Core SDK Power Management: MSP432, CC13xx/CC26xx, and CC32xx SimpleLink MCUs

User's Guide

February 2017
SPRUI18F

Contents

Read This First

About This Manual

This manual describes TI's Power Manager for CC13xx/CC26xx, CC32xx, and MSP432 devices. It provides information for application developers and driver developers. The Core SDK version number as of the publication of this manual is v3.10. If no changes are required to this document in a subsequent version of the Core SDK, this manual remains valid for such versions.

Notational Conventions

This document uses the following conventions:

- Program listings, program examples, and interactive displays are shown in a special typeface. Examples use a bold version of the special typeface for emphasis. Here is a sample program listing:

```
#include <xdc/runtime/System.h>
int main(void){
    System_printf("Hello World!\n");
    return (0);
}
```

- Square brackets ([and]) identify an optional parameter. If you use an optional parameter, you specify the information within the brackets. Unless the square brackets are in a **bold** typeface, do not enter the brackets themselves.

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February 14, 2017

Power Management Overview

This chapter provides an overview of TI's Power Manager. It starts with a definition of terms, and then summarizes the configuration interfaces and APIs that make up the Power Manager.

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1.1 Overview

Power management offers significant extension of the time that batteries used to power an embedded application last. However, the application, operating system, and peripheral drivers can be adversely impacted if dynamic power-saving transitions occur when they are performing important operations. To manage such impacts, it is useful to provide power management capabilities for these components to coordinate and safely manage the transitions to and from power saving states.

The SimpleLink MCU SDK includes a Power Manager framework that supports the CC13xx/CC26xx, CC32xx, and MSP432 devices. The same top-level APIs, concepts, and conventions are used for all three MCU families.

The same device-level implementation is shared by the CC13xx and CC26xx. File names, function names, and constants for this shared implementation use "CC26XX" as a prefix for both CC13xx and CC26xx devices.

Where "CC32xx" is used, support for CC3220, CC3220S, and CC3220SF are indicated unless specified otherwise.

This document provides a summary of the power management APIs, and their relevancy to the different components of the embedded application. It includes chapters with guidelines for developers of both power policies and device drivers.

1.2 Definitions / Terms

- **Constraint.** A constraint is a system-level declaration that prevents a specific action. For example, when initiating an I/O transfer, a driver can declare a constraint to temporarily prohibit a transition into a device sleep state. Without this communication to the Power Manager, a decision might be made to transition to a sleep state during the data transfer, which would cause the transfer to fail. After the transfer is complete, the driver releases the constraint it had declared. Constraints are declared with the Power_setConstraint() API, and released with the Power_releaseConstraint() API.
- **Dependency.** A dependency is a declaration by a driver that it depends upon the availability of a particular hardware resource. For example, a UART driver would declare a dependency upon the UART peripheral, which triggers the Power Manager to arbitrate and enable clocks (and power, as necessary) to the peripheral, if not already enabled. A dependency does not prevent specific actions by the Power Manager, for example, transition into a sleep state—constraints are used for that purpose. However, as the Power Manager transitions the device in and out of sleep states, upon wakeup it automatically restores dependencies that were established before the sleep state.
- **Notification.** A notification is a callback mechanism that allows a driver to be notified of specific power transitions or "events". To receive a notification the driver registers in advance, for the specific events it wants to be notified of, with the Power_registerNotify() API. For example, a driver may register to receive both the PowerCC26XX_ENTERING_STANDBY event (to be notified before the device transitions to standby), and the PowerCC26XX_AWAKE_STANDBY event (to be notified after the device has awoken from standby). Note that notifications are strictly that - there is no "voting" at the time the transition is being signaled. If a component is not able to accommodate a particular power transition, it needs to "vote in advance," by setting a constraint.
- **Policy Function.** A function that implements a Power Policy.
- **Power Manager.** The Power management module (ti.drivers.Power).
- **Power Policy.** A function that makes power saving decisions and initiates those savings with calls to the Power Manager APIs.
- **Reference Policy.** A reference Power Policy provided with the SDK, which aggressively activates power saving states when possible.
- **Sleep State.** A device state where the CPU is inactive and portions of the device are in reduced power-saving states. Sleep states are generally device-specific and may include: clock and clock domain gating, power domain gating, with and without state retention, as well as reduced operating frequencies and voltages.

1.3 Power Manager API

The Power Manager API is used at a variety of development levels. In general, drivers are responsible for defining their specific requirements in relation to when power saving states can be used and what actions must be performed before and after use of a power saving state.

- **Application development:** Applications generally enable use of the Power Manager and otherwise do not use the Power Manager APIs to a significant extent. This chapter describes the minor changes needed to enable Power Manager use in Section 1.3.1 and Section 1.3.2.
- **Application Power Policy selection:** The Power Policy determines how aggressive the application will be about putting the device into a power saving state when the Idle thread runs. Chapter 4 describes the provided Power Policy options and how to customize a Power Policy to meet the needs of your application.
- **Driver development:** A device driver communicates with the Power Manager to enable/disable access to its peripherals and to set/release constraints to temporarily limit activity by the Power Manager. Drivers also register with the Power Manager for notification about power transitions. The driver may need to take action in response to a notification that the device is going into or coming out of a power saving state, or if the device performance level (MSP432 only) is going to change or has just changed. These actions may include saving registers or re-initializing the peripheral. Chapter 5 describes the process of adding Power Manager code to a driver, using a DMA-based SPI driver as an example.

1.3.1 Static Configuration

Certain Power Manager features are statically configurable via a Power Manager configuration object defined in the board file. The elements of the configuration object are device-family specific, and are defined in the relevant Power*.h device-specific header file.

For example, for CC32xx, a configuration structure of type PowerCC32XX_ConfigV1 needs to be declared for the application. This structure and its elements are defined in `PowerCC32XX.h`. The structure is typically declared in the device-specific file included by the `Board.h` file, which in this case is `CC3220S_LAUNCHXL.c` or `CC3220SF_LAUNCHXL.c`. If this structure is not included in the application, the application will fail to link.

The configuration object is defined and declared in the following locations:

Target	Configuration Struct	Defined	Declared	Reference Policy Function
CC13xx / CC26xx	PowerCC26XX_Config	PowerCC26XX.h	CC1350STK.c CC2650_LAUNCHXL.c CC2650DK_4XS.c CC2650DK_5XD.c CC2650DK_7ID.c CC2650STK.c etc.	PowerCC26XX_standbyPolicy()
CC32xx	PowerCC32XX_ConfigV1	PowerCC32XX.h	CC3220S_LAUNCHXL.c CC3220SF_LAUNCHXL.c	PowerCC32XX_sleepPolicy()
MSP432	PowerMSP432_ConfigV1	PowerMSP432.h	MSP_EXP432P401RLP.c	PowerMSP432_sleepPolicy()

See Chapter 3 and the online reference documentation for more about configuring power management.

1.3.2 Runtime Configuration

For each target, one of the configuration elements of the Power configuration structure (that is, PowerCC32XX_ConfigV1, PowerCC26XX_Config, or PowerMSP432V1_Config) is the "enablePolicy" flag. This Boolean determines whether the configured Power policy function is called on each pass through the Idle loop. This flag is typically set to "false" in the SDK examples. This allows the application to be initially run in a debugger without possible side-effects due to transitions into a low-power state. This is especially critical for CC32xx devices, because sleep transitions usually cause a debugger detach.

The Power_enablePolicy() API allows the application to explicitly enable the policy at runtime, overriding the setting in the static configuration structure. This allows a common board file to be used for several applications, because individual applications can individually enable the Power policy when appropriate.

The Power_disablePolicy() API allows the application to explicitly disable the policy at runtime.

1.3.3 API Functions

For API details, see the reference documentation, which you can access as follows:

1. Go to the `<SDK_INSTALL_DIR>/docs` directory.
2. View the **Documentation_Overview.html** web page.
3. Follow the link to the **TI Drivers Runtime APIs (doxygen)**.
4. Select the **Power.h** link in the "Driver Interfaces" column, along with the device-family specific implementation, for example `PowerCC32XX.h`.

Note: If your application was developed using a version prior to TI-RTOS 2.15 for CC26xx, note that some changes have been made to the Power APIs. See the TI-RTOS Migration 2.15 wiki page for details.

The following are the Power Manager APIs.

- **Power_enablePolicy()** enables the configured power policy function to run on each pass through the OS Idle loop. See Section 1.3.2 and Section 4.2.
- **Power_disablePolicy()** disables the configured power policy function at runtime.
- **Power_setPolicy()** chooses a different power policy at runtime.
- **Power_getConstraintMask()** gets a bitmask that identifies the current set of declared constraints. See Section 4.4 and Section 5.2.3.
- **Power_getDependencyCount()** gets the number of dependencies currently declared upon a resource. See Section 5.4.1.
- **Power_getPerformanceLevel()** gets the current performance level for the device. (MSP432 only)
- **Power_getTransitionLatency()** gets the minimal transition latency for a sleep state, in units of microseconds. See Section 4.4.
- **Power_getTransitionState()** gets the current Power Manager transition state.
- **Power_init()** is a function that needs to be called at startup to initialize the Power Manager state.
- **Power_registerNotify()** registers a function to be called upon a specific power event. See Section 5.2.2, Section 5.3.1, and Section 5.4.3.

- **Power_releaseConstraint()** releases a constraint that was previously set. See Section 5.2.3, Section 5.3.2, and Section 5.4.5.
- **Power_releaseDependency()** releases a dependency that was previously set. See Section 5.2.1, Section 5.3.4, and Section 5.4.6.
- **Power_setConstraint()** sets an operational constraint. See Section 5.2.3, Section 5.3.2, and Section 5.4.2.
- **Power_setDependency()** sets a dependency on a manageable resource. See Section 5.2.1, Section 5.3.1, and Section 5.2.1.
- **Power_setPerformanceLevel()** transitions the device to a new performance level. (MSP432 only)
- **Power_shutdown()** puts the device into a lowest-power shutdown state.
- **Power_sleep()** puts the device into a predefined sleep state. See Section 4.4 and Section 5.2.2.
- **Power_unregisterNotify()** unregisters a function from event notification. See Section 5.4.7.

1.3.4 Instrumentation

The Power Manager does not log any actions or provide information to the ROV tool.

The Power Manager provides an Assert if Power_releaseConstraint() or Power_releaseDependency() are called more times than the corresponding Power_setConstraint() or Power_setDependency() API. There are also asserts for: an invalid sleepState for Power_sleep(), an invalid shutdownState for Power_shutdown(), and invalid pointers for Power_registerNotify().

Application Development with the Power Manager

This chapter tells application developers how power management works. Simply enabling the Power Manager and using TI Drivers results in automatic power savings when the processor is idle.

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2.1 How Power Management Works: The Default Case

Enabling the Power Manager and using TI Drivers results in automatic power savings when the processor is idle. Application developers do not need to write power management code; it is available by default.

Applications that include the Power Manager framework reduce their power usage because a target-specific power policy is invoked during application idle time to make informed decisions about when to activate and maximize power savings. These target-specific power policies understand the reduced power states available on the target. The TI Drivers communicate with the Power Manager to enable and disable peripheral resources and transitions.

From an application development perspective, minimal or no application code is necessary to manage power usage. However, APIs are available for the application to customize its power usage as desired.

This chapter is intended for use by application developers. Chapter 4 and Chapter 5 are for use by developers who want to customize the provided power policies and for device driver writers, respectively.

2.1.1 Power Manager Initialization

Power_init() must be called by the application before any other Power APIs.

For SDK applications on all target families, Power_init() is called automatically as part of Board_initGeneral(). This call must precede other driver initialization calls, for example:

```
int main(void)
{
    /* Call board init functions */
    Board_initGeneral();
    GPIO_init();
    UART_init();
...
```

To add Power Manager support to an empty example, add a call to Power_init() before calling any other code (such as driver startups) that might make Power API calls.

The actions performed by Power_init() vary by target family. In general, this function initializes the Power Manager and readies its use by drivers.

If you are curious about the actions performed by Power_init(), the target-specific implementation is provided in `<SDK_INSTALL_DIR>/source/ti/drivers/power`.

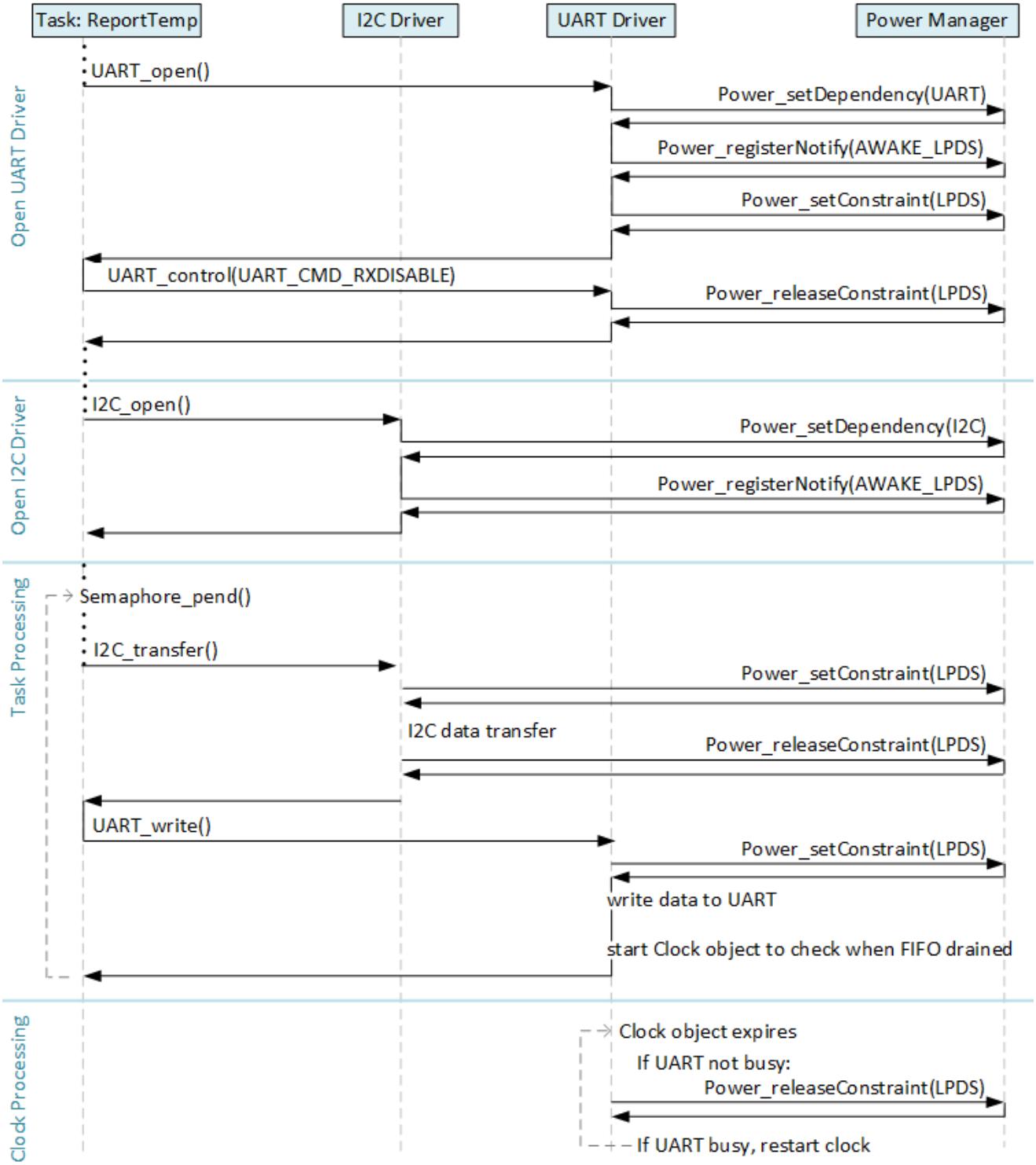
2.1.2 Driver Initialization, Constraint Management, and Notifications

The TI Drivers manage their dependencies and power constraints automatically by communicating directly with the Power Manager.

When your application initializes a driver, that driver declares its dependencies upon various peripheral modules to the Power Manager.

TI Drivers also set constraints when specific power transitions must be prohibited. For example, when a UART is opened to read data, it must be awake and able to receive the data, so it sets a power constraint to ensure the Power Manager does not take an action that would limit the driver's ability to receive data. Another example is a PWM driver, which needs the underlying timer to be active to generate the PWM output. The driver declares a power constraint to ensure this.

The following figure shows typical actions that occur as TI Drivers register with the Power Manager and a Task uses the drivers. In this case, a hypothetical temperature reporting task, ReportTemp, is posted by some other "control" thread. The application reads from the I2C peripheral and writes to the UART. The I2C and UART drivers control how the Power Manager is able to make use of the Low-Power Deep Sleep (LPDS) state, which is available for CC32xx devices.



Note that the figures simplifies certain arguments. For example, the constraint shown as "LPDS" would be "PowerCC32XX_DISALLOW_LPDS" in actual code.

During the Task's initialization, the Task opens both the UART and I2C drivers. Those open calls result in calls to the Power Manager to set dependencies, constraints, and to register for notification of AWAKE_LPDS events.

TI Drivers register with the Power Manager to receive notifications of power events that affect them. A driver that receives such a notification has a chance to save its state or signal some other (external) device as needed before the power transition. Notification is available for both power down and power up events. In this example, both drivers register for notification when the device awakes from the LPDS state.

Notice that after the UART is opened, the Task issues a UART_control() call to tell the driver it won't receive any UART data. This allows the driver to release the constraint set when the driver was opened that prohibited LPDS. By default, the UART driver might need to receive data, in which case the device must be prohibited from entering LPDS so that the UART can listen for data. Since data is only written to the UART in this example, the RX function can be disabled, so that LPDS won't be unnecessarily prohibited.

After the ReportTemp Task is initialized, it eventually calls Semaphore_pend() to wait for a trigger from the control thread to sample the temperature (via an I^2C peripheral) and report the value out the UART port.

Once triggered, the Task calls I2C_transfer() to get the temperature. Before the transfer, the I2C driver sets a constraint to prohibit LPDS during the transfer. Once the transfer is complete, the I2C driver releases the constraint it had set to prohibit LPDS.

Once the I^2C data has arrived, the Task manipulates the data to format an output string and then calls UART_write() to send the report out the UART.

The UART driver begins the writing process by setting a constraint to prohibit LPDS during the write. Then it pushes the data out the UART.

After the write is complete, special handling is necessary with certain UARTs to ensure that the data gets off the chip before LPDS is allowed again. This is because LPDS completely powers off the UART, which could truncate data that was still in the UART's FIFO buffer, waiting to be clocked out the bus. To do this, a kernel Clock object is started when the last byte is put in the FIFO.

When the Clock object expires, the Clock function checks to see if the UART is still busy. If NOT, then it calls Power_releaseConstraint() to allow LPDS again. If the UART is still busy, the Clock object is started again; it expires later to recheck the status of the UART.

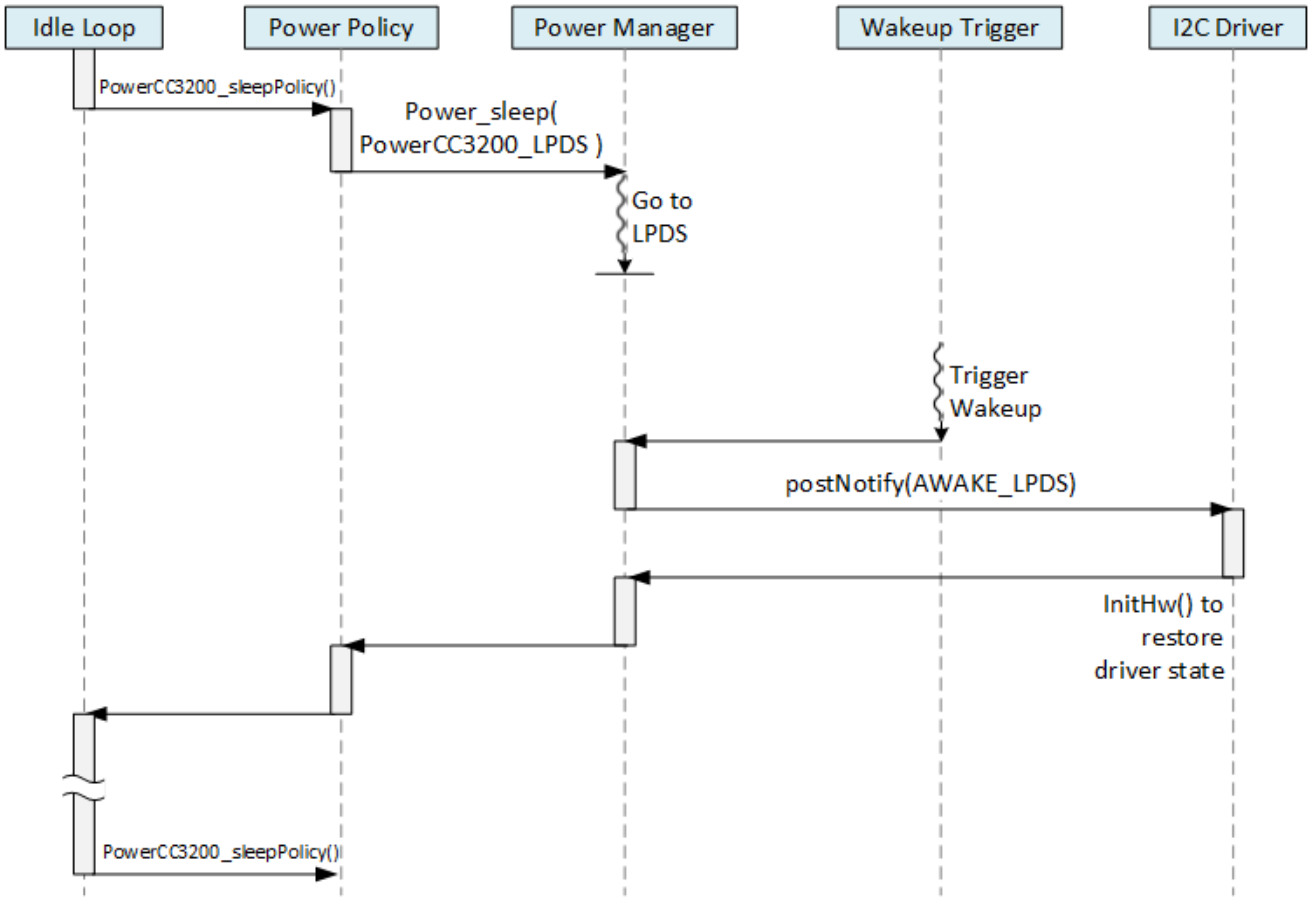
Meanwhile, when UART_write() has completed, the ReportTemp Task goes back to pending on the Semaphore waiting for the next trigger to read the temperature.

2.1.3 Application Idle Time Management

The Power Manager automatically manages the power state when the processor is idle.

When the processor is idle, the power policy runs and chooses the lowest possible power state allowed. The power policy is run by the kernel's Idle loop. The power policy calculates the minimum time until processing is needed again and compares that to the amount of time it takes to transition in and out of a power saving state. Based on this calculation, it chooses the best power saving state as appropriate.

The following figure shows typical actions that happen automatically during the TI-RTOS Kernel's Idle loop in an application that uses the I2C driver. The processor is put in the Low-Power Deep Sleep (LPDS) state, but is woken up in response to a triggering event. The Power Manager notifies the I2C driver so that the driver can restore its state.



The power policy calls the Power_sleep() API to activate the power savings. The processor stays in the sleep state until a wakeup event occurs. The available wakeups vary by device and sleep state, but in general the processor wakes up due to a timed wakeup (from a timer active during the sleep state) or an interrupt signal from an external input, or from a network coprocessor.

For example on the CC26xx, the power policy checks to see if any constraints currently disallow the Wait For Interrupt (WFI), Idle Power Down (IDLE_PD), or STANDBY states. If STANDBY or IDLE_PD states are allowed, the power policy calculates the amount of time until the next wakeup scheduled by the Clock module. It compares this amount of time to the transition latency for the STANDBY state (the lowest power state). If there is enough time, it schedules a wakeup event (allowing enough time for the

processor to wake up before processing is needed) and goes into the STANDBY state. If the power policy did not have enough time to go into the STANDBY state, it powers down various power domains and puts the CPU in IDLE_PD (which is not as deep as the STANDBY state).

In some cases, background activity is managed automatically by the Power Manager. For example, on CC26xx/CC13xx devices, RCOSC calibration, crystal startup, and clock source switching are performed.

2.2 Enabling and Disabling the Power Policy

By default, the SDK example applications (except on CC32xx, see Section 2.3) enable the Power Manager power policy. They do this either by setting the enablePolicy parameter to True in the configuration or by calling the Power_enablePolicy() API from application code.

Static configuration of the enablePolicy parameter is part of the Power<*target*>_Config structure in the board file. What is configured here will be in effect as soon as the application starts up.

An application can call the following APIs to control use of the power policy:

- **Power_enablePolicy()** enables the power policy at runtime if it was disabled in either the static configuration or by calling Power_disablePolicy().
- **Power_disablePolicy()** disables the power policy at runtime. For example, an application might call this to quickly disable all power saving transitions rather than by setting several power constraints. When the application is ready, it can re-enable the policy by calling Power_enablePolicy().
- **Power_setPolicy()** selects a different power policy function at runtime. Advanced applications can use this API to change the power policy based on application-defined criteria or tradeoffs between power savings and dynamic application capabilities. For example:

```
/*
 *  ======== myPolicy ========
 */
void myPolicy(void)
{
    ...
}

...
Power_setPolicy(myPolicy);
...
```

For MSP432, the Power Manager provides two power policies. The default power policy, Power_sleepPolicy(), does not use MSP432's deep sleep states. PowerMSP432_deepSleepPolicy(), the more aggressive power policy, results in greater power savings. However, there are consequences you should understand related to Clock ticks being halted during deep sleep. See the Note in Section 4.5 for details.

2.3 Power Management and Debugging

For some targets you may want to disable some or all power management during debugging:

- **MSP432.** The Deep Sleep state is not enabled by default because DEEPSLEEP_0 and DEEPSLEEP_1 disable peripheral modules and cause Clock ticks to be suspended during sleep. We recommend that you create and debug your application using the lighter weight Power_sleepPolicy(). After debugging the application, you may want to select the more aggressive Power_deepSleepPolicy(). See Section 4.5 for an important note about the consequences of Clock ticks being halted during deep sleep.

  When you use the Power_deepSleepPolicy(), clocks and peripherals are forced into a clock-gated state during deep sleep. They resume activity when the device wakes up.

- **CC32xx.** If the Low-Power Deep Sleep (LPDS) state is activated, any debug session is terminated. The debugger cannot reattach until you power cycle the CC32xx. With some debug configurations, even the Cortex M Wait For Interrupt (WFI) state causes the debug session to terminate.

  For this reason, the power policy is disabled by default for the CC32xx. We recommend that you create and debug your application without power management. After debugging the application, enable power management, and conduct further testing with limited debugger capabilities.

2.4 Power Management and Output to UART

Because LPDS terminates any debug session for CC32xx and the debugger cannot be reconnected without resetting the device, using the UART to receive printf-style messages is a useful strategy for CC32xx. Use of the UART allows some information to be sent to the terminal after CC32xx LPDS is activated.

This strategy is also available for all other supported targets.

There are two ways to use the UART: through the Display middleware driver (which simplifies setup) and by using the UART driver directly.

2.4.1 Using the Display Middleware Driver for UART-Based Debugging

The Display middleware driver provides an easy way to use the UART. This driver is used in the SDK examples.

Since the Display driver uses a UART internally, the application does not need to perform any of the UART open, control, or write calls. The Display driver takes care of disabling UART RX, so Display's use of the UART does not prohibit sleep.

To use the Display driver, an application should do the following:

1. Include the Display driver header file:

```
#include <ti/display/Display.h>
```

2. Open a display for UART use:

```
display = Display_open(Display_Type_UART, NULL);
if (display == NULL) {
    while (1);
}
```

3. Print to the display using the Display_printf() API. For example:

```
Display_printf(display, 0, 0, "I2C Initialized!\n");
...
Display_printf(display, 0, 0, "Sample %u: %d (C)\n", i, temperature);
....
Display_printf(display, 0, 0, "I2C closed!\n");
```

Note: With the CC32xx, you should not use Display_Type_HOST with the Display driver if LPDS may be activated.

2.4.2 Using the UART Driver for Debugging

An alternative to using the Display driver is to configure use of the UART driver directly. As with the Display driver, this strategy can be used with all devices, but it is shown here for CC32xx because LPDS terminates any debug session for CC32xx.

Using the UART driver directly allows additional customer-specific UART data transfers to be performed beyond those supported with the Display driver.

The "UART Power" example sends such output to the UART. The following statements are from the uartpower.c file in that example.

After UART_open() is called, a UART_control() call disables receive mode for the port.

```
/* Stop the receive to go into low power state */
UART_control(uart0, UART_CMD_RXDISABLE, NULL);
```

Within the UART_control() API, the constraint that prevents LPDS is released as follows. The UART does not need to be woken up to receive or listen, so the constraint preventing LPDS can be removed.

```
case (UART_CMD_RXDISABLE):
    if (object->state.rxEnabled) {
        MAP_UARTIntDisable(hwAttrs->baseAddr, UART_INT_RX | UART_INT_RT);
        Power_releaseConstraint(PowerCC32XX_DISALLOW_LPDS);
```

The application, after writing to the UART, calls Task_sleep() to idle the task for 5 seconds:

```
/* Write to UART0 */
for (;;) {
    for (i = 0; i < NLOOPS; i++) {
        UART_write(uart0, (const void *)dummyBuffer, sizeof(dummyBuffer));
    }

    UART_write(uart0, (const void *)sleepMsg, sizeof(sleepMsg));

    /* Sleep for 5 seconds */
    Task_sleep(5000);

    /* Blink the LED to indicate that we woke up. */
    blinkLED(Board_LED0, 2);
```

The Task_sleep() call allows the power policy to run within the Idle loop. Since there is no constraint against using LPDS and 5 seconds is enough time for LPDS, the power policy will choose LPDS.

When the device wakes after 5 seconds, the state is restored, including the UART driver state. The Clock module services the 5 second timeout, and posts an internal semaphore, which results in the CPU getting back to the Task right after the Task_sleep() call. An LED is blinked. The loop then repeats—writing some data to the UART, sleeping, and blinking an LED.

2.5 Power Management APIs Used by Applications

Applications can optionally call the following APIs. These APIs are not required, but are available to the application developer.

- **Power_enablePolicy()** and **Power_disablePolicy()** controls when the policy is active at runtime.
- **Power_setPolicy()** chooses a different power policy at runtime.
- **Power_setConstraint()** and **Power_releaseConstraint()** set and release constraints for specific power transitions (in addition to constraints drivers are already managing).
- **Power_setPerformanceLevel()** scales the device performance level between available operating points.
- **Power_registerNotify()** registers an application callback function to be triggered upon specific power transition events.
- **Power_shutdown()** puts the device in its lowest-power state, which requires a full application reboot to power up again.

2.6 Power Management for Direct I/O

Some applications perform simple direct I/O without using TI Drivers. Such applications should follow the same approach described in Chapter 5. That is, they should:

- Call Power_setDependency() for a peripheral when enabling the peripheral.
- Call Power_releaseDependency() when no longer using the peripheral.
- Call Power_setConstraint() as necessary to prohibit certain sleep states.
- Call Power_releaseConstraint() as soon as those sleep states can be allowed again.
- Call Power_registerNotify() to register callback functions as necessary to handle sleep transition events.
- Call Power_unregisterNotify() if necessary when such callbacks are no longer necessary.

2.7 Optimizing Power Management

For optimal power savings, an application can assist the Power Manager by following these general guidelines:

- Avoid "busy waiting" (repeated checks to see if a condition is met) on a resource or condition. Instead, use interrupts, OS timing services, or OS synchronization services (such as Semaphore_pend()) that block and allow other code to run. If no other code needs to run, power saving transitions become possible while waiting.
- Don't open drivers or leave drivers open if the application is not using them. When opened, drivers may set power constraints that unnecessarily limit the actions of the Power Manager. Instead, open drivers as needed and close them when they are not needed.

- If possible, optimize the application for speed (vs. memory in some cases) to reduce active cycles. This allows for more cycles to be spent in low power states.
- Be aware of the tradeoffs between accuracy and power consumption. Some applications over-calculate results, for example by using higher precision math than needed or wide data types when smaller types would suffice. Unnecessary accuracy or over-calculation increases the application footprint and consumes more CPU cycles, which reduces the amount of time the CPU can rest in a sleep state.

The following items are more specific recommendations for power reduction in your applications:

- **Clock.TickMode_PERIODIC.** If the Clock module is used with Clock.TickMode_PERIODIC (which is the default for CC32xx and MSP432), consider slowing the tick rate by specifying the maximum period that still meets application timing requirements. The default Clock.tickPeriod causes the Clock to tick every 1 millisecond. Depending on your application's timing requirements, this resolution might be unnecessarily high. For example, a system tick every 100 milliseconds meets the timing needs of some applications. Such slower tick rates can significantly reduce the number of CPU wakeups for Clock ticks, which allows for more time spent in sleep states. This mode is recommended for CC32xx and MSP432 devices.
- **Clock.TickMode_DYNAMIC.** If the Clock module is used with Clock.TickMode_DYNAMIC, unnecessary timer ticks are suppressed. The number of timer interrupts is reduced to the minimum required to support the scheduled timeouts. For some devices, the default tick mode is TickMode_DYNAMIC if the mode is not specified in the application configuration. See the wiki information on Clock Tick Suppression for details. This mode is recommended for CC13xx/CC26xx devices.

Some UART drivers allow applications to disable receive mode and release the corresponding power constraints. This is useful if you are using UART for output only.

For example, the UARTCC32XX driver allows the UART_control() API to be called with UART_CMD_RXDISABLE. This control command causes the driver to release the PowerCC32XX_DISALLOW_LPDS constraint, because the driver has been told it does not need to stay active to be able to receive data. The UART Power example (see Section 2.3) uses this UART_control() call to allow the power policy to select LPDS.

Similarly, for the UARTMSP432 driver, calling UART_control() with UART_CMD_RXDISABLE releases the DISALLOW_DEEPSLEEP_0 and DISALLOW_PERF_CHANGES constraints. Without these constraints set, the power policy can select a deep sleep state when appropriate and can allow the performance level to be changed.

2.8 What Next?

If you are an application developer, you can ignore the remaining chapters in most cases. Chapter 4 is for use by developers who want to customize the provided power policies. Chapter 5 is for use by device driver writers.

Power Management Configuration

This chapter provides more detail about the configuration interfaces available for the Power Manager.

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3.1 Static Configuration of Power Management

Certain Power Manager features are statically configurable via a Power Manager configuration object defined in the board file. The elements of the configuration object are device-family specific, and are defined in the relevant Power*.h device-specific header file.

For example, for CC32xx, a configuration structure of type PowerCC32XX_ConfigV1 needs to be declared for the application. This structure and its elements are defined in `PowerCC32XX.h`. The structure is typically declared in the device-specific file included by the `Board.h` file, which in this case is `CC3220S_LAUNCHXL.c` or `CC3220SF_LAUNCHXL.c`. If this structure is not included in the application, the application will fail to link.

The configuration object is defined and declared in the following locations:

Target	Configuration Struct	Defined	Declared	Reference Policy Function
CC13xx / CC26xx	PowerCC26XX_Config	PowerCC26XX.h	CC1350STK.c CC2650_LAUNCHXL.c CC2650DK_4XS.c CC2650DK_5XD.c CC2650DK_7ID.c CC2650STK.c etc.	PowerCC26XX_standbyPolicy()
CC32xx	PowerCC32XX_ConfigV1	PowerCC32XX.h	CC3220S_LAUNCHXL.c CC3220SF_LAUNCHXL.c	PowerCC32XX_sleepPolicy()
MSP432	PowerMSP432_ConfigV1	PowerMSP432.h	MSP_EXP432P401RLP.c	PowerMSP432_sleepPolicy()

Definitions of configuration objects are made in the header files for each target that are located in the `<SDK_INSTALL_DIR>/source/ti/drivers/power` directory.

Declarations of configuration objects are made in board files for a particular target. These are located in the `<SDK_INSTALL_DIR>/source/ti/boards` directory.

Reference policy functions are provided in the `Power<target>_tirtos.c` file located in the `<SDK_INSTALL_DIR>/kernel/tirtos/packages/ti/dpl` directory and in the `Power<target>_freertos.c` file located in the `<SDK_INSTALL_DIR>/kernel/freertos/dpl` directory.

For details, see the reference documentation, which you can access as follows:

1. Go to the `<SDK_INSTALL_DIR>/docs` directory.
2. View the **Documentation_Overview.html** web page.
3. Follow the link to the **TI Drivers Runtime APIs (doxygen)**.
4. Select the **Power.h** link in the "Driver Interfaces" column, along with the device-family specific implementation, for example `PowerCC32XX.h`.

This example shows the configuration object elements for CC13xx/CC26xx.

```
const PowerCC26XX_Config PowerCC26XX_config = {
    .policyInitFxn      = NULL,
    .policyFxn          = &PowerCC26XX_standbyPolicy,
    .calibrateFxn       = &PowerCC26XX_calibrate,
    .enablePolicy       = TRUE,
    .calibrateRCOSC_LF  = TRUE,
    .calibrateRCOSC_HF  = TRUE,
};
```

This example shows the configuration object elements for CC32xx:

```
const PowerCC32XX_ConfigV1 PowerCC32XX_config = {
    .policyInitFxn = &PowerCC32XX_initPolicy,
    .policyFxn = &PowerCC32XX_sleepPolicy,
    .enterLPDSHookFxn = NULL,
    .resumeLPDSHookFxn = NULL,
    .enablePolicy = false,
    .enableGPIOWakeupLPDS = true,
    .enableGPIOWakeupShutdown = false,
    .enableNetworkWakeupLPDS = false,
    .wakeupGPIOSourceLPDS = PRCM_LPDS_GPIO13,
    .wakeupGPIOTypeLPDS = PRCM_LPDS_FALL_EDGE,
    .wakeupGPIOFxnLPDS = NULL,
    .wakeupGPIOFxnLPDSArg = 0,
    .wakeupGPIOSourceShutdown = 0,
    .wakeupGPIOTypeShutdown = 0,
    .ramRetentionMaskLPDS = PRCM_SRAM_COL_1 | PRCM_SRAM_COL_2 |
                            PRCM_SRAM_COL_3 | PRCM_SRAM_COL_4,
    .keepDebugActiveDuringLPDS = false,
    .ioRetentionShutdown = PRCM_IO_RET_GRP_1,
    .pinParkDefs = parkInfo,
    .numPins = sizeof(parkInfo) / sizeof(PowerCC32XX_ParkInfo)
};
```

This example shows the configuration object elements for MSP432:

```
const PowerMSP432_ConfigV1 PowerMSP432_config = {
    .policyInitFxn = &PowerMSP432_initPolicy,
    .policyFxn = &PowerMSP432_sleepPolicy,
    .initialPerfLevel = 2,
    .enablePolicy = false,
    .enablePerf = true,
    .enablePinParking = true
};
```

3.1.1 Include Files

To use the Power API, the application should include both the `Power.h` header file and the appropriate device-specific Power header file. It can then call Power_enablePolicy() in main() or somewhere else in the program. For example, use these statements for CC13xx/CC26xx:

```
#include <ti/drivers/Power.h>
#include <ti/drivers/power/PowerCC26XX.h>

...

Power_enablePolicy();
```

The device-specific header file should be included as shown above, because applications typically use device-specific resource IDs, events, and sleep states.

3.2 Target-Specific Power Conservation

Although the same Power Manager API can be used across supported targets, different targets support different power conservation states using the Power Manager.

3.2.1 CC13xx/CC26xx Power Management

CC13xx/CC26xx supports three sleep states: CPU wait for interrupt (WFI), IDLE_PD (WFI plus CPU domain power gating), and STANDBY (all device power domains powered off). In addition, the power manager implements low-frequency RCOSC (RCOSC_LF) calibration and high-frequency RCOSC (RCOSC_HF) calibration.

The default power policy considers a sleep latency of 1 millisecond to determine if it should choose to enter the STANDBY state.

By default, RCOSC calibration is enabled. RCOSC calibration can be turned off by modifying the default configuration object as highlighted in bold below:

```
const PowerCC26XX_Config PowerCC26XX_config = {
    .policyInitFxn       = NULL,
    .policyFxn           = &PowerCC26XX_standbyPolicy,
    .calibrateFxn = &PowerCC26XX_noCalibrate, /* default is &PowerCC26XX_calibrate */
    .enablePolicy        = TRUE,
    .calibrateRCOSC_LF   = FALSE,             /* default is TRUE */
    .calibrateRCOSC_HF   = FALSE,             /* default is TRUE */
```

The following power events are supported:

- PowerCC26XX_ENTERING_STANDBY
- PowerCC26XX_ENTERING_SHUTDOWN
- PowerCC26XX_AWAKE_STANDBY
- PowerCC26XX_AWAKE_STANDBY_LATE
- PowerCC26XX_XOSC_HF_SWITCHED

Note that clients registered for PowerCC26XX_AWAKE_STANDBY are notified just after the domains are powered up. Clients registered for PowerCC26XX_AWAKE_STANDBY_LATE are notified after interrupts have been re-enabled.

The following constraints can be set or unset:

- PowerCC26XX_SB_VIMS_CACHE_RETAIN
- PowerCC26XX_SD_DISALLOW
- PowerCC26XX_SB_DISALLOW
- PowerCC26XX_IDLE_PD_DISALLOW
- PowerCC26XX_NEED_FLASH_IN_IDLE

Details regarding the implementation are provided in the `ti/drivers/power/PowerCC26XX.h` file.

3.2.2 CC32xx Power Management

CC32xx supports two sleep states: CPU wait for interrupt (WFI) and Low-Power Deep Sleep (LPDS). The reference power policy looks at the amount of idle time remaining to determine which sleep state it can transition to. It first checks to see if there is enough time to transition into LPDS. If it cannot transition into LPDS (for example, there is not enough time or a constraint has been set prohibiting LPDS), it goes to the CPU wait for interrupt state.

The default power policy considers a sleep latency of 20 milliseconds to determine if it should choose to enter the LPDS state.

LPDS is the lowest power state that can be used while continuing to maintain the application context (through memory retention) and the networking context to retain any existing WiFi connection. This state has entry-exit latency overheads.

The following power events are supported:

- PowerCC32XX_ENTERING_LPDS
- PowerCC32XX_ENTERING_SHUTDOWN
- PowerCC32XX_AWAKE_LPDS

The following constraints can be set or unset:

- PowerCC32XX_DISALLOW_LPDS
- PowerCC32XX_DISALLOW_SHUTDOWN

Details regarding the implementation are provided in the `ti/drivers/power/PowerCC32XX.h` file.

CC32xx Pin Parking Configuration and Management

When the CC32xx goes into LPDS, there can be significant leakage currents from I/O pins that are left floating (drifting somewhere between high or low), in a high-impedance state. To avoid such leakage, no pins should be left floating. Instead pins should be pulled to either a logic high or low, using internal pull resistors within the device pin pad configuration registers.

The CC32xx provides sophisticated pin configuration and multiplexing options. The Power Manager cannot read enough information from the dynamic pin configuration settings to generally determine safe parking states for an individual application. Therefore, the pin parking information should be statically configured by the application developer in the board file.

The provided board files configure CC32xx pin parking by default in the PowerCC32XX_ConfigV1 structure.

```
const PowerCC32XX_ConfigV1 PowerCC32XX_config = {
    .policyInitFxn = &PowerCC32XX_initPolicy,
    .policyFxn = &PowerCC32XX_sleepPolicy,

    ...

    .ioRetentionShutdown = PRCM_IO_RET_GRP_1,
    .pinParkDefs = parkInfo,
    .numPins = sizeof(parkInfo) / sizeof(PowerCC32XX_ParkInfo)
};
```

The pinParkDefs element points to an array of structures that define the parking state for each pin. If pinParkDefs is NULL, then no pins will be parked. In other words, to disable pin parking, set pinParkDefs to NULL.

The numPins config indicates the number of elements in the pinParkDefs array; this can be calculated as shown above.

By default, pinParkDefs points to the parkInfo array, which is included in the board files with the appropriate settings for the parkable pins on the TI Launchpad. For different boards, which have different circuit connections, this parking table should be modified to define the appropriate parking states to use while in LPDS. The default parkInfo array is as follows:

```
PowerCC32XX_ParkInfo parkInfo[] = {
    /*       PIN                    PARK STATE                  PIN ALIAS (FUNCTION)
     -----------------  ------------------------------   --------------------   */
    {PowerCC32XX_PIN01, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO10               */
    {PowerCC32XX_PIN02, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO11               */
    {PowerCC32XX_PIN03, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO12               */
    {PowerCC32XX_PIN04, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO13               */
    {PowerCC32XX_PIN05, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO14               */
    {PowerCC32XX_PIN06, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO15               */
    {PowerCC32XX_PIN07, PowerCC32XX_DONT_PARK},          /* GPIO16 (UART1_TX)    */
    {PowerCC32XX_PIN08, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO17               */
    {PowerCC32XX_PIN11, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* FLASH_SPI_CLK        */
    {PowerCC32XX_PIN12, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* FLASH_SPI_DOUT       */
    {PowerCC32XX_PIN13, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* FLASH_SPI_DIN        */
    {PowerCC32XX_PIN14, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* FLASH_SPI_CS         */
    {PowerCC32XX_PIN15, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO22               */
    {PowerCC32XX_PIN16, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* TDI (JTAG DEBUG)     */
    {PowerCC32XX_PIN17, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* TDO (JTAG DEBUG)     */
    {PowerCC32XX_PIN19, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* TCK (JTAG DEBUG)     */
    {PowerCC32XX_PIN20, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* TMS (JTAG DEBUG)     */
    {PowerCC32XX_PIN18, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO28               */
    {PowerCC32XX_PIN21, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* SOP2                 */
    {PowerCC32XX_PIN29, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* ANTSEL1              */
    {PowerCC32XX_PIN30, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* ANTSEL2              */
    {PowerCC32XX_PIN45, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* DCDC_ANA2_SW_P       */
    {PowerCC32XX_PIN50, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO0                */
    {PowerCC32XX_PIN52, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* RTC_XTAL_N           */
    {PowerCC32XX_PIN53, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO30               */
    {PowerCC32XX_PIN55, PowerCC32XX_DONT_PARK},          /* GPIO1 (UART0_TX)     */
    {PowerCC32XX_PIN57, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO2                */
    {PowerCC32XX_PIN58, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO3                */
    {PowerCC32XX_PIN59, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO4                */
    {PowerCC32XX_PIN60, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO5                */
    {PowerCC32XX_PIN61, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO6                */
    {PowerCC32XX_PIN62, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO7                */
    {PowerCC32XX_PIN63, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO8                */
    {PowerCC32XX_PIN64, PowerCC32XX_WEAK_PULL_DOWN_STD}, /* GPIO9                */
};
```

You can use the following parking states:

- PowerCC32XX_NO_PULL_HIZ
- PowerCC32XX_WEAK_PULL_UP_STD
- PowerCC32XX_WEAK_PULL_DOWN_STD
- PowerCC32XX_WEAK_PULL_UP_OPENDRAIN
- PowerCC32XX_WEAK_PULL_DOWN_OPENDRAIN
- PowerCC32XX_DRIVE_LOW
- PowerCC32XX_DRIVE_HIGH
- PowerCC32XX_DONT_PARK

On older CC32xx devices, the no pull, pull up (PU), and pull down (PD) states are supported. On some newer devices, the pin pads are enhanced to allow individual pins to be driven to a low or high logic level during LPDS.

If you want a pin to be left unparked, specify the PowerCC32XX_DONT_PARK state. For example, for a UART TX pin, the device automatically parks the pin in a high state during the transition to LPDS, so the Power Manager does not need to explicitly park the pin. So the entry in the array for such a pin should specify PowerCC32XX_DONT_PARK.

Note that pins managed by the GPIO driver (GPIOCC32XX) are, by default, parked in their current logic state when LPDS is activated. This allows an application to set GPIO pin states that will persist during LPDS. What this means is that, for GPIO-driver managed pins, if the pins are specified in the parking table in the board file, then the static state specified in the board file will by default be ignored; instead the dynamic state of the pin at entry to LPDS will be used.

This default behavior for GPIO-driver managed pins can be overridden by specifying GPIOCC32XX_USE_STATIC for a pin in the GPIO driver configuration structures. Then, specify the corresponding static states you want to use in the parking table in the board file.

Most applications have a significant number of unused pins (those not managed by any driver). These unused pins are parked to the states statically defined in the board file.

3.2.3 MSP432 Power Management

MSP432 supports Sleep and Deep Sleep states. In addition, the performance level of the target can be set to one of three levels. Setting the performance level changes the target's clock speeds and core voltage levels that trade performance for power conservation.

Transition latencies are very short for the MSP432—about 24 microseconds maximum—so latency thresholds are not considered for MSP432 when deciding whether to enter Deep Sleep.

The following power events are supported:

- PowerMSP432_ENTERING_SLEEP
- PowerMSP432_ENTERING_DEEPSLEEP
- PowerMSP432_ENTERING_SHUTDOWN
- PowerMSP432_AWAKE_SLEEP
- PowerMSP432_AWAKE_DEEPSLEEP
- PowerMSP432_START_CHANGE_PERF_LEVEL
- PowerMSP432_DONE_CHANGE_PERF_LEVEL

The following constraints can be set or unset:

- PowerMSP432_DISALLOW_SLEEP
- PowerMSP432_DISALLOW_DEEPSLEEP_0
- PowerMSP432_DISALLOW_DEEPSLEEP_1
- PowerMSP432_DISALLOW_SHUTDOWN_0
- PowerMSP432_DISALLOW_SHUTDOWN_1
- PowerMSP432_DISALLOW_PERFLEVEL_0
- PowerMSP432_DISALLOW_PERFLEVEL_1

- PowerMSP432_DISALLOW_PERFLEVEL_2
- PowerMSP432_DISALLOW_PERF_CHANGES

The Power driver for MSP432 uses ARM-centric naming of sleep states. That is, the states are sleep, deepsleep, and shutdown. The mapping of these sleep states to the LPM modes in the device data sheet is as follows:

- PowerMSP432_SLEEP = LPM0
- PowerMSP432_DEEPSLEEP_0 = LPM3
- PowerMSP432_DEEPSLEEP_1 = LPM4
- PowerMSP432_SHUTDOWN_0 = LPM3.5
- PowerMSP432_SHUTDOWN_1 = LPM4.5

Details regarding the implementation are provided in the `ti/drivers/power/PowerMSP432.h` file.

For details about ways to achieve better power savings on the MSP432 by using the Watchdog timer, see the TI-RTOS MSP432 Timer wiki topic.

MSP432 Pin Parking Configuration and Management

When the MSP432 goes into a deepsleep state (DEEPSLEEP_0 or DEEPSLEEP_1) there can be significant leakage currents from I/O pins that are left floating (drifting somewhere between high or low), in a high-impedance state. To avoid such leakage, no pins should be left floating. Instead pins should be pulled to either a logic high or low, using internal pull resistors within the device pin pads.

The Power Manager enables MSP432 automatic pin parking by default. The configuration setting for this is the enableParking element in the PowerMSP432_ConfigV1 structure:

```
const PowerMSP432_ConfigV1 PowerMSP432_config = {
    .policyInitFxn = &PowerMSP432_initPolicy,
    .policyFxn = &PowerMSP432_sleepPolicy,
    .initialPerfLevel = 2,
    .enablePolicy = true,
    .enablePerf = true,
    .enableParking = true
};
```

When enableParking is true (the default) and the device goes to DEEPSLEEP_0 or DEEPSLEEP_1, pull up or pull down resistors will be enabled, as appropriate, to pull the pins high or low, versus left floating.

For each input pin configured in GPIO mode, the Power Manager senses the current logic level of the pin (0 or 1), and then enables the appropriate pull resistor—pull down (PD) or pull up (PU)—to park the pins. Parking is done before the CPU goes to deep sleep. On wakeup, the pull resistor settings for each pin are restored to the state they were in before going to deep sleep.

Pins are not parked if they are not configured as input or are not configured for GPIO. This prevents the Power Manager from driving peripheral or analog function pins to improper states for external circuitry.

If you want your application to control pin parking in some other manner, you can set the Power Manager's enableParking configuration element to false.

Power Policies

This chapter provides an overview of Power Policy concepts. It includes definitions of terms and the role of a Power Policy. It discusses how to enable and select a specific Power Policy. Reference policies are used to describe key concepts. It concludes with instructions for creating and enabling your own custom Power Policy.

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4.1 Purpose of a Power Policy

The purpose of a Power Policy is to make a decision regarding power savings when the CPU is idle. The CPU is considered idle when the operating system's Idle loop is executed, when all application threads are blocked pending I/O, or blocked pending some other application event.

To make this decision, the Power Policy should consider factors such as:

- Constraints that have been declared to the Power Manager, which may disallow certain processor sleep states
- The time until the next OS-scheduled processing
- The transition latency in/out of allowed sleep states

To maximize power savings, the Power Policy should select the deepest power saving state that meets all the considered criteria. The selected power saving state can vary on each execution of the Idle loop, depending upon the changing values of the criteria that are being considered.

Once the Power Policy has decided upon the best allowed power savings, it will either: 1) make a function call to the Power Manager to enact the sleep state, or 2) for lighter saving, with minimal latency, invoke the savings directly (for example, by invoking the processor’s native wait for interrupt instruction).

Upon the next interrupt that wakes the CPU, the corresponding interrupt service routine (ISR) will be run as part of wakeup processing, pre-empting execution of the Idle loop. The ISR may perform all the necessary processing, or it may ready an application thread that had been previously blocked. In either case, when all the processing triggered by the interrupt completes, the OS Idle loop runs again, and the Power Policy function resumes execution from the point where interrupts were re-enabled after device wakeup. The Power Policy function will then exit, and then be called again from the OS Idle loop, which will allow it to once again look at criteria and choose a power saving state.

4.2 How to Select and Enable a Power Policy

The Power Policy to be used, and whether it should be enabled to run at startup, is specified in the Power Manager configuration structure in the board configuration file. For example, for CC32xx, the relevant elements are highlighted in green below:

```
/* ======== PowerCC32XX_config ======== */
const PowerCC32XX_ConfigV1 PowerCC32XX_config = {
    &PowerCC32XX_initPolicy,                    /* policyInitFxn */
    &PowerCC32XX_sleepPolicy,                   /* policyFxn */
    NULL,                                       /* enterLPDSHookFxn */
    NULL,                                       /* resumeLPDSHookFxn */
    false,                                      /* enablePolicy (default = false) */
    true,                                       /* enableGPIOWakeupLPDS */
    false,                                      /* enableGPIOWakeupShutdown */
    false,                                      /* enableNetworkWakeupLPDS */
    PRCM_LPDS_GPIO13,                           /* wakeupGPIOSourceLPDS */
    PRCM_LPDS_FALL_EDGE,                        /* wakeupGPIOTypeLPDS */
    NULL,                                       /* wakeupGPIOFxnLPDS */
    0,                                          /* wakeupGPIOFxnLPDSArg */
    0,                                          /* wakeupGPIOSourceShutdown */
    0,                                          /* wakeupGPIOTypeShutdown */
    PRCM_SRAM_COL_1|PRCM_SRAM_COL_2|PRCM_SRAM_COL_3|PRCM_SRAM_COL_4
                                                /* ramRetentionMaskLPDS */
    false,                                      /* keepDebugActiveDuringLPDS */
    PRCM_IO_RET_GRP_1,                          /* ioRetentionShutdown */
    parkInfo,                                   /* pinParkDefs */
    sizeof(parkInfo) / sizeof(PowerCC32XX_ParkInfo)  /* numPins */
};
```

In this example, the Power Policy is the reference "PowerCC32XX_sleepPolicy". This policy determines the lowest allowed sleep state currently appropriate, and activates that sleep state by calling the Power Manager's Power_sleep() API. If you want to use a derivative of this policy or create your own, you can specify a new function name for policyFxn.

The reference policy performs some initialization at startup, so the "PowerCC32XX_initPolicy" is specified for the policyInitFxn. Similar to the power policy function, you can substitute your own policy initialization function. If your policy does not need any initialization, you should specify "NULL" for the policyInitFxn.

Finally, the enablePolicy flag in the configuration structure indicates whether the Power Policy should be invoked on each pass through the OS Idle loop. When starting development of a new application, this element should normally be set to zero (that is, false) to allow easier application startup up and debugging (without the Power Manager opportunistically trying to save power during idle time). Once the application is working, this flag can be set to true to enable power savings by default. Or, as an alternative, the Power_enablePolicy() API can be called (once) at runtime to enable invocation of the policy function on each pass through the Idle loop.

4.3 CC13xx/CC26xx Reference Power Policy

For CC13xx/CC26xx, the SDK includes a Power Policy that opportunistically puts the device into STANDBY state during periods of extended inactivity. If the STANDBY state is disallowed because of a constraint or because of inadequate time to transition in/out of STANDBY, the policy selects lighter power savings instead.

The CC13xx/CC26xx reference power policy—named PowerCC26XX_standbyPolicy()—is shown in the following sections to describe concepts and demonstrate a practical implementation of a Policy Function.

Note that this is an aggressive policy, which enacts STANDBY to power off portions of the device whenever possible. Depending upon the application, it may be best to begin application development using a lighter-weight power policy—for example, the Power_doWFI() policy—and then after basic application debugging is complete, enable the aggressive STANDBY policy.

The STANDBY policy is implemented in:

- `PowerCC26XX_tirtos.c` located in the `<SDK_INSTALL_DIR>/kernel/tirtos/packages/ti/dpl` directory.
- `PowerCC26XX_freertos.c` located in the `<SDK_INSTALL_DIR>/kernel/freertos/dpl` directory.

This document shows code examples from the TI-RTOS version of the power policy. The actions performed by the FreeRTOS version of the power policy are equivalent.

The first step of the policy is to disable interrupts (step 1) by calling CPUcpsid(). This prevents pre-emption during the decision making process.

The next step is to query the constraints (step 2) that have been declared to the Power Manager.

In this policy, if either STANDBY or IDLE_PD (power down) are disallowed, the light-weight idling option of simple Wait for Interrupt (WFI) is invoked, using the driverlib PRCMSleep() API (step 3). The goal of this early check is to decide if WFI is the only option as quickly as possible, and when appropriate to go to WFI immediately.

```
/* disable interrupts */
CPUcpsid();

/* query the declared constraints */
constraints = Power_getConstraintMask();

/* do quick check to see if only WFI allowed; if yes, do it now */
if ((constraints &
     ((1 << PowerCC26XX_SB_DISALLOW) | (1 << PowerCC26XX_IDLE_PD_DISALLOW))) ==
     ((1 << PowerCC26XX_SB_DISALLOW) | (1 << PowerCC26XX_IDLE_PD_DISALLOW))) {
    PRCMSleep();
}
```

If the WFI option was not chosen, the next step is to see if there is enough time to transition in/out of STANDBY. The Power_SB_DISALLOW constraint is checked (step 4). If STANDBY is not disallowed, the Clock_getTicksUntilInterrupt() API will be called, to query how many Clock Module tick periods will occur until the next scheduled processing (step 5).

If there is indeed sufficient time to transition in/out of STANDBY, then the policy has now made the decision to go into STANDBY (step 6). However, there will be some latency to wake up the device from STANDBY, to be ready to perform the processing that had been scheduled. To ensure the processor is ready in time to perform the scheduled processing, the policy will schedule an early wakeup event, by starting a Clock object that will cause an early device wakeup, prior to the application-scheduled work.

The Clock module schedules functions to run based upon Clock tick periods, so the number of ticks needed to wakeup early are subtracted from the expected ticks until wakeup, to determine the number of ticks until the early wakeup (step 7). Once this early wakeup time is determined, the policy uses Clock APIs to start a Clock object to trigger the early wakeup (step 8). Note that the Power Manager provides a pre-created, dedicated Clock object that a Power Policy can use for this purpose. The handle for that Clock object is used in step 8 below.

Now that the early wakeup has been scheduled in the Clock module, the policy calls to the Power Manager's Power_sleep() API to do the transition into STANDBY (step 9).

```
/* check if any sleep states are allowed for automatic activation */
else {

    /* check if we are allowed to go to STANDBY */
4   if ((constraints & (1 << PowerCC26XX_SB_DISALLOW)) == 0) {

        /*
         * Check how many ticks until the next scheduled wakeup. A value of
         * zero indicates a wakeup will occur as the current Clock tick
         * period expires; a very large value indicates a very large number
         * of Clock tick periods will occur before the next scheduled wakeup.
         */
5       ticks = Clock_getTicksUntilInterrupt();
        /* convert ticks to usec */
        time = ticks * Clock_tickPeriod;

        /* check if can go to STANDBY */
6       if (time > Power_getTransitionLatency(PowerCC26XX_STANDBY,
             Power_TOTAL)) {

            /* schedule the wakeup event */
7           ticks -= PowerCC26XX_WAKEDELAYSTANDBY / Clock_tickPeriod;
            Clock_setTimeout(Clock_handle(&PowerCC26XX_module.clockObj), ticks);
8           Clock_start(Clock_handle(&PowerCC26XX_module.clockObj));

            /* go to STANDBY state */
9           Power_sleep(PowerCC26XX_STANDBY);
10          Clock_stop(Clock_handle(&PowerCC26XX_module.clockObj));
11          justIdle = FALSE;
        }
    }
```

Once the device has awoken from STANDBY, and the wakeup processing which preempts the policy has completed, the CPU returns to the policy function. At this point (step 10) there is a call to stop the early wakeup Clock event, in case it was not the reason the device exited STANDBY (for example, if a GPIO interrupt awoke the device before the next scheduled processing). The next step is to set `justIdle` to FALSE (step 11), so that the policy function will unwind and return, to enable a fresh evaluation of the sleep criteria at the top of the policy function, the next time it is invoked in the Idle loop.

If the device was not transitioned into STANDBY, the `justIdle` flag will still be "TRUE", so the alternative code is invoked (below).

The next best option to STANDBY is IDLE_PD, and a check is made (step 12) to see if there is a constraint preventing this.

If IDLE_PD is *not* disallowed, there are a few steps the policy invokes before idling the CPU. Some of the steps performed are simplified here. The policy enables cache retention (step 13), enables the CPU domain to be powered down when deep sleep is activated (step 14), a sync operation is invoked to ensure settings have propagated to the Always On (AON) domain (step 15), and then a driverlib call is made to invoke CPU deep sleep (step 16). Once the device wakes up, another sync of the AON domain is forced (step 17), and the policy function unwinds to return execution to the Idle loop.

If IDLE_PD *was* disallowed, the policy will simply invoke WFI (with driverlib's PRCMSleep()) (step 18).

```
        /* idle if allowed */
        if (justIdle) {

            /*
             * power off the CPU domain; VIMS will power down if SYSBUS is
             * powered down, and SYSBUS will power down if there are no
             * dependencies
             * NOTE: if radio driver is active it must force SYSBUS enable to
             * allow access to the bus and SRAM
             */
12          if ((constraints & (1 << PowerCC26XX_IDLE_PD_DISALLOW)) == 0) {

13              PRCMRetentionEnable();
14              PRCMPowerDomainOff(PRCM_DOMAIN_CPU);
15              SysCtrlAonSync();

16              PRCMDeepSleep();

                /* make sure MCU and AON is in sync */
17              SysCtrlAonUpdate();
            }
            else {
18              PRCMSleep();
            }
        }
    }

    /* re-enable interrupts */
19  CPUcpsie();
```

Finally, interrupts are re-enabled by the CPUcpsie() call (step 19). Note that if Power_sleep() was called to put the device into STANDBY (step 9), interrupts will be re-enabled within the Power_sleep() API, before late "awake" notifications are sent. So, the wakeup ISR will run at that point within Power_sleep() where interrupts are re-enabled. If lighter sleep is used with the driverlib APIs (step 16 and 18), interrupts will still be disabled when those functions return. So the wakeup ISR won't run until CPUcpsie() is called (step 19).

4.4 CC32xx Reference Power Policy

For CC32xx, the SDK includes a Power Policy that opportunistically puts the device into a sleep state during periods of extended inactivity. The policy favors the lowest power state that is appropriate. If the lowest state is not permitted (for example, because there is not enough anticipated idle time for that transition, or there is a constraint declared on that sleep state), it will next favor the next deepest power state, and so on. If none of the sleep states are appropriate, as a final option it will invoke the wait for interrupt (WFI) instruction to idle the CPU until the next interrupt.

The CC32xx Sleep policy is implemented in:

- `PowerCC32XX_tirtos.c` located in the `<SDK_INSTALL_DIR>/kernel/tirtos/packages/ti/dpl` directory.
- `PowerCC32XX_freertos.c` located in the `<SDK_INSTALL_DIR>/kernel/freertos/dpl` directory.

This document shows code examples from the TI-RTOS version of the power policy. The actions performed by the FreeRTOS version of the power policy are equivalent.

The reference policy—named PowerCC32XX_sleepPolicy()—is shown in the following sections to describe concepts and show practical implementation of a Policy Function.

Note that this is an aggressive policy; it enacts the lowest power state whenever possible. For the CC32xx, Low-Power Deep Sleep (LPDS) is used to power off portions of the device whenever possible. For this device, it is best to begin application development with automatic power transitions disabled, and then after basic application debugging is complete, enable the policy with constraints set to permit the lightest sleep state only. Once that is found to be working, progressively release more constraints to allow transitions to deeper sleep states.

The first step of the policy is to disable interrupts (step 1) by calling CPUcpsid(). This prevents pre-emption during the decision making process.

The next step is to disable the TI-RTOS Kernel schedulers, with calls to Swi_disable() and Task_disable() (step 2). These disables ensure that if a notification function readies a Swi or Task to run, that the scheduler will not immediately switch context to that new thread. Instead, the switch will be deferred until later, when appropriate, during wakeup and "unwinding" of the sleep state.

Next, Power_getConstraintMask() is called (step 3) to query the constraints that have been declared to the Power Manager.

```
/* disable interrupts */
CPUcpsid();

/* disable Swi and Task scheduling */
swiKey = Swi_disable();
taskKey = Task_disable();

/* query the declared constraints */
constraintMask = Power_getConstraintMask();
```

The next few steps analyze some of the current constraints on power savings. The returned constraintMask is checked (step 4) to see if the LPDS sleep state is allowed.

If LPDS is allowed, we still need to determine if there is enough time to transition into LPDS. The Clock_getTicksUntilTimeout() API is called (step 5) to find how many Clock module tick periods will occur before the next scheduled activity. This tick count is converted to microseconds (step 6), and compared with the device-specific constant for the total transition latency of LPDS (step 7).

```
/* check if there is a constraint to disallow LPDS */
if ((constraintMask & LPDS_DISALLOWED) == 0) {

    /* query Clock for the next tick that has a scheduled timeout */
    deltaTick = Clock_getTicksUntilTimeout();

    /* convert next tick to units of microseconds in the future */
    deltaTime = deltaTick * Clock_tickPeriod;

    /* check if there is enough time to transition to/from LPDS */
    if (deltaTime > PowerCC32XX_TOTALTIMELPDS) {
```

If there is sufficient time to transition in and out of LPDS, then the policy has come to the decision to enter LPDS. However, there will be some latency to wake up the device from LPDS to be ready to perform the processing that is scheduled. To ensure that the processor is ready in time to perform the scheduled processing, the policy needs to compute an earlier wakeup time to accommodate the wake latency (later, in step 12).

To determine the earlier wakeup time, first the current tick count is obtained with Clock_getTicks() and the Real Time Clock (RTC) count is sampled (step 8). An earlier API call (step 5) got the number of future ticks when work was scheduled (deltaTick). However, since the actual tick count for that work is unknown, we get the current tick value and add the delta to that (step 10).

To avoid drift over time when computing elapsed ticks based on RTC counts, the policy references the tick count and RTC count from an initial reference time. These reference values are obtained and stored before the first time LPDS is activated (step 9). The tick count for the next scheduled work is computed by adding the deltaTick count from step 5 and the current tick count from step 8 (step 10).

```
        /* decision is now made, going to transition to LPDS ... */
        /* get current Clock tick count */
8       beforeTick = Clock_getTicks();

        /* sample the RTC count before sleep */
        beforeRTC = getCountsRTC();

9       /* if this is the first LPDS activation stash initial counts */
        if (first) {
            firstTick = beforeTick;
            firstRTC = beforeRTC;
            first = false;
        }

10      /* set tick count for next scheduled work */
        workTick = beforeTick + deltaTick;
```

The SYSTICK timer is stopped (step 11), but will be started again later (step 23).

Note that because the Clock module is configured to use the SYSTICK counter, there are some consequences of having the Clock module stopped during LPDS, even though the Clock is reset to the correct time based on the RTC after the device returns from LPDS. See Section 4.4.1 for details.

The policy then subtracts the latency to allow for LPDS from the future time (in units of microseconds) where there is work to do (step 12), and the interval is converted from microseconds to RTC counts, which is the units for the LPDS interval timer (step 13).

The LPDS interval timer is 32-bits wide, but the calculated RTC counts are 64-bit numbers. So the calculated RTC count is clipped to the maximum 32-bit value of 0xFFFFFFFF to set it to the maximum LPDS interval if the calculated RTC count is larger than the maximum interval (step 14). This is the maximum timed interval that can be specified.

```
        /* stop SYSTICK */
11      Clock_tickStop();

        /* compute the time interval for the LPDS wake timer */
12      deltaTime -= PowerCC32XX_TOTALTIMELPDS;

        /* convert the interval in usec to units of RTC counts */
13      remain = (deltaTime * 32768) / 1000000;

        /* if necessary clip the interval to a max 32-bit value */
14      if (remain > 0xFFFFFFFF) {
            remain = 0xFFFFFFFF;
        }
```

The wakeup interval is set with the DriverLib API MAP_PRCMLPDSIntervalSet() (step 15). The LPDS interval timer is enabled as an LPDS wakeup source (step 16). Then the Policy calls Power_sleep() to transition the device to LPDS (step 17).

```
15      /* set the interval for the LPDS wake timer */
        MAP_PRCMLPDSIntervalSet(remain);

16      /* enable the LPDS interval timer as an LPDS wake source */
        MAP_PRCMLPDSWakeupSourceEnable(PRCM_LPDS_TIMER);

17      /* now go to LPDS */
        Power_sleep(PowerCC32XX_LPDS);
```

Once the device has awoken from LPDS, and the Power_sleep() API returns, the RTC count is obtained (step 18), a new Clock tick value is calculated (step 19), and the difference in the RTC count before and after sleep is calculated (step 20).

```
18      /* get the RTC count after wakeup */
        wakeRTC = getCountsRTC();

        /* calculate new Clock tick value based upon current RTC count,
           syncing back to firstTick and firstRTC:
         *  1. delta RTC = wakeRTC - firstRTC
         *  2. convert delta RTC to delta Clock tick periods
         *  3. new tick = firstTick + delta Clock tick periods
         */
19      newTick = (((wakeRTC - firstRTC) * 1000000) /
            (32768 * Clock_tickPeriod)) + firstTick;

        /* determine delta ticks based on RTC counts during LPDS */
20      deltaTicksPerRTC = (((wakeRTC - beforeRTC) * 1000000) /
            (32768 * Clock_tickPeriod));
```

If the device woke up before the time of the next scheduled interrupt (step 21), the Clock module's internal tick count is updated to reflect the elapsed time.

If the device woke up at the time of or after the next interrupt was scheduled (step 22), the Clock module's internal tick count is updated to reflect a tick just before the next tick when work needs to be performed. Then, Clock_doTick() is called enough times to account for the number of missed ticks. This allows the Clock to post its Swi, so that ticks that weren't serviced on time will be handled.

```
            /* next update Clock's internal tick count to reflect elapsed time,
             * accommodating eventual rollover of the 32-bit Clock tick count */

            /* first, handle normal case of early wake (before workTick) */
21          if (deltaTicksPerRTC < deltaTick) {
                /* just set count to newTick */
                Clock_setTicks(newTick);
            }
            /* else, if woke on workTick or later */
22          else {
                /* update tick count, trigger Clock Swi to run ASAP
                 *   1. set tick count to workTick - 1
                 *   2. call Clock_doTick() as many times as necessary to
                 * account for the number of missed ticks. [Each call will
                 * increment tick count and post the Clock Swi, which will
                 * run Clock_workFunc(), which uses the Swi post count to
                 * catch up for ticks that weren't serviced on time.]
                 */
                Clock_setTicks(workTick - 1);
                for (i = 0; i < (deltaTicksPerRTC - deltaTick + 1); i++) {
                    ti_sysbios_knl_Clock_doTick(0);
                }
            }
```

Once the Clock ticks are updated, the Clock module is reconfigured and restarted (step 23).

```
            /* reconfigure and restart the SYSTICK timer */
23          Clock_tickReconfig();
            Clock_tickStart();

            /* set a flag to indicate LPDS was invoked */
            slept = TRUE;
        }
    }
```

Next, interrupts are re-enabled (step 24). For LPDS, if the device is awoken by the LPDS interval timer, no ISR will run following wakeup. The Swi and Task schedulers are also restored to their previous states (steps 25 and 26). If the wakeup ISR or a notification function readied a thread to run (for example, if Semaphore_post() is called in the notification function to trigger a Task to run), the thread will run later, once the appropriate scheduler is restored (the Task scheduler for the case of a Semaphore).

When immediate work is completed, and all threads are again blocked, the Idle loop resumes, at the end of the policy function, which returns and allows another pass through the Idle loop (and another invocation of the policy function). If the policy did not attempt LPDS (as indicated by the returnFromSleep flag, step 27), as the lightest sleep option, the policy invokes wait for interrupt via the MAP_PRCMSleepEnter() API. This gates the CPU clock until the next interrupt occurs.

```
    /* re-enable interrupts */
24  CPUcpsie();

    /* restore Swi scheduling */
25  Swi_restore(swiKey);

    /* restore Task scheduling */
26  Task_restore(taskKey);

    /* sleep only if we are not returning from one of the sleep states above */
27  if (!(slept)) {
        MAP_PRCMSleepEnter();
    }
}
```

4.4.1 Effects of LPDS on Clock Module and SYSTICK

In PowerCC32XX_sleepPolicy() the Clock module is configured to use the NVIC SYSTICK counter (running at the CPU frequency) while the device is awake. When the device transitions to LPDS, the SYSTICK counter is powered off (along with the CPU). The Real Time Clock (RTC) continues to run during LPDS.

Upon waking from LPDS, the RTC is read to determine the current time, and this is converted to the corresponding Clock tick, as if the Clock module had continued to tick during LPDS. The Clock tick count is updated, the SYSTICK counter is restarted, and the Clock module resumes providing timing services. These updates are all implemented within PowerCC32XX_sleepPolicy() (step 23). Clock ticks are stopped before calling Power_sleep() and resumed after Power_sleep() returns following wakeup.

Understanding this behavior is important because:

- The Clock module is stopped and the tick count is not updating during any notifications sent by Power_sleep() and during the hook functions enterLPDSHookFxn, resumeLPDSHookFxn, and wakeupGPIOFxnLPDS.
- The Clock module is not restarted until after Power_sleep() returns to the policy. Therefore, no new Clock objects can be started by any notification functions or by the mentioned hook functions (all called from within Power_sleep()).

  This is because the Clock module tick count is updated by the policy after Power_sleep() returns but before restarting Clock, and that update can cause the tick count to leap over any newly started Clock objects. Such Clock objects will consequently not timeout until much later when the Clock tick counter rolls over and increments to the timeout value.

  As an alternative to creating Clock objects in notification or hook functions, you can post software interrupt (Swi) objects. By the time the new Swi objects run, the Clock module has already been re-synchronized and restarted, and Clock objects can be started from the Swi functions without issue.

Additionally, by default SYSTICK is configured as the Timestamp provider. So from the time SYSTICK is stopped by the policy until it is restarted again after wakeup, the timestamp values will not be incrementing. Because of implementation details with certain timing, the reported timestamps after a wakeup can appear to go back in time by up to one Clock tick period.

The recommended alternative is to use the RTC as the Timestamp provider, which will not have this limitation. Since the RTC continues to run, timestamps will be available during the entire LPDS sequence. However, the Timestamp resolution with RTC as the provider will be 32768 Hz; with SYSTICK as the provider, the Timestamp resolution is the CPU frequency.

You can use the following statements in the *.cfg configuration file for your application to use RTC as the Timestamp provider:

```
var Timestamp = xdc.useModule('xdc.runtime.Timestamp');
var TimestampRTC = xdc.useModule('ti.sysbios.family.arm.cc32xx.TimestampProvider');

Timestamp.SupportProxy = TimestampRTC;
```

4.5 MSP432 Reference Power Policy

For MSP432, the SDK provides two power policies. This is because the Deep Sleep states disable peripheral modules and causes Clock ticks to stop working. We recommend that you debug applications using the less aggressive Power_sleepPolicy(). After debugging the application, you can select the more aggressive Power_deepSleepPolicy().

The default policyFxn is PowerMSP432_sleepPolicy(). The MSP432 reference policyInitFxn is PowerMSP432_initPolicy().

The alternate policyFxn is PowerMSP432_deepSleepPolicy(). This section describes the alternate policy because it provides more information about the sleep policies available on the MSP432.

The MSP432 policy functions are implemented in:

- `PowerMSP432_tirtos.c` located in the `<SDK_INSTALL_DIR>/kernel/tirtos/packages/ti/dpl` directory.
- `PowerMSP432_freertos.c` located in the `<SDK_INSTALL_DIR>/kernel/freertos/dpl` directory.

This document shows code examples from the TI-RTOS version of the power policy. The actions performed by the FreeRTOS version of the power policy are equivalent.

PowerMSP432_deepSleepPolicy() opportunistically puts the device into a sleep state during periods of extended inactivity. The policy favors the lowest power state that is appropriate. If the lowest state is not permitted (because there is a constraint declared on that sleep state), it will favor the next deepest power state, and so on. If none of the sleep states are appropriate, as a final option it will invoke the wait for interrupt (WFI) instruction to idle the CPU until the next interrupt.

Note that this is an aggressive policy; it enacts the lowest power state whenever possible. It is often best to begin application development with automatic power transitions disabled, and then after basic application debugging is complete, enable the policy with constraints set to permit the lightest sleep state only. Once that is found to be working, progressively release more constraints to allow transitions to deeper sleep states.

Note: Clock ticks halt during MSP432 deep sleep states. This is a significant consequence in that timeouts scheduled by the Clock module are suspended during deep sleep, and so will not be able to wake up the device.

For example, when Task_sleep() is called, it blocks the execution of the Task for a number of system ticks. But if the power policy puts the device into deep sleep, the Clock ticking is suspended while the device is in deep sleep. In other words, the timer generating Clock ticks is halted. So the timeout that would normally trigger resumption of the Task_sleep() call is suspended too, and the device will not be able to wake to service the timeout at the anticipated time. Instead, the device will need to be awoken by another source. When awoken, the Clock module will start ticking again, but the time spent in deep sleep will not be factored in to future timeouts.

In summary, on MSP432, if timeouts via the Clock module are needed, then the default, lighter-weight sleep policy Power_sleepPolicy() should be used. If wakeups from deep sleep are triggered by other sources (such as a GPIO line changing state), then the PowerMSP432_deepSleepPolicy() allows much better power savings.

The first step of the policy is to disable interrupts (step 1) by calling CPUcpsid(). This prevents pre-emption during the decision making process.

The next step is to disable the TI-RTOS Kernel schedulers, with calls to Swi_disable() and Task_disable() (step 2). These disables ensure that if a notification function readies a Swi or Task to run, that the scheduler will not immediately switch context to that new thread. Instead, the switch will be deferred until later, when appropriate, during wakeup and "unwinding" of the sleep state.

Next, Power_getConstraintMask() is called (step 3) to query the constraints that have been declared to the Power Manager.

```
1  /* disable interrupts */
   CPUcpsid();

2  /* disable Swi and Task scheduling */
   swiKey = Swi_disable();
   taskKey = Task_disable();

3  /* query the declared constraints */
   constraintMask = Power_getConstraintMask();
```

The next step determines whether the constraints prevent the use of the Deep Sleep 1 state, the deepest level (step 4). If this state is allowed, Power_sleep() is called (step 5). When the device returns from Deep Sleep 1, a flag is set to indicate that the device slept (step 6).

```
 /* check if can go to DEEPSLEEP_1 */
if ((constraints & ((1 << PowerMSP432_DISALLOW_SLEEP) |
                    (1 << PowerMSP432_DISALLOW_DEEPSLEEP_0) |
                    (1 << PowerMSP432_DISALLOW_DEEPSLEEP_1))) == 0) {

    /* go to DEEPSLEEP_1 */
    Power_sleep(PowerMSP432_DEEPSLEEP_1);

    /* set 'slept' to true*/
    slept = true;
}
```

The policy next checks to see if the device did not go into Deep Sleep 1 but is allowed to go into Deep Sleep 0 (step 7). If so, it sleeps and sets the flag as with Deep Sleep 1 (step 8).

```
/* if didn't sleep yet, now check if can go to DEEPSLEEP_0 */
if (!slept && ((constraints & ((1 << PowerMSP432_DISALLOW_SLEEP) |
                    (1 << PowerMSP432_DISALLOW_DEEPSLEEP_0))) == 0)) {

    /* go to DEEPSLEEP_0 */
    Power_sleep(PowerMSP432_DEEPSLEEP_0);

    /* set 'slept' to true*/
    slept = true;
}
```

The policy checks to see if the device did not go into either Deep Sleep state but is allowed to go into Sleep state (step 9). If so, it sleeps and sets the flag as with the previous sleep states (step 10).

```
/* if didn't sleep yet, now check if can go to SLEEP */
if (!slept && ((constraints & (1 << PowerMSP432_DISALLOW_SLEEP)) == 0)) {

    /* go to SLEEP */
    Power_sleep(PowerMSP432_SLEEP);

    /* set 'slept' to true*/
    slept = true;
}
```

Next, interrupts are re-enabled (step 11). The Swi and Task schedulers are also restored to their previous states (steps 12 and 13). If the wakeup ISR or a notification function, readied a thread to run (for example, if Semaphore_post() is called in the ISR to trigger a Task to run), the thread will run later, once the appropriate scheduler is restored (the Task scheduler for the case of a Semaphore).

When immediate work is completed, and all threads are again blocked, the Idle loop resumes, at the end of the policy function, which returns and allows another pass through the Idle loop (and another invocation of the policy function). If the policy did not sleep (as indicated by the slept flag), as the lightest sleep option, the policy invokes the wait for interrupt via assembly.

```
    /* re-enable interrupts */
11  CPUcpsie();

    /* restore Swi scheduling */
12  Swi_restore(swiKey);

    /* restore Task scheduling */
13  Task_restore(taskKey);

    /* if didn't sleep yet, just do WFI */
14  if (!slept) {
        __asm(" wfi");
    }
}
```

4.6 Creating a Custom Power Policy

You may want to write your own Power Policy, for example, to factor application-specific information into the decision process. The provided reference power policies are general policies; they do not consider non-Clock triggered wakeup events. If you want to factor other wakeup events into the policy or add other application-specific criteria, you can do so by creating a custom Power Policy.

You can start with the provided power policy function or start from scratch. Create a new Policy Function, and compile and link the new function into your application. Select your new policy by substituting its name for the "policyFxn" in the Power Manager configuration object, for example, the PowerCC32XX_ConfigV1 object in the CC32xx board file, `CC3220S_LAUNCHXL.c` or `CC3220SF_LAUNCHXL.c`. For example:

```
const PowerCC32XX_ConfigV1 PowerCC32XX_config = {
    .policyInitFxn             = &PowerCC32XX_initPolicy,
    .policyFxn                 = &PowerCC32XX_sleepPolicy,
    .enterLPDSHookFxn          = NULL,
    .resumeLPDSHookFxn         = NULL,
    .enablePolicy              = false,
    .enableGPIOWakeupLPDS      = true,
    .enableGPIOWakeupShutdown  = false,
    .enableNetworkWakeupLPDS   = false,
    .wakeupGPIOSourceLPDS      = PRCM_LPDS_GPIO13,
    .wakeupGPIOTypeLPDS        = PRCM_LPDS_FALL_EDGE,
    .wakeupGPIOFxnLPDS         = NULL,
    .wakeupGPIOFxnLPDSArg      = 0,
    .wakeupGPIOSourceShutdown  = 0,
    .wakeupGPIOTypeShutdown    = 0,
    .ramRetentionMaskLPDS      = PRCM_SRAM_COL_1 | PRCM_SRAM_COL_2 |
                                 PRCM_SRAM_COL_3 | PRCM_SRAM_COL_4
    .keepDebugActiveDuringLPDS = false,
    .ioRetentionShutdown       = PRCM_IO_RET_GRP_1,
    .pinParkDefs               = parkInfo,
    .numPins                   = sizeof(parkInfo) / sizeof(PowerCC32XX_ParkInfo)
};
```

By default, the Policy Function is invoked in the operating system's Idle loop, as this is the "natural" idle point for an application. Depending upon the application, the Idle loop may run frequently or infrequently, with a short or long duration before being preempted. So your policy must look at other criteria (besides the fact that the Idle loop is running) to make an appropriate decision.

When the Policy Function is enabled to run in the Idle loop, it will idle the CPU on each pass through the Idle loop—for CC32xx, either for LPDS or simple WFI—with the result that any other work the application places in the Idle loop will be invoked only once per idling of the CPU. This may be fine for your application, or you may want to move that other work out of the Idle loop to a higher priority-thread context.

The Policy Function can, in theory, be run from another thread context (if you explicitly call your Policy Function from that thread). But lower-priority threads would be blocked from execution unless the Policy Function routinely decides to not invoke any idling of the CPU.

The Power_getTransitionLatency() API reports the minimum device transition latency to get into/out of a specific sleep state. It does not include any additional latency that may be incurred due to the latency of Power event notifications. So if your application has a significant number of notification clients, or notification latency, you'll want to factor that into the decision for activation of a sleep state.

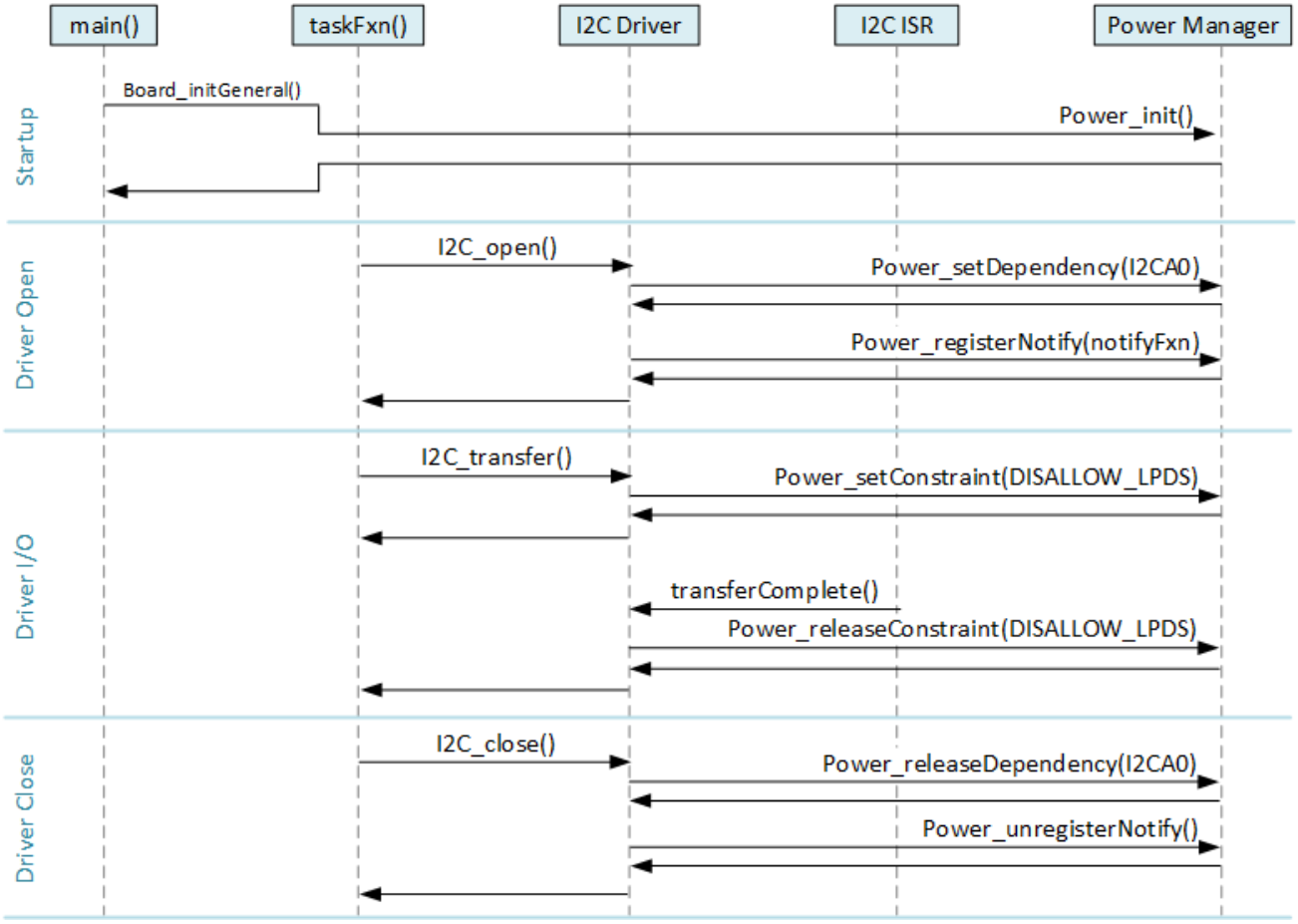
Power Management for Drivers

This chapter provides an overview of how a device driver should interact with the Power Manager. It summarizes the different types of communication between a device driver and the Power Manager. An SPI driver (for CC32xx) is used as an example to illustrate the key function calls. The document concludes with a set of guidelines for the driver writer.

Topic **Page**

5.1 Driver Activity Overview

The following diagram provides an overview of the flow of dependencies, notification, and constraints in an application that uses the I2C driver. The driver interacts with the Power Manager by setting and releasing dependencies, registering and unregistering for notifications of power events, and setting and releasing constraints on which power states are not permitted at certain times during execution.



5.2 Types of Interaction

A device driver needs to read/write peripheral registers, and usually there is an initial step required to allow CPU access to the peripheral. For example, on a CC32xx device, a peripheral must have its clocks enabled first, otherwise an exception will occur when the CPU tries to access the peripheral. On a CC13xx/CC26xx device, a peripheral must have its clocks and the relevant power domain enabled.

There are different ways to do this enabling. For example, the driver could write directly to clock and control registers, or it could use DriverLib APIs for this. However, if each driver does this independently, there will be inevitable problems when there are shared clock or power domain control registers. These problems can be avoided by using the Power Manager's APIs, which will properly synchronize and arbitrate the access to shared registers.

Similarly, the Power Manager APIs can be used to properly enable and disable multiple peripherals that share power domains. On the CC13xx/CC26xx, for example, one device driver may be using the GPIO module (which resides in the PERIPH domain) and another may be using the I2S module (also in the PERIPH domain). Suppose the I2S driver is closed and part of cleanup explicitly disables I2S clocks and turns off the PERIPH power domain. When this happens, the GPIO module will immediately cease to function because its power domain was just turned OFF.

5.2.1 Set/Release of Dependencies

The Power Manager provides two APIs for drivers to use to enable/disable access to peripherals (generally called "resources"): Power_setDependency() and Power_releaseDependency(). And the Power Manager uses a small device-specific database to represent the resource dependency tree for the device, so that it can arbitrate the enable/disable calls, and know when to properly enable/disable shared resources.

TI Drivers call Power_setDependency() to enable access to a specific peripheral. If the declaration is the first for the peripheral (that is, it is currently disabled), the Power Manager proceeds to activate the peripheral. The first step is to check to see if there is a "parent" resource. On the CC13xx/CC26xx, for example, the UART peripheral resides in the SERIAL domain, so the SERIAL domain is the "parent". If there is a parent resource, the Power Manager will next check to see if it is activated. If it is not, then the parent will be activated first. For example, for the UART, the SERIAL power domain will be switched ON. After the parent(s) are activated, the "child" resource (for example, the UART peripheral in this case) is activated. And then Power_setDependency() returns to the caller (the driver).

The enable/disable status of each resource is reference counted. So for example, if a dependency is set on a resource, if another active resource shares the same parent resource, that parent resource won't be turned ON again (because it is already ON), but the reference count for the parent resource is incremented.

There is a companion API for drivers to release a dependency and disable a resource: Power_releaseDependency(). This API will appropriately decrement the reference counts for resources, and when those counts reach zero, disable the resource (for both child and parent resources).

Reference counts allow the Power Manager to know precisely when a particular resource (child or parent) should actually be enabled/disabled.

Typically a driver declares its resource needs by calling Power_setDependency() in its "open" function, and releases those resources by calling Power_releaseDependency() in its "close" function. It is critical that the driver writer call these APIs in pairs, to maintain proper reference counts, and to enable the Power Manager to power down resources when they are no longer needed.

5.2.2 Registration and Notification

Some power transitions can adversely affect drivers. There is a constraint mechanism (described next) that allows a driver to prohibit certain transitions. For example, disallowing sleep during an active I/O transaction. But in addition to this, when transitions are allowed, there may be need for drivers to adapt to the transitions. For example, if a sleep state causes peripheral register context to be lost, the driver needs to restore that register context once the device is awake from the sleep state.

The Power Manager provides a callback mechanism for this purpose. Drivers register with the Power Manager for notifications of specific transitions they care about. These transitions are identified as power "events". For example, for CC32xx, the PowerCC32XX_ENTERING_LPDS event is used to signal that a transition to LPDS has been initiated. If a driver needs to do something when the event is signaled, for example, to save some state, or maybe externally signal that the driver will be suspended, it can do this in the callback. Once the Power Manager has notified all drivers that have registered for a particular power event, it will then proceed with the power transition.

The API drivers use to register for notifications is: Power_registerNotify(). With this call a driver specifies the event(s) that it wants to be notified of (one or more events), a callback function (provided by the driver) that the Power Manager should call when the event(s) occurs, an optional event-specific argument, and an arbitrary client argument that can be sent when the callback is invoked.

The callback function is called from the thread context where the power transition was initiated. For example, from the Idle task context, when a Power Policy has made a decision to go to sleep, and has invoked the Power_sleep() API. When the callback function is invoked the driver should take the necessary action, and return from the callback as quickly as possible. The callback function cannot block, or call any operating system blocking APIs. It must return with minimal latency, to allow the transition to proceed as quickly as possible.

Notifications are sent once a decision has been made and a transition is in progress. Drivers cannot "vote" at this point because the transition is in progress. They must take the necessary action, and return immediately.

Typically drivers registers for notifications in the driver's "open" function, and un-register for notifications in the "close" function.

5.2.3 Set/Release of Constraints

As described earlier, constraints can be used by drivers to temporarily prohibit certain power transitions, which would otherwise cause a driver to fail to function. The Power Manager provides the Power_setConstraint() API for declaring these constraints, and the Power_releaseConstraint() API to call when the constraint can be lifted.

Constraints are intended to be temporary and dynamic, and only declared when absolutely necessary. Once a constraint is no longer necessary, it should be released, to allow the Power Manager to aggressively reduce power consumption.

Similar to dependencies, constraints are reference counted. So to maintain proper reference counts, it is critical that a driver calls the Power_setConstraint() and Power_releaseConstraint() APIs in pairs.

Note that there is also a Power_getConstraintMask() API that allows a query of a bitmask that represents the currently active constraints. This API is used by a Power Policy when making a decision to go to a particular sleep state. Drivers might use the API to query active constraints, but they should not rely on the fact that a constraint is already raised, and not raise the constraint on their own. (Because another driver may release its constraints at any time.) If a driver has a constraint, it should declare it with Power_setConstraint(), and release it as soon as possible, with Power_releaseConstraint().

5.3 Example: CC32xx SPI Driver

This section uses the CC32xx SPI driver to illustrate the interaction between a driver and the Power Manager. The code shown in the following sections focuses on interactions with the Power Manager. Code that the SPI driver uses to perform its read and write action is not shown. See the `SPICC32XXDMA.c` file for the full source code.

Section 5.4 then summarizes the concepts in a set of guidelines for the driver writer.

5.3.1 SPICC32XXDMA_open()

When the SPI driver opens, it first declares a power dependency upon the SPI peripheral, with a call to Power_setDependency() (step 1). Since this driver is using DMA, it also declares a dependency upon DMA (step 2).

```
/* Register power dependency - i.e. power up and enable clock for SPI. */
Power_setDependency(object->powerMgrId);

Power_setDependency(PowerCC32XX_PERIPH_UDMA);
```

After several other setup activities not related to power, the driver registers its Power notification function—SPICC32XXDMA_postNotify()—to be called upon wakeup from LPDS (step 3)

```
Power_registerNotify(&(object->notifyObj), PowerCC32XX_AWAKE_LPDS,
        SPICC32XXDMA_postNotify, (uintptr_t)handle);
```

5.3.2 SPICC32XXDMA_transfer()

When initiating a transfer, the driver declares a constraint to the Power Manager (step 4) by calling Power_setConstraint() to prevent a transition into LPDS during the transfer. Without this constraint, the Power Policy running in the Idle thread might decide to transition the device into a sleep state while a SPI transfer is in progress, which would cause the transfer to fail.

```
/* Set constraints to guarantee transaction */
Power_setConstraint(PowerCC32XX_DISALLOW_LPDS);
```

When the transfer completes in SPICC32XXDMA_hwiFxn(), the driver releases the constraint that it had raised previously (step 5). Now the SPI driver is no longer prohibiting sleep states, and the device can be transitioned to sleep if appropriate.

```
    /* Release constraint since transaction is done */
    Power_releaseConstraint(PowerCC32XX_DISALLOW_LPDS);
```

5.3.3 Notification Callback

As shown in Section 5.3.1, in SPICC32XXDMA_open() the driver registered for a notification when the device is awoken from LPDS. The notification callback that the driver registered is shown below.

SPI and DMA peripheral registers lose their context during LPDS, so the SPICC32XXDMA_postNotify() function calls SPICC32XXDMA_initHw() to restore the DMA state and the SPI peripheral state (step 6).

To signal successful completion back to the Power Manager, the notify function returns a status of Power_NOTIFYDONE (step 7):

```
/*
 *  ======== SPICC32XXDMA_postNotify ========
 *  This function is called to notify the SPI driver of an ongoing transition
 *  out of LPDS state. clientArg should be pointing to a hardware module which has
 *  already been opened.
 */
static int SPICC32XXDMA_postNotify(unsigned int eventType, uintptr_t eventArg,
       uintptr_t clientArg)
{

    SPICC32XXDMA_initHw((SPI_Handle)clientArg);

    return (Power_NOTIFYDONE);
}
```

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5.3.4 SPICC32XXDMA_close()

When the driver is being closed, it needs to release the dependencies it had declared upon the SPI (step 8) and DMA (step 9).

```
   /* Release power dependency on SPI. */
   Power_releaseDependency(object->powerMgrId);
   Power_releaseDependency(PowerCC32XX_PERIPH_UDMA);
```

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It also needs to un-register for notification callbacks (step 10) by calling Power_unregisterNotify().

```
   Power_unregisterNotify(&(object->notifyObj));
```

10

5.4 Guidelines for Driver Writers

This section summarizes a set of guidelines and steps for enabling a driver to interact with the Power Manager. Notice in Section 5.3 that the amount of code required to enable a driver to use the Power Manager is small.

5.4.1 Use Power_setDependency() to enable peripheral access

Before accessing any peripheral registers, call Power_setDependency() specifying the peripheral's resource ID. For example, in the driver's UARTCC32XX_open() function:

```
Power_setDependency(PowerCC32XX_PERIPH_UARTA0);
```

This call enables peripheral clocks (for run and sleep states) and powers up the corresponding power domain if it is not already powered.

The Power Manager uses reference counting of all Power_setDependency() and Power_releaseDependency() calls for each resource. It arbitrates access to shared "parent" resources, enabling and disabling them only as needed. It is critical that your driver participate in this arbitration by calling these APIs; if it does not, there will likely be exceptions raised as your application runs.

It is also critical that your driver call Power_setDependency() and Power_releaseDependency() in matched pairs. For example, if Power_setDependency() is called twice for the resource, but Power_releaseDependency() is only called once, the resource remains in an enabled/powered state, when it could and should be disabled/powered down. You can use the Power_getDependencyCount() to get the current number of dependencies set on a resource.

5.4.2 Use Power_setConstraint() to disallow power transitions as necessary

If it needs to temporarily prevent a particular power transition, the driver should call Power_setConstraint(). For example, when initiating an un-interruptible I/O transaction, the driver can declare a constraint that the LPDS sleep state cannot be initiated:

```
Power_setConstraint(PowerCC32XX_DISALLOW_LPDS);
```

As soon as the constraint can be lifted, the driver should release the constraint with a call to Power_releaseConstraint(), to enable aggressive power savings.

The Power Manager uses reference counting for constraints, so it is critical that your driver call Power_setConstraint() and Power_releaseConstraint() in matched pairs.

Note that the Power_setContraint() and Power_releaseConstraint() APIs do not "touch" the device clock and power control registers. They simply track and count the declaration and release of constraints. So these APIs can be called from any thread context.

5.4.3 Use Power_registerNotify() to register for appropriate power event notifications

If your device driver needs to know about certain power transitions, it should register for notification of the corresponding power events, using the Power_registerNotify() API.

For example, on CC32xx devices, during LPDS, the shared peripheral power domain is powered OFF. The domain is powered back ON upon wakeup. The content of peripheral registers is re-initialized to reset values when the domain is powered back ON. So your device driver may need to save some state

before the device goes into LPDS. If the driver registers for the PowerCC32XX_ENTERING_LPDS event, it will receive advance notification of the transition, and can save the critical state data, as well as perform any other steps necessary for preparation for LPDS.

For example, the driver might de-assert an I/O line, which will hold off further communication from a peer on a communication bus, until the device wakes from LPDS, and re-asserts the I/O line. Similarly, the driver probably needs to take some specific action upon wakeup (for example, re-initializing peripheral registers), so it should register for notification for the PowerCC32XX_AWAKE_LPDS event. And when that event is signaled, take the necessary action.

If there are multiple instances of a device driver (for example, three active instances of a UART driver), the "clientArg" passed with the Power_registerNotify() call can be used to distinguish different behavior when the notification callback functions are invoked. For example, the first instance of the driver specifies a clientArg of "1":

```
Power_registerNotify(&obj1, PowerCC32XX_ENTERING_LPDS |
                            PowerCC32XX_AWAKE_LPDS, notifyFxn, 1);
```

The second instance of the driver specifies a clientArg of "2":

```
Power_registerNotify(&obj2, PowerCC32XX_ENTERING_LPDS |
                            PowerCC32XX_AWAKE_LPDS, notifyFxn, 2);
```

When the PowerCC32XX_ENTERING_LPDS event is signaled, the "notifyFxn()" callback will be called twice. For the first driver instance the call is:

```
notifyFxn(PowerCC32XX_ENTERING_LPDS, 0, 1);
```

and for the second it is:

```
notifyFxn(PowerCC32XX_ENTERING_LPDS, 0, 2);
```

Finally, the device driver should only register for those events that it needs to know about. In other words, there is no need to register for an event that is a "don't care" for the driver. For example, the driver may not need to do anything before a transition into LPDS. If this is the case, it should not register for the PowerCC32XX_ENTERING_LPDS event.

5.4.4 Minimize work done in notification callbacks

Notification callback functions should be minimal functions, in which the driver performs just the necessary steps for a particular power transition, and then returns as quickly as possible.

Callback functions must not call any operating system blocking APIs—for example, Semaphore_pend().

The callback function is called from the context where the Power Manager API was invoked for initiating a particular power transition. So the callback function must be careful if it accesses shared data structures that may be used in different thread contexts.

5.4.5 Release constraints when they are no longer necessary

When a driver no longer needs to prohibit specific power transitions, it must release the corresponding constraints it declared with Power_setConstraint(). For example, when the driver no longer needs to inhibit LPDS, it calls:

```
Power_releaseConstraint(PowerCC32XX_DISALLOW_LPDS);
```

It is critical that drivers use constraints only when necessary, and release the constraints as soon as possible.

The Power Manager uses reference counting for constraints, so it is critical that your driver call Power_setConstraint() and Power_releaseConstraint() in matched pairs.

5.4.6 Call Power_releaseDependency() when peripheral access is no longer needed

When a driver no longer requires access to a peripheral it should "release" the peripheral by calling Power_releaseDependency(), specifying the peripheral's resource ID. For example, in the driver's "close" function:

```
Power_releaseDependency(PowerCC32XX_PERIPH_DTHE);
```

This call disables peripheral clocks, and if appropriate, powers OFF the corresponding power domain. It is critical that your driver release its dependencies dynamically, to allow the Power Manager to enact aggressive power savings.

The Power Manager uses reference counting of all Power_setDependency() and Power_releaseDependency() calls for each resource. It is critical that your driver call Power_setDependency() and Power_releaseDependency() in matched pairs.

5.4.7 Un-register for event notifications with Power_unregisterNotify()

If a driver is closing or otherwise no longer needs notifications, it must un-register its callback with the Power Manager using the Power_unregisterNotify() API. Otherwise, notifications may be sent to the closed driver. For example, to un-register for the events that were previously specified for notifyObj:

```
Power_unregisterNotify(&notifyObj);
```

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