SX9501

Ultra Low Power, Four Channels
Capacitive Proximity/Button Solution with Dedicated Outputs

GENERAL DESCRIPTION

The SX9501 is a low-cost, very low power 4-channel capacitive controller that can operate either as a proximity or button sensor. It operates directly from an input supply voltage of 2.7 to 5.5V.

The SX9501 is simple to use since there are no host software interfacing requirements. All touch or proximity communication is direct on a set of dedicated active low open drain outputs, enabling interfacing to separate host voltage supplies.

The SX9501 is highly programmable for wide range of applications, featuring six (6) digitally controlled hardware inputs to set capacitive sensors sensitivity, detection threshold, and hysteresis.

Additionally, the SX9501 includes sophisticated on-chip auto-calibration circuitry to regularly perform sensitivity adjustments, maintaining peak performance over a wide variation of temperature, humidity and noise environments, providing simplified product development and enhanced performance.

A dedicated transmit enable (TXEN) pin is available to synchronize capacitive measurements for applications that require synchronous detection, enabling very low supply current and high noise immunity by only measuring proximity when requested.

KEY PRODUCT FEATURES

- **2.7 – 5.5V Input Supply Voltage**
- **Capacitive Sensor Inputs**
  - 4 fF Capacitance Resolution
  - Stable Proximity & Touch Sensing With Temperature
  - Capacitance Offset Compensation to 30pF
- **Active Sensor Guarding**
- **Automatic Calibration**
- **Ultra Low Power Consumption:**
  - Active Mode: 122 uA
  - Doze Mode: 26 uA
  - Sleep Mode: 2.1 uA
- **Individual Capacitive Sensor Dedicated Outputs**
  - Direct Capacitive Sensor Mapping To Outputs
  - Open Drain Outputs With 6 mA Sink Current
- **Two (2) Reset Sources: POR, NRST pin**
- **-40°C to +85°C Operation**
- **Compact Size: 3 x 3mm Thin QFN package**
- **Pb & Halogen Free, RoHS/WEEE compliant**

APPLICATIONS

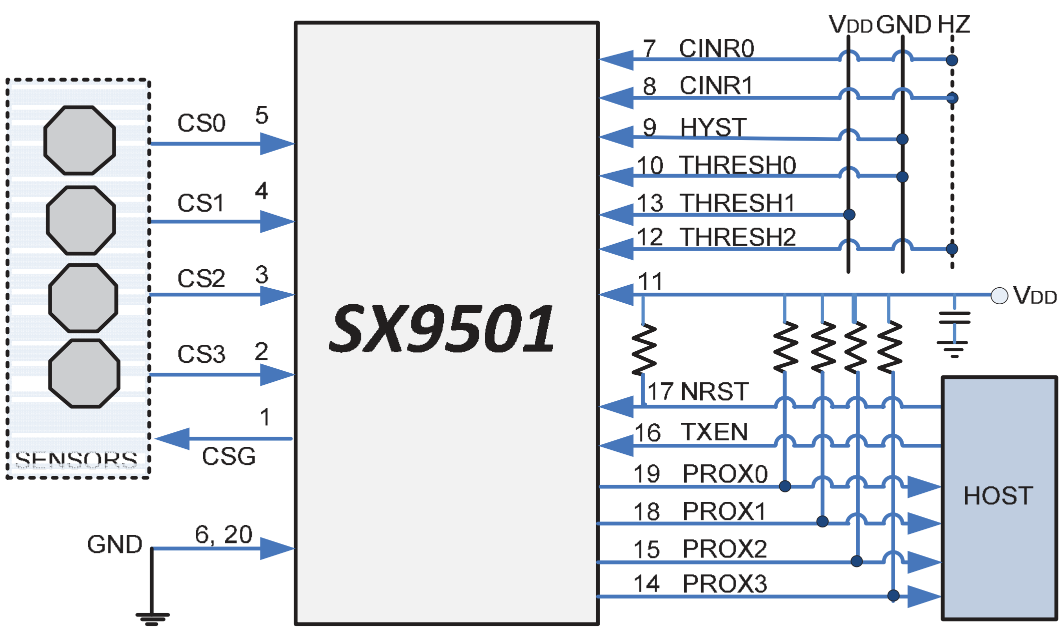
- TV
- Mechanical button replacement
- Mobile Appliances

ORDERING INFORMATION

Part Number	Package	Marking
SX9501IULTRT [1]	QFN-20	ZC92
SX9500EVKA [2]	Eval. Kit	

[1] 3000 Units/reel
[2] Cf. §7.3 for more information

TYPICAL APPLICATION CIRCUIT



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1 General Description

1.1 Pin Diagram

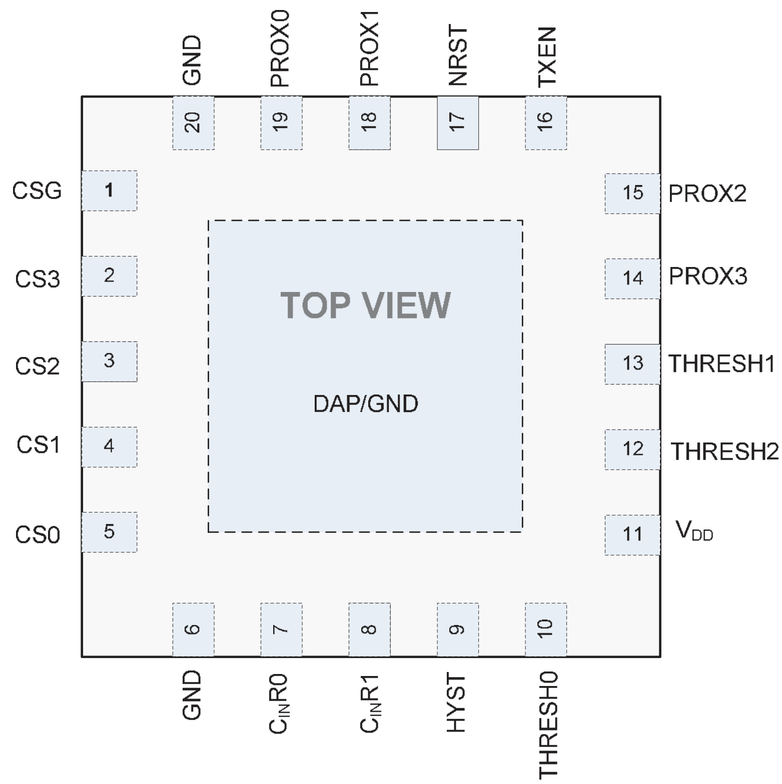
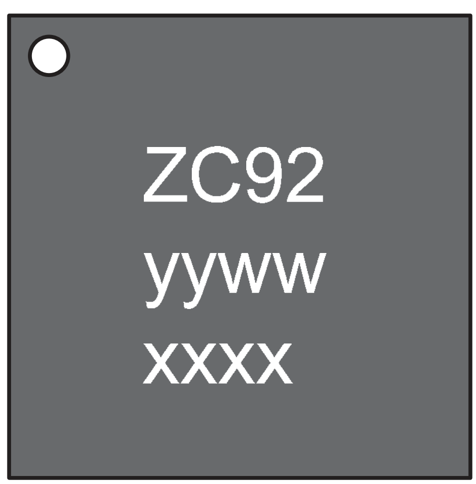


Figure 1: Pin Diagram

1.2 Marking Information



yyww= Date Code
xxxx = Lot Number

Figure 2: Marking Information

1.3 Pin Description

Number	Name	Type	Description
1	CSG	Analog	Capacitive Sensor Guard/Shield
2	CS3	Analog	Capacitive Sensor 3, do not connect if not used
3	CS2	Analog	Capacitive Sensor 2, do not connect if not used
4	CS1	Analog	Capacitive Sensor 1, do not connect if not used
5	CS0	Analog	Capacitive Sensor 0, do not connect if not used
6	GND	Ground	Ground
7	CINR0	Input	Sensitivity/Range bit 0, 3-state, connect to V_{DD} ,GND or leave open
8	CINR1	Input	Sensitivity/Range bit 1, 3-state, connect to V_{DD} ,GND or leave open
9	HYST	Input	Hysteresis, 3-state, connect to V_{DD} ,GND or leave open
10	THRESH0	Input	Detection Threshold bit 0, 3-state, connect to V_{DD} ,GND or leave open
11	V_{DD}	Power	Chip power supply
12	THRESH2	Input	Detection Threshold bit 2, 3-state, connect to V_{DD} ,GND or leave open
13	THRESH1	Input	Detection Threshold bit 1, 3-state, connect to V_{DD} ,GND or leave open
14	PROX3	Digital Output	CS3 detection output, active LOW, requires pull-up to max V_{DD}
15	PROX2	Digital Output	CS2 detection output, active LOW, requires pull-up to max V_{DD}
16	TXEN	Digital Input	Transmit Enable, active HIGH (Tie to V_{DD} if not used).
17	NRST	Digital Input	External reset, active LOW (Tie to V_{DD} if not used).
18	PROX1	Digital Output	CS1 detection output, active LOW, requires pull-up to max V_{DD}
19	PROX0	Digital Output	CS0 detection output, active LOW, requires pull-up to max V_{DD}
20	GND	Ground	Ground
DAP	GND	Ground	Exposed Pad. Connect to Ground

Table 1: Pin Description

1.4 Acronyms

DAP Die Attach Paddle
RF Radio Frequency

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 “Operating Conditions”, is not implied. Exposure to Absolute Maximum Rating conditions for extended periods may affect device reliability and proper functionality.

Parameter	Symbol	Min	Max	Unit
Supply Voltage	V_{DD}	-0.5	6.0	V
Input Voltage (non-supply pins)	V_{IN}	-0.5	V_{DD}+0.3	
Input Current (non-supply pins)	I_{IN}	-10	10	mA
Operating Junction Temperature	T_{JCT}	-40	125	°C
Reflow Temperature	T_{RE}	-	260	
Storage Temperature	T_{STOR}	-50	150	
ESD HBM (Human Body model, to JESD22-A114)	ESD_{HBM}	8	-	kV

Table 2: Absolute Maximum Ratings

2.2 Operating Conditions

Parameter	Symbol	Min	Max	Unit
Supply Voltage	V_{DD}	2.7	5.5	V
PROX [3:0] Output Supply Voltage	PV_{DD}	-	V_{DD}	V
Ambient Temperature	T_A	-40	85	°C

Table 3: Operating Conditions

2.3 Thermal Characteristics

Parameter	Symbol	Typical	Unit
Thermal Resistance – Junction to Air (Static Airflow)	θ_{JA}	34	°C/W

Table 4: Thermal Characteristics

Note: θ_{JA} is calculated from a package in still air, mounted to 3" x 4.5", 4-layer FR4 PCB with thermal vias under exposed pad per JESD51 standards.

2.4 Electrical Specifications

All values are valid within the operating conditions unless otherwise specified.
Typical values are given for T_A= +25°C, VDD=3.3V unless otherwise specified.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Current Consumption						
Sleep (TXEN low)	I_{SLEEP}		-	2.1	-	µA
Doze (TXEN high, no prox detected)	I_{DOZE}	C_{IN}R0 = C_{IN}R1 = low	-	26	-	µA
Active (TXEN high, prox detected)	I_{ACTIVE}	C_{IN}R0 = C_{IN}R1 = low	-	122	-	µA
Outputs: PROX[3:0]						
Output Current	I_{OL}	VOL = 0.4V	6	-	-	mA
Inputs: C_{IN}R[1:0], HYST, THRESH[2:0], TXEN						
Input logic high	V_{IH}		0.7 x V_{DD}	-	V_{DD} + 0.3	V
Input logic low	V_{IL}		-0.3	-	0.8	V
Input leakage current	I_L	CMOS input	-1	-	1	µA
Hysteresis	V_{HYS}		-	0.05x V_{DD}	-	V
Input Capacitance	IN_{CAPMAX}	Maximum capacitance allowed on these pins	-	50	-	pF
TXEN Delay	$TXEN_{ACTDLY}$	Delay between TXEN rising edge and SX9501 starting measurements	-	100	-	µs

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input: NRST						
Input logic high	V_{IH}		0.7 x V_{DD}	-	V_{DD} + 0.3	V
Input logic low	V_{IL}		-	-	0.6	V
NRST minimum pulse width	$T_{RESETPW}$		-	20	-	ns
Start-up						
Power-up time	T_{POR}		-	1	-	ms

Table 5: Electrical Specifications

3 PROXIMITY SENSING INTERFACE

3.1 Introduction

The purpose of the proximity sensing interface is to detect when a conductive object (usually a body part i.e. finger, palm, face, etc) is in the proximity of the system. Note that proximity sensing can be done thru the air or thru a solid (typically plastic) overlay (also called “touch” sensing).

The chip’s proximity sensing interface is based on capacitive sensing technology. An overview is given in figure below.

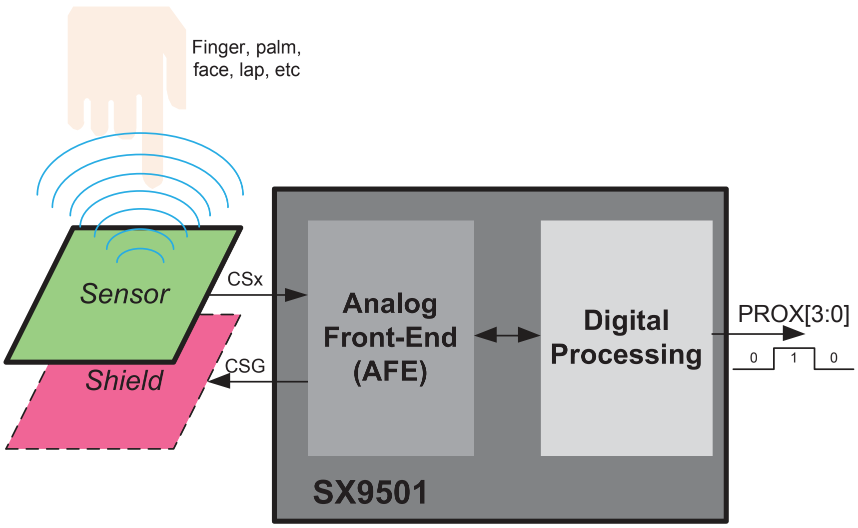


Figure 3: Proximity Sensing Interface Overview

- The sensor can be a simple copper area on a PCB or FPC for example. Its capacitance (to ground) will vary when a conductive object is moving in its proximity.
- The optional shield can be also be a simple copper area on a PCB or FPC below/under/around the sensor. It is used to protect the sensor against potential surrounding noise sources and improve its global performance. It also brings directivity to the sensing, for example sensing objects approaching from top only.
- The analog front-end (AFE) performs the raw sensor’s capacitance measurement and converts it into a digital value. It also controls the shield.
- The digital processing block computes the raw capacitance measurement from the AFE and extracts a binary information corresponding to the proximity status of each sensor, i.e. object is “Far” or “Close”.

3.2 Scan Period

To save power and since the proximity event is slow by nature, the chip will be waken-up regularly at every programmed scan period to first sense sequentially each of the CSx pins and then process new proximity samples/info. The chip will be in idle mode most of the time. This is illustrated in figure below

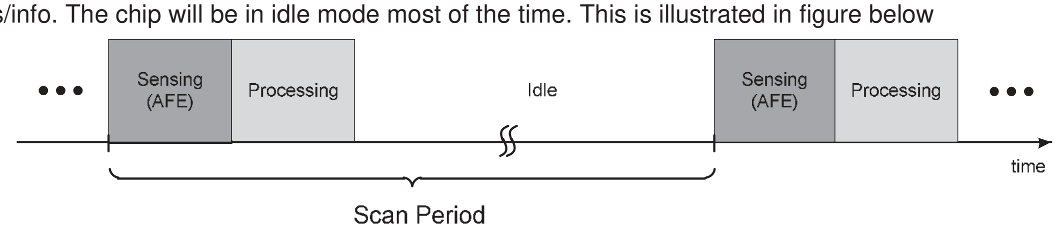


Figure 4: Proximity Sensing Sequencing

During the Idle phase, the SX9501's analog circuits are turned off. Upon expiry of the idle timer, a new scan period cycle begins.

The scan period determines the minimum reaction time (actual/final reaction time also depends on debounce and filtering settings). It is fixed to 30ms in Active mode and 240ms in Doze mode.

3.3 Analog Front-End (AFE)

3.3.1 Capacitive Sensing Basics

Capacitive sensing is the art of measuring a small variation of capacitance in a noisy environment. As mentioned above, the chip's proximity sensing interface is based on capacitive sensing technology. In order to illustrate some of the user choices and compromises required when using this technology it is useful to understand its basic principles.

To illustrate the principle of capacitive sensing we will use the simplest implementation where the sensor is a copper plate on a PCB.

The figure below shows a cross-section and top view of a typical capacitive sensing implementation. The sensor connected to the chip is a simple copper area on top layer of the PCB. It is usually surrounded (shielded) by ground for noise immunity (shield function) but also indirectly couples via the grounds areas of the rest of the system (PCB ground traces/planes, housing, etc). For obvious reasons (design, isolation, robustness …) the sensor is stacked behind an overlay which is usually integrated in the housing of the complete system.

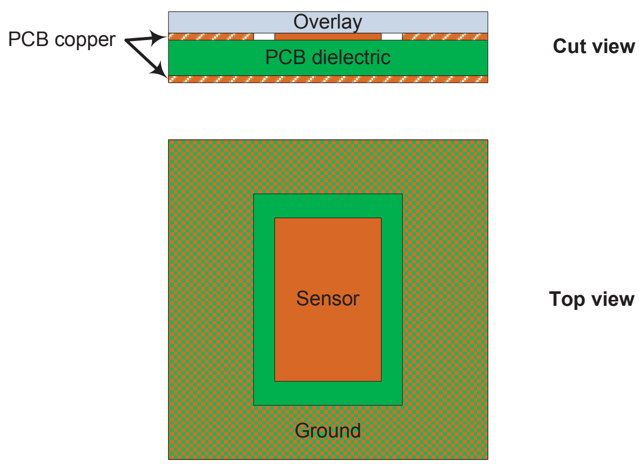


Figure 5: Typical Capacitive Sensing Implementation

When the conductive object to be detected (finger/palm/face, etc) is not present, the sensor only sees an inherent capacitance value C_{Env} created by its electrical field's interaction with the environment, in particular with ground areas.

When the conductive object (finger/palm/face, etc) approaches, the electrical field around the sensor will be modified and the total capacitance seen by the sensor increased by the user capacitance C_{User}. This phenomenon is illustrated in the figure below.

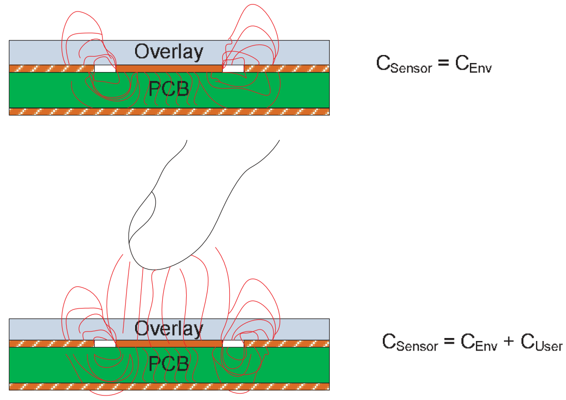


Figure 6: Proximity Effect on Electrical Field and Sensor Capacitance

The challenge of capacitive sensing is to detect this relatively small variation of C_{Sensor} (C_{User} usually contributes for a few percent only) and differentiate it from environmental noise (C_{Env} also slowly varies together with the environment characteristics like temperature, etc). For this purpose, the chip integrates an auto offset compensation mechanism which dynamically monitors and removes the C_{Env} component to extract and process C_{User} only.

In first order, C_{User} can be estimated by the formula below:

$$C_{User} = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot A}{d}$$

A is the common area between the two electrodes hence the common area between the user's finger/palm/face and the sensor.

d is the distance between the two electrodes hence the proximity distance between the user and the system.

ε_0 is the free space permittivity and is equal to 8.85 10e-12 F/m (constant)

ε_r is the dielectric relative permittivity.

Typical permittivity of some common materials is given in the table below.

Material	Typical ε_r
Glass	8
FR4	5
Acrylic Glass	3
Wood	2
Air	**1**

Table 6: Typical Permittivity of Some Common Materials

From the discussions above we can conclude that the most robust and efficient design will be the one that minimizes C_{Env} value and variations while improving C_{User}.

3.3.2 AFE Block Diagram

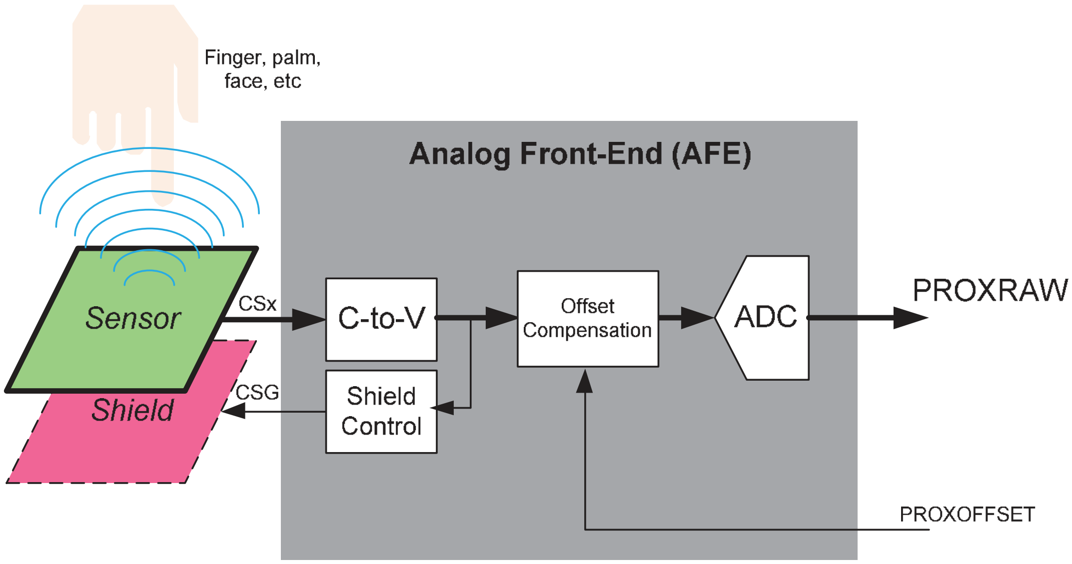


Figure 7: Analog Front-End Block Diagram

3.3.3 Offset Compensation

Offset compensation consists in performing a one-time measurement of C_{Env} and subtracting it to the total capacitance C_{Sensor} in order to feed the ADC with the closest contribution of C_{User} only.

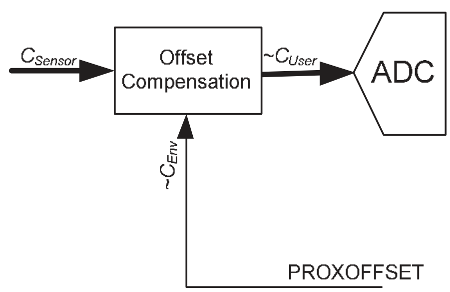


Figure 8: Offset Compensation Block Diagram

The ADC input C_{User} is the total capacitance C_{Sensor} to which C_{Env} is subtracted.

There are two possible compensation sources which are illustrated in the figure below. When set to 1 by any of these sources, COMPSTAT will only be reset once the compensation is completed.

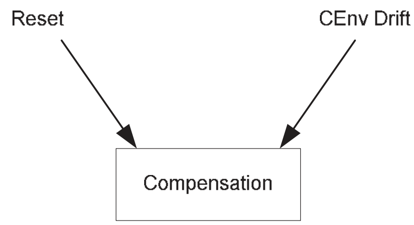


Figure 9: Compensation Request Sources

- <u>Reset:</u> a compensation for all sensors is automatically requested when a reset is performed (power-up, NRST pin)
- <u>CEnv Drift:</u> a compensation for all sensors is automatically requested if it is detected that C_{Env} has drifted beyond a pre-programmed range.

Note that when a compensation occurs all sensors' flags PROX[3:0] will show inactive status (ie no proximity detected) independently from the user's actual presence.

3.4 Digital Processing

The main purpose of the digital processing block is to convert the raw capacitance information coming from the AFE (PROXRAW) into robust and reliable digital flags PROX[3:0] indicating if something is close to the proximity sensors.

The offset compensation performed in the AFE is a one-time measurement. However, the environment capacitance C_{Env} may vary with time (temperature, nearby objects, etc). Hence, in order to get the best estimation of C_{User} (PROXDIFF) it is needed to dynamically track and subtract C_{Env} variations. This is performed by filtering PROXUSEFUL to extract its slow variations (PROXAVG).

PROXDIFF is then compared to a user programmable threshold (THRESH[2:0]) +/- hysteresis (HYST) to extract PROX[3:0] value.

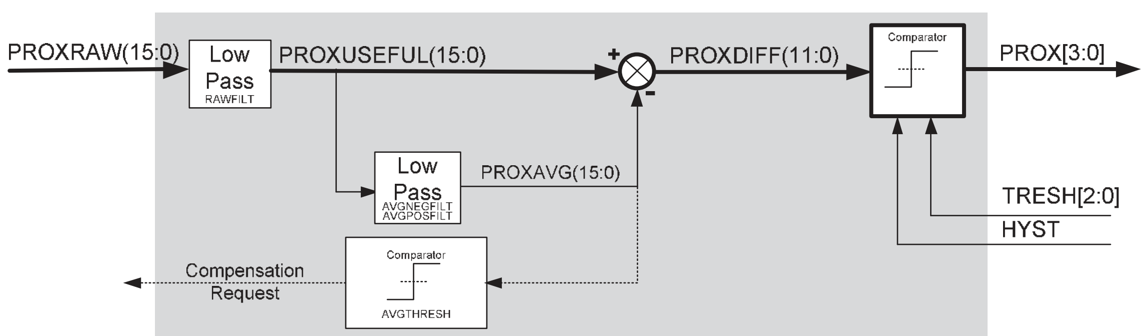


Figure 10: Digital Processing Block Diagram

3.5 Operational Modes

3.5.1 Active

Active mode is automatically enabled as soon as at least one of the sensors detects proximity. In this mode all sensors are scanned at a scan period of 30ms.

3.5.2 Doze

In most applications, the reaction/sensing time needs to be fast when the user is present (proximity detected), but can be slow when no detection has been done for some time.

Doze mode is automatically enabled when no sensor detects proximity. In this mode all sensors are scanned at a scan period of 240ms.

This allows reaching low average power consumption values at the expense obviously of longer reaction times.

As soon as proximity is detected on any sensor, the chip will automatically switch to Active mode while when it has not detected an object for 240ms; it will automatically switch back to Doze mode.

3.5.3 Sleep

Sleep mode can be entered by pulling low TXEN pin. It places the SX9501 in its lowest power mode, with sensor scanning completely disabled and idle period set to continuous.

3.5.4 TXEN Pin

The TXEN input enables proximity sensing when HIGH, likewise when the TXEN input is LOW, the SX9501 is in Sleep mode. Specifically, on the rising edge of TXEN the SX9501 will begin measuring the sensors normally as long as TXEN remains HIGH. When TXEN goes LOW the current measurement sequence will complete and then measurement will cease until the next rising edge of TXEN.

This feature can be used to synchronize proximity sensing with noisy and/or RF activity for example.

4 RESET

4.1 Power-up

Chip is ready once V_{DD} has met the minimum input voltage requirements and a T_{POR} time has expired.

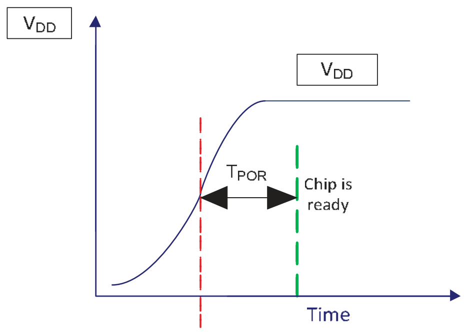


Figure 11: Power-up

4.2 NRST Pin

When the host asserts NRST LOW (for min. $T_{RESETPW}$) and then HIGH, the SX9501 will reset and will become active after T_{POR}. When not used, this pin must be pulled high to V_{DD}.

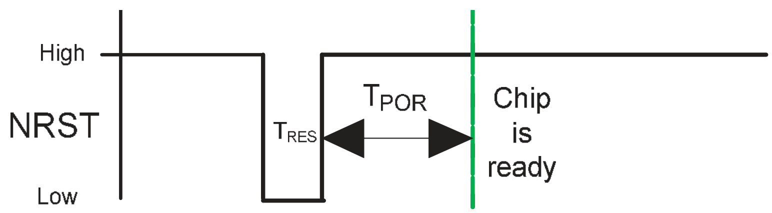


Figure 12: Hardware Reset

5 PINS DESCRIPTION

5.1 V_{DD}

This is the device's supply pin. It should be set between 2.7V and 5.5V.

5.2 TXEN

This signal can be used in many applications if a conversion trigger/enable is needed. This input pin synchronizes the Capacitance Sensing inputs in systems that need to (for example) transmit RF signals. When this signal is active, SX9501 performs capacitive measurements. If this input becomes inactive during the middle of a measurement, the SX9501 will complete all remaining measurements and will enter sleep mode until TXEN goes active again.

5.3 Capacitive Sensing Interface (CS0, CS1, CS2, CS3, CSG)

The Capacitance Sensing input pins CS0, CS1, CS2 and CS3 are connected directly to the Capacitance Sensing Interface circuitry which converts the sensed capacitance into digital values. The Capacitive Sensor Guard (CSG) output provides a guard reference to minimize the parasitic sensor pin capacitances to ground. Capacitance sensor pins which are not used must not be connected. Additionally, CSx pins must be connected directly to the capacitive sensors using a minimum length circuit trace to minimize external "noise" pick-up.

The capacitance sensor and capacitive sensor guard pins are protected from ESD events to VDD and GND.

5.4 PROX[3:0]

These pins are open-drain outputs that require an external pull-up (max VDD) and are protected from ESD events to VDD and GND.

5.5 HYST, C_{IN}R[1:0], THRESH[2:0], NRST and TXEN

The HYST, C_{IN}R, THRESH, NRST, and TXEN pins are high impedance input pins that are protected from ESD events to V_{DD} and GND.

The HYST, C_{IN}R, and THRESH inputs are designed to be either connected to VDD, GND, or open circuited (no connect), while NRST and TXEN must be connected to a logic level, either directly or through an external pull-up resistor.

6 CONFIGURATION

6.1 Introduction

The SX9501 can be seen as an SX9500 programmed with the settings below:

Address	Register	Value
0x06	RegProxCtrl0	0x0F
0x07	RegProxCtrl1	010000**ww**b
0x08	RegProxCtrl2	00001**xxx**b
0x09	RegProxCtrl3	0x65
0x0A	RegProxCtrl4	0x80
0x0B	RegProxCtrl5	0x16
0x0C	RegProxCtrl6	000**yyyyy**b
0x0D	RegProxCtrl7	01**zz**0000b
0x0E	RegProxCtrl8	0x00

Table 7: Equivalent SX9500 Settings

In order to allow some flexibility to match with the different designs/applications requirements, the most critical parameters (**ww**, **xxx**, **yyyyy** and **zz** above) are defined thru external pins as described in the following sections.

Each of these pins can be set to 0, 1 or HZ (floating, not connected). Settings apply equally to all sensors.

Important: The external pins configuration is only read and taken into account once during the reset; it cannot be changed dynamically during normal operation.

6.2 CINR[1:0]

These pins control the RANGE (**ww**) and RESOLUTION (**xxx**) parameters as defined below:

CINR1	CINR0	RANGE (ww)	RESOLUTION (xxx)
0	0	Small (11)	Medium Coarsest (010)
HZ	0		Medium Coarse (011)
1	0		Medium (100)
0	HZ		Medium Fine (101)
HZ	HZ		Finest (111)
1	HZ	Medium Small (10)	Coarse (001)
0	1		Medium Coarse (011)
HZ	1		Medium (100)
1	1		Medium Fine (101)

Table 8: CINR[1:0] Configuration

RANGE defines the input capacitance range while RESOLUTION defines the capacitance measurement resolution/precision.

Recommended setting is CINR[1:0]=[HZ;HZ] i.e. both pins left floating.

6.3 THRESH[2:0]

These pins control the PROXTHRESH (**yyyyy**) parameter as defined below:

THRESH2	THRESH1	THRESH0	PROXTHRESH (yyyyy)
0	0	0	0 (00000)
HZ	0	0	20 (00001)
1	0	0	40 (00010)
0	HZ	0	60 (00011)
HZ	HZ	0	80 (00100)
1	HZ	0	100 (00101)
0	1	0	120 (00110)
HZ	1	0	140 (00111)
1	1	0	160 (01000)
0	0	HZ	180 (01001)
HZ	0	HZ	200 (01010)
1	0	HZ	220 (01011)
0	HZ	HZ	240 (01100)
HZ	HZ	HZ	260 (01101)
1	HZ	HZ	280 (01110)
0	1	HZ	300 (01111)
HZ	1	HZ	350 (10000)
1	1	HZ	400 (10001)
0	0	1	450 (10010)
HZ	0	1	500 (10011)
1	0	1	600 (10100)
0	HZ	1	700 (10101)
HZ	HZ	1	800 (10110)
1	HZ	1	900 (10111)
0	1	1	1000 (11000)
HZ	1	1	1100 (11001)
1	1	1	1200 (11010)

Table 9: THRESH[2:0] Configuration

PROXTHRESH defines the proximity detection threshold.
Low values allow good sensitivity/distance while higher values allow better noise immunity.

6.4 HYST

This pin controls the HYST (**zz**) parameter as defined below:

HYST	HYST (zz)
0	32 (00)
HZ	64 (01)
1	128 (10)

Table 10: HYST Configuration

HYST defines the proximity detection hysteresis applied to PROXTHRESH.

Recommended setting is HYST=0 i.e. pin connected to GND.

7 Application Information

7.1 Typical Application Circuit

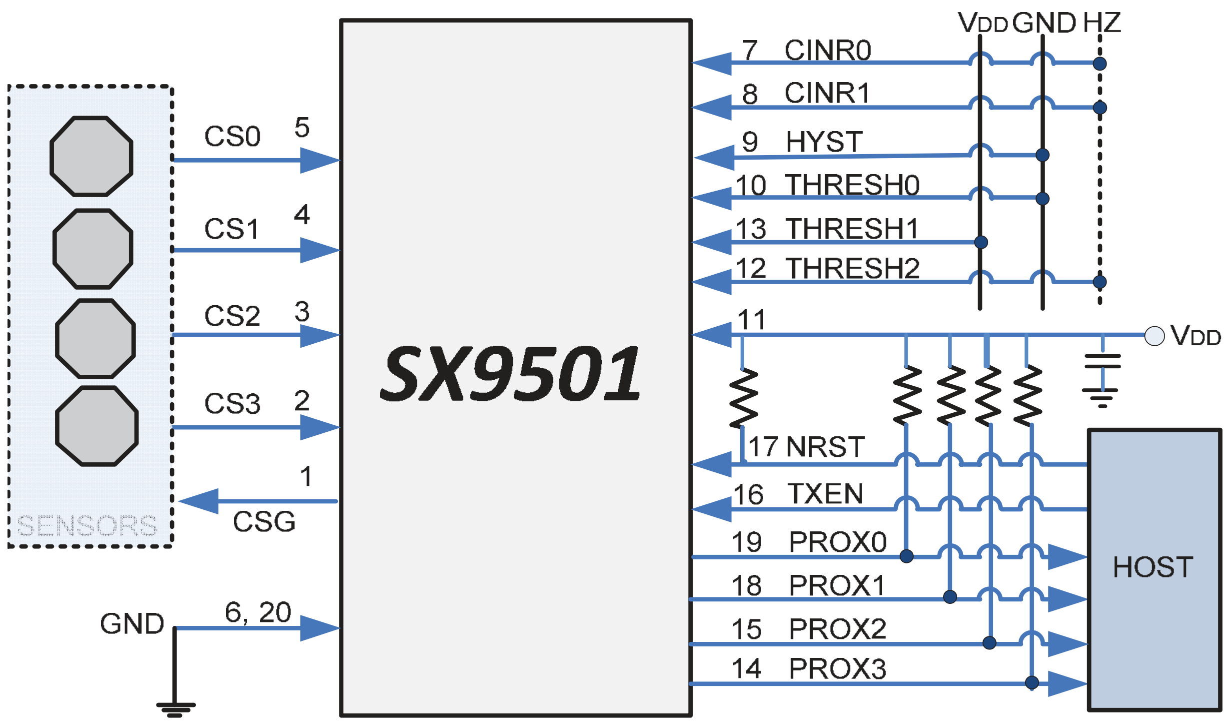


Figure 13: Typical Application Circuit

7.2 External Components Recommended Values

Symbol	Description	Note	Min	Typ.	Max	Unit
CVDD	Supply decoupling capacitor		-	100	-	nF
RPULL	Host interface pull-ups	+/- 50%	-	10	-	kΩ

Table 11: External Components Recommended Values

7.3 Evaluation

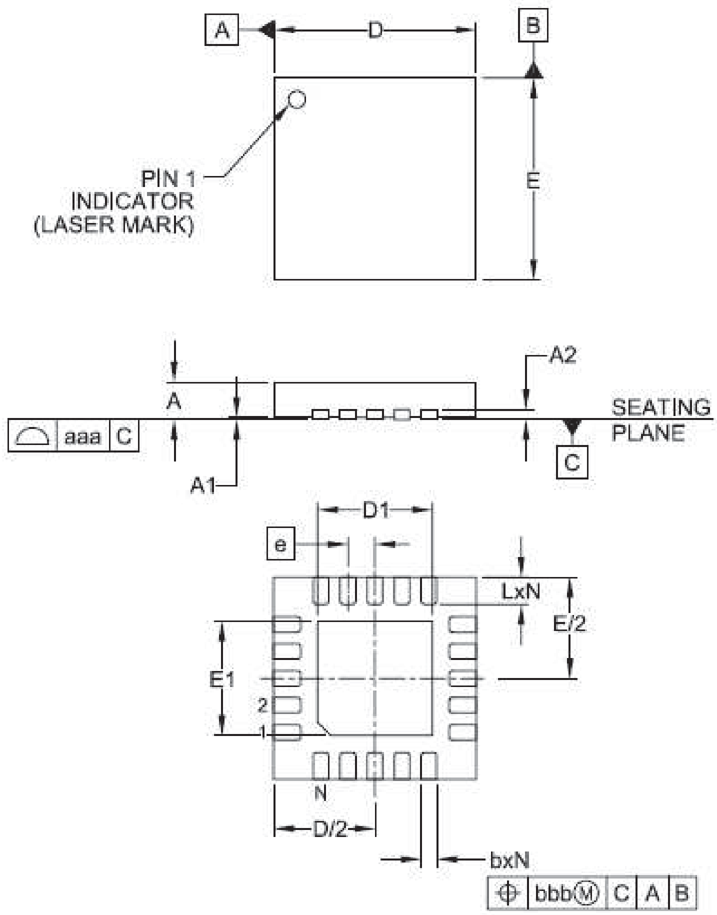
SX9500EVKA can be used for performance evaluation and parameters fine-tuning of the SX9501.

The settings listed in §6.1 should be first programmed to the on-board chip using the GUI.

Then RANGE, RESOLUTION, PROXTHRESH and HYST can be played with according to the values available thru the SX9501 pins (Cf. §6.2, 6.3, and 6.4) to find the best configuration.

8 Packaging Information

8.1 Outline Drawing



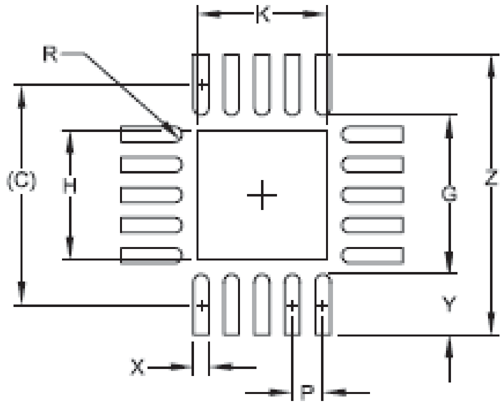
DIM	INCHES			MILLIMETERS		
	MIN	NOM	MAX	MIN	NOM	MAX
A	.020	-	.024	0.50	-	0.60
A1	.000	-	.002	0.00	-	0.05
A2	(.006)			(0.152)		
b	.006	.008	.010	0.15	0.20	0.25
D	.114	.118	.122	2.90	3.00	3.10
D1	.061	.067	.071	1.55	1.70	1.80
E	.114	.118	.122	2.90	3.00	3.10
E1	.061	.067	.071	1.55	1.70	1.80
e	.016 BSC			0.40 BSC		
L	.012	.016	.020	0.30	0.40	0.50
N	20			20		
aaa	.003			0.08		
bbb	.004			0.10		

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.
3. DAP IS 1.90 x 1.90mm.

Figure 14: Outline Drawing

8.2 Land Pattern



DIMENSIONS		
DIM	INCHES	MILLIMETERS
C	(.114)	(2.90)
G	.083	2.10
H	.067	1.70
K	.067	1.70
P	.016	0.40
R	.004	0.10
X	.008	0.20
Y	.031	0.80
Z	.146	3.70

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. THIS LAND PATTERN IS FOR REFERENCE PURPOSES ONLY. CONSULT YOUR MANUFACTURING GROUP TO ENSURE YOUR COMPANY'S MANUFACTURING GUIDELINES ARE MET.
3. THERMAL VIAS IN THE LAND PATTERN OF THE EXPOSED PAD SHALL BE CONNECTED TO A SYSTEM GROUND PLANE. FAILURE TO DO SO MAY COMPROMISE THE THERMAL AND/OR FUNCTIONAL PERFORMANCE OF THE DEVICE.

Figure 15: Land Pattern

Contact Information

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