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CAP1133

3 Channel Capacitive Touch Sensor with 3 LED Drivers

General Description

The CAP1133, which incorporates RightTouch® technology, is a multiple channel Capacitive Touch sensor with multiple power LED drivers. It contains three (3) individual capacitive touch sensor inputs with programmable sensitivity for use in touch sensor applications. Each sensor input automatically recalibrates to compensate for gradual environmental changes.

The CAP1133 also contains three (3) LED drivers that offer full-on / off, variable rate blinking, dimness controls, and breathing. Each of the LED drivers may be linked to one of the sensor inputs to be actuated when a touch is detected. As well, each LED driver may be individually controlled via a host controller.

The CAP1133 includes Multiple Pattern Touch recognition that allows the user to select a specific set of buttons to be touched simultaneously. If this pattern is detected, then a status bit is set and an interrupt generated.

Additionally, the CAP1133 includes circuitry and support for enhanced sensor proximity detection.

The CAP1133 offers multiple power states operating at low quiescent currents. In the Standby state of operation, one or more capacitive touch sensor inputs are active and all LEDs may be used.

Deep Sleep is the lowest power state available, drawing 5uA (typical) of current. In this state, no sensor inputs are active. Communications will wake the device.

Applications

- Desktop and Notebook PCs
- LCD Monitors
- Consumer Electronics
- Appliances

Features

- Three (3) Capacitive Touch Sensor Inputs
  - Programmable sensitivity
  - Automatic recalibration
  - Individual thresholds for each button
- Proximity Detection
- Multiple Button Pattern Detection
- Calibrates for Parasitic Capacitance
- Analog Filtering for System Noise Sources
- Press and Hold feature for Volume-like Applications
- SMBus / I^2C Compliant Communication Interface
- Low Power Operation
  - 5uA quiescent current in Deep Sleep
  - 50uA quiescent current in Standby (1 sensor input monitored)
  - Samples one or more channels in Standby
- Three (3) LED Driver Outputs
  - Open Drain or Push-Pull
  - Programmable blink, breathe, and dimness controls
  - Can be linked to Capacitive Touch Sensor inputs
- Available in 10-pin 3mm x 3mm RoHS compliant DFN package

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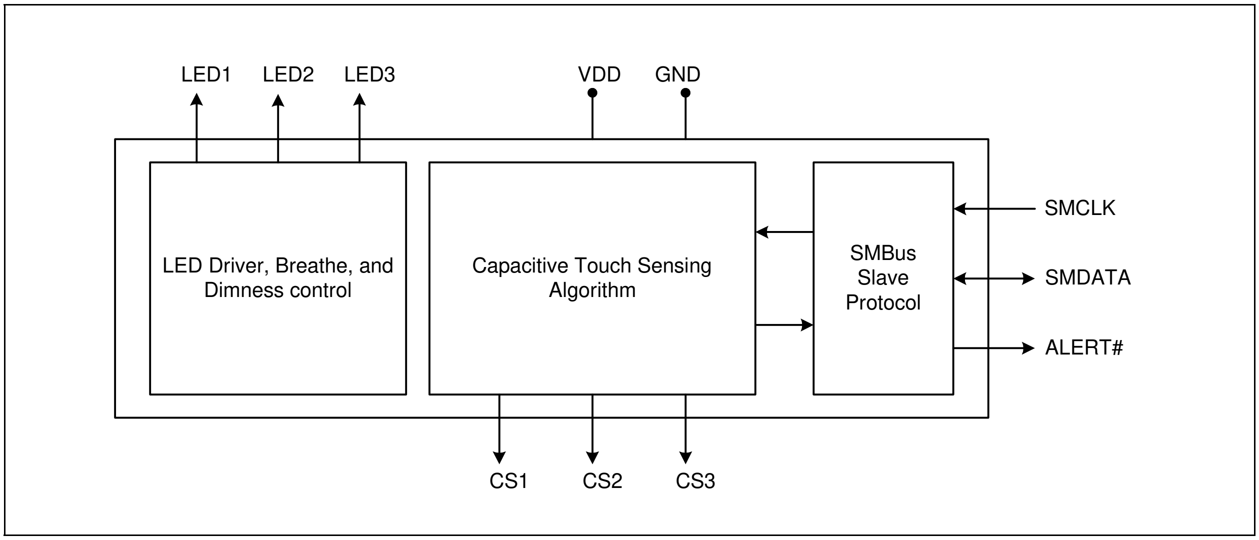
1.0 BLOCK DIAGRAM



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2.0 PIN DESCRIPTION

FIGURE 2-1: *CAP1133 Pin Diagram (10-Pin DFN)*

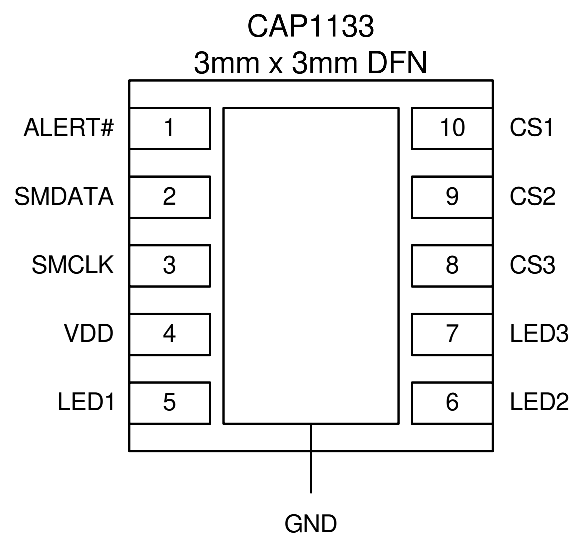

TABLE 2-1: PIN DESCRIPTION FOR CAP1133

Pin Number	Pin Name	Pin Function	Pin Type	Unused Connection
1	ALERT#	Active low alert / interrupt output usable for SMBus alert	OD (5V)	Connect to Ground
		Active high alert / interrupt output usable for SMBus alert	DO	leave open
2	SMDATA	Bi-directional, open-drain SMBus data - requires pull-up	DIOD (5V)	n/a
3	SMCLK	SMBus clock input - requires pull-up resistor	DI (5V)	
4	VDD	Positive Power supply	Power	n/a
5	LED1	Open drain LED 1 driver (default)	OD (5V)	Connect to Ground
		Push-pull LED 1 driver	DO	leave open or connect to Ground
6	LED2	Open drain LED 2 driver (default)	OD (5V)	Connect to Ground
		Push-pull LED 2 driver	DO	leave open or connect to Ground
7	LED3	Open drain LED 3 driver (default)	OD (5V)	Connect to Ground
		Push-pull LED 3 driver	DO	leave open or connect to Ground

TABLE 2-1: PIN DESCRIPTION FOR CAP1133 (CONTINUED)

Pin Number	Pin Name	Pin Function	Pin Type	Unused Connection
8	CS3	Capacitive Touch Sensor Input 3	AIO	Connect to Ground
9	CS2	Capacitive Touch Sensor Input 2	AIO	Connect to Ground
10	CS1	Capacitive Touch Sensor Input 1	AIO	Connect to Ground
Bottom Pad	GND	Ground	Power	n/a

APPLICATION NOTE: When the ALERT# pinis configured as an active low output, it will be open drain. When it is configured as an active high output, it will be push-pull.

APPLICATION NOTE: For the 5V tolerant pins that have a pull-up resistor, the pull-up voltage must not exceed 3.6V when the CAP1133 is unpowered.

The pin types are described in Table 2-2. All pins labeled with (5V) are 5V tolerant.

TABLE 2-2: PIN TYPES

Pin Type	Description
Power	This pin is used to supply power or ground to the device.
DI	Digital Input - This pin is used as a digital input. This pin is 5V tolerant.
AIO	Analog Input / Output -This pin is used as an I/O for analog signals.
DIOD	Digital Input / Open Drain Output - This pin is used as a digital I/O. When it is used as an output, it is open drain and requires a pull-up resistor. This pin is 5V tolerant.
OD	Open Drain Digital Output - This pin is used as a digital output. It is open drain and requires a pull-up resistor. This pin is 5V tolerant.
DO	Push-pull Digital Output - This pin is used as a digital output and can sink and source current.
DIO	Push-pull Digital Input / Output - This pin is used as an I/O for digital signals.

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3.0 ELECTRICAL SPECIFICATIONS

TABLE 3-1: ABSOLUTE MAXIMUM RATINGS

Voltage on 5V tolerant pins (V_{5VT_PIN})	-0.3 to 5.5	V
Voltage on 5V tolerant pins ($\lvert V_{5VT\_PIN} - V_{DD}\rvert$) Note 3-2	0 to 3.6	V
Voltage on VDD pin	-0.3 to 4	V
Voltage on any other pin to GND	-0.3 to VDD + 0.3	V
Package Power Dissipation up to T_A = 85°C for 10 pin DFN (see Note 3-3)	0.7	W
Junction to Ambient (θ_{JA})	77.7	°C/W
Operating Ambient Temperature Range	-40 to 125	°C
Storage Temperature Range	-55 to 150	°C
ESD Rating, All Pins, HBM	8000	V

Note 3-1 Stresses above those listed could cause permanent damage to the device. This is a stress rating only and functional operation of the device at any other condition above those indicated in the operation sections of this specification is not implied.

Note 3-2 For the 5V tolerant pins that have a pull-up resistor, the voltage difference between V_{5VT_PIN} and V_{DD} must never exceed 3.6V.

Note 3-3 The Package Power Dissipation specification assumes a recommended thermal via design consisting of a 2x2 matrix of 0.3mm (12mil) vias at 1.0mm pitch connected to the ground plane with a 1.6 x 2.3mm thermal landing.

TABLE 3-2: ELECTRICAL SPECIFICATIONS

V_{DD} = 3V to 3.6V, T_A = 0°C to 85°C, all typical values at T_A = 27°C unless otherwise noted.						
Characteristic	**Symbol**	**Min**	**Typ**	**Max**	**Unit**	**Conditions**
DC Power						
Supply Voltage	V_{DD}	3.0	3.3	3.6	V	
Supply Current	I_{STBY}		120	170	uA	Standby state active 1 sensor input monitored No LEDs active Default conditions (8 avg, 70ms cycle time)
	I_{STBY}		50		uA	Standby state active 1 sensor input monitored No LEDs active 1 avg, 140ms cycle time,
	I_{DSLEEP}		5	15	uA	Deep Sleep state active LEDs at 100% or 0% Duty Cycle No communications T_A < 40°C 3.135 < V_{DD} < 3.465V
	I_{DD}		500	600	uA	Capacitive Sensing Active No LEDs active
Capacitive Touch Sensor Inputs						
Maximum Base Capacitance	C_{BASE}		50		pF	Pad untouched
Minimum Detectable Capacitive Shift	ΔC_{TOUCH}	20			fF	Pad touched - default conditions (1 avg, 35ms cycle time, 1x sensitivity)
Recommended Cap Shift	ΔC_{TOUCH}	0.1		2	pF	Pad touched - Not tested
Power Supply Rejection	PSR		±3	±10	counts / V	Untouched Current Counts Base Capacitance 5pF - 50pF Maximum sensitivity Negative Delta Counts disabled All other parameters default
Timing						
Time to communications ready	t_{COMM_DLY}			15	ms	
Time to first conversion ready	t_{CONV_DLY}		170	200	ms	
LED Drivers						
Duty Cycle	$DUTY_{LED}$	0		100	%	Programmable
Drive Frequency	f_{LED}		2		kHz	
Sinking Current	I_{SINK}			24	mA	V_{OL} = 0.4
Sourcing Current	I_{SOURCE}			24	mA	V_{OH} = V_{DD} - 0.4
Leakage Current	I_{LEAK}			±5	uA	powered or unpowered TA < 85°C pull-up voltage $\leq$ 3.6V if unpowered
I/O Pins						
Output Low Voltage	V_{OL}			0.4	V	I_{SINK_IO} = 8mA
Output High Voltage	V_{OH}	V_{DD} - 0.4			V	I_{SOURCE_IO} = 8mA
Input High Voltage	V_{IH}	2.0			V	

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TABLE 3-2: ELECTRICAL SPECIFICATIONS (CONTINUED)

V_{DD} = 3V to 3.6V, T_A = 0°C to 85°C, all typical values at T_A = 27°C unless otherwise noted.						
Characteristic	**Symbol**	**Min**	**Typ**	**Max**	**Unit**	**Conditions**
Input Low Voltage	V_{IL}			0.8	V	
Leakage Current	I_{LEAK}			±5	uA	powered or unpowered T_A < 85°C pull-up voltage ≤ 3.6V if unpowered
SMBus Timing						
Input Capacitance	C_{IN}		5		pF	
Clock Frequency	f_{SMB}	10		400	kHz	
Spike Suppression	t_{SP}			50	ns	
Bus Free Time Stop to Start	t_{BUF}	1.3			us	
Start Setup Time	$t_{SU:STA}$	0.6			us	
Start Hold Time	$t_{HD:STA}$	0.6			us	
Stop Setup Time	$t_{SU:STO}$	0.6			us	
Data Hold Time	$t_{HD:DAT}$	0			us	When transmitting to the master
Data Hold Time	$t_{HD:DAT}$	0.3			us	When receiving from the master
Data Setup Time	$t_{SU:DAT}$	0.6			us	
Clock Low Period	t_{LOW}	1.3			us	
Clock High Period	t_{HIGH}	0.6			us	
Clock / Data Fall Time	t_{FALL}			300	ns	Min = 20+0.1C_{LOAD} ns
Clock / Data Rise Time	t_{RISE}			300	ns	Min = 20+0.1C_{LOAD} ns
Capacitive Load	C_{LOAD}			400	pF	per bus line

Note 3-4 The ALERT pin will not glitch high or low at power up if connected to VDD or another voltage.

Note 3-5 The SMCLK and SMDATA pins will not glitch low at power up if connected to VDD or another voltage.

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4.0 COMMUNICATIONS

4.1 Communications

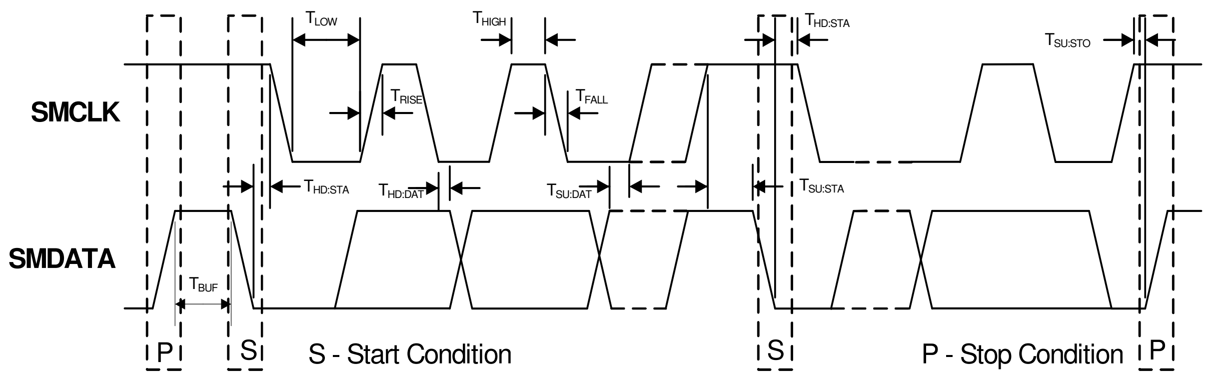
The CAP1133 communicates using the SMBus or I^2C protocol.

The supports the following protocols: Send Byte, Receive Byte, Read Byte, Write Byte, Read Block, and Write Block. In addition, the device supports I^2C formatting for block read and block write protocols.

4.2 System Management Bus

The CAP1133 communicates with a host controller, such as an SIO, through the SMBus. The SMBus is a two-wire serial communication protocol between a computer host and its peripheral devices. A detailed timing diagram is shown in Figure 4-1. Stretching of the SMCLK signal is supported; however, the CAP1133 will not stretch the clock signal.

FIGURE 4-1: *SMBus Timing Diagram*



4.2.1 SMBUS START BIT

The SMBus Start bit is defined as a transition of the SMBus Data line from a logic ‘1’ state to a logic ‘0’ state while the SMBus Clock line is in a logic ‘1’ state.

4.2.2 SMBUS ADDRESS AND RD / $\overline{\text{WR}}$ BIT

The SMBus Address Byte consists of the 7-bit slave address followed by the RD / $\overline{\text{WR}}$ indicator bit. If this RD / $\overline{\text{WR}}$ bit is a logic ‘0’, then the SMBus Host is writing data to the slave device. If this RD / $\overline{\text{WR}}$ bit is a logic ‘1’, then the SMBus Host is reading data from the slave device.

The CAP1133 responds to SMBus address 0101_000(r/w).

4.2.3 SMBUS DATA BYTES

All SMBus Data bytes are sent most significant bit first and composed of 8-bits of information.

4.2.4 SMBUS ACK AND NACK BITS

The SMBus slave will acknowledge all data bytes that it receives. This is done by the slave device pulling the SMBus Data line low after the 8th bit of each byte that is transmitted. This applies to both the Write Byte and Block Write protocols.

The Host will NACK (not acknowledge) the last data byte to be received from the slave by holding the SMBus data line high after the 8th data bit has been sent. For the Block Read protocol, the Host will ACK each data byte that it receives except the last data byte.

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4.2.5 SMBUS STOP BIT

The SMBus Stop bit is defined as a transition of the SMBus Data line from a logic '0' state to a logic '1' state while the SMBus clock line is in a logic '1' state. When the CAP1133 detects an SMBus Stop bit and it has been communicating with the SMBus protocol, it will reset its slave interface and prepare to receive further communications.

4.2.6 SMBUS TIMEOUT

The CAP1133 includes an SMBus timeout feature. Following a 30ms period of inactivity on the SMBus where the SMCLK pin is held low, the device will timeout and reset the SMBus interface.

The timeout function defaults to disabled. It can be enabled by setting the TIMEOUT bit in the Configuration register (see Section 6.6, "Configuration Registers").

4.2.7 SMBUS AND I²C COMPATIBILITY

The major differences between SMBus and I²C devices are highlighted here. For more information, refer to the SMBus 2.0 and I²C specifications. For information on using the CAP1133 in an I²C system, refer to AN 14.0 Dedicated Slave Devices in I²C Systems.

1. CAP1133 supports I²C fast mode at 400kHz. This covers the SMBus max time of 100kHz.
2. Minimum frequency for SMBus communications is 10kHz.
3. The SMBus slave protocol will reset if the clock is held at a logic '0' for longer than 30ms. This timeout functionality is disabled by default in the CAP1133 and can be enabled by writing to the TIMEOUT bit. I²C does not have a timeout.
4. The SMBus slave protocol will reset if both the clock and data lines are held at a logic '1' for longer than 200µs (idle condition). This function is disabled by default in the CAP1133 and can be enabled by writing to the TIMEOUT bit. I²C does not have an idle condition.
5. I²C devices do not support the Alert Response Address functionality (which is optional for SMBus).
6. I²C devices support block read and write differently. I²C protocol allows for unlimited number of bytes to be sent in either direction. The SMBus protocol requires that an additional data byte indicating number of bytes to read / write is transmitted. The CAP1133 supports I²C formatting only.

4.3 SMBus Protocols

The CAP1133 is SMBus 2.0 compatible and supports Write Byte, Read Byte, Send Byte, and Receive Byte as valid protocols as shown below.

All of the below protocols use the convention in Table 4-1.

TABLE 4-1: PROTOCOL FORMAT

Data Sent to Device	Data Sent to the HOst
Data sent	Data sent

4.3.1 SMBUS WRITE BYTE

The Write Byte is used to write one byte of data to a specific register as shown in Table 4-2.

TABLE 4-2: WRITE BYTE PROTOCOL

Start	Slave Address	WR	ACK	Register Address	ACK	Register Data	ACK	Stop
1 ->0	0101_000	0	0	XXh	0	XXh	0	0 -> 1

4.3.2 SMBUS READ BYTE

The Read Byte protocol is used to read one byte of data from the registers as shown in Table 4-3.

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TABLE 4-3: READ BYTE PROTOCOL

Start	Slave Address	WR	ACK	Register Address	ACK	Start	Slave Address	RD	ACK	Register Data	NACK	Stop
1->0	0101_000	0	0	XXh	0	1 ->0	0101_000	1	0	XXh	1	0 -> 1

4.3.3 SMBUS SEND BYTE

The Send Byte protocol is used to set the internal address register pointer to the correct address location. No data is transferred during the Send Byte protocol as shown in Table 4-4.

APPLICATION NOTE: The Send Byte protocol is not functional in Deep Sleep (i.e., DSLEEP bit is set).

TABLE 4-4: SEND BYTE PROTOCOL

Start	Slave Address	WR	ACK	Register Address	ACK	Stop
1 -> 0	0101_000	0	0	XXh	0	0 -> 1

4.3.4 SMBUS RECEIVE BYTE

The Receive Byte protocol is used to read data from a register when the internal register address pointer is known to be at the right location (e.g., set via Send Byte). This is used for consecutive reads of the same register as shown in Table 4-5.

APPLICATION NOTE: The Receive Byte protocol is not functional in Deep Sleep (i.e., DSLEEP bit is set).

TABLE 4-5: RECEIVE BYTE PROTOCOL

Start	Slave Address	RD	ACK	Register Data	NACK	Stop
1 -> 0	0101_000	1	0	XXh	1	0 -> 1

4.4 I^{2}C Protocols

The CAP1133 supports I^{2}C Block Write and Block Read.

The protocols listed below use the convention in Table 4-1.

4.4.1 BLOCK WRITE

The Block Write is used to write multiple data bytes to a group of contiguous registers as shown in Table 4-6.

APPLICATION NOTE: When using the Block Write protocol, the internal address pointer will be automatically incremented after every data byte is received. It will wrap from FFh to 00h.

TABLE 4-6: BLOCK WRITE PROTOCOL

Start	Slave Address	WR	ACK	Register Address	ACK	Register Data	ACK
1 ->0	0101_000	0	0	XXh	0	XXh	0
Register Data	ACK	Register Data	ACK	. . .	Register Data	ACK	Stop
XXh	0	XXh	0	. . .	XXh	0	0 -> 1

4.4.2 BLOCK READ

The Block Read is used to read multiple data bytes from a group of contiguous registers as shown in Table 4-7.

APPLICATION NOTE: When using the Block Read protocol, the internal address pointer will be automatically incremented after every data byte is received. It will wrap from FFh to 00h.

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TABLE 4-7: BLOCK READ PROTOCOL

Start	Slave Address	WR	ACK	Register Address	ACK	Start	Slave Address	RD	ACK	Register Data
1->0	0101_000	0	0	XXh	0	1 ->0	0101_000	1	0	XXh
ACK	Register Data	ACK	Register Data	ACK	Register Data	ACK	. . .	Register Data	NACK	Stop
0	XXh	0	XXh	0	XXh	0	. . .	XXh	1	0 -> 1

5.0 GENERAL DESCRIPTION

The CAP1133 is a multiple channel Capacitive Touch sensor with multiple power LED drivers. It contains three (3) individual capacitive touch sensor inputs with programmable sensitivity for use in touch sensor applications. Each sensor input automatically recalibrates to compensate for gradual environmental changes.

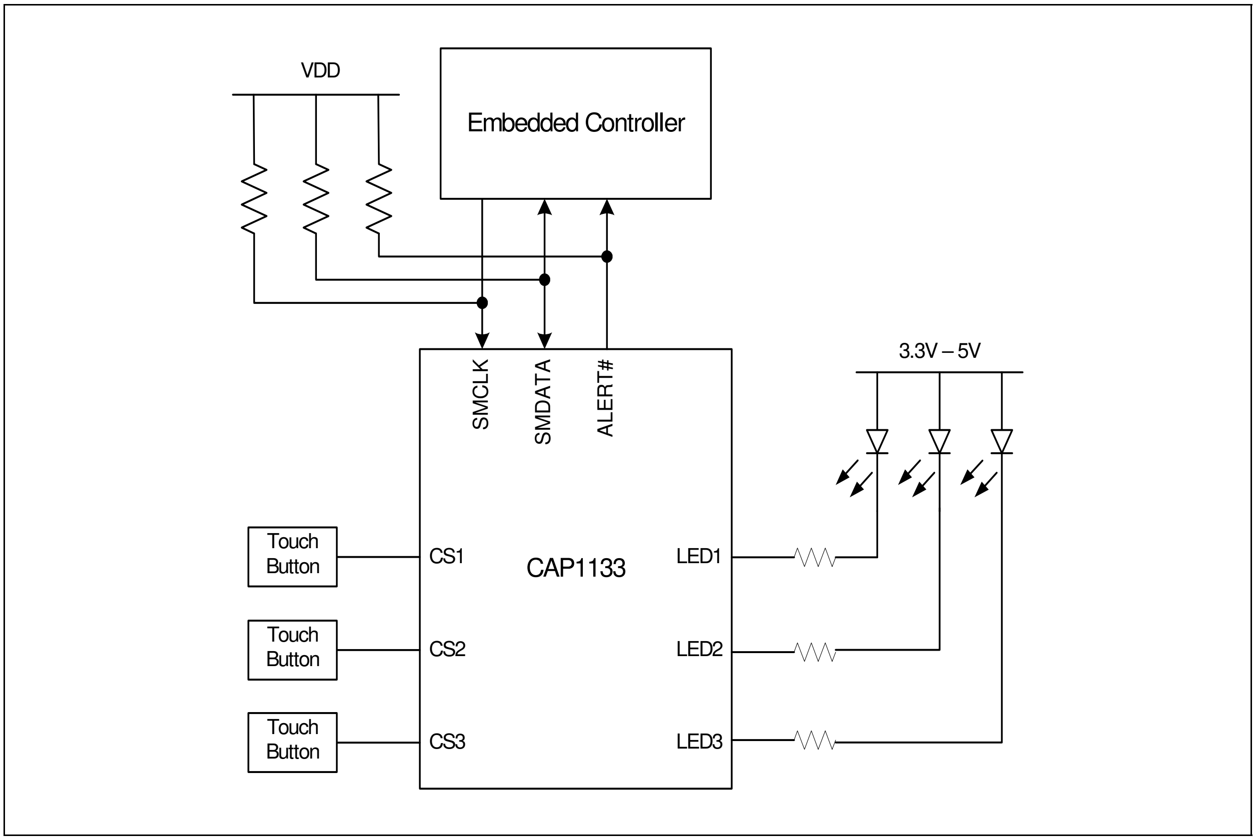
The CAP1133 also contains three (3) low side (or push-pull) LED drivers that offer full-on / off, variable rate blinking, dimness controls, and breathing. Each of the LED drivers may be linked to one of the sensor inputs to be actuated when a touch is detected. As well, each LED driver may be individually controlled via a host controller.

The CAP1133 offers multiple power states. It operates at the lowest quiescent current during its Deep Sleep state. In the low power Standby state, it can monitor one or more channels and respond to communications normally.

The device communicates with a host controller using SMBus / I^{2}C. The host controller may poll the device for updated information at any time or it may configure the device to flag an interrupt whenever a touch is detected on any sensor pad.

A typical system diagram is shown in Figure 5-1.

FIGURE 5-1: *System Diagram for CAP1133*



5.1 Power States

The CAP1133 has three operating states depending on the status of the STBY and DSLEEP bits. When the device transitions between power states, previously detected touches (for inactive channels) are cleared and the status bits reset.

1. Fully Active - The device is fully active. It is monitoring all active capacitive sensor inputs and driving all LED channels as defined.
2. Standby - The device is in a lower power state. It will measure a programmable number of channels using the Standby Configuration controls (see Section 6.20 through Section 6.22). Interrupts will still be generated based on the active channels. The device will still respond to communications normally and can be returned to the Fully Active state of operation by clearing the STBY bit.

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3. Deep Sleep - The device is in its lowest power state. It is not monitoring any capacitive sensor inputs and not driving any LEDs. All LEDs will be driven to their programmed non-actuated state and no PWM operations will be done. While in Deep Sleep, the device can be awakened by SMBus communications targeting the device. This will not cause the DSLEEP to be cleared so the device will return to Deep Sleep once all communications have stopped.

APPLICATION NOTE: In the Deep Sleep state, the LED output will be either high or low and will not be PWM'd at the min or max duty cycle.

5.2 LED Drivers

The CAP1133 contains three (3) LED drivers. Each LED driver can be linked to its respective capacitive touch sensor input or it can be controlled by the host. Each LED driver can be configured to operate in one of the following modes with either push-pull or open drain drive.

1. Direct - The LED is configured to be on or off when the corresponding input stimulus is on or off (or inverted). The brightness of the LED can be programmed from full off to full on (default). Additionally, the LED contains controls to individually configure ramping on, off, and turn-off delay.
2. Pulse 1 - The LED is configured to “Pulse” (transition ON-OFF-ON) a programmable number of times with programmable rate and min / max brightness. This behavior may be actuated when a press is detected or when a release is detected.
3. Pulse 2 - The LED is configured to “Pulse” while actuated and then “Pulse” a programmable number of times with programmable rate and min / max brightness when the sensor pad is released.
4. Breathe - The LED is configured to transition continuously ON-OFF-ON (i.e. to “Breathe”) with a programmable rate and min / max brightness.

When an LED is not linked to a sensor and is actuated by the host, there’s an option to assert the ALERT# pin when the initiated LED behavior has completed.

5.2.1 LINKING LEDS TO CAPACITIVE TOUCH SENSOR INPUTS

All LEDs can be linked to the corresponding capacitive touch sensor input so that when the sensor input detects a touch, the corresponding LED will be actuated at one of the programmed responses.

5.3 Capacitive Touch Sensing

The CAP1133 contains three (3) independent capacitive touch sensor inputs. Each sensor input has dynamic range to detect a change of capacitance due to a touch. Additionally, each sensor input can be configured to be automatically and routinely re-calibrated.

5.3.1 SENSING CYCLE

Each capacitive touch sensor input has controls to be activated and included in the sensing cycle. When the device is active, it automatically initiates a sensing cycle and repeats the cycle every time it finishes. The cycle polls through each active sensor input starting with CS1 and extending through CS3. As each capacitive touch sensor input is polled, its measurement is compared against a baseline “Not Touched” measurement. If the delta measurement is large enough, a touch is detected and an interrupt is generated.

The sensing cycle time is programmable (see Section 6.10, "Averaging and Sampling Configuration Register").

5.3.2 RECALIBRATING SENSOR INPUTS

There are various options for recalibrating the capacitive touch sensor inputs. Recalibration re-sets the Base Count Registers (Section 6.24, "Sensor Input Base Count Registers") which contain the “not touched” values used for touch detection comparisons.

APPLICATION NOTE: The device will recalibrate all sensor inputs that were disabled when it transitions from Standby. Likewise, the device will recalibrate all sensor inputs when waking out of Deep Sleep.

5.3.2.1 Manual Recalibration

The Calibration Activate Registers (Section 6.11, "Calibration Activate Register") force recalibration of selected sensor inputs. When a bit is set, the corresponding capacitive touch sensor input will be recalibrated (both analog and digital). The bit is automatically cleared once the recalibration routine has finished.

> **Note:** During this recalibration routine, the sensor inputs will not detect a press for up to 200ms and the Sensor Base Count Register values will be invalid. In addition, any press on the corresponding sensor pads will invalidate the recalibration.

5.3.2.2 Automatic Recalibration

Each sensor input is regularly recalibrated at a programmable rate (see Section 6.17, "Recalibration Configuration Register"). By default, the recalibration routine stores the average 64 previous measurements and periodically updates the base “not touched” setting for the capacitive touch sensor input.

> **Note:** Automatic recalibration only works when the delta count is below the active sensor input threshold. It is disabled when a touch is detected.

5.3.2.3 Negative Delta Count Recalibration

It is possible that the device loses sensitivity to a touch. This may happen as a result of a noisy environment, an accidental recalibration during a touch, or other environmental changes. When this occurs, the base untouched sensor input may generate negative delta count values. The NEG_DELTA_CNT bits (see Section 6.17, "Recalibration Configuration Register") can be set to force a recalibration after a specified number of consecutive negative delta readings.

> **Note:** During this recalibration, the device will not respond to touches.

5.3.2.4 Delayed Recalibration

It is possible that a “stuck button” occurs when something is placed on a button which causes a touch to be detected for a long period. By setting the MAX_DUR_EN bit (see Section 6.6, "Configuration Registers"), a recalibration can be forced when a touch is held on a button for longer than the duration specified in the MAX_DUR bits (see Section 6.8, "Sensor Input Configuration Register").

> **Note:** Delayed recalibration only works when the delta count is above the active sensor input threshold. If enabled, it is invoked when a sensor pad touch is held longer than the MAX_DUR bit setting.

5.3.3 PROXIMITY DETECTION

Each sensor input can be configured to detect changes in capacitance due to proximity of a touch. This circuitry detects the change of capacitance that is generated as an object approaches, but does not physically touch, the enabled sensor pad(s). When a sensor input is selected to perform proximity detection, it will be sampled from 1x to 128x per sampling cycle. The larger the number of samples that are taken, the greater the range of proximity detection is available at the cost of an increased overall sampling time.

5.3.4 MULTIPLE TOUCH PATTERN DETECTION

The multiple touch pattern (MTP) detection circuitry can be used to detect lid closure or other similar events. An event can be flagged based on either a minimum number of sensor inputs or on specific sensor inputs simultaneously exceeding an MTP threshold or having their Noise Flag Status Register bits set. An interrupt can also be generated. During an MTP event, all touches are blocked (see Section 6.15, "Multiple Touch Pattern Configuration Register").

5.3.5 LOW FREQUENCY NOISE DETECTION

Each sensor input has an EMI noise detector that will sense if low frequency noise is injected onto the input with sufficient power to corrupt the readings. If this occurs, the device will reject the corrupted sample and set the corresponding bit in the Noise Status register to a logic ‘1’.

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5.3.6 RF NOISE DETECTION

Each sensor input contains an integrated RF noise detector. This block will detect injected RF noise on the CS pin. The detector threshold is dependent upon the noise frequency. If RF noise is detected on a CS line, that sample is removed and not compared against the threshold.

5.4 ALERT# Pin

The ALERT# pin is an active low (or active high when configured) output that is driven when an interrupt event is detected.

Whenever an interrupt is generated, the INT bit (see Section 6.1, "Main Control Register") is set. The ALERT# pin is cleared when the INT bit is cleared by the user. Additionally, when the INT bit is cleared by the user, status bits are only cleared if no touch is detected.

5.4.1 SENSOR INTERRUPT BEHAVIOR

The sensor interrupts are generated in one of two ways:

1. An interrupt is generated when a touch is detected and, as a user selectable option, when a release is detected (by default - see Section 6.6). See Figure 5-3.
2. If the repeat rate is enabled then, so long as the touch is held, another interrupt will be generated based on the programmed repeat rate (see Figure 5-2).

When the repeat rate is enabled, the device uses an additional control called MPRESS that determines whether a touch is flagged as a simple “touch” or a “press and hold”. The MPRESS[3:0] bits set a minimum press timer. When the button is touched, the timer begins. If the sensor pad is released before the minimum press timer expires, it is flagged as a touch and an interrupt is generated upon release. If the sensor input detects a touch for longer than this timer value, it is flagged as a “press and hold” event. So long as the touch is held, interrupts will be generated at the programmed repeat rate and upon release (if enabled).

APPLICATION NOTE: Figure 5-2 and Figure 5-3 show default operation which is to generate an interrupt upon sensor pad release and an active-low ALERT# pin.

APPLICATION NOTE: The host may need to poll the device twice to determine that a release has been detected.

FIGURE 5-2: *Sensor Interrupt Behavior - Repeat Rate Enabled*

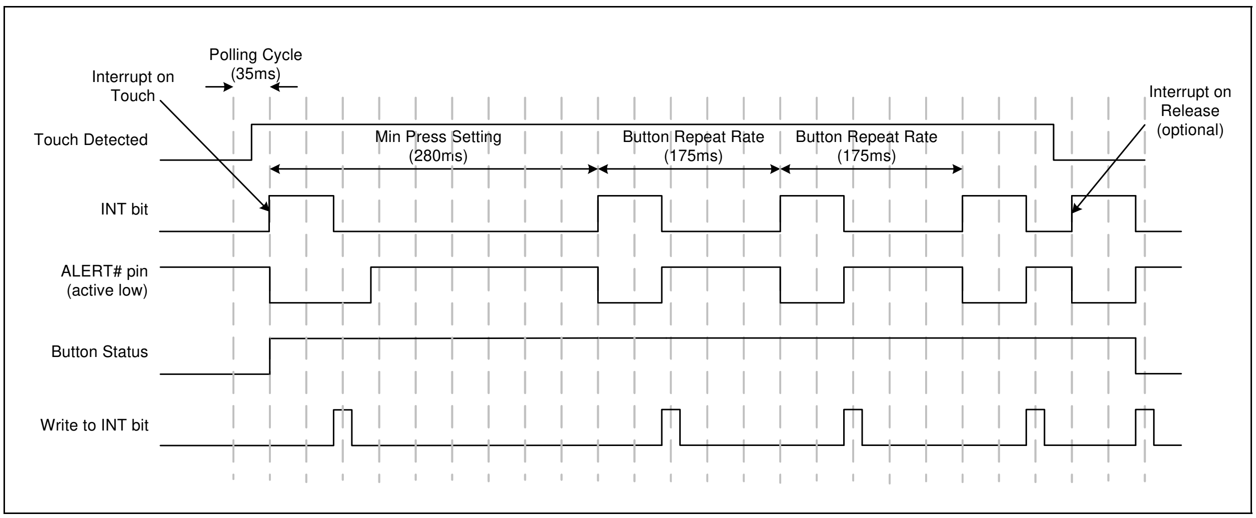
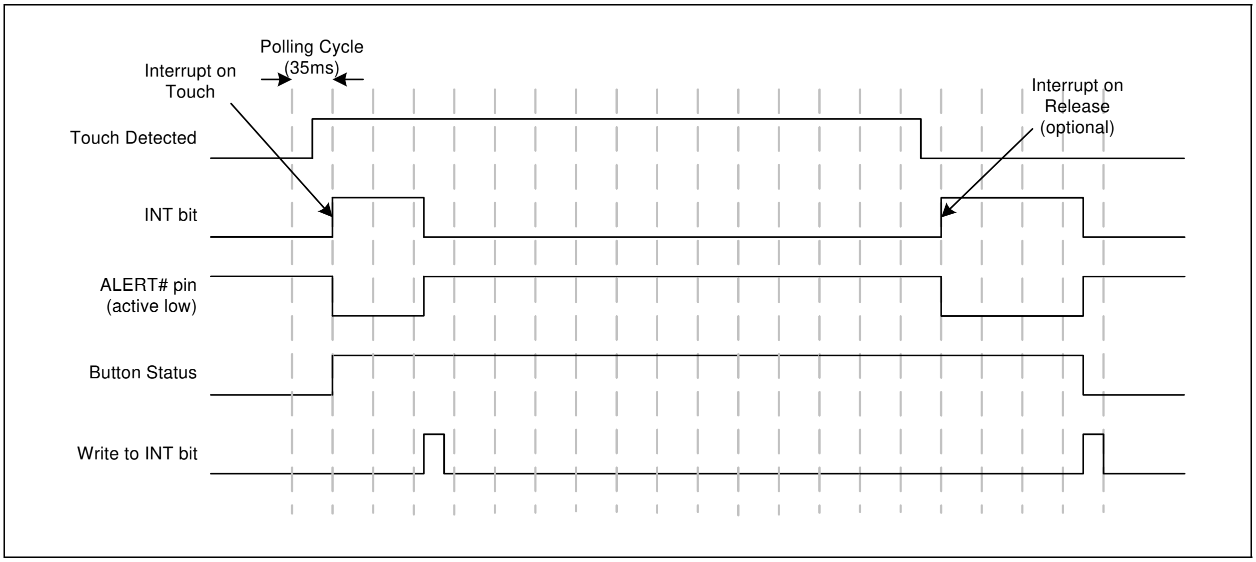


FIGURE 5-3: *Sensor Interrupt Behavior - No Repeat Rate Enabled*



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6.0 REGISTER DESCRIPTION

The registers shown in Table 6-1 are accessible through the communications protocol. An entry of '-' indicates that the bit is not used and will always read '0'.

TABLE 6-1: REGISTER SET IN HEXADECIMAL ORDER

Register Address	R/W	Register Name	Function	Default Value	Page
00h	R/W	Main Control	Controls general power states and power dissipation	00h	Page 21
02h	R	General Status	Stores general status bits	00h	Page 22
03h	R	Sensor Input Status	Returns the state of the sampled capacitive touch sensor inputs	00h	Page 22
04h	R	LED Status	Stores status bits for LEDs	00h	Page 22
0Ah	R	Noise Flag Status	Stores the noise flags for sensor inputs	00h	Page 23
10h	R	Sensor Input 1 Delta Count	Stores the delta count for CS1	00h	Page 23
11h	R	Sensor Input 2 Delta Count	Stores the delta count for CS2	00h	Page 23
12h	R	Sensor Input 3 Delta Count	Stores the delta count for CS3	00h	Page 23
1Fh	R/W	Sensitivity Control	Controls the sensitivity of the threshold and delta counts and data scaling of the base counts	2Fh	Page 24
20h	R/W	Configuration	Controls general functionality	20h	Page 25
21h	R/W	Sensor Input Enable	Controls whether the capacitive touch sensor inputs are sampled	07h	Page 26
22h	R/W	Sensor Input Configuration	Controls max duration and auto-repeat delay for sensor inputs operating in the full power state	A4h	Page 27
23h	R/W	Sensor Input Configuration 2	Controls the MPRESS controls for all sensor inputs	07h	Page 28
24h	R/W	Averaging and Sampling Config	Controls averaging and sampling window	39h	Page 28
26h	R/W	Calibration Activate	Forces re-calibration for capacitive touch sensor inputs	00h	Page 30
27h	R/W	Interrupt Enable	Enables Interrupts associated with capacitive touch sensor inputs	07h	Page 30
28h	R/W	Repeat Rate Enable	Enables repeat rate for all sensor inputs	07h	Page 30
2Ah	R/W	Multiple Touch Configuration	Determines the number of simultaneous touches to flag a multiple touch condition	80h	Page 31
2Bh	R/W	Multiple Touch Pattern Configuration	Determines the multiple touch pattern (MTP) configuration	00h	Page 31
2Dh	R/W	Multiple Touch Pattern	Determines the pattern or number of sensor inputs used by the MTP circuitry	07h	Page 32
2Fh	R/W	Recalibration Configuration	Determines re-calibration timing and sampling window	8Ah	Page 33
30h	R/W	Sensor Input 1 Threshold	Stores the delta count threshold to determine a touch for Capacitive Touch Sensor Input 1	40h	Page 34

TABLE 6-1: REGISTER SET IN HEXADECIMAL ORDER (CONTINUED)

Register Address	R/W	Register Name	Function	Default Value	Page
31h	R/W	Sensor Input 2 Threshold	Stores the delta count threshold to determine a touch for Capacitive Touch Sensor Input 2	40h	Page 34
32h	R/W	Sensor Input 3 Threshold	Stores the delta count threshold to determine a touch for Capacitive Touch Sensor Input 3	40h	Page 34
38h	R/W	Sensor Input Noise Threshold	Stores controls for selecting the noise threshold for all sensor inputs	01h	Page 34
Standby Configuration Registers					
40h	R/W	Standby Channel	Controls which sensor inputs are enabled while in standby	00h	Page 35
41h	R/W	Standby Configuration	Controls averaging and cycle time while in standby	39h	Page 35
42h	R/W	Standby Sensitivity	Controls sensitivity settings used while in standby	02h	Page 36
43h	R/W	Standby Threshold	Stores the touch detection threshold for active sensor inputs in standby	40h	Page 37
44h	R/W	Configuration 2	Stores additional configuration controls for the device	40h	Page 25
Base Count Registers					
50h	R	Sensor Input 1 Base Count	Stores the reference count value for sensor input 1	C8h	Page 37
51h	R	Sensor Input 2 Base Count	Stores the reference count value for sensor input 2	C8h	Page 37
52h	R	Sensor Input 3 Base Count	Stores the reference count value for sensor input 3	C8h	Page 37
LED Controls					
71h	R/W	LED Output Type	Controls the output type for the LED outputs	00h	Page 38
72h	R/W	Sensor Input LED Linking	Controls linking of sensor inputs to LED channels	00h	Page 38
73h	R/W	LED Polarity	Controls the output polarity of LEDs	00h	Page 38
74h	R/W	LED Output Control	Controls the output state of the LEDs	00h	Page 39
77h	R/W	Linked LED Transition Control	Controls the transition when LEDs are linked to CS channels	00h	Page 40
79h	R/W	LED Mirror Control	Controls the mirroring of duty cycles for the LEDs	00h	Page 41
81h	R/W	LED Behavior 1	Controls the behavior and response of LEDs 1 - 3	00h	Page 41
84h	R/W	LED Pulse 1 Period	Controls the period of each breathe during a pulse	20h	Page 43
85h	R/W	LED Pulse 2 Period	Controls the period of the breathing during breathe and pulse operation	14h	Page 45
86h	R/W	LED Breathe Period	Controls the period of an LED breathe operation	5Dh	Page 46
88h	R/W	LED Config	Controls LED configuration	04h	Page 46
90h	R/W	LED Pulse 1 Duty Cycle	Determines the min and max duty cycle for the pulse operation	F0h	Page 47

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TABLE 6-1: REGISTER SET IN HEXADECIMAL ORDER (CONTINUED)

Register Address	R/W	Register Name	Function	Default Value	Page
91h	R/W	LED Pulse 2 Duty Cycle	Determines the min and max duty cycle for breathe and pulse operation	F0h	Page 47
92h	R/W	LED Breathe Duty Cycle	Determines the min and max duty cycle for the breathe operation	F0h	Page 47
93h	R/W	LED Direct Duty Cycle	Determines the min and max duty cycle for Direct mode LED operation	F0h	Page 47
94h	R/W	LED Direct Ramp Rates	Determines the rising and falling edge ramp rates of the LEDs	00h	Page 47
95h	R/W	LED Off Delay	Determines the off delay for all LED behaviors	00h	Page 48
B1h	R	Sensor Input 1 Calibration	Stores the upper 8-bit calibration value for sensor input 1	00h	Page 51
B2h	R	Sensor Input 2 Calibration	Stores the upper 8-bit calibration value for sensor input 2	00h	Page 51
B3h	R	Sensor Input 3 Calibration	Stores the upper 8-bit calibration value for sensor input 3	00h	Page 51
B9h	R	Sensor Input Calibration LSB 1	Stores the 2 LSBs of the calibration value for sensor inputs 1 - 3	00h	Page 51
FDh	R	Product ID	Stores a fixed value that identifies each product	54h	Page 51
FEh	R	Manufacturer ID	Stores a fixed value that identifies Microchip	5Dh	Page 52
FFh	R	Revision	Stores a fixed value that represents the revision number	83h	Page 52

During Power-On-Reset (POR), the default values are stored in the registers. A POR is initiated when power is first applied to the part and the voltage on the VDD supply surpasses the POR level as specified in the electrical characteristics. Any reads to undefined registers will return 00h. Writes to undefined registers will not have an effect.

When a bit is “set”, this means that the user writes a logic ‘1’ to it. When a bit is “cleared”, this means that the user writes a logic ‘0’ to it.

6.1 Main Control Register

TABLE 6-2: MAIN CONTROL REGISTER

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
00h	R/W	Main Control	GAIN[1:0]		STBY	DSLEEP	-	-	-	INT	00h

The Main Control register controls the primary power state of the device.

Bits 7 - 6 - GAIN[1:0] - Controls the gain used by the capacitive touch sensing circuitry. As the gain is increased, the effective sensitivity is likewise increased as a smaller delta capacitance is required to generate the same delta count values. The sensitivity settings may need to be adjusted along with the gain settings such that data overflow does not occur.

APPLICATION NOTE: The gain settings apply to both Standby and Active states.

TABLE 6-3: GAIN BIT DECODE

GAIN[1:0]		Capacitive Touch Sensor Gain
1	**0**	
0	0	1

TABLE 6-3: GAIN BIT DECODE (CONTINUED)

GAIN[1:0]		Capacitive Touch Sensor Gain
1	0	
0	1	2
1	0	4
1	1	8

Bit 5 - STBY - Enables Standby.

- ‘0’ (default) - Sensor input scanning is active and LEDs are functional.
- ‘1’ - Capacitive touch sensor input scanning is limited to the sensor inputs set in the Standby Channel register (see Section 6.20). The status registers will not be cleared until read. LEDs that are linked to capacitive touch sensor inputs will remain linked and active. Sensor inputs that are no longer sampled will flag a release and then remain in a non-touched state. LEDs that are manually controlled will be unaffected.
- Bit 4 - DSLEEP - Enables Deep Sleep by deactivating all functions. ‘0’ (default) - Sensor input scanning is active and LEDs are functional.
- ‘1’ - All sensor input scanning is disabled. All LEDs are driven to their programmed non-actuated state and no PWM operations will be done. The status registers are automatically cleared and the INT bit is cleared.

Bit 0 - INT - Indicates that there is an interrupt. When this bit is set, it asserts the ALERT# pin. If a channel detects a touch and its associated interrupt enable bit is not set to a logic ‘1’, no action is taken.

This bit is cleared by writing a logic ‘0’ to it. When this bit is cleared, the ALERT# pin will be deasserted and all status registers will be cleared if the condition has been removed.

- ‘0’ - No interrupt pending.
- ‘1’ - A touch has been detected on one or more channels and the interrupt has been asserted.

6.2 Status Registers

TABLE 6-4: STATUS REGISTERS

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
02h	R	General Status	-	-	-	LED	-	MULT	MTP	TOUCH	00h
03h	R	Sensor Input Status	-	-	-	-	-	CS3	CS2	CS1	00h
04h	R	LED Status	-	-	-	-	-	LED3_DN	LED2_DN	LED1_DN	00h

All status bits are cleared when the device enters the Deep Sleep (DSLEEP = ‘1’ - see Section 6.1).

6.2.1 GENERAL STATUS - 02H

Bit 4 - LED - Indicates that one or more LEDs have finished their programmed activity. This bit is set if any bit in the LED Status register is set.

Bit 2 - MULT - Indicates that the device is blocking detected touches due to the Multiple Touch detection circuitry (see Section 6.14). This bit will not cause the INT bit to be set and hence will not cause an interrupt.

Bit 1 - MTP - Indicates that the device has detected a number of sensor inputs that exceed the MTP threshold either via the pattern recognition or via the number of sensor inputs (see Section 6.15). This bit will cause the INT bit to be set if the MTP_ALERT bit is also set. This bit will not be cleared until the condition that caused it to be set has been removed.

Bit 0 - TOUCH - Indicates that a touch was detected. This bit is set if any bit in the Sensor Input Status register is set.

6.2.2 SENSOR INPUT STATUS - 03H

The Sensor Input Status Register stores status bits that indicate a touch has been detected. A value of ‘0’ in any bit indicates that no touch has been detected. A value of ‘1’ in any bit indicates that a touch has been detected.

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All bits are cleared when the INT bit is cleared and if a touch on the respective capacitive touch sensor input is no longer present. If a touch is still detected, the bits will not be cleared (but this will not cause the interrupt to be asserted - see Section 6.6).

Bit 2 - CS3 - Indicates that a touch was detected on Sensor Input 3. This sensor input can be linked to LED3.

Bit 1 - CS2 - Indicates that a touch was detected on Sensor Input 2. This sensor input can be linked to LED2.

Bit 0 - CS1 - Indicates that a touch was detected on Sensor Input 1. This sensor input can be linked to LED1.

6.2.3 LED STATUS - 04H

The LED Status Registers indicate when an LED has completed its configured behavior (see Section 6.31, "LED Behavior Register") after being actuated by the host (see Section 6.28, "LED Output Control Register"). These bits are ignored when the LED is linked to a capacitive sensor input. All LED Status bits are cleared when the INT bit is cleared.

Bit 2 - LED3_DN - Indicates that LED3 has finished its behavior after being actuated by the host.

Bit 1 - LED2_DN - Indicates that LED2 has finished its behavior after being actuated by the host.

Bit 0 - LED1_DN - Indicates that LED1 has finished its behavior after being actuated by the host.

6.3 Noise Flag Status Registers

TABLE 6-5: NOISE FLAG STATUS REGISTERS

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
0Ah	R	Noise Flag Status			-	-	-	CS3_ NOISE	CS2_ NOISE	CS1_ NOISE	00h

The Noise Flag Status registers store status bits that are generated from the analog block if the detected noise is above the operating region of the analog detector or the RF noise detector. These bits indicate that the most recently received data from the sensor input is invalid and should not be used for touch detection. So long as the bit is set for a particular channel, the delta count value is reset to 00h and thus no touch is detected.

These bits are not sticky and will be cleared automatically if the analog block does not report a noise error.

APPLICATION NOTE: If the MTP detection circuitry is enabled, these bits count as sensor inputs above the MTP threshold (see Section 5.3.4, "Multiple Touch Pattern Detection") even if the corresponding delta count is not. If the corresponding delta count also exceeds the MTP threshold, it is not counted twice.

APPLICATION NOTE: Regardless of the state of the Noise Status bits, if low frequency noise is detected on a sensor input, that sample will be discarded unless the DIS_ANA_NOISE bit is set. As well, if RF noise is detected on a sensor input, that sample will be discarded unless the DIS_RF_NOISE bit is set.

6.4 Sensor Input Delta Count Registers

TABLE 6-6: SENSOR INPUT DELTA COUNT REGISTERS

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
10h	R	Sensor Input 1 Delta Count	Sign	64	32	16	8	4	2	1	00h
11h	R	Sensor Input 2 Delta Count	Sign	64	32	16	8	4	2	1	00h
12h	R	Sensor Input 3 Delta Count	Sign	64	32	16	8	4	2	1	00h

The Sensor Input Delta Count registers store the delta count that is compared against the threshold used to determine if a touch has been detected. The count value represents a change in input due to the capacitance associated with a touch on one of the sensor inputs and is referenced to a calibrated base “Not Touched” count value. The delta is an instantaneous change and is updated once per sensor input per sensing cycle (see Section 5.3.1, "Sensing Cycle").

The value presented is a standard 2's complement number. In addition, the value is capped at a value of 7Fh. A reading of 7Fh indicates that the sensitivity settings are too high and should be adjusted accordingly (see Section 6.5).

The value is also capped at a negative value of 80h for negative delta counts which may result upon a release.

6.5 Sensitivity Control Register

TABLE 6-7: SENSITIVITY CONTROL REGISTER

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
1Fh	R/W	Sensitivity Control	-	DELTA_SENSE[2:0]			BASE_SHIFT[3:0]				2Fh

The Sensitivity Control register controls the sensitivity of a touch detection.

Bits 6-4 DELTA_SENSE[2:0] - Controls the sensitivity of a touch detection. The sensitivity settings act to scale the relative delta count value higher or lower based on the system parameters. A setting of 000b is the most sensitive while a setting of 111b is the least sensitive. At the more sensitive settings, touches are detected for a smaller delta capacitance corresponding to a "lighter" touch. These settings are more sensitive to noise, however, and a noisy environment may flag more false touches with higher sensitivity levels.

APPLICATION NOTE: A value of 128x is the most sensitive setting available. At the most sensitivity settings, the MSB of the Delta Count register represents 64 out of ~25,000 which corresponds to a touch of approximately 0.25% of the base capacitance (or a ΔC of 25fF from a 10pF base capacitance). Conversely, a value of 1x is the least sensitive setting available. At these settings, the MSB of the Delta Count register corresponds to a delta count of 8192 counts out of ~25,000 which corresponds to a touch of approximately 33% of the base capacitance (or a ΔC of 3.33pF from a 10pF base capacitance).

TABLE 6-8: DELTA_SENSE BIT DECODE

DELTA_SENSE[2:0]			Sensitivity Multiplier
2	1	0	
0	0	0	128x (most sensitive)
0	0	1	64x
0	1	0	32x (default)
0	1	1	16x
1	0	0	8x
1	0	1	4x
1	1	0	2x
1	1	1	1x - (least sensitive)

Bits 3 - 0 - BASE_SHIFT[3:0] - Controls the scaling and data presentation of the Base Count registers. The higher the value of these bits, the larger the range and the lower the resolution of the data presented. The scale factor represents the multiplier to the bit-weighting presented in these register descriptions.

APPLICATION NOTE: The BASE_SHIFT[3:0] bits normally do not need to be updated. These settings will not affect touch detection or sensitivity. These bits are sometimes helpful in analyzing the Cap Sensing board performance and stability.

TABLE 6-9: BASE_SHIFT BIT DECODE

BASE_SHIFT[3:0]				Data Scaling Factor
3	2	1	0	
0	0	0	0	1x
0	0	0	1	2x
0	0	1	0	4x
0	0	1	1	8x

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TABLE 6-9: BASE_SHIFT BIT DECODE (CONTINUED)

BASE_SHIFT[3:0]				Data Scaling Factor
3	2	1	0	
0	1	0	0	16x
0	1	0	1	32x
0	1	1	0	64x
0	1	1	1	128x
1	0	0	0	256x
All others				256x (default = 1111b)

6.6 Configuration Registers

TABLE 6-10: CONFIGURATION REGISTERS

ADDR	R/W	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
20h	R/W	Configuration	TIMEOUT	-	DIS_ DIG_ NOISE	DIS_ ANA_ NOISE	MAX_ DUR_EN	-	-	-	A0h (Rev B) 20h (rev C)
44h	R/W	Configuration 2	INV_LINK_ TRAN	ALT_ POL	BLK_PWR_ CTRL	BLK_POL_ MIR	SHOW_ RF_ NOISE	DIS_ RF_ NOISE	-	INT_ REL_n	40h

The Configuration registers control general global functionality that affects the entire device.

6.6.1 CONFIGURATION - 20H

Bit 7 - TIMEOUT - Enables the timeout and idle functionality of the SMBus protocol.

- ‘0’ (default for Functional Revision C) - The SMBus timeout and idle functionality are disabled. The SMBus interface will not time out if the clock line is held low. Likewise, it will not reset if both the data and clock lines are held high for longer than 200us. This is used for I^2C compliance.
- ‘1’ (default for Functional Revision B) - The SMBus timeout and idle functionality are enabled. The SMBus interface will time out if the clock line is held low for longer than 30ms. Likewise, it will reset if both the data and clock lines are held high for longer than 200us.

Bit 5 - DIS_DIG_NOISE - Determines whether the digital noise threshold (see Section 6.19, "Sensor Input Noise Threshold Register") is used by the device. Setting this bit disables the feature.

- ‘0’ - The digital noise threshold is used. If a delta count value exceeds the noise threshold but does not exceed the touch threshold, the sample is discarded and not used for the automatic re-calibration routine.
- ‘1’ (default) - The noise threshold is disabled. Any delta count that is less than the touch threshold is used for the automatic re-calibration routine.

Bit 4 - DIS_ANA_NOISE - Determines whether the analog noise filter is enabled. Setting this bit disables the feature.

- ‘0’ (default) - If low frequency noise is detected by the analog block, the delta count on the corresponding channel is set to 0. Note that this does not require that Noise Status bits be set.
- ‘1’ - A touch is not blocked even if low frequency noise is detected.

Bit 3 - MAX_DUR_EN - Determines whether the maximum duration recalibration is enabled.

- ‘0’ (default) - The maximum duration recalibration functionality is disabled. A touch may be held indefinitely and no re-calibration will be performed on any sensor input.
- ‘1’ - The maximum duration recalibration functionality is enabled. If a touch is held for longer than the MAX_DUR bit settings, then the re-calibration routine will be restarted (see Section 6.8).

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