nRF52 Power Management

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Overview

The nRF52 Power Management module provides battery protection features to prevent over-discharge, minimise likelihood of brownout and flash corruption conditions existing, and enable safe voltage-based recovery.

Features

Boot Voltage Protection

- Checks battery voltage immediately after boot and before mesh operations commence
- If voltage is below a configurable threshold (e.g., 3300mV), the device configures voltage wake (LPCOMP + VBUS) and enters protective shutdown (SYSTEMOFF)
- Prevents boot loops when battery is critically low
- Skipped when external power (USB VBUS) is detected

Voltage Wake (LPCOMP + VBUS)

- Configures the nRF52's Low Power Comparator (LPCOMP) before entering SYSTEMOFF
- Enables USB VBUS detection so external power can wake the device
- Device automatically wakes when battery voltage rises above recovery threshold or when VBUS is detected

Early Boot Register Capture

- Captures RESETREAS (reset reason) and GPREGRET2 (shutdown reason) before SystemInit() clears them
- Allows firmware to determine why it booted (cold boot, watchdog, LPCOMP wake, etc.)
- Allows firmware to determine why it last shut down (user request, low voltage, boot protection)

Shutdown Reason Tracking

Shutdown reason codes (stored in GPREGRET2):

Code	Name	Description
0x00	NONE	Normal boot / no previous shutdown
0x4C	LOW_VOLTAGE	Runtime low voltage threshold reached
0x55	USER	User requested powerOff()
0x42	BOOT_PROTECT	Boot voltage protection triggered

Supported Boards

Board	Implemented	LPCOMP wake	VBUS wake
Seeed Studio XIAO nRF52840 (`xiao_nrf52`)	Yes	Yes	Yes
RAK4631 (`rak4631`)	Yes	Yes	Yes
Heltec T114 (`heltec_t114`)	Yes	Yes	Yes
Promicro nRF52840	No	No	No
RAK WisMesh Tag	No	No	No
Heltec Mesh Solar	No	No	No
LilyGo T-Echo / T-Echo Lite	No	No	No
SenseCAP Solar	Yes	Yes	Yes
WIO Tracker L1 / L1 E-Ink	No	No	No
WIO WM1110	No	No	No
Mesh Pocket	No	No	No
Nano G2 Ultra	No	No	No
ThinkNode M1/M3/M6	No	No	No
T1000-E	No	No	No
Ikoka Nano/Stick/Handheld (nRF)	No	No	No
Keepteen LT1	No	No	No
Minewsemi ME25LS01	No	No	No

Notes:

- "Implemented" reflects Phase 1 (boot lockout + shutdown reason capture).
- User power-off on Heltec T114 does not enable LPCOMP wake.

- VBUS detection is used to skip boot lockout on external power, and VBUS wake is configured alongside LPCOMP when supported hardware exposes VBUS to the nRF52.

Technical Details

Architecture

The power management functionality is integrated into the `NRF52Board` base class in `src/helpers/NRF52Board.cpp`. Board variants provide hardware-specific configuration via a `PowerMgtConfig` struct and override `initiateShutdown(uint8_t reason)` to perform board-specific power-down work and conditionally enable voltage wake (LPCOMP + VBUS).

Early Boot Capture

A static constructor with priority 101 in `NRF52Board.cpp` captures the RESETREAS and GPREGRET2 registers before:

- SystemInit() (priority 102) - which clears RESETREAS
- Static C++ constructors (default priority 65535)

This ensures we capture the true reset reason before any initialisation code runs.

Board Implementation

To enable power management on a board variant:

1. **Enable in platformio.ini**:

```ini

-D NRF52_POWER_MANAGEMENT

```

1. **Define configuration in variant.h**:

```c

#define PWRMGT_VOLTAGE_BOOTLOCK 3300 // Won't boot below this voltage (mV)

#define PWRMGT_LPCOMP_AIN 7 // AIN channel for voltage sensing

#define PWRMGT_LPCOMP_REFSEL 2 // REFSEL (0-6=1/8..7/8, 7=ARef, 8-15=1/16..15/16)

```

1. **Implement in board .cpp file**:

```cpp
#ifdef NRF52_POWER_MANAGEMENT
const PowerMgtConfig power_config = {
.lpcomp_ain_channel = PWRMGT_LPCOMP_AIN,
.lpcomp_refsel = PWRMGT_LPCOMP_REFSEL,
.voltage_bootlock = PWRMGT_VOLTAGE_BOOTLOCK
};
void MyBoard::initiateShutdown(uint8_t reason) {
// Board-specific shutdown preparation (e.g., disable peripherals)
bool enable_lpcomp = (reason == SHUTDOWN_REASON_LOW_VOLTAGE ||
reason == SHUTDOWN_REASON_BOOT_PROTECT);
if (enable_lpcomp) {
configureVoltageWake(power_config.lpcomp_ain_channel, power_config.lpcomp_refsel);
}
enterSystemOff(reason);
}
#endif
void MyBoard::begin() {
NRF52Board::begin(); // or NRF52BoardDCDC::begin()
// ... board setup ...
#ifdef NRF52_POWER_MANAGEMENT
checkBootVoltage(&power_config);
#endif
```

}

```

For user-initiated shutdowns, `powerOff()` remains board-specific. Power management only arms LPCOMP for automated shutdown reasons (boot protection/low voltage).

1. **Declare override in board .h file**:

```cpp

#ifdef NRF52_POWER_MANAGEMENT

void initiateShutdown(uint8_t reason) override;

#endif

```

Voltage Wake Configuration

The LPCOMP (Low Power Comparator) is configured to:

- Monitor the specified AIN channel (0-7 corresponding to P0.02-P0.05, P0.28-P0.31)
- Compare against VDD fraction reference (REFSEL: 0-6=1/8..7/8, 7=ARef, 8-15=1/16..15/16)
- Detect UP events (voltage rising above threshold)
- Use 50mV hysteresis for noise immunity
- Wake the device from SYSTEMOFF when triggered

VBUS wake is enabled via the POWER peripheral USBDETECTED event whenever `configureVoltageWake()` is used. This requires USB VBUS to be routed to the nRF52 (typical on nRF52840 boards with native USB).

LPCOMP Reference Selection (PWRMGT_LPCOMP_REFSEL):

REFSEL	Fraction	VBAT @ 1M/1M divider (VDD=3.0-3.3)	VBAT @ 1.5M/1M divider (VDD=3.0-3.3)
0	1/8	0.75-0.82 V	0.94-1.03 V
1	2/8	1.50-1.65 V	1.88-2.06 V
2	3/8	2.25-2.47 V	2.81-3.09 V
3	4/8	3.00-3.30 V	3.75-4.12 V
4	5/8	3.75-4.12 V	4.69-5.16 V
5	6/8	4.50-4.95 V	5.62-6.19 V
```

REFSEL	Fraction	VBAT @ 1M/1M divider (VDD=3.0-3.3)	VBAT @ 1.5M/1M divider (VDD=3.0-3.3)
6	7/8	5.25-5.77 V	6.56-7.22 V
7	ARef	-	-
8	1/16	0.38-0.41 V	0.47-0.52 V
9	3/16	1.12-1.24 V	1.41-1.55 V
10	5/16	1.88-2.06 V	2.34-2.58 V
11	7/16	2.62-2.89 V	3.28-3.61 V
12	9/16	3.38-3.71 V	4.22-4.64 V
13	11/16	4.12-4.54 V	5.16-5.67 V
14	13/16	4.88-5.36 V	6.09-6.70 V
15	15/16	5.62-6.19 V	7.03-7.73 V

Important: For boards with a voltage divider on the battery sense pin, LPCOMP measures the divided voltage. Use:

`VBAT_threshold ≈ (VDD * fraction) * divider_scale`, where `divider_scale = (Rtop + Rbottom) / Rbottom` (e.g., 2.0 for 1M/1M, 2.5 for 1.5M/1M, 3.0 for XIAO).

SoftDevice Compatibility

The power management code checks whether SoftDevice is enabled and uses the appropriate API:

- When SD enabled: `sd_power_*` functions
- When SD disabled: Direct register access (NRF_POWER->*)

This ensures compatibility regardless of BLE stack state.

CLI Commands

Power management status can be queried via the CLI:

Command	Description
`get pwrmgt.support`	Returns "supported" or "unsupported"
`get pwrmgt.source`	Returns current power source - "battery" or "external" (5V/USB power)
`get pwrmgt.bootreason`	Returns reset and shutdown reason strings
`get pwrmgt.bootmv`	Returns boot voltage in millivolts

On boards without power management enabled, all commands except `get pwrmgt.support` return:

```
ERROR: Power management not supported
```

Debug Output

When `MESH_DEBUG=1` is enabled, the power management module outputs:

```
DEBUG: PWRMGT: Reset = Wake from LPCOMP (0x20000); Shutdown = Low Voltage (0x4C)
DEBUG: PWRMGT: Boot voltage = 3450 mV (threshold = 3300 mV)
DEBUG: PWRMGT: LPCOMP wake configured (AIN7, ref=3/8 VDD)
```

Phase 2 (Planned)

- Runtime voltage monitoring
- Voltage state machine (Normal -> Warning -> Critical -> Shutdown)
- Configurable thresholds
- Load shedding callbacks for power reduction
- Deep sleep integration
- Scheduled wake-up
- Extended sleep with periodic monitoring

References

- nRF52840 Product Specification - POWER
- nRF52840 Product Specification - LPCOMP
- SoftDevice S140 API - Power Management

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