AN 21.4

CAP1188 Family LED Configuration Options

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INTRODUCTION

This application note contains guidelines for the successful implementation of LEDs using the following RightTouch™ capacitive sensors: CAP1188, CAP1166, CAP1133, CAP1128, and CAP1126.

References

Data Sheet for the RightTouch device of interest

Note: It is important to always refer to the Microchip Data Sheets and the Reference Design Schematics for complete and current information regarding any Capacitive Sensor designs. Additionally, the circuit examples shown in this document are for illustrative purposes only.

Document and Device Differences

In this document, the CAP1188 is used to illustrate various LED configurations. The CAP1166, CAP1133, CAP1128, and CAP1126 devices are similar with the exception of the number of capacitive sensors and LED drivers. Consult the device data sheet for specifics regarding the device you are using.

CONFIGURING LEDS TO MATCH BOARD DESIGN

In a board design, there's flexibility in how LEDs are connected. Two common methods of using LEDs include 1) using an external voltage source to generate the current needed to light the LED, and 2) using the RightTouch device to source the current needed. In addition, in some designs, button presses actuate the LEDs; in others, LEDs are controlled by the host. The RightTouch devices can be configured to accommodate these variations.

Output Type

The LED pins can be connected as open-drain or push-pull.

The LED Output Type Register (71h) controls the type of output for the LED pins, with each bit corresponding to an LED. For example, bit 0 corresponds with LED1 output type, bit 1 corresponds with LED2 output type, etc. A '0' in the bit position configures the associated pin as open-drain. A '1' in the bit position configures the associated pin as push-pull. The default for this register is 00h, which configures the pins as open-drain.

Polarity

LEDs can be configured such that if the LED pin is driven to a logic '0', the LED will be on and the CAP11xx LED pin is sinking the LED current. Conversely, if the LED pin is driven to a logic '1', the LED will be off and there is no current flow (see External Voltage Source on page 2). Because LEDs can also be installed in an opposite configuration (see RightTouch Device Sourcing Current on page 3), the RightTouch devices have a control to determine the logical polarity.

The LED Polarity Register (73h) determines the polarity of the LED pins, with each bit corresponding to an LED. A '0' in the bit position inverts the signal on the associated LED pin. A '1' in the bit position leaves the signal as it is. The default for these registers is 00h, which configures the pins as inverted.

LED Actuation Control

LEDs can be linked to their corresponding capacitive sensor input so that LED actuation is controlled by capacitive sensor touches and releases, or LED actuation can be controlled by the host.

Sensor LED Linking Register (72h) determines whether the LED is linked to its corresponding sensor input, with each bit corresponding to an LED. A ‘0’ in the bit position indicates the LED is not linked to the sensor. It is controlled via the LED Output Control Register. A ‘1’ in the bit position indicates the LED is linked to the sensor. The default for this register is 00h, which configures the LEDs so they are not linked to sensors.

Note:	When an LED is linked to a sensor, the corresponding bit in the LED Output Control register is ignored (i.e. the linked LED cannot be controlled via the host).

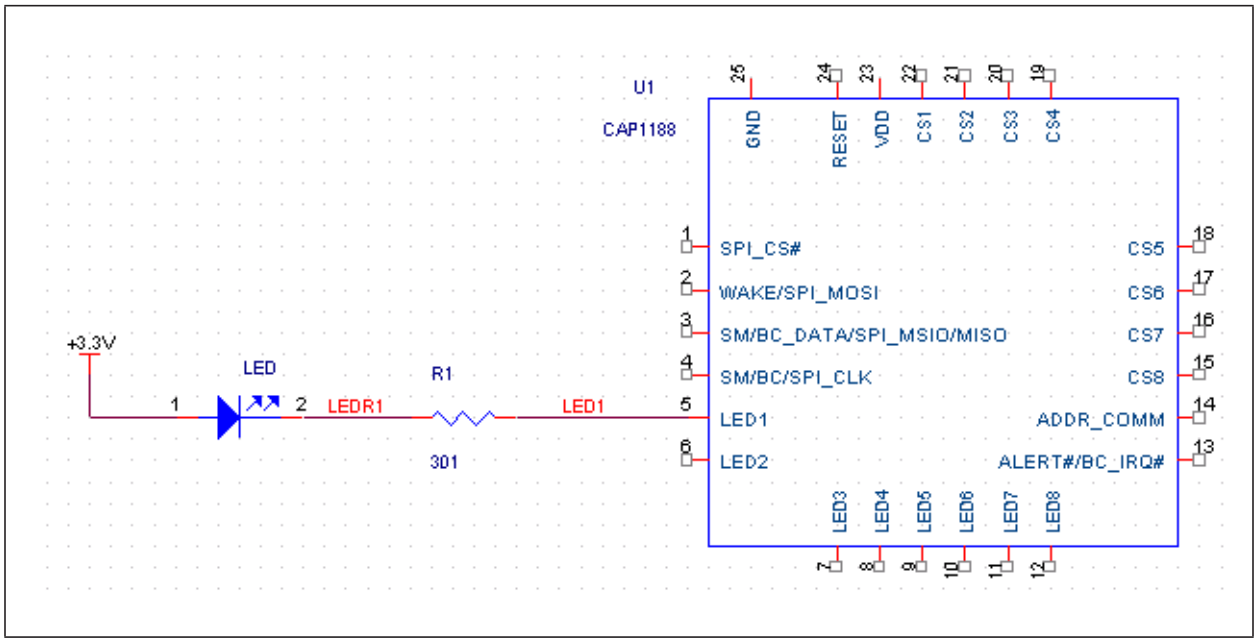
For LEDs that are not linked to sensors, the LED Output Control Register (74h) determines whether the LED is actuated or not. A ‘0’ in the bit position indicates the LED is not actuated. A ‘1’ in the bit position indicates the LED is actuated. The default for these registers is 00h, which configures the LEDs so they are not actuated.

CONFIGURATION FOR HARDWARE EXAMPLES

External Voltage Source

Figure 1 is a circuit example using an external voltage source.

FIGURE 1: *CAP1188 LED External Voltage Source Example*



The typical CAP1114 configuration for the circuit in Figure 1 is shown in Table 1.

TABLE 1: CAP1188 EXTERNAL VOLTAGE SOURCE EXAMPLE CONFIGURATION

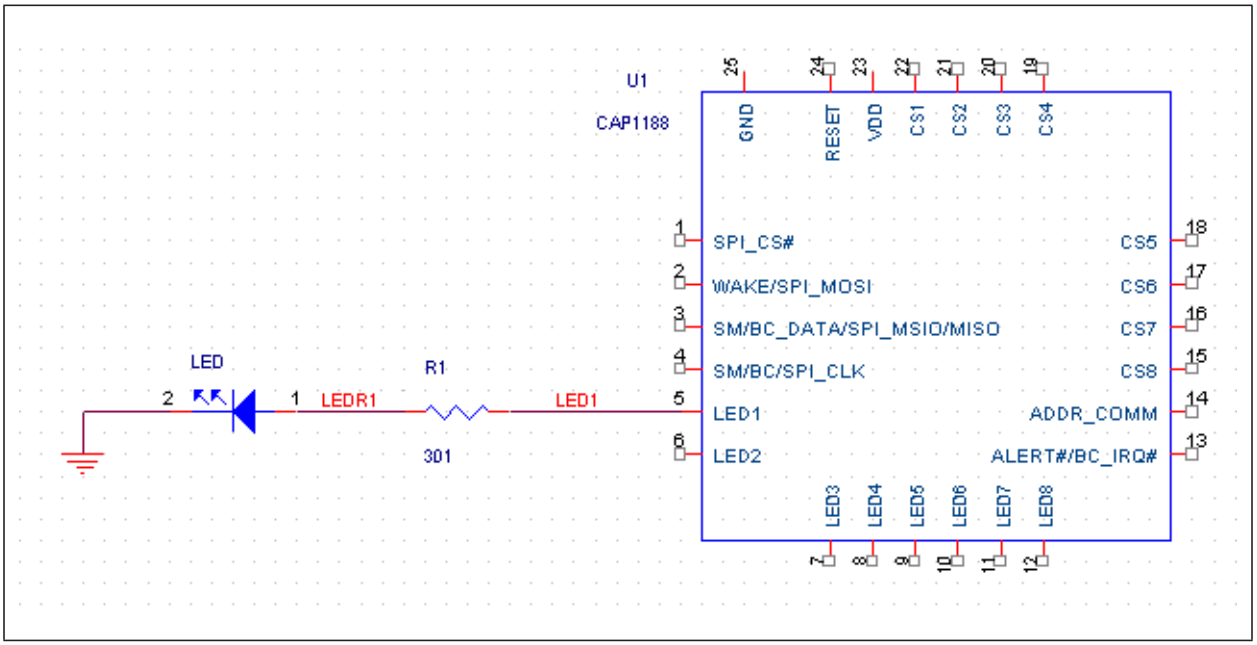
LED1 Configuration	Register	ADDR	Value	Comments
LED1 pin is open-drain.	LED Output Type Register	71h	00h	default
LED1 pin has inverted polarity.	LED Polarity Register	73h	00h	This will permit a '1' (actuate) written to the LED Output Control register to illuminate the LED.

Using the circuit in Figure 1 and the configuration in Table 1, LED1 can be illuminated by writing 01h to the LED Output Control Register 74h. Writing 00h to register 74h will turn off LED1.

RightTouch Device Sourcing Current

Figure 2 is a circuit example using the CAP1114 to source current for LED1.

FIGURE 2: *CAP1188 Sourcing LED Current Example*



The typical CAP1114 configuration for the circuit in Figure 2 is shown in Table 2.

TABLE 2: RIGHTTOUCH CURRENT SOURCE EXAMPLE CONFIGURATION

LED1 Configuration	Register	ADDR	Value	Comments
LED1 pin is push-pull.	LED Output Type Register	71h	01h	
LED1 pin has non-inverted polarity.	LED Polarity Register	73h	01h	This will permit a '1' (actuate) written to the LED Output Control register to illuminate the LED.

Using the circuit in Figure 2 and the configuration in Table 2, LED1 can be illuminated by writing 01h to the LED Output Control Register 74h. Writing 00h to register 74h will turn off LED1.

CONFIGURING LED OPERATION

The RightTouch LED drivers have four LED behaviors which can be used to control LED operation, whether the LED is actuated by the host or through a touch / release to a linked sensor. Brightness of the LEDs, as well as the transition rate from on to off, can be programmed for each behavior.

LED Behavior

Each LED can be assigned one of the following four behaviors:

- Direct: The LED is driven on or off.
- Pulse 1: The LED is configured to pulse (fade ON-OFF-ON) a programmable number of times.
- Pulse 2: The LED is configured to pulse while actively being driven, and then pulse a programmable number of times when the driving condition is removed.
- Breathe: The LED is configured to fade ON-OFF-ON continuously while actively being driven.

The LED Behavior Registers (81h - 82h of the CAP1188 and CAP1166, and 81h for the CAP1133, CAP1128, and CAP1126) control the type of behavior assigned to an LED, with every 2 bits corresponding to an LED. For example, bits 1-0 correspond with LED1 behavior type, bits 3-2 correspond with LED2 behavior type, etc. The bits are decoded to determine the behavior type, as shown in Table 3. The default for these registers is 00h, which configures each LED to use Direct behavior.

TABLE 3: LED BEHAVIOR REGISTER BIT DECODE

LEDX_CTL [1:0]		Behavior	Description	Start Trigger	Stop Trigger
1	0				
0	0	Direct	The LED is driven to the programmed state (active or inactive).	Touch Detected or LED Output Control bit set	Release Detected or LED Output Control bit cleared
0	1	Pulse 1	The LED will pulse a programmed number of times. During each pulse the LED will breathe up to the maximum brightness and back down to the minimum brightness so that the total pulse period matches the programmed value.	Touch or Release Detected or LED Output Control bit set or cleared (see Pulse 1 Start Trigger on page 5)	n/a
1	0	Pulse 2	The LED will pulse when the start trigger is detected. When the stop trigger is detected, it will pulse a programmable number of times then return to its minimum brightness.	Touch Detected or LED Output Control bit set	Release Detected or LED Output Control bit cleared
1	1	Breathe	The LED will breathe. It will be driven with a duty cycle that ramps up from the programmed minimum duty cycle (default 0%) to the programmed maximum duty cycle (default 100%) and then back down. Each ramp takes up 50% of the programmed period.	Touch Detected or LED Output Control bit set	Release Detected or LED Output Control bit cleared

PULSE 1 START TRIGGER

For Pulse 1 behavior, the pulses can be triggered to start when the LED is actuated (a touch is detected or the host sets the LED Output Control bit) or when the LED is de-actuated (a release is detected or the host clears the LED Output Control bit).

The LED Pulse 1 Period Register (84h) bit 7 (ST_TRIG) controls the Pulse 1 start trigger. The default for this bit is 0, which configures Pulse 1 behavior to start pulsing when a touch is detected or the drive bit is set. If the bit is set to 1, Pulse 1 behavior starts pulsing when a release is detected or the drive bit is cleared.

This setting will apply to all LEDs which have their behavior set to Pulse 1.

Pulse Count

The number of pulses (breaths) performed for the Pulse 1 and Pulse 2 behaviors are controlled by bits in the LED Configuration Register (88h). Bits 5-3 are decoded to determine the Pulse 2 count and bits 2-0 are decoded to determine Pulse 1 count. The decode and defaults are shown in Table 4.

TABLE 4: PULSEx_CNT DECODE

PULSEx_CNT[2:0]			Number of Pulses / Breaths	Default for Behavior
2	**1**	**0**		
0	0	0	1	Pulse 2 default
0	0	1	2	
0	1	0	3	
0	1	1	4	
1	0	0	5	Pulse 1 default
1	0	1	6	
1	1	0	7	
1	1	1	8	

LED Brightness

LED brightness is determined by duty cycles. An LED can either be on or off. To make an LED appear less bright, pulse width modulation (PWM) is used. The less time an LED is on, the dimmer it appears.

Each of the four behavior types has its own settings for minimum and maximum duty cycles, as shown in Table 5. The defaults set the maximum duty cycle to 100% and the minimum duty cycle to 0% for all behaviors.

TABLE 5: LED BEHAVIOR DUTY CYCLE REGISTERS

ADDR	Register	B7	B6	B5	B4	B3	B2	B1	B0	Default
90h	LED Pulse 1 Duty Cycle	LED_P1_MAX_DUTY[3:0]				LED_P1_MIN_DUTY[3:0]				F0h
91h	LED Pulse 2 Duty cycle	LED_P2_MAX_DUTY[3:0]				LED_P2_MIN_DUTY[3:0]				F0h
92h	LED Breathe Duty Cycle	LED_BR_MAX_DUTY[3:0]				LED_BR_MIN_DUTY[3:0]				F0h
93h	Direct Duty Cycle	LED_DR_MAX_DUTY[3:0]				LED_DR_MIN_DUTY[3:0]				F0h

The bits are decoded as shown in Table 6 to determine the duty cycle settings.

TABLE 6: LED DUTY CYCLE DECODE

x_MAX/MIN_DUTy [3:0]				Maximum Duty Cycle	Minimum Duty Cycle
3	2	1	0		
0	0	0	0	7%	0%
0	0	0	1	9%	7%
0	0	1	0	11%	9%
0	0	1	1	14%	11%
0	1	0	0	17%	14%
0	1	0	1	20%	17%
0	1	1	0	23%	20%
0	1	1	1	26%	23%
1	0	0	0	30%	26%
1	0	0	1	35%	30%
1	0	1	0	40%	35%
1	0	1	1	46%	40%
1	1	0	0	53%	46%
1	1	0	1	63%	53%
1	1	1	0	77%	63%
1	1	1	1	100%	77%

LED Transition Rate (Pulse, Breathe, and Ramp)

Transition rate refers to how fast the LED changes from on to off to on. For Pulse 1 and Pulse 2 behaviors, the transition rate for each pulse is controlled by the Pulse 1 Period and the Pulse 2 Period respectively. For Breathe behavior, the transition rate is controlled by the Breathe Period. For Direct behavior, transition rate is determined by the rise rate, fall rate, and off delay.

PULSE AND BREATHE PERIODS

The following registers are used to set Pulse 1, Pulse 2, and Breathe periods:

TABLE 7: LED PERIOD REGISTERS

Register	Address	Default Register Value	Default Period (ms)
Pulse 1 Period	84h	20h	1024
Pulse 2 Period	85h	20h	1024
Breathe Period	86h	5Dh	2976

In each period register, each LSB represents 32ms. To determine the total breathe period (from low duty cycle to high duty cycle and back to low), multiply the decimal value of the register setting by 32 (see Note 1:). For example, a setting of 18h (24d) would represent a period of 768ms. The total range is from 32ms to 4.064 seconds. Table 8 shows some examples. The defaults for the Pulse 1 Period and Pulse 2 Period registers are both 20h (32d), which sets the periods at 1024ms for any LEDs which have their behavior set to Pulse 1 or Pulse 2. The default for the Breathe Period is 5Dh (93d), which sets the period at 2976ms for any LEDs which have their behavior set to Breathe.

Note 1: In the Pulse 1 Period Register (84h), bit 7 is used to indicate when the behavior should begin (see Pulse 1 Start Trigger on page 5). The default is 0. If the bit is set to 1, it should not be included when calculating the period time. Only bits 6-0 are used to calculate the time. For example, if the bit 7 is set to 1 and register 84h is set to 58h, use 18h (24d) to determine the period.

2: Due to constraints on the LED Drive PWM operation, any period less than 160ms (05h) may not be achievable. The device will breathe at the minimum period possible as determined by the period and min / max duty cycle settings.

TABLE 8: LED PULSE / BREATHE PERIOD EXAMPLES

Setting (HEX)	Setting (Decimal)	Total Pulse / Breathe Period (ms)
00h	0	32
01h	1	32
02h	2	64
03h	3	96
. . .	. . .	. . .
7Dh	125	4000
7Eh	126	4032
7Fh	127	4064

DIRECT RAMPS

The following registers are used to set Direct behavior rates:

TABLE 9: LED DIRECT BEHAVIOR RATE REGISTERS

Register	Address	Default Register Value	Default Rates
LED Direct Ramp Rates	94h	00h	no rise or fall ramps
LED Off Delay	95h	00h	no off delay

Rise rate, fall rate, and off delay each have 3-bit settings. Changes to these rates take effect immediately.

The rise and fall rate bits and off delay bits are decoded, as shown in Table 10, to determine the rate. The defaults for these registers are 00h, which sets no on/off ramps or off delay for any LEDs which have their behavior set to Direct.

TABLE 10: RISE / FALL / DELAY RATE CYCLE DECODE

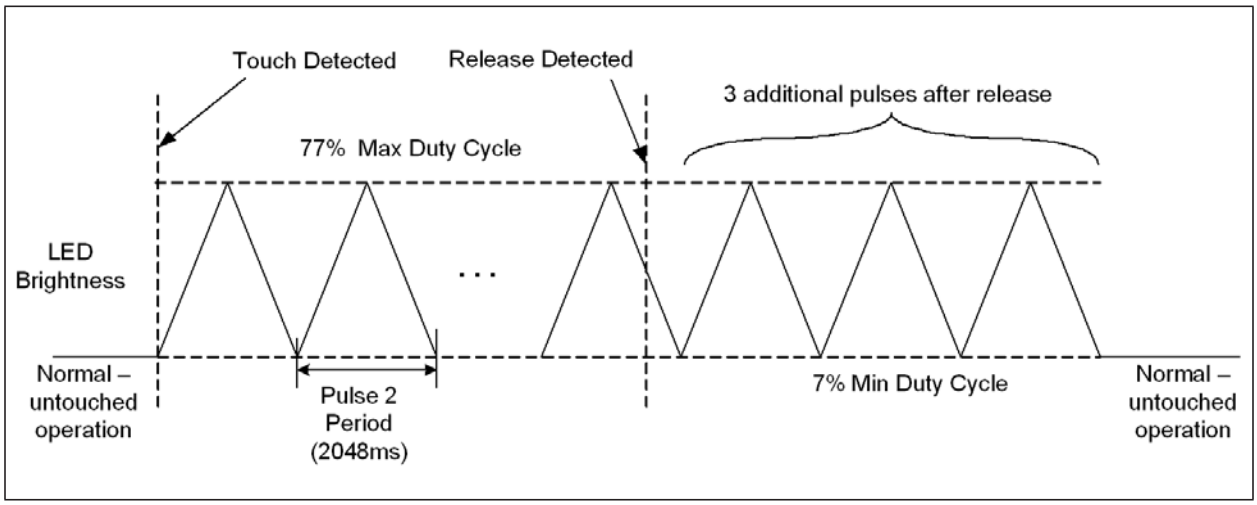
RISE_RATE / FALL_RATE / DIR_OFF_DLY[2:0]			Rise / Fall / OFF DELAY Time
2	**1**	**0**	
0	0	0	0
0	0	1	250ms
0	1	0	500ms
0	1	1	750ms
1	0	0	1s
1	0	1	1.25s
1	1	0	1.5s
1	1	1	2s

CONFIGURATION FOR LED OPERATION EXAMPLES

Pulse 2 Behavior Example

This example assumes a system configured as shown in External Voltage Source on page 2.

FIGURE 3: *CAP1114 Pulse 2 Behavior Example*



The configuration for the Pulse 2 behavior for shown in Figure 3 for LED 1 is shown in Table 11.

TABLE 11: CAP1188 PULSE 2 BEHAVIOR EXAMPLE CONFIGURATION

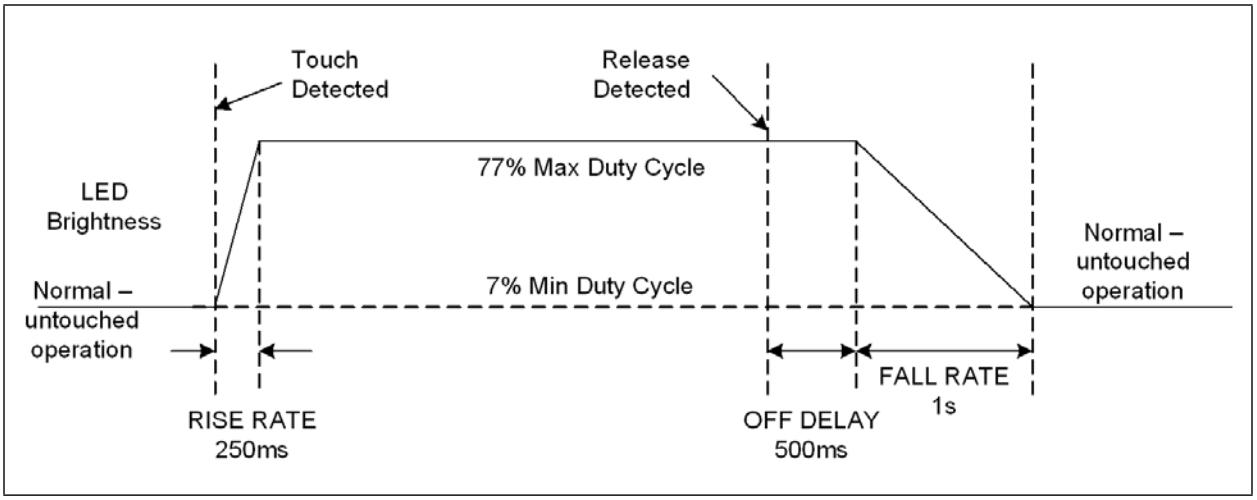
LED1 Configuration	Register	ADDR	Value	Comments
LED1 is linked to sensor CS1.	Sensor LED Linking	72h	01h	
Pulse 2 Count is set to 3.	LED Configuration Register	88h	08h	Bits 5-3 set to 010 (decoded to 3 pulses).
Pulse 2 Period is set to 4s.	Pulse 2 Period	85h	40h	Bits 6-0 set to 40h (64d) (decoded to 2048ms).
Pulse 2 Min Duty Cycle is set to 7% and Max Duty Cycle is set to 77%.	Pulse 2 Duty Cycle	91h	E1h	Bits 7-4 set to 1110 (decoded to 77% max) and bits 3-0 set to 0001 (decoded to 7% min).
LED1 Behavior is Pulse 2.	LED Behavior	81h	02h	Bits 1-0 set to 10 (decoded to Pulse 2).

Using the example in Figure 3 and the configuration in Table 11, LED1 will be illuminated at 7% duty cycle when no touch is detected. When a touch on LED1 is detected, the LED will breathe from 7% duty cycle to 77% duty cycle and back to 7% duty cycle in 250ms. When a release on LED1 is detected, LED1 will breathe 3 times.

Direct Behavior Example

This example assumes a system configured as shown in External Voltage Source on page 2.

FIGURE 4: *CAP1188 Direct Behavior Example*



The configuration for the Direct behavior for shown in Figure 4 for LED 1 is shown in Table 12.

TABLE 12: CAP1188 DIRECT BEHAVIOR EXAMPLE CONFIGURATION

LED1 Configuration	Register	ADDR	Value	Comments
LED1 is linked to sensor CS1.	Sensor LED Linking	72h	01h	
Rise Rate is set to 250ms and Fall Rate is set to 1s.	LED Direct Ramp Rates	94h	0Ch	Bits 5-3 set to 001 (decoded to 250ms rise) and bits 2-0 set to 100 (decoded to 1s fall).
Off Delay is set to 500ms.	LED Off Delay	95h	01h	Bits 2-0 set to 010 (decoded to 500ms off delay).
Direct Min Duty Cycle is set to 7% and Max Duty Cycle is set to 77%.	Direct Duty Cycle	93h	E1h	Bits 7-4 set to 1110 (decoded to 77% max) and bits 3-0 set to 0001 (decoded to 7% min).
LED1 Behavior is Direct.	LED Behavior	81h	00h	Bits 1-0 set to 00 (decoded to Direct).

Using the example in Figure 4 and the configuration in Table 12, LED1 will be illuminated at 7% duty cycle when no touch is detected. When a touch on LED1 is detected, the LED will ramp from 7% duty cycle to 77% duty cycle in 250ms. When a release on LED1 is detected, LED1 will ramp from 77% duty cycle to 7% duty cycle in 1 second after a delay of 500ms.

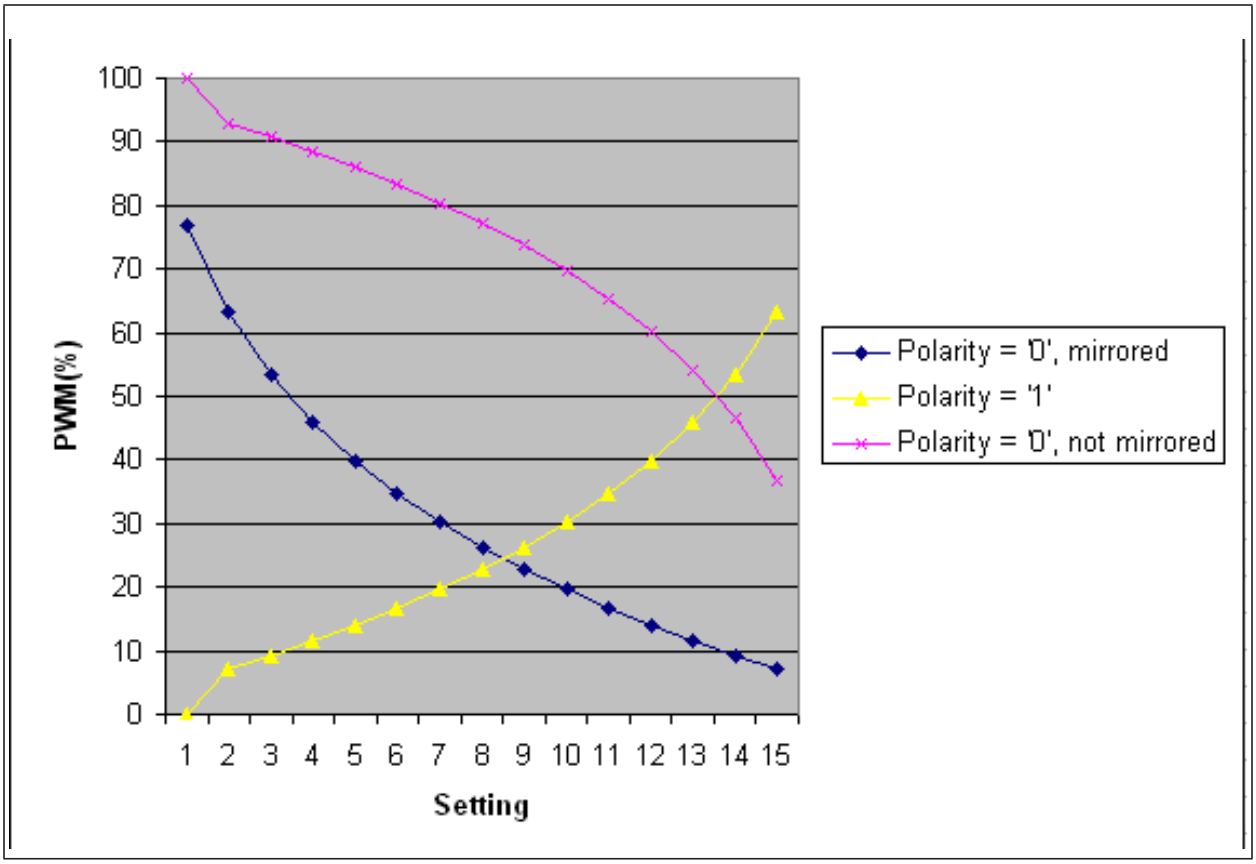
ADVANCED TOPICS

Mirroring

The LED Mirror Control Registers determine the meaning of duty cycle settings when polarity is non-inverted for each LED channel. When the polarity bit is set to ‘1’ (non-inverted), to obtain correct steps for LED ramping, pulse, and breathe behaviors, the min and max duty cycles need to be relative to 100%, rather than the default, which is relative to 0%. The algorithm automatically adjusts the logarithmic response so the steps are more even. The LED Mirror controls work with the polarity controls with respect to LED brightness but do not have a direct effect on the output pin drive.

Figure 5 shows PWM points generated for the same duty cycle settings, but with different polarity and mirroring settings. With the polarity bit set to ‘1’, more points are generated at the lower PWM percents. The human eye can more easily discern changes below 75% PWM, so this helps the eye see a smooth LED transition from minimum duty cycle to maximum duty cycle. When the polarity bit is cleared (‘0’) but is not mirrored, more points are generated above 75% PWM. This causes the LED to appear stay on at 100% duty cycle and then suddenly ramp down.

FIGURE 5: *Representation of LED Response Non-Inverted, Not Mirrored*



For systems configured as shown in External Voltage Source on page 2 or RightTouch Device Sourcing Current on page 3, mirror controls are automatically set as necessary by default. It is recommended that the default configuration is retained, which is as follows:

1. The BLK_POL_MIR bit is ‘0’ in the Configuration 2 Register (44h). This allows the device to update mirror controls automatically.
2. When the Polarity bit for an LED is cleared (i.e. ‘0’) in the LED Polarity Register (73h), the LEDx_MIR_EN bit is cleared in the LED Mirror Control Register (79h). The LED logarithmic response does not need to be adjusted.
3. When the Polarity bit for an LED is set (i.e. ‘1’), the LEDx_MIR_EN bit for the LED is set to ‘1’. The LED logarithmic response will be adjusted.

Transitioning LEDs from Host Control to Linked

RightTouch devices contain controls to transition an LED from actuated host control to untouched linked sensor control without a disruption in the appearance of the LED. Perform the steps below to transition an LED from host control to linked:

1. Configure the LEDs for the system (see Configuring LEDs to Match Board Design on page 1) and desired operation (see Configuring LED Operation on page 4).
2. Set the LEDx_DR bit for the LED to ‘1’ in the LED Output Control Register (74h). This actuates the LED pin.
3. Set the INV_LINK_TRAN bit to ‘1’ in the Configuration 2 Register (44h). This will invert the touch signal.
4. Set the LEDx_TRAN bit to ‘1’ for the LED in the Linked LED Transition Control Register (77h). This will prevent the LED from changing states when it changes from host control to linked. It will also permit the LED to change states when the sensor is touched if the INV_LINK_TRAN bit is set.
5. Set the CSx_LEDx bit to ‘1’ in the Sensor LED Linking Register (72h). This links to LED to the sensor. The LED pin will not change states when it’s linked.
6. Touch the sensor. The linked LED pin will change states.

LED Ramp Alert

When an LED is not linked to a sensor, the RightTouch device can be configured to assert the ALERT# pin when an LED that is actuated by the LED Output Control Register has finished its configured behavior.

This is controlled by bit 6 RAMP_ALERT in the LED Configuration Register (88h). The default setting (‘0’) is to not assert the ALERT# pin.

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APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision	Section/Figure/Entry	Correction
REV A	REV A replaces previous SMSC version Rev. 1.0 (11-05-12)	
Rev. 1.0 (11-05-12)	Co-branded document	
Rev. 1.0 (04-26-10)	Formal document release	

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ISBN: 9781620779095

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