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Low Power, Capacitive Button Touch and Proximity Controller (8 sensors) with LED Drivers and Analog Output

GENERAL DESCRIPTION

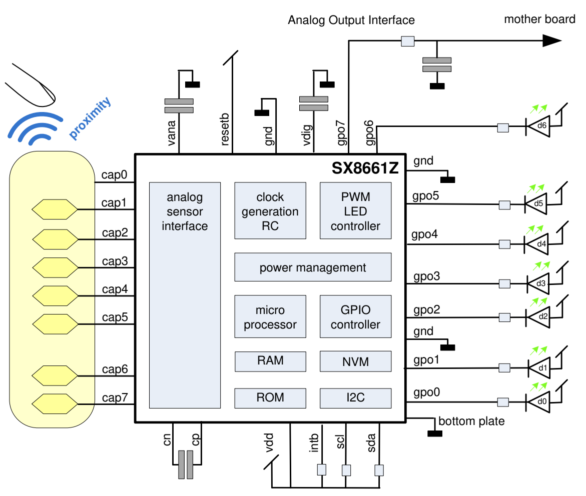
The SX8661Z is an ultra low power, fully integrated 8-channel solution for capacitive touch-button and proximity detection applications. Unlike many capacitive touch solutions, the SX8661Z features dedicated capacitive sense inputs (that requires no external components) in addition to 8 general purpose I/O ports (GPIO). Each of the 8 on-chip GPIO/LED driver is equipped with independent PWM source for enhanced visual effect such as dimming, and breathing.

The SX8661Z includes a capacitive 10 bit ADC analog interface with automatic compensation up to 100pF. The high resolution capacitive sensing supports a wide variety of touch pad sizes and shapes and allows capacitive buttons to be created using thick overlay materials (up to 5mm) for an extremely robust and ESD immune system design.

The SX8661Z incorporates a versatile firmware that was specially designed to simplify capacitive touch solution design and offers reduced time-to-market. Integrated multi-time programmable memory provides the ultimate flexibility to modify key firmware parameters (gain, threshold, scan period, auto offset compensation) in the field without the need for new firmware development.

The SX8661Z supports the 400 kHz I²C serial bus data protocol and includes a field programmable slave address. The tiny 4mm x 4mm footprint makes it an ideal solution for portable, battery powered applications where power and density are at a premium.

TYPICAL APPLICATION CIRCUIT



KEY PRODUCT FEATURES

- Complete 8 Sensors Capacitive Touch-Button Solution
  - Up to 8 LED Drivers for individual Visual Feedback with Auto Lightening
  - Configurable Single or Continuous Fading Mode
  - 256 steps PWM Linear and Logarithmic control
- Proximity Sensing up to several centimetres
- High Resolution Capacitive Sensing
  - Up to 100pF of Offset Cap. Compensation at Full Sensitivity
  - Capable of Sensing up thru 5mm thick Overlay Materials
- Up to 2 Analog Output Interfaces (AOI-A and AOI-B)
  - Enable button detection thru host's ADC
- Support of buzzer for audible feedback
- User-selectable Button Reporting Configuration
  - Report Single or Report Strongest
- Extremely Low Power
  - 8uA (typ) in Sleep Mode
  - 70uA (typ) in Doze Mode (195ms)
  - 200uA (typ) in Active Mode (30ms)
- Programmable Scanning Period from 15ms to several seconds
- Auto Offset Compensation
  - Eliminates false triggers due to environmental factors (temperature, humidity)
  - Initiated on power-up and configurable intervals
- Multi-Time In-Field Programmable Firmware Parameters for Ultimate Flexibility
  - On-chip user programmable memory for fast, self contained start-up
- No External Components per Sensor Input
- Internal Clock Requires No External Components
- Differential Sensor Sampling for Reduced EMI
- Optional 400 KHz I²C Interface with Programmable Address
- -40°C to +85°C Operation

APPLICATIONS

- LCD TVs, Monitors
- White Goods
- Notebook/Netbook/Portable/Handheld computers
- Consumer Products, Instrumentation, Automotive
- Mechanical Button Replacement

ORDERING INFORMATION

Part Number	Temperature Range	Package
SX8661I07ZULTRT[1]	-40°C to +85°C	Lead Free MLPQ-UT28

[1] 3000 Units/reel
* This device is RoHS/WEEE compliant and Halogen Free

Table of Contents

1 General Description

1.1 Pin Diagram

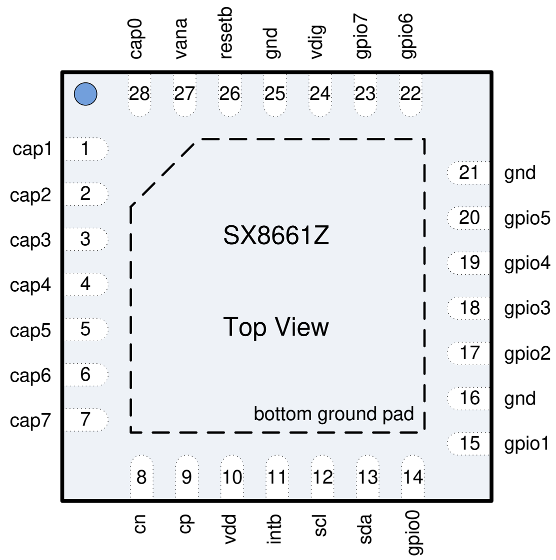
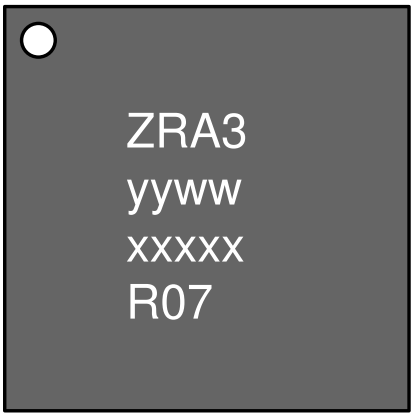


Figure 1 Pinout Diagram

1.2 Marking information



yyww = Date Code
xxxxx = Semtech lot number
R07 = Semtech Code

Figure 2 Marking Information

1.3 Pin Description

Number	Name	Type	Description
1	CAP1	Analog	Capacitive Sensor 1
2	CAP2	Analog	Capacitive Sensor 2
3	CAP3	Analog	Capacitive Sensor 3
4	CAP4	Analog	Capacitive Sensor 4
5	CAP5	Analog	Capacitive Sensor 5
6	CAP6	Analog	Capacitive Sensor 6
7	CAP7	Analog	Capacitive Sensor 7
8	CN	Analog	Integration Capacitor, negative terminal (1nF between CN and CP)
9	CP	Analog	Integration Capacitor, positive terminal (1nF between CN and CP)
10	VDD	Power	Main input power supply
11	INTB	Digital Output	Interrupt, active LOW, requires pull up resistor (in host or external)
12	SCL	Digital Input	I2C Clock, requires pull up resistor (in host or external)
13	SDA	Digital Input/Output	I2C Data, requires pull up resistor (in host or external)
14	GPIO0	Digital Input/Output	General Purpose Input/Output 0
15	GPIO1	Digital Input/Output	General Purpose Input/Output 1
16	GND	Ground	Ground
17	GPIO2	Digital Input/Output	General Purpose Input/Output 2
18	GPIO3	Digital Input/Output	General Purpose Input/Output 3
19	GPIO4	Digital Input/Output	General Purpose Input/Output 4
20	GPIO5	Digital Input/Output	General Purpose Input/Output 5
21	GND	Ground	Ground
22	GPIO6	Digital Input/Output	General Purpose Input/Output 6
23	GPIO7	Digital Input/Output	General Purpose Input/Output 7
24	VDIG	Analog	Digital Core Decoupling, connect to a 100nF decoupling capacitor
25	GND	Ground	Ground
26	RESETB	Digital Input	Active Low Reset. Connect to VDD if not used.
27	VANA	Analog	Analog Core Decoupling, connect to a 100nF decoupling capacitor
28	CAP0	Analog	Capacitive Sensor 0
bottom plate	GND	Ground	Exposed pad connect to ground

Table 1 Pin description

1.4 Simplified Block Diagram

The simplified block diagram of the SX8661Z is illustrated in Figure 3.

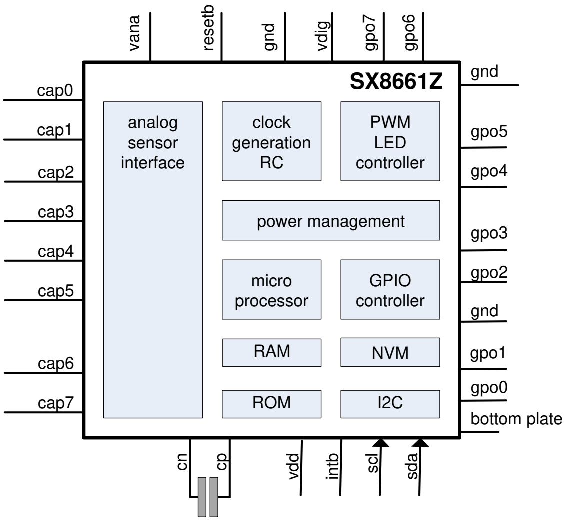


Figure 3 Simplified block diagram of the SX8661Z

1.5 Acronyms

AOI	Analog Output Interface
ASI	Analog Sensor Interface
DCV	Digital Compensation Value
GPO	General Purpose Output
GPP	General Purpose PWM
MTP	Multiple Time Programmable
NVM	Non Volatile Memory
PWM	Pulse Width Modulation
QSM	Quick Start Memory
SPM	Shadow Parameter Memory
SPO	Special Purpose Output

2 Electrical Characteristics

2.1 Absolute Maximum Ratings

Stresses above the values listed in "Absolute Maximum Ratings" may cause permanent damage to the device.

This is a stress rating only and functional operation of the device at these, or any other conditions beyond the "Recommended Operating Conditions", is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Parameter	Symbol	Min.	Max.	Unit
Supply Voltage	VDD	-0.5	3.9	V
Input voltage (non-supply pins)	V_{IN}	-0.5	3.9	V
Input current (non-supply pins)	I_{IN}		10	mA
Operating Junction Temperature	T_{JCT}		125	°C
Reflow temperature	T_{RE}		260	°C
Storage temperature	T_{STOR}	-50	150	°C
ESD HBM (Human Body model)(i)	ESD_{HBM}	3		kV
Latchup(ii)	I_{LU}	± 100		mA

Table 2 Absolute Maximum Ratings

(i) Tested to JEDEC standard JESD22-A114
(ii) Tested to JEDEC standard JESD78

2.2 Recommended Operating Conditions

Parameter	Symbol	Min.	Max.	Unit
Supply Voltage	VDD	2.7	3.6	V
Supply Voltage Drop(iii, iv, v)	VDD_{drop}		100	mV
Supply Voltage for NVM programming	VDD	3.6	3.7	V
Ambient Temperature Range	T_A	-40	85	°C

Table 3 Recommended Operating Conditions

(iii) Performance for 2.6V < VDD < 2.7V might be degraded.

(iv) Operation is not guaranteed below 2.6V. Should VDD briefly drop below this minimum value, then the SX8661Z may require;

- a hardware reset issued by the host using the RESETB pin
- a software reset issued by the host using the I2C interface

(v) In the event the host processor is reset or undergoes a power OFF/ON cycle, it is recommended that the host also resets the SX8661Z and assures that parameters are re-written into the SPM (should these differ to the parameters held in NVM).

2.3 Thermal Characteristics

Parameter	Symbol	Min.	Max.	Unit
Thermal Resistance - Junction to Ambient (vi)	θ_{JA}		25	°C/W

Table 4 Thermal Characteristics

(vi) Static airflow

2.4 Electrical Specifications

All values are valid within the operating conditions unless otherwise specified.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Current consumption						
Active mode, average	$I_{OP,active}$	30ms scan period, 8 sensors enabled, common sensitivity 0 proximity sensing OFF		200	275	uA
Doze mode, average	$I_{OP,Doze}$	195ms scan period, 8 sensors enabled, common sensitivity 0 proximity sensing OFF		70	100	uA
Sleep	$I_{OP,sleep}$	I2C listening, sensors disabled		8	17	uA
Active mode, average (Quick Start application)	$I_{QS,active}$	30ms scan period, 8 sensors enabled, sensitivity 2 for buttons sensitivity 7 for proximity proximity sensing ON		800	1100	uA
Doze mode, average (Quick Start application)	$I_{QS,Doze}$	195ms scan period, 8 sensors enabled, sensitivity 2 for buttons sensitivity 7 for proximity proximity sensing ON		160	220	uA
ResetB, SCL, SDA						
Input logic high	V_{IH}		0.7*VDD		VDD + 0.3	V
Input logic low	V_{IL}	VSS applied to GND pins	VSS - 0.3		0.8	V
Input leakage current	L_I	CMOS input			±1	uA
Pull up resistor	R_{PU}	when enabled		660		kΩ
Pull down resistor	R_{PD}	when enabled		660		kΩ
GPIO set as Output, IntB, SDA						
Output logic high	V_{OH}	I_{OH}<4mA	VDD-0.4			V
Output logic low	V_{OL}	$I_{OL,GPIO}$<12mA $I_{OL,SDA,INTB}$<4mA			0.4	V
Start-up						
Power up time	t_{por}	time between rising edge VDD and rising INTB			275	ms
RESETB						
ResetB pulse width	t_{res}		50			ns

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Recommended External components						
capacitor between VDIG, GND	C_{vdig}	type 0402, tolerance +/-50%		100		nF
capacitor between VANA, GND	C_{vana}	type 0402, tolerance +/-50%		100		nF
capacitor between CP, CN	C_{int}	type 0402, COG, tolerance +/-5%		1		nF
capacitor between VDD, GND	C_{vdd}	type 0402, tolerance +/-50%	270			nF

Table 5 Electrical Specifications

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
I2C Timing Specifications (i)						
SCL clock frequency	f_{SCL}				400	KHz
SCL low period	t_{LOW}		1.3			us
SCL high period	t_{HIGH}		0.6			us
Data setup time	$t_{SU;DAT}$		100			ns
Data hold time	$t_{HD;DAT}$		0			ns
Repeated start setup time	$t_{SU;STA}$		0.6			us
Start condition hold time	$t_{HD;STA}$		0.6			us
Stop condition setup time	$t_{SU;STO}$		0.6			us
Bus free time between stop and start	t_{BUF}		500			us
Input glitch suppression	t_{SP}				50	ns

Table 6 I2C Timing Specification

Notes:
(i) All timing specifications, Figure 4 and Figure 5, refer to voltage levels (V_{IL}, V_{IH}, V_{OL}) defined in Table 5.

The interface complies with slave F/S mode as described by NXP: “I2C-bus specification, Rev. 03 - 19 June 2007”

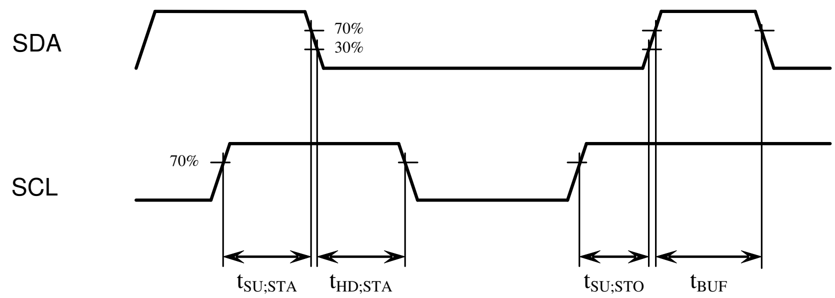


Figure 4 I2C Start and Stop timing

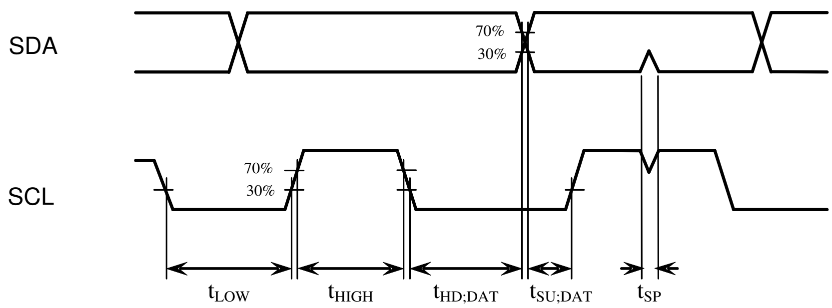


Figure 5 I2C Data timing

3 Functional Description

3.1 Introduction

3.1.1 General

The SX8661Z is intended to be used in applications which require capacitive sensors covered by isolating overlay material and which need to detect the proximity of a finger/hand though the air. A finger approaching the capacitive sensors will change the charge that can be loaded on the sensors. The SX8661Z measures the change of charge and converts that into digital values (ticks). The larger the charge on the sensors, the larger the number of ticks will be. The charge to ticks conversion is done by the SX8661Z Analog Sensor Interface (ASI).
The ticks are further processed by the SX8661Z and converted in a high level, easy to use information for the user's host.
The information between SX8661Z and the user's host is passed through the I2C interface with an additional interrupt signal indicating that the SX8661Z has new information. For buttons this information is simply touched or released. The SX8661Z can operate without the I2C and interrupt by using the analog output interface (GPIO7 and/or GPIO6) which voltage level indicates the button touched or GPO with the autolight function.

3.1.2 GPIOs

Feedback to the user is using General Purpose Input Output (GPIO) pins. The SX8661Z offers up to eight individual configurable GPIO pins. The GPIO can e.g. be set as a LED driver which slowly fade-in when a finger touches a button or proximity is detected and slowly fade-out when the button is released or finger goes out of proximity. Fading intensity variations can be logarithmic or linear. Interval speed and initial and final light intensity can be selected by the user. The fading is done using a 256 step PWM. The SX8661Z has eight individual PWM generators, one for each GPIO pin.
The LED fading-in and fading-out mode is called the GPO (fading) mode.
The LED fading can be initiated automatically by the SX8661Z by setting the SX8661Z autolightening feature. A simple touch on a sensor and the corresponding LED will fade-in without any host interaction over the I2C.
In case the autolightening feature is disabled then the host will decide to start a LED fading-in period, simply by setting the GPO pin to 'high' using one I2C command. The SX8661Z will then slowly fade-in the LED using the PWM autonomously.
In case the host needs to have full control of the LED intensity then the host can set the GPIO in the PWM mode (GPP). The host is then able to set the PWM pulse width freely at the expense of an increased I2C occupation.
The GPIOs can be set further in special purpose output (SPO) for the buzzer or analog output interface.

3.1.3 Analog Output Interface A and B (SPO mode)

The Analog Output Interface (AOI) is a PWM output signal between ground and VDD. The duty cycle of the AOI output will change depending on which button is touched. A host controller can then measure the mean voltage delivered on the AOI output and determine which button is touched at any given time.
The AOI feature allows the SX8661Z device to replace directly legacy mechanical button controllers in a quick and effortless manner. The SX8661Z supports up to two Analog Output Interfaces, AOI-A and AOI-B (on GPIO7 and GPIO6 respectively). The SX8661Z allows buttons to be mapped on either AOI-A or AOI-B. The button mapping as well as the mean voltage level that each button produces on a AOI output can be configured by the user through a set of parameters described in later chapters (see 5.6).

3.1.4 Buzzer (SPO mode)

The SX8661Z can drive a buzzer (on GPIO5) to provide audible feedback on button touches. The buzzer duration is set to approximately 30ms per default (see 5.7).

3.1.5 Parameters

The SX8661Z has many low level built-in, fixed algorithms and procedures. To allow a lot of freedom for the user and adapt the SX8661Z for different applications these algorithms and procedures can be configured with a large set of parameters which will be described in the following sections. Examples of parameters are which sensors are buttons, which GPIO is used for outputs, for the Analog Output Interfaces, the Buzzer or LEDs and which GPIO is mapped to which button.
Sensitivity and detection thresholds of the sensors are part of these parameters. Assuming that overlay material and sensors areas are identical then the sensitivities and thresholds will be the same for each sensor. In case sensors are not of the same size then sensitivities or thresholds might be chosen individually per sensor.
So a smaller size sensor can have a larger sensitivity while a big size sensor may have the lower sensitivity.

3.1.6 Configuration

During a development phase the parameters can be determined and fine tuned by the users and downloaded over the I2C in a dynamic way. The parameter set can be downloaded over the I2C by the host each time the SX8661Z boots up. This allows a flexible way of setting the parameters at the expense of I2C occupation.
In case the parameters are frozen they can be programmed in Multiple Time Programmable (MTP) Non Volatile Memory (NVM) on the SX8661Z. The programming needs to be done once (over the I2C). The SX8661Z will then boot up from the NVM and additional parameters from the host are not required anymore.
In case the host desires to overwrite the boot-up NVM parameters (partly or even complete) this can be done by additional I2C communications.

3.2 Scan Period

The basic operation Scan period of the SX8661Z sensing interface can be split into three periods over time.

In the first period (Sensing) the SX8661Z is sensing all enabled CAP inputs, from CAP0 towards CAP7.

In the second period (Processing) the SX8661Z processes the sensor data, verifies and updates the GPIO and the I2C.

In the third period (Timer) the SX8661Z is set in a low power mode and waits until a new cycle starts.

Figure 6 shows the different SX8661Z periods over time.

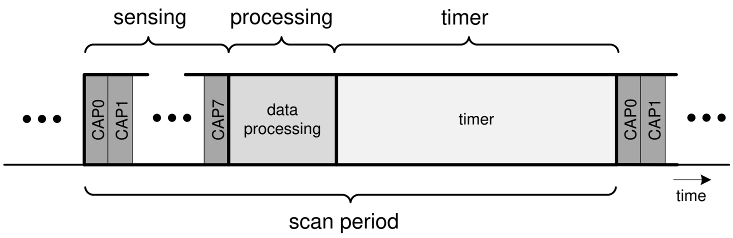


Figure 6 Scan Period

The scan period determines the minimum reaction time of the SX8661Z. The scan period can be configured by the host from 15ms to values larger than a second.
The reaction time is defined as the interval between a touch on the sensor and the moment that the SX8661Z generates the interrupt on the INTB pin. The shorter the scan period the faster the reaction time will be.
Very low power consumptions can be obtained by setting very long scan periods with the expense of having longer reaction times.
All external events like GPIO, I2C and the interrupt are updated in the processing period, so once every scan period.

3.3 Operation modes

The SX8661Z has 3 operation modes. The main difference is found in the reaction time (corresponding to the scan period) and power consumption.

Active mode offers fast scan periods. The typical reaction time is 30ms. All enabled sensors are scanned and information data is processed within this interval.

Doze mode increases the scan period time which increases the reaction time to 195ms typical and at the same time reduces the operating current.

Sleep mode turns the SX8661Z OFF, except for the I2C peripheral, minimizing operating current while maintaining the power supplies. In Sleep mode the SX8661Z does not do any sensor scanning. The Sleep mode will be exited by any I2C access.

The user can specify other scan periods for the Active and Doze mode and decide for other compromises between reaction time and power consumption.

In most applications the reaction time needs to be fast when fingers are present, but can be slow when no person uses the application. In case the SX8661Z is not used for a specific time it will go from Active mode into Doze mode and power will be saved. This time-out is determined by the Passive Timer which can be configured by the user or turned OFF if not required.
To leave Doze mode and enter Active mode this can be done by a simple touch on any button.

The host can decide to force the operating mode by issuing commands over the I2C (using register GpioOpMode) and take fully control of the SX8661Z. The diagram in Figure 7 shows the available operation modes and the possible transitions.

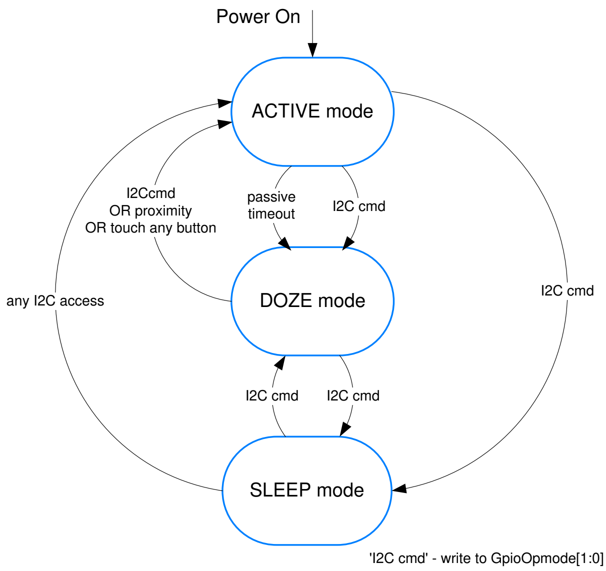


Figure 7 Operation modes

3.4 Sensors on the PCB

The capacitive sensors are relatively simple copper areas on the PCB connected to the eight SX8661Z capacitive sensor input pins (CAP0…CAP7).The sensors are covered by isolating overlay material (typically 1mm...3mm). The area of a sensor is typically one square centimetre which corresponds about to the area of a finger touching the overlay material. The area of a proximity sensor is usually a factor larger as the smaller touch sensors.
The capacitive sensors can be setup as ON/OFF buttons for touch sensing and CAP0 offers additionally proximity sensing (see example Figure 8) for control applications.

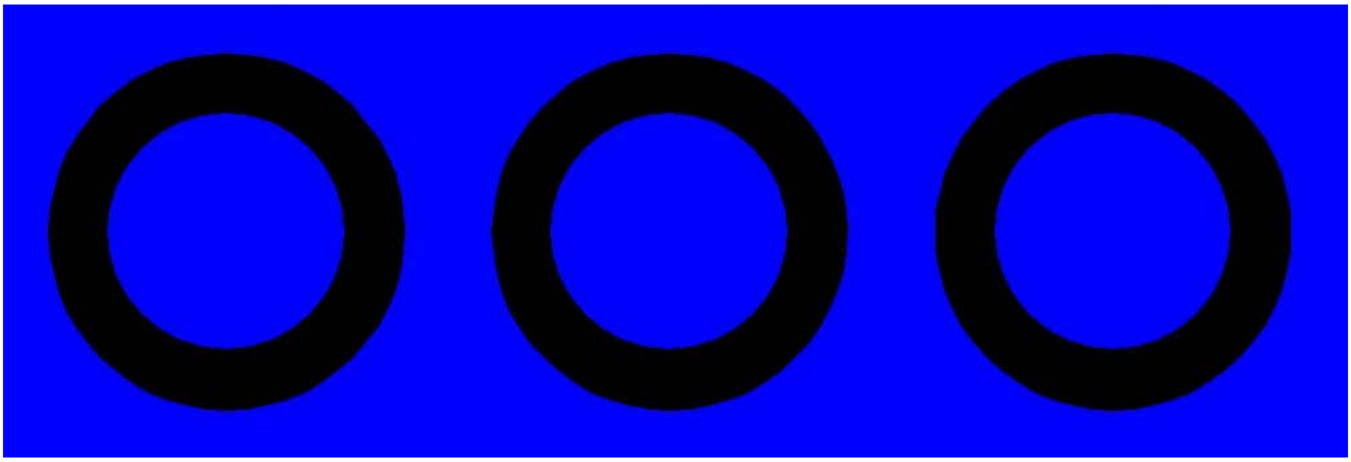


Figure 8 PCB top layer of three touch buttons sensors surrounded by a proximity sensor

Please refer to the layout guidelines application note [1], for more details.

3.5 Button Information

The touch buttons have two simple states (see Figure 9): ON (touched by finger) and OFF (released and no finger press).

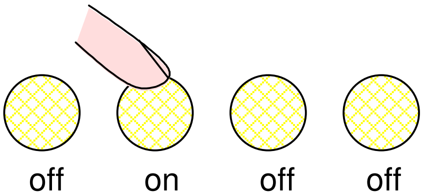


Figure 9 Buttons

A finger is detected as soon as the number of ticks from the ASI reaches a user-defined threshold plus a hysteresis.

A release is detected if the tick from the ASI goes below the threshold minus a hysteresis. The hysteresis around the threshold avoids rapid touch and release signalling during transients.

Buttons can also be used to do proximity sensing. The principle of proximity sensing operation is exactly the same as for touch buttons except that proximity sensing is done several centimeters above the overlay through the air. ON state means that finger/hand is detected by the sensor and OFF state means the finger/hand is far from the sensor and not detected.

3.6 Buzzer

The SX8661Z has the ability to drive a buzzer (on GPIO5) to provide an audible indication that a button has been touched. The buzzer is driven by a square signal for approximately 30ms (default). During the first phase (15ms) the signal's frequency is default 4KHz while in the second phase (15ms) the signal's frequency default is 8KHz.
The buzzer is activated only once during any button touch and is not repeated for long touches. The user can choose to enable or disable the buzzer by configuration and define the idle level, frequencies and phase durations (see 5.7).

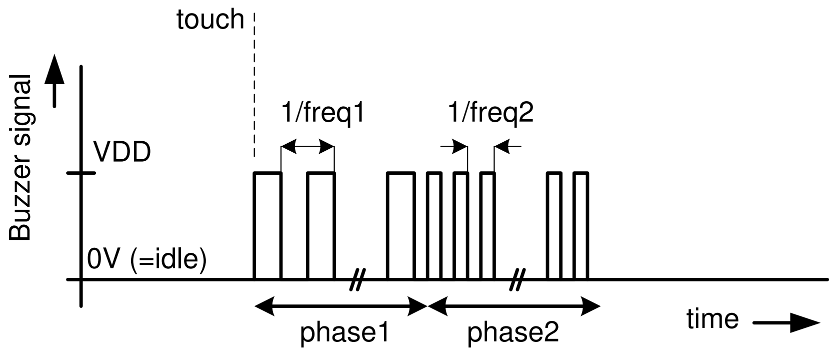


Figure 10 Buzzer behavior

3.7 Analog Output Interface

The Analog Output Interface outputs a PWM signal with a varying duty cycle depending on which button is touched. By filtering (with a simple RC filter) the PWM signal results in a DC voltage, different for each button touch. The host controller measures the DC voltage level and determines which buttons has been touched.

In the case of single button touches, each button produces its own voltage level as configured by the user (see 5.6 and Table 7).
Figure 11 show how the AOI will behave when the user touches and releases different buttons.
The AOI will switch between the AOI idle level and the level for each button.

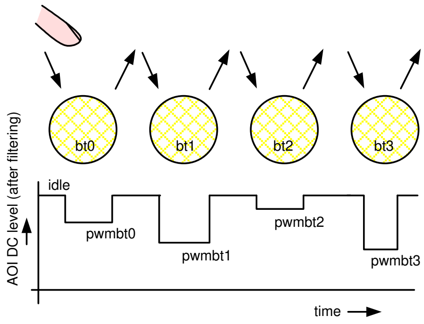


Figure 11 AOI behavior

The PWM blocks used in AOI modes are 8-bits based and clocked at 2MHz typically.
The PWM period can be set to 256 (default) or 64. The 256 period offers a better granularity at a lower frequency, while the 64 period is faster and with fewer steps.
Figure 12 shows the PWM definition of the AOI.

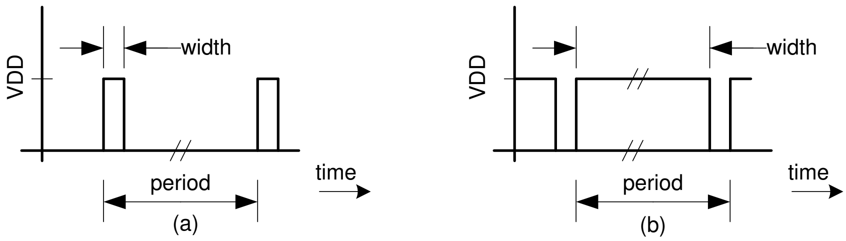


Figure 12 PWM definition, (a) small pulse width, (b) large pulse width

Table 7 describes the AOI level index versus the PWM pulse width. The user can select 256 steps (index) in case the period is set to 255.
In case the period is set to 64 then the index from 0 to 63 applies.

Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width
0	0	**32**	33	**64**	65	**96**	97	**128**	129	**160**	161	**192**	193	**224**	225
1	2	**33**	34	**65**	66	**97**	98	**129**	130	**161**	162	**193**	194	**225**	226
2	3	**34**	35	**66**	67	**98**	99	**130**	131	**162**	163	**194**	195	**226**	227
3	4	**35**	36	**67**	68	**99**	100	**131**	132	**163**	164	**195**	196	**227**	228
4	5	**36**	37	**68**	69	**100**	101	**132**	133	**164**	165	**196**	197	**228**	229
5	6	**37**	38	**69**	70	**101**	102	**133**	134	**165**	166	**197**	198	**229**	230
6	7	**38**	39	**70**	71	**102**	103	**134**	135	**166**	167	**198**	199	**230**	231
7	8	**39**	40	**71**	72	**103**	104	**135**	136	**167**	168	**199**	200	**231**	232
8	9	**40**	41	**72**	73	**104**	105	**136**	137	**168**	169	**200**	201	**232**	233
9	10	**41**	42	**73**	74	**105**	106	**137**	138	**169**	170	**201**	202	**233**	234
10	11	**42**	43	**74**	75	**106**	107	**138**	139	**170**	171	**202**	203	**234**	235
11	12	**43**	44	**75**	76	**107**	108	**139**	140	**171**	172	**203**	204	**235**	236
12	13	**44**	45	**76**	77	**108**	109	**140**	141	**172**	173	**204**	205	**236**	237
13	14	**45**	46	**77**	78	**109**	110	**141**	142	**173**	174	**205**	206	**237**	238
14	15	**46**	47	**78**	79	**110**	111	**142**	143	**174**	175	**206**	207	**238**	239

Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width	Index	Width
15	16	47	48	79	80	111	112	143	144	175	176	207	208	239	240
16	17	48	49	80	81	112	113	144	145	176	177	208	209	240	241
17	18	49	50	81	82	113	114	145	146	177	178	209	210	241	242
18	19	50	51	82	83	114	115	146	147	178	179	210	211	242	243
19	20	51	52	83	84	115	116	147	148	179	180	211	212	243	244
20	21	52	53	84	85	116	117	148	149	180	181	212	213	244	245
21	22	53	54	85	86	117	118	149	150	181	182	213	214	245	246
22	23	54	55	86	87	118	119	150	151	182	183	214	215	246	247
23	24	55	56	87	88	119	120	151	152	183	184	215	216	247	248
24	25	56	57	88	89	120	121	152	153	184	185	216	217	248	249
25	26	57	58	89	90	121	122	153	154	185	186	217	218	249	250
26	27	58	59	90	91	122	123	154	155	186	187	218	219	250	251
27	28	59	60	91	92	123	124	155	156	187	188	219	220	251	252
28	29	60	61	92	93	124	125	156	157	188	189	220	221	252	253
29	30	61	62	93	94	125	126	157	158	189	190	221	222	253	254
30	31	62	63	94	95	126	127	158	159	190	191	222	223	254	255
31	32	63	64	95	96	127	128	159	160	191	192	223	224	255	256

Table 7 AOI Level index vs. PWM pulse width (normal polarity)

The AOI reports always one button. The AOI can be split over two GPIO pins (AOI-A, AOI-B). The AOI-A interface is connected to pin GPIO7 and the AOI-B is connected to pin GPIO6. The user can map any button to either AOI-A or AOI-B or both.
In case buttons are split to both AOI pins, multiple button touches are still resulting in one AOI reporting.

In most applications only one AOI pin will be selected. The two AOI pins allow the user a more coarse detection circuitry at the host. Assuming a 3.3V supply and 8 buttons on one single AOI then the AOI levels could be separated with around 0.3…0.4V. In case of using the two AOI pins, 4 buttons could be mapped on AOI-A separated with around 0.8V (similar for 4 buttons on AOI-B) which step is about the double in case of a single AOI.

In case of a single touch the reported button is straight forward (as in Figure 11).
If more than one button is touched the reported depends on the selected button reporting mode parameter (5.5).
Three reporting modes exist for the SX8661Z (All, Single and Strongest).
The All reporting mode is applicable only for the I2C reporting (AOI is not available). In All-mode all buttons that are touched are reported in the I2C buttons status bits.
In the Single-mode a single touched button will be reported on the AOI and the I2C. All touches that occur afterwards will not be reported as long as the first touch sustains. Only when the first reported button is released will the SX860 report another touch.
Figure 13 shows the Single-mode reporting in case of 2 touches occurring over time.

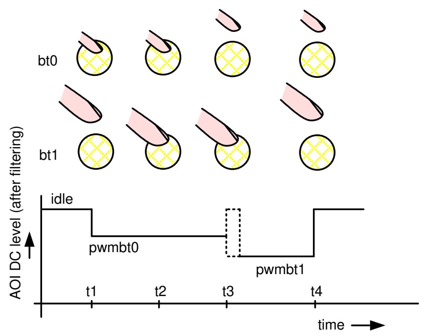


Figure 13 Single-mode reporting with 2 touches

At time t1 button0 is touched and reported on the AOI. At time t2 button1 is touched as well but not reported. At time t3 the button0 is released and button1 will be reported immediately (or after one scan period at idle level).
At time t4 both buttons are released and the AOI reports the idle level.

The button with the lowest Cap pin index will be reported in case of a simultaneous touch (that means touches occurring within the same scan period).

In the Strongest-mode the strongest touched button will be reported on the AOI and the I2C. All touches that occur afterwards representing a weaker touch will not be reported. Only a touch which is stronger will be reported by the SX860.
Figure 14 shows the Strongest-mode reporting in case of 2 touches (with bt1 the strongest touch).

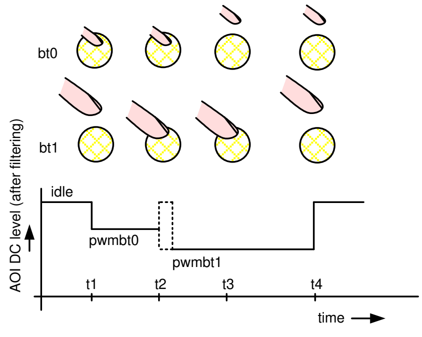


Figure 14 Strongest-mode reporting with 2 touches

At time t1 button0 is touched and reported on the AOI. At time t2 button1 is touched as well. As bt1 is the strongest touch it will be reported on the AOI immediately (or after one scan period at idle level). At time t3 the button0 is released while the AOI continues to report button1. At time t4 both buttons are released and the AOI reports the idle level.

In some special cases (when the buzzer is suspected to load heavily the power supply) the user may choose the AOI to go to 0V, to VDD or to the AOI idle level for the duration the buzzer is active.

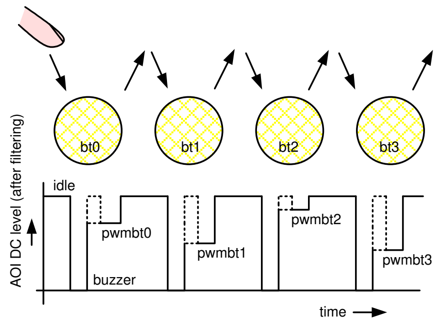


Figure 15 AOI behavior with 0V buzzer state

In Figure 15 the AOI will go to 0V each time the buzzer is active. The AOI returns then to either the idle mode for one scan period or goes immediately to the PWM button level.

In case the SX8661Z is set to sleep mode the AOIs will go to 0V.

3.8 Analog Sensing Interface

The Analog Sensing Interface (ASI) converts the charge on the sensors into ticks which will be further digitally processed. The basic principle of the ASI will be explained in this section.

The ASI consists of a multiplexer selecting the sensor, analog switches, a reference voltage, an ADC sigma delta converter, an offset compensation DAC and an external integration capacitor (see Figure 16).

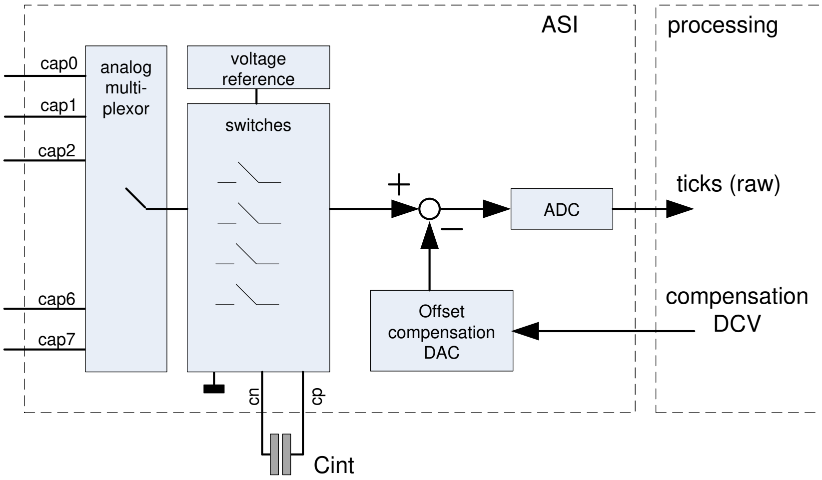


Figure 16 Analog Sensor Interface

To get the ticks representing the charge on a specific sensor the ASI will execute several steps.

The charge on a sensor cap (e.g CAP0) will be accumulated multiple times on the external integration capacitor, Cint.

This results in an increasing voltage on Cint proportional to the capacitance on CAP0.

At this stage the offset compensation DAC is enabled. The compensation DAC generates a voltage proportional to an estimation of the external capacitance. The estimation is obtained by the offset compensation procedure executed e.g. at power-up.

The difference between the DAC output and the charge on Cint is the desired signal. In the ideal case the difference of charge will be converted to zero ticks if no finger is present and the number of ticks becomes high in case a finger is present.

The difference of charge on Cint and the DAC output will be transferred to the ADC (Sigma Delta Integrator).

After the charge transfer to the ADC the steps above will be repeated.

The larger the number the cycles are repeated the larger the signal out of the ADC with improved SNR. The sensitivity is therefore directly related to the number of cycles.

The SX8661Z allows setting the sensitivity for each sensor individually in applications which have a variety of sensors sizes or different overlays or for fine-tuning performances. The optimal sensitivity is depending heavily on the final application. If the sensitivity is too low the ticks will not pass the thresholds and touch/proximity detection will not be possible. In case the sensitivity is set too large, some power will be wasted and false touch/proximity information may be output (i.e. for touch buttons => finger not touching yet, for proximity sensors => finger/hand not close enough).

Once the ASI has finished the first sensor, the ticks are stored and the ASI will start measuring the next sensor until all (enabled) sensors pins have been treated.

In case some sensors are disabled then these result in lower power consumption simply because the ASI is active for a shorter period and the following processing period will be shorter.

The ticks from the ASI will then be handled by the digital processing.

The ASI will shut down and wait until new sensing period will start.

3.9 Offset Compensation

The capacitance at the CAP pins is determined by an intrinsic capacitance of the integrated circuit, the PCB traces, ground coupling and the sensor planes. This capacitance is relatively large and might become easily some tens of pF. This parasitic capacitance will vary only slowly over time due to environmental changes.

A finger touch is in the order of one pF. If the finger approaches the sensor this occurs typically fast.

The ASI has the difficult task to detect and distinguish a small, fast changing capacitance, from a large, slow varying capacitance. This would require a very precise, high resolution ADC and complicated, power consuming, digital processing.

The SX8661Z features a 16 bit DAC which compensates for the large, slow varying capacitance already in front of the ADC. In other words the ADC converts only the desired small signal. In the ideal world the ADC will put out zero ticks even if the external capacitance is as high as 100pF.

At each power-up of the SX8661Z the Digital Compensation Values (DCV) are estimated by the digital processing algorithms. The algorithm will adjust the compensation values such that zero ticks will be generated by the ADC.

Once the correct compensation values are found these will be stored and used to compensate each CAP pin.

If the SX8661Z is shut down the compensation values will be lost. At a next power-up the procedure starts all over again. This assures that the SX8661Z will operate under any condition. Powering up at e.g. different temperatures will not change the performance of the SX8661Z and the host does not have to do anything special.

The DCVs do not need to be updated if the external conditions remain stable.

However if e.g. temperature changes this will influence the external capacitance. The ADC ticks will drift then slowly around zero values basically because of the mismatch of the compensation circuitry and the external capacitance.

In case the average value of the ticks become higher than the positive noise threshold (configurable by user) or lower than the negative threshold (configurable by user) then the SX8661Z will initiate a compensation procedure and find a new set of DCVs.

Compensation procedures can as well be initiated by the SX8661Z on periodic intervals. Even if the ticks remain within the positive and negative noise thresholds the compensation procedure will then estimate new sets of DCVs.

Finally the host can initiate a compensation procedure by using the I2C interface. This is e.g. required after the host changed the sensitivity of sensors.

3.10 Processing

The first processing step of the raw ticks, coming out of the ASI, is low pass filtering to obtain an estimation of the average capacitance: tick-ave (see Figure 17).
This slowly varying average is important in the detection of slowly changing environmental changes.

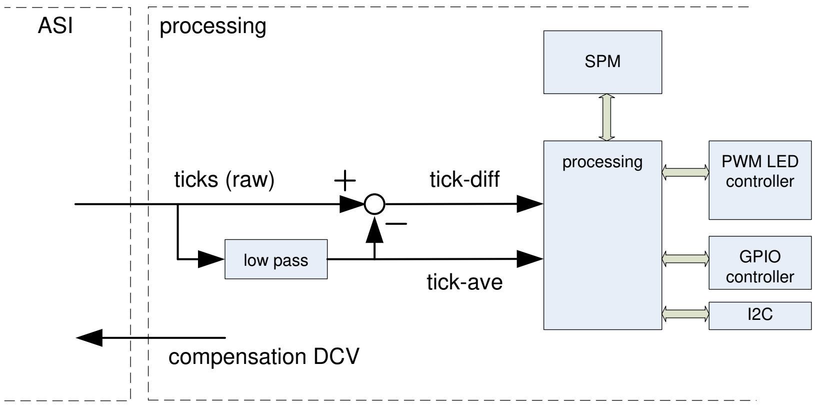


Figure 17 Processing

The difference of the tick average and the raw ticks, tick-diff, is a good estimation of rapid changing input capacitances.
The tick-diff, tick-ave and the configuration parameters in the SPM are then processed and determines the sensor information, I2C registers status and PWM control.

3.11 Configuration

Figure 18 shows the building blocks used for configuring the SX8661Z.

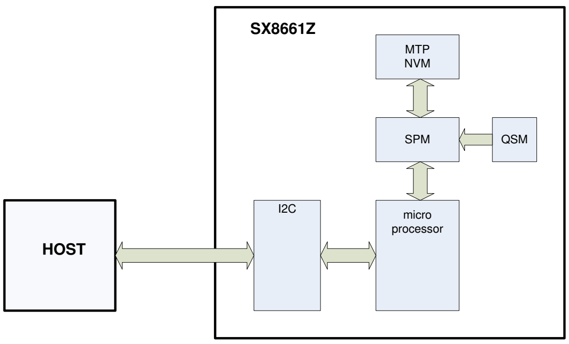


Figure 18 Configuration

The default configuration parameters of the SX8661Z are stored in the Quick Start Memory (QSM). This configuration data is setup to a very common application for the SX8661Z with 8 buttons. Without any programming or host interaction the SX8661Z will start up in the Quick Start Application.
The QSM settings are fixed and cannot be changed by the user.

In case the application needs different settings than the QSM settings then the SX8661Z can be setup and/or programmed over the I2C interface.

The configuration parameters of the SX8661Z can be stored in the Multiple Time Programmable (MTP) Non Volatile Memory (NVM). The NVM contains all those parameters that are defined and stable for the application. Examples are the number of sensors enabled, sensitivity, active and Doze scan period. The details of these parameters are described in the next chapters.

At power up the SX8661Z checks if the NVM contains valid data. In that case the configuration parameter source becomes the NVM. If the NVM is empty or non-valid then the configuration source becomes the QSM. In the next step the SX8661Z copies the configuration parameter source into the Shadow Parameter Memory (SPM). The SX8661Z is operational and uses the configuration parameters of the SPM.

During power down or reset event the SPM loses all content. It will automatically be reloaded following power up or at the end of the reset event.

The host will interface with the SX8661Z through the I2C bus and the analog output interface.

The I2C of the SX8661Z consists of 16 registers. Some of these I2C registers are used to read the status and information of the buttons. Other I2C registers allow the host to take control of the SX8661Z. The host can e.g. decide to change the operation mode from active mode to Doze mode or go into sleep (according Figure 7).

Two additional modes allow the host to have an access to the SPM or indirect access to the NVM.

These modes are required during development, can be used in real time or in-field programming.

Figure 19 shows the Host SPM mode. In this mode the host can decide to overwrite the SPM. This is useful during the development phases of the application where the configuration parameters are not yet fully defined and as well during the operation of the application if some parameters need small deviations from the QSM or NVM content.

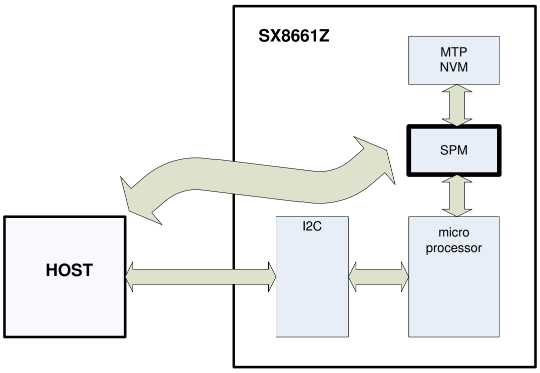


Figure 19 Host SPM mode

The content of the SPM remains valid as long as the SX8661Z is powered. After a power down the host needs to re-write the SPM at the next power-up.

Figure 20 shows the Host NVM mode. In this mode the host will be able to write the NVM.

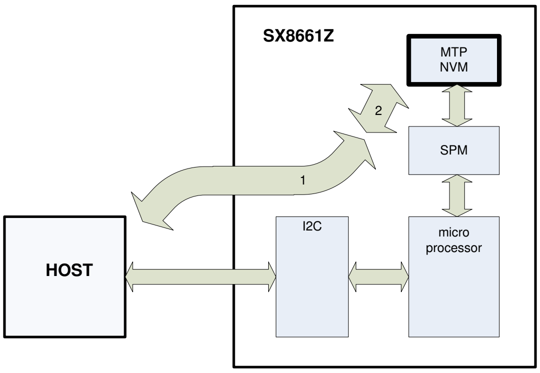


Figure 20 Host NVM mode

The writing of the host towards the NVM is not done directly but done in 2 steps (Figure 20).

In the first step the host writes to the SPM (as in Figure 19). In the second step the host signals the SX8661Z to copy the SPM content into the NVM.

Initially the NVM memory is empty and it is required to determine a valid parameter set for the application. This can be done during the development phase using dedicated evaluation hardware representing the final application. This development phase uses probably initially the host SPM mode which allows faster iterations.

Once the parameter set is determined this can be written to the NVM over the I2C using the 2 steps approach by the host or a dedicated programmer for large volumes production (as described in the paragraphs 6.6 and 6.7).

3.12 Power Management

The SX8661Z uses on-chip voltage regulators which are controlled by the on-chip microprocessor. The regulators need to be stabilized with an external capacitor between VANA and ground and between VDIG and ground (see Table 5). Both regulators are designed to only drive the SX8661Z internal circuitry and must not be loaded externally.

3.13 Clock Circuitry

The SX8661Z has its own internal clock generation circuitry that does not require any external components. The clock circuitry is optimized for low power operation and is controlled by the on-chip microprocessor. The typical operating frequency of the oscillating core is 16.7MHz from which all other lower frequencies are derived.

3.14 I2C interface

The I2C interface allows the communication between the host and the SX8661Z.

The I2C slave implemented on the SX8661Z is compliant with the standard (100kb/s) and fast mode (400kb/s)
The default SX8661Z I2C address equals 0b010 1011.
A different I2C address can be programmed by the user in the NVM.

3.15 Interrupt

3.15.1 Power up

During power up the INTB is kept low. Once the power up sequence is terminated the INTB is cleared autonomously. The SX8661Z is then ready for operation. The AOI levels are updated at the latest one scan period after the rising edge of INTB.

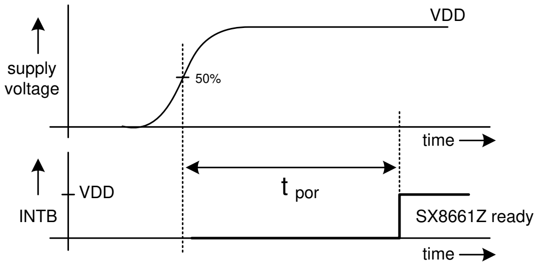


Figure 21 Power Up vs. INTB

During the power on period the SX8661Z stabilizes the internal regulators, RC clocks and the firmware initializes all registers.

During the power up the SX8661Z is not accessible and I2C communications are forbidden. The GPIOs set as inputs with a pull up resistor.
As soon as the INTB rises the SX8661Z will be ready for I2C communication. The GPIOs are then configured according the parameters in the SPM.
The value of INTB before power up depends on the INTB pull up resistor supply voltage.

3.15.2 Assertion

INTB is updated in Active or Doze mode once every scan period.

The INTB will be asserted at the following events:

- if a Button event occurred (touch or release if enabled). I2C register CapStatLsb show the detailed status of the Buttons,
- when actually entering Active or Doze mode via a host request (may be delayed by 1 scan period). I2C register CompOpmode shows the current operation mode,
- once compensation procedure is completed either through automatic trigger or via host request (may be delayed by 1 scan period),
- once SPM write is effective (may be delayed by 1 scan period),
- once NVM burn procedure is completed (may be delayed by 1 scan period),
- during reset (power up, hardware RESETB, software reset).

3.15.3 Clearing

The clearing of the INTB is done as soon as the host performs a read to any of the SX8661Z I2C registers.

