ENGR-2350
Embedded Control

Timer Examples
Power Consumption, LPMs

Timers: Examples

Example 1: Configure a TIMG module to interrupt every 100µs assuming a BUSCLK of 12 MHz and a divider of 4.

A. Use this Timer to implement a program delay of 500ms
   i. Redo with a divider of 64 and `.period=50000;`

B. Measure the time between a “start” and “stop” signal; e.g., the length of time a button is pressed
   i. Do this approximately (using longer resets from above)
   ii. Do this “exactly”

Timers: Examples

Example 2: What is the smallest possible divider that may be used to generate a 10 ms period? Assume using a BUSCLK of 32 MHz.

- What is the time resolution for this configuration?

- Small divider ➜ Fast counting ➜ short count period ➜ higher time resolution

Timers: Examples

Example 3: Configure a TIMG module to interrupt every 1s using LFCLK = 32.768 kHz.

A. Use this Timer to cycle through random colors lit by the RGB LED on the launchpad board

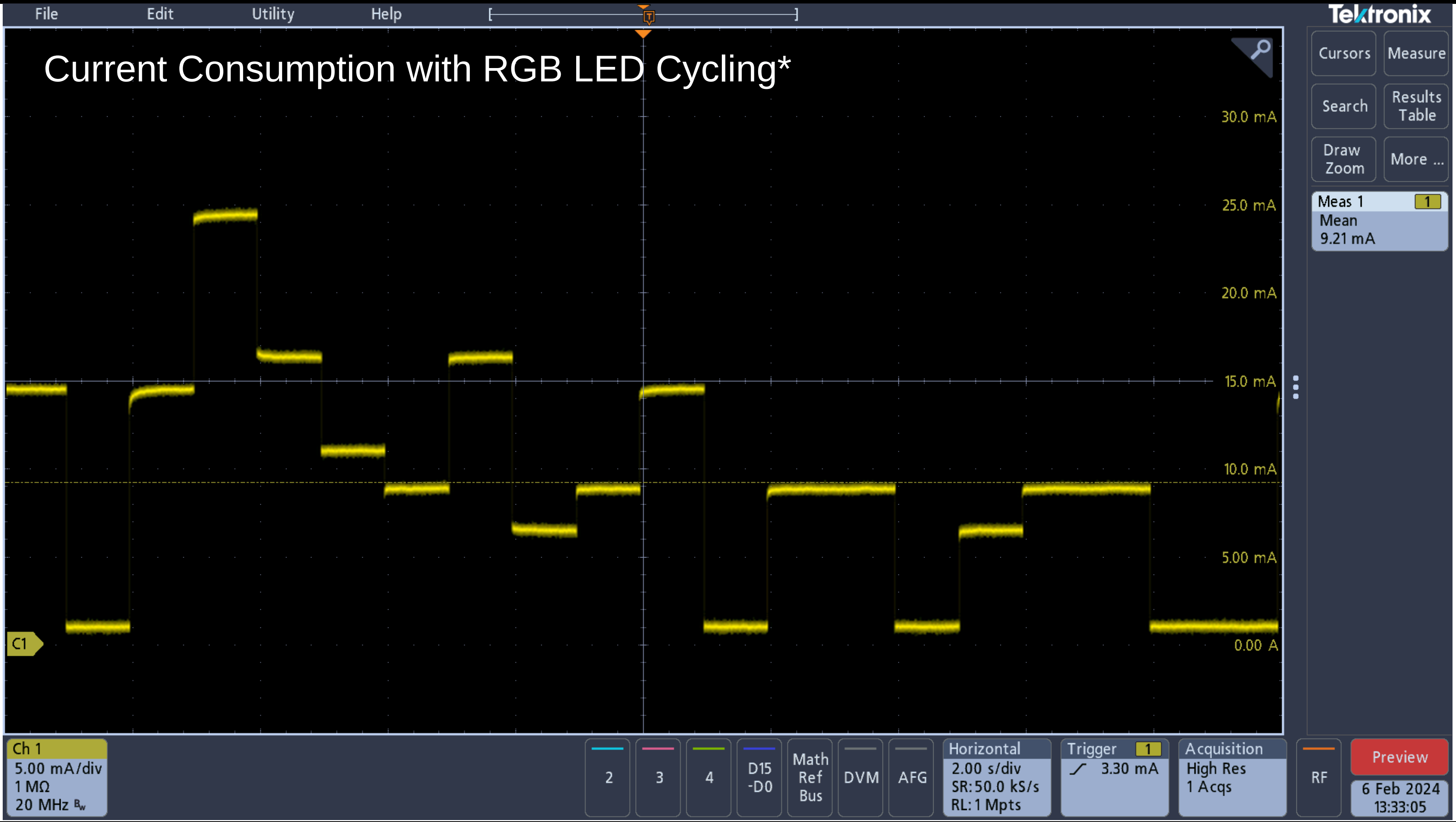
B. Make the microcontroller more power efficient…

- You will not need to know how to do this! This is an FYI type thing.

Microcontroller Power Consumption

Microcontroller CPU consumes significant power:

- Faster clock, more current
- Not dependent on type of operations performed, e.g.:
  - while(1){}
  - while(1){ i++; }
  - Complicated DSP routine
- How to reduce?


File
Edit
Utility
Help
Tektronix
Current Consumption with RGB LED Cycling*
30.0 mA
25.0 mA
20.0 mA
15.0 mA
10.0 mA
5.00 mA
0.00 A
C1
Cursors
Measure
Search
Results Table
Draw Zoom
More ...
Meas 1
Mean
9.21 mA
Ch 1
5.00 mA/div
1 MΩ
20 MHz
2
3
4
D15 -D0
Math Ref Bus
DVM
AFG
Horizontal
2.00 s/div
SR: 50.0 kS/s
RL: 1 Mpts
Trigger
3.30 mA
Acquisition
High Res
1 Acqs
RF
Preview
6 Feb 2024
13:33:05

Microcontroller Power Reduction

- **Reduce clock rate:** evaluate code slower
- **Reduce core voltage:** May lead to errors/resets due to “brown-out”
- Follow instructions in datasheet to minimize stray current consumption from peripherals:

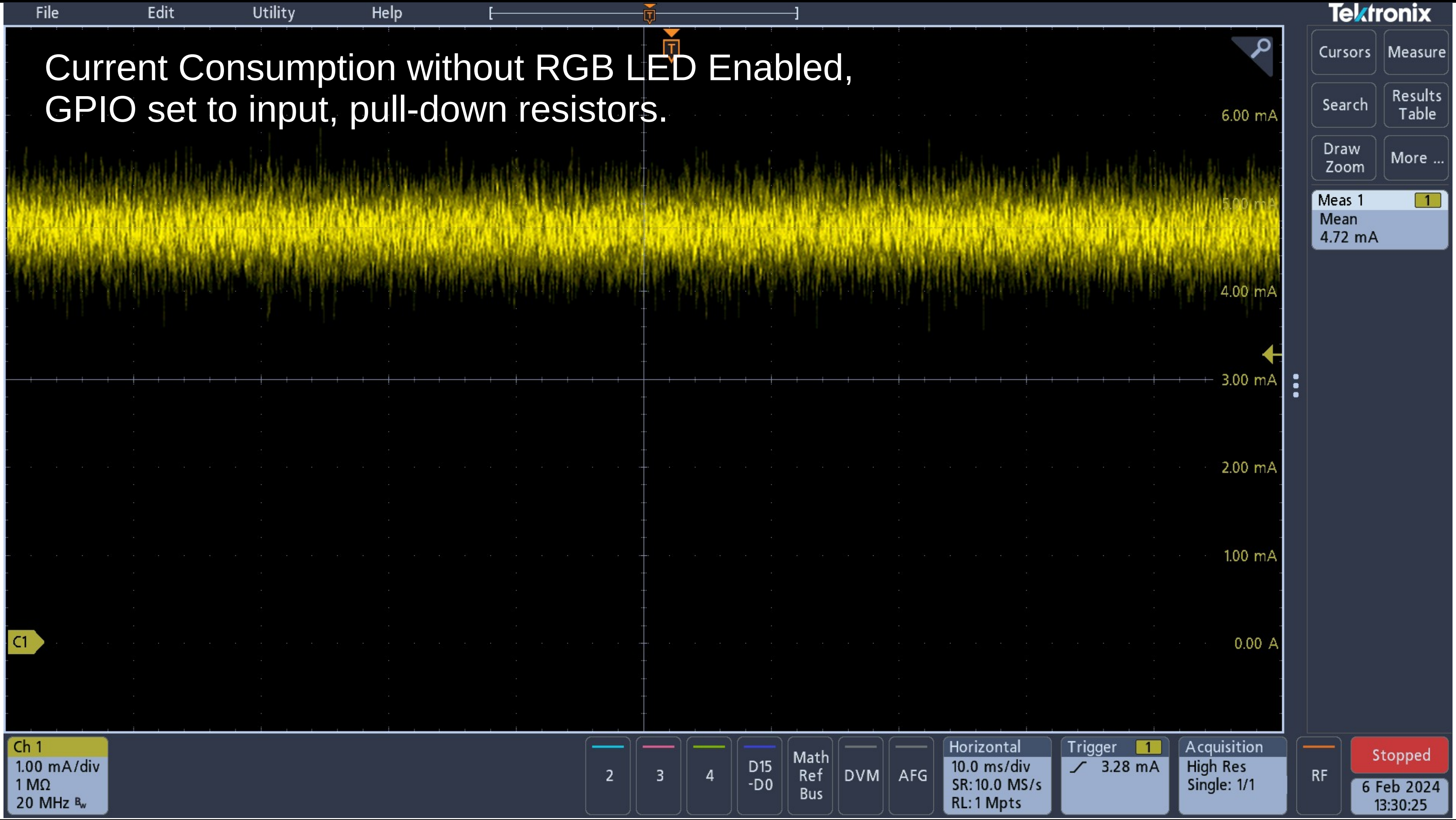
6.4 Connections for Unused Pins

Table 6-4 lists the correct termination of unused pins.

Table 6-4. Connection of Unused Pins

PIN (1)	POTENTIAL	COMMENT
PAx and PBx	Open	Set corresponding pin functions to GPIO (PINCMx.PF = 0x1) and configure unused pins to output low or input with the internal pullup or pulldown resistor enabled.
NRST	VCC	NRST is an active-low reset signal. Pull the pin high to VCC, or the device cannot start. For more information, see Section 9.1.

(1) Any unused pin with a function that is shared with general-purpose I/O must follow the "PAx and PBx" unused pin connection guidelines.


Current Consumption without RGB LED Enabled,
GPIO set to input, pull-down resistors.
File
Edit
Utility
Help
Tektronix
Cursors
Measure
Search
Results Table
Draw Zoom
More ...
Meas 1
Mean
4.72 mA
6.00 mA
5.00 mA
4.00 mA
3.00 mA
2.00 mA
1.00 mA
0.00 A
C1
Ch 1
1.00 mA/div
1 MΩ
20 MHz
2
3
4
D15 -D0
Math Ref Bus
DVM
AFG
Horizontal
10.0 ms/div
SR: 10.0 MS/s
RL: 1 Mpts
Trigger
3.28 mA
Acquisition
High Res
Single: 1/1
RF
Stopped
6 Feb 2024
13:30:25

Microcontroller Power Reduction

- **Reduce clock rate:** evaluate code slower
- **Reduce core voltage:** May lead to errors/resets due to “brown-out”
- Follow instructions in datasheet to minimize stray current consumption from peripherals
- Push operations to peripherals
  - Hardware peripherals typically more power efficient if operation is supported

For all following slides:
Microcontroller referenced is **MSP432P401R** NOT the **MSPM0G3507**

Why: MSP432P401R had better power documentation andmuch better low-power modes as compared to the MSPM0G3507

The MSP432P401R was used in Embedded Control from Fall 2021 to Spring 2025

Table in Sec. 5-23: **Current Consumption of Digital Peripherals**

TI SLAS826F **MSP43P401R** Datasheet

PARAMETER	TEST CONDITIONS	TYP	MAX	UNIT
I_{TIMER_A}	Timer_A configured as PWM timer with 50% duty cycle	5		µA/MHz
$I_{TIMER32}$	Timer32 enabled	3.5		µA/MHz
I_{UART}	eUSCI_A configured in UART mode	6.5		µA/MHz
I_{SPI}	eUSCI_A configured in SPI master mode	5		µA/MHz
I_{I2C}	eUSCI_B configured in I^2C master mode	5		µA/MHz
I_{WDT_A}	WDT_A configured in interval timer mode	6		µA/MHz
I_{RTC_C}	RTC_C enabled and sourced from 32-kHz LFXT	100		nA
I_{AES256}	AES256 active	19		µA/MHz
I_{CRC32}	CRC32 active	2		µA/MHz

Microcontroller Power Reduction

- **Reduce clock rate:** evaluate code slower
- **Reduce core voltage:** May lead to errors/resets due to “brown-out”
- Follow instructions in datasheet to minimize stray current consumption from peripherals
- Push operations to peripherals
  - Hardware peripherals typically more power efficient if operation is supported.
  - Allows for reduced clock rates and ...

Microcontroller Low Power Modes

- Manipulate the powered/operation states of the CPU and/or peripherals.
  - Turn off CPU when not needed!
  - Let peripherals do the hard work
  - Various levels of “Low Power Modes” may exist...

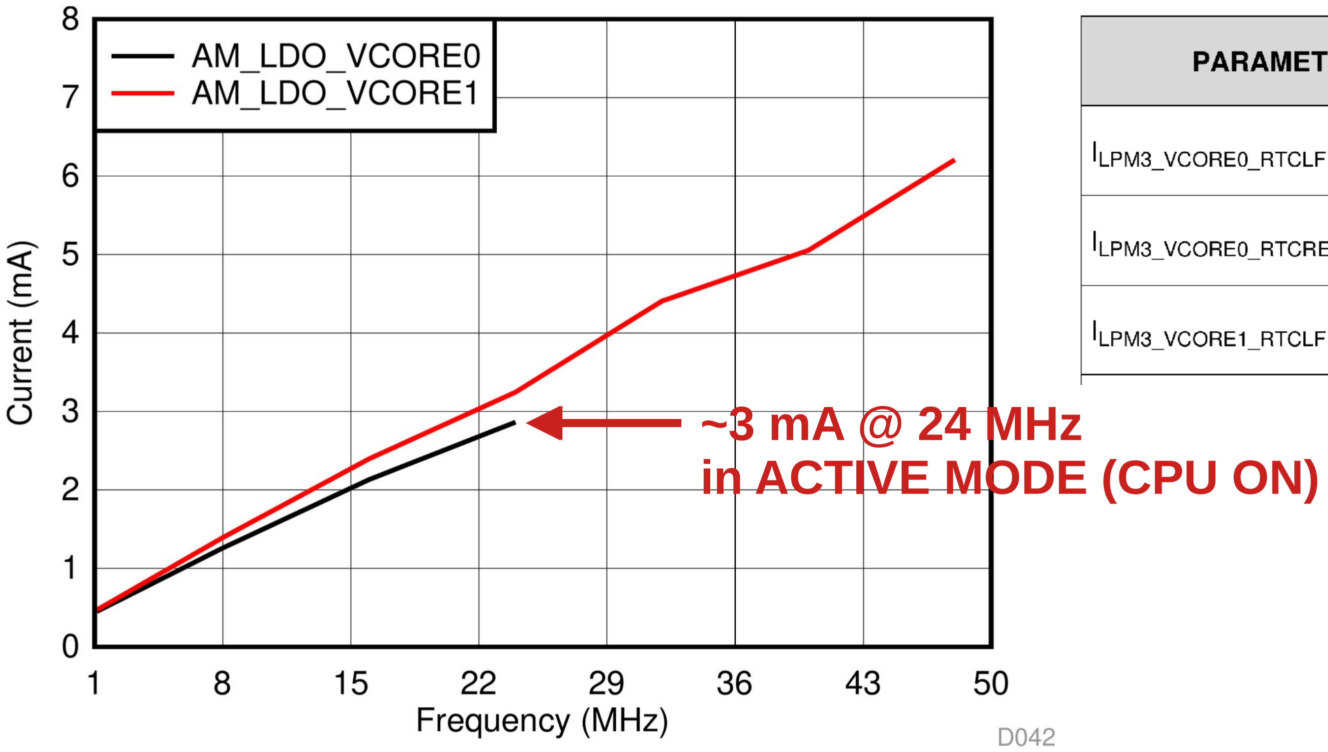
Table 6-42. Operating Modes   TI SLAS826F **MSP43P401R** Datasheet

OPERATING MODE	DESCRIPTION
AM_LDO_VCORE0	LDO based active mode, normal performance, core voltage level 0
LPM0_LDO_VCORE0	Same as above, except that CPU is OFF (no code execution)
AM_LDO_VCORE1	LDO based active mode, maximum performance, core voltage level 1
LPM0_LDO_VCORE1	Same as above, except that CPU is OFF (no code execution)
AM_DCDC_VCORE0	DC-DC based active mode, normal performance, core voltage level 0
LPM0_DCDC_VCORE0	Same as above, except that CPU is OFF (no code execution)
AM_DCDC_VCORE1	DC-DC based active mode, maximum performance, core voltage level 1
LPM0_DCDC_VCORE1	Same as above, except that CPU is OFF (no code execution)
AM_LF_VCORE0	LDO based low-frequency active mode, core voltage level 0
LPM0_LF_VCORE0	Same as above, except that CPU is OFF (no code execution)
AM_LF_VCORE1	LDO based low-frequency active mode, core voltage level 1
LPM0_LF_VCORE1	Same as above, except that CPU is OFF (no code execution)
LPM3_VCORE0	LDO based low-power mode with full state retention, core voltage level 0, RTC and WDT can be active
LPM3_VCORE1	LDO based low-power mode with full state retention, core voltage level 1, RTC and WDT can be active
LPM4_VCORE0	LDO based low-power mode with full state retention, core voltage level 0, all peripherals disabled.
LPM4_VCORE1	LDO based low-power mode with full state retention, core voltage level 1, all peripherals disabled
LPM3.5	LDO based low-power mode, core voltage level 0, no retention of peripheral registers, RTC and WDT can be active
LPM4.5	Core voltage turned off, wake-up only through pin reset or wake-up capable I/Os

Table 6-1. Operating Modes TI SLAS704F **MSP430FR5969** Datasheet

MODE	AM		LPM0	LPM1	LPM2	LPM3	LPM4	LPM3.5	LPM4.5	
	ACTIVE	**ACTIVE, FRAM OFF**[1]	**CPU Off**[2]	**CPU OFF**	**STANDBY**	**STANDBY**	**OFF**	**RTC ONLY**	**SHUTDOWN WITH SVS**	**SHUTDOWN WITHOUT SVS**
Maximum system clock	16 MHz		16 MHz	16 MHz	50 kHz	50 kHz	0[3]	50 kHz	0[3]	
Typical current consumption, T_A = 25°C	103 µA/MHz	65 µA/MHz	70 µA at 1 MHz	35 µA at 1 MHz	0.7 µA	0.4 µA	0.3 µA	0.25 µA	0.2 µA	0.02 µA
Typical wake-up time	N/A		instant	6 µs	6 µs	7 µs	7 µs	250 µs	250 µs	1000 µs
Wake-up events	N/A		all	all	LF I/O Comp	LF I/O Comp	I/O Comp	RTC I/O	I/O	
CPU	**on**		off	off	off	off	off	reset	reset	
FRAM	**on**	off[1]	standby (or off[1])	off	off	off	off	off	off	
Peripherals in high-frequency state[4]	**yes**		**yes**	**yes**	no	no	no	reset	reset	
Peripherals in low-frequency state[4]	**yes**		**yes**	**yes**	**yes**	**yes**[5]	no	RTC	reset	
Peripherals in unclocked state[4]	**yes**		**yes**	**yes**	**yes**	**yes**[5]	**yes**[5]	reset	reset	
MCLK	**on** (16 MHz_{MAX})		off	off	off	off	off	off	off	
SMCLK	optional[6] (16 MHz_{MAX})		optional[6] (16 MHz_{MAX})	optional[6] (16 MHz_{MAX})	off	off	off	off	off	
ACLK	**on** (50 kHz_{MAX})		**on** (50 kHz_{MAX})	**on** (50 kHz_{MAX})	**on** (50 kHz_{MAX})	**on** (50 kHz_{MAX})	off	off	off	
External clock	optional (16 MHz_{MAX})		optional (16 MHz_{MAX})	optional (16 MHz_{MAX})	optional (50 kHz_{MAX})	optional (50 kHz_{MAX})	optional (50 kHz_{MAX})	off	off	
Full retention	**yes**		**yes**	**yes**	**yes**	**yes**	**yes**	no	no	

Current Consumption Figures Specifications TI SLAS826F **MSP43P401R** Datasheet



Flash Execution V_{CC} = 3 V T_A = 25°C

Figure 5-13. Frequency vs Current Consumption

PARAMETER	V_{CC}	25°C TYP	25°C MAX	UNIT
$I_{LPM3\_VCORE0\_RTCLF}$ (7) (8)	2.2 V	0.64		µA
	3.0 V	0.66	0.85	
$I_{LPM3\_VCORE0\_RTCREFO}$ (9) (8)	2.2 V	1.07		µA
	3.0 V	1.16	1.35	
$I_{LPM3\_VCORE1\_RTCLF}$ (7) (8)	2.2 V	0.93		µA
	3.0 V	0.95	1.35	

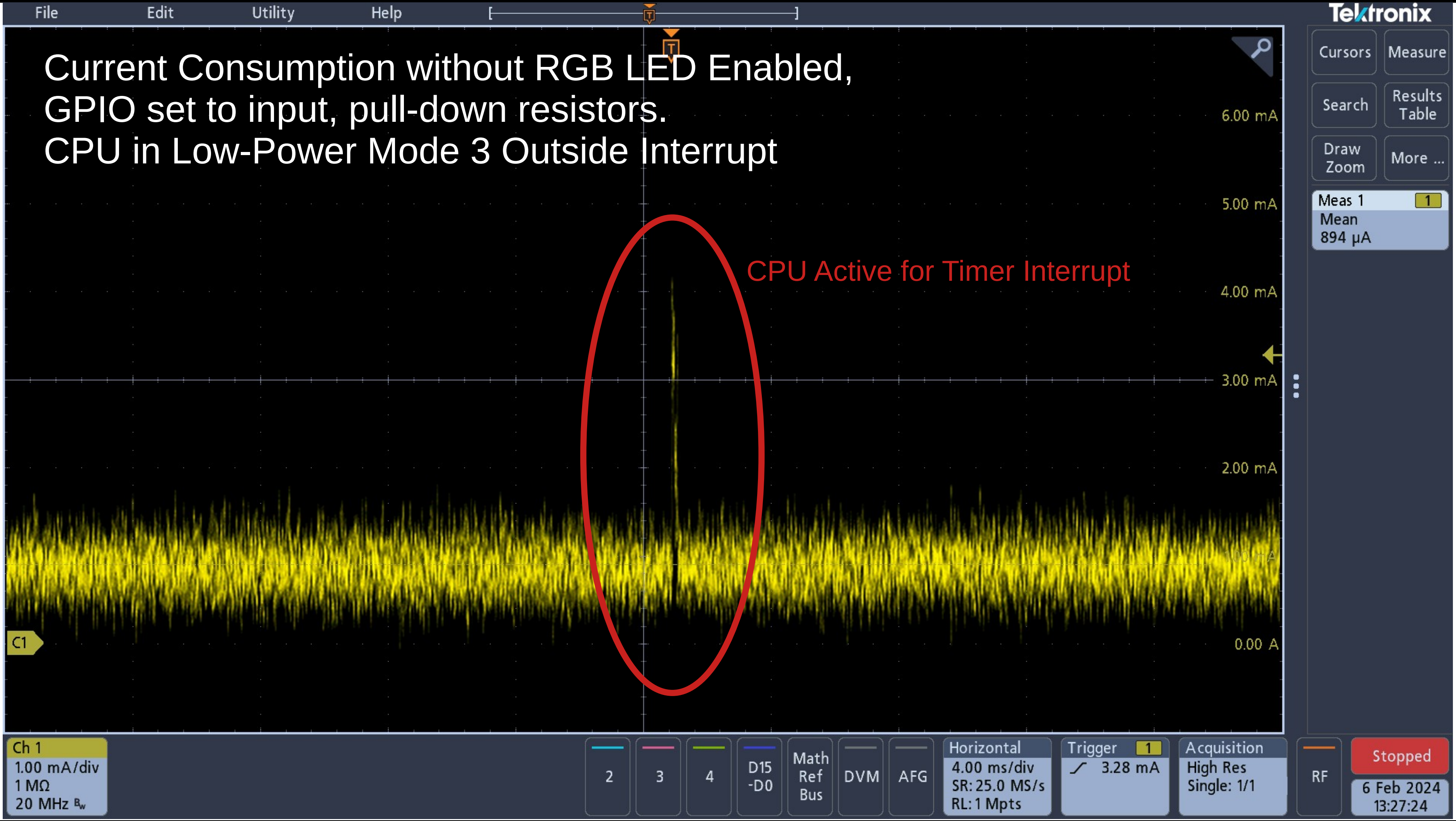
max 1.35 µA in LPM3 (CPU OFF)

Timers: Examples

Example 2: Configure a timer module to interrupt every 1s using ACLK = 32.768 kHz. (ACLK same as LFCLK)

- Use this Timer to cycle through random colors lit by the RGB LED.
- Make the microcontroller more power efficient…
  - By putting the CPU in **Low Power Mode 3** when not in use

Current Consumption without RGB LED Enabled, GPIO set to input, pull-down resistors. CPU in Low-Power Mode 3 Outside Interrupt

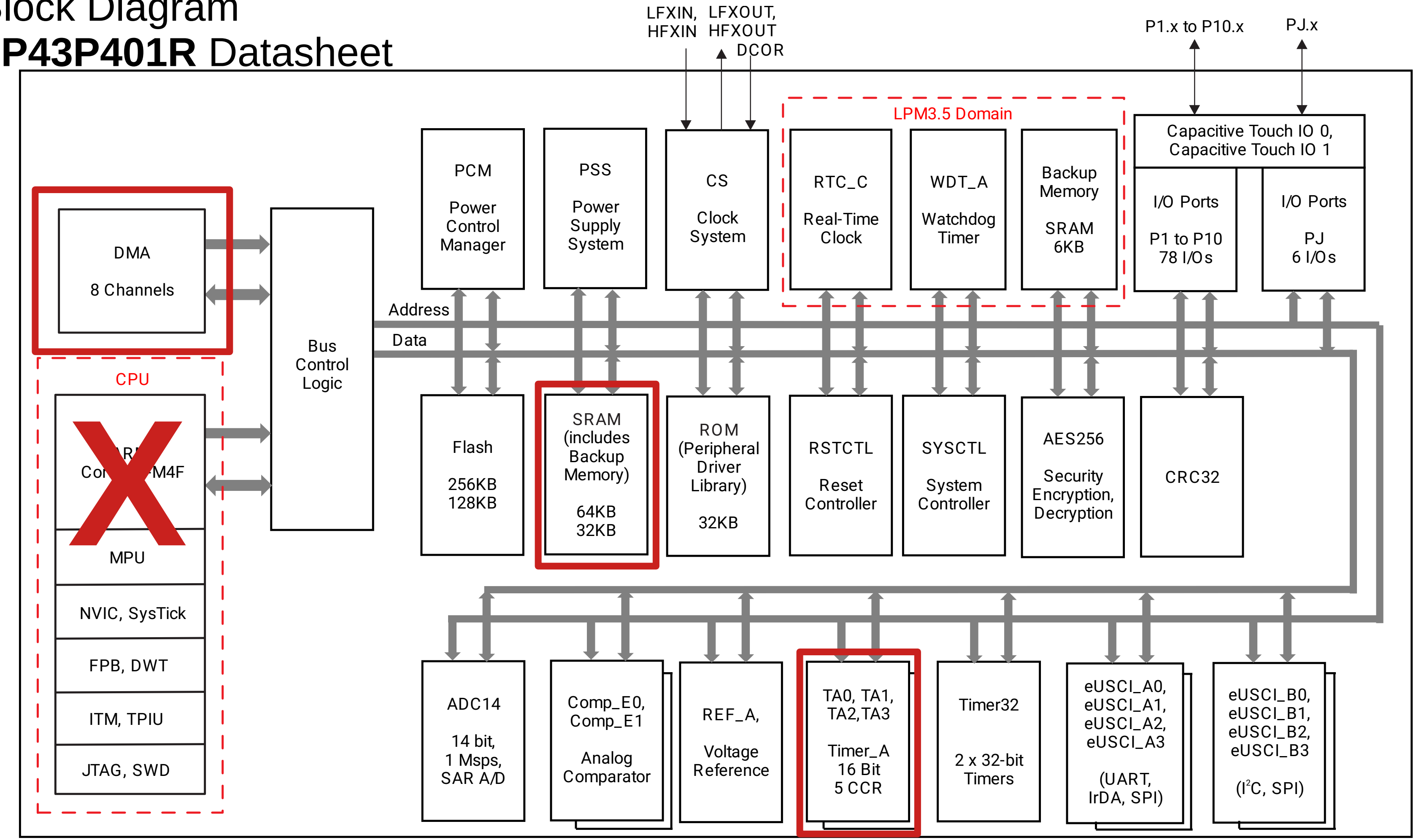


Timers: Examples

Example 2: Configure a timer module to interrupt every 1s using ACLK = 32.768 kHz. (ACLK same as LFCLK)

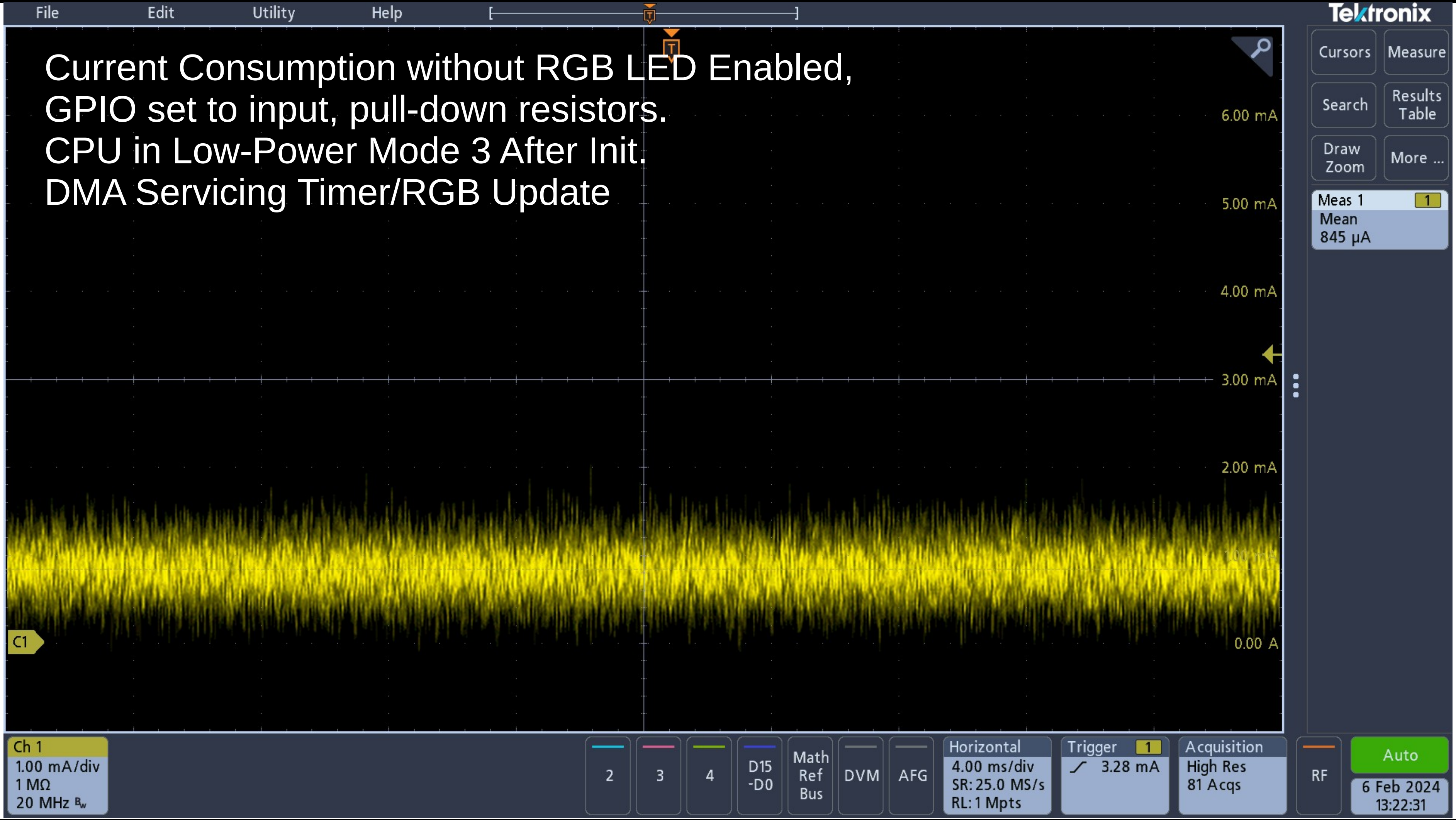
- Use this Timer to cycle through random colors lit by the RGB LED
- Make the microcontroller more power efficient…
  - By putting the CPU in **Low Power Mode 3** when not in use
- Eliminate the need for the CPU after startup
  - Use hardware to update RGB LED from memory!

MSP432P401R Block Diagram
TI SLAS826F **MSP43P401R** Datasheet



DMA – Direct Memory Access

- A module/peripheral that can move information to/from memory to registers *without CPU intervention*.
  - Basic operation: A “trigger” causes the DMA to do one or more transfers of data.
  - Successive triggers can increment through an array.
  - CPU may be OFF for entire process
  - Ex.: PCI Buses make extensive use of DMA modules


File
Edit
Utility
Help
Tektronix
Current Consumption without RGB LED Enabled,
GPIO set to input, pull-down resistors.
CPU in Low-Power Mode 3 After Init.
DMA Servicing Timer/RGB Update
6.00 mA
5.00 mA
4.00 mA
3.00 mA
2.00 mA
0.00 A
C1
Cursors
Measure
Search
Results Table
Draw Zoom
More ...
Meas 1
Mean
845 μA
Ch 1
1.00 mA/div
1 MΩ
20 MHz
2
3
4
D15 -D0
Math Ref Bus
DVM
AFG
Horizontal
4.00 ms/div
SR: 25.0 MS/s
RL: 1 Mpts
Trigger
3.28 mA
Acquisition
High Res
81 Acqs
RF
Auto
6 Feb 2024
13:22:31

Current Measurements

- State 1: No LPM3: ~4.75 mA ↣ ~16 mW
- State 2: LMP3 Outside Interrupt: ~ 895 µA* ↣ ~3.0 mW
- State 3: LMP3+DMA: ~ 845 µA* ↣ ~2.8 mW

* Datasheet indicates these numbers should be much lower! Maybe measurement limitation OR missing some additional current consumption reductions.