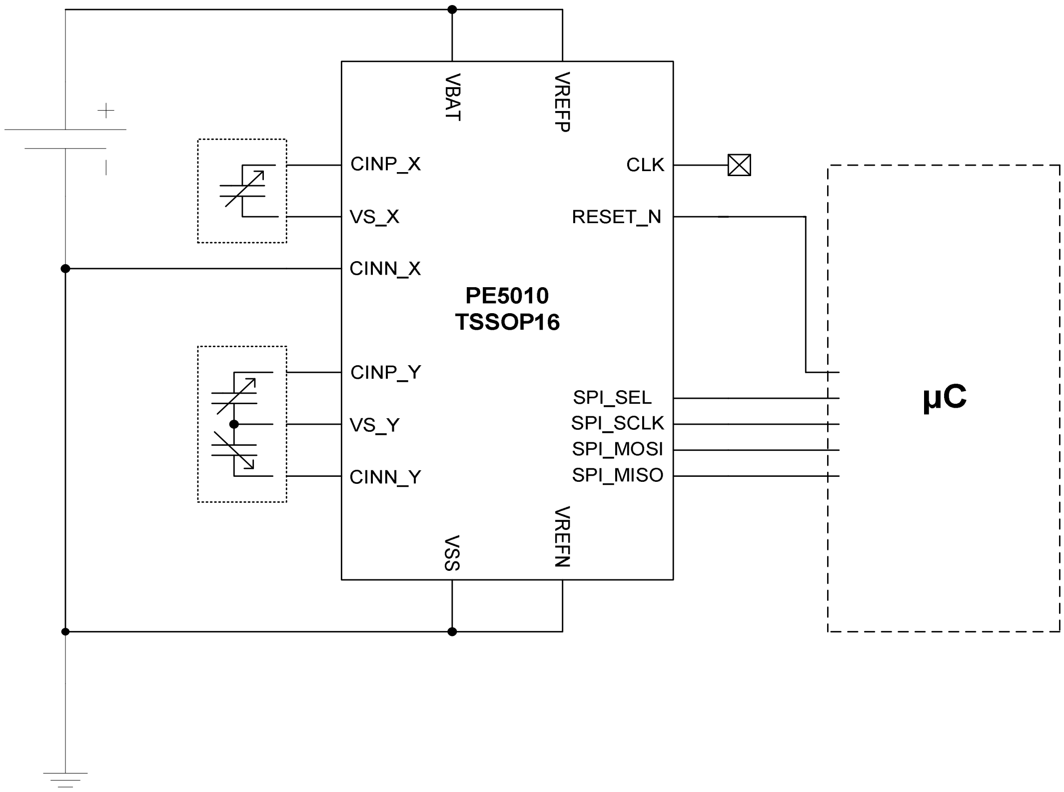

Figure 2 – Schematic of a typical application circuit

5 Pin Assignment / Package

The PE5010 is housed in a TSSOP16 package.

Table 1 – Pin assignment

TSSOP16 Pin No.	Pin Name	I/O	Function
1	CINP_Y	analogue	Positive Input Channel Y
2	VS_Y	analogue	Virtual ground Channel Y
3	CINN_Y	analogue	Negative Input Channel Y
4	CINP_X	analogue	Positive Input Channel X
5	VS_X	analogue	Virtual ground Channel X
6	CINN_X	analogue	Negative Input Channel X
7	SPI_SCLK	input (PD)	SPI clock signal
8	VDDA	analogue	Battery (+)
9	SPI_MOSI	input (PD)	SPI receiving data
10	SPI_MISO	output	SPI sending data
11	SPI_SEL	input (PD)	SPI select signal
12	GNDA	analogue	Battery (-)
13	VREFP	analogue	Positive reference voltage for CDC
14	CLK	inout(PD)	External clock
15	RESET_N	input (PD)	CDC Reset signal
16	VREFN	analogue	Negative reference voltage for CDC

PU = Pull Up, PD = Pull Down, OD = Open Drain

5.1 TSSOP16 Package Dimensions

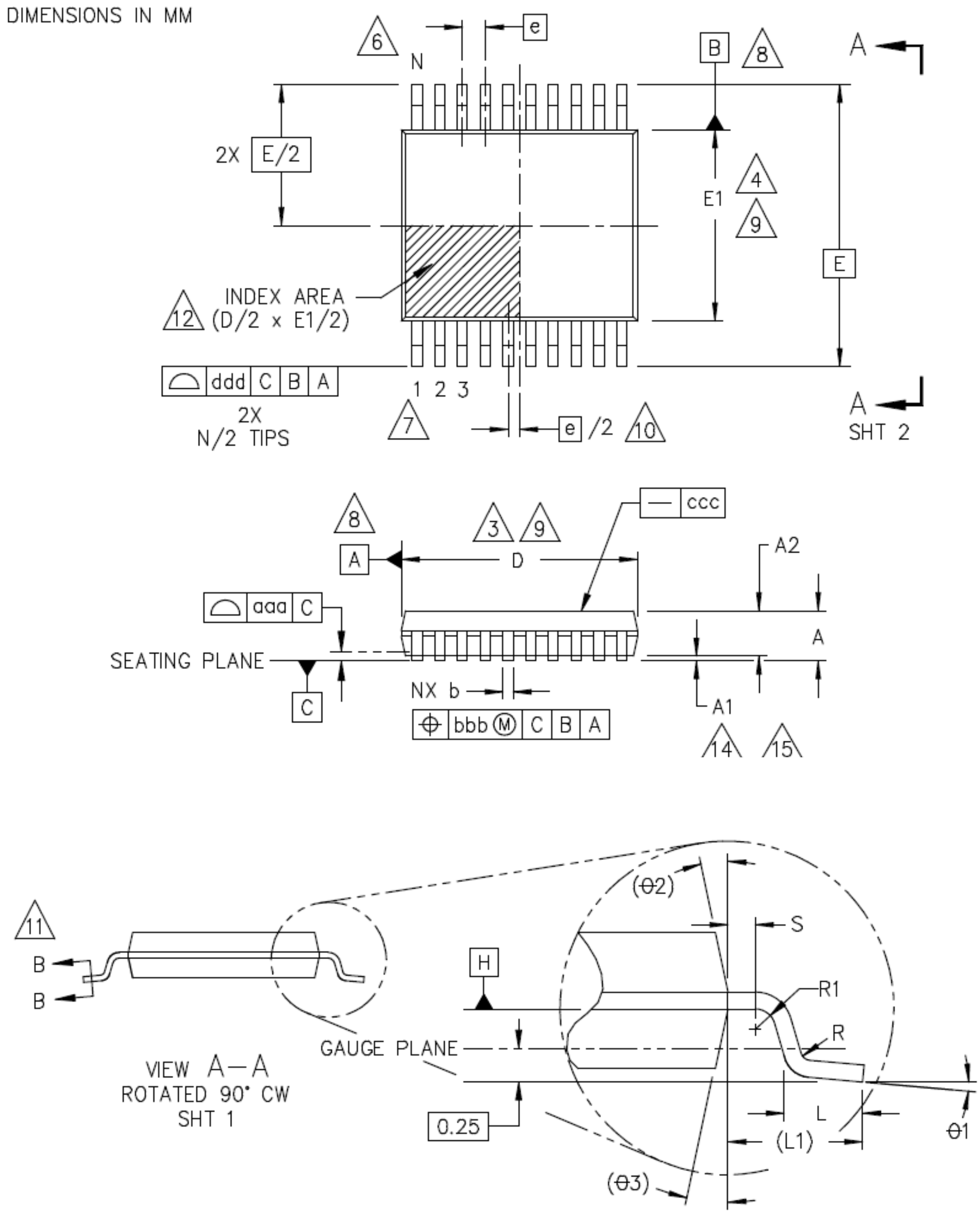

Figure 3 – TSSOP16 package dimensions

Table 2 – TSSOP16 package dimensions

SYMBOL	COMMON DIMENSIONS (Millimetres)		
	MIN	NOM	MAX
A	-	-	1,20
A1	0.05	-	0.15
A2	0.80	1.00	1.00
D	4.90	5.00	5.10
N		16	
b	0.19	-	0.30
b1	0.19	0.22	0.25
c	0.09	-	0.20
c1	0.09	-	0.16
E	6.40 BSC		
E1	4.30	4.40	4.50
e	0.65 BSC		
L	0.45	0.60	0.75
L1	1.00 REF		
R	0.09	-	-
R1	0.09	-	-
S	0.20	-	-
Θ1	0°	-	8°
Θ2	12 REF		
Θ3	12 REF		
SYMBOL	**TOLERANCES OF FORM AND POSITION**		
aaa	0.10		
bbb	0.10		
ccc	0.05		
ddd	0.20		
REF	11-360		
ISSUE	A		

6 Electrical Parameters

6.1 Absolute Maximum Ratings

Table 3 – Absolute maximum ratings

Parameter	Symbol	Min	Typ	Max	Unit
Junction-Temperature	T_{chip}	-40		120	°C
Input voltage	V_{in}	-0.3		V_{bat}+0.7	V
Output voltage	V_{out}	-0.3		V_{bat}+0.7	V
Battery voltage	V_{bat}	-0.3		3.6	V
Operating voltage	V_{dd}	-0.3		V_{bat}+0.7	V

Stress exceeding maximum ratings may damage the device. Maximum ratings are stress ratings only. Functional operation above the recommended operating conditions is not implied. Extended exposure to stress above the recommended operating conditions may affect device reliability.

6.2 Typical Operating Conditions

Table 4 – Typical operating conditions

Parameter	Symbol	Min	Typ	Max	Unit	Comment
Operating temperature	T_{amb}	-40	27	85	°C	
Operating voltage	V_{BAT}	3,0	3,3	3,6	V	
Current consumption	I_0		<100		nA	Power down
	I_{DD}		100		uA	Measure cycle[1)]
Clock frequency	f_{clk}	0,6	1	1,4	MHz	5bit trim able
Conversion time per channel	t_{conv}		4,1		ms	for f_{clk} = 1MHz
Capacitive Input Range	C_{in}	-2		+2	pF	differential mode
	C_{in}	-4		+4	pF	single-ended mode
Accuracy			1		fF	differential mode
			2		fF	single-ended mode
Offset Capacitance	C_0	11	12,6		pF	6Bit
Resolution Offset Capacitance	ΔC_0	175	200		fF	

[1)] … measurement both channels in 100ms

6.3 Characteristics

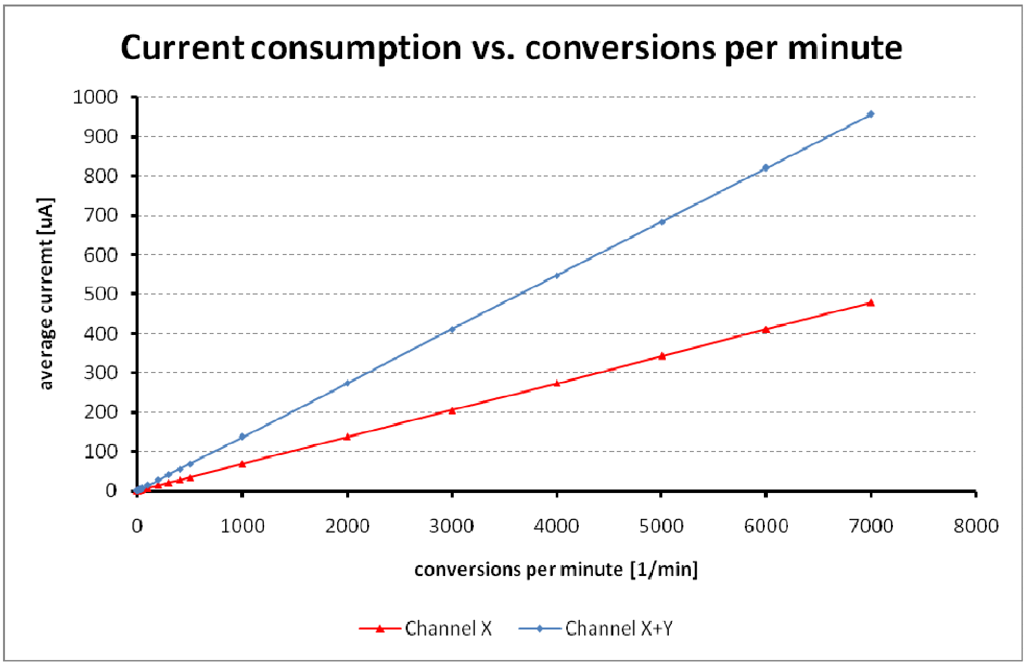

Figure 4 - Current consumption vs. conversions per minute

7 Functional Description

7.1 General

The PE5010 is a 12-bit sigma-delta capacitive-to-digital converter (CDC) with SPI. The capacitance to be measured is connected directly to the inputs of the PE5010. There are two channels on the device. Both are capable to accomplish single-ended or differential measurements.

The PE5010 can detect capacitance changes from single-ended capacitors in a range of ±4pF with a resolution of 2fF. Changes in differential sensors can be detected in a range of ±2pF with a resolution of 1fF. The basic capacitance, especially for single-ended mode, can be balanced in a range of ±12pF with internal adjustable capacitances. The offset calibration has to be done by a microcontroller. An example algorithm can be found in this document.

The PE5010 can be calibrated automatically. The actual measurement value is detected and set as a reference. Different SPI commands allow to access and manipulate all functions of the circuit.

All results have to be evaluated simultaneously as there is no possibility for internal storage.

The IC contains an integrated trimable RC clock generator. An external clock can be used optionally through the clk PIN. This way the conversion speed and current consumption can be adjusted.

7.2 Differential Mode

The 5010 is designed to detect relative changes in capacitance. Deflecting the sensor from equilibrium will lead to a change of the measurement result proportional to the capacitive change. The maximum detectable change is 2pF in both directions. The maximum absolute capacitance per differential pair shall not exceed 20pF. If one needs to measure larger sensors this is possible in some cases with additional external elements, for detailed information please contact our support.

As a complete symmetric sensor is practically not achievable in most cases due to sensor mismatch, routing, parasitic capacitances, the PE5010 has the possibility to compensate internally in both directions. The internal capacitance is stimulated in an inverted mode to the external sensors and therefore subtracted from the external capacitance. This leads to a lower absolute value without changing sensitivity. When using a large sensor capacitance it is preferable to lower both sides of the differential sensors by increasing the internal capacitance to ensure the specified conversion time.

As the PE5010 detects relative changes it is additionally necessary to set a reference value (calibration constant) for initial condition. For standard measurements this constant shall be set to 0x0800 - that is half of the conversion range. Conducting a conversion with a complete symmetric capacitive sensor in equilibrium then will lead to a 0x0800 or 2048 as measurement result.

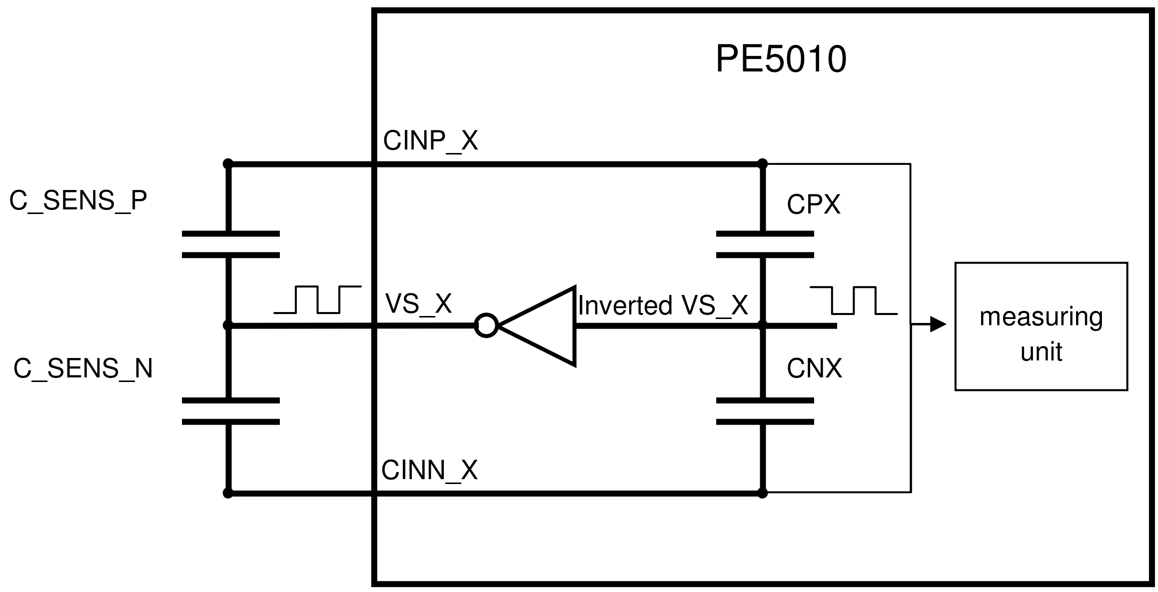

Figure 5 – Offset cancelation unit in differential mode

7.3 Single Ended Mode

The single ended mode works on the same principle like the differential mode but leaves the DIFF_SENS_N capacitance static. The measure unit is disconnected internally from the CINN_X pin while remaining connected to CINP_X and the offset cancelation network. The static part of this pseudo differential sensor is formed by the cancelation network.

Depending on the direction of change the initial measurement value can be shifted to 4096 (for detecting decreasing sensor values, low CNX), set to middle (for detecting both directions, CNX equal to sensor) or set near 0 (for detecting increasing sensor values, high CNX).

Depending on the sensor capacitance and direction of change the internal capacitances (12pF) may not be sufficient. In this case the differential mode has to be used with a static compensation capacitance between VS_X and CINN_X.

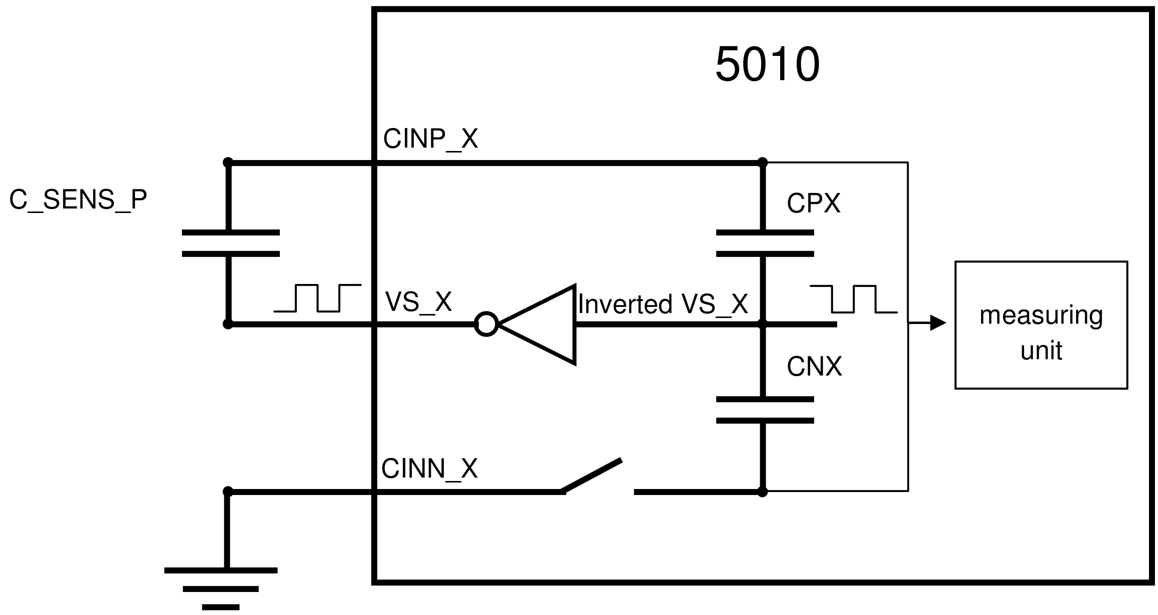

Figure 6 – Offset cancelation unit in single ended mode

8 User Interface

8.1 Register Overview

Table 5 - SPI addresses

Addr. [7:0]	Register	Bits	Description
01h	CDC Activation	SPI[0]: EN	Enable CDC
02h	StartChannelX	SPI[0]: StartX	Start measurement on channel X
03h	StartChannelY	SPI[0]: StartY	Start measurement on channel X
04h	CalibStartX	SPI[0]: CalibX	Sets calibration constant channel X automatically (not recommended)
05h	CalibStartY	SPI[0]: CalibY	Sets calibration constant channel Y automatically (not recommended)
10h	CalibConstX	SPI[11:0]: CalibConstX	Reference value for equilibrium channel X (shall be set to x0800)
11h	CalibConstY	SPI[11:0]: CalibConstY	Reference value for equilibrium channel Y (shall be set to x0800)
12h	CPNX	SPI[15] : DIFFENX SPI[14:8] : CPX SPI[6:0] : CNX	Offset cancelation control register channel X
13h	CPNY	SPI[15] : DIFFENY SPI[14:8] : CPY SPI[6:0] : CNY	Offset cancelation control register channel Y
14h	Clk1MTrim	SPI[15] : EnPad SPI[4:0] : FTRIM	Clock control register
80h	ReadChannelX	SPI[11:0]: DataX	Conversion result channel X
81h	ReadChannelY	SPI[11:0]: DataY	Conversion result channel Y

8.2 Register Description

Reg01h: write (CDC Activation)

Adress:	0x01															
SER_MODE	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'	EN
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

EN : '0' Disable CDC / 1 Enable CDC

Reg02h: read/write (StartChannelX)

Adress:	0x02															
SER_MODE	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'	StartX
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

StartX : '1' starts conversion on channel X

The output is mapped to register 0x80, the data of the previous conversion on channel X will be send back when register has been written

Reg03h: read/write (StartChannelY)

Adress:	0x03															
SER_MODE	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'	StartY
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

StartY : '1' starts conversion on channel Y

The output is mapped to register 0x81, the data of the previous conversion on channel Y will be send back when register has been written

Reg04h: write (CalibStartX)

Adress:	0x04															
SER_MODE	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'	CalibX
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

CalibX : '1' starts measurement and sets internal calibration constant (see. Reg10h) to actual measured sensor value (not recommended for standard conversion) -> following measurement will result in x0800

Reg05h: write (CalibStartY)

Adress:	0x05															
SER_MODE	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'	CalibY
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

CalibY : '1' starts measurement and sets internal calibration constant (see. Reg11h) to actual measured sensor value (not recommended for standard conversion) -> following measurement will result in x0800

Reg10h: read/write (CalibConstX)

Adress:	0x10															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	CalibConstX											
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

CalibConstX <11:0>: defines reference for measured value, shall be set to x0800 for standard measurement as changing will cut the sensing range

Reg11h: read/write (CalibConstX)

Adress:	0x11															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	CalibConstY											
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

CalibConstY <11:0>: defines reference for measured value, shall be set to x0800 for standard measurement as changing will cut the sensing range

Reg12h: read/write (CPNX)

Adress:	0x12															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	DiffEnX	EnCPX	CPX						'0'	EnCNX	CNX					
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

DiffEnX : Enables differential mode (see 0) channel X
EnCPX : Enables positive offset cancelation network for channel X
CPX : trim register for positive offset cancelation network channel X (6bit 0...12pF, decreases C_SENS_P)
EnCNX : Enables negative offset cancelation network for channel X
CNX : trim register for negative offset cancelation network channel X (6bit 0...12pF, decreases C_SENS_N)

Reg13h: read/write (CPNY)

Adress:	0x13															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	DiffEnY	EnCPY	CPY						'0'	EnCNY	CNY					
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

DiffEnY : Enables differential mode (see 0) channel Y
EnCPY : Enables positive offset cancelation network for channel Y
CPY : trim register for positive offset cancelation network channel Y
(6bit 0...12pF, decreases C_SENS_P)
EnCNY : Enables negative offset cancelation network for channel Y
CNY : trim register for negative offset cancelation network channel Y
(6bit 0...12pF, decreases C_SENS_N)

Reg14h: read/write (Clk1MTrim)

Adress:	0x14															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	EnPad	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	FTRIM				
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

EnPad : '1' disables clock generator and uses external clock at Pin 14 as input
(0...VDDA, 2pf pad load)
FTRIM : frequency trim register for internal clock generator 5bit 0.6…1.4Mhz;
set to 0x0e for 1Mhz default

Reg80h: read (ReadChannelX)

Adress:	0x80															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	DataX											
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

DataX <11:0>: measurement result for channel X is stored here until next conversion

Reg81h: read (ReadChannelY)

Adress:	0x81															
SER_MODE	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EN	'0'	'0'	'0'	'0'	DataY											
RESET	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'	'0'

DataY <11:0>: measurement result for channel Y is stored here until next conversion

9 Measurement Sequence

The following sequences describe conditions for X channel but are also valid for the Y channel.

Set pin RESET_N to high for all following sequences.

If there is no supply voltage or RESET_N is low, all data in the PE5010 will be lost (calibration constant, trim values, measurement data).

Note: The conversion time is depending on the clock frequency.

After enabling the CDC it is necessary to wait for the start up time of approximately 100µs.
All registers are zero after reset. Calibration constant, clock trim register and offset compensation has to be configured after every reset.

There is no ready flag that indicates the end of a conversion. There are different possibilities of firmware implementation:

1. The user has to wait for 4100 clock cycles after starting measurement (SPI_SEL goes high). The internal frequency can be measured on PIN VS_X or VS_X as they are stimulated with the internal clock. For a typical measurement at 1 Mhz, 5ms delay will provide enough safety margin.

2. The StartChannel register can be polled with 0x001, a change in capacitance will result in a change of the register output and the CDC will be started again.

3. The PE5010 is reset before every measurement and the ReadChannelX register is polled for a value other than zero (needs new configuration for each measurement)

Table 6 – typical differential measurement on calibration channel X

Step	Address	Data [15:0]	Description
1	0x01	0x0001	Enable CDC
2			Wait for 100us
3	0x14	0x000e	Set clock to 1Mhz
4	0x10	0x0800	Set Calibration constant to 1MSB
5	0x12	0xC040	enable Differential Mode and Offsetcompensation (CPX/ CNX = 0, configure according to the sensor requirements)
6	0x02	0x0001	Start measurement channel X
7			Wait 5ms
8	0x80	0x0000	Read Sensor Data

10 Offset Calibration Sequence

For determining the offset calibration capacitance in equilibrium the calibration constant must be set to 0x0800. Then an initial measurement is performed. If the measured value is larger than 0x0800, the sensor has a positive offset that is cancelled by increasing CPX. If the measured value is smaller than 0x0800, CNX has to be increased.

If you use sensors with large self capacitance (> 12pF) sensing performance can be enhanced by setting both CPX and CNX to maximum (lowers overall capacitance). If the measuring result is larger than 0x0800 decrease CNX, otherwise decrease CPX.

The following example c-code shows an automatic offset cancelation routine:

```
int16_t  data, data_old;
uint16_t i, TrimValue;

// CDC enable
spi_transmit(0x01, 0x0001);
_delay_ms(1);
// 1MHZ OSC
spi_transmit(0x14, 0x000e);
// default settings channel x
spi_transmit(0x10, 0x0800);
spi_transmit(0x12, 0xC040);
// start measurement
spi_transmit(0x02, 0x0000);
_delay_ms(5);
// get measurement results
data_old=spi_transmit(0x80, 0x0000);
//configure for positive offset
if (data_old>2048){
    for (i=1;i<64;i++){

        // set trim value, start and get results
        TrimValue=0xC040+(i<<8);
        spi_transmit(0x12, TrimValue);
        spi_transmit(0x02, 0x0000);
        _delay_ms(5);
        data=spi_transmit(0x80, 0x0000);

        //break if previous measurement result is closer to 0x0800 than actual
        if ((data_old-2048) < (2048-data)) {i--;break;}
        data_old=data;
    }
    //use TrimValue with the measurement result closest to 0x0800
    TrimValue=0xC040+(i<<8);
    spi_transmit(0x12, TrimValue);
}
//configure for negative offset
else {
    for (i=1;i<64;i++){

        // set trim value, start and get results
        TrimValue=0xC040+i;
        spi_transmit(0x12, TrimValue);
        spi_transmit(0x02, 0x0000);
```

```
        _delay_ms(5);
        data=spi_transmit(0x80, 0x0000);

        //break if previous measurement result is closer to 0x0800 than actual
        if ((data_old-2048) > (2048-data)) {i--;break;}
        data_old=data;

    }
    //use TrimValue with the measurement result closest to 0x0800
    TrimValue=0xC040+i;
    spi_transmit(0x12, TrimValue);
}
```

11 Serial Interface

The register of the PE5010 can be accessed through a standard serial interface with SPI protocol. Clock frequency for this interface is limited to 1MHz. Transmission of address and data is executed with MSB first. When the data word is shorter than 16 bit the leading bits will have to be filled with '0'.

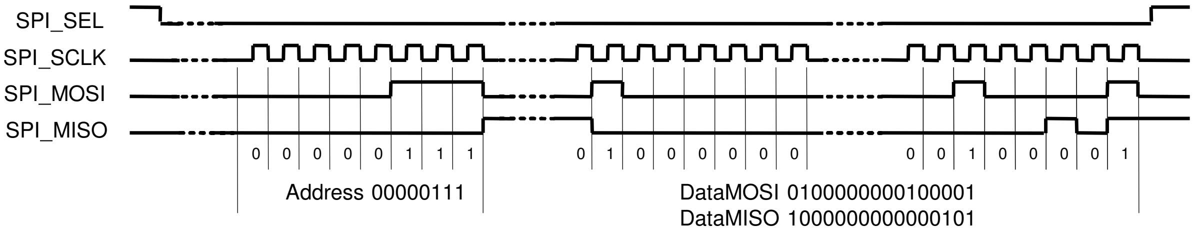

Figure 5 – SPI scheme

SPI_SEL	Activate SPI Transfer (low active, pull down input)
SPI_SCLK	SPI-Clock (pull down input)
SPI_MOSI	Serial Data Input (pull down input)
SPI_MISO	Serial Data Output

All input pins of the interface have pull down resistors. If no idle current into the pins is wanted, the pins must be set to high z or tied to ground.The SPI_SEL is low active, as in most SPI standards, and defines begin and end of a data transfer (frame: address8, data16).

The data input (MOSI) will be latched with the rising clock edge into the chip. The data output (MISO) can be read by a µC while the clock line is high.

It is important to have a low clock line when SPI_SEL will be switched to low – otherwise a rising clock pulse will be generated at this transition.

List of abbreviations

Σ-Δ	Sigma-Delta
µC	Microcontroller
ADC	Analogue to digital converter
ADDR	Address
CalibConstX	Calibration constant for X-sensor
CalibConstY	Calibration constant for Y-sensor
CalibConst	Calibration constant
CDC	Capacitive-to-Digital Converter
CLK1MTRIM	Trim data for 1MHz clock
CNENX	Enable negative capacity on X-sensor
CNENY	Enable negative capacity on Y-sensor
CNX	Data of negative capacity for X-sensor
CNY	Data of negative capacity for Y-sensor
CP	positive capacity register
CN	negative capacity register
CPENX	Enable positive capacity on X-sensor
CPENY	Enable positive capacity on Y-sensor
CPX	Data of positive capacity for X-sensor
CPY	Data of positive capacity for Y-sensor
DIFF_ENX	Differential enable for X-sensor
DIFF_ENY	Differential enable for Y-sensor
RFU	Reserved for future use
SPI	Serial programmable interface
SPI_MISO	SPI master in slave out
SPI_MOSI	SPI master out slave in
SPI_SCLK	SPI system clock
SPI_SEL	SPI select

12 Contact

Germany

Stuttgart

Productivity Engineering
Process Integration GmbH
Behringstrasse 7
D-71083 Herrenberg
Germany
Phone.: +49 (0) 70322798 0
Fax: +49 (0) 70322798 29
Email: info@pe-gmbh.com
Web: www.pe-gmbh.com

Dresden

Productivity Engineering GmbH
Branch
Sachsenallee 9
D-01723 Kesselsdorf
Germany
Phone.: +49 (0) 35204777 00
Fax: +49 (0) 35204777 000
Email: info@pe-gmbh.com