# AN13660

## MCU-Link的能耗测量功能

第0.1版—2024年1月24日 应用笔记

文档信息

| 信息 | 内容 |
|---|---|
| 关键词 | AN13660、MCU-Link、功率测量、LPC553x、LPC55S3x |
| 摘要 | 本应用笔记表明，MCU-Link是一款功能强大且可靠的工具，可在不同的应用中进行功率测量。 |

# 1 介绍

MCU Link是一款功能强大、且经济高效的硬件调试器，可与MCUXpresso IDE无缝配合使用。它与支持CMSIS-DAP协议的工具/IDE兼容，还具有USB转通用异步收发器（UART）的桥接功能（VCOM），可在目标MCU和主机之间提供串行连接。

MCU-Link的设计有三种：

- MCU-Link基础型号
- MCU-Link PRO
- 板载MCU-Link

MCU-Link PRO和板载MCU-Link的设计支持能耗的测量。

MCU-Link基于双Arm Cortex-M33核、主频为150 MHz的LPC55S69微控制器，具有高速USB接口，支持高性能调试。MCU-Link调试工具提供了一种高级工具，即MCU-Link PRO。除了MCU-Link基础版提供的SWD调试、SWO分析和USB转UART桥接功能外，PRO型号还添加了J-Link LITE固件选项、能耗测量、模拟信号监测器、USB转SPI和$I^2C$桥接功能，以及用于外设仿真的板载LPC804。MCU-Link也可在一些恩智浦微控制器评估板上实现，被称为板载MCU-Link（OB）。MCU-Link OB功能可能因不同的电路板而有变化，但通常包括能耗测量、USB桥接器和J-Link LITE固件选项。

所有版本的MCU-Link均使用相同的固件镜像，且都兼容Windows 10、MacOS和Linux。

为了简便起见，本文中提到的MCU-Link均指板载MCU-Link型号。

# 2 目标

本应用笔记表明，MCU-Link是一款功能强大且可靠的工具，可在不同的应用中进行功率测量。本文展示了MCU-Link在不同功率设置下的结果，并与第三方工具进行了比较。对于本应用，使用的是LPC55S36-EVK。此评估板配备有板载MCU-Link。

# 3 MCU-Link概述

MCU-Link支持基于SWD的目标调试，包括由SWO跟踪/I/O分析支持所实现的功能，并支持目标调试系统（运行电压为1.2V至5V）。它添加了J-Link LITE固件选项、模拟信号监测器（1.2V至3.6V）、USB转SPI和$I^2C$桥接器。它还具有许多便于嵌入式软件开发的功能，如能耗分析等。能耗测量的分辨率取决于所使用的板载MCU-Link支持的最大电流量程。具体的电流量程和相应的分辨率请参阅用户手册。

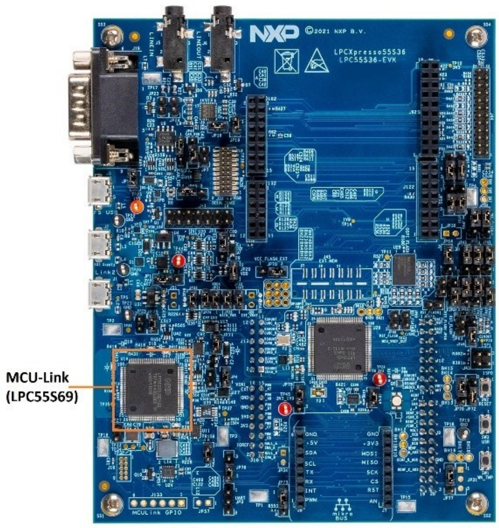


**图1. MCU-Link作为LPC55S36-EVK的板载调试器和能耗测量工具**

MCU-Link包含用于测量目标MCU的供电电压和电流的电路。MCUXpresso IDE中的能耗测量功能可以显示这些测量数据，以及能量和功耗。测量硬件会自动选择低量程或高量程电流，以便在低电流下提供更高的精度。从低电流到高电流的自动量程切换可以避免感应电阻两端的压降过大。

MCU-Link的功率测量功能专为低功耗测量而打造，适用于运行电压最高为3.6 V的目标MCU。此设计使用LPC55S69的16位ADC，功率数据采样率高达100kS/s。在高采样率下，MCUXpresso IDE可能无法捕获所有数据，因此必须使用该工具的能耗测量配置设置中的配置选项来调整采样率。

## 4 LPC55S36-EVK概述

LPC55S36是一款基于Arm Cortex-M33的嵌入式应用微控制器。该芯片包含高达256 KB的片上闪存、高达128KB的片上SRAM、带缓存和动态解密功能的FlexSPI。它还配备了多个外设，其中最引人注目的是全速USB主设备和从设备接口（可无需晶体工作）、CAN FD接口、多种定时器、八个灵活的串行通讯外设、一个SPI滤波器、一个QuadFlash滤波器、一个DMIC、一个I3C接口、两个16位2.0 Msamples/sec ADC、四个比较器、三个12位1 Msample/sec DAC、三个运放、两个FlexPWM定时器和两个QEI。

为了提供更完整的分析，使用了LPC55S36 MCU提供的所有节能模式，如图2所示。

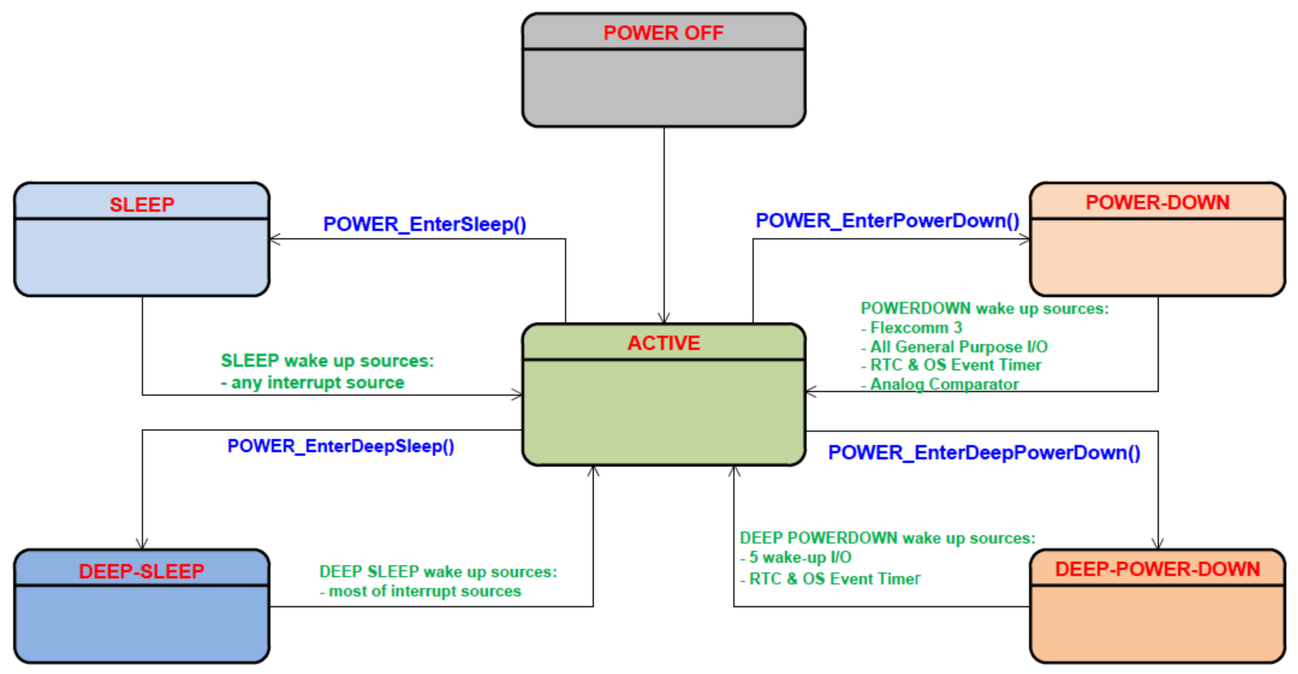


**图2. 支持多种功率模式的芯片**

## 4.1 睡眠模式

睡眠模式通过停止Cortex-M33内核来节省一些电量，而不会影响外设，也无需很长的唤醒时间。CPU的时钟被关闭。外设和存储器处于活动状态并正常运行。CPU停止，且指令执行暂停，直到发生复位或中断。睡眠模式仅消除处理器本身、内存系统和相关控制器以及内部总线使用的动态功耗。保持留处理器状态和寄存器、外设寄存器以及内部SRAM值。

## 4.2 深度睡眠模式

在深度睡眠模式下，整个芯片保持通电状态，但闪存和ROM关闭，与睡眠模式相比所需的唤醒时间更长。与睡眠模式一样，CPU的系统时钟被禁用。默认情况下，模拟模块处于掉电状态，但如果需要其作为唤醒源，可以通过电源API选择模拟模块继续运行。主时钟和所有外设时钟均被禁用。

## 4.3 掉电模式

掉电模式通过以下方式消除几乎所有的片上功耗：

- 消除几乎所有模拟模块的功耗
- 通过关闭DCDC和LDO_CORE消除几乎所有数字外设的功耗

闪存也被禁用。任何未配置为保持其内部状态的SRAM实体都将丢失其数据。当唤醒事件发生时，Cortex-M33 CPU代码将从停止处恢复执行。

### 4.4 深度掉电模式

深度掉电模式可以消除几乎所有的片上功耗，但需要明显更长的唤醒时间。为了最大限度地节省电力，电源域被关闭。只有常开电源域PMU、PMC、RTC和操作系统事件定时器保持上电状态。除了RTC和OS事件定时器（如果需要的话）外，整个芯片的时钟都会关闭。当从这种模式唤醒时，芯片将重新启动。

## 5 能耗测量的硬件配置

为了避免感应电阻两端的压降过大，从低电流测量到高电流测量的自动切换仅由硬件控制。当从高电流测量切换到低电流测量时，通过监测电路的中断，触发MCU-Link固件控制切换回低电流测量。每次MCU-Link上电时，测量电路都会进行自校准。

要测量EVK的特定电源轨，必须移除一些跳线（JP74和JP75）。可以使用这两个点将MCU-Link能耗测量电路与任何电源轨连接起来，就像连接电流表一样。可以将JP74（脚2）和JP75（脚2）的跳线连接到电路板上的任何可用的电源轨。要测量总电流，只需要移除JP33，因为它已经与这两个端子连接。

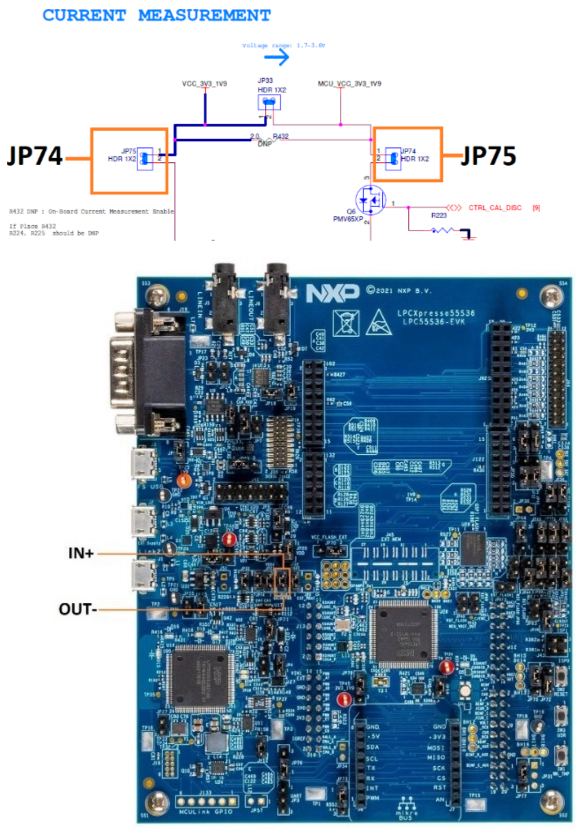


图3．JP74和JP75的原理图及其在LPC55S36-EVK上的物理位置

例如，要测量主电源轨，请移除跳线JP28，并将其两端连接到JP74和JP75。

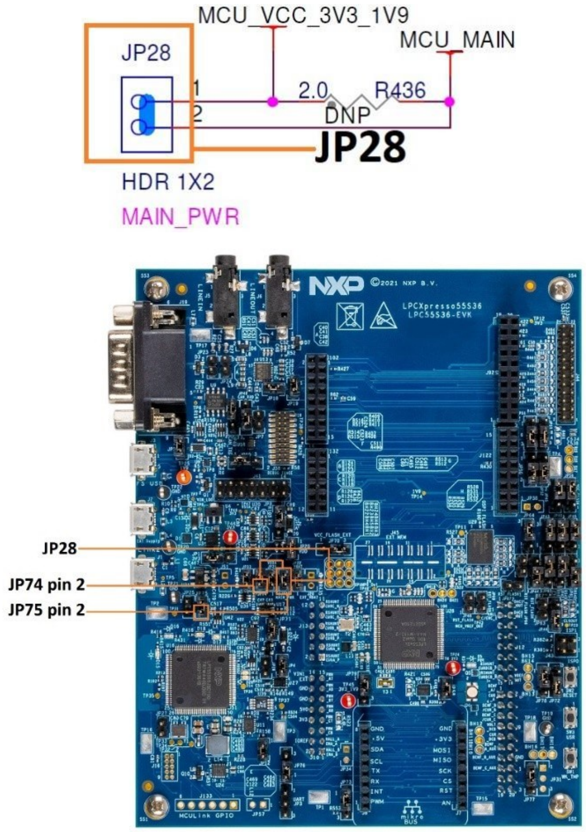


**图4. 使用板载MCU-Link测量主电源电流时需要移除的跳线**

## 6 MCU-Link与Joulescope的对比测试

为了提供一个MCU-Link能耗测量功能精度的示例，本节介绍了如何在LPC55S36-EVK上使用Joulescope和MCU-Link重现测试结果。

需要以下工具：

- MCUXpresso IDE 11.5.1版或更高版本
- MCU-Link CMSIS-DAP V2.250或更高版本的固件更新
- LPC55S36-EVK SDK版本2.10.2或更高版本

要构建并运行此示例，请执行以下步骤：

1. 打开MCUXpresso IDE。


图5. MCUXpresso IDE

2. 在左下角找到“快速启动”面板，然后单击“**导入SDK示例**”。

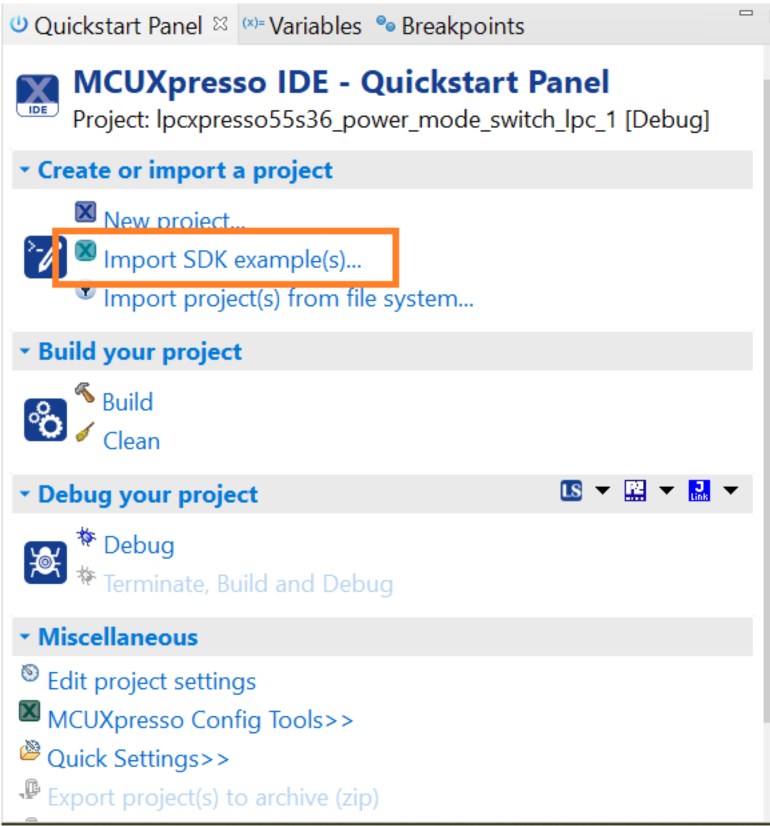


图6. “快速启动”面板

3. 单击LPC55S36-EVK板，然后单击“**下一步**”。

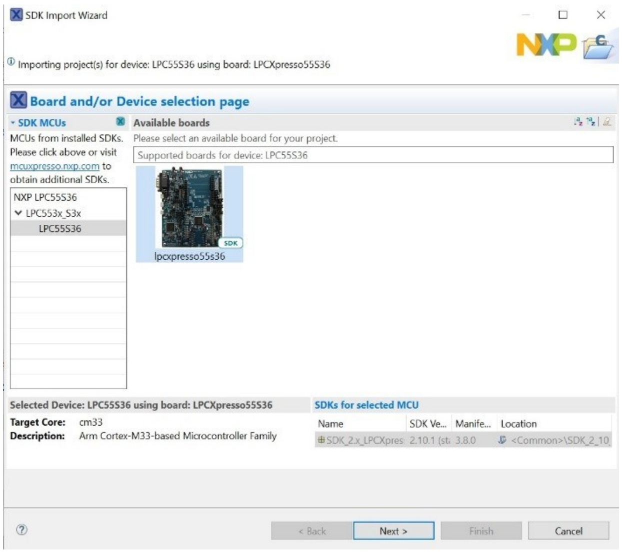


**图7. 选择电路板**

4. 从LPC55S36-EVK SDK中导入一个示例**power_mode_switch**，然后单击“**完成**”。

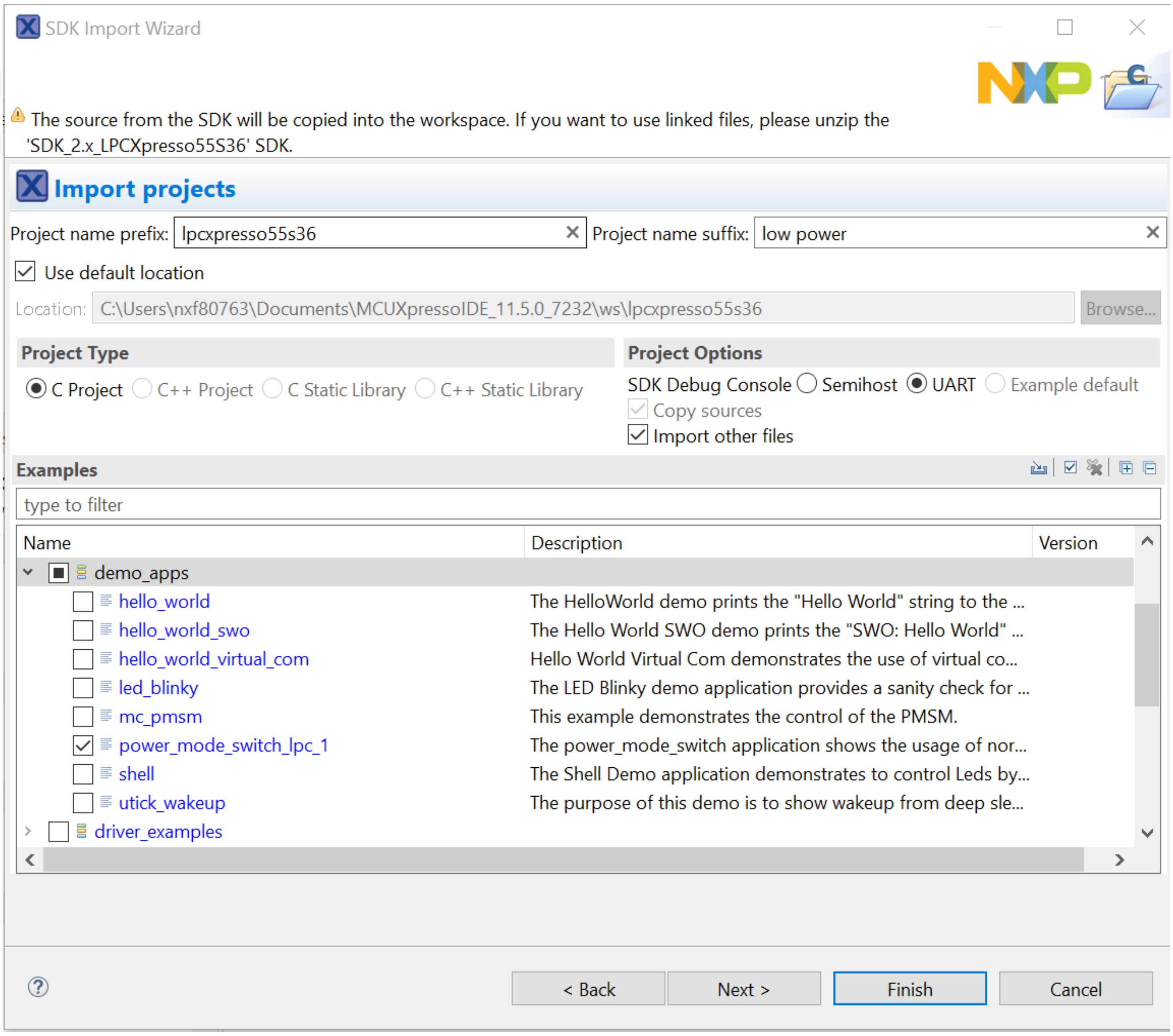


**图8. 从SDK中选择示例**

5. 选择工程并进行编译。工程成功编译后，选择“**调试**”。

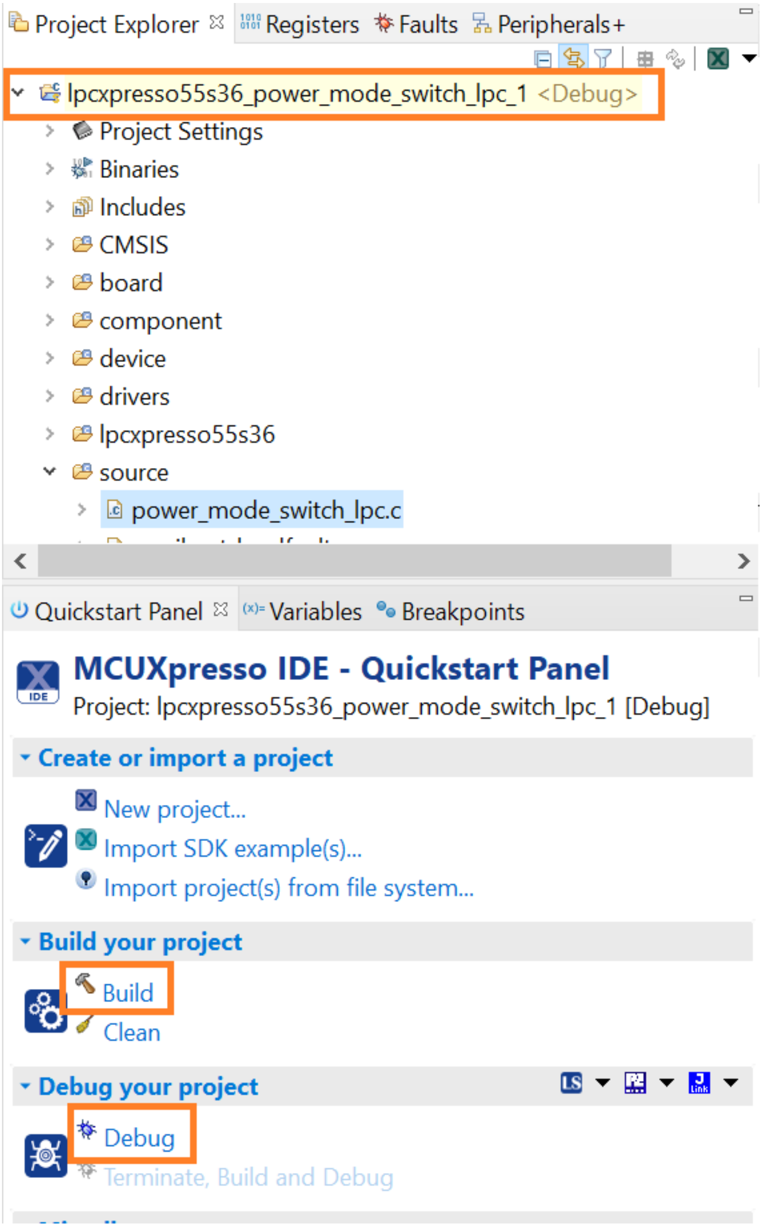


**图9. 选择、编译并调试工程**

6. 停止调试会话并打开串行终端，选择MCU-Link端口。如上所述，使用以下设置对串行控制台进行配置：
   - 波特率为115200
   - 无奇偶校验位
   - 8个数据位
   - 1个停止位

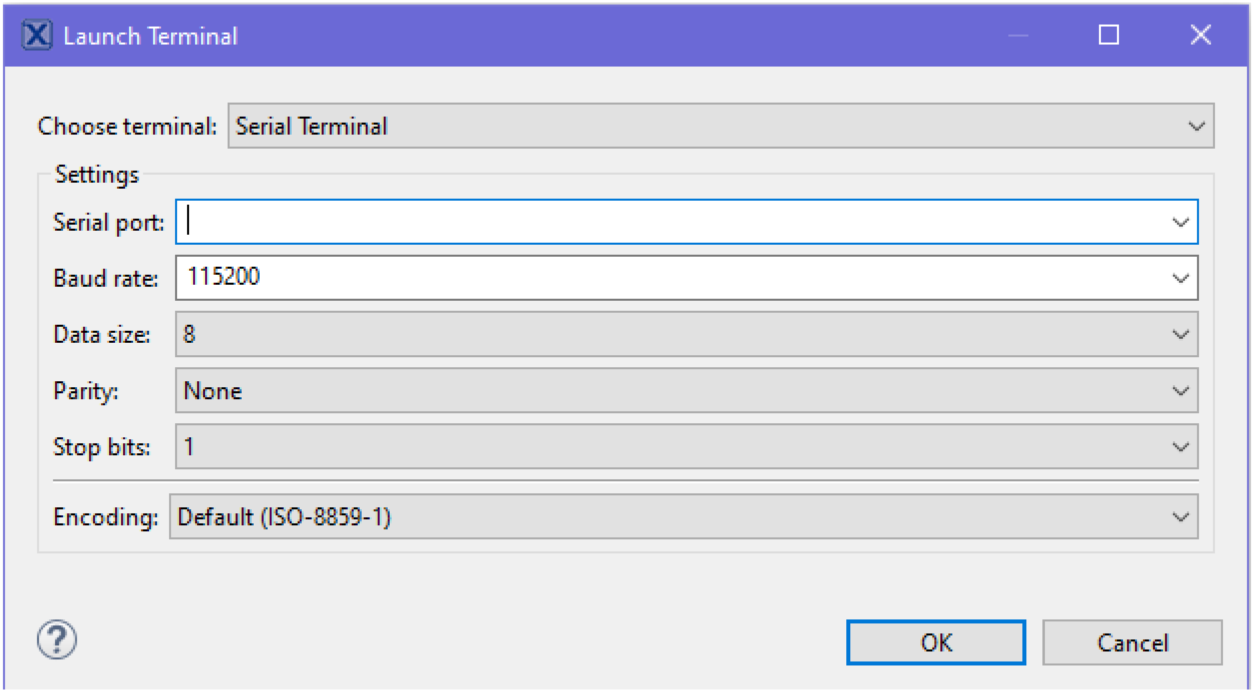


**图10. MCUXpresso IDE提供了一个终端窗口**

7. 使用SW2（Reset）开关重置电路板，串行终端将显示输出。
8. 通过键盘输入数字1、2、3或4，使LPC55S3x/LPC553x进入睡眠模式、深度睡眠模式、掉电模式或深度掉电模式。

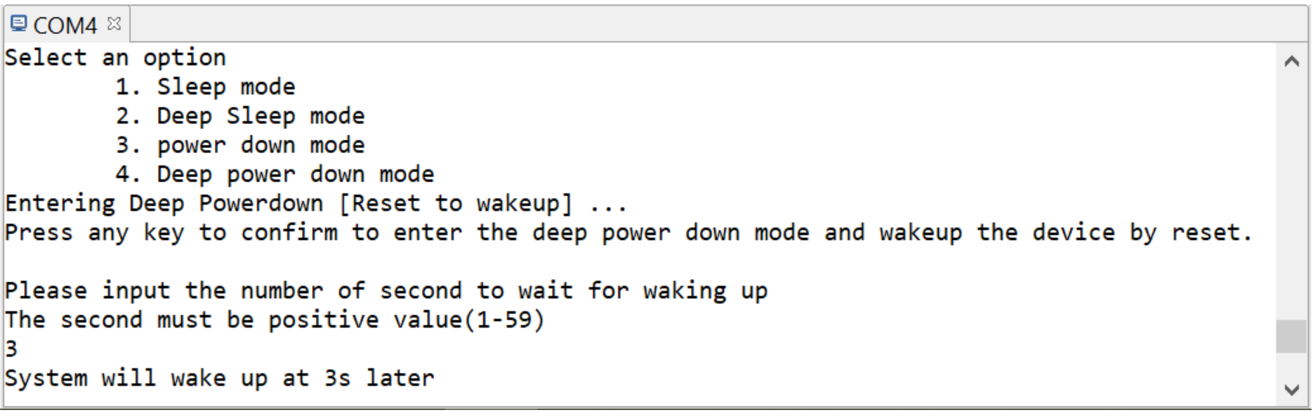


**图11. SDK中的示例**

对于下面的测试结果，对SDK示例进行了调整，以改进测量，并在功率模式之间自动切换，以便进行更清晰的比较。此外，在所有功率模式期间都启用了RTC，并通过警示进入下一个功率模式。下载AN13660SW，并使用“快速启动”菜单中的“**从文件系统导入**”选项。

## 7 电流测量

在下面的例子中，可以查看通过LPC55S36-EVK上的JP28在主电源轨上测量的电流。该应用程序将RTC定时器作为低功耗模式的唤醒源，并提供一个时间框架，以便更好地了解在该功率设置期间测量的电流。

## 7.1 使用MCU-Link进行电流测量

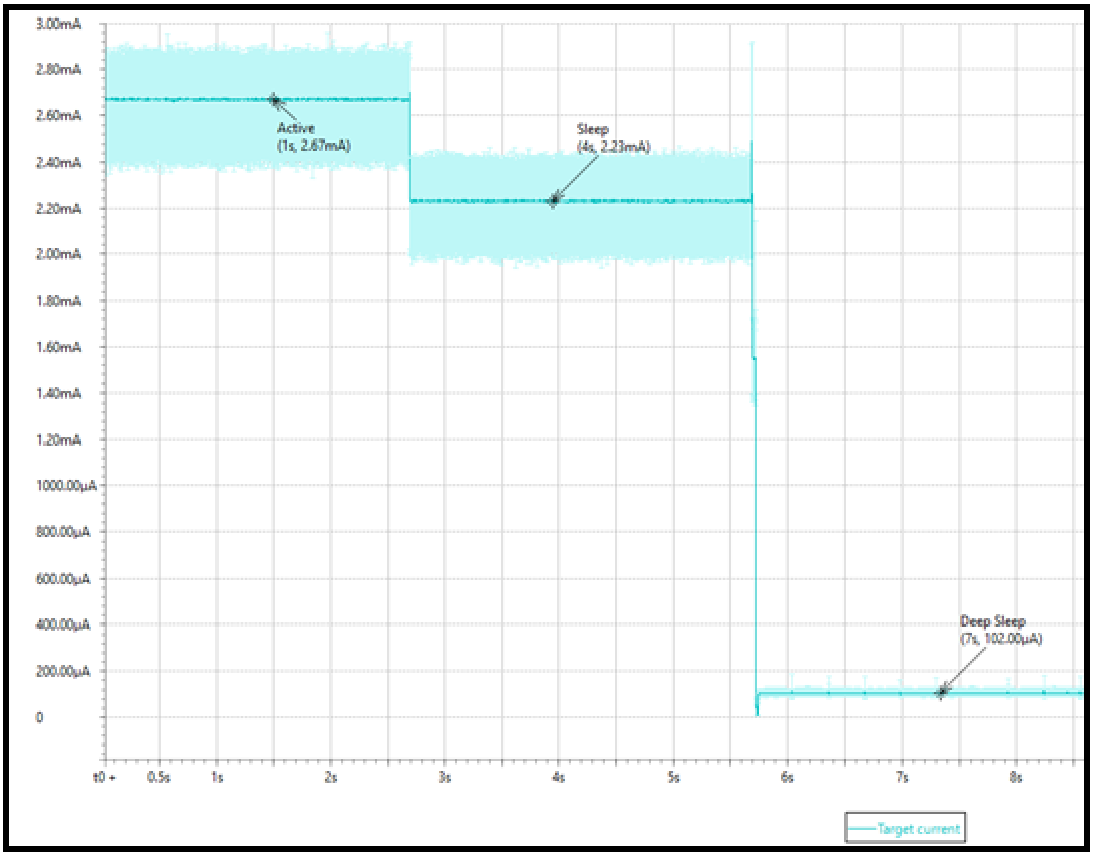


图12. MCU-Link的能耗测量窗口

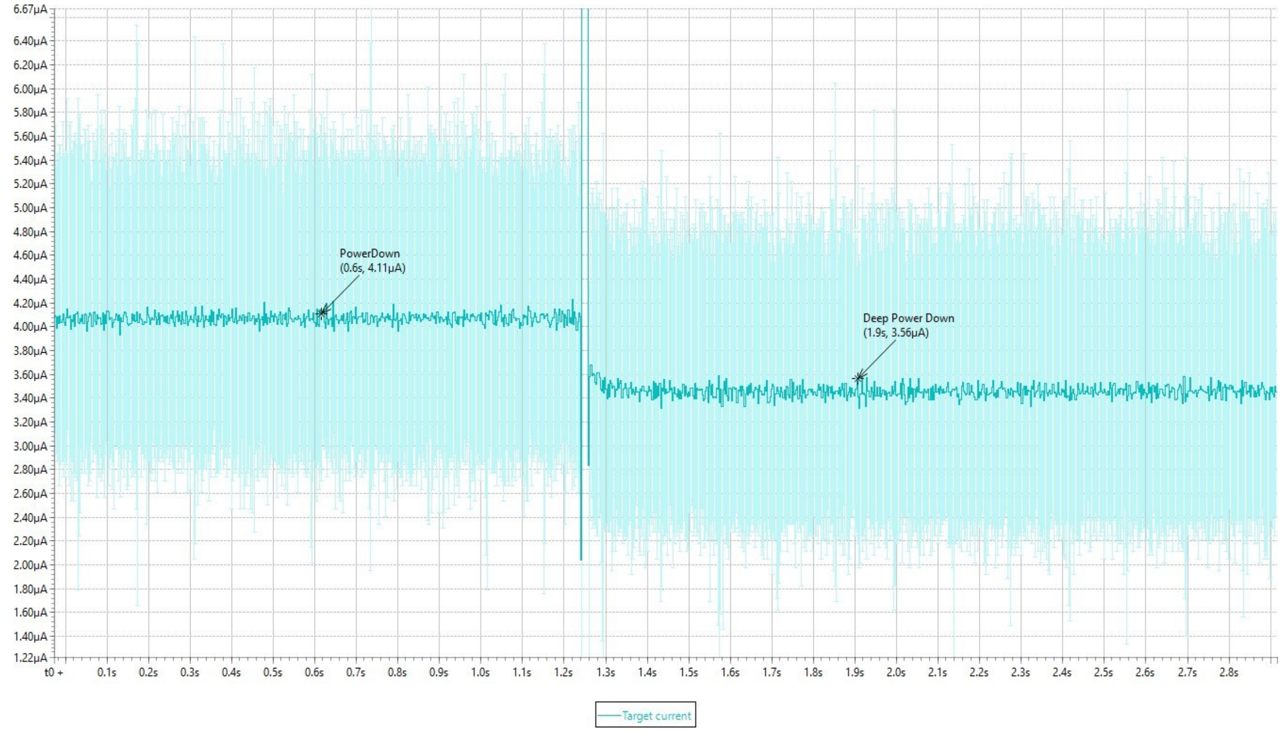


**图13. MCU-Link能耗测量窗口的掉电和深度掉电**

通过测量LPC55S36-EVK板上感应电阻两端的压降来测量目标MCU消耗的电流。对于电流测量，支持的电压范围为1.7V–3.6V。

| 目标MCU电流 | 供电电压 | 供电电压跳线 | 感应电阻 |
|---|---|---|---|
| IDD电流（总电流） | MCU_VCC_3V3_1V9 | JP33 | R432 |
| VDD电流 | MCU_VDD | JP20 | R433 |
| VDDA电流 | MCU_VDDA | JP21 | R434 |
| VBAT电流 | MCU_VBAT | JP22 | R435 |
| VDD_MAIN电流 | MCU_MAIN | JP28 | R436 |

跳线JP74和JP75在MCU-Link电流测量电路中分别控制MCU_VCC_3V3_1V9和VCC_3V3_1V9电源的可用性。测量硬件自动选择低电流量程或高电流量程，以便在低电流下提供更高的精度。从消耗的低电流到高电流的自动量程切换能够避免感应电阻两端的压降过大。MCU-Link固件会触发切换回低电流测量。

每当LPC55S36-EVK板上电时，测量电路都会进行自校准。无需用户干预即可设置校准或调整测量范围。此功率测量功能适用于低功耗测量，目标MCU的运行电压最高为3.6V。该设计使用LPC55S69的16位模数转换器（ADC），功率数据采样率高达100kS/s。

最大可测量电流为50mA。精度可能随温度变化而变化，此表仅供参考。

| 测量量程 | 分辨率 | 精度（典型值） |
|---|---|---|
| 200 nA至400 µA | 200 nA | 1% |

| 测量量程 | 分辨率 | 精度（典型值） |
|---|---|---|
| > 400 µA至50 mA | 5 µA | 1% |

## 7.2 使用Joulescope测量电流


**图14．Joulescope窗口**

## 7.3 Joulescope与MCU-Link的对比

**表1. Joulescope与MCU-Link对比**

| 模式 | Joulescope | MCU-Link |
|---|---|---|
| 活动 | 2.79 mA | 2.67 mA |
| 睡眠 | 2.33 mA | 2.23 mA |
| 深度睡眠 | 102.31 µA | 102.00 µA |
| 掉电 | 4.17 µA | 4.11 µA |
| 深度掉电 | 4.09 µA | 3.56 µA |

# 8 结论

总而言之，MCU-Link PRO无论作为独立设备还是板载设备，都是进行低功耗应用测量分析的极佳选择。在上面可以看到，其电流测量结果与第三方产品相当。它的高分辨率允许对应用程序进行微调，并看到电流根据已启用或禁用的模块而出现的变化，以及配置触发条件以测量特定时刻的电流。

## 9 参考资料

- 《MCU-Link Pro》（文档UM11673）
- 《LPC553x参考手册》（文档LPC553xRM）
- 《LPC553x产品数据手册》（文档LPC553x）
- 《LPC55S36-EVK板用户手册》（文档LPC55S36-EVKUM）
- LPC55S36-EVK原理图

## 10 修订历史

表2汇总了对本文的修订。

**表2. 修订历史**

| 文档ID | 发布日期 | 说明 |
|---|---|---|
| AN13660 v.0.1 | 2024年1月24日 | 从首页移除了Arm标识 |
| AN13660 v.0.0 | 2022年6月15日 | 首次公开发布 |

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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.

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**Date of release: 24 January 2024**
**Document identifier: AN13660**