
CAP1114 LED Configuration Options

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INTRODUCTION

This application note contains guidelines for the successful implementation of LEDs using the CAP1114 RightTouch™ capacitive sensor.

References

CAP1114 Data Sheet

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

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 CAP1114 to source the current needed. In addition, in some designs, button presses actuate the LEDs; in others, LEDs are controlled by the host. The CAP1114 can be configured to accommodate these variations.

LED Direction

LED pins 1 through 8 can be used as GPIOs or as LEDs. In order to use the pins to drive LEDs, the pins must be configured as outputs.

The LED / GPIO Direction Register (70h) determines the direction of the LED pins, with each bit corresponding to an LED. For example, bit 0 corresponds with LED1 direction, bit 1 corresponds with LED2 direction, etc. A '0' in the bit position configures the associated pin as an input, so it cannot be used to drive an LED. A '1' in the bit position configures the associated pin as an output. The default for this register is 00h, which configures the pins as inputs.

Note: LEDs 9 through 11 are output-only pins, so they do not have a direction bit associated with them.
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Output Type

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

Note: LEDs 9 through 11 are only open-drain type outputs, so they do not have an output type bit associated with them.

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.

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Polarity

LEDs can be configured such that if the LED pin is driven to a logic '0', the LED will be on and the CAP1114 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 3](#)). Because LEDs can also be installed in an opposite configuration (see [Right-Touch Device Sourcing Current on page 4](#)), the CAP1114 has a control to determine the logical polarity.

The LED Polarity Registers (75h and 76h) determine 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.

Note: LEDs 9 and 10 can be linked to the slider (sensors 8-11). When linked, LED 9 is actuated when a Down event is detected, and LED 10 is actuated when a Up event is detected. The link is controlled by register 80h bit 7.
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Sensor LED Linking Register (80h) 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).
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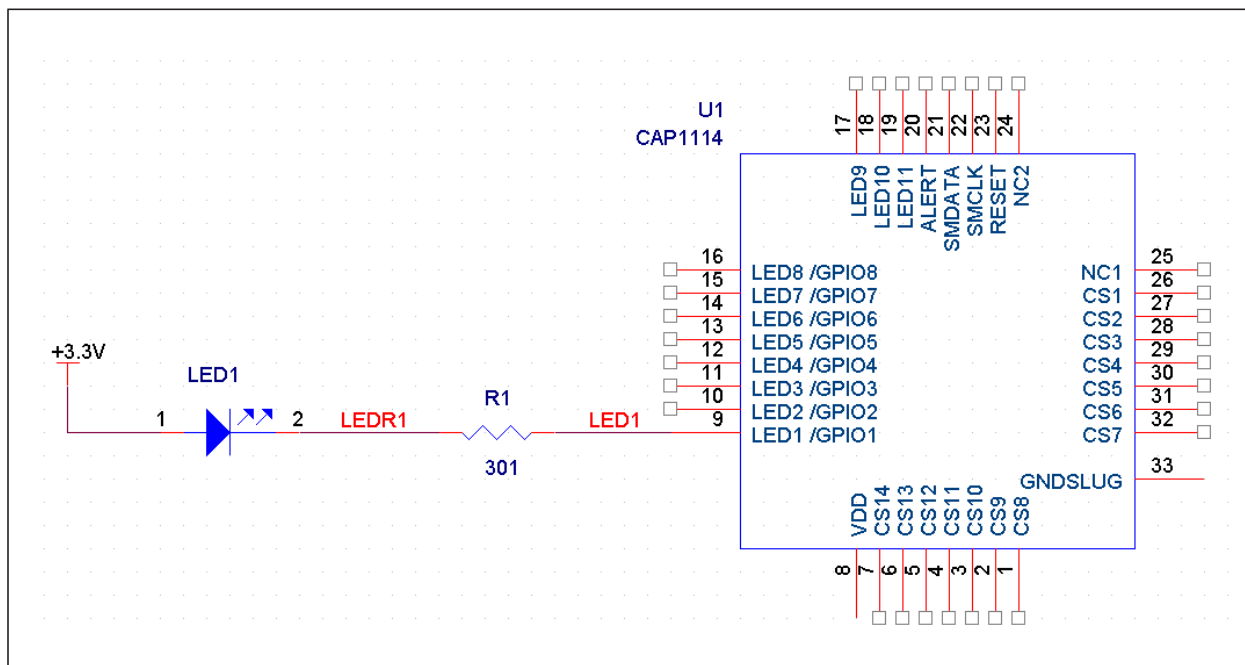
For LEDs that are not linked to sensors, the LED Output Control Registers (73h and 74h) determine whether the LED is actuated or not. A '0' in the bit position indicates the LED is not actuated. A '1' in the bit position indicates the LED is actuated. The default for these registers is 00h, which configures 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: CAP1114 LED External Voltage Source Example



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

TABLE 1: CAP1114 EXTERNAL VOLTAGE SOURCE EXAMPLE CONFIGURATION

LED1 Configuration	Register	ADDR	Value	Comments
LED1 pin is an output.	LED / GPIO Direction Register	70h	01h	
LED1 pin is open-drain.	LED Output Type Register	71h	00h	default
LED1 pin has inverted polarity.	LED Polarity Register	75h	00h	This will permit a '1' (actuate) written to the LED Output Control register to illuminate the LED.

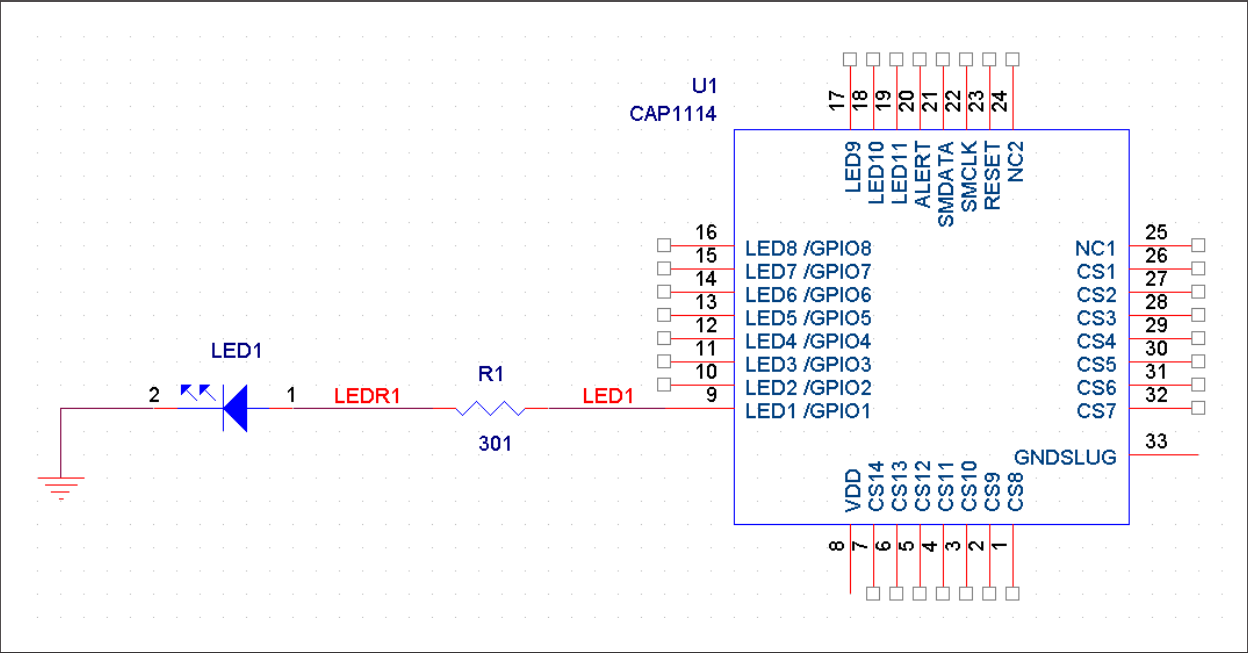
Using the circuit in Figure 1 and the configuration in Table 1, LED1 can be illuminated by writing 01h to the LED Output Control Register 73h. Writing 00h to register 73h will turn off LED1.

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RightTouch Device Sourcing Current

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

FIGURE 2: CAP1114 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 an out-put.	LED / GPIO Direction Register	70h	01h	
LED1 pin is push-pull.	LED Output Type Register	71h	01h	
LED1 pin has non-inverted polarity.	LED Polarity Register	75h	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 73h. Writing 00h to register 73h will turn off LED1.

CONFIGURING LED OPERATION

The CAP1114 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 - 83h) 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.

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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	
0	0	1	2	
0	1	0	3	
0	1	1	4	
1	0	0	5	Pulse 1 default and Pulse 2 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%

TABLE 6: LED DUTY CYCLE DECODE (CONTINUED)

x_MAX/MIN_DUTy [3:0]				Maximum Duty Cycle	Minimum Duty Cycle
3	2	1	0		
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

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TABLE 8: LED PULSE / BREATHE PERIOD EXAMPLES (CONTINUED)

Setting (HEX)	Setting (Decimal)	Total Pulse / Breathe Period (ms)
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.

In the CAP1114, the off delay can be set up to 5s. Because rates changes take effect immediately, reducing the off delay setting while an LED is in a long off delay behavior will reduce the delay. For example, if an LED with direct behavior has been actuated and unactuated with a 5s delay and the off delay is changed to 1s before the off delay has completed, the off delay will be reduced to the new off delay. If the new off delay is shorter than the time already spent in the off delay, the LED will stop the delay immediately and start the fall. If the fall rate was also changed, the new fall rate will be used.

Note: In the CAP1114, if a non-zero fall time is desired, the rise rate must be set to be equal to the desired fall rate. This should be done as a register write after the LED has been actuated and before it is unactuated.

The rise and fall rate bits are decoded, as shown in [Table 10](#), to determine the rate. The off delay bits are decoded as shown in [Table 11](#). 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 RATE CYCLE DECODE

RISE_RATE / FALL_RATE [2:0]			Rise / Fall 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

TABLE 11: OFF DELAY SETTINGS

DIR_OFF_DLY [2:0]			OFF Delay
2	1	0	
0	0	0	0
0	0	1	0.5s
0	1	0	1.0s
0	1	1	1.5s
1	0	0	2.0s

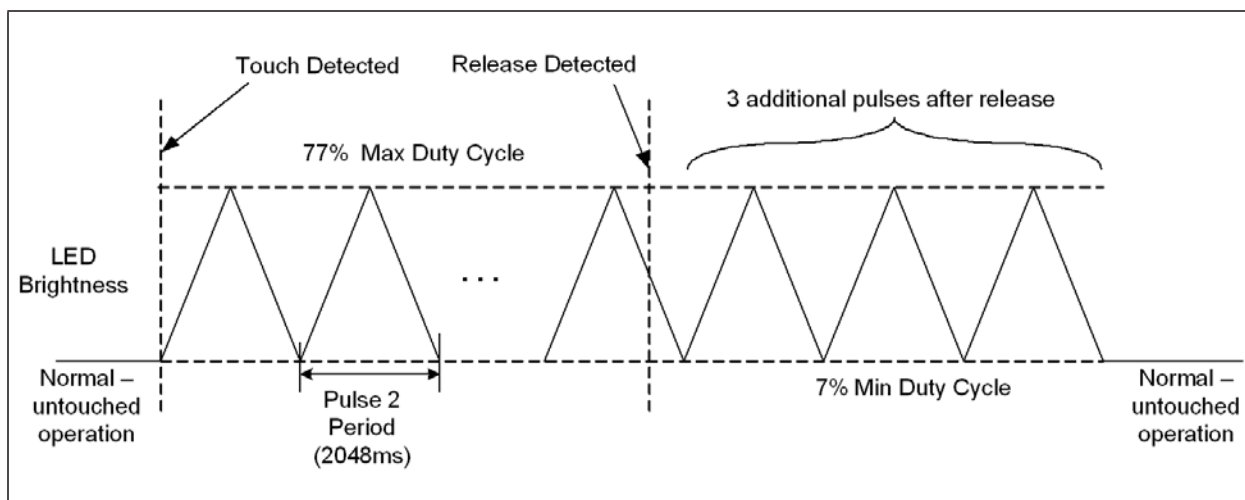
TABLE 11: OFF DELAY SETTINGS (CONTINUED)

DIR_OFF_DLY [2:0]			OFF Delay
2	1	0	
1	0	1	3.0s
1	1	0	4.0s
1	1	1	5.0s

CONFIGURATION FOR LED OPERATION EXAMPLES

Pulse 2 Behavior Example

This example assumes a system configured as shown in [External Voltage Source on page 3](#).

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 12](#).

TABLE 12: CAP1114 PULSE 2 BEHAVIOR EXAMPLE CONFIGURATION

LED1 Configuration	Register	ADDR	Value	Comments
LED1 is linked to sensor CS1.	Sensor LED Linking	80h	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).

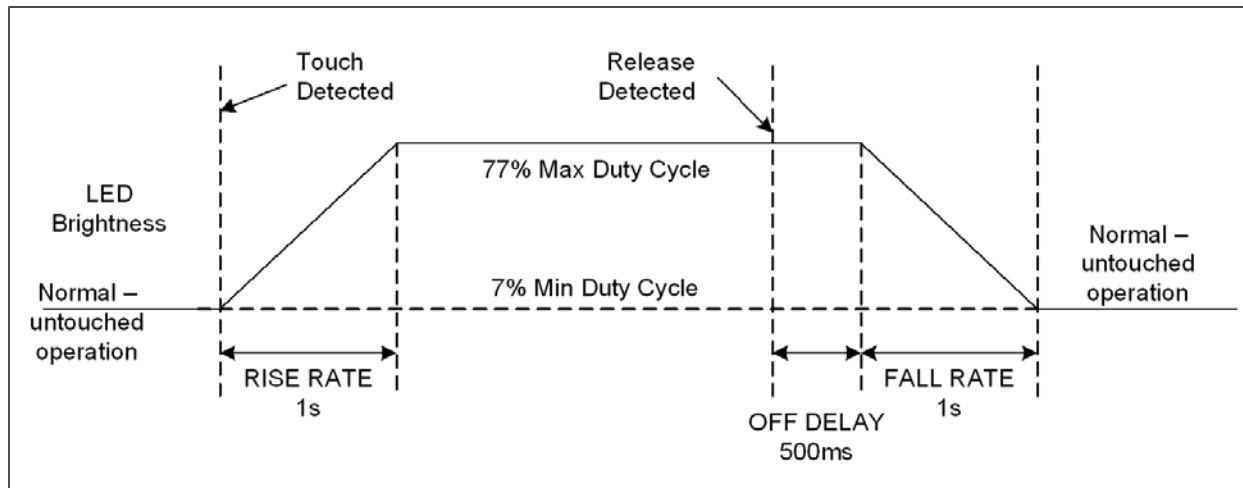
Using the example in [Figure 3](#) and the configuration in [Table 12](#), LED1 will be illuminated at 7% duty cycle when no touch is detected. When a touch on LED1 is detected, the LED will breathe from 7% duty cycle to 77% duty cycle and back to 7% duty cycle in 250ms. When a release on LED1 is detected, LED1 will breathe 3 times.

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Direct Behavior Example

This example assumes a system configured as shown in [External Voltage Source on page 3](#).

FIGURE 4: CAP1114 Direct Behavior Example



The configuration for the Direct behavior for shown in [Figure 4](#) for LED 1 is shown in [Table 13](#).

TABLE 13: CAP1114 DIRECT BEHAVIOR EXAMPLE CONFIGURATION

LED1 Configuration	Register	ADDR	Value	Comments
LED1 is linked to sensor CS1.	Sensor LED Linking	80h	01h	
Rise Rate is set to 1s and Fall Rate is set to 1s.	LED Direct Ramp Rates	94h	0Ch	Bits 5-3 set to 100 (decoded to 1s 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 001 (decoded to 0.5s 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 13](#), 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 1 second. 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.

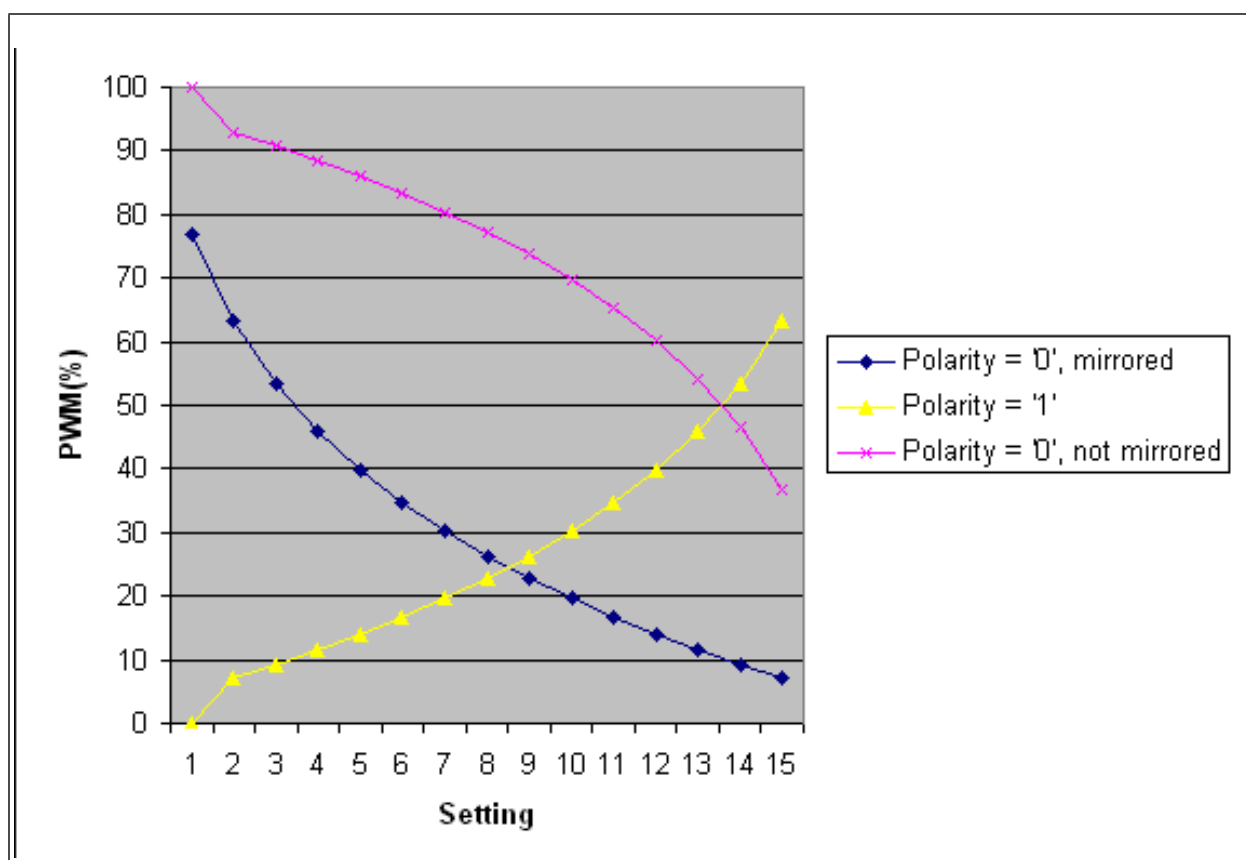
ADVANCED TOPICS

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 3](#) or [RightTouch Device Sourcing Current on page 4](#), 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 (40h). 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 (75h and 76h), the LEDx_MIR_EN bit is cleared in the LED Mirror Control Register (79h - 7Ah). 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

The CAP1114 contains 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 5](#)).
2. Set the LEDx_DR bit for the LED to '1' in the LED Output Control Registers (73h and 74h). This actuates the LED pin.
3. Set the INV_LINK_TRAN bit to '1' in the Configuration 2 Register (40h). This will invert the touch signal.
4. Set the LEDx_TRAN bit to '1' for the LED in the Linked LED Transition Control Registers (77h - 78h). 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 (80h). 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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