AN13660

MCU-Link Energy Measurement Capabilities

Rev. 0.1 — 24 January 2024 | Application note

Document information

Information	Content
Keywords	AN13660, MCU-Link, Power Measurement, LPC553x, LPC55S3x
Abstract	This application note demonstrates that the MCU-Link is a powerful and reliable tool for power measurements in different applications.

1 Introduction

MCU-Link is a powerful and cost-effective debug probe that can be used seamlessly with MCUXpresso IDE. It is compatible with tools/IDEs that support CMSIS-DAP protocol. It also includes a USB to Universal Asynchronous Receiver Transmitter (UART) bridge feature (VCOM) that can be used to provide a serial connection between the target MCU and a host computer.

There are three MCU-Link designs:

- MCU-Link base model

- MCU-Link PRO

- MCU-Link on-board

PRO and on-board designs have support for energy measurement.

MCU-Link is based on the dual Arm Cortex-M33 core LPC55S69 microcontroller running at 150 MHz and features a high-speed USB interface for high performance debug. The MCU-Link debugging tool offers an advanced tool, MCU-Link PRO. In addition to SWD debug, SWO profiling and a USB to UART bridge features found in the base MCU-Link, the PRO model adds a J-Link LITE firmware option, energy measurement, analog signal monitor, USB to SPI and I^2C bridging capability and an on-board LPC804 for peripheral emulation. MCU-Link is also implemented on some NXP microcontroller evaluation boards; these implementations are referred to as MCU-Link On Board (OB). MCU-Link OB features may vary between boards, but typically include energy measurement, USB bridges and the J-Link LITE firmware option.

All versions of MCU-Link use the same firmware images and all are compatible with Windows 10, MacOS, and Linux.

For the rest of this document, for simplicity, any usage of MCU-Link refers to the MCU-Link on-board model.

2 Objective

This application note demonstrates that the MCU-Link is a powerful and reliable tool for power measurements in different applications. This document shows the results of the MCU-Link in different power settings and compare to a third-party tool. For the purpose of this application, we use the LPC55S36-EVK. This evaluation board comes with the MCU-Link available on board.

3 MCU-Link overview

MCU-Link provides support for SWD-based target debug, including features enabled by SWO trace/profiling I/O support, and supports target debug systems (running from 1.2 V to 5 V). It adds a J-Link LITE firmware option, analog signal monitor (1.2 to 3.6 V), USB to SPI, and I^2C. It also includes many features to facilitate embedded software development like energy consumption analysis. The resolution for energy measurement depends on the maximum current range supported by the board MCU-Link implementation used. Refer to the user manual for specific current range and corresponding resolution.

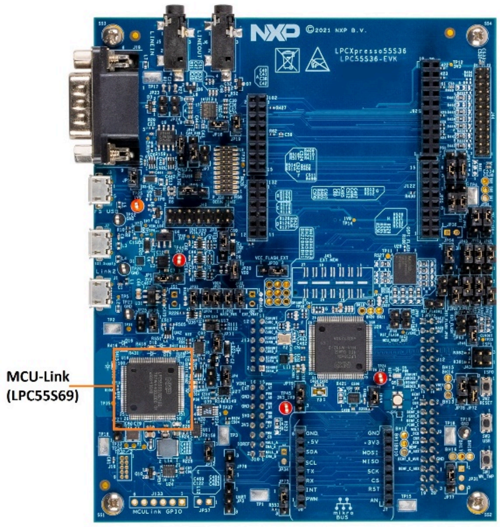

Figure 1. MCU-Link as an on-board debugger and energy measurement tool for the LPC55S36-EVK

The MCU-Link includes circuitry to measure supply voltage and current drawn of the target. The energy measurement features in MCUXpresso IDE can display this measurement data along with energy and power consumption. The measurement hardware automatically selects either a low or high range current to provide higher accuracy at low currents. Automatic range switching from low current drawn to high current drawn avoids excessive voltage drop across the sense resistors.

The power measurement feature is intended for low power measurements, with a target MCU running at up to 3.6 V. The design uses the LPC55S69 16-bit ADC, with power data sampled at up to 100kS/s. At high sample rates, MCUXpresso IDE may not capture all data, so the sample rate must be adjusted using the configuration options in the energy measurement configuration settings in that tool.

4 LPC55S36-EVK overview

LPC55S36 is an Arm Cortex-M33 based microcontroller for embedded applications. This device includes up to 256 KB on-chip flash, up to 128 KB of on-chip SRAM, FlexSPI with cache and dynamic decryption. Among the many peripherals that it includes the most notable in this device are full-speed USB host and device interface with crystal-less operation, CAN FD, a variety of timers, eight flexible serial communication peripherals, one SPI Filter, one QuadFlash Filter, one DMIC, one I3C interface, two 16-bit 2.0 Msamples/sec ADCs, four comparators, three 12-bit 1 Msample/sec DACs, three OpAmps, two FlexPWM timers, and two QEIs.

To provide a more complete analysis, we use all power-saving modes available in the LPC55S36 MCU device, as shown in Figure 2.

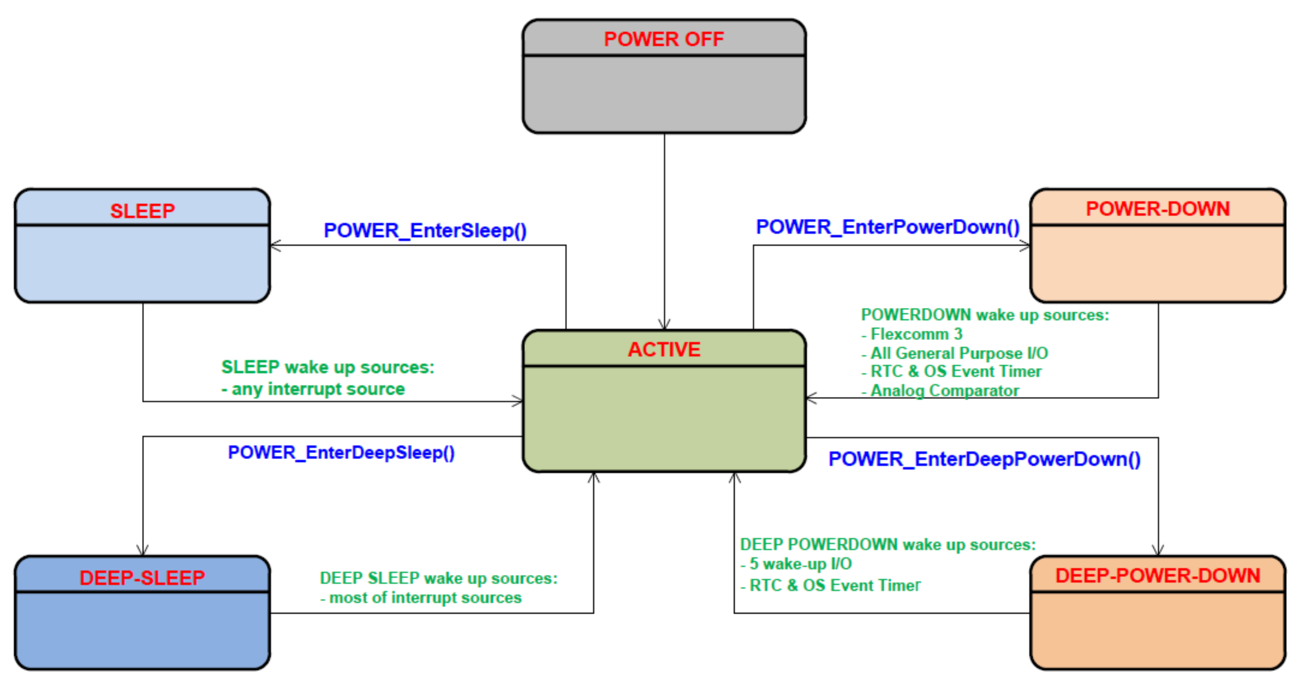

Figure 2. Device supporting a variety of power modes

4.1 Sleep mode

Sleep mode saves some power by stopping the Cortex-M33 core without affecting peripherals or requiring significant wake-up time. The clock to the CPU is shut off. Peripherals and memories are active and operational. The CPU is stopped and execution of instructions is suspended until either a reset or an interrupt occurs. Sleep mode only eliminates dynamic power used by the processor itself, memory systems and related controllers, and internal buses. The processor state and registers, peripheral registers, and internal SRAM values are maintained.

4.2 Deep-sleep mode

In Deep-sleep mode, the full device remains powered, but flash and ROM are shut down, with the cost of a longer wakeup time compared to the SLEEP mode. The system clock to the CPU is disabled as in sleep-mode. Analog blocks are powered down by default but can be selected to keep running through the power API if needed as wake-up sources. The main clock and all peripheral clocks are disabled.

4.3 Power-down mode

Power-down mode turns off nearly all on-chip power consumption by:

- eliminating power used by almost all analog modules
- eliminating almost all digital peripherals power by shutting down the DCDC and the LDO_CORE

The flash memory is also disabled. Any SRAM instance that is not configured to maintain its internal state will lose it. When a wake-up event occurs, the Cortex-M33 CPU code execution resumes from where it has stopped.

4.4 Deep power-down mode

Deep power-down mode shuts down virtually all on-chip power consumption but requires a significantly longer wakeup time. For maximal power savings, the power domains are shut down. Only the Always-on power domain PMU, PMC, the RTC and the OS Event Timer stays powered. Clocks are shut off to the entire chip device with the exception of the RTC and the OS Event Timer if they are needed. On wake up, the device reboots.

5 Hardware configurations for energy measurement

To avoid excessive voltage drop across the sense resistor, the automatic switching from low current measurement to high current measurement is controlled solely by hardware. When switching from high current to low current measurement the MCU-Link firmware controls the switch back to low current measurements triggered by an interrupt from a monitoring circuit. The measurement circuit self-calibrates each time the MCU-Link is powered on.

To measure certain rails of the EVK, some jumpers (JP74 and JP75) must be removed. We can use these two points to connect the MCU-Link energy measurement circuit in line with any supply rail, just as one would connect an ammeter. You can connect jumpers from JP74 (pin2) and JP75 (pin2) to any power rail that is available on board. To measure the total current, it is only necessary to remove JP33, since it is already connected to these two terminals.

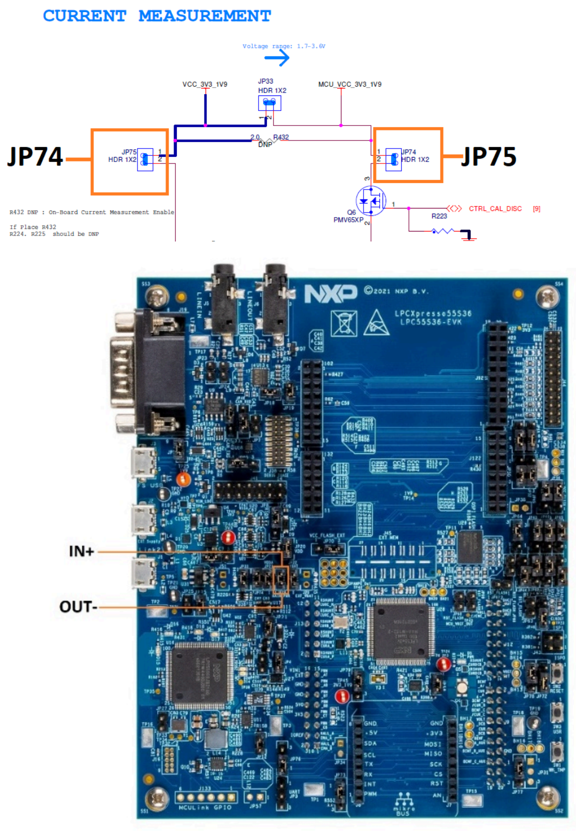

Figure 3. JP74 and JP75 Schematic and Physical location on LPC55S36-EVK

For example, to measure the main power rail, remove jumper JP28 and connect the two ends to JP74 and JP75.

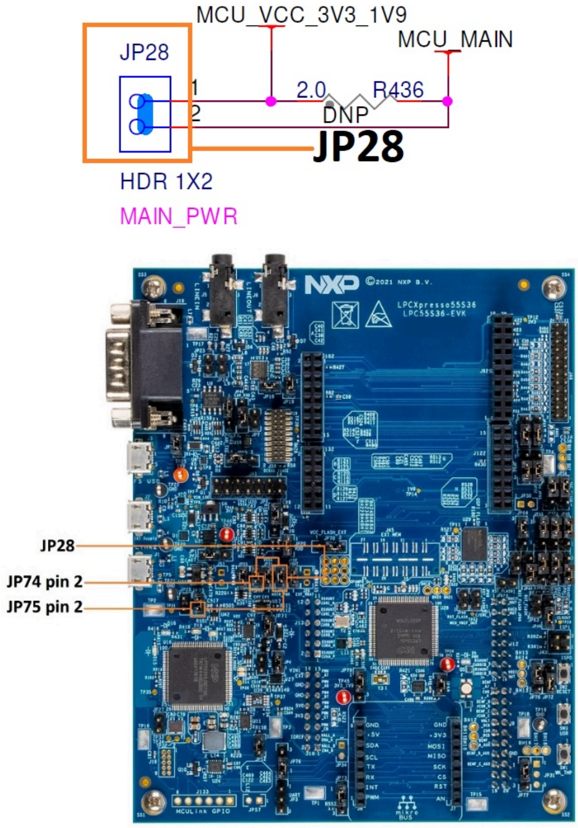

Figure 4. Jumpers that need to be removed for Main Power current measurement with on board MCU-Link

6 Comparative tests between MCU-Link and Joulescope

To provide an example of the accuracy of the MCU-Link energy measurement feature, this section describes how to reproduce test results made using a Joulescope and an MCU-Link on an LPC55S36-EVK.

Tools as below are needed:

- MCUXpresso IDE version 11.5.1 or above
- Firmware update for MCU-Link CMSIS-DAP V2.250 or higher
- LPC55S36-EVK SDK version 2.10.2 or above

To build and run the example, perform the following steps:

1. Open the MCUXpresso IDE.

Figure 5. MCUXpresso IDE

2. Find the QuickStart Panel in the lower left-hand corner and then click on **Import SDK example(s)…**.

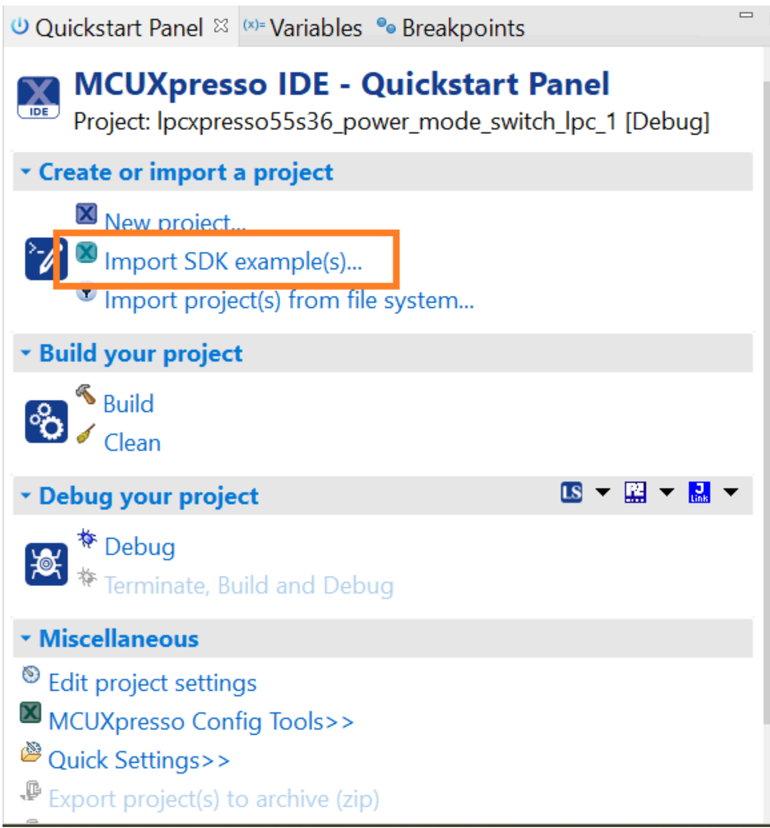

Figure 6. QuickStart panel

3. Click on the LPC55S36-EVK board then click on **Next**.

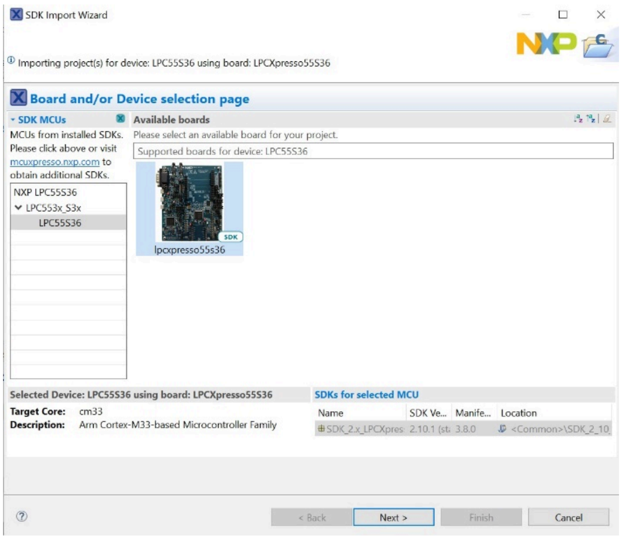

Figure 7. Selecting board

4. Import an example from the LPC55S36-EVK SDK **power_mode_switch**, then click on **Finish**.

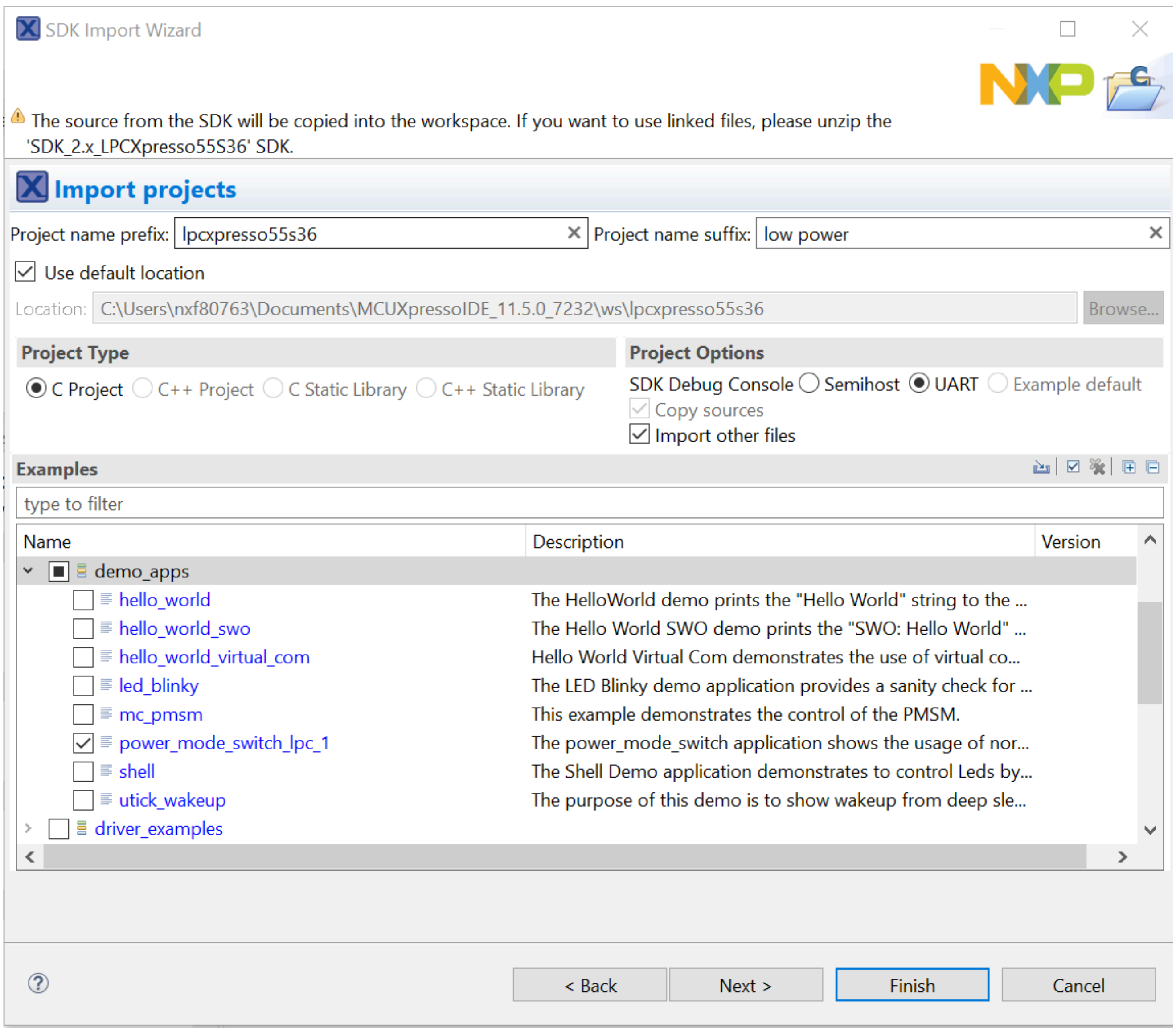

Figure 8. Selecting example from the SDK

5. Select the project and build it. Once the project has built successfully, select **Debug**.

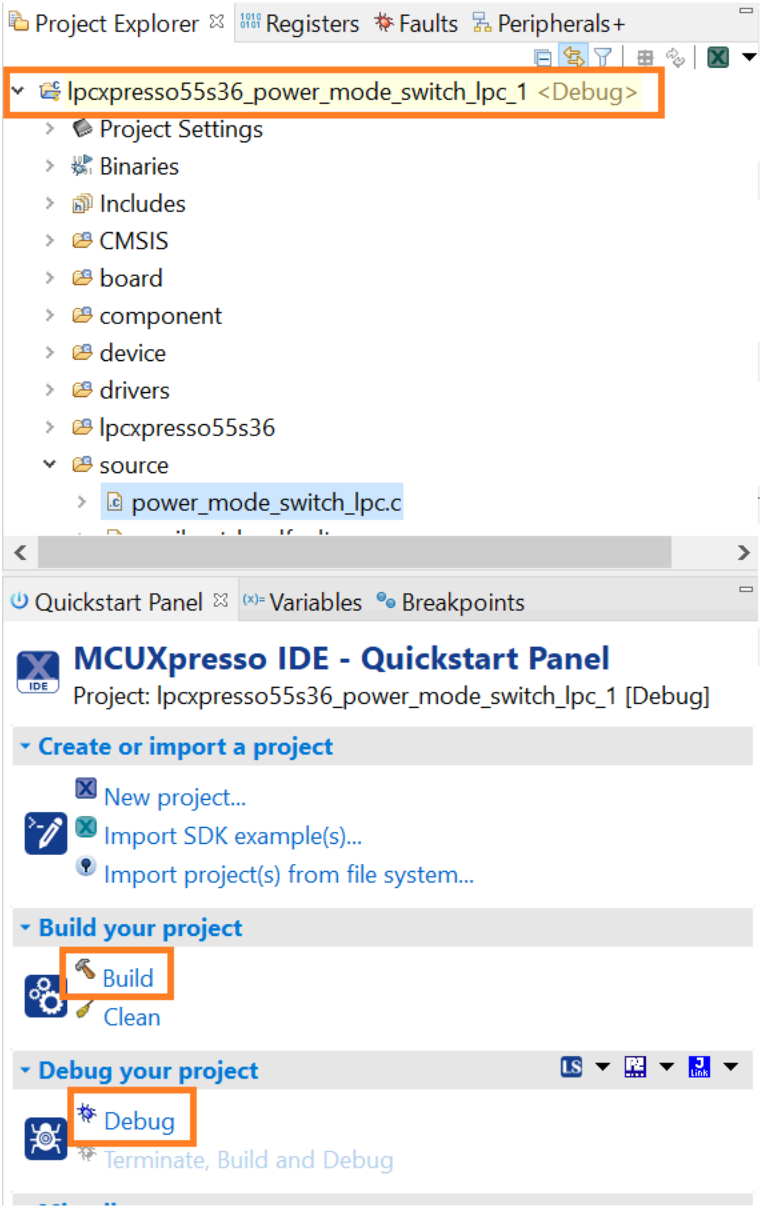

Figure 9. Selecting, building, and debugging the project

6. Stop the debug session and open a serial terminal select the MCU-Link port. Use the following settings for serial console as mentioned:
   - Baud rate 115200
   - No Parity
   - 8 Data bits
   - 1 Stop bits

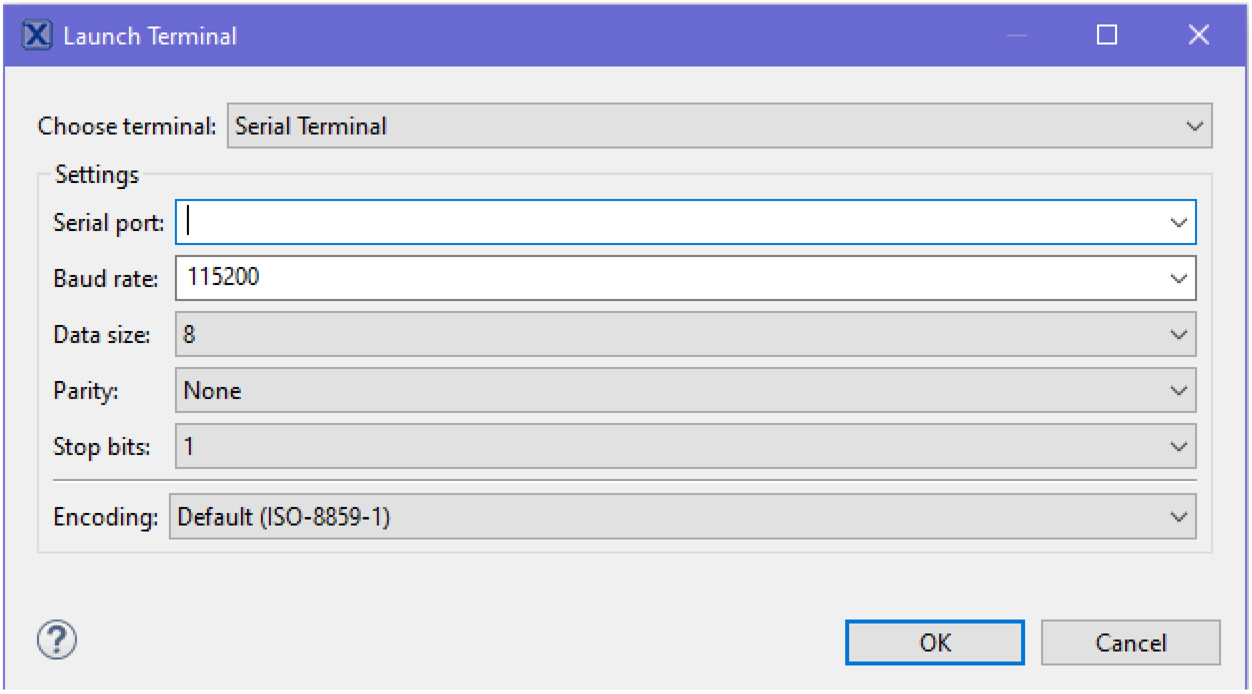

Figure 10. MCUXpresso IDE offers a terminal window

7. Reset the board using SW2 (RESET) switch and the serial terminal displays output.
8. Enter a number 1, 2, 3, or 4 from the keyboard to put LPC55S3x/LPC553x into sleep mode, deep-sleep mode, power-down mode, or deep power-down mode.

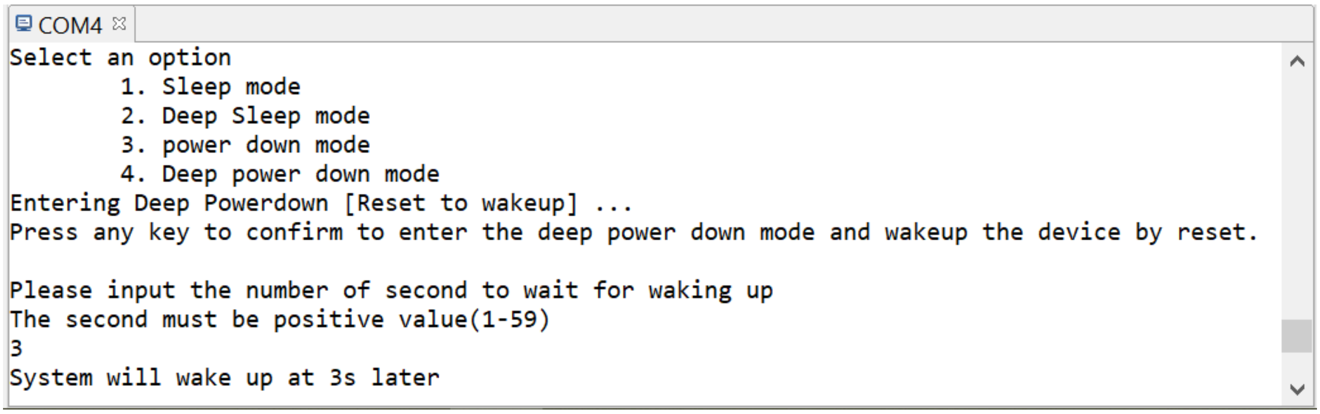

Figure 11. Example from SDK

For the test results below, adjustments to the SDK example were made, to improve measurements as well as automatically switch between power modes to allow for cleaner comparison. In addition, the RTC was enabled during all power modes and used the alarm to move on to the next power mode. Download AN13660SW and use the **Import from file system** option from the Quickstart menu.

7 Current measurements

In the following example, we can see the current measured on the main power rail through JP28 on the LPC55S36-EVK. The application runs the RTC timer as a wake-up source for the low power modes and provides a time frame to better appreciate the current measured during that power setting.

7.1 Current measurement with MCU-Link

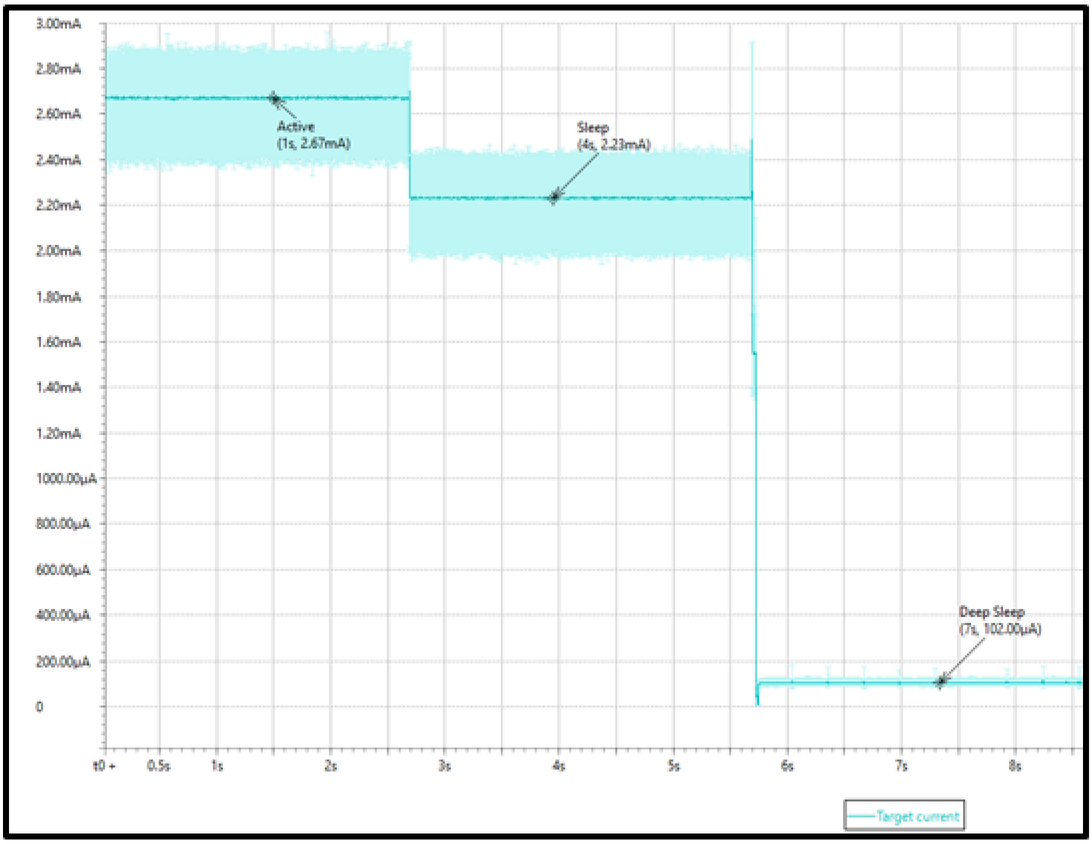

Figure 12. MCU-Link energy measurement window

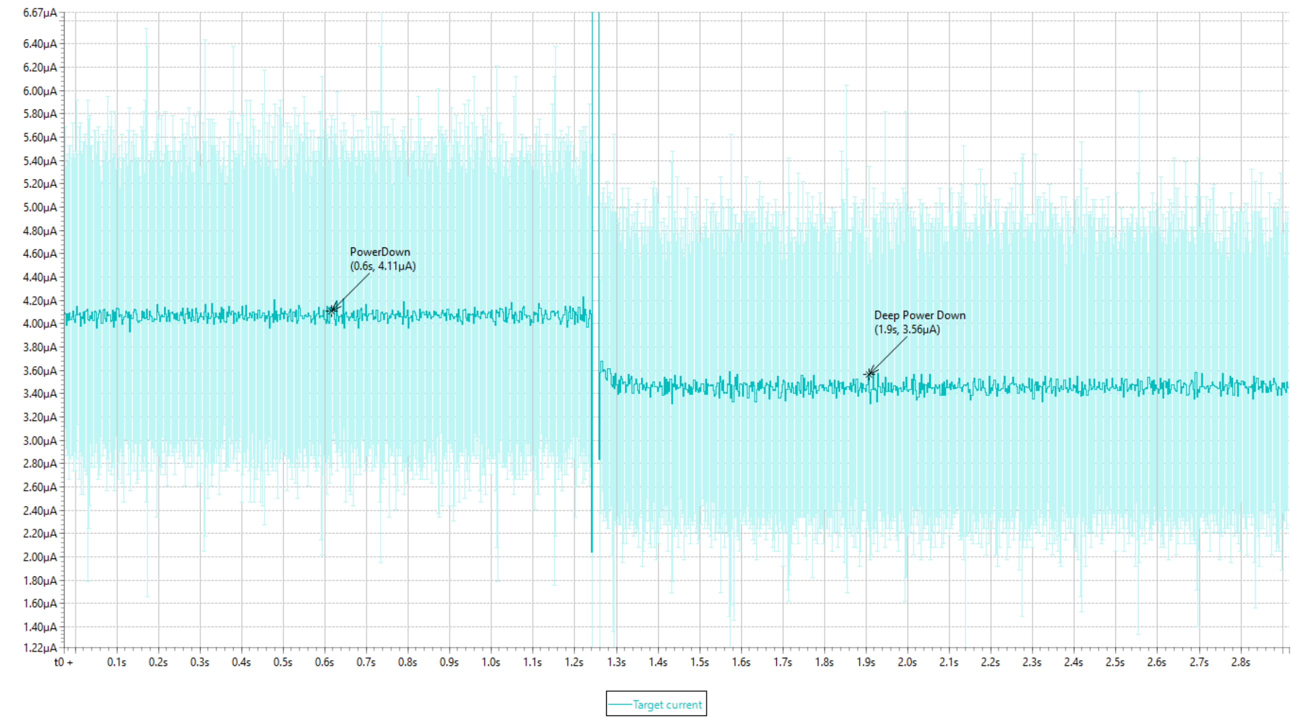

Figure 13. MCU-Link energy measurement window power-down and deep power-down

The current drawn by the target MCU is measured by measuring the voltage drop across sense resistors in the LPC55S36-EVK board. For current measurement, the supported voltage range is 1.7 V – 3.6 V.

Target MCU current	Supply voltage	Supply voltage jumper	Sense resistor
IDD current (total current)	MCU_VCC_3V3_1V9	JP33	R432
VDD current	MCU_VDD	JP20	R433
VDDA current	MCU_VDDA	JP21	R434
VBAT current	MCU_VBAT	JP22	R435
VDD_MAIN current	MCU_MAIN	JP28	R436

Jumpers JP74 and JP75 control the availability of the MCU_VCC_3V3_1V9 and VCC_3V3_1V9 supplies, respectively, in the MCU-Link current measurement circuit. The measurement hardware automatically selects either a low or high range current to provide higher accuracy at low currents. Automatic range switching from low current drawn to high current drawn avoids excessive voltage drop across the sense resistor. The MCU-Link firmware triggers the switch back to low current measurements.

The measurement circuit self-calibrates each time the LPC55S36-EVK board is powered on. No user intervention is required to set up the calibration or adjust the measurement ranges. The power measurement feature is intended for low-power measurements, with a target MCU running at up to 3.6 V. The design uses the LPC55S69 16-bit Analog to Digital Converter (ADC), with power data sampled at up to 100 kS/s.

Maximum measurable current is 50 mA. Accuracy may vary with temperature and is provided for reference purposes only.

Measurement range	Resolution	Accuracy (typical)
200 nA to 400 µA	200 nA	1 %

Measurement range	Resolution	Accuracy (typical)
> 400 µA to 50 mA	5 µA	1 %

7.2 Current Measurement with the Joulescope

Figure 14. Joulescope window

7.3 Joulescope vs MCU-Link

Table 1. Joulescope vs MCU-Link

Mode	Joulescope	MCU-Link
Active	2.79 mA	2.67 mA
Sleep	2.33 mA	2.23 mA
Deep sleep	102.31 µA	102.00 µA
Power down	4.17 µA	4.11 µA
Deep power-down	4.09 µA	3.56 µA

8 Conclusion

In conclusion, the MCU-Link PRO as a standalone or on-board device is an excellent option, for low power application measurement analysis. We can see that the current measurement is comparable to the third party product seen above. The small resolution allows to finetune our application and see the changes in current depending on the modules that have been enabled or disabled, as well as configure trigger conditions to measure the current in certain moments.

9 References

- *MCU-Link Pro* (document UM11673)
- *LPC553x Reference Manual* (document LPC553xRM)
- *LPC553x Product data sheet* (document LPC553x)
- *LPC55S36-EVK Board User Manual* (document LPC55S36-EVKUM)
- LPC55S36-EVK Schematic

10 Revision history

Table 2 summarizes the revisions to this document.

Table 2. Revision history

Document ID	Release date	Description
AN13660 v.0.1	24 January 2024	Removed Arm logo from front-page
AN13660 v.0.0	15 June 2022	Initial public release

Legal information

Definitions

Draft — A draft status on a document indicates that the content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included in a draft version of a document and shall have no liability for the consequences of use of such information.

Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information. NXP Semiconductors takes no responsibility for the content in this document if provided by an information source outside of NXP Semiconductors.

In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory.

Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms and conditions of commercial sale of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in life support, life-critical or safety-critical systems or equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors and its suppliers accept no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products.

NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Terms and conditions of commercial sale — NXP Semiconductors products are sold subject to the general terms and conditions of commercial sale, as published at https://www.nxp.com/profile/terms, unless otherwise agreed in a valid written individual agreement. In case an individual agreement is concluded only the terms and conditions of the respective agreement shall apply. NXP Semiconductors hereby expressly objects to applying the customer's general terms and conditions with regard to the purchase of NXP Semiconductors products by customer.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from competent authorities.

Suitability for use in non-automotive qualified products — Unless this document expressly states that this specific NXP Semiconductors product is automotive qualified, the product is not suitable for automotive use. It is neither qualified nor tested in accordance with automotive testing or application requirements. NXP Semiconductors accepts no liability for inclusion and/or use of non-automotive qualified products in automotive equipment or applications.

In the event that customer uses the product for design-in and use in automotive applications to automotive specifications and standards, customer (a) shall use the product without NXP Semiconductors' warranty of the product for such automotive applications, use and specifications, and (b) whenever customer uses the product for automotive applications beyond NXP Semiconductors' specifications such use shall be solely at customer's own risk, and (c) customer fully indemnifies NXP Semiconductors for any liability, damages or failed product claims resulting from customer design and use of the product for automotive applications beyond NXP Semiconductors' standard warranty and NXP Semiconductors' product specifications.

Translations — A non-English (translated) version of a document, including the legal information in that document, is for reference only. The English version shall prevail in case of any discrepancy between the translated and English versions.

Security — Customer understands that all NXP products may be subject to unidentified vulnerabilities or may support established security standards or specifications with known limitations. Customer is responsible for the design and operation of its applications and products throughout their lifecycles to reduce the effect of these vulnerabilities on customer's applications and products. Customer's responsibility also extends to other open and/or proprietary technologies supported by NXP products for use in customer's applications. NXP accepts no liability for any vulnerability. Customer should regularly check security updates from NXP and follow up appropriately.

Customer shall select products with security features that best meet rules, regulations, and standards of the intended application and make the ultimate design decisions regarding its products and is solely responsible for compliance with all legal, regulatory, and security related requirements concerning its products, regardless of any information or support that may be provided by NXP.

NXP has a Product Security Incident Response Team (PSIRT) (reachable at PSIRT@nxp.com) that manages the investigation, reporting, and solution release to security vulnerabilities of NXP products.

NXP B.V. — NXP B.V. is not an operating company and it does not distribute or sell products.

Trademarks

Notice: All referenced brands, product names, service names, and trademarks are the property of their respective owners.

NXP — wordmark and logo are trademarks of NXP B.V.

AMBA, Arm, Arm7, Arm7TDMI, Arm9, Arm11, Artisan, big.LITTLE, Cordio, CoreLink, CoreSight, Cortex, DesignStart, DynamIQ, Jazelle, Keil, Mali, Mbed, Mbed Enabled, NEON, POP, RealView, SecurCore, Socrates, Thumb, TrustZone, ULINK, ULINK2, ULINK-ME, ULINK-PLUS, ULINKpro, μVision, Versatile — are trademarks and/or registered trademarks of Arm Limited (or its subsidiaries or affiliates) in the US and/or elsewhere. The related technology may be protected by any or all of patents, copyrights, designs and trade secrets. All rights reserved.

J-Link — is a trademark of SEGGER Microcontroller GmbH.

Contents

Date of release: 24 January 2024
Document identifier: AN13660