STM32가 제안하는 초저전력 IoT 어플리케이션 구현하기

STMicroelectronics Korea - MMS

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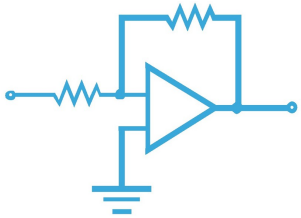
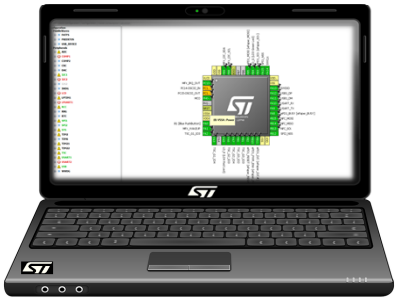
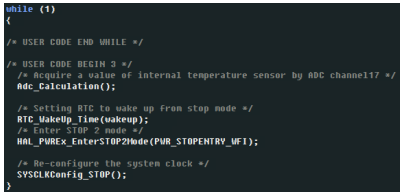
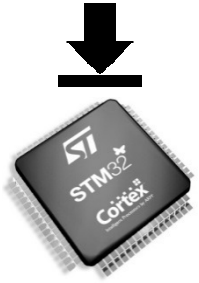
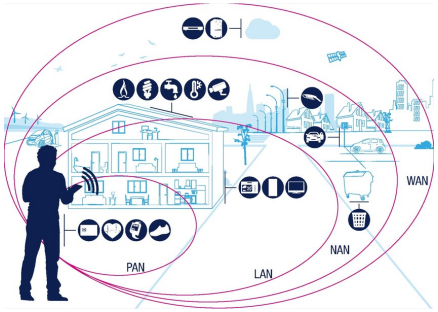
IoT Application design process

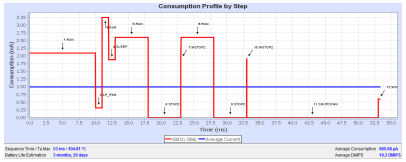












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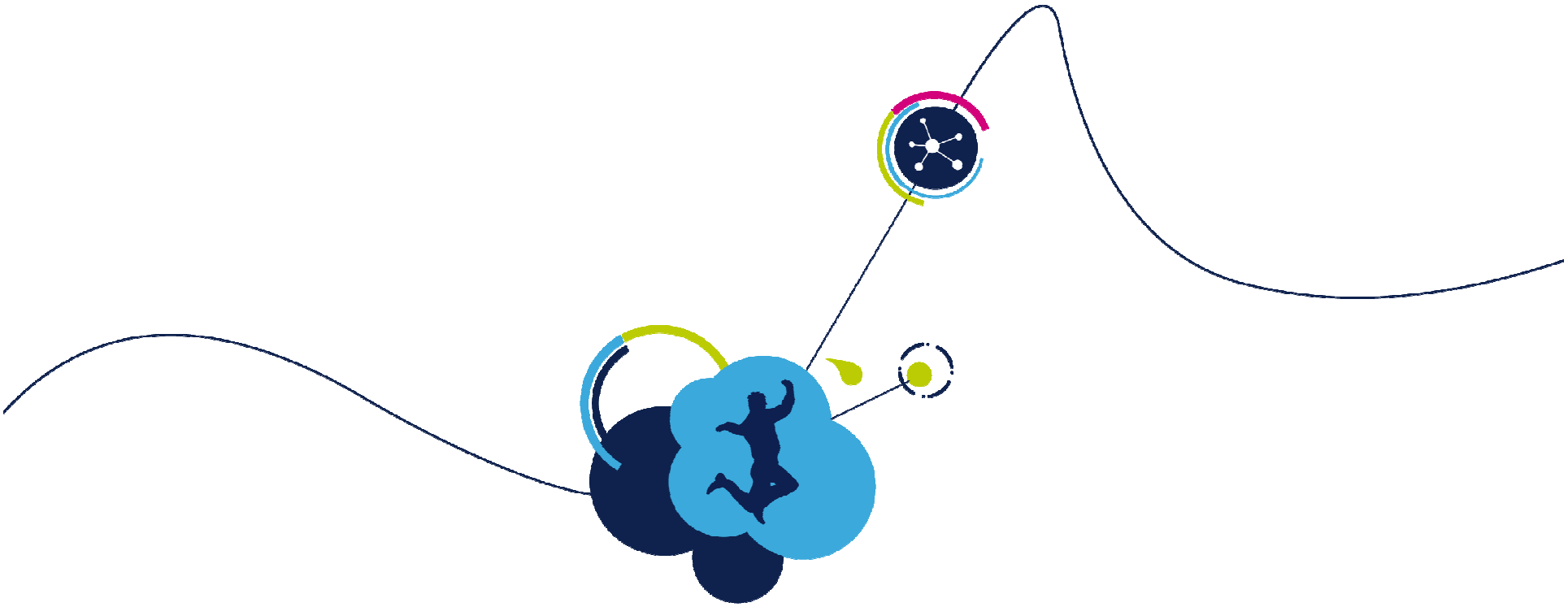

Ultra Low Power MCU Families

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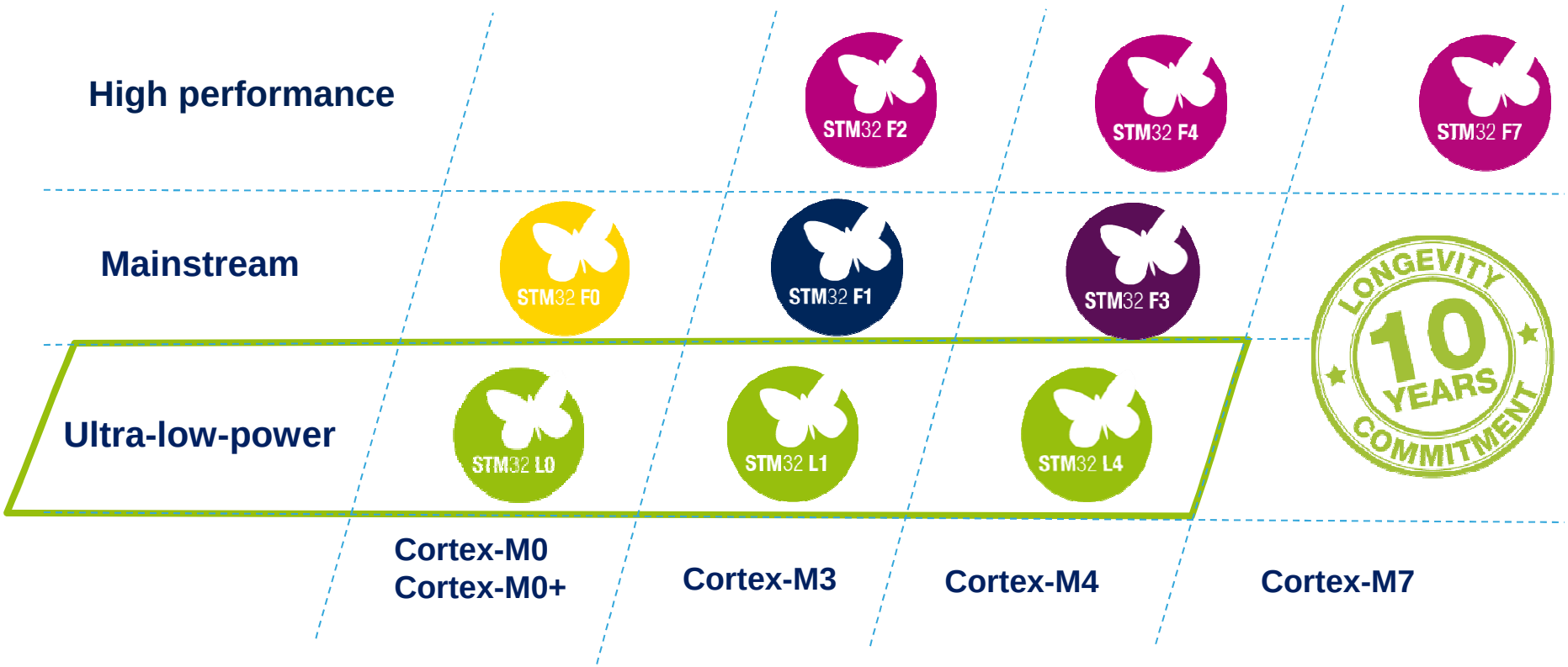
Great Investment

9 product series / 32 product lines / 600 P/N



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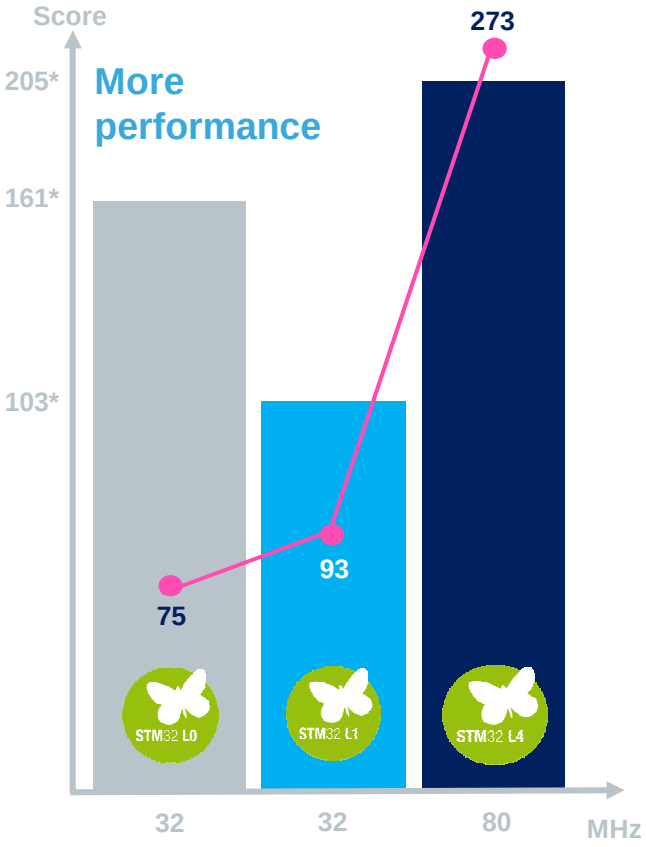
STM32L ULP offer

Completed the ultra-low-power family



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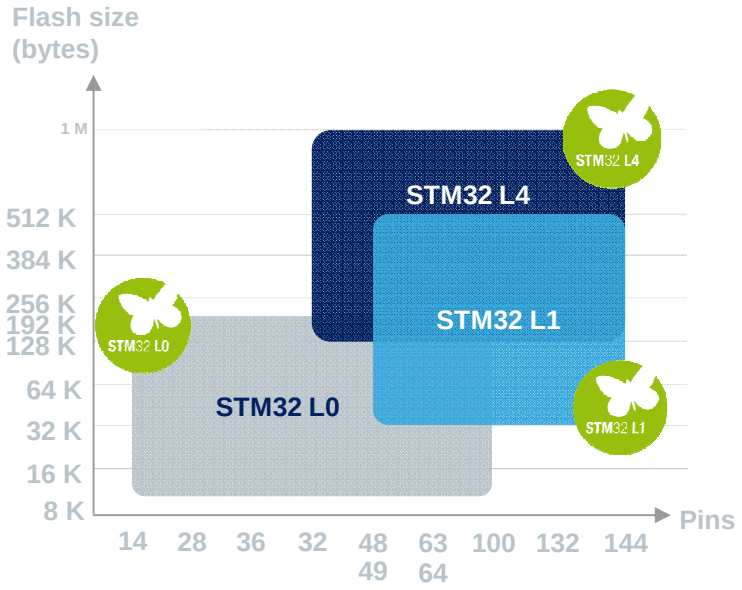
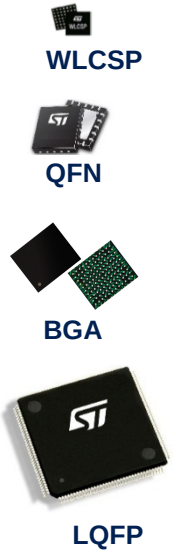
More memory and pin counts



More packages



STM32L ULP offer

Completed the ultra-low-power family

Cost-smart ULP Champion

Cortex-M0+ @ 32 MHz
Operating range:
1.65 to 3.6V
8/16-bit applications
Numerous pin counts

3 product lines,
Cost-effective,
Smaller packages
USB, LCD, Analog
16 to 192 Kbytes of Flash
Up to 20 Kbytes of SRAM

Broad Range Foundation

Cortex-M3 @ 32 MHz
Operating range:
1.65 to 3.6V
Wide choice of memory sizes

3 product lines,
USB, LCD, AES,
Rich Analog
True EEPROM,
Dual bank Flash (RWW)
32 to 512 Kbytes of Flash
Up to 80 Kbytes of SRAM

ULP with performance

Cortex-M4 w/ FPU @ 80 MHz
Operating range:
1.71 to 3.6V
Advanced Peripheral Performance

3 product lines,
ADC 5 Msps, PGA, Compar.,
DAC, op amp, USB OTG,
LCD, AES
256 Kbytes to 1 Mbyte of Flash
Up to 128 Kbytes of SRAM

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STM32L1 – Market proven solution

STM32L1 Product lines

Cortex®-M3 (32 MHz with MPU)

- Low voltage 1.65 to 3.6V
- Dynamic voltage scaling
- 5 clock sources
- Advanced RTC w/ cal.
- Multiple USART, SPI, I²C
- 16- and 32-bit timers
- - 40 to 85 °C oper. temp. Up to 105 °C in LP Modes
- 2 watchdogs
- Brown-out Reset
- Programmable voltage detector (PVD)
- DMA
- Reset circuitry POR/PDR
- 12-bit ADC 1 MSPS
- 12-bit DAC

Product line	Flash memory (KB)	RAM (KB)	EEPROM (KB)	Memory I/F	Op amps	Comp.	Temp. sensor	Capacitive touch	Segment LCD driver	128-bit AES
STM32L100 Value line	32 to 256	4 to 16	2	-	-	-	-	-	Up to 8x28	-
STM32L151 STM32L152	32 to 512	16 to 80	4 to 16	SDIO FSMC	●	●	●	●	- Up to 8x40	-
STM32L162	256 to 512	32 to 80	8 to 16	SDIO FSMC	●	●	●	●	Up to 8x40	●

STM32L1 Ultra-low-power

- ARM® Cortex® -M3 at 32 MHz – 33 DMIPS
- Dynamic run mode: down to 177 µA/MHz
- Stop with Full RAM retention 435 nA (1.3 µA with RTC)
- Standby mode + RTC: 900 nA with backup registers
- Standby mode: 280 nA with backup registers
- Dual-bank Flash memory and True embedded EEPROM
- Operates at up to 105 °C

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STM32L0 – Entry level solution

STM32L0 Product lines

Cortex®-M0+ (32 MHz with MPU)

- Low voltage 1.65 to 3.6V
- Dynamic Voltage Scaling
- 5 clock sources
- Advanced RTC w/ calibration
- Multiple USART, SPI, I²C
- Multiple 16-bit timers
- - 40 to 125°C Operating
- 2 watchdogs
- Program Voltage Detector
- Reset circuitry POR/PDR
- Brown Out Reset
- DMA
- Comparators
- Temperature sensor
- AES 128-bit

Product line	FLASH (KB)	RAM (KB)	EEPROM (KB)	12-bit ADC 1.14 Msps	LP[1] UART	LP[1] 16-bit timer	12-bit DAC	Touch sense	True RNG	USB 2.0 FS Crystal-less	Segment LCD Driver
STM32L0x1 Access	Up to 192 (dual bank)	20	6 (rww)[2]	Down to 1,65V	•	•					
STM32L0x2 USB	Up to 192 (dual bank)	20	6 (rww)[2]	Down to 1,65V	•	•	Up to 2	•	•	•	
STM32L0x3 USB & LCD	Up to 192 (dual bank)	20	6 (rww)[2]	Down to 1,65V	•	•	Up to 2	•	•	•	Up to 8x48 Or 4x52

Note 1: Low-power peripherals available in ultra-low-power modes
Note 2 : Read while write from flash to EEPROM

STM32L0 Ultra-low-power

- ARM® Cortex® -M0+ at 32 MHz
- Dynamic run mode down to 87 µA/MHz
- Stop mode with RAM + LTC (low-power time clock): 440 nA
- Wakeup: 3.5 µs (RAM) / 5 µs (Flash memory)
- 12/16-bit ADC: 1 MSPS – 240 µA – 1.65 V capable
- Unique ID / 128-bit AES / Flash Proprietary Stack protection
- Operates at up to 125 °C

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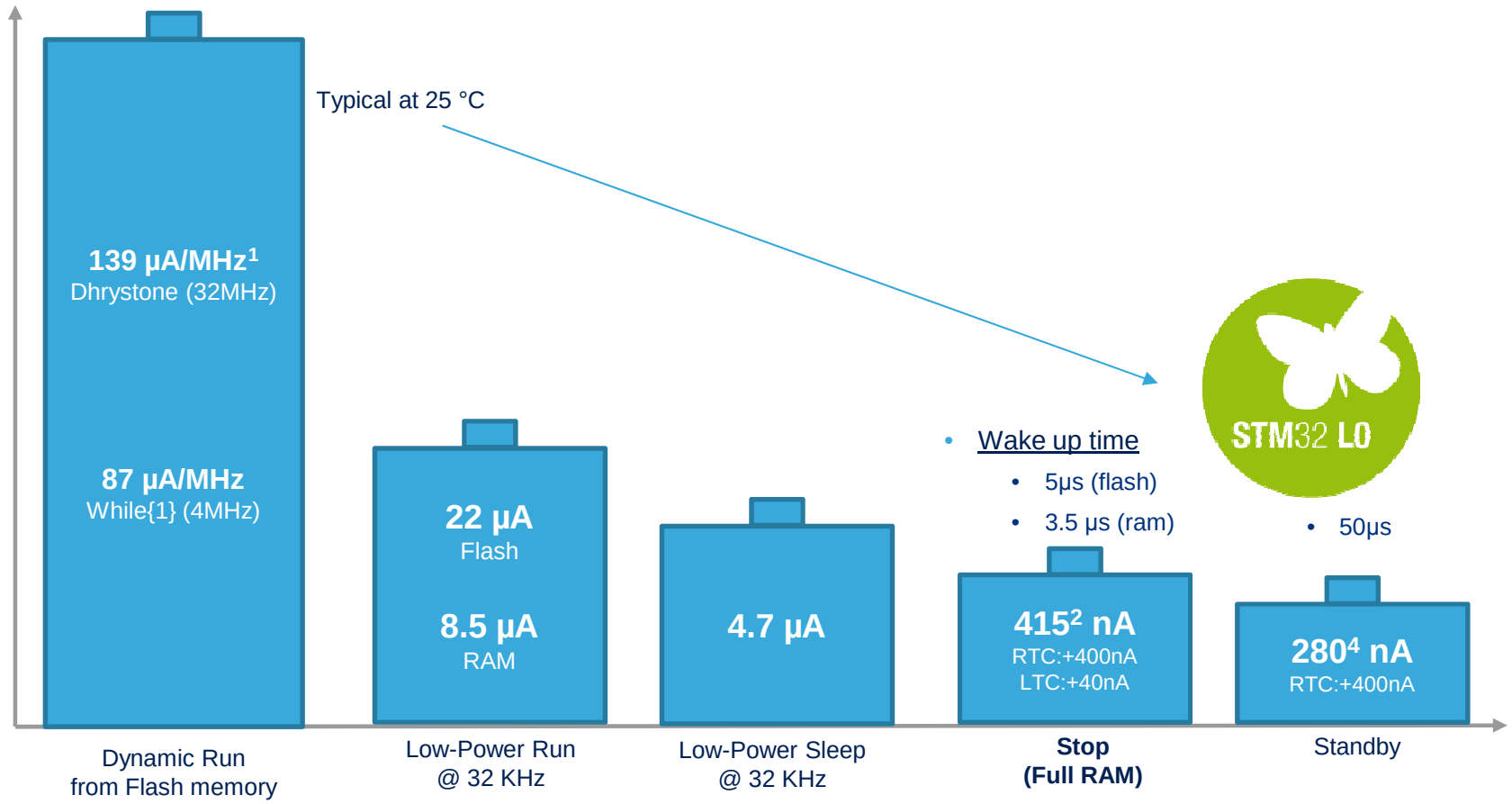
STM32L05* - power consumption



1. Dhrystone power consumption value executed from Flash (Prefetch off) with VDD=3.3V
2. STOP mode consumption with **Full Ram data retention** (RTC value given with LSE low-drive using 32,768kHz crystal)
3. LTC**:** Low-power Time Counter @ 100Hz with external oscillator (LSE)
4. STANDBY mode consumption with **20Byte of backup register and Power supply monitoring**

STM32L4 – Performance solution

STM32L4 Product lines

Cortex®-M4 (DSP + FPU) – 80 MHz

- ART Accelerator™
- USART, SPI, I²C
- QuadSPI
- 16- and 32-bit timers
- SAI + audio PLL
- SWP
- 1x CAN
- 2x 12-bit DAC
- Temperature sensor
- Low voltage 1.71 to 3.6 V
- V_{BAT} mode
- Unique ID
- Capacitive touch sensing

Product line	Flash memory (KB)	RAM (KB)	Memory I/F	2 x Op amps	2 x Comp.	4x / 8ch Sigma Delta Interface	5 MSPS, 12- bit ADC 16-bit HW over sampling	USB 2.0 OTG FS	Segment LCD Driver	128/ 256-bit AES
STM32L471 Access	512 to 1024	128	SDIO FSMC	●	●	●	3			
STM32L475 USB OTG	256 to 1024	128	SDIO FSMC	●	●	●	3	●		
STM32L476 USB OTG & LCD	256 to 1024	128	SDIO FSMC	●	●	●	3	●	Up to 8x40	
STM32L486 USB OTG & LCD & AES	1024	128	SDIO FSMC	●	●	●	3	●	Up to 8x40	●

STM32L4 Ultra-low-power

- ARM® Cortex® -M4 at 80 MHz with DSP + FPU – 100 DMIPS
- Dynamic run mode at 100 µA/MHz
- Down to 600 nA with 32 kHz RTC + 32 Kbytes of RAM + I/Os
- Down to 265 nA with 32 kHz RTC or 44 nA without RTC
- 12/16-bit ADC with 5 MSPS – 240 µA – 1.65 V capable
- Operates at up to 125 °C

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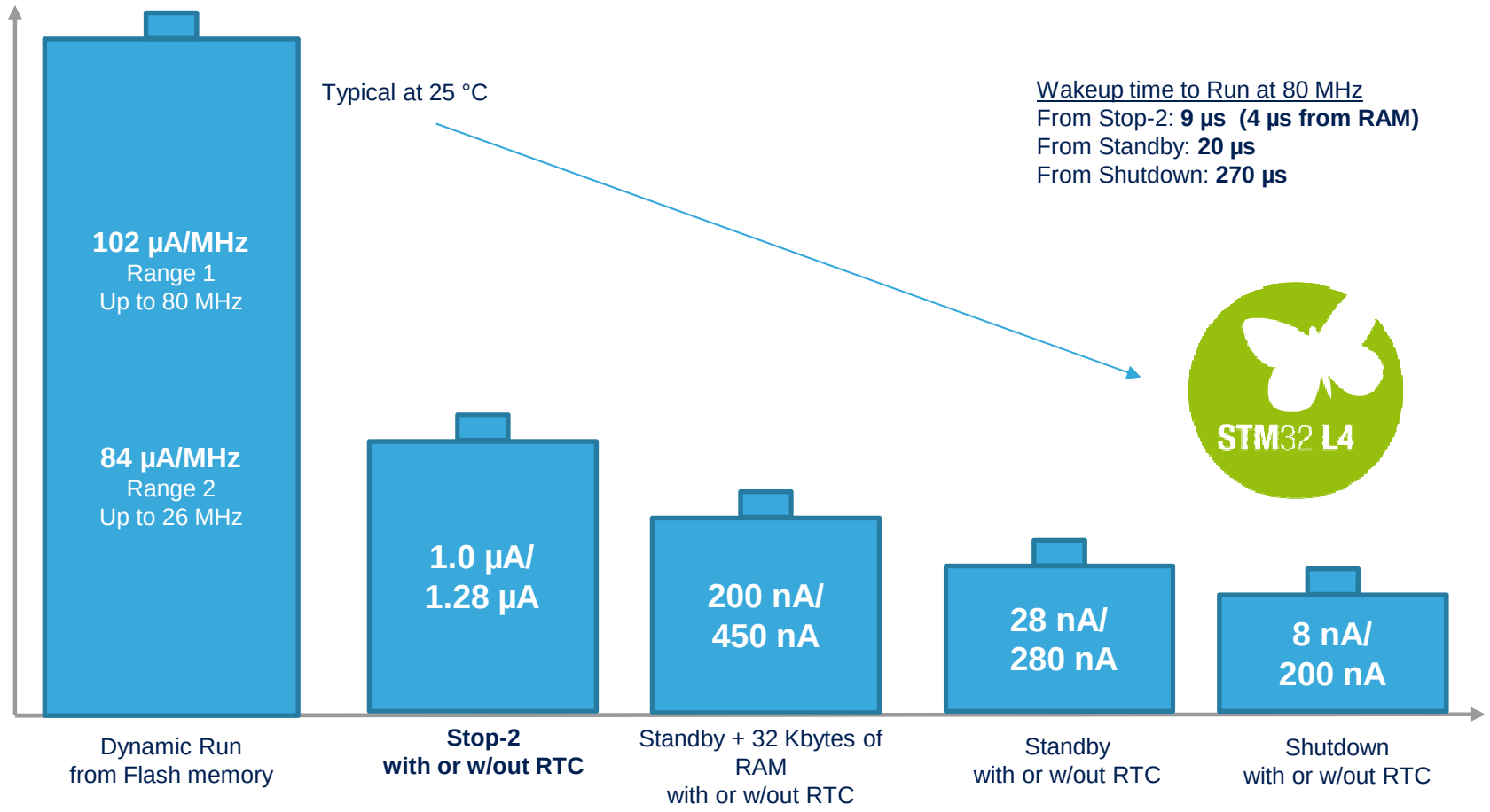
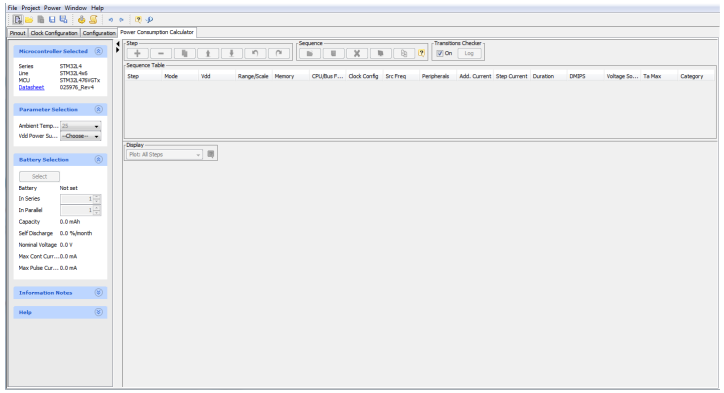
STM32L4 - power consumption



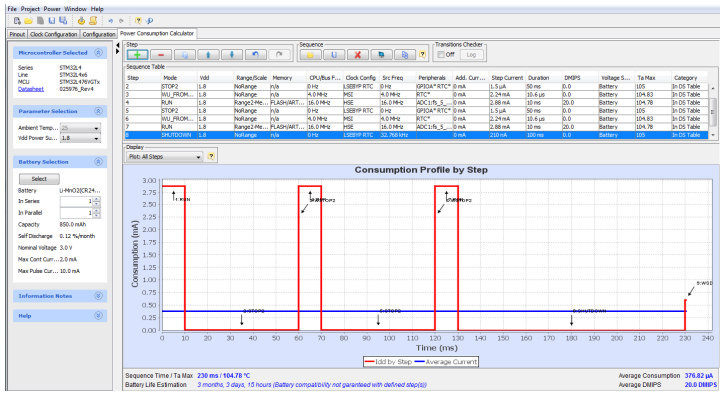
Ecosystem – STM32CubeMX

Power Consumption Calculator

- STM32CubeMX offers the Power Consumption Calculator tab, which, given a microcontroller, a battery model and a user-defined power sequence.



- Provides the following results :
  - Average current consumption
  - Battery life
  - Average DMIPs
  - Max. ambient temperature(T_{AMAX})



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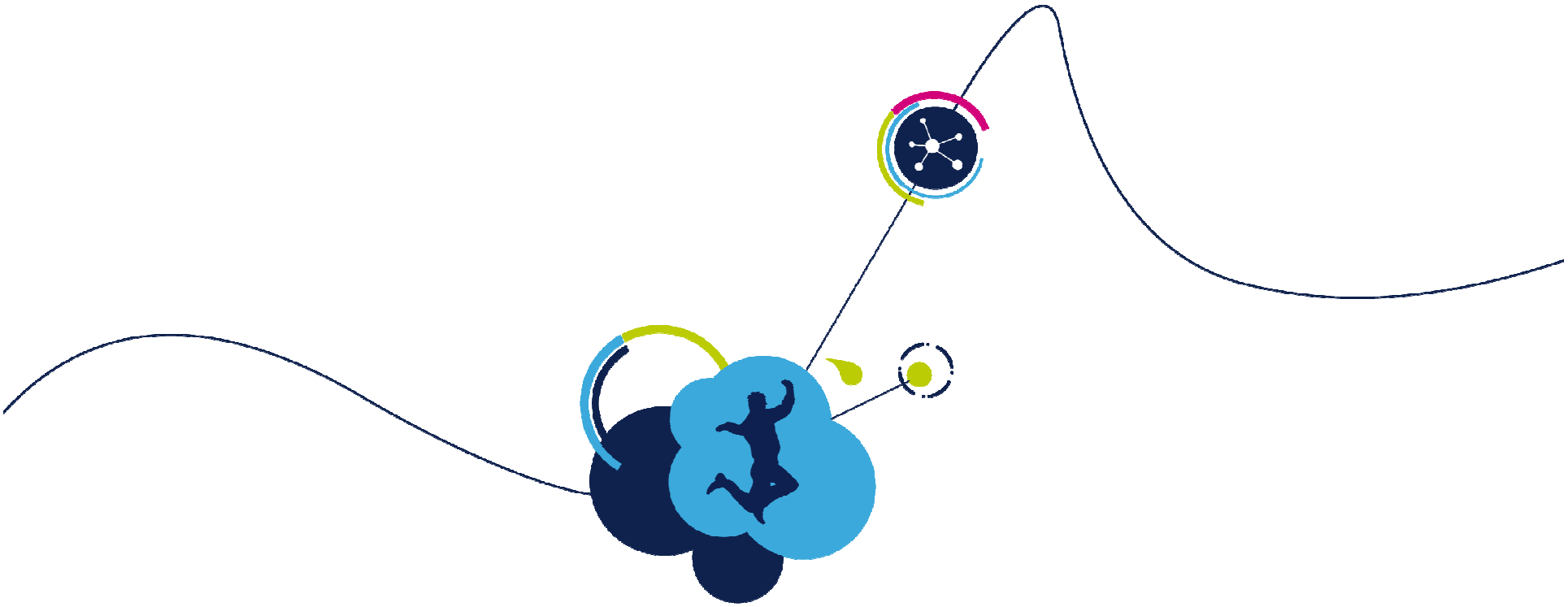

Power Management

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STM32 Low Power modes

- The STM32 features a variety of low power modes
  - LPRUN
  - SLEEP and LPSLEEP
  - STOP
  - STANDBY
  - SHUTDOWN

- STM32F4 vs STM32L0 vs STM32L4 : Low power modes

Low Power Mode	STM32F4	STM32L0	STM32L4
	-	LPRUN	LPRUN
	SLEEP	SLEEP	SLEEP
	-	LPSLEEP	LPSLEEP
	STOP	STOP	STOP0
			STOP1
			STOP2
	STANDBY	STANDBY	STANDBY
	-	-	SHUTDOWN
	VBAT	-	VBAT

STM32L4 Low Power modes

STM32L4 low power modes summary

Mode	Regulator	CPU	Flash	SRAM	Clocks	Peripherals In Bold : wakeup source
Run	R1 R2	Yes	ON(1)	ON	Any	All
LPRun	LPR	Yes	ON(1)	ON	Any *except PLL*	All except OTG, SDMMC, RNG
Sleep	R1 R2	No	ON(1)	ON(2)	Any	All **Any IT or event**
LPSleep	LPR	No	ON(1)	ON(2)	Any *except PLL*	All except OTG, SDMMC, RNG **Any IT or event**
Stop 0	R1 R2	No	OFF	ON	LSE/LSI	**Reset pin, all I/Os BOR,PVD,PVM,RTC,LCD,IWDG, COMPx,DACx,OPAMPx,USARTx, LPUART,I2Cx,LPTIMx,OTG_FS, SWPMI**
Stop 1	LPR	No	OFF	ON	LSE/LSI	**Reset pin, all I/Os BOR,PVD,PVM,RTC,LCD,IWDG, COMPx,DACx,OPAMPx,USARTx, LPUART,I2Cx,LPTIMx,OTG_FS, SWPMI**
Stop 2	LPR	No	OFF	ON	LSE/LSI	**Reset pin, all I/Os BOR,PVD,PVM,RTC,LCD,IWDG, COMPx,LPUART,I2C3,LPTIM1**
Standby	LPR OFF	DOWN	OFF	SRAM2 ON DOWN	LSE/LSI	**Reset pin, 5 WKUPx pins BOR, RTC, IWDG**
Shutdown	OFF	DOWN	OFF	DOWN	LSE	**Reset pin, 5 WKUPx pins RTC**

1. Can be put in power-down and clock can be gated off
2. SRAM can be gated off independently

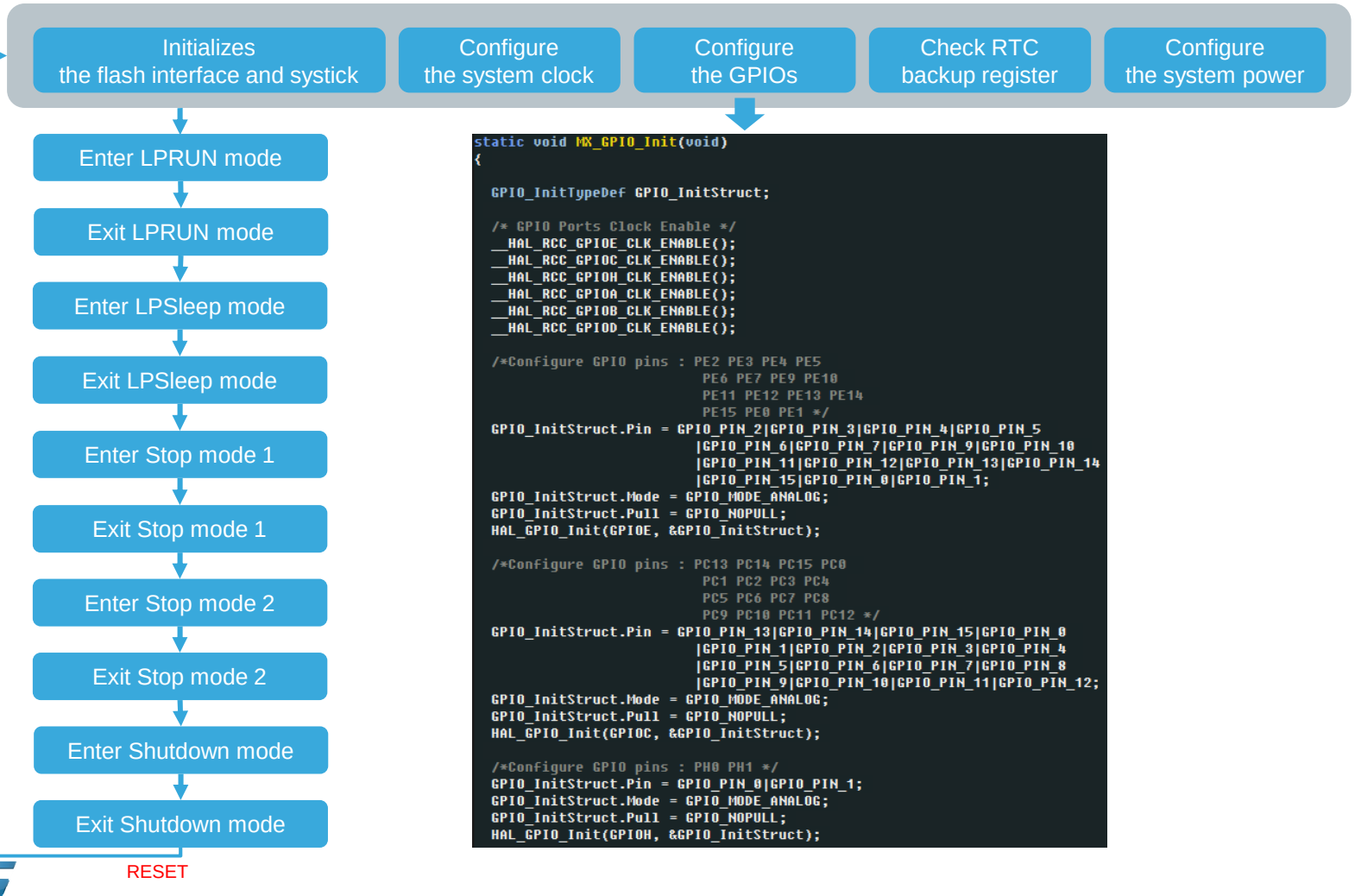
Implementation of Low Power Mode

How to initialize STM32L4


```
void SystemClock_Config(void)
{

  RCC_OscInitTypeDef RCC_OscInitStruct;
  RCC_ClkInitTypeDef RCC_ClkInitStruct;

    /**Initializes the CPU, AHB and APB busses clocks
    */
  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_MSI;
  RCC_OscInitStruct.MSIState = RCC_MSI_ON;
  RCC_OscInitStruct.MSICalibrationValue = 0;
  RCC_OscInitStruct.MSIClockRange = RCC_MSIRANGE_8;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_NONE;
  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
  {
    Error_Handler();
  }

    /**Initializes the CPU, AHB and APB busses clocks
    */
  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_HCLK|RCC_CLOCKTYPE_SYSCLK
                              |RCC_CLOCKTYPE_PCLK1|RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_MSI;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV16;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV16;

  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_0) != HAL_OK)
  {
    Error_Handler();
  }

    /**Configure the main internal regulator output voltage
    */
  if (HAL_PWREx_ControlVoltageScaling(PWR_REGULATOR_VOLTAGE_SCALE1) != HAL_OK)
  {
    Error_Handler();
  }
```

Implementation of Low Power Mode

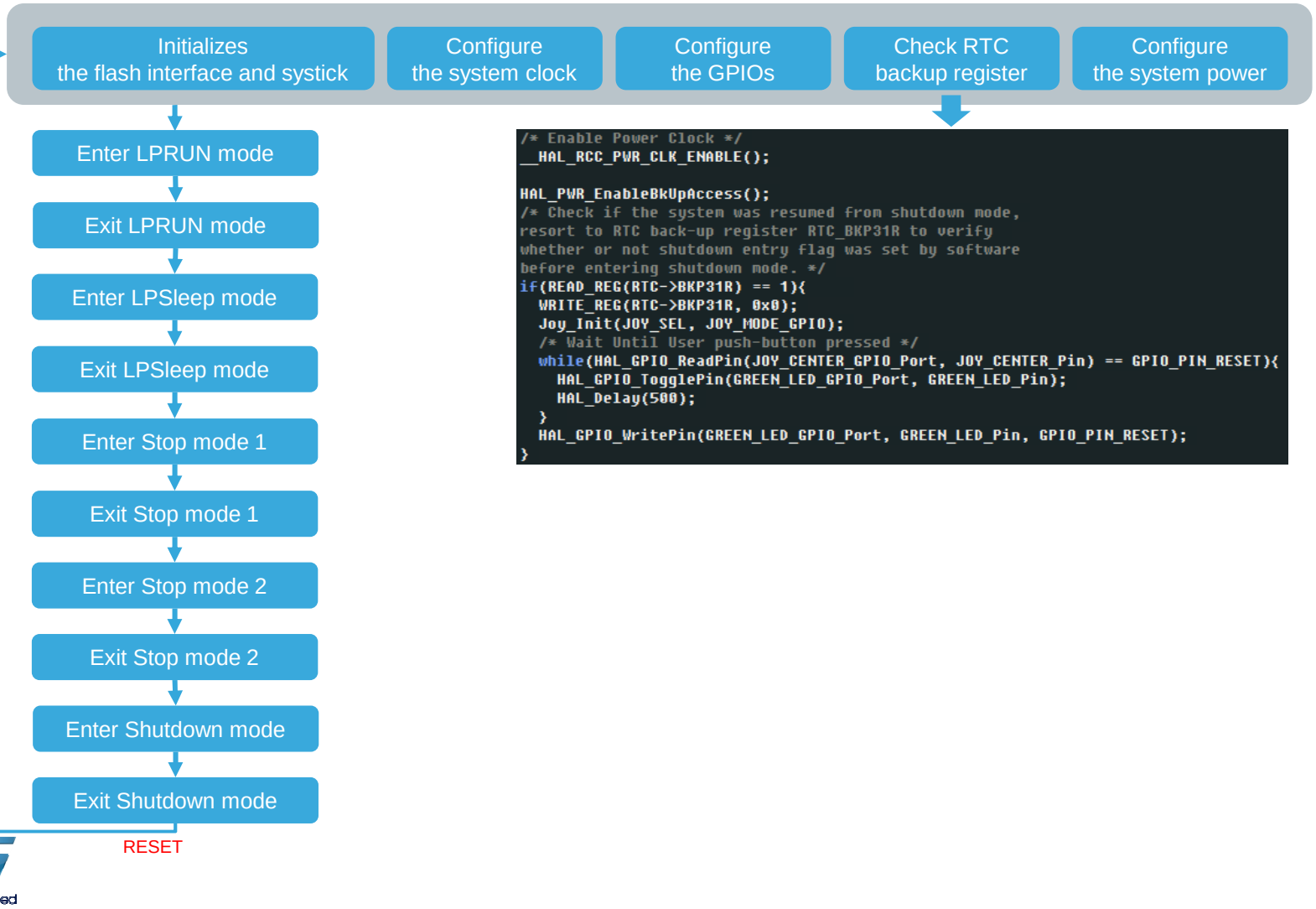
How to initialize STM32L4




```
static void MX_GPIO_Init(void)
{

  GPIO_InitTypeDef GPIO_InitStruct;

  /* GPIO Ports Clock Enable */
  __HAL_RCC_GPIOE_CLK_ENABLE();
  __HAL_RCC_GPIOC_CLK_ENABLE();
  __HAL_RCC_GPIOH_CLK_ENABLE();
  __HAL_RCC_GPIOA_CLK_ENABLE();
  __HAL_RCC_GPIOB_CLK_ENABLE();
  __HAL_RCC_GPIOD_CLK_ENABLE();

  /*Configure GPIO pins : PE2 PE3 PE4 PE5
                           PE6 PE7 PE9 PE10
                           PE11 PE12 PE13 PE14
                           PE15 PE0 PE1 */
  GPIO_InitStruct.Pin = GPIO_PIN_2|GPIO_PIN_3|GPIO_PIN_4|GPIO_PIN_5
                        |GPIO_PIN_6|GPIO_PIN_7|GPIO_PIN_9|GPIO_PIN_10
                        |GPIO_PIN_11|GPIO_PIN_12|GPIO_PIN_13|GPIO_PIN_14
                        |GPIO_PIN_15|GPIO_PIN_0|GPIO_PIN_1;
  GPIO_InitStruct.Mode = GPIO_MODE_ANALOG;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOE, &GPIO_InitStruct);

  /*Configure GPIO pins : PC13 PC14 PC15 PC0
                           PC1 PC2 PC3 PC4
                           PC5 PC6 PC7 PC8
                           PC9 PC10 PC11 PC12 */
  GPIO_InitStruct.Pin = GPIO_PIN_13|GPIO_PIN_14|GPIO_PIN_15|GPIO_PIN_0
                        |GPIO_PIN_1|GPIO_PIN_2|GPIO_PIN_3|GPIO_PIN_4
                        |GPIO_PIN_5|GPIO_PIN_6|GPIO_PIN_7|GPIO_PIN_8
                        |GPIO_PIN_9|GPIO_PIN_10|GPIO_PIN_11|GPIO_PIN_12;
  GPIO_InitStruct.Mode = GPIO_MODE_ANALOG;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOC, &GPIO_InitStruct);

  /*Configure GPIO pins : PH0 PH1 */
  GPIO_InitStruct.Pin = GPIO_PIN_0|GPIO_PIN_1;
  GPIO_InitStruct.Mode = GPIO_MODE_ANALOG;
  GPIO_InitStruct.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOH, &GPIO_InitStruct);
```

Implementation of Low Power Mode

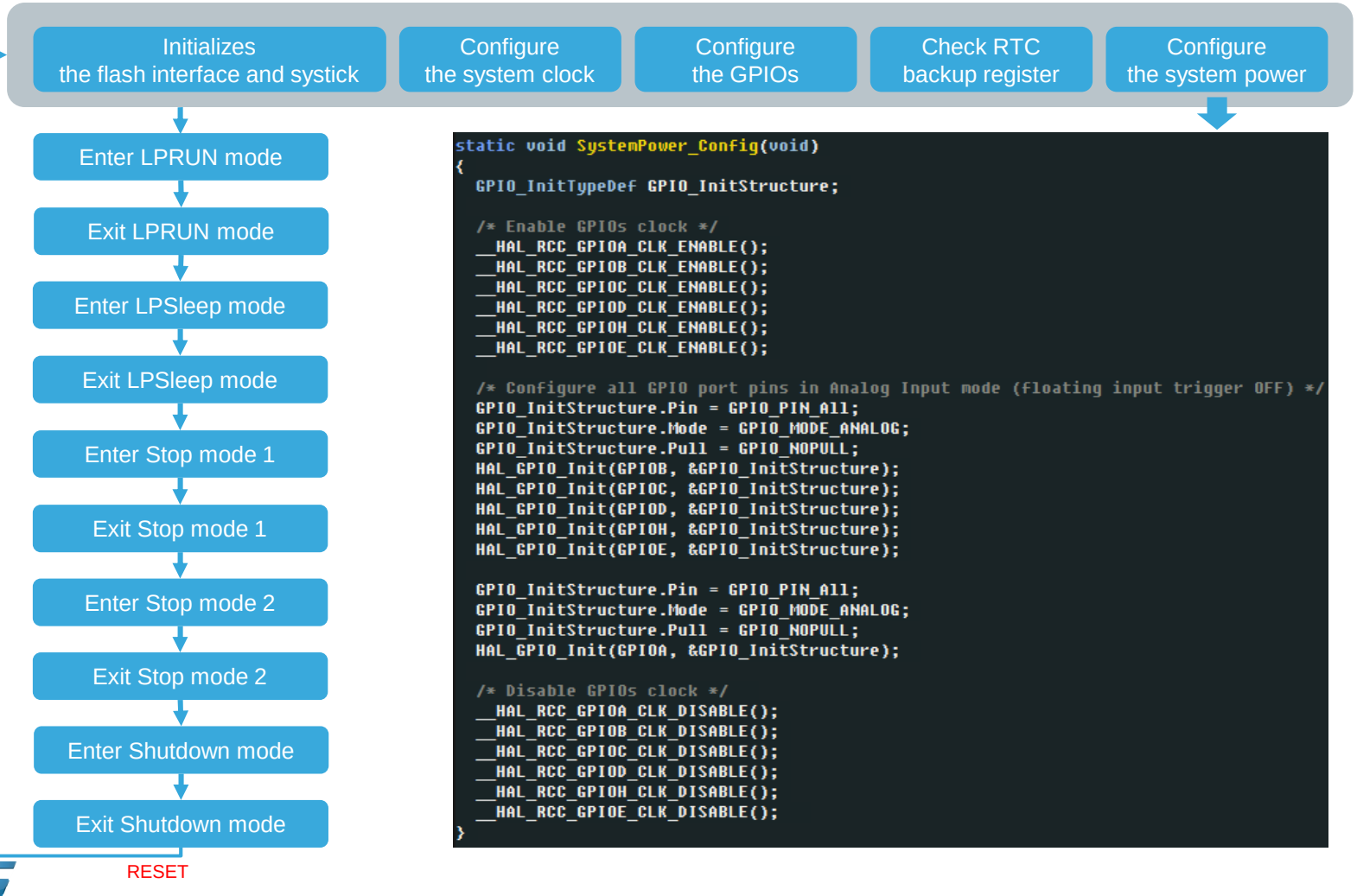
How to initialize STM32L4




```
/* Enable Power Clock */
__HAL_RCC_PWR_CLK_ENABLE();

HAL_PWR_EnableBkUpAccess();
/* Check if the system was resumed from shutdown mode,
resort to RTC back-up register RTC_BKP31R to verify
whether or not shutdown entry flag was set by software
before entering shutdown mode. */
if(READ_REG(RTC->BKP31R) == 1){
  WRITE_REG(RTC->BKP31R, 0x0);
  Joy_Init(JOY_SEL, JOY_MODE_GPIO);
  /* Wait Until User push-button pressed */
  while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET){
    HAL_GPIO_TogglePin(GREEN_LED_GPIO_Port, GREEN_LED_Pin);
    HAL_Delay(500);
  }
  HAL_GPIO_WritePin(GREEN_LED_GPIO_Port, GREEN_LED_Pin, GPIO_PIN_RESET);
}
```

Implementation of Low Power Mode

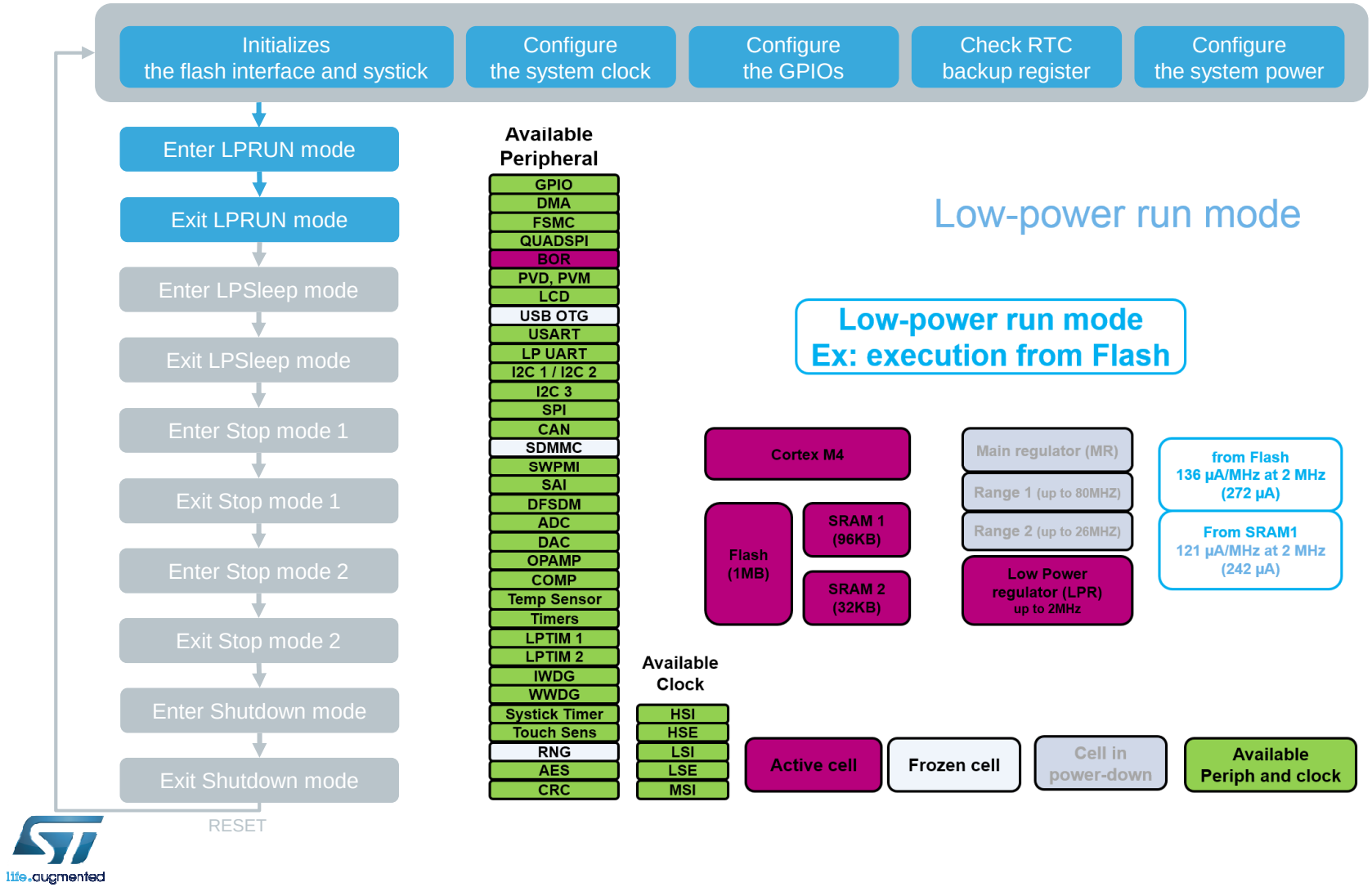
How to initialize STM32L4




```
static void SystemPower_Config(void)
{
  GPIO_InitTypeDef GPIO_InitStructure;

  /* Enable GPIOs clock */
  __HAL_RCC_GPIOA_CLK_ENABLE();
  __HAL_RCC_GPIOB_CLK_ENABLE();
  __HAL_RCC_GPIOC_CLK_ENABLE();
  __HAL_RCC_GPIOD_CLK_ENABLE();
  __HAL_RCC_GPIOH_CLK_ENABLE();
  __HAL_RCC_GPIOE_CLK_ENABLE();

  /* Configure all GPIO port pins in Analog Input mode (floating input trigger OFF) */
  GPIO_InitStructure.Pin = GPIO_PIN_All;
  GPIO_InitStructure.Mode = GPIO_MODE_ANALOG;
  GPIO_InitStructure.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOB, &GPIO_InitStructure);
  HAL_GPIO_Init(GPIOC, &GPIO_InitStructure);
  HAL_GPIO_Init(GPIOD, &GPIO_InitStructure);
  HAL_GPIO_Init(GPIOH, &GPIO_InitStructure);
  HAL_GPIO_Init(GPIOE, &GPIO_InitStructure);

  GPIO_InitStructure.Pin = GPIO_PIN_All;
  GPIO_InitStructure.Mode = GPIO_MODE_ANALOG;
  GPIO_InitStructure.Pull = GPIO_NOPULL;
  HAL_GPIO_Init(GPIOA, &GPIO_InitStructure);

  /* Disable GPIOs clock */
  __HAL_RCC_GPIOA_CLK_DISABLE();
  __HAL_RCC_GPIOB_CLK_DISABLE();
  __HAL_RCC_GPIOC_CLK_DISABLE();
  __HAL_RCC_GPIOD_CLK_DISABLE();
  __HAL_RCC_GPIOH_CLK_DISABLE();
  __HAL_RCC_GPIOE_CLK_DISABLE();
}
```

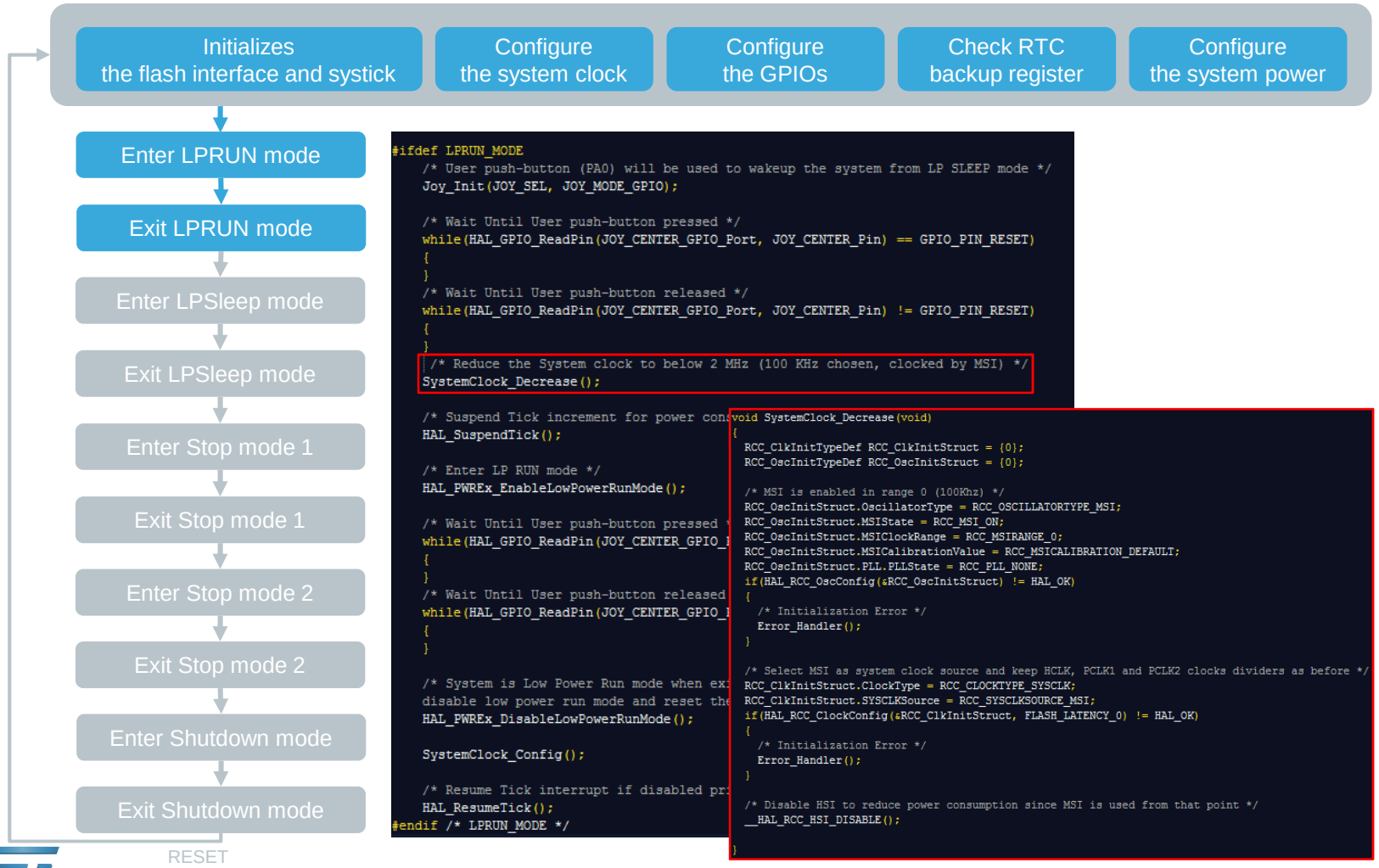
Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)



Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)



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Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)


```
#ifdef LPRUN_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_GPIO);

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }
    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment for power consumption purposes       */
    HAL_SuspendTick();

    /* Enter LP RUN mode */
    HAL_PWREx_EnableLowPowerRunMode();

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
    disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();

    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Run mode entry */
    HAL_ResumeTick();
#endif /* LPRUN_MODE */
```

Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)


```
#ifdef LPRUN_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_GPIO);

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }
    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment for power consumption purposes        */
    HAL_SuspendTick();

    /* Enter LP RUN mode */
    HAL_PWREx_EnableLowPowerRunMode();

    /* Wait Until User push-button pressed
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_
    {
    }
    /* Wait Until U
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
    disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();

    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Run mode entry */
    HAL_ResumeTick();
#endif /* LPRUN_MODE */
```

```
void HAL_PWREx_EnableLowPowerRunMode(void)
{
  /* Set Regulator parameter */
  SET_BIT(PWR->CR1, PWR_CR1_LPR);
}
```

Bit 14 **LPR**: Low-power run

When this bit is set, the regulator is switched from main mode (MR) to low-power mode (LPR).

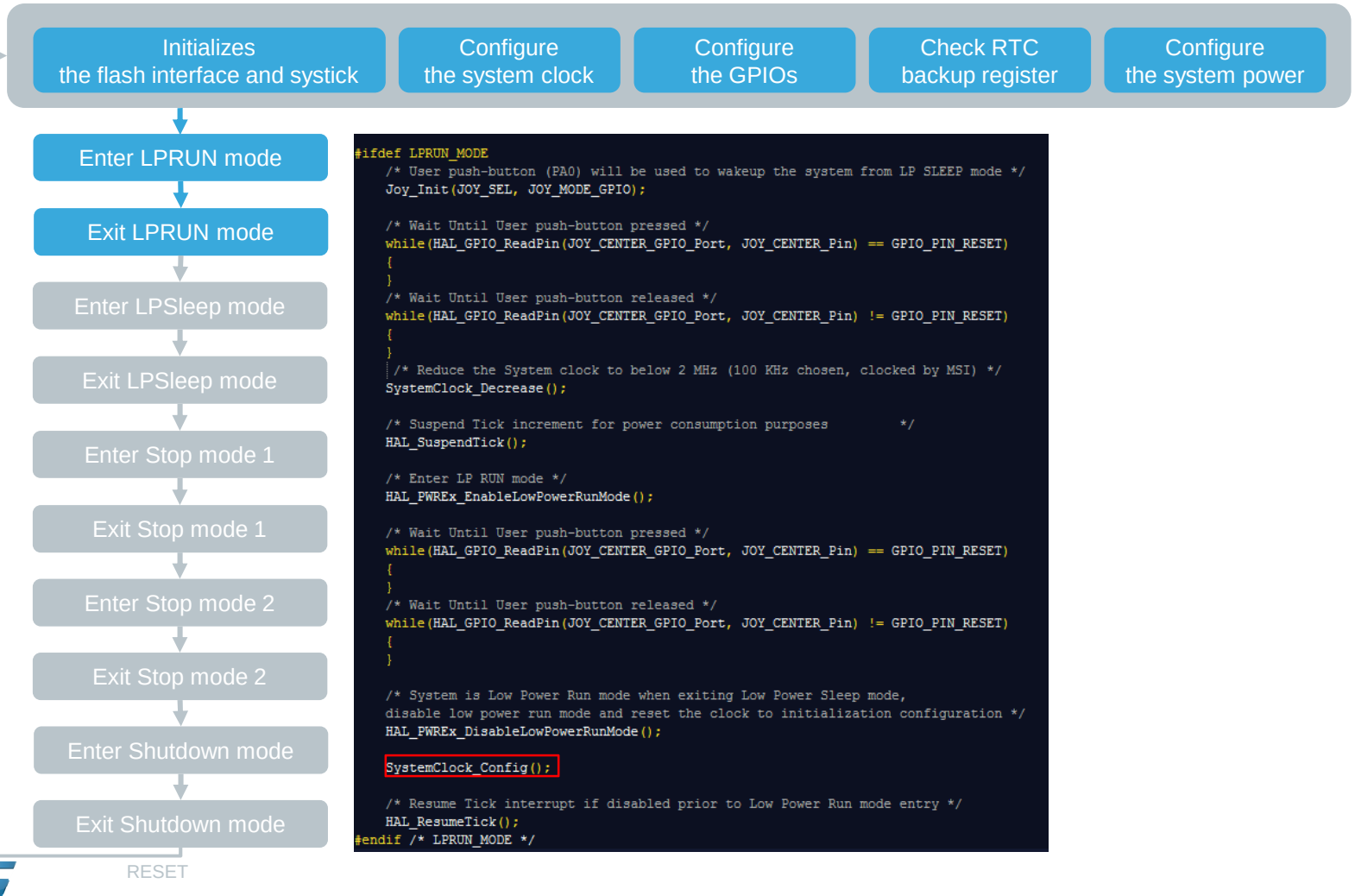
Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)


```
#ifdef LPRUN_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_GPIO);

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }
    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment for power consumption purposes        */
    HAL_SuspendTick();

    /* Enter LP RUN mode */
    HAL_PWREx_EnableLowPowerRunMode();

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
    disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();

    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Run mode entry */
    HAL_ResumeTick();
#endif /* LPRUN_MODE */
```

Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)




```
#ifdef LPRUN_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_GPIO);

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }
    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment for power consumption purposes        */
    HAL_SuspendTick();

    /* Enter LP RUN mode */
    HAL_PWREx_EnableLowPowerRunMode();

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
    disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();

    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Run mode entry */
    HAL_ResumeTick();
#endif /* LPRUN_MODE */
```

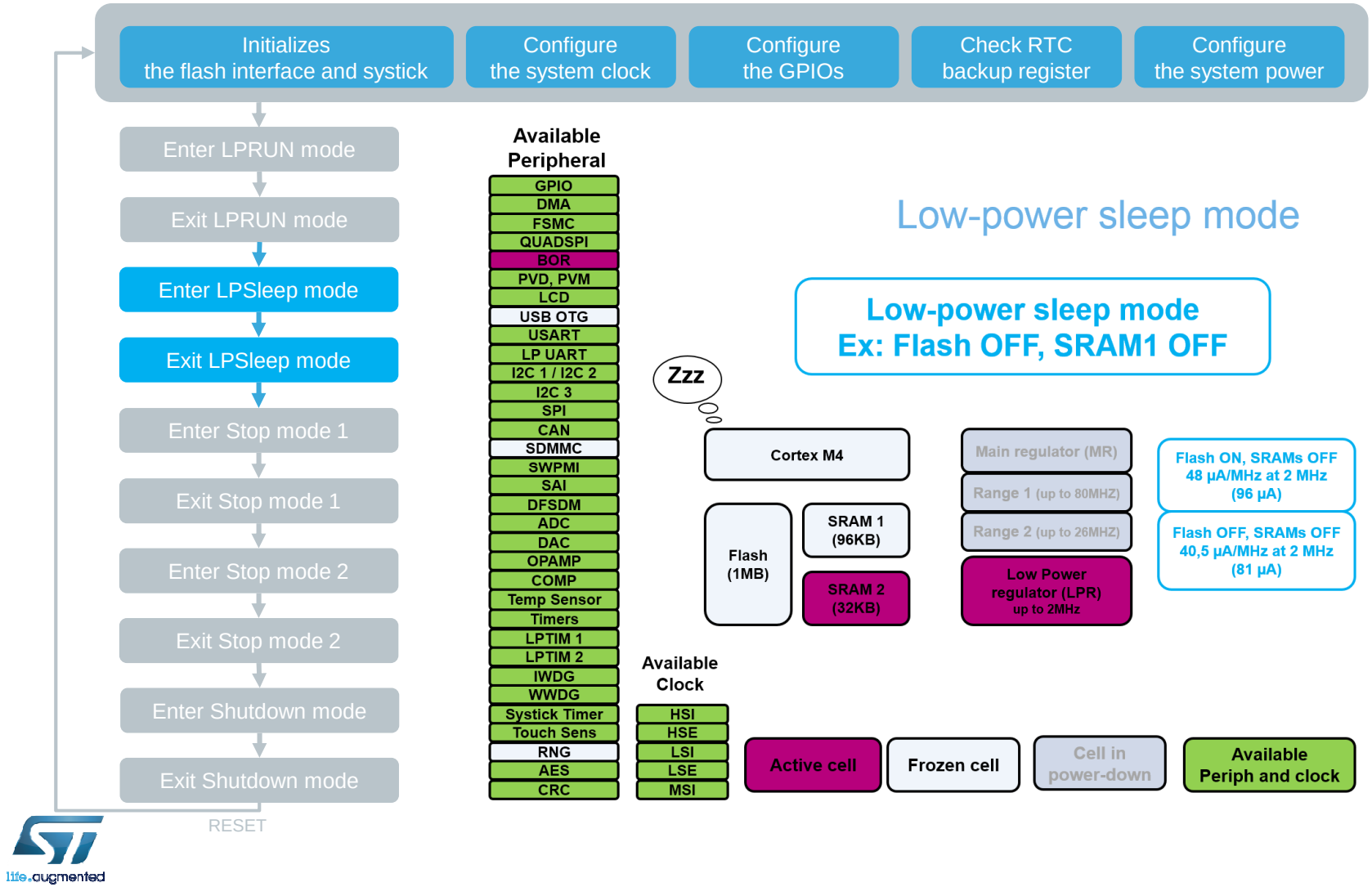
Implementation of Low Power Mode

Low Power Run Mode (LPRun mode)


```
#ifdef LPRUN_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_GPIO);

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }
    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment for power consumption purposes        */
    HAL_SuspendTick();

    /* Enter LP RUN mode */
    HAL_PWREx_EnableLowPowerRunMode();

    /* Wait Until User push-button pressed */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) == GPIO_PIN_RESET)
    {
    }
    /* Wait Until User push-button released */
    while(HAL_GPIO_ReadPin(JOY_CENTER_GPIO_Port, JOY_CENTER_Pin) != GPIO_PIN_RESET)
    {
    }

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
    disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();

    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Run mode entry */
    HAL_ResumeTick();
#endif /* LPRUN_MODE */
```

Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)



Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)


```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment to prevent wakeup by Systick interrupt.          */
    /* Otherwise the Systick interrupt will wake up the device within 1ms      */
    /* (HAL time base).                                                        */
    HAL_SuspendTick();

    /* Enable Flash power down mode during Sleep mode     */
    __HAL_FLASH_SLEEP_POWERDOWN_ENABLE();

    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Enter Sleep Mode , wake up is done once Key push button is pressed */
    HAL_PWR_EnterSLEEPMode(PWR_LOWPOWERREGULATOR_ON, PWR_SLEEPENTRY_WFI);

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
       disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();
    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Sleep mode entry */
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)


```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment to prevent wakeup by Systick interrupt.          */
    /* Otherwise the Systick interrupt will wake up the device within 1ms      */
    /* (HAL time base).                                                        */
    HAL_SuspendTick();

    /* Enable Flash power down mode during Sleep mode      */
    __HAL_FLASH_SLEEP_POWERDOWN_ENABLE();

    /* Periphera
    PeripheralCl

    /* Enter Sle
    HAL_PWR_EnterSLEEPMode(PWR_LOWPOWERREGULATOR_ON, PWR_SLEEPENTRY_WFI);

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
       disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();
    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Sleep mode entry */
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

```
/**
  * @brief  Enable the FLASH power down during Low-Power sleep mode
  * @retval none
  */
#define __HAL_FLASH_SLEEP_POWERDOWN_ENABLE()    SET_BIT(FLASH->ACR, FLASH_ACR_SLEEP_PD)
```

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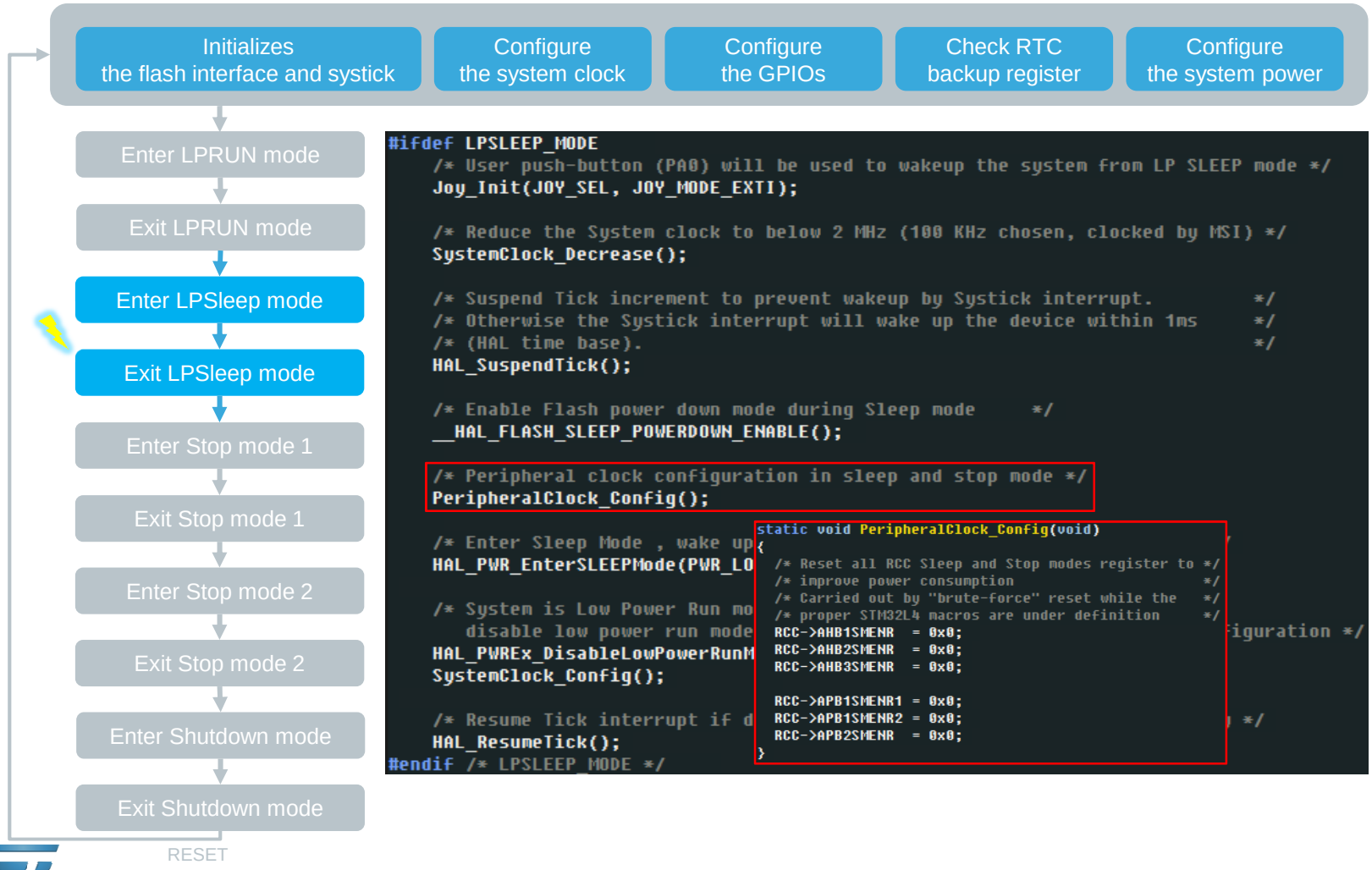
Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)




```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment to prevent wakeup by Systick interrupt.          */
    /* Otherwise the Systick interrupt will wake up the device within 1ms      */
    /* (HAL time base).                                                        */
    HAL_SuspendTick();

    /* Enable Flash power down mode during Sleep mode      */
    __HAL_FLASH_SLEEP_POWERDOWN_ENABLE();

    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Enter Sleep Mode , wake up
    HAL_PWR_EnterSLEEPMode(PWR_LO

    /* System is Low Power Run mo
       disable low power run mode
    HAL_PWREx_DisableLowPowerRunM
    SystemClock_Config();

    /* Resume Tick interrupt if d
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

```
static void PeripheralClock_Config(void)
{
  /* Reset all RCC Sleep and Stop modes register to */
  /* improve power consumption                      */
  /* Carried out by "brute-force" reset while the   */
  /* proper STM32L4 macros are under definition     */
  RCC->AHB1SMENR  = 0x0;
  RCC->AHB2SMENR  = 0x0;
  RCC->AHB3SMENR  = 0x0;

  RCC->APB1SMENR1 = 0x0;
  RCC->APB1SMENR2 = 0x0;
  RCC->APB2SMENR  = 0x0;
}
```

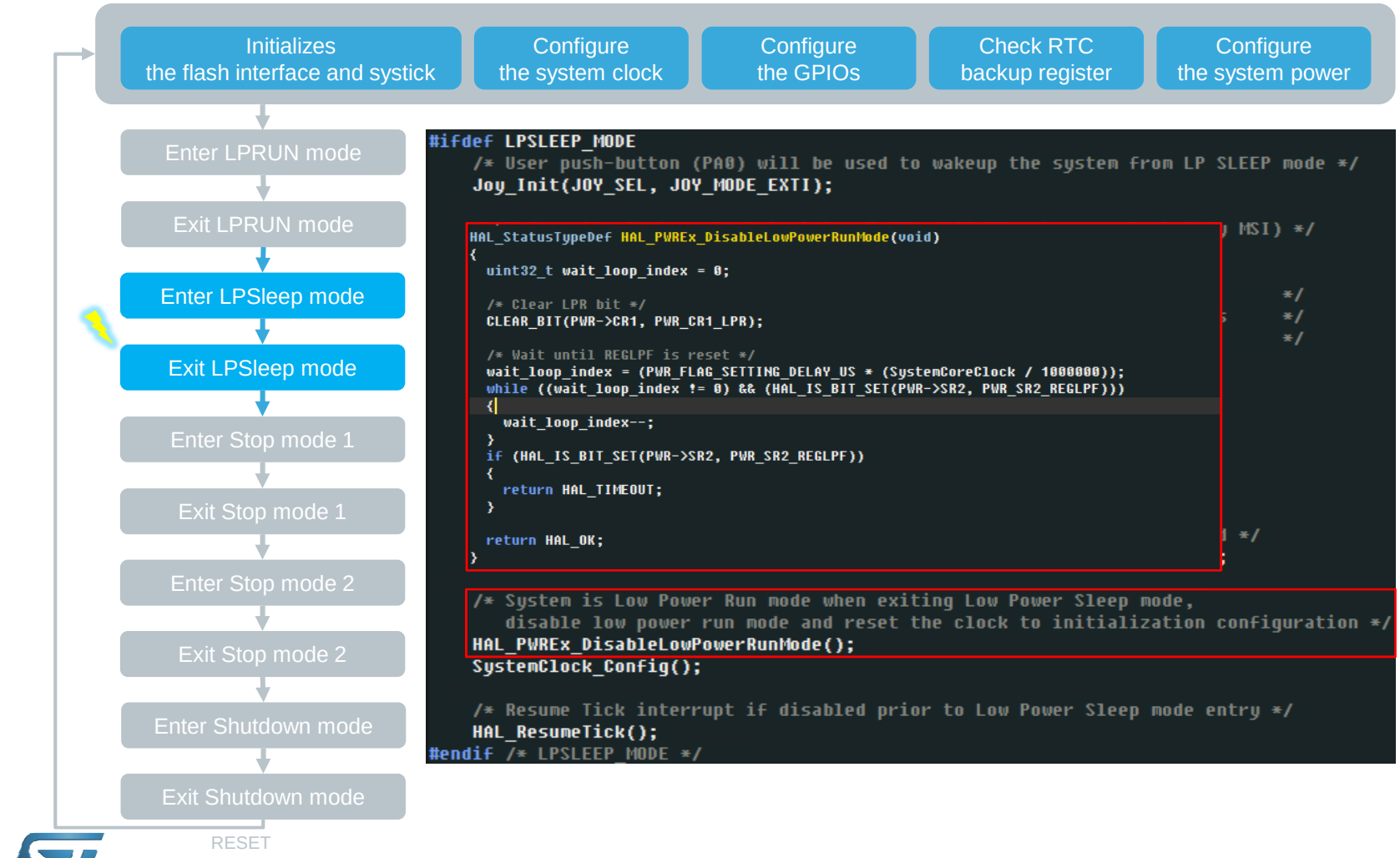
Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)


```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment to prevent wakeup by Systick interrupt.          */
    /* Otherwise the Systick interrupt will wake up the device within 1ms      */
    /* (HAL time base).                                                        */
    HAL_SuspendTick();

    /* Enable Flash power down mode during Sleep mode     */
    __HAL_FLASH_SLEEP_POWERDOWN_ENABLE();

    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Enter Sleep Mode , wake up is done once Key push button is pressed */
    HAL_PWR_EnterSLEEPMode(PWR_LOWPOWERREGULATOR_ON, PWR_SLEEPENTRY_WFI);

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
       disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();
    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Sleep mode entry */
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

Implementation of Low Power Mode

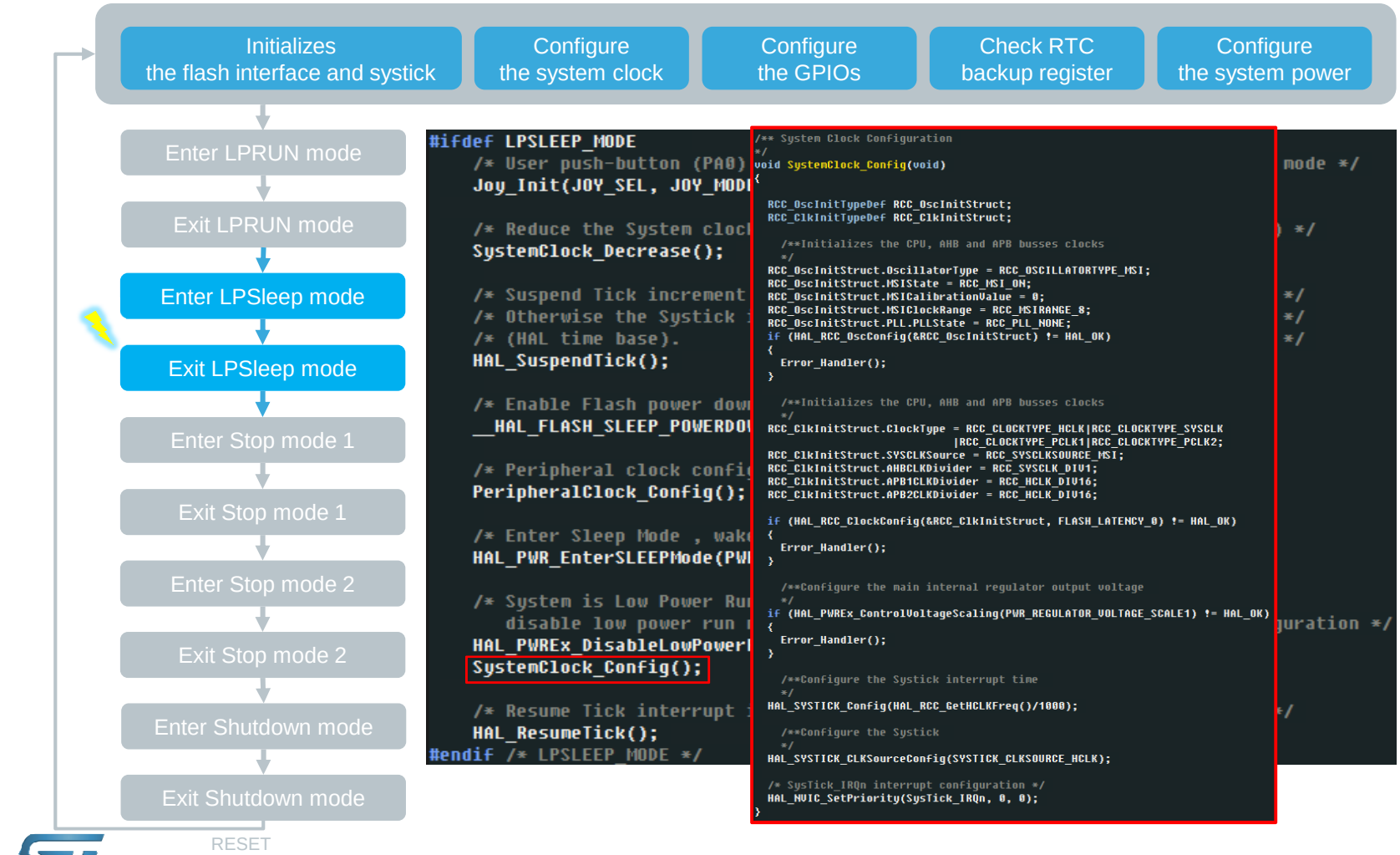
Low Power Sleep Mode (LPSleep Mode)




```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

HAL_StatusTypeDef HAL_PWREx_DisableLowPowerRunMode(void)
{
  uint32_t wait_loop_index = 0;

  /* Clear LPR bit */
  CLEAR_BIT(PWR->CR1, PWR_CR1_LPR);

  /* Wait until REGLPF is reset */
  wait_loop_index = (PWR_FLAG_SETTING_DELAY_US * (SystemCoreClock / 1000000));
  while ((wait_loop_index != 0) && (HAL_IS_BIT_SET(PWR->SR2, PWR_SR2_REGLPF)))
  {
    wait_loop_index--;
  }
  if (HAL_IS_BIT_SET(PWR->SR2, PWR_SR2_REGLPF))
  {
    return HAL_TIMEOUT;
  }

  return HAL_OK;
}

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
       disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();
    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Sleep mode entry */
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)



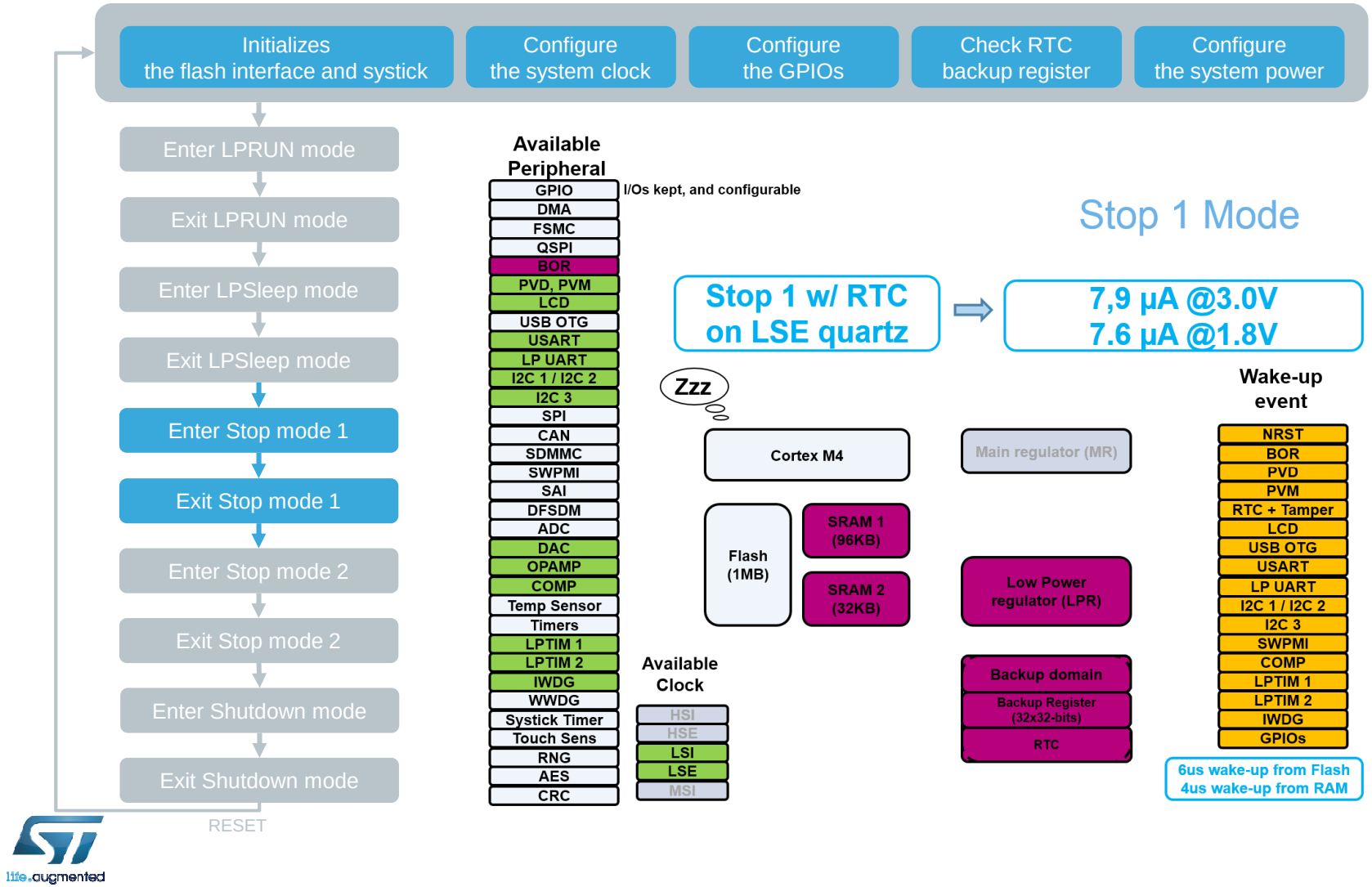
Implementation of Low Power Mode

Low Power Sleep Mode (LPSleep Mode)


```
#ifdef LPSLEEP_MODE
    /* User push-button (PA0) will be used to wakeup the system from LP SLEEP mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Reduce the System clock to below 2 MHz (100 KHz chosen, clocked by MSI) */
    SystemClock_Decrease();

    /* Suspend Tick increment to prevent wakeup by Systick interrupt.          */
    /* Otherwise the Systick interrupt will wake up the device within 1ms      */
    /* (HAL time base).                                                        */
    HAL_SuspendTick();

    /* Enable Flash power down mode during Sleep mode     */
    __HAL_FLASH_SLEEP_POWERDOWN_ENABLE();

    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Enter Sleep Mode , wake up is done once Key push button is pressed */
    HAL_PWR_EnterSLEEPMode(PWR_LOWPOWERREGULATOR_ON, PWR_SLEEPENTRY_WFI);

    /* System is Low Power Run mode when exiting Low Power Sleep mode,
       disable low power run mode and reset the clock to initialization configuration */
    HAL_PWREx_DisableLowPowerRunMode();
    SystemClock_Config();

    /* Resume Tick interrupt if disabled prior to Low Power Sleep mode entry */
    HAL_ResumeTick();
#endif /* LPSLEEP_MODE */
```

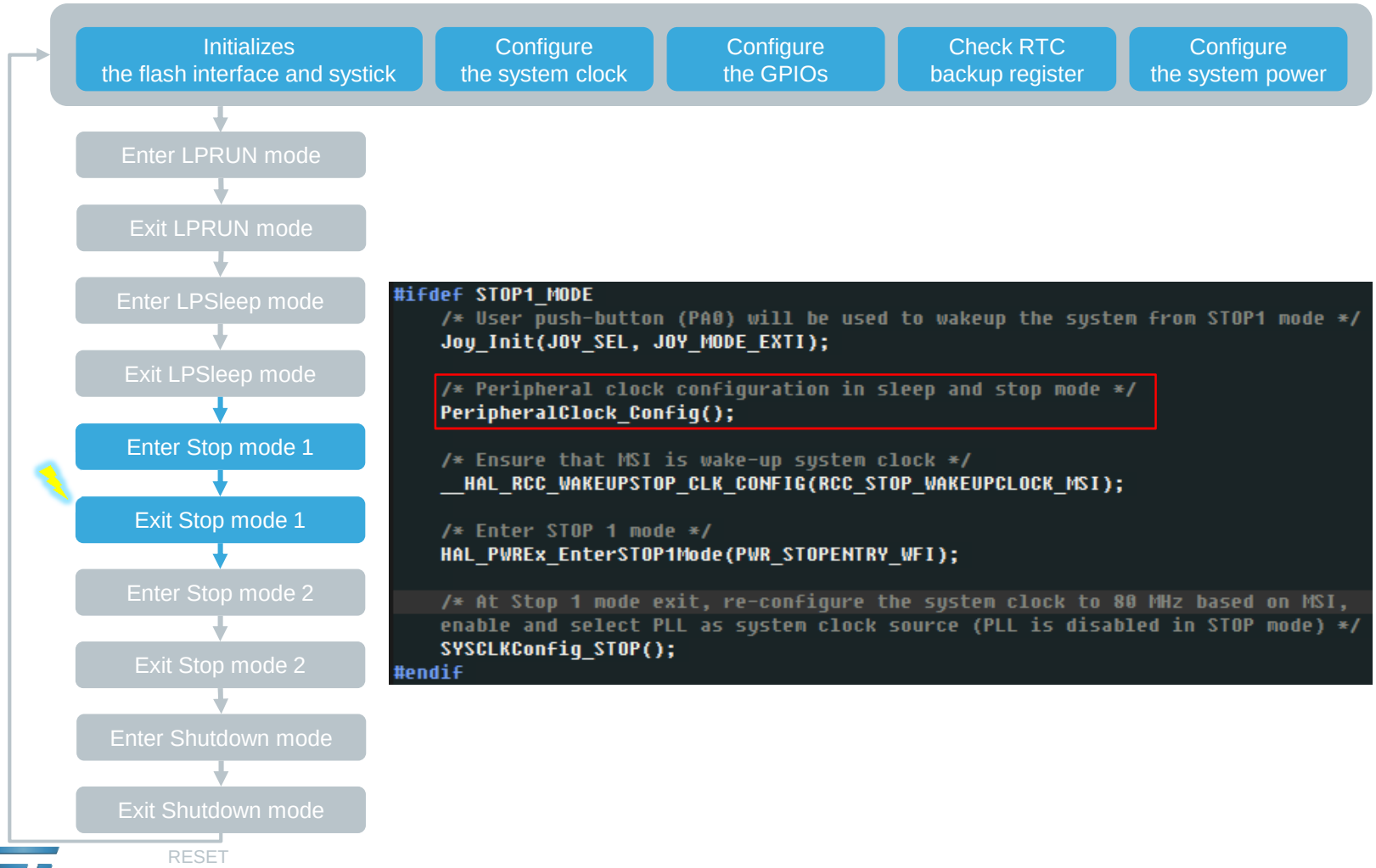
Implementation of Low Power Mode

STOP1 Mode



Implementation of Low Power Mode

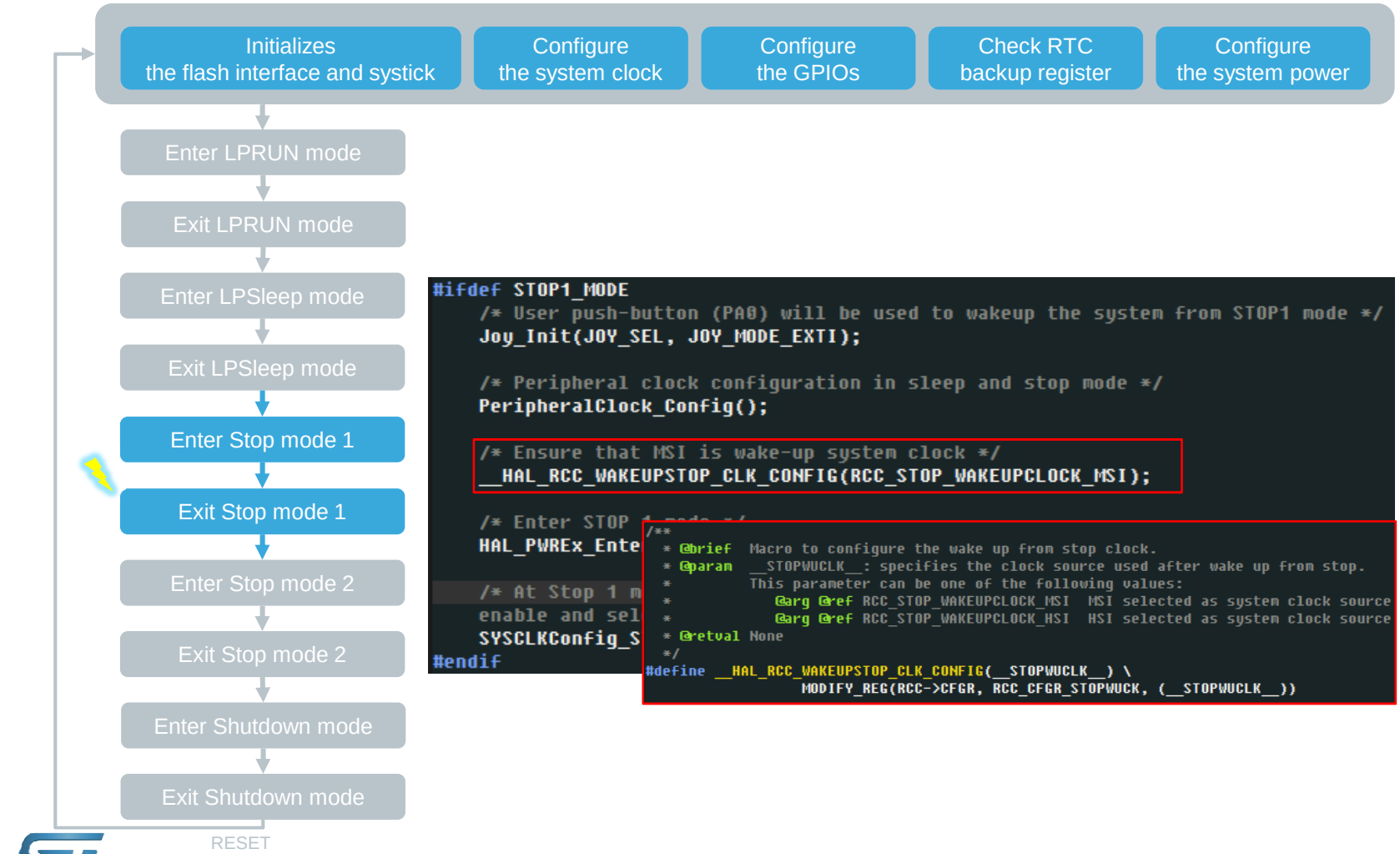
STOP1 Mode




```
#ifdef STOP1_MODE
    /* User push-button (PA0) will be used to wakeup the system from STOP1 mode */
    Joy_Init(JOY_SEL, JOY_MODE_EXTI);

    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Ensure that MSI is wake-up system clock */
    __HAL_RCC_WAKEUPSTOP_CLK_CONFIG(RCC_STOP_WAKEUPCLOCK_MSI);

    /* Enter STOP 1 mode */
    HAL_PWREx_EnterSTOP1Mode(PWR_STOPENTRY_WFI);

    /* At Stop 1 mode exit, re-configure the system clock to 80 MHz based on MSI,
    enable and select PLL as system clock source (PLL is disabled in STOP mode) */
    SYSCLKConfig_STOP();
#endif
```

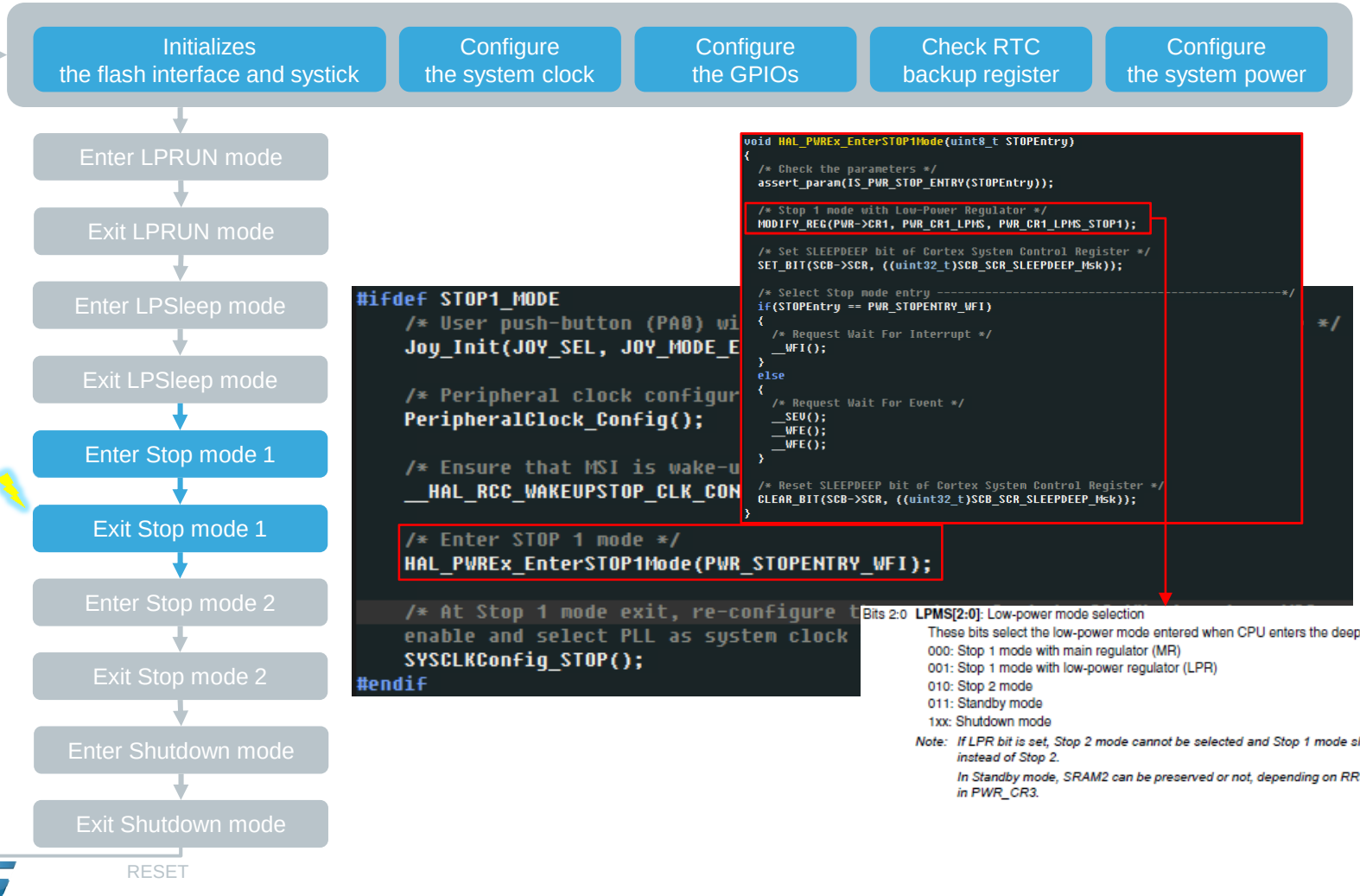
Implementation of Low Power Mode

STOP1 Mode



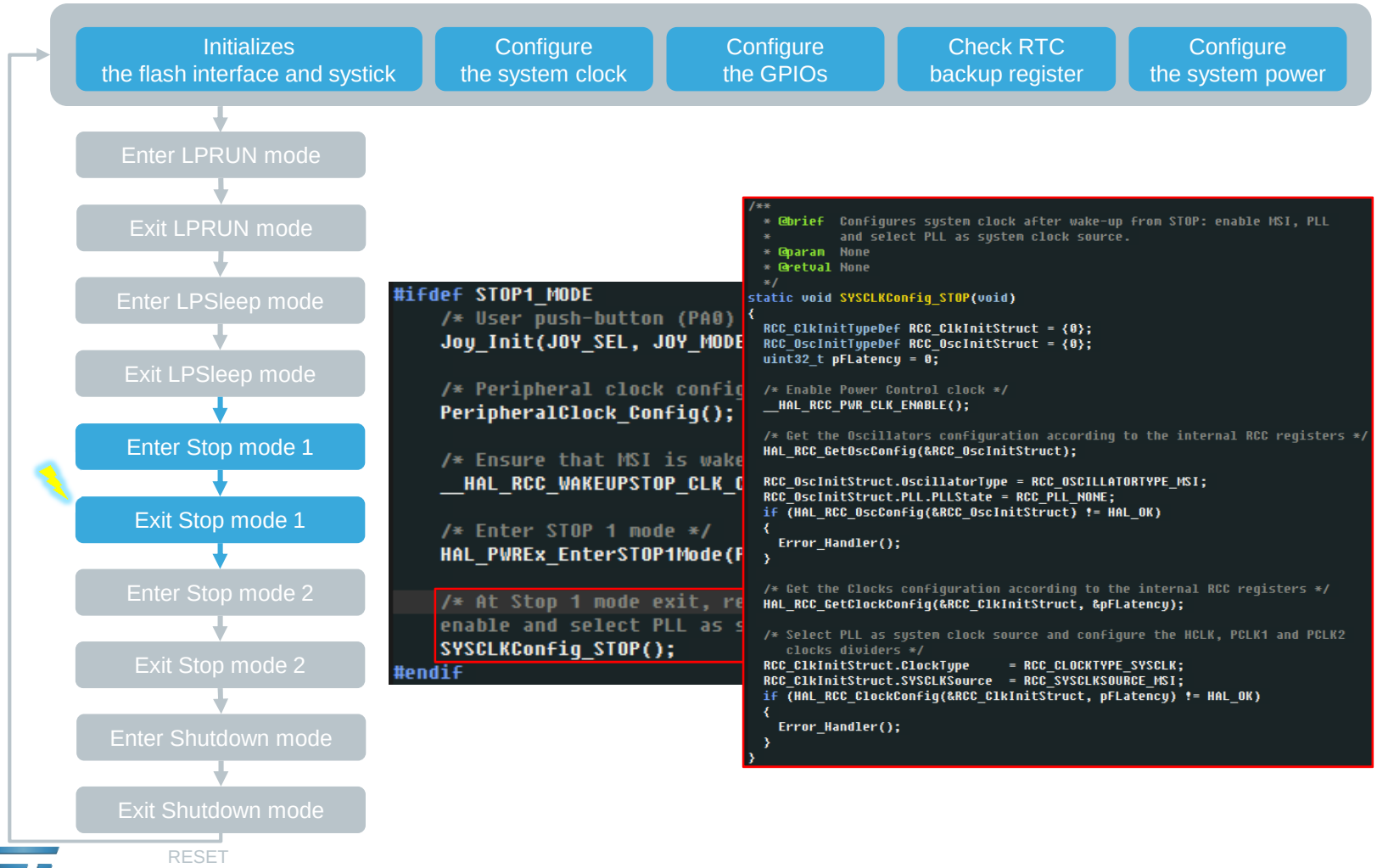
Implementation of Low Power Mode

STOP1 Mode



Implementation of Low Power Mode

STOP1 Mode

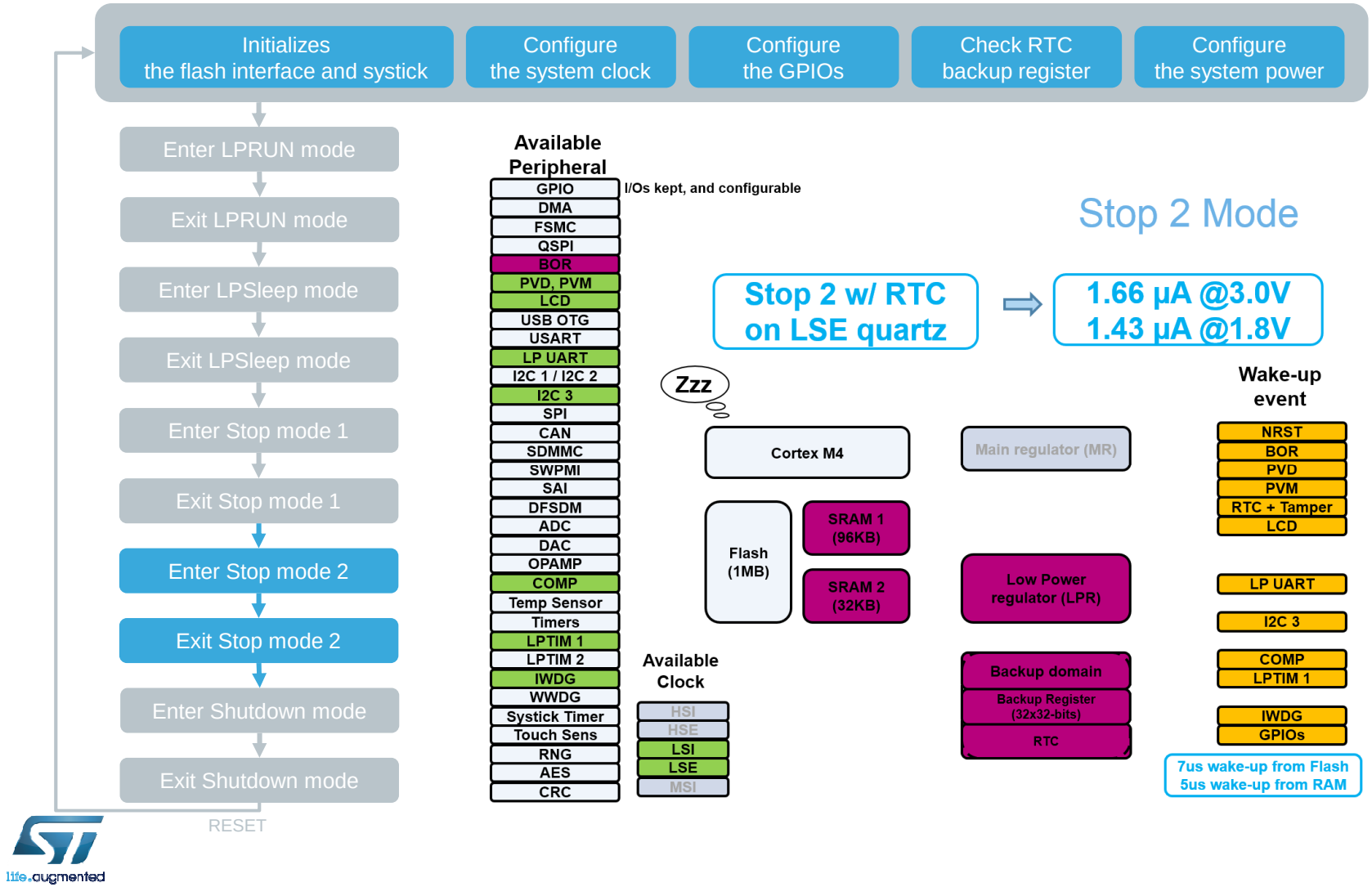



```
#ifdef STOP1_MODE
    /* User push-button (PA0)
    Joy_Init(JOY_SEL, JOY_MODE

    /* Peripheral clock config
    PeripheralClock_Config();

    /* Ensure that MSI is wake
    __HAL_RCC_WAKEUPSTOP_CLK_C

    /* Enter STOP 1 mode */
    HAL_PWREx_EnterSTOP1Mode(P

    /* At Stop 1 mode exit, re
    enable and select PLL as s
    SYSCLKConfig_STOP();
#endif
```

```
/**
  * @brief  Configures system clock after wake-up from STOP: enable MSI, PLL
  *         and select PLL as system clock source.
  * @param  None
  * @retval None
  */
static void SYSCLKConfig_STOP(void)
{
  RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};
  RCC_OscInitTypeDef RCC_OscInitStruct = {0};
  uint32_t pFLatency = 0;

  /* Enable Power Control clock */
  __HAL_RCC_PWR_CLK_ENABLE();

  /* Get the Oscillators configuration according to the internal RCC registers */
  HAL_RCC_GetOscConfig(&RCC_OscInitStruct);

  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_MSI;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_NONE;
  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
  {
    Error_Handler();
  }

  /* Get the Clocks configuration according to the internal RCC registers */
  HAL_RCC_GetClockConfig(&RCC_ClkInitStruct, &pFLatency);

  /* Select PLL as system clock source and configure the HCLK, PCLK1 and PCLK2
     clocks dividers */
  RCC_ClkInitStruct.ClockType     = RCC_CLOCKTYPE_SYSCLK;
  RCC_ClkInitStruct.SYSCLKSource  = RCC_SYSCLKSOURCE_MSI;
  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, pFLatency) != HAL_OK)
  {
    Error_Handler();
  }
}
```

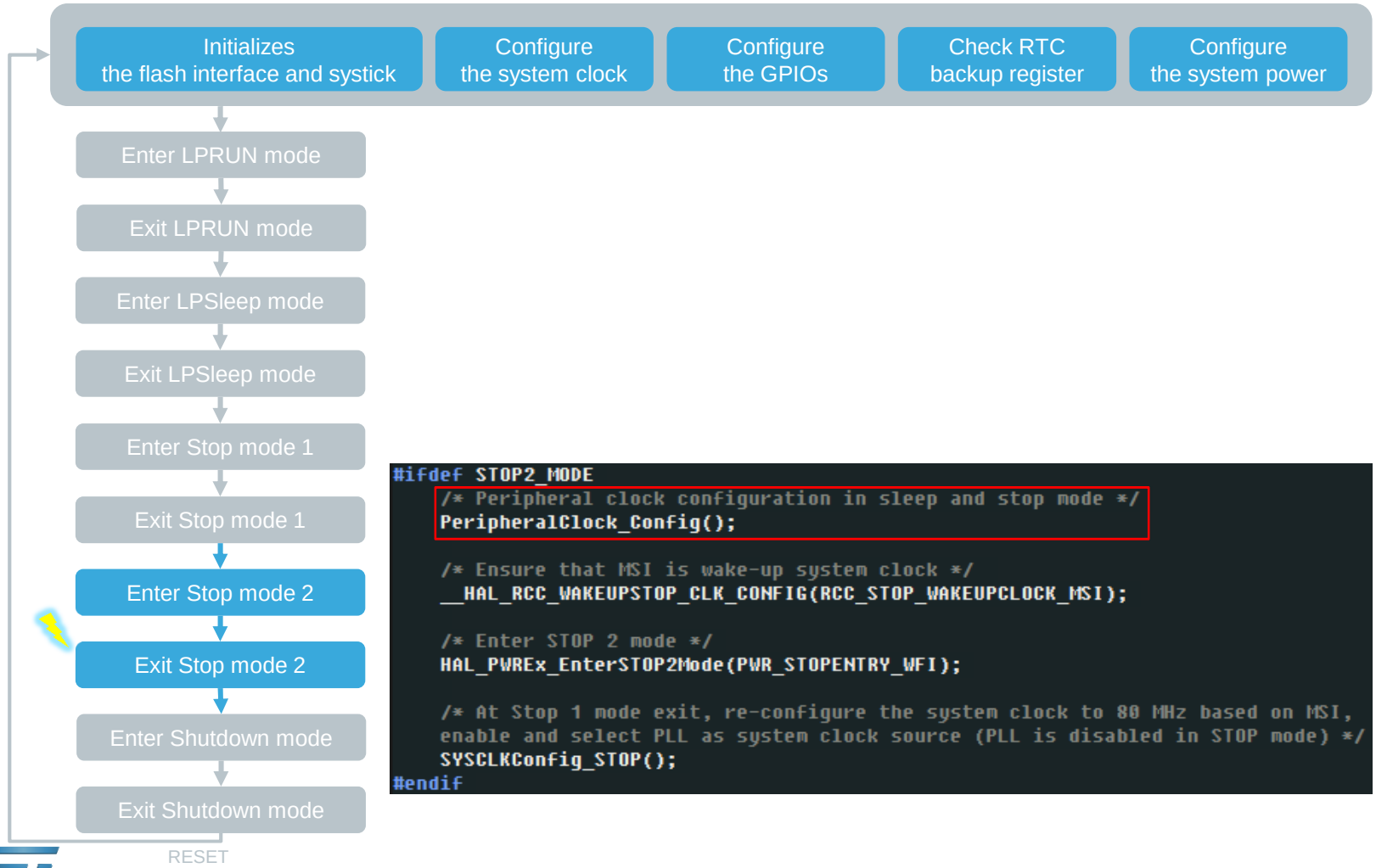
Implementation of Low Power Mode

STOP2 Mode



Implementation of Low Power Mode

STOP2 Mode




```
#ifdef STOP2_MODE
    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Ensure that MSI is wake-up system clock */
    __HAL_RCC_WAKEUPSTOP_CLK_CONFIG(RCC_STOP_WAKEUPCLOCK_MSI);

    /* Enter STOP 2 mode */
    HAL_PWREx_EnterSTOP2Mode(PWR_STOPENTRY_WFI);

    /* At Stop 1 mode exit, re-configure the system clock to 80 MHz based on MSI,
    enable and select PLL as system clock source (PLL is disabled in STOP mode) */
    SYSCLKConfig_STOP();
#endif
```

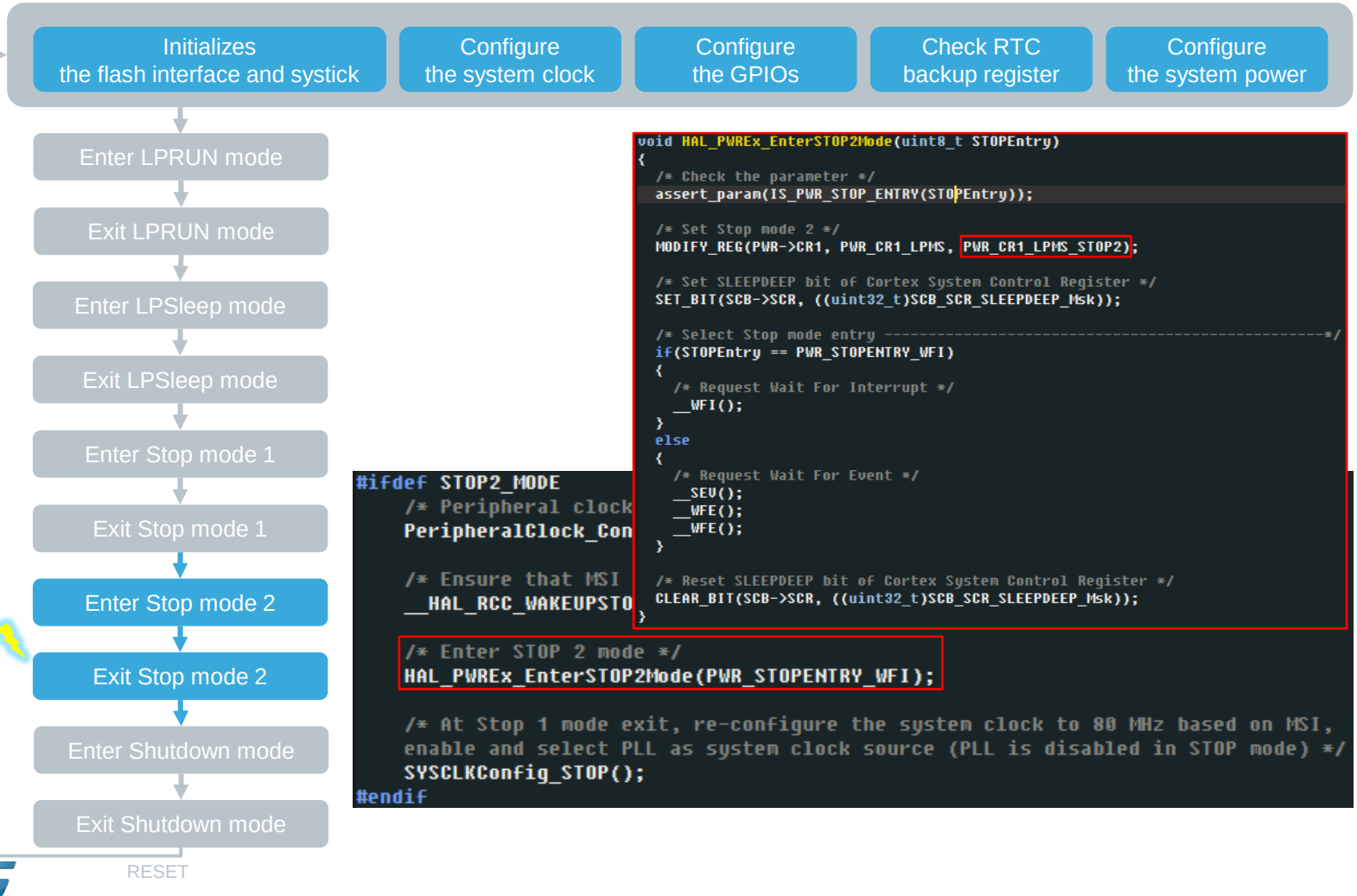
Implementation of Low Power Mode

STOP2 Mode


```
#ifdef STOP2_MODE
    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Ensure that MSI is wake-up system clock */
    __HAL_RCC_WAKEUPSTOP_CLK_CONFIG(RCC_STOP_WAKEUPCLOCK_MSI);

    /* Enter STOP 2 mode */
    HAL_PWREx_EnterSTOP2Mode(PWR_STOPENTRY_WFI);

    /* At Stop 1 mode exit, re-configure the system clock to 80 MHz based on MSI,
    enable and select PLL as system clock source (PLL is disabled in STOP mode) */
    SYSCLKConfig_STOP();
#endif
```

Implementation of Low Power Mode

STOP2 Mode




```
void HAL_PWREx_EnterSTOP2Mode(uint8_t STOPEntry)
{
  /* Check the parameter */
  assert_param(IS_PWR_STOP_ENTRY(STOPEntry));

  /* Set Stop mode 2 */
  MODIFY_REG(PWR->CR1, PWR_CR1_LPMS, PWR_CR1_LPMS_STOP2);

  /* Set SLEEPDEEP bit of Cortex System Control Register */
  SET_BIT(SCB->SCR, ((uint32_t)SCB_SCR_SLEEPDEEP_Msk));

  /* Select Stop mode entry --------------------------------------------------*/
  if(STOPEntry == PWR_STOPENTRY_WFI)
  {
    /* Request Wait For Interrupt */
    __WFI();
  }
  else
  {
    /* Request Wait For Event */
    __SEV();
    __WFE();
    __WFE();
  }

  /* Reset SLEEPDEEP bit of Cortex System Control Register */
  CLEAR_BIT(SCB->SCR, ((uint32_t)SCB_SCR_SLEEPDEEP_Msk));
}
```

```
#ifdef STOP2_MODE
    /* Peripheral clock
    PeripheralClock_Con

    /* Ensure that MSI
    __HAL_RCC_WAKEUPSTO

    /* Enter STOP 2 mode */
    HAL_PWREx_EnterSTOP2Mode(PWR_STOPENTRY_WFI);

    /* At Stop 1 mode exit, re-configure the system clock to 80 MHz based on MSI,
    enable and select PLL as system clock source (PLL is disabled in STOP mode) */
    SYSCLKConfig_STOP();
#endif
```

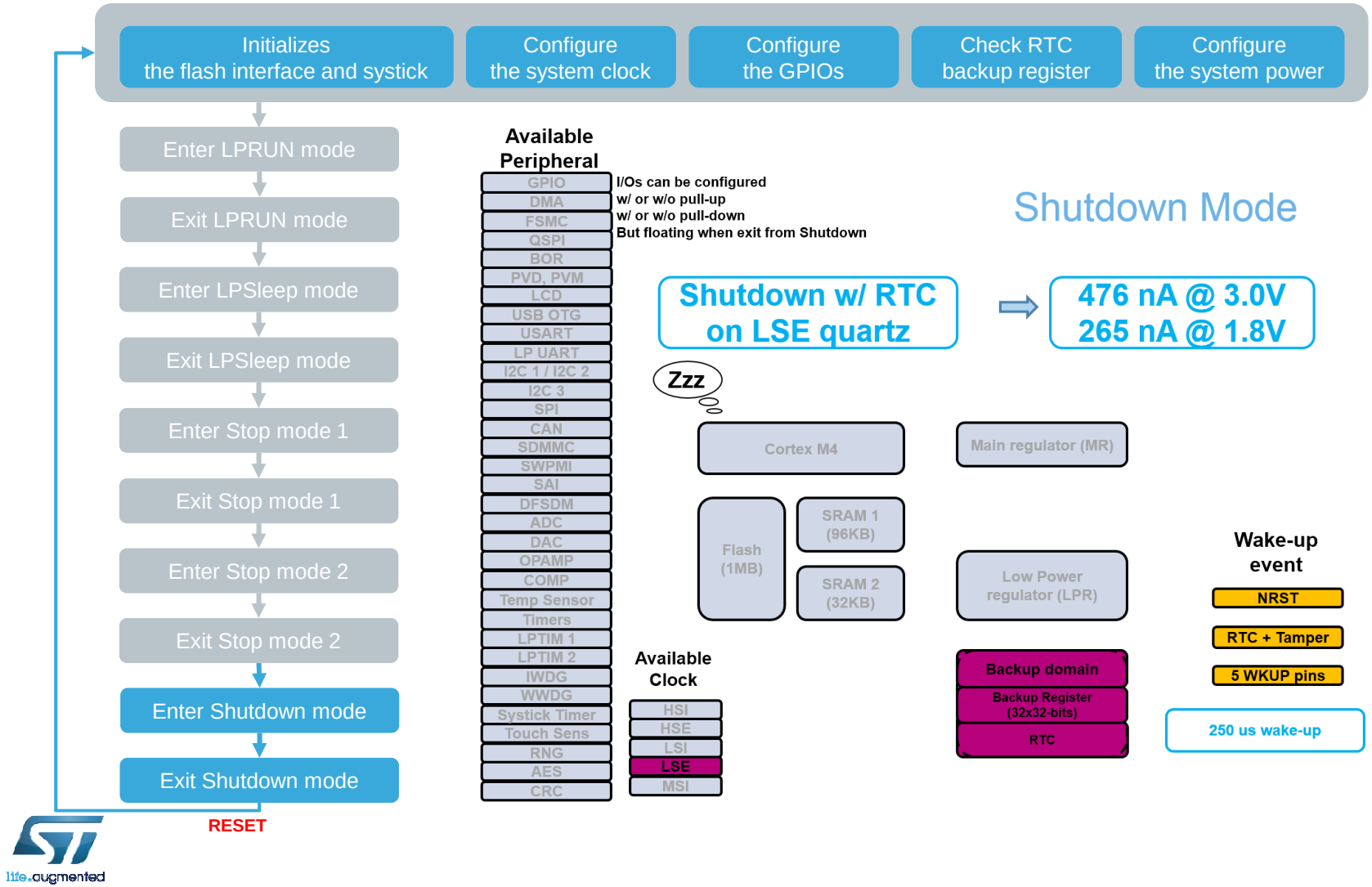
Implementation of Low Power Mode

STOP2 Mode


```
#ifdef STOP2_MODE
    /* Peripheral clock configuration in sleep and stop mode */
    PeripheralClock_Config();

    /* Ensure that MSI is wake-up system clock */
    __HAL_RCC_WAKEUPSTOP_CLK_CONFIG(RCC_STOP_WAKEUPCLOCK_MSI);

    /* Enter STOP 2 mode */
    HAL_PWREx_EnterSTOP2Mode(PWR_STOPENTRY_WFI);

    /* At Stop 1 mode exit, re-configure the system clock to 80 MHz based on MSI,
    enable and select PLL as system clock source (PLL is disabled in STOP mode) */
    SYSCLKConfig_STOP();
#endif
```

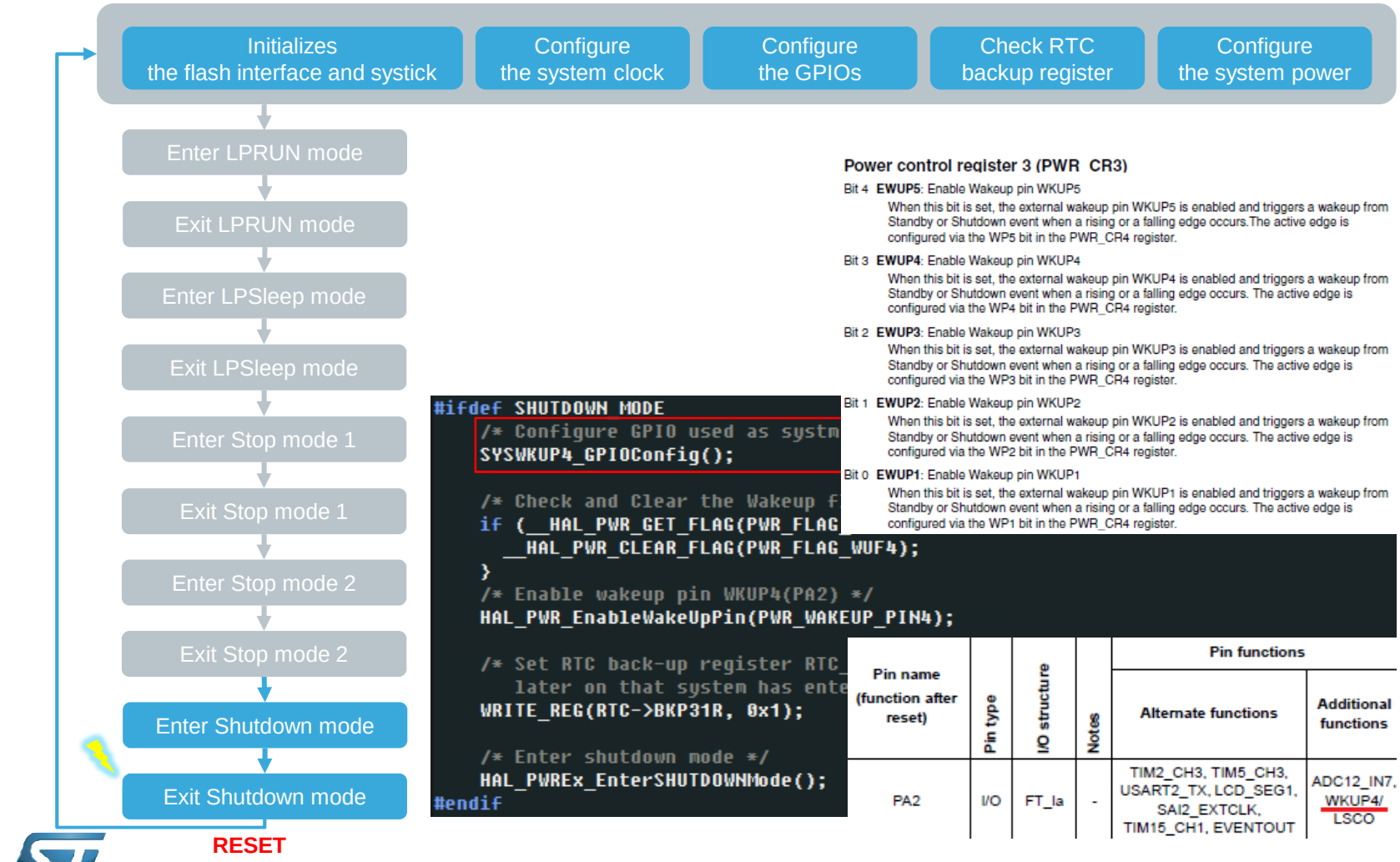
Implementation of Low Power Mode

Shutdown Mode



Implementation of Low Power Mode

Shutdown Mode




```
#ifdef SHUTDOWN_MODE
    /* Configure GPIO used as systm
    SYSWKUP4_GPIOConfig();

    /* Check and Clear the Wakeup f
    if (__HAL_PWR_GET_FLAG(PWR_FLAG
      __HAL_PWR_CLEAR_FLAG(PWR_FLAG_WUF4);
    }
    /* Enable wakeup pin WKUP4(PA2) */
    HAL_PWR_EnableWakeUpPin(PWR_WAKEUP_PIN4);

    /* Set RTC back-up register RTC_
       later on that system has ente
    WRITE_REG(RTC->BKP31R, 0x1);

    /* Enter shutdown mode */
    HAL_PWREx_EnterSHUTDOWNMode();
#endif
```

Power control register 3 (PWR_CR3)

Bit 4 **EWUP5**: Enable Wakeup pin WKUP5
When this bit is set, the external wakeup pin WKUP5 is enabled and triggers a wakeup from Standby or Shutdown event when a rising or a falling edge occurs.The active edge is configured via the WP5 bit in the PWR_CR4 register.

Bit 3 **EWUP4**: Enable Wakeup pin WKUP4
When this bit is set, the external wakeup pin WKUP4 is enabled and triggers a wakeup from Standby or Shutdown event when a rising or a falling edge occurs. The active edge is configured via the WP4 bit in the PWR_CR4 register.

Bit 2 **EWUP3**: Enable Wakeup pin WKUP3
When this bit is set, the external wakeup pin WKUP3 is enabled and triggers a wakeup from Standby or Shutdown event when a rising or a falling edge occurs. The active edge is configured via the WP3 bit in the PWR_CR4 register.

Bit 1 **EWUP2**: Enable Wakeup pin WKUP2
When this bit is set, the external wakeup pin WKUP2 is enabled and triggers a wakeup from Standby or Shutdown event when a rising or a falling edge occurs. The active edge is configured via the WP2 bit in the PWR_CR4 register.

Bit 0 **EWUP1**: Enable Wakeup pin WKUP1
When this bit is set, the external wakeup pin WKUP1 is enabled and triggers a wakeup from Standby or Shutdown event when a rising or a falling edge occurs. The active edge is configured via the WP1 bit in the PWR_CR4 register.

Pin name (function after reset)	Pin type	I/O structure	Notes	Pin functions	
				Alternate functions	Additional functions
PA2	I/O	FT_la	-	TIM2_CH3, TIM5_CH3, USART2_TX, LCD_SEG1, SAI2_EXTCLK, TIM15_CH1, EVENTOUT	ADC12_IN7, WKUP4/ LSCO

Implementation of Low Power Mode

Shutdown Mode


```
#ifdef SHUTDOWN_MODE
    /* Configure GPIO used as systm wakeup pin4(PA2). */
    SYSWKUP4_GPIOConfig();

    /* Check and Clear the Wakeup flag */
    if (__HAL_PWR_GET_FLAG(PWR_FLAG_WUF4) != RESET){
      __HAL_PWR_CLEAR_FLAG(PWR_FLAG_WUF4);
    }
    /* Enable wakeup pin WKUP4(PA2) */
    HAL_PWR_EnableWakeUpPin(PWR_WAKEUP_PIN4);

    /* Set RTC back-up register RTC_BKP31R to indicate
       later on that system has entered shutdown mode  */
    WRITE_REG(RTC->BKP31R, 0x1);

    /* Enter shutdown mode */
    HAL_PWREx_EnterSHUTDOWNMode();
#endif
```

Implementation of Low Power Mode

Shutdown Mode


```
#ifdef SHUTDOWN_MODE
    /* Configure GPIO used as systm wakeup pin4(PA2). */
    SYSWKUP4_GPIOConfig();

    /* Check and Clear the Wakeup flag */
    if (__HAL_PWR_GET_FLAG(PWR_FLAG_WUF4) != RESET){
      __HAL_PWR_CLEAR_FLAG(PWR_FLAG_WUF4);
    }
    /* Enable wakeup pin WKUP4(PA2) */
    HAL_PWR_EnableWakeUpPin(PWR_WAKEUP_PIN4);

    /* Set RTC back-up register RTC_BKP31R to indicate
       later on that system has entered shutdown mode  */
    WRITE_REG(RTC->BKP31R, 0x1);

    /* Enter shutdown mode */
    HAL_PWREx_EnterSHUTDOWNMode();
#endif
```

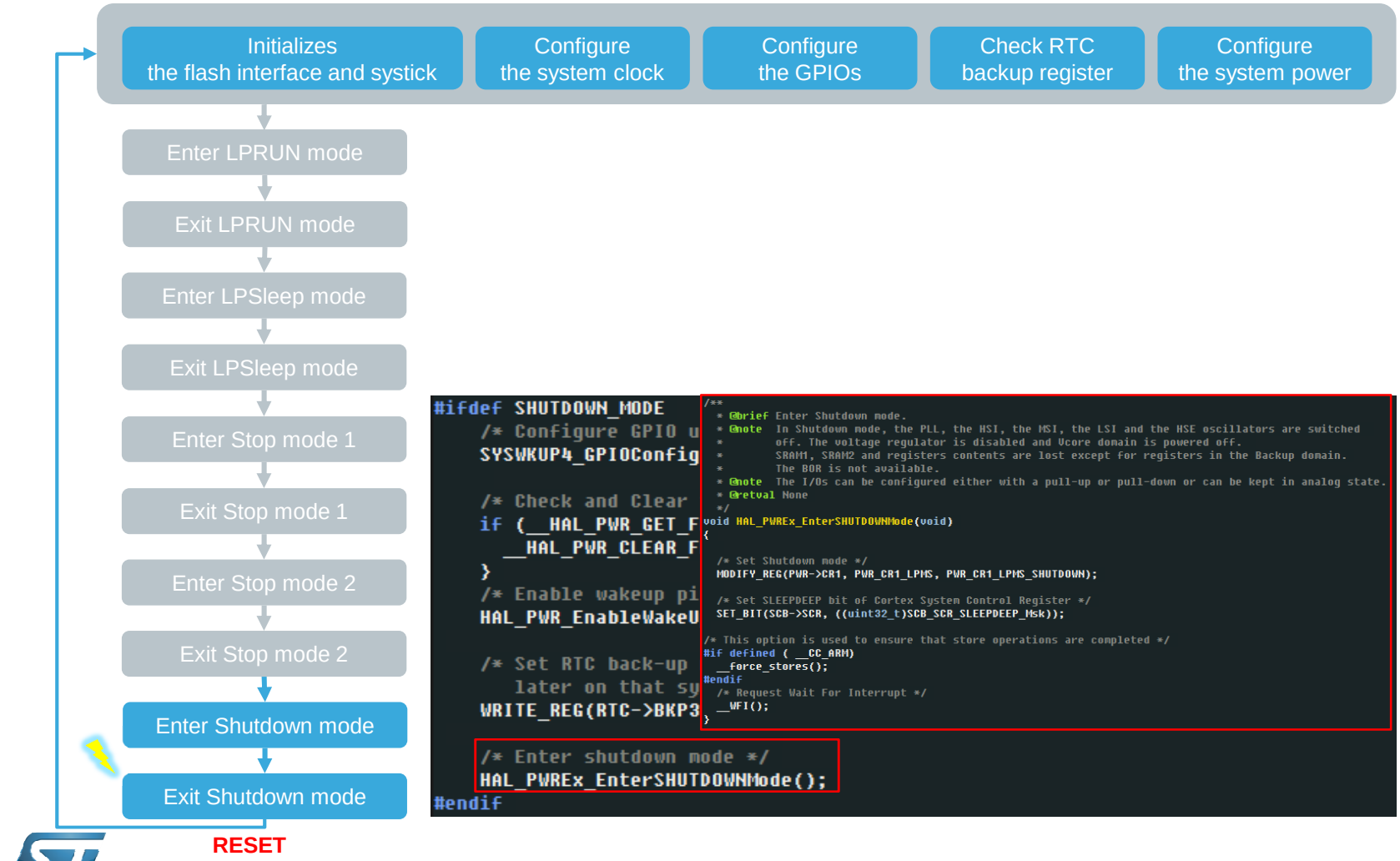
Implementation of Low Power Mode

Shutdown Mode


```
#ifdef SHUTDOWN_MODE
    /* Configure GPIO used as systm wakeup pin4(PA2). */
    SYSWKUP4_GPIOConfig();

    /* Check and Clear the Wakeup flag */
    if (__HAL_PWR_GET_FLAG(PWR_FLAG_WUF4) != RESET){
      __HAL_PWR_CLEAR_FLAG(PWR_FLAG_WUF4);
    }
    /* Enable wakeup pin WKUP4(PA2) */
    HAL_PWR_EnableWakeUpPin(PWR_WAKEUP_PIN4);

    /* Set RTC back-up register RTC_BKP31R to indicate
       later on that system has entered shutdown mode  */
    WRITE_REG(RTC->BKP31R, 0x1);

    /* Enter shutdown mode */
    HAL_PWREx_EnterSHUTDOWNMode();
#endif
```

Implementation of Low Power Mode

Shutdown Mode

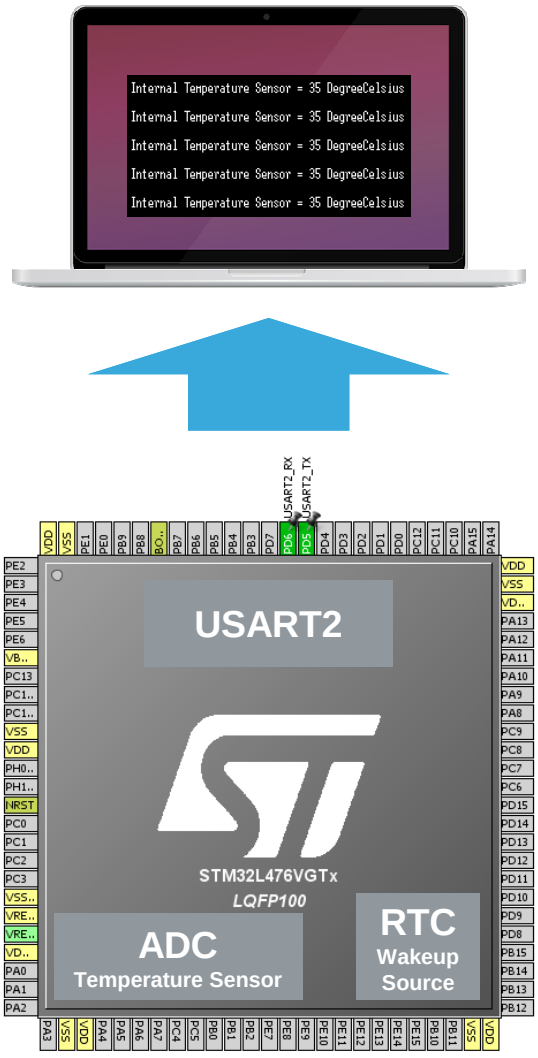



```
#ifdef SHUTDOWN_MODE
    /* Configure GPIO u
    SYSWKUP4_GPIOConfig

    /* Check and Clear
    if (__HAL_PWR_GET_F
       __HAL_PWR_CLEAR_F
    }
    /* Enable wakeup pi
    HAL_PWR_EnableWakeU

    /* Set RTC back-up
       later on that sy
    WRITE_REG(RTC->BKP3

    /* Enter shutdown mode */
    HAL_PWREx_EnterSHUTDOWNMode();
#endif
```

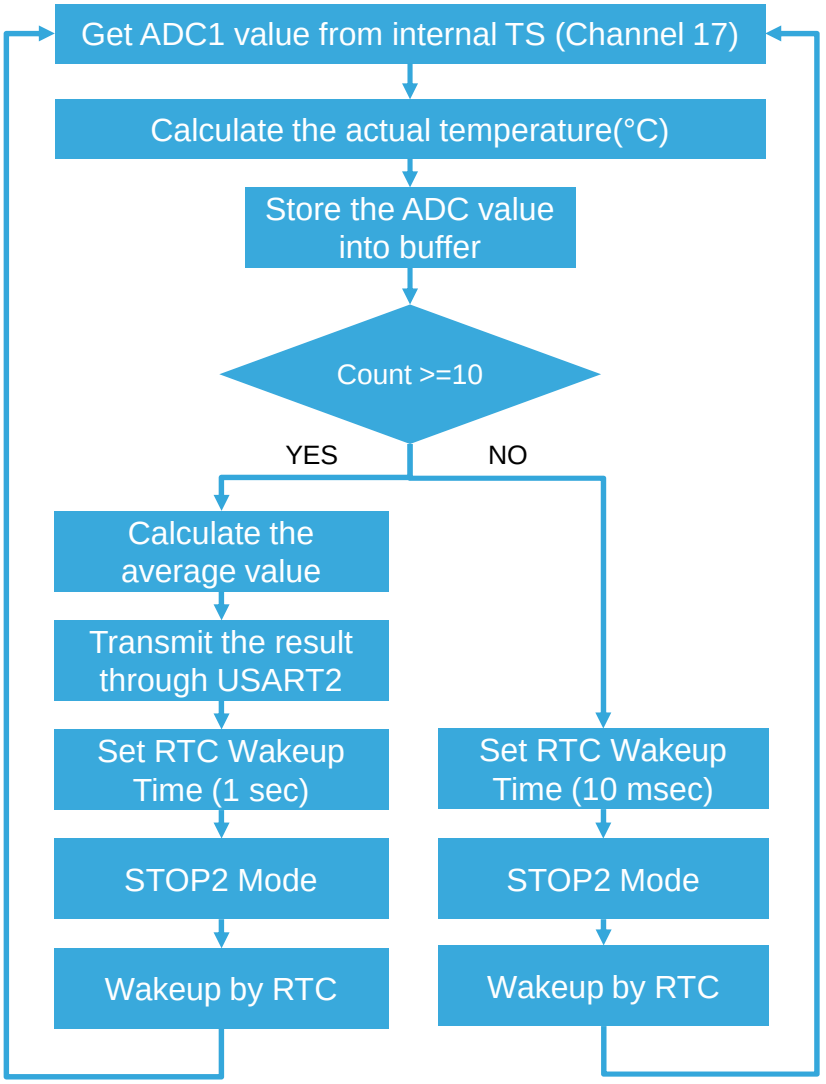
```
/**
  * @brief Enter Shutdown mode.
  * @note  In Shutdown mode, the PLL, the HSI, the MSI, the LSI and the HSE oscillators are switched
  *        off. The voltage regulator is disabled and Vcore domain is powered off.
  *        SRAM1, SRAM2 and registers contents are lost except for registers in the Backup domain.
  *        The BOR is not available.
  * @note  The I/Os can be configured either with a pull-up or pull-down or can be kept in analog state.
  * @retval None
  */
void HAL_PWREx_EnterSHUTDOWNMode(void)
{

  /* Set Shutdown mode */
  MODIFY_REG(PWR->CR1, PWR_CR1_LPMS, PWR_CR1_LPMS_SHUTDOWN);

  /* Set SLEEPDEEP bit of Cortex System Control Register */
  SET_BIT(SCB->SCR, ((uint32_t)SCB_SCR_SLEEPDEEP_Msk));

/* This option is used to ensure that store operations are completed */
#if defined ( __CC_ARM)
  __force_stores();
#endif
  /* Request Wait For Interrupt */
  __WFI();
}
```

Use Case

Block Diagram



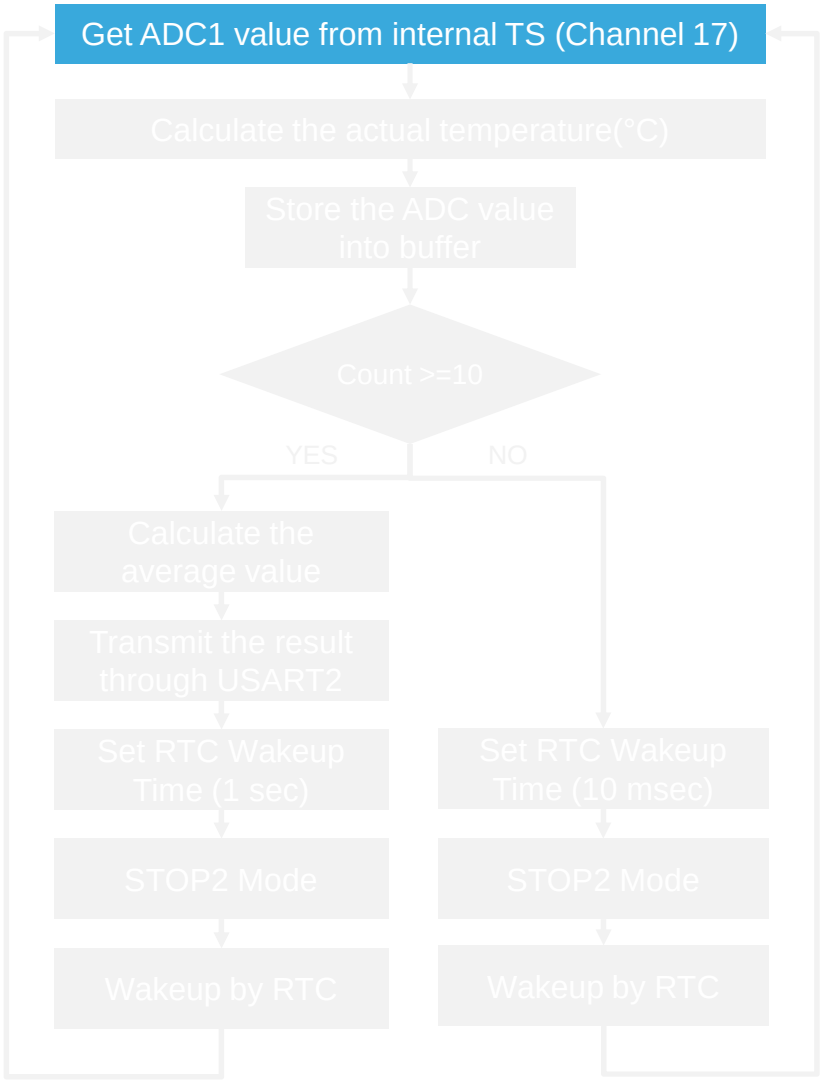
Flow Chart



Use Case

Step 1. Get ADC value

```
if (HAL_ADCEx_Calibration_Start(&hadc1, ADC_SINGLE_ENDED) !=  HAL_OK)
{
  /* ADC Calibration Error */
  Error_Handler();
}
HAL_Delay(1);

if(HAL_ADC_Start(&hadc1) != HAL_OK){
  Error_Handler();
}

if(HAL_ADC_PollForConversion(&hadc1, 10) != HAL_OK){
  Error_Handler();
}

value_adc = HAL_ADC_GetValue(&hadc1);
```



Step 2. Calculate the actual temperature & Store the ADC value

```
/* 30 'c temperature calibration */
uint16_t ts_cal1 = *(volatile uint16_t *)(0x1FFF75A8);
/* 110 'c temperature calibration */
uint16_t ts_cal2 = *(volatile uint16_t *)(0x1FFF75CA);

float first = (float)(110 - 30) / (float)(ts_cal2 - ts_cal1);
float second = first * (float)(value_adc - ts_cal1);
float final = second + 30.0f;

adc_vals[adc_count++] = (uint16_t)final;

HAL_ADC_Stop(&hadc1);
```

Calculate the actual temperature using the following formula:

$$\text{Temperature (in °C)} = \frac{110\,°C - 30\,°C}{TS\_CAL2 - TS\_CAL1} \times (TS\_DATA - TS\_CAL1) + 30\,°C$$

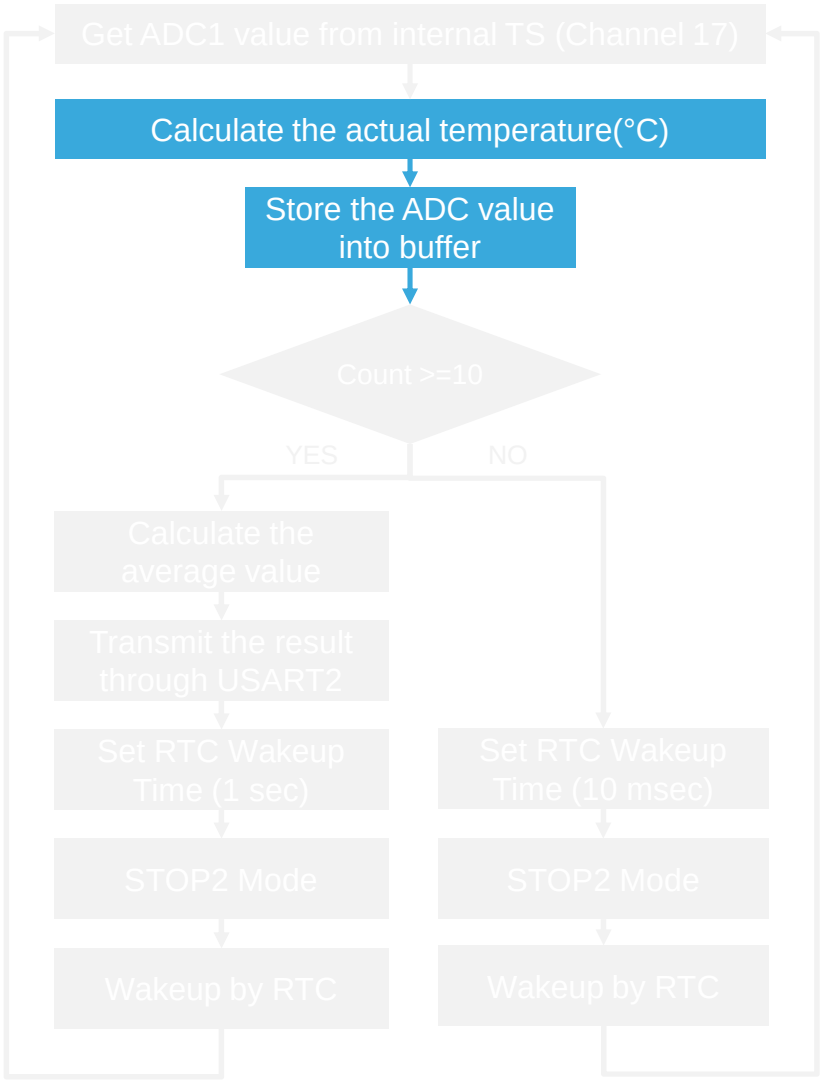
Where:

- TS_CAL2 is the temperature sensor calibration value acquired at 110°C
- TS_CAL1 is the temperature sensor calibration value acquired at 30°C
- TS_DATA is the actual temperature sensor output value converted by ADC

Refer to the device datasheet for more information about TS_CAL1 and TS_CAL2 calibration points.

Table 8. Temperature sensor calibration values

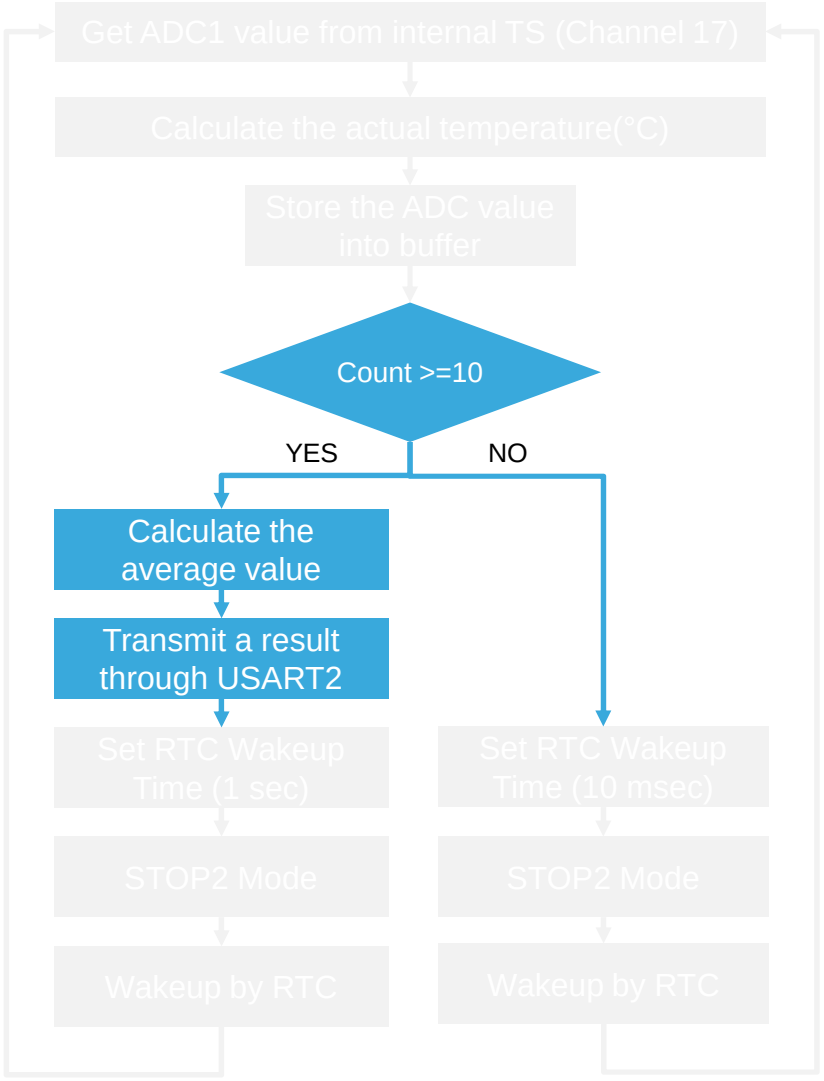
Calibration value name	Description	Memory address
TS_CAL1	TS ADC raw data acquired at a temperature of 30 °C (± 5 °C), $V_{DDA} = V_{REF+}$ = 3.0 V (± 10 mV)	0x1FFF 75A8 - 0x1FFF 75A9
TS_CAL2	TS ADC raw data acquired at a temperature of 110 °C (± 5 °C), $V_{DDA} = V_{REF+}$ = 3.0 V (± 10 mV)	0x1FFF 75CA - 0x1FFF 75CB



Use Case

Step 3. Check ADC count & Transmit a result through USART

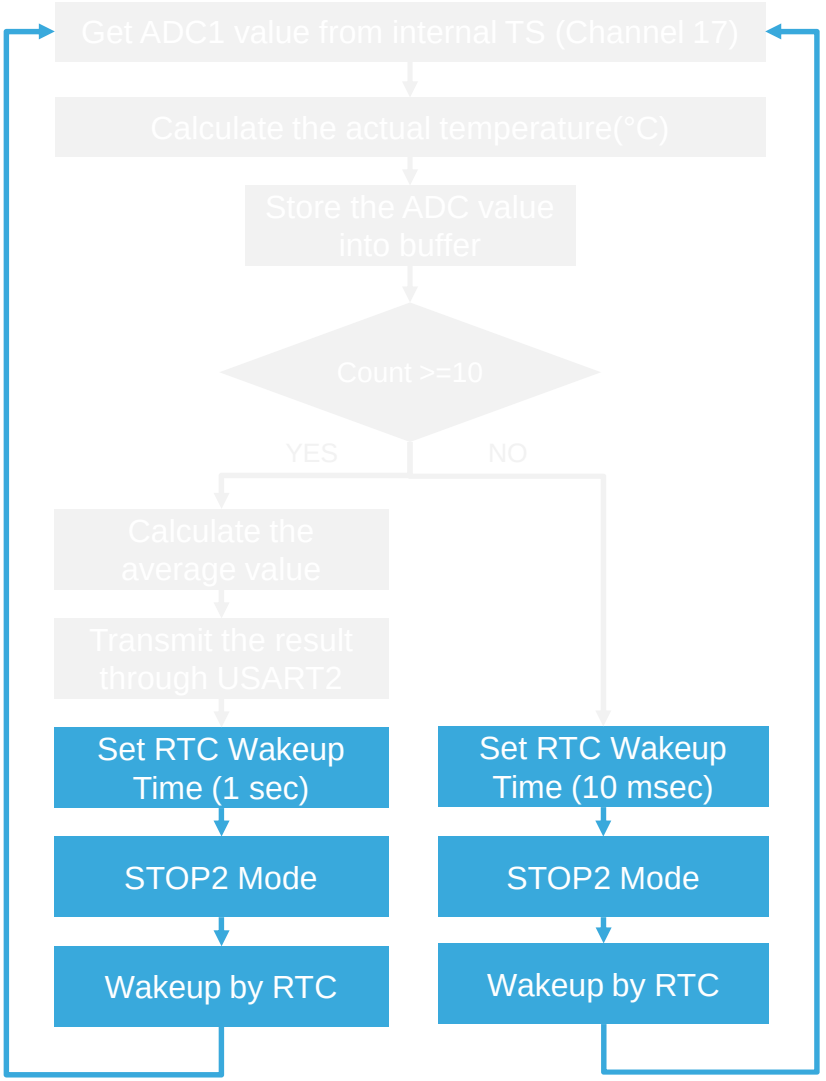
```
if (adc_count >= 10) {
  for(int i=0; i<10; i++){
    sum_temp += adc_vals[i];
  }
  avr_temp = sum_temp / 10;
  adc_count = 0;
  printf("\n\r Internal Temperature Sensor = %d DegreeCelsius\n\r", avr_temp);
  wakeup = WAKEUP_TIME_1s;
}else{
  wakeup = WAKEUP_TIME_10ms;
}
```



Use Case

Step 4. Set RTC wakeup time & Enter Stop mode

```
/* Setting RTC to wake up from stop mode */
RTC_WakeUp_Time(wakeup);

/* Enter STOP 2 mode */
HAL_PWREx_EnterSTOP2Mode(PWR_STOPENTRY_WFI);

/* Re-configure the system clock */
SYSCLKConfig_STOP();
```



Use Case

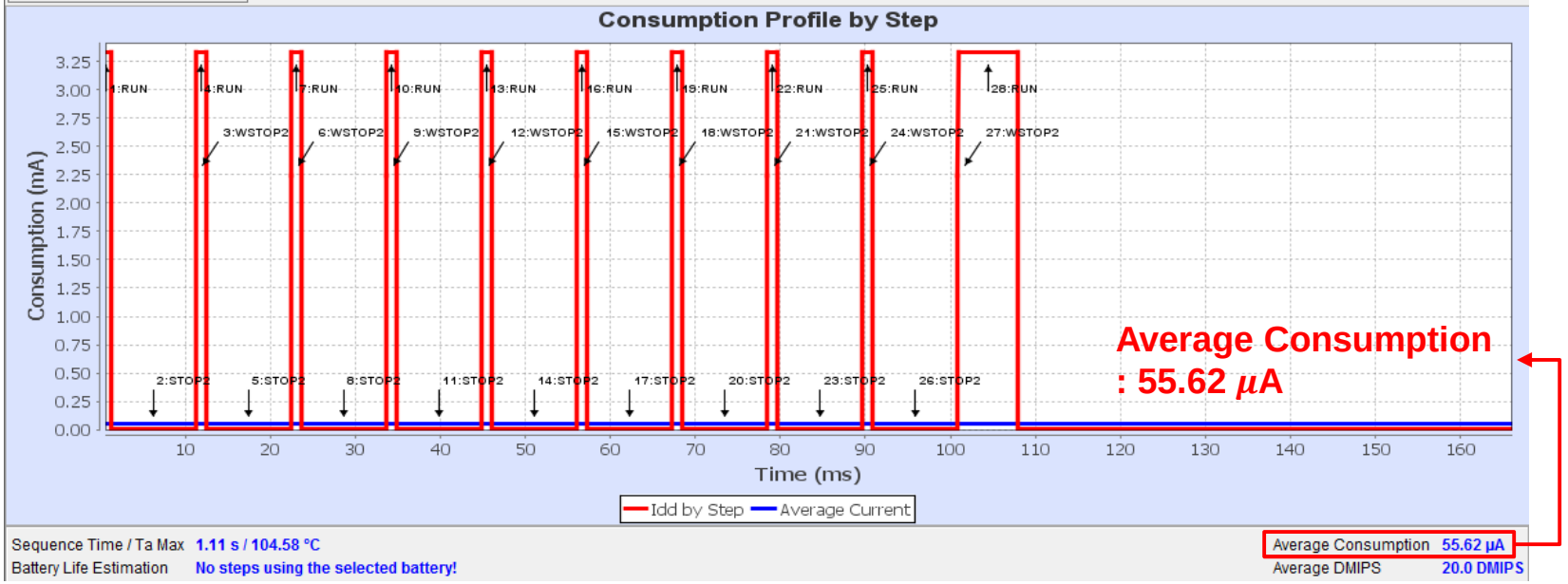
- Power Consumption Simulation using STM32CubeMX

Step | Sequence | Transitions Checker (Off, Log)

Sequence Table

Step	Mode	Vdd	Range/Scale	Memory	CPU/Bus F...	Clock Config	Src Freq	Peripherals	Add. Curr...	Step Current	Duration	DMIPS	Voltage S...	Ta Max	Category
24	WU_FROM...	3.0	NoRange	n/a	4.0 MHz	MSI	4.0 MHz	GPIOD* RTC*	0 mA	2.24 mA	10.6 µs	0.0	Vbus	104.72	In DS Table
25	RUN	3.0	Range1-High	FLASH/ART...	16.0 MHz	HSE	16.0 MHz	ADC1:fs_5_...	0 mA	3.33 mA	1.2 ms	20.0	Vbus	104.58	In DS Table
26	STOP2	3.0	NoRange	n/a	0 Hz	LSI RTC	37.0 kHz	GPIOD* RTC*	0 mA	1.64 µA	10 ms	0.0	Vbus	105	In DS Table
27	WU_FROM...	3.0	NoRange	n/a	4.0 MHz	MSI	4.0 MHz	GPIOD* RTC*	0 mA	2.24 mA	10.6 µs	0.0	Vbus	104.72	In DS Table
28	RUN	3.0	Range1-High	FLASH/ART...	16.0 MHz	HSE	16.0 MHz	ADC1:fs_5_...	0 mA	3.33 mA	7.1 ms	20.0	Vbus	104.58	In DS Table
29	STOP2	3.0	NoRange	n/a	0 Hz	LSI RTC	37.0 kHz	GPIOD* RTC*	0 mA	1.64 µA	1 s	0.0	Vbus	105	In DS Table
30	WU_FROM...	3.0	NoRange	n/a	4.0 MHz	MSI	4.0 MHz	GPIOD* RTC*	0 mA	2.24 mA	10.6 µs	0.0	Vbus	104.72	In DS Table

Display — Plot: All Steps



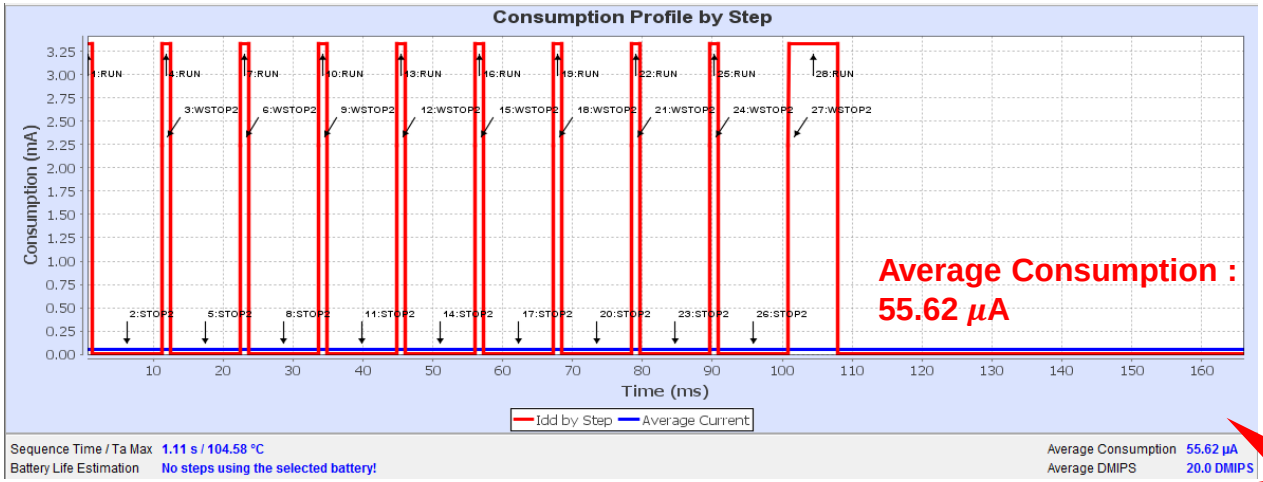
Average Consumption : 55.62 µA

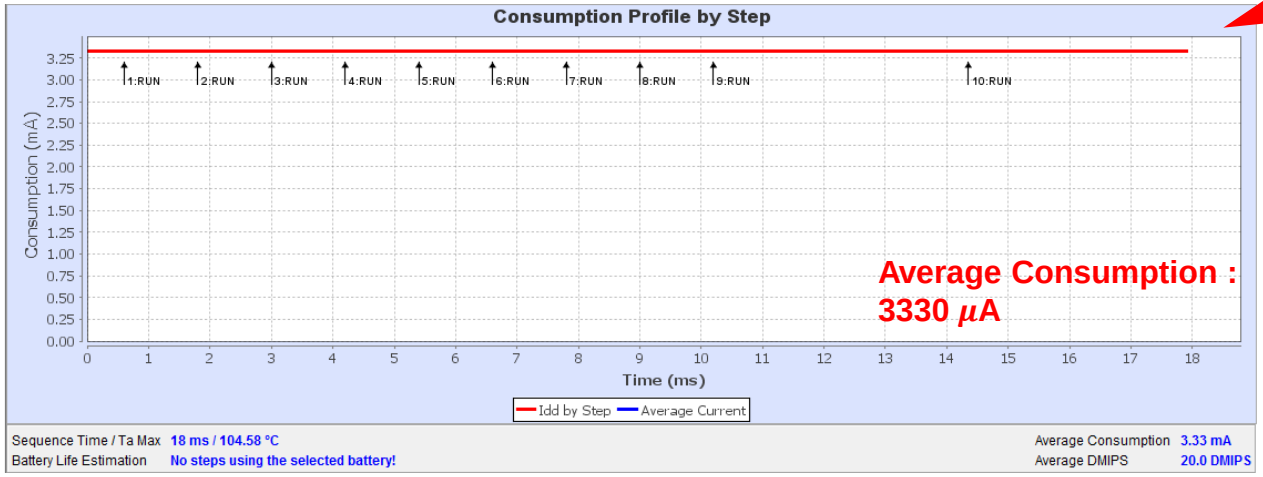
Sequence Time / Ta Max 1.11 s / 104.58 °C
Battery Life Estimation No steps using the selected battery!

Average Consumption 55.62 µA
Average DMIPS 20.0 DMIPS

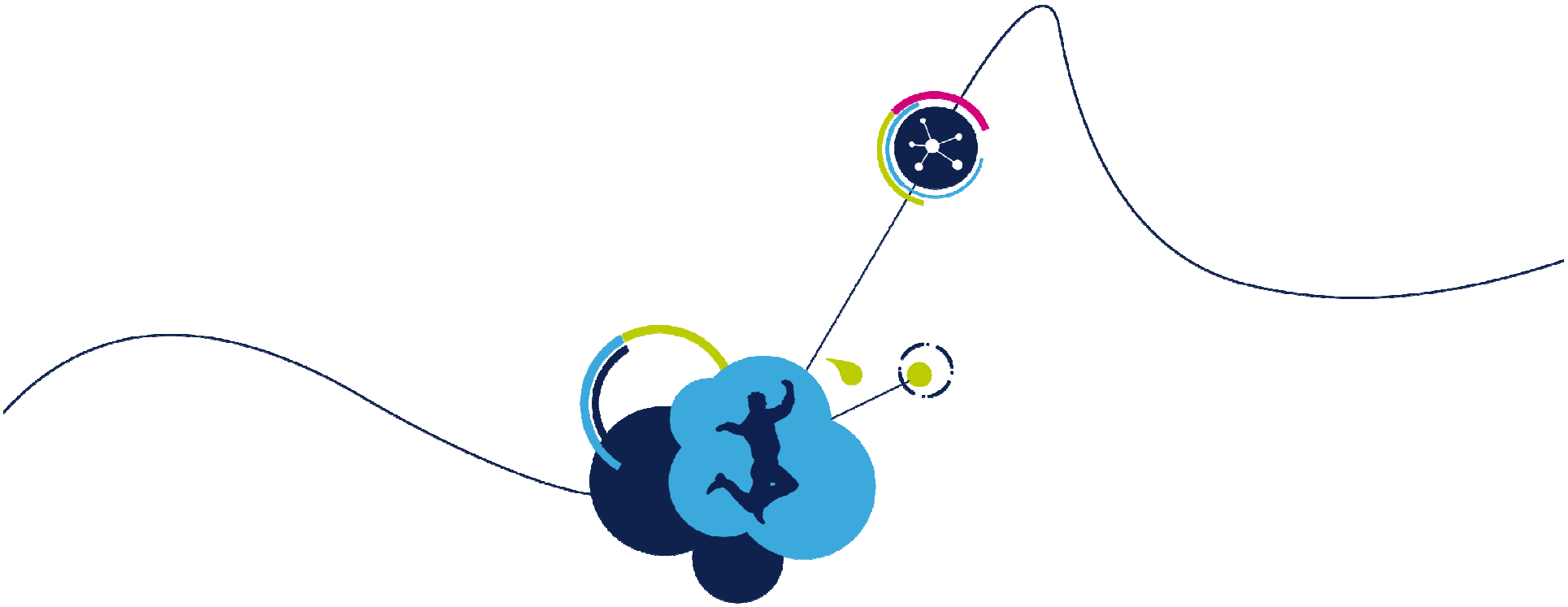
Use Case

Using Stop mode periodically VS Using Run mode only





98.32% 감소



Low Power Peripherals

life.augmented

Batch Acquisition mode (BAM)

Feature summary

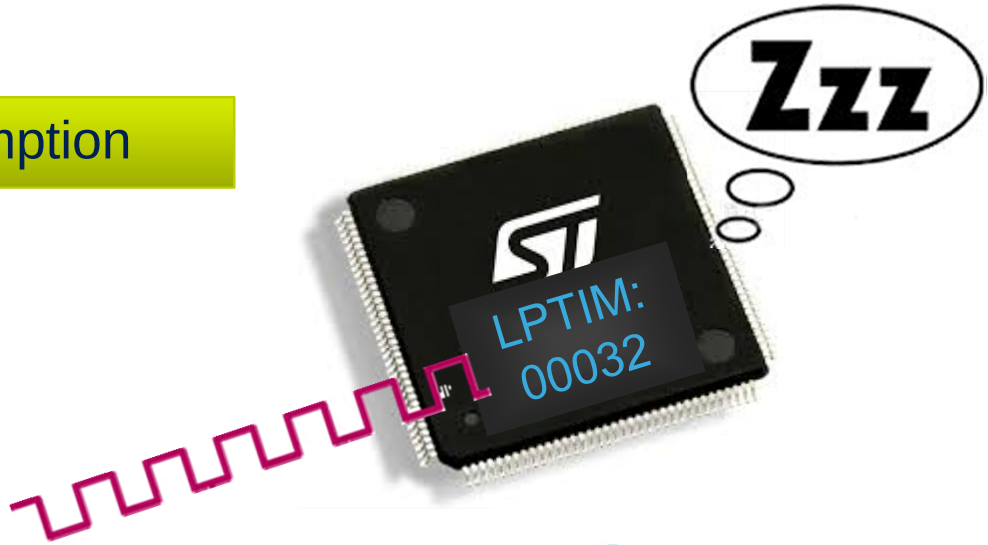
- Optimized mode for transferring data with communication peripherals, while the rest of the device is in low power.
- The BAM feature allows to keep some communication interface (I2C, SPI,…) active while in Sleep mode (CPU clock not working).

1. Only the needed communication peripheral + 1 DMA + 1 SRAM (SRAM1 or SRAM2) are configured with clock enable in Sleep mode
2. Flash is put in power-down mode and Flash clock is gated off during Sleep
3. Enter either Sleep or Low-power sleep mode
   - Note that I2C clock can be at 16 MHz even in low-power sleep mode, allowing 1 MHz Fast-mode Plus support. U(S)ART/LPUART clock can also be HSI.

Low Power Timer - LPTIM

Features Summary

- Asynchronous running capability
- Ultra low power-consumption



- Timeout function for wakeup from low power modes

Low Power UART - LPUART

LPUART Features

- LPUART includes all necessary hardware support to make asynchronous serial communications possible with minimum power consumption.
- Only LSE 32.768 is required to allow UART communication at up to 9600 baud → For this purpose, the baudrate generation has been changed comparing to the USART peripheral.
- Higher baudrates can be reached when the LPUART is clocked by clock sources different from the LSE clock.
- Baudrate generation and Implementation are summarized in the next slides.

USB – Link Power Management

USB-LPM

- LPM is a new power-saving state called “Sleep”, with fast entry and exit times, compared to traditional “Suspend” mode.

- Benefits : Power consumption optimization across both the host and USB devices while idle, and extend battery life of hand-held applications.

	L1 (Sleep)	L2 (Suspend)
Entry	Explicitly entered via LPM extended transaction	Implicitly entered via 3 ms of link inactivity
Exit	Device- or host-initiated via resume signaling; Remote-wake can be (optionally enabled/disabled via the LPM transaction	Device- or host-initiated via resume signaling; Remote-wake can be (optionally enabled/disabled by software
Signaling	Low- and full-speed idle	Low- and full-speed idle
Latencies	**Entry : ~ 10 µs** **Exit : > 70 µs to 1 ms (host-specific)**	**Entry : ~ 3 ms** **Exist : > 20 ms (Resume signaling)** **+ 10 ms (Resume recovery)**
Link Power Consumption	~0.6 mW (data line- pull-ups)	~0.6 mW (data line- pull-ups)
Device Power Consumption	Device power consumption level is application/implementation specific	Device consumption is limited to ≤2.5 mA
Hot Removal	Natively detected per USB 2.0 mechanisms	Natively detected per USB 2.0 mechanisms

The existing suspend/resume mechanisms have been proven to be inadequate for current and future generation mobile platforms. The bus-imposed resume latencies are so long that the mechanism doesn't support response times that are useful in many applications, especially in hand-held platforms

Thank you

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