STM32L1x current consumption measurement
and touch sensing demonstration firmware

Introduction

This application note provides an overview of the demonstration firmware delivered with the STM32L-DISCOVERY and 32L152CDISCOVERY evaluation boards. It allows you to explore the rich set of power saving modes available in the STM32L1x microcontroller and use the STM32L1xx DISCOVERY embedded IDD measurement circuit to demonstrate the real capabilities of the Ultra low power microcontroller STM32L1x.

The demonstration application does not require any additional hardware. Once the STM32L1xx DISCOVERY is powered-up through a USB cable connected to the host PC, the application is ready to display the STM32L1x power consumption of each low-power mode selected by the user.

In addition the demonstration firmware allows you to explore the touch sensing capabilities of the STM32L1x microcontroller demonstrated by sensing the linear touch sensor or the set of four touchkeys.

Reference documents

The current consumption measurement and touch sensing demonstration firmware is included in the STSW-STM32072 STM32L1 discovery firmware package available from http://www.st.com.

- STM32L1 discovery kits: STM32L-DISCOVERY and 32L152CDISCOVERY (UM1079)
- Getting started with software development toolchains for the STM32L-DISCOVERY and 32L152CDISCOVERY board (UM1451)

The above documents are available at http://www.st.com.

Table 1 lists the microcontrollers, evaluation tools and software concerned by this application note.

Table 1. Applicable products, evaluation tools and software

Type	Part numbers
Microcontrollers	STM32L1 Series
Evaluation tools	STM32L-DISCOVERY, 32L152CDISCOVERY
MCU software	STSW-STM32072

Contents

1 Application description

STM32L1xx DISCOVERY stands either for STM32L-DISCOVERY or 32L152CDISCOVERY evaluation kit throughout the document.

1.1 Used hardware components

This application example uses the hardware components available on STM32L1xx DISCOVERY; on-board LEDs (green LD3 and blue LD4), the 6-digit/4-bar LCD glass display, the user push-button and touch sense slider. No additional components are required.

1.2 STM32L1xx DISCOVERY hardware settings

The I_{DD} jumper JP1 must be placed in position ON for standard operation (except for bias current record operation, see *Section 1.5.2*).
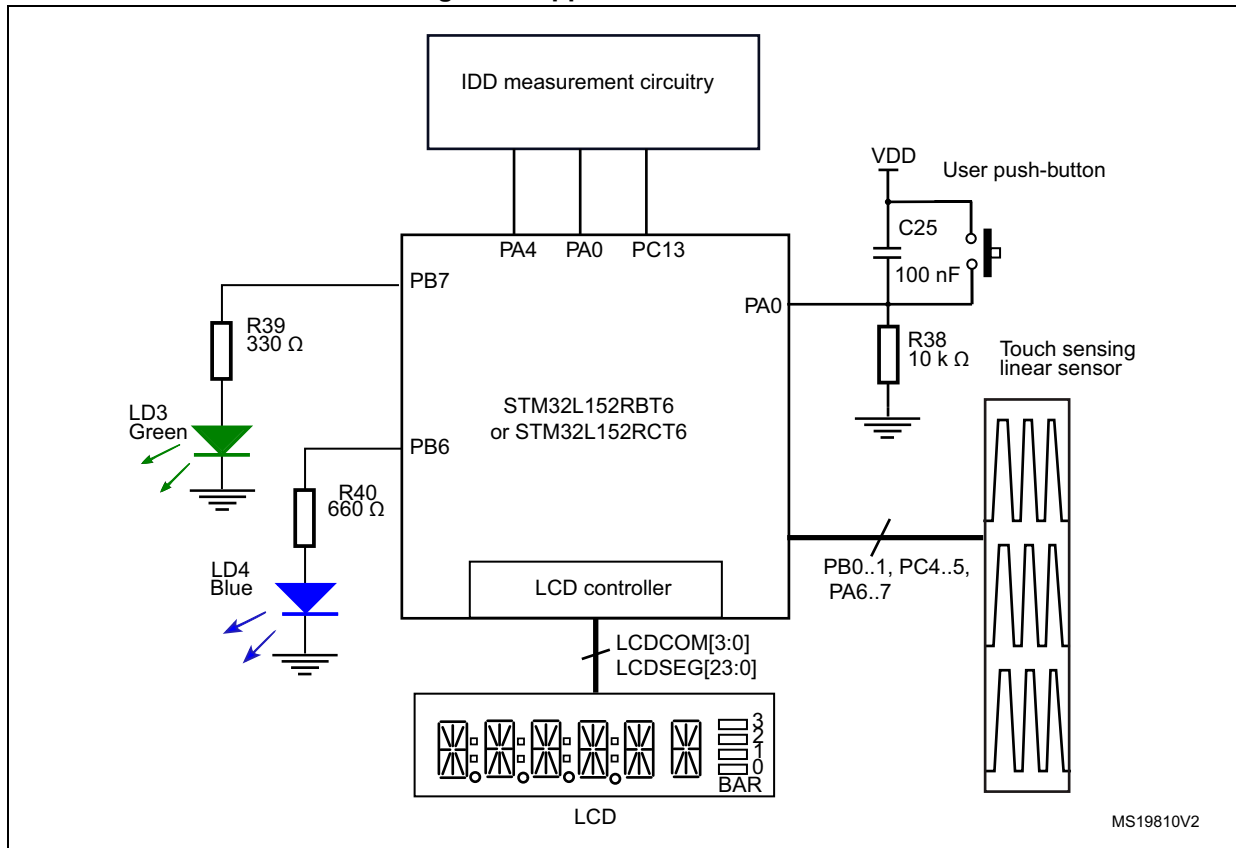
Both jumpers on CN3 must be fitted to allow communication of STM32L15x with ST-Link debugging tool thru SWD interface.

Note: *All solder bridges must be in the default state as described in UM1079.*

1.3 Application schematics

Figure 1 shows the simplified application electrical schematics.

Figure 1. Application schematics

1.4 Application principle

1.4.1 Overview

STM32L1xx DISCOVERY includes specific analog and logic hardware that is connected to STM32L152 microcontroller and which is intended to measure and display the supply I_{DD} current when the device is placed in different power consumption modes such as:

- Run mode
- Sleep mode
- Low power run mode
- Low power sleep mode
- Stop mode with operating RTC
- Stop mode without RTC
- Standby mode

The user reads the value displayed on the STM32L1xx DISCOVERY's LCD panel, to know how much power the device is currently consuming.

With this demonstration, you can obtain an overview of low power modes and supply current requirements for each low power mode available on STM32L152.

The firmware associated with this application note also provides a demonstration of the touch sensing functionality available on STM32L1xx DISCOVERY. The touch sensing electrodes can be configured either as a linear touch sensor to perform linear sensing of finger position displayed as a percentage on the LCD, or, it can be configured as a group of four independent touchkeys.

It also includes a manufacturing test mode for performing a quick diagnosis of the STM32L1xx DISCOVERY related to this application example. See *Section 1.5.3: Manufacturing test* for details regarding the test activation and for an explanation of the different test modes.

1.4.2 I_{DD} measurement principle

The STM32L1xx DISCOVERY I_{DD} measurement circuitry consists of measuring the high side shunt voltage value V at the terminals of a high precision serial resistor (1%) inserted between the +3V3 power supply and the V_{DD} pin of the MCU. Depending on the device power modes, the application uses R or [2000 + 2] x R as the equivalent resistor value by closing or opening K1. In Run mode, the current is in the range of mA, K1 is closed, and the equivalent resistor is R. In low power modes, the current is in the µA range, K1 is opened, and the equivalent resistance is 2002 x R.

Figure 2. I_{DD} measurement equivalent circuitry
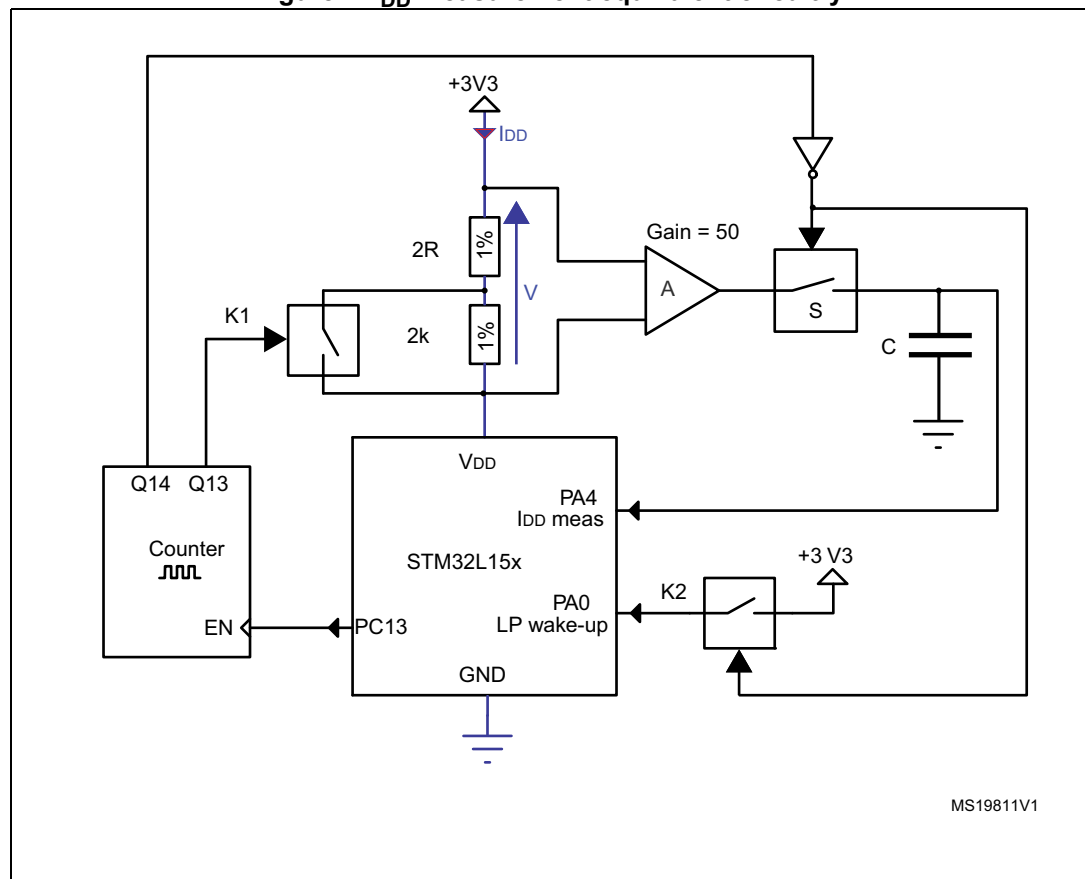
This resistor is connected between the differential inputs of a high-side current sense operational amplifier (A) with a fixed gain that amplifies the voltage (V) present on the resistors. A sample and hold stage is placed at the operational amplifier output and is then

connected to an analog input of the MCU (PA4 I_{DD} Measurement) that finally converts the resulting voltage, image of the consumption current.

In low power modes only, a counter enabled by STM32L15x (PC13 pin) manages the measurement timing while the microcontroller is idle. The microcontroller is woken-up after a 150 ms delay when the rising edge is triggered on a wake-up pin (PA0) controlled by the K2 switch.

While the microcontroller is in one of the power saving modes, a capacitor (C) is charged with the voltage amplified by the operational amplifier. The microcontroller can later sample (during its wake-up phase - 50 ms) the value of capacitor voltage proportional to the current consumption of MCU in low power mode. Switch S is opened at device start-up in order to keep the charge collected in capacitor (C) intact while the microcontroller is in low power mode.

The current measurement precision is enhanced by taking into account the current bias of high-side current operational amplifier. When JP1 is placed in OFF position (I_{DD} measurement circuitry disabled), a special test invoked by the user at device start-up measures this current value and stores it in the non-volatile memory. Once this value is stored in the device, it is deducted from the next I_{DD} measurement to compensate errors due to I bias current (see *Section 1.5.2: Bias current record*).

For additional information related to the I_{DD} measurement feature, please refer to section 4.7, Built-in IDD measurement circuit of the STM32L1 discovery kits: STM32L-DISCOVERY and 32L152CDISCOVERY user manual (UM1079).

1.5 Getting started with the application

This STM32L1xx DISCOVERY example application has 3 application modes that can be run:

- Demo mode (touch sensor, I_{DD} measurement)
- Bias current record
- Manufacturing test

Demo mode is available at application power-up while the two others are invoked by the user using a specific procedure that is described in detail later in this chapter. However, for best performance, it is recommended to measure and record the bias current before starting evaluation of low power mode I_{DD} current.

1.5.1 Demo mode - Touch sensing demonstration and I_{DD} measurement

Once the application is powered-up via the USB cable (or by external power supply), it starts displaying a welcome message and then, after a few seconds, the value of the V_{DD} voltage applied to the STM32L1x device.

LD3 (green LED) and LD4 (blue LED) blink alternately. As soon as I_{DD} consumption values are displayed, both LEDs are turned off.

The User push-button allows you to change the functions as described in the state diagram in *Figure 3*.

The first step is a demonstration of the linear touch sensor function followed by a touchkey demo activated by pressing the user button.

When the used push button is pressed again, the power consumption measurement functions are launched. These functions consist of configuring the device for each low power consumption mode and then measuring and displaying the result on the LCD panel.

Figure 3. Function Change state diagram
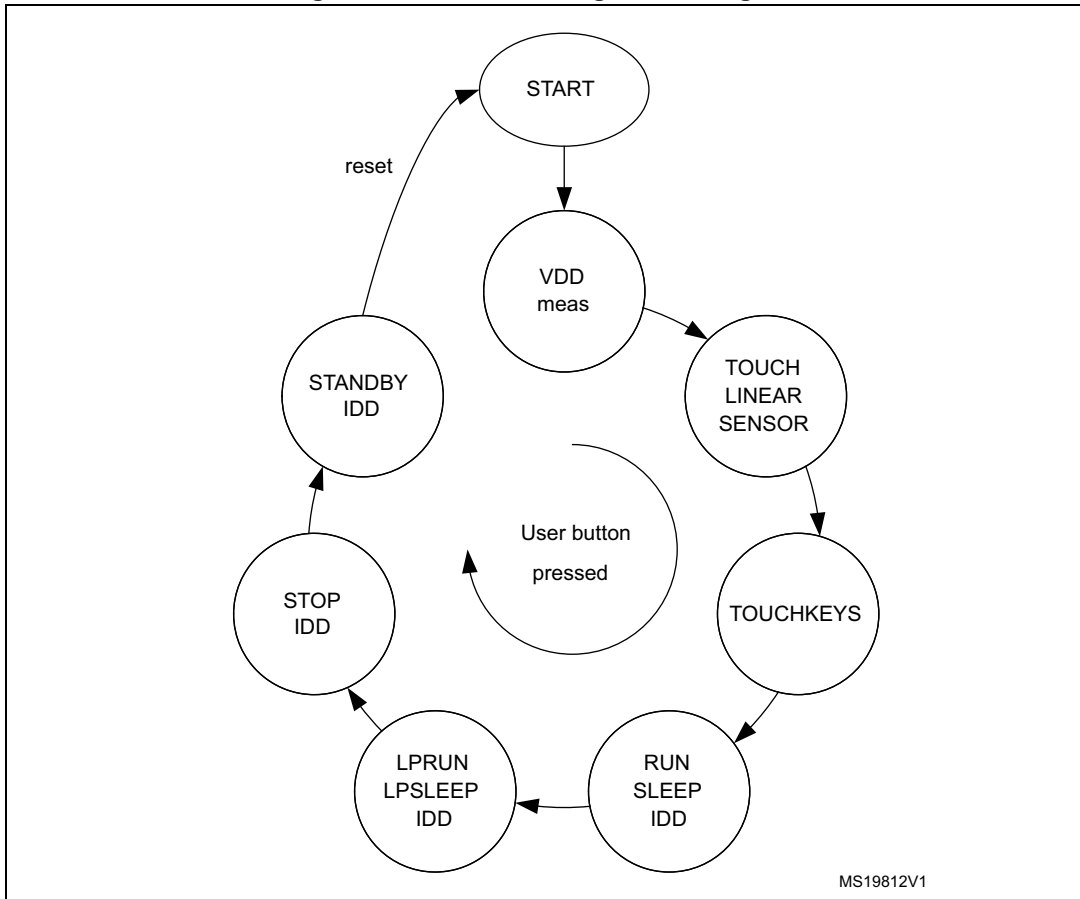
BAR0 to BAR3 are used by the application to indicate ongoing measurements as shown in *Table 1*.

In order to save power during the I_{DD} measurement in *Stop mode without LCD*, the LCD is switched off. Once the measurement is performed the LCD is switched on to display the power consumption value.

Table 1. Bars and LCD display linked to functions

Function	Bars
VDD / Linear sensor / Touch buttons	
Run mode / Sleep mode	

Table 1. Bars and LCD display linked to functions (continued)

Function	Bars
Low power run / Low power sleep	
STOP / STOP without LCD	
STANDBY mode	

1.5.2 Bias current record

This operation consists of storing the bias current value of operational amplifier A (see *Figure 2*) in the data memory. The bias current value is taken into account for low power measurements in order to minimize measurement errors. Once recorded, this value is kept in non-volatile memory for later use. It is recommended to perform this operation when you start your evaluation in order to obtain the best precision.

This mode is only accessible at application power-up by executing the following steps in the order below:

1. Switch OFF STM32L1xx DISCOVERY
2. Place JP1 in OFF position (I_{DD} measurement disabled)
3. Keep USER push-button pressed while powering ON the STM32L1xx DISCOVERY
4. At power on, a scrolling message "Bias Current" is displayed
5. Release the USER push-button; the bias current value is displayed and immediately stored in non-volatile memory

Once this operation completed, replace JP1 in ON position so that the measurement circuitry is connected again to the STM32L152 (I_{DD} measurement enabled).

1.5.3 Manufacturing test

You can access this mode while Demo mode is running, by pressing the USER push-button for more than 3 seconds and by releasing it. This allows you to verify that the hardware modules needed by the STM32L1xx DISCOVERY for this example are working properly.

In this mode, application checks the LSE oscillator (Low Speed External), V_{DD} voltage value, I_{DD} RUN, OA bias and LP (low power) I_{DD} currents. The currents are tested for lower and upper limits. For each test function, the application displays "OK" and the measured values when available. If all checks are successfully completed, then the message "TEST OK" is continuously displayed. If one of the tests fails, then the application alerts the user by continuously displaying the test name followed by "NO OK".

To exit this manufacturing test, press the RESET button.

Note: *Generally, if the manufacturing test is not successful, first check that JP1 is placed in the ON position and that all solder bridges are in default position. If errors are found in the Low*

power and Halt modes I_{DD} measurements, the bias current record operation should be performed again.

1.6 Low power modes

The low power modes used in this application are listed below. The microcontroller can be woken up from any power saving mode by an external wake-up event generated by counter U3.

- **Sleep mode:** The CPU is stopped, the peripherals kept running. The system is clocked by the MSI oscillator at a frequency of 4 MHz.

- **Low power run mode**: The CPU and some of the peripherals are running. During Low power run mode, the code is executed from RAM and the CPU is clocked at a frequency of 32 kHz by the MSI oscillator. Flash and data EEPROM are stopped and the voltage regulator is configured in Ultra low power mode.

- **Low power sleep mode:** The CPU is stopped. The system clock frequency is reduced to 32 kHz. Flash and Data EEPROM are in power down mode and the voltage regulator is configured in Ultra low power mode.

- **Stop mode:** The Core is in Deepsleep mode, Flash, Data EEPROM and all clocks except LSE are in power down mode. All peripherals except the LCD are disabled. The voltage regulator is in low power mode.

- **Stop mode without LCD:** This is the same as Stop mode except that the LCD controller is also disabled in this case.

- **Standby mode:** This is the deepest low power mode. The voltage regulator is disabled. Core, peripherals, RAM, Flash and Data EEPROM are powered off. Power is maintained for the RTC registers, backup registers and standby circuitry. Device wake-up is done by an external wake-up event, generating a system reset.

For further information, please refer to *STM32L15x reference manual (RM0038)* where you can find more details about all the available configurations for each STM32L15x low power mode.

2 Software description

2.1 STM32L1x peripherals used by the application

This application example uses the following STM32L1x peripherals with the settings described below:

ADC

ADC performs analog-to-digital conversions of the internal reference voltage (V_{DD} voltage display) and of the voltage coming from the operational amplifier that is the image of I_{DD} current.

- ADC resolution: 12-bit
- ADC conversion mode: single
- ADC sampling time: 192 cycles

SYSTICK Timer

The Systick timer is used to generate the delay needed for display or wait loops.

GPIOs

Port C and Port E are connected to the USER push-button and the LEDs.

- PB1 set as an input floating pin with interrupt connected to the USER push-button
- PB7 (green LD3) and PB6 (blue LD4) set as an output push-pull
- PA0 set as a wake-up pin configured either as an input floating pin with interrupt with detection on rising edge or as an alternate function AFIO0 (WKUP1) during Standby mode.
- PA6, PA7, PC4, PC5, PB0, PB1 are used for linear touch sensor or touchkeys during the touch sensor demonstration.
- During the low power modes, I/Os are placed in analog input mode to reduce power consumption except for a few pins related to the hardware interface (PB7 - green LD3 PB6 - blue LD4, PA4 - I_{DD} measurement pin, PA0 - LP WakeUp pin and PC13 - IDD timer enable). This means that all Schmitt triggers on unused standard I/O pins are disabled to reduce power consumption.

LCD controller

The different functions available in the firmware library for LCD are used to initialize, clear, display strings and scrolling messages needed in the application code. For some low power mode measurements, the LCD controller is turned OFF to minimize the current consumption of the STM32L152.

Clock

The MSI (the multi speed internal oscillator) oscillator is selected as clock source. The application manages the peripheral clocks depending on the selected power saving mode. When the device enters low power run mode, MSI is switched to range 0 until the device is woken-up by an external event. When exiting Low power run mode, the MCU switches the HSI oscillator back ON. LSE is switched ON during Manufacturing test mode (see *Section 1.5.3*) to check its functionality.

2.2 STM32L1x standard firmware library configuration

The *stm32l*1xx_conf.h file of the STM32L1x standard firmware library allows you to configure the library by enabling the peripheral functions used by the application.

The header files of library modules are included in the *stm32l*1xx_conf.h file as listed bellow.

#include stm32l1xx_adc.h

#include stm32l1xx_exti.h

#include stm32l1xx_flash.h

#include stm32l1xx_gpio.h

#include stm32l1xx_syscfg.h

#include stm32l1xx_lcd.h

#include stm32l1xx_pwr.h

#include stm32l1xx_rcc.h

#include stm32l1xx_rtc.h

#include "misc.h"

The corresponding library modules has to be present in the project for successful compilation and linking.

2.3 Application software flow

2.3.1 Main application

After powering up the STM32L1xx DISCOVERY, the initialization of the peripherals and LCD display is performed and then the application immediately checks whether the USER push-button is pressed. If pressed, then the application goes to the Bias current record operation. Otherwise, Demo mode (I_{DD} measurement) is automatically selected. If during Demo mode, the user presses the USER key for more than 3 seconds, then the application enters manufacturing test. To exit manufacturing test, the application needs to be restarted by pressing the RESET button.

2.3.2 Demo mode (I_{DD} measurement)

When Demo mode is launched, it starts displaying a welcome message and then, after a few seconds, the V_{DD} value.

The user then selects one of the I_{DD} measurement functions by pressing successively on the USER pushbutton (as described in *Section 1.5.1*).

These functions are mainly divided in 2 steps:

- Configuring the device according to the selected power mode
- I_{DD} measurement and display (this part is common for all power modes)

The Demo mode sequence is as follows:

Figure 4. Demo mode sequence
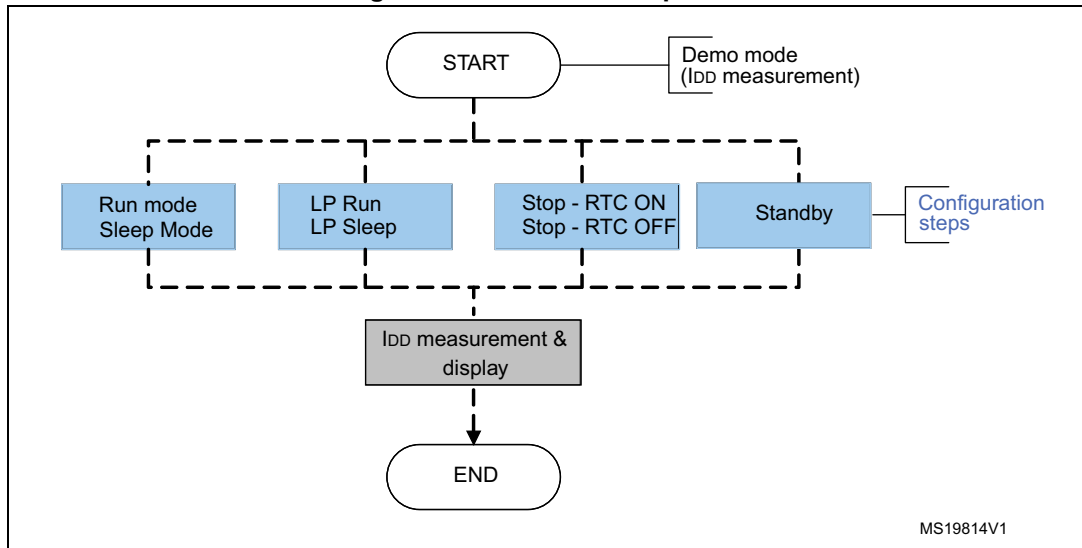
Low power modes configuration

For I_{DD} measurement in Run mode, there is no particular setup needed other that performed during the STM32L1x power on initialization. For this function, the application goes directly to I_{DD} measurement and display routine.

The configuration of device for Low power run, Sleep, Stop with and without RTC is detailed in *Figure 5*. Please, see RM0038 for more details about low power modes available on STM32L1x.

Figure 5. Low power mode flowchart
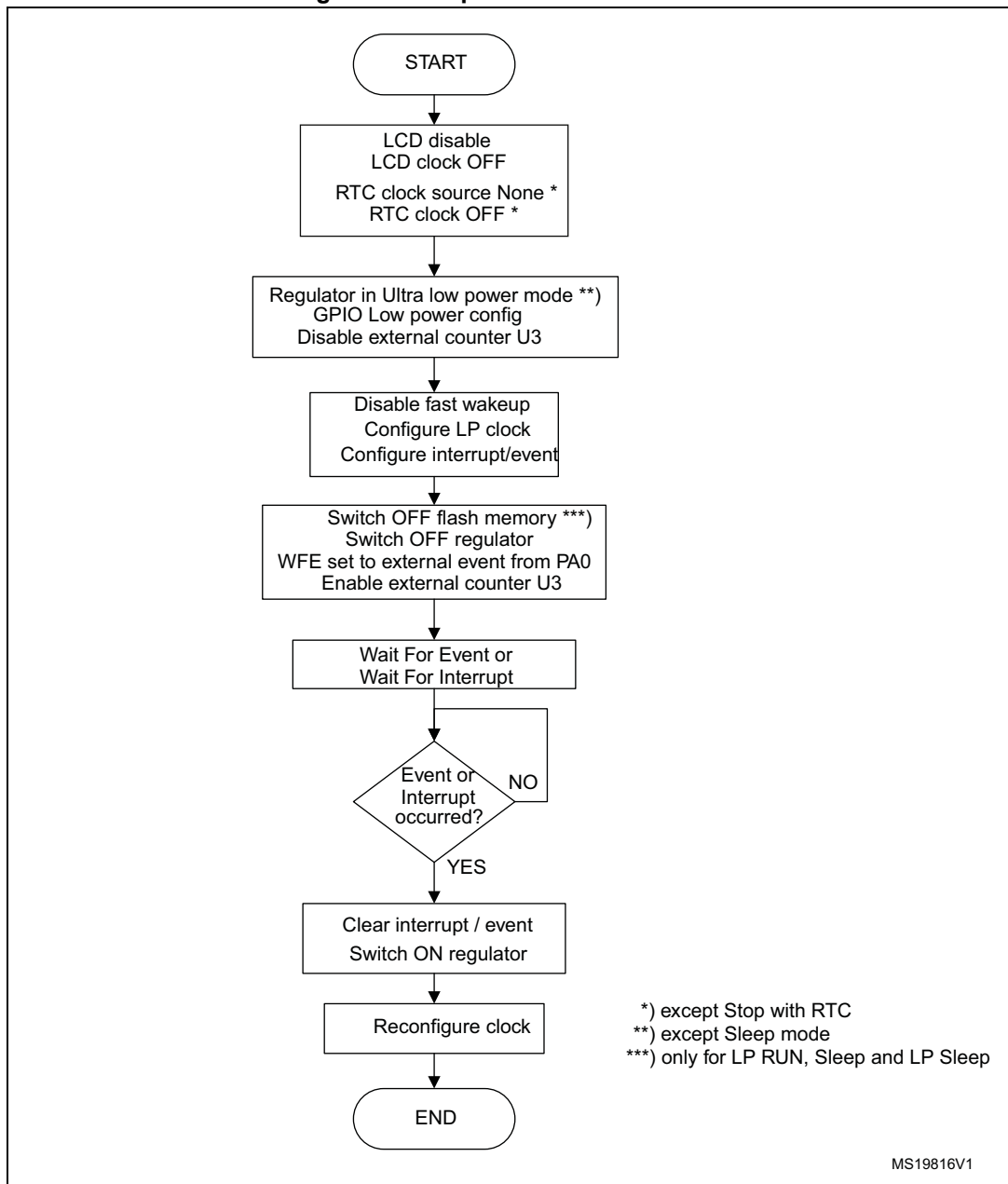
In Standby mode, the device is in its deepest energy saving state. The device enters the Cortex-M3 deepsleep mode and the voltage regulator is disabled. All oscillators are switched off. SRAM and register contents are lost with the exception of the RTC registers, RTC backup registers and Standby circuitry. The device is woken up from this mode by an external wakeup event generated by the U3 counter invoking a system reset.
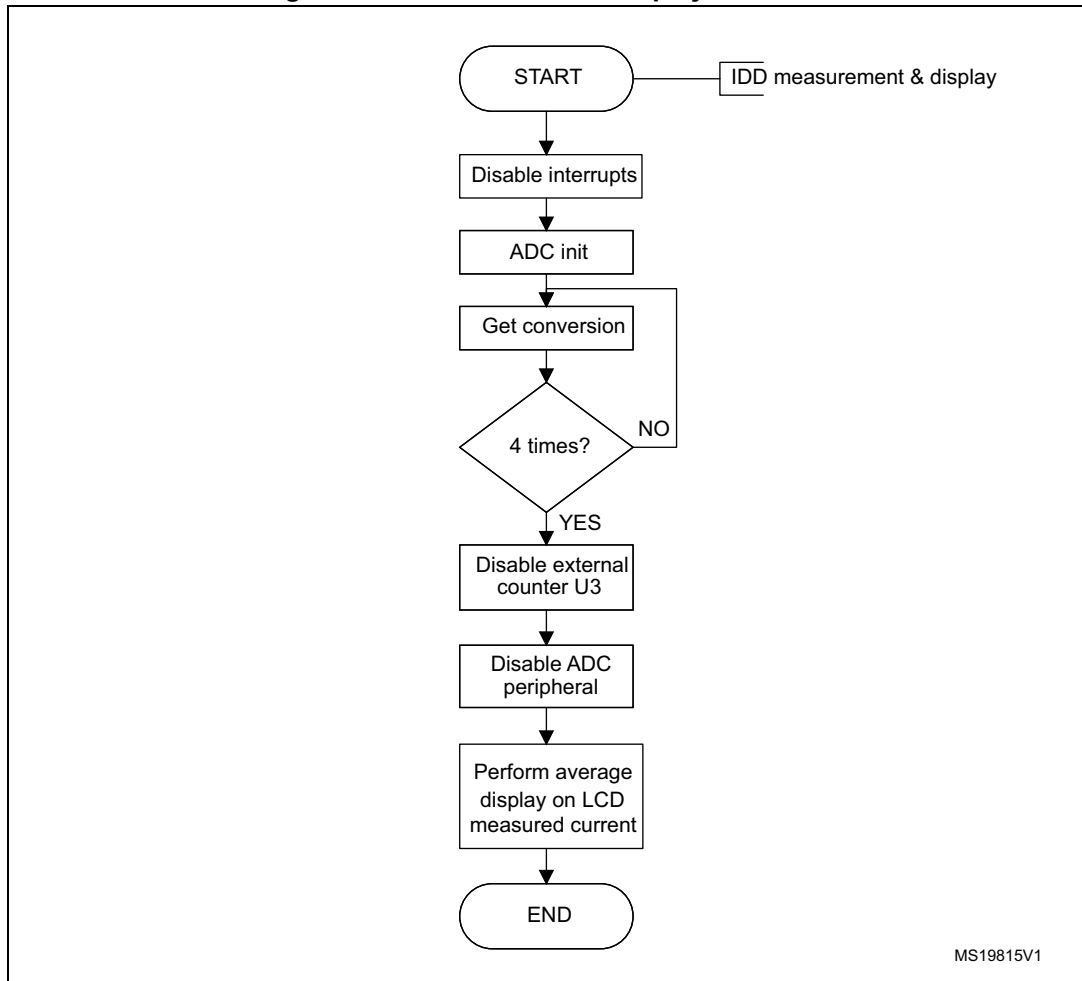
Figure 6. Standby mode flowchart
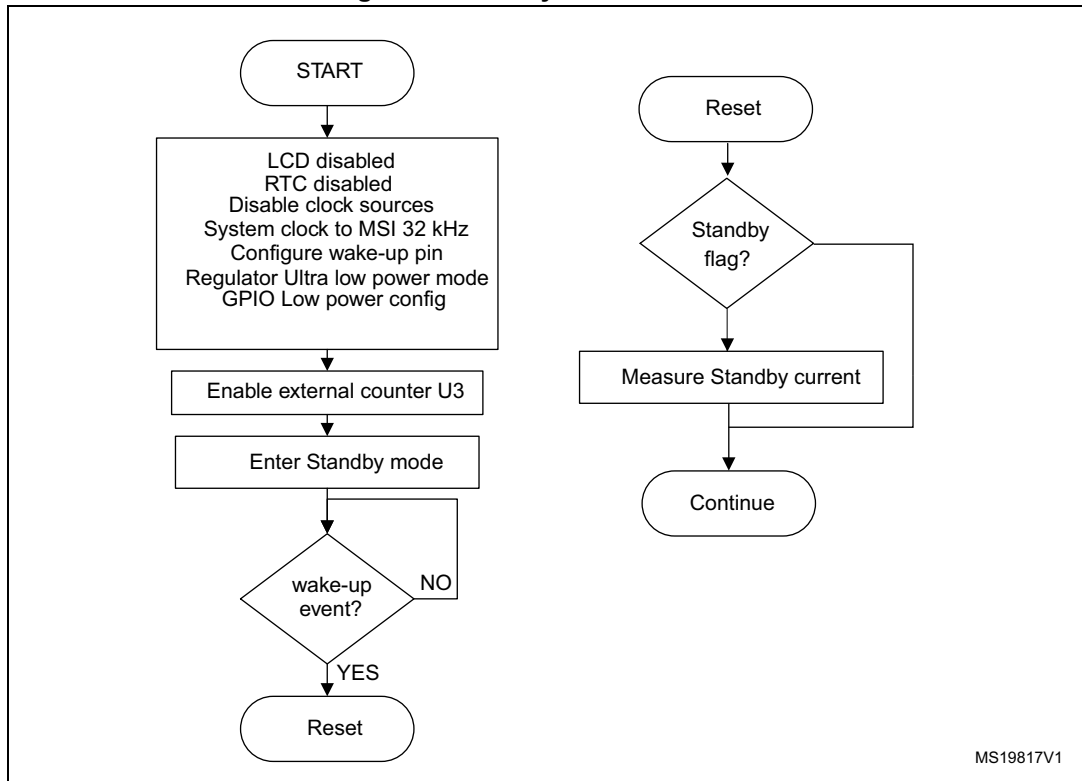
I$_{DD}$ measurement and display

The following flowchart describes the I$_{DD}$ measurement process.

Figure 7. Measurement and display flowchart

As shown in *Figure 7*, the ADC conversion is performed 4 times in succession and an average value is computed. The average value is displayed on the LCD.

3 Conclusion

This application note shows the demonstration firmware delivered with your STM32L-DISCOVERY or 32L152CDISCOVERY kit. This example allows you to evaluate the touch sensing capability of STM32L1xx microcontrollers and demonstrate its Ultra low power features by providing the measured current consumption values in selected low power modes directly on the LCD.

The low-cost STM32L-DISCOVERY or 32L152CDISCOVERY kit with the firmware example associated with this application note provides a starting point for your own evaluation of current consumption of application specific tasks running on the Ultra low power STM32L1x microcontroller.

4 Revision history

Table 2. Document revision history

Date	Revision	Changes
04-Jul-2011	1	Initial release
27-Jun-2013	2	Added 32L152CDISCOVERY. Removed PM0062 and added UM1451 in *Reference documents*. Updated *Clock* section.

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