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STLED325

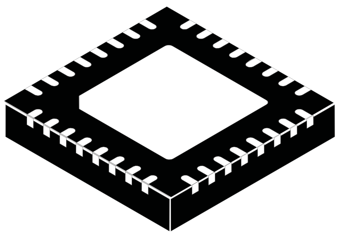
I²C interfaced, advanced LED controller/driver with keyscan, standby power management and real time clock (RTC)

Features

- LED controller driver with 13 outputs (8 segments/5 digits)
- Standby power management to host
- Integrated low-power, accurate RTC
- Integrated remote control decoding:
  - Philips (RC5, RCMM)
  - Thomson (RCA, R2000)
  - NEC and R-STEP
- Wake-up using front panel keys, remote control, real time clock (RTC), extra pin (AV or CEC)
- Battery or super-cap back up mode for real time clock (RTC)
- Keyscanning (8x2 matrix)
- Low power consumption in standby mode
- I^2C serial bus interface (SCL, SDA)
- 16-step dimming circuit to control the display brightness
- 5.0 V (± 10%) for V_{CC}
- Built-in thermal protection circuit
- External crystal with internal oscillator for real time clock (RTC)

Applications

- Set-top boxes
- White goods
- Home appliances
- DVD players, VCRs, DVD-R



QFN32
(5 x 5 mm)

Description

The STLED325 is a compact LED controller/ driver that interfaces microprocessors to LED displays through serial I^2C interface. It drives LEDs connected in common anode configuration and includes keyscanning for an 8 x 2 key matrix which automatically scans and de-bounces a matrix of up to 16 switches.

Furthermore, the STLED325 provides standby power management to the host. It also integrates a low-power, highly-accurate RTC and a remote-control decoder. All functions are programmable using the I^2C bus. Low power consumption during standby mode is achieved.

The STLED325 controller/driver is ideal as a single peripheral device to interface the front panel display with a single-chip host IC like CPU.

Table 1. Device summary

Order code	Temp range (° C)	Package	Comments
STLED325QTR	-40 to +85 °C	QFN32	250 parts per reel

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1 Description

The STLED325 is a compact LED controller/driver that interfaces microprocessors to LED displays through serial I^2C interface. It drives LED connected in common anode con-figuration. The STLED325 drives up to 40 discrete LEDs in 8 segment/5 digit configuration while functioning from a supply voltage of 5 V. The maximum segment current for the display digits is set through a single external resistor. Individual digits may be addressed and updated without rewriting the entire display. Additionally it includes keyscanning for an 8 x 2 key matrix which automatically scans and de-bounces a matrix of up to 16 switches.

Furthermore, it provides standby power management to the host. The STLED325 also integrates a low-power, highly-accurate RTC and a remote-control decoder. All functions are pro-grammable using the I^2C bus. Low power consumption during standby mode is achieved. STLED325 supports numeric-type displays and reduces the overall BOM costs through high integration. Also it provides ESD protection of greater than 2 kV HBM.
The LED controller/driver is ideal as a single peripheral device to interface the front panel display with a single-chip Host IC like CPU.

2 Functional and application diagram

Figure 1. Functional block diagram

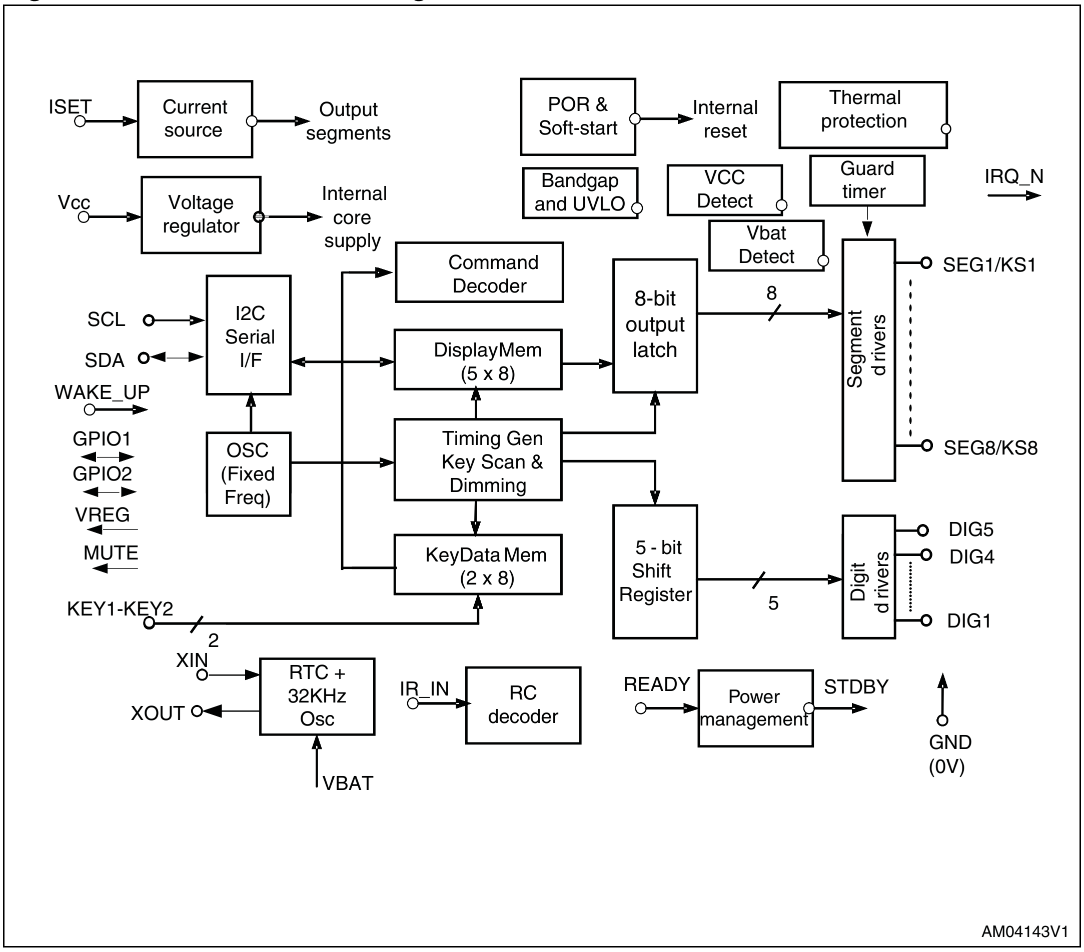


Figure 2. Application diagram

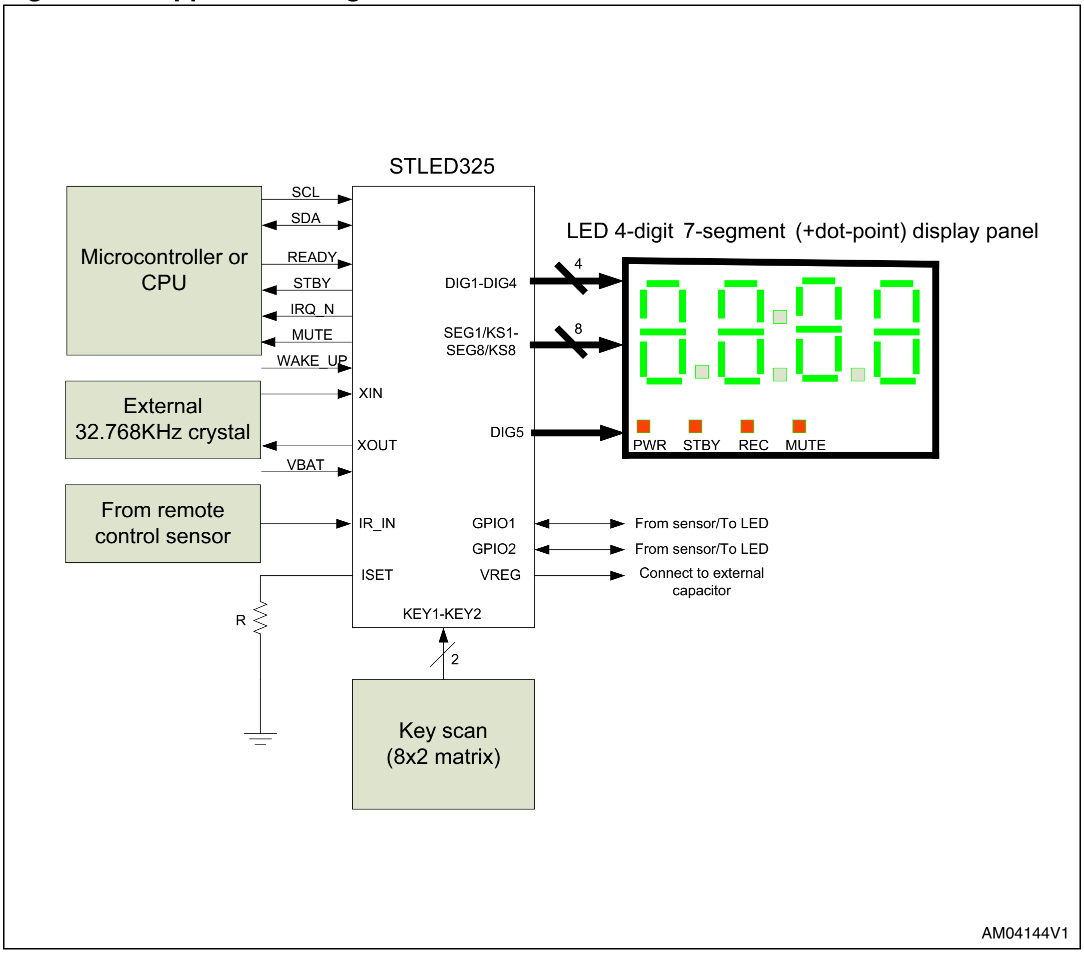
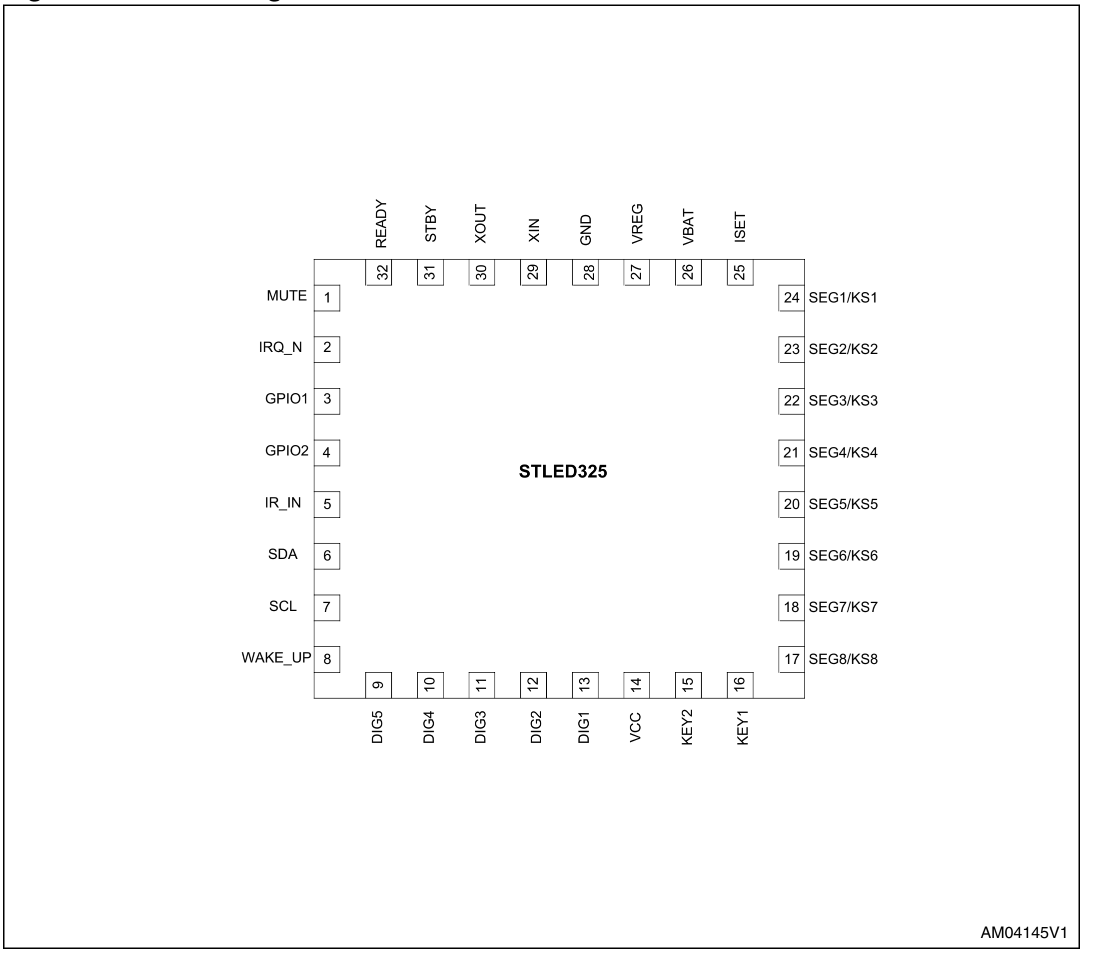


Figure 3. Pin configurations



3 Functional description

The STLED325 is a common anode LED driver controller which can be used to drive red, green or blue LEDs as the current is adjustable through the external resistor. In the common anode configuration, the digit outputs source the current to the anodes while the segment outputs sink the current from the cathodes. The configurable output current can be used to drive LEDs with different current ratings (red, green or blue). The brightness can be controlled through the I^2C interface as described later. The outputs can be connected together in parallel to drive a single LED. In this case, two parallel current sources of equal value drive a single LED. The external resistor value can be set accordingly to determine the desired output current.
Soft-start limits the inrush current during power-up. The built-in thermal protection turns off the display when the temperature exceeds 140°C with a small hysteresis of 15°C. The display is blanked (LEDs are turned off or in high-Z state) on power-up.

3.1 Low power mode of operation

When not used, the STLED325 goes into low power mode of operation wherein the current consumption drops to less than 1 mA. During this mode, the data configured is maintained as long as the supply voltage is still present (the contents of the internal RAM need the supply voltage to be present). Port configuration and output levels are restored when the STLED325 is taken out of shutdown. For minimum supply current in shutdown mode, logic inputs should be at GND or V_{CC}.

3.2 I^2C serial interface

The interface is used to write configuration and display data to the STLED325. The serial interface comprises of a shift register into which SDA is clocked on the rising edge of the SCL after a valid start of communication. When communication is stopped, transitions on SCL do not clock in the data. During this time, the data are parallel-loaded into a latch. The 8-bit data is then decoded to determine and execute the command.
For an overflow condition, if more bytes are written, then they are ignored whereas if more bytes are read, then the extra bytes are stuffed with 1’s.

3.3 Initial power up

On initial power-up, all control registers are reset, the display is blanked and the STLED325 is in the low-power mode. All the outputs are in high-impedance state at initial power-up. The SDA is pulled high by an external pull-up resistor. The display driver has to be configured before the display can be used.

3.4 Display types

Figure 4. Display types

Seven segment display with dot point and common-anode LED panel

3.5 Keyscan

The full keyscan is illustrated in the later section of the datasheet. One diode is required per key switch. The keyscan circuit detects any combination of keys being pressed during each de-bounce cycle.
The keyscan matrix on the STLED325 passes command from the front panel to the host processor through the SDA pin on STLED325. The STLED325 can be programmed to wake-up the system from standby using any of the 16 keys pressed on the front panel. These wake-up keys are also referred to as hot-keys.

3.6 Timers

3.6.1 Guard timer

For safety related applications, a guard timer is integrated in the STLED325. The guard timer gives enhanced reliability to the device.

The guard timer can be used to detect an out of-control microprocessor. The user programs the guard timer by setting the desired amount of time-out into the Guard timer. This guard time has an initial de-fault value of 10s upon first power-up and subsequently can be configured from 1s to 15s during normal operation. If a time period of longer than 15s is desired, then the watchdog timer from RTC can be used. It can also be disabled after first power-up. If the processor does not clear the timer within the specified period, the STLED325 puts the system in the standby mode.

This is only active from L to H transition on READY or WAKE_UP pin but it is not level-based. The guard timer count is cleared by the guard timer clear/reset bit. While in normal mode, the count starts from the previously count value that was in the register. During the cold boot up or warm boot up, the count starts from the configured value.

3.6.2 Watchdog timer

Another watchdog timer is present in the Watchdog timer register at address 09h of the RTC register map. This watchdog timer can be used to program timer values of greater than 15s. Bits BMB4-BMB0 store a binary multiplier and the three bits RB2-RB0 select the resolution where:

000 = 1/16 second (16 Hz);

001 = 1/4 second (4 Hz);

010 = 1 second (1 Hz);

011 = 4 seconds (1/4 Hz); and

100 = 1 minute (1/60 Hz).

The Watchdog timer is programmed by setting the desired timeout into the Watchdog register, address 09h. The amount of timeout time is determined to be the multiplication of the 5-bit multiplier value with the resolution values depicted by the watchdog resolution bits.

The Watchdog timer is disabled when its register is cleared by writing a value of 00h.

Hence the Watchdog function is not enabled upon power on. It is enabled when a non-zero value is written into its register. The Watchdog timer is reset by performing a write to the watchdog register, then the time-out period starts over.

If the processor does not reset the timer within the specified timeout period, and when the timeout occurs, the watchdog flag is set. The watchdog timer of RTC is cleared by writing a 00 value and starts again whenever any new value is written to it.

The WatchDogEn Flag can be disabled or enabled by writing to the register bit and the reset of watchdog timer is done by writing to the register.

3.7 Power-on-reset and soft-start

The device integrates two internal power-on-reset circuits which initialize the digital logic upon power up. One circuit is for the V_{CC} power and the other is for the V_{BAT} power. The soft-start circuit limits the inrush current and high peak current during power-up. This is done by delaying the input circuit’s response to the external applied voltage. During soft-start, the input resistance is higher which lowers the in-rush current when the supply voltage is applied.

3.8 LED drivers

The constant current capability is up to 40 mA per output segment and is set for all the outputs using a single external resistor. When acting as digit drivers, the outputs source current to the display anodes. When acting as segment drivers, the LED outputs sink current from the display common cathodes. The outputs are high impedance when not being used as digit or segment drivers.

Each port configured as a LED segment driver behaves as a digitally-controlled constant current sink. The LED drivers are suitable for both discrete LEDs and common anode (CA) numeric LED digits. When fully configured as a LED driver, the STLED325 controls up to 8 LED segments in a single digit with individual 8-step adjustment of the constant current through each LED segment. A single resistor sets the maximum segment current for all the segments, with a maximum of 40 mA per segment. The STLED325 drives any combination of discrete LEDs and common anode (CA) digits for numeric displays.

The recommended value of RSET is the minimum allowed value, since it sets the display driver to the maximum allowed segment current. RSET can be a higher value to set the segment current to a lower maximum value where desired. The user must also ensure that the maximum current specifications of the LEDs connected to the drivers are not exceeded.

3.9 Over temperature cut-off

The STLED325 contains an internal temperature sensor that turns off all outputs when the die temperature exceeds 140°C. The outputs are enabled again when the die temperature drops below 125°C. Register contents are not affected, so when a driver is over-dissipating, the external symptom will be the load LEDs cycling between on and off as the driver repeatedly overheats and cools, alternately turning the LEDs off and then back on again. This feature will protect the device from damage due to excessive power dissipation. It is important to have good thermal conduction with a proper lay-out to reduce thermal resistance.

3.10 Standby mode

By utilizing the standby function, the host processor and other ICs can be turned off to reduce power consumption. The STLED325 is able to wake-up the system when programmed hotkeys are detected to signal that the full operation of the system is required. The hotkeys can be entered to the system through the front panel keys or through the infrared (IR) remote control or the Real Time Clock (RTC) alarm or through the wake-up pin. STLED325 supports multiple remote control protocols decoding by setting the appropriate register.

The STLED325 is able to cut-off the power to the main board for standby operation for good power management. STBY will be set to high when READY signal goes from high to low, I^2C command for standby is seen or when the guard timer has finished counting down to 0, whichever occurs first.

In the normal mode of operation, the STBY is asserted only when the guard timer has finished counting down to 0. This is meant to put the system into stand-by even though standby command was not issued by the host or READY signal did not go low. This occurs as the guard timer register was not cleared before it finished counting down to 0.

3.10.1 Cold boot up

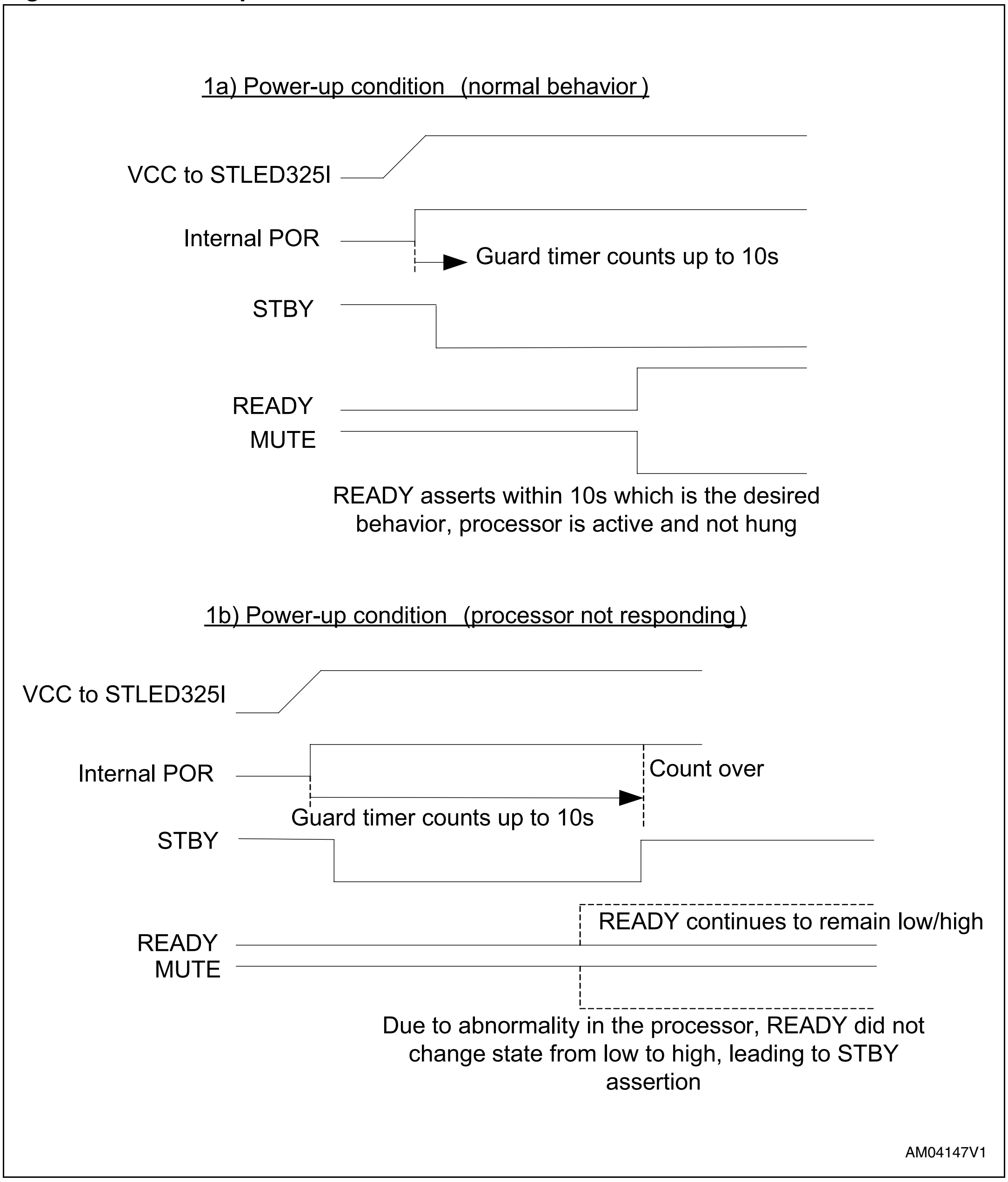
When power is first applied to the system, the STLED325 is reset. It will then manage the power to the main board by bringing the STBY pin to a low level.

This wakes up the main processor which asserts the READY pin to a high level to indicate to STLED325 of a proper boot-up sequence.

If the microprocessor does not assert the READY pin to a high within 10s (default), the STLED325 cuts off the power to the Host by asserting the STBY pin. The high level on READY pin signifies that the processor is ready. After this, the processor can configure the STLED325 by sending the various I^2C commands for configuration of display, RC protocol, RTC display mapping, hot-keys.

The power-up behavior in 2 conditions is shown in *Figure 5*.

Figure 5. Power-up condition



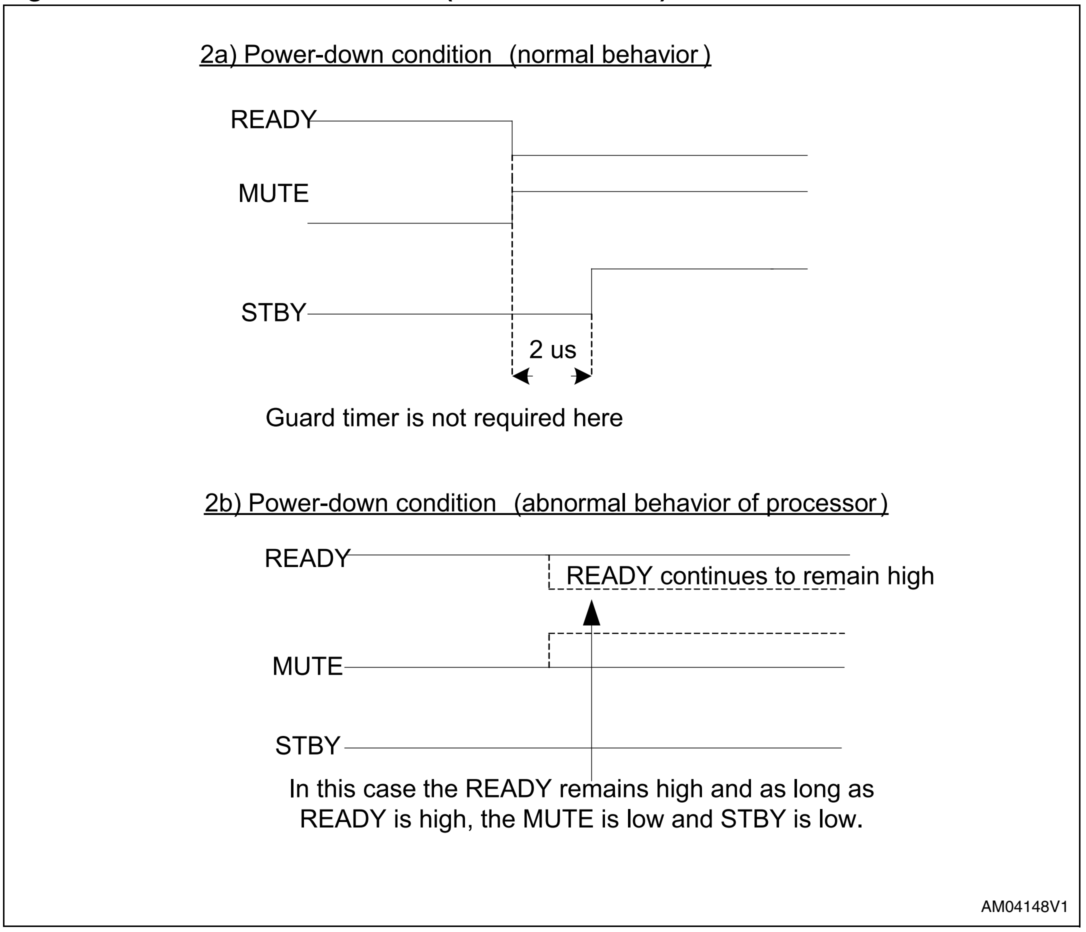
Note:
1. *Guard timer is turned off by default upon READY assertion.*
2. *If Guard timer is to be kept on during READY high condition, the guard timer registers must be set accordingly by proper commands through I^2C bus.*
3. *In this power-up condition, Guard timer is triggered by internal POR pulse.*
4. *During power-up, the Guard timer value is 10s.*

3.10.2 Entering standby mode

The STLED325 controls the power to the main board using the STBY pin. During normal operation, the STBY pin is a low level which externally controls a Power MOS switch to enable power to the main board. The STLED325 asserts the STBY pin to a high when any one of the following conditions occur:

– Processor fails to respond by enabling the READY pin within 10s upon first power-up (cold boot up)
– Guard timer counts down to 0s
– Processor makes the READY pin to low (can happen in various conditions such as user presses STBY key on front panel, STBY key on remote control, etc).

Figure 6. Power down condition (normal behavior)



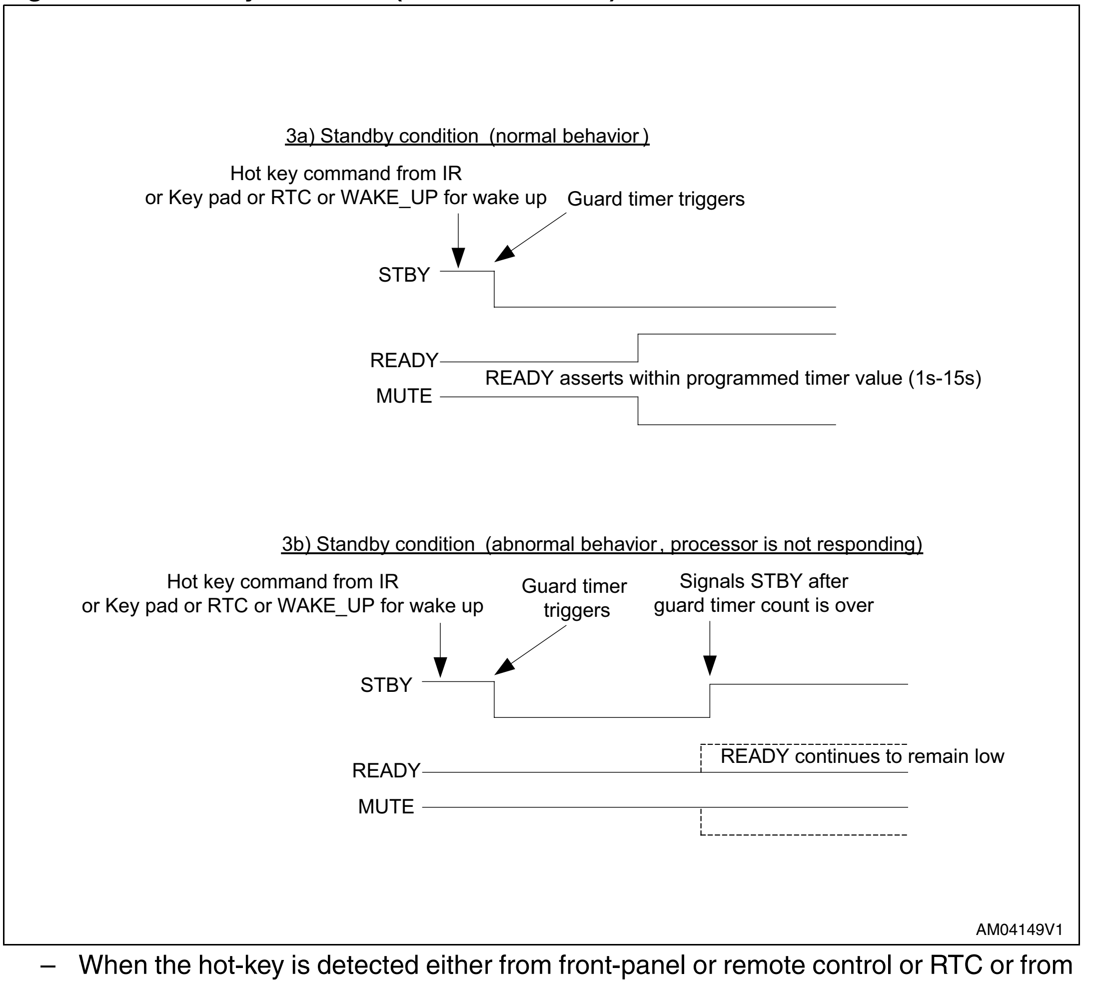
– Guard timer can be kept on during normal condition when READY is high (depending on the user).
– In this condition, the guard timer can be disabled or enabled. If the guard timer is enabled, the timer needs to be cleared before the programmed count of the timer is reached. If the programmed count is reached, the STBY will be asserted.
– It is advisable not to enable the guard timer during normal operation.

3.10.3 Wake-up

The STLED325 can wake-up from any one of the following sources:

- Front-panel keys
- Remote-control keys
- Real time clock (RTC) in 3 conditions (alarm, watchdog timer, oscillator fail)
- External wake-up pin (by a low to high transition on this pin)
- GPIO status changes
- READY pin goes from low to high

Figure 7. Standby condition (normal behavior)



- When the hot-key is detected either from front-panel or remote control or RTC or from a transition (low to high transition) on WAKE_UP pin during stand-by, the STBY pin de-asserts.
- The de-assertion of the STBY triggers the guard timer.
- The timer value is the programmed value by the user (1-15s). If the user did not change the value before entering standby, then it remains 10s.
- Also note that the guard timer is off when the STLED325 is in the standby mode.

The guard timer is thus triggered by a de-assertion of the STBY signal or by internal power on reset signal.

3.11 Real time clock (RTC)

The STLED325 integrates a low power Serial RTC with a built-in 32.768 kHz oscillator (external crystal controlled). Eight bytes of the SRAM are used for the clock/calendar function and are configured in binary coded decimal (BCD) format. An additional 12 bytes of SRAM provide status/ control of alarm and watchdog functions. Addresses and data are transferred serially via a two line, bi-directional I^2C interface. The built-in address register is incremented automatically after each WRITE or READ data byte. Note that all 4 digits must be enabled before using the RTC display.

Functions available to the user include a non-volatile, time-of-day clock/calendar, alarm interrupts and watchdog timer. The eight clock address locations contain the century, year, month, date, day, hour, minute, second and tenths/hundredths of a second in 24 hour BCD format. Corrections for 28, 29 (leap year - valid until year 2100), 30 and 31 day months are made automatically.

The RTC operates as a slave device through the slave address of the STLED325 on the serial bus. Access is obtained by implementing a start condition followed by the correct device slave address. The 16 bytes contained in the device can then be accessed sequentially in the following order:

- 1. Reserved
- 2. Seconds register
- 3. Minutes register
- 4. Hours register
- 5. Day register
- 6. Date register
- 7. Century/month register
- 8. Year register
- 9. Calibration register
- 10. Watchdog register
- 11 - 16. Alarm registers

The RTC keeps track of the date and time. Once the date and time are set, the clock works when the STLED325 is in normal operation and standby operation. Wake-up alarm feature is also included in the RTC module. The accuracy of the RTC is approximately 20 ppm (±50secs/month). How-ever this much depends on the accuracy of the external crystal used.

The wake-up alarm is programmed to wake up once the date and time set are met. This feature is present in normal and standby mode of operation. Only one date and time is available for setting.

The real time clock (RTC) uses an external 32.768 kHz quartz crystal to maintain an accurate internal representation of the second, minute, hour, day, date, month, and year. The RTC has leap-year correction. The clock also corrects for months having fewer than 31 days.

3.11.1 Reading the real time clock

The RTC is read by initiating a Read command and specifying the address corresponding to the register of the real time clock. The RTC registers can then be read in a sequential read mode. Alarms occurring during a read are unaffected by the read operation.

3.11.2 Writing to the real time clock

The time and date may be set by writing to the RTC registers. The new RTC time can be updated by writing to the RTC registers. The new time only takes affect after a complete write cycle. If the write cycle is incomplete, the new time value is discarded. A single byte may be written to the RTC without affecting the other bytes.

3.11.3 Register table for RTC

Table 2. Register table for RTC

Addr	D7	D6	D5	D4	D3	D2	D1	D0	Functional/range BCD format	
00h	Reserved				Reserved					
01h	OSC_ST	10 seconds			Seconds				Seconds	00-59
02h	Rsvd	10 minutes			Minutes				Minutes	00-59
03h	MD_HM_MS		10 hours		Hours (24 hours format)				Hours	00-23
04h	Rsvd	Rsvd	Rsvd	Rsvd	Rsvd	Day of week			Day	01-7
05h	Rsvd	Rsvd	10 date		Day of month				Date	01-31
06h	CB1	CB0	Rsvd	10M	Month				Century/month	0-3/01-12
07h	10 years				Year				Year	00-99
08h	12/24	Rsvd	Cal_sign	Calibration					Calibration	
09h	RB2	BMB4	BMB3	BMB2	BMB1	BMB0	RB1	RB0	Watchdog	
0Ah	AFE	Rsvd	ABE	Al 10M	Alarm month				Al month	01-12
0Bh	RPT4	RPT5	Al 10 date		Alarm date				Al date	01-31
0Ch	RPT3	RPT6	Al 10 hour		Alarm hour				Al hour	00-23
0Dh	RPT2	Alarm 10 minutes			Alarm minutes				Al min	00-59
0Eh	RPT1	Alarm 10 seconds			Alarm seconds				Al sec	00-59
0Fh	WDFEn	Alarm: day of week			Rsvd (bypass mode)				Flags	

Legend:

Cal_Sign = Sign bit

OSC_ST = Oscillator Stop bit

BMB0 – BMB4 = watchdog multiplier bits

CB = Century bits

ABE = Alarm in battery back up mode enable bit

AFE = Alarm flag enable

RB0 – RB2 = watchdog resolution bits

RPT1 – RPT6 = alarm repeat mode bits

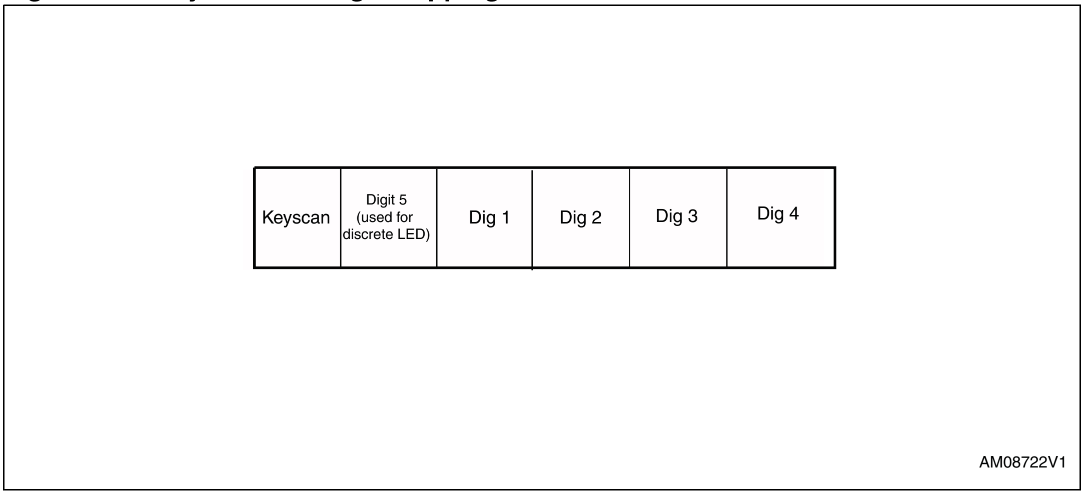
WDFEn = watchdog flag enable

12/24 = 12 hour or 24 hour format (‘0’ for 24-hour format and ‘1’ for 12-hour format). For 12 hour PM display, the 8th segment of last digit (digit 4) is driven to indicate PM mode through a dot on the last digit.

It is recommended to fill the unused bits in the register map to 0 upon a cold boot up. The timekeepers and alarm store data in BCD format, while the calibration, watchdog bits are in binary format.

The structure of the frame is shown below. For RTC, all the Dig1 to Dig4 must be configured to show the proper time.

Figure 8. Keyscan and digit mapping



If the date programmed in the RTC exceeds a valid date value, then the RTC does not function as desired. So the invalid dates should never be programmed into the RTC.

3.11.4 Setting alarm clock registers

Address locations 0Ah-0Eh contain the alarm settings. The alarm can be configured to go off at a prescribed time on a specific month, date, hour, minute, or second or repeat every year, month, day, hour, minute, or second. It can also be programmed to go off while the STLED325 is in the standby mode to serve as a system wake-up call.

Bits RPT6-RPT1 put the alarm in the repeat mode of operation. Codes not listed in the table default to the once per second mode to quickly alert the user of an incorrect alarm setting.

Note that by default, the alarm repeat mode is enabled and by default the repeat frequency is set to “once per year”.

Address locations 0Ah to 0Eh contain the alarm settings. The alarm can be configured to go off at a prescribed time. The default repeat alarm mode is once per year. Programming the RPT[6:1] bits changes the repeat alarm mode.

Table 3. Alarm repeat modes

RPT5	RPT4	RPT3	RPT2	RPT1	RPT6	Repeat alarm mode
1	1	1	1	1	1	Once per week
1	1	1	1	1	0	Once per second
1	1	1	1	0	0	Once per minute
1	1	1	0	0	0	Once per hour
1	1	0	0	0	0	Once per day
1	0	0	0	0	0	Once per month
0	0	0	0	0	0	Once per year

If the RPT value is other than the valid ones listed in the table, the default repeat alarm mode is once per second so as to quickly alert the user of an incorrect alarm setting. When the clock information matches the alarm clock settings based on the match criteria defined by RPT[6:1], then the alarm flag is set. Then if the alarm flag enable bit, is also set, this will activate the alarm interrupt. Interrupt is cleared by reading the Interrupt registers.

3.11.5 Century bits

The clock shall include correction for leap years. The clock shall also correct for months fewer than 31 days. Corrections for 28, 29 (leap year –valid until year 2100), 30, 31 day months must be made automatically.

The two Century bits increment in a binary fashion at the turn of the century, and handles all leap years correctly. See table for additional explanation.

Table 4. Century bits examples

CB[0]	CB[1]	Leap year?	Example (1)
0	0	Yes	2000
0	1	No	2100
1	0	No	2200
1	1	No	2300

1. Leap year occurs every 4 years (for years evenly divisible by 4), except for years evenly divisible by 100. The only exceptions are those years evenly divisible by 400. (The year 2000 was a leap year, year 2100 is not.)

3.11.6 Initial power-on defaults

Upon application of power to the device, the register bits in the RTC initially power-on in the state indicated in table below.

Table 5. Initial power-on defaults

OSC_ST	AFE	WDFEn
0	0	0

Initial power-on defaults value of the RTC registers.

Note: All other control bits power-up in a default state of 0 unless otherwise specified.

3.11.7 Programmable display

The default display of the RTC time is the 2 MSB digit for hour and the 2 LSB digit for minutes. However, if the MD_HM_MS bit is set, then the RTC display for the digits can be changed according to *Table 6*.

Table 6. RTC display

MD_HM_MS	RTC display
10	Date-month
00	Hour-minute (default and recommended)
01	Minute-second
11	Month-date

3.11.8 Lookup table with ppm against the calibration register values

The lookup table of the calibration register values for the equivalent ppm is shown in *Table 7* below:

Table 7. LUT with ppm against the calibration register values

Sign bit	Counts/bit					PPM
0	0	0	0	0	0	0
0	0	0	0	0	1	2
0	0	0	0	1	0	4
0	0	0	0	1	1	6
0	0	0	1	0	0	8
0	0	0	1	0	1	10
0	0	0	1	1	0	12
0	0	0	1	1	1	14
0	0	1	0	0	0	16
0	0	1	0	0	1	18
0	0	1	0	1	0	20
0	0	1	0	1	1	22
0	0	1	1	0	0	24
0	0	1	1	0	1	26
0	0	1	1	1	0	28
0	0	1	1	1	1	31
0	1	0	0	0	0	33
0	1	0	0	0	1	35
0	1	0	0	1	0	37
0	1	0	0	1	1	39
0	1	0	0	0	0	41
0	1	0	0	0	1	43
0	1	0	0	1	0	45
0	1	0	0	1	1	47

Table 7. LUT with ppm against the calibration register values (continued)

Sign bit	Counts/bit					PPM
0	1	1	1	0	0	49
0	1	1	1	0	1	51
0	1	1	1	1	0	53
0	1	1	1	1	1	55
0	1	1	1	0	0	57
0	1	1	1	0	1	59
0	1	1	1	1	0	61
0	1	1	1	1	1	63
1	0	0	0	0	0	0
1	0	0	0	0	1	-4
1	0	0	0	1	0	-8
1	0	0	0	1	1	-12
1	0	0	1	0	0	-16
1	0	0	1	0	1	-20
1	0	0	1	1	0	-24
1	0	0	1	1	1	-28
1	0	1	0	0	0	-33
1	0	1	0	0	1	-37
1	0	1	0	1	0	-41
1	0	1	0	1	1	-45
1	0	1	1	0	0	-49
1	0	1	1	0	1	-53
1	0	1	1	1	0	-57
1	0	1	1	1	1	-61
1	1	0	0	0	0	-65
1	1	0	0	0	1	-69
1	1	0	0	1	0	-73
1	1	0	0	1	1	-77
1	1	0	0	0	0	-81
1	1	0	0	0	1	-85
1	1	0	0	1	0	-90
1	1	0	0	1	1	-94
1	1	1	1	0	0	-98
1	1	1	1	0	1	-102
1	1	1	1	1	0	-106
1	1	1	1	1	1	-110
1	1	1	1	0	0	-114
1	1	1	1	0	1	-118
1	1	1	1	1	0	-122
1	1	1	1	1	1	-126