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Bluetooth® low energy, A Very Low Power Solution

Bluetooth® low energy is a new low-power, open, RF networking standard by the same team that developed the "classic" *Bluetooth* technology (*Bluetooth* SIG) found in most of today's cellular phones, laptops and even automobiles. *Bluetooth* low energy is designed to enable connectivity of power-sensitive devices operating on primary cells – alkaline or coin cells – for long periods of time ranging from months to potentially several years. The *Bluetooth* creators recognize and are responding to the need and opportunity for an open wireless network focused on very low-power, low-cost operation in relatively close proximity to the user. This personal area network, or PAN, is capable of piggy-backing on existing *Bluetooth* technology's popularity and ubiquity.

Features and Benefits

TI's first product to support the new *Bluetooth* low energy single-mode standard is the CC254x family. The CC254x, single-mode *Bluetooth* low energy devices will support a *Bluetooth* low energy master and/or slave role, and must be extremely power efficient to ensure that a battery operated device can operate for months or years without the need to replace batteries.

The CC2540 is a cost-effective, low-power, true system-on-chip (SoC) for *Bluetooth* low energy applications. The device operates as a 1 Mbps GFSK RF transceiver in the 2.4 GHz range, and combined with TI's *Bluetooth* low energy protocol stack, profiles, and application code, provides everything necessary to build a compliant *Bluetooth* low energy single-mode product. 128K and 256K FLASH w/ 8K RAM options for the device exist with an openly programmable interface to allow for application code to co-reside on the chip allowing a low-cost, true single chip solution. The device supports 21 GPIO, 2 USARTs, ADC, USB 2.0, IR generation circuitry, Timers, Op-Amp, Comparator, and more, to allow for the development of flexible and diverse applications directly on the chip in the areas of sports and fitness, mobile accessories, consumer health and wellness, medical, remote controls, and more.

Battery Power Consumption

Designers of portable equipment using coin cell or alkaline batteries are challenged by system level energy budget considerations, mainly driven by MCU and RF current consumption, as well as by the capacity and specification limits battery manufacturers provide. When designing a battery powered wireless product, the effect of power draw from the *Bluetooth* low energy chip in particular is critical to the success and longevity of the product. Power consumption for a transceiver must be calculated using the various states of the radio. For example, as shown in figure 1, you cannot look at peak RX or TX current to assess overall power consumption since the time in low power "sleep" mode dominates overall power consumption.

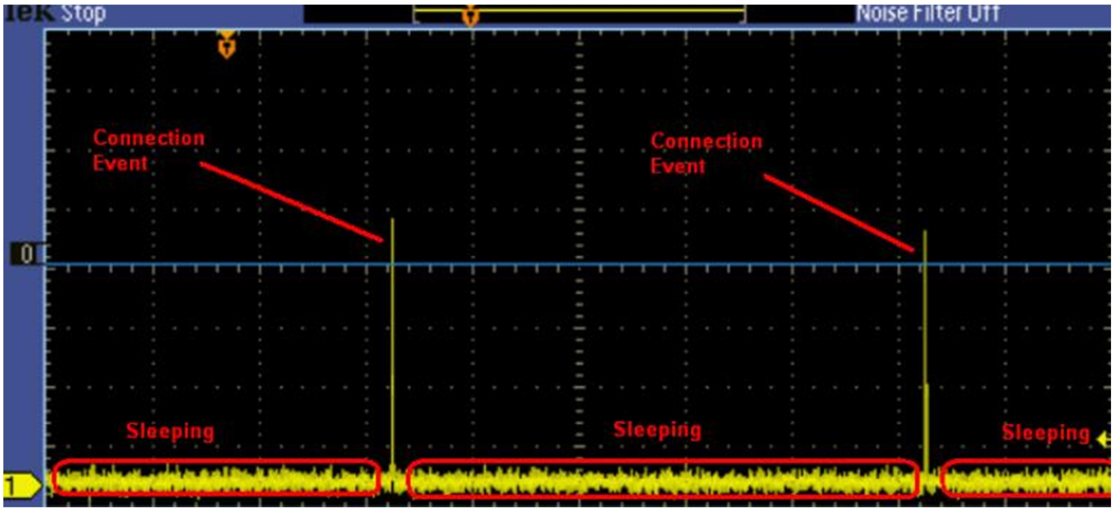


Figure 1: Current Consumption versus Time during a Bluetooth low energy Connection

Thus, in addition to its rich feature set, the CC2540 was designed to truly optimize performance with respect to power efficiency. This was necessary to ensure that a variety of applications and use cases would be implementable in a way that ensured very long battery life times. Since time in the low power (sleep) state dominates power consumption in very low duty cycle protocols like *Bluetooth* low energy, the CC2540 was designed with three "sleep" power modes in place. Power Mode 1, with a 3-us Wake up consumes on the order of 235uA. Power Mode 2, with wakeup via a sleep timer, consumes approximately 0.9uA. Finally Power Mode 3, with wakeup on external interrupt only can reduce power to as little as 0.4uA. Of course these are raw values for the chip and don't include additional components, leak, or other sources of power consumption or battery drain.

To further analyze the overall power consumption of a *Bluetooth* low energy device, we must consider the state transitions and current consumption during the "connection event". This includes an analysis of the current consumption by the MCU during processing, wake up and transceiver state transitions (e.g. RX->TX), idle time, etc… Figure 2 breaks down the connection interval based on empirically collected results using the CC2540.

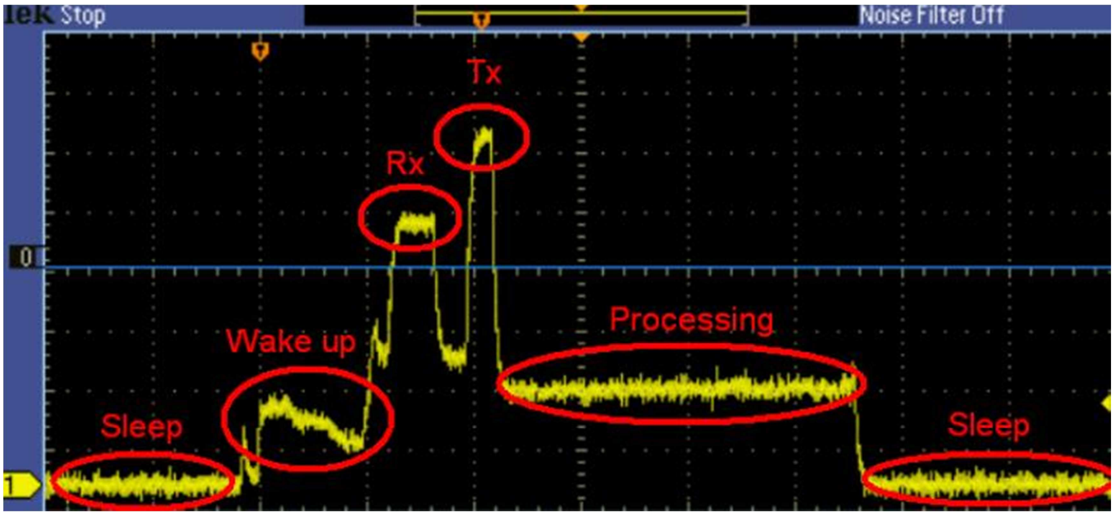


Figure 2: Current Consumption Vs. Time during Connection Interval

Between connection events the CC2540 will go into Power Mode 2, where the internal digital voltage regulator is turned off, along with the 16MHz RCOSC and the 32 MHz crystal oscillator. The 32 kHz sleep timer remains active while the RAM and registers are retained. The only way that the device will wake up is if an I/O interrupt or sleep timer interrupt occurs.

System Overview

Appnote AN092: Measuring *Bluetooth* Low Energy Power Consumption, available on the CC2540 product folder page of TI's website provides further information on the hardware and software modifications used to create a test setup. For our *Bluetooth* low energy software stack, we utilize the IAR Embedded Workbench for writing, debugging, loading, and testing the applications.

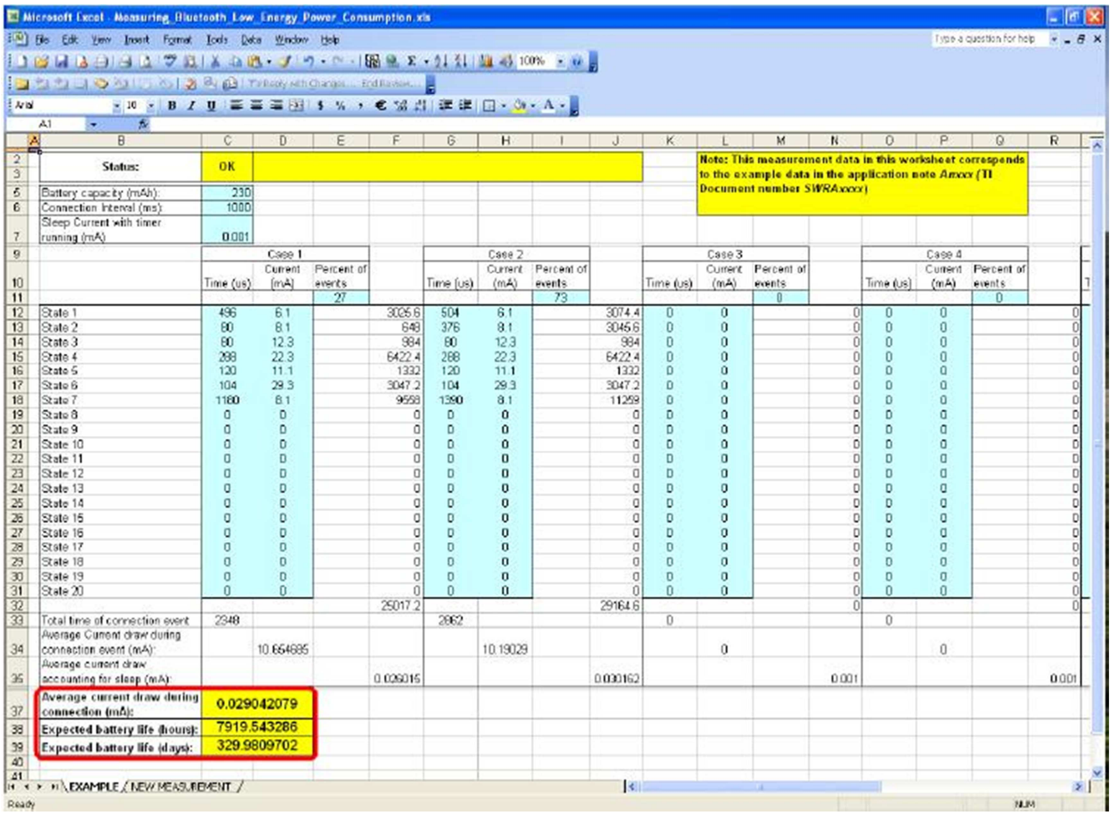
Using an oscilloscope and some slight modifications to our CC2540DK-MINI kit to allow us to measure current draw during operation, we were able to assess each state during sleep and connection events to determine the time and current consumption during operation. These are shown below in Figure 3.

	Time (µs)	Current (mA)
State 1 (wake-up)	504	6.1
State 2 (pre-processing)	376	8.1
State 3 (pre-Rx)	80	12.3
State 4 (Rx)	288	22.3
State 5 (Rx-to-Tx)	120	11.1
State 6 (Tx)	104	29.3
State 7 (post-processing)	1390	8.1

Figure 3: Time and Current Measurements from Capture with 2.8ms Awake Time

Processing Results

With these numbers in place, the task of calculating overall battery longevity then comes down to simply adding the battery capacity of the battery or batteries in your product and the connection interval in which you would like to transmit and/or receive data between master and slave to a series of formulas that were easily derived.



	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2–3	Status:	OK									Note: This measurement data in this worksheet corresponds to the example data in the application note Anxxx (TI Document number SWRAxxxx)						
5	Battery capacity (mAh):	230															
6	Connection Interval (ms):	1000															
7	Sleep Current with timer running (mA):	0.001															
9		Case 1				Case 2				Case 3				Case 4			
10		Time (us)	Current (mA)	Percent of events		Time (us)	Current (mA)	Percent of events		Time (us)	Current (mA)	Percent of events		Time (us)	Current (mA)	Percent of events	
11				27				73				0				0	
12	State 1	496	6.1		3025.6	504	6.1		3074.4	0	0		0	0	0		0
13	State 2	80	8.1		648	376	8.1		3045.6	0	0		0	0	0		0
14	State 3	80	12.3		984	80	12.3		984	0	0		0	0	0		0
15	State 4	288	22.3		6422.4	288	22.3		6422.4	0	0		0	0	0		0
16	State 5	120	11.1		1332	120	11.1		1332	0	0		0	0	0		0
17	State 6	104	29.3		3047.2	104	29.3		3047.2	0	0		0	0	0		0
18	State 7	1180	8.1		9558	1390	8.1		11259	0	0		0	0	0		0
19	State 8	0	0		0	0	0		0	0	0		0	0	0		0
20	State 9	0	0		0	0	0		0	0	0		0	0	0		0
21	State 10	0	0		0	0	0		0	0	0		0	0	0		0
22	State 11	0	0		0	0	0		0	0	0		0	0	0		0
23	State 12	0	0		0	0	0		0	0	0		0	0	0		0
24	State 13	0	0		0	0	0		0	0	0		0	0	0		0
25	State 14	0	0		0	0	0		0	0	0		0	0	0		0
26	State 15	0	0		0	0	0		0	0	0		0	0	0		0
27	State 16	0	0		0	0	0		0	0	0		0	0	0		0
28	State 17	0	0		0	0	0		0	0	0		0	0	0		0
29	State 18	0	0		0	0	0		0	0	0		0	0	0		0
30	State 19	0	0		0	0	0		0	0	0		0	0	0		0
31	State 20	0	0		0	0	0		0	0	0		0	0	0		0
32					25017.2				29164.6				0				0
33	Total time of connection event	2348				2862				0				0			
34	Average Current draw during connection event (mA):		10.654685				10.19029				0				0		
35	Average current draw accounting for sleep (mA):				0.026015				0.030162				0.001				0.001
37	**Average current draw during connection (mA):**	**0.029042079**															
38	**Expected battery life (hours):**	**7919.543286**															
39	**Expected battery life (days):**	**329.9809702**															

Figure 4: Excel Spreadsheet used for Device Lifetime Calculation

While the above is an overly simplified explanation of the entire process we have gone through to allow for calculating overall battery lifetime for a *Bluetooth* low energy product, a more detailed explanation can be found in Appnote AN092 as mentioned above. The ultimate spreadsheet created for calculating battery life is available as part of the application note and can be seen in Figure 4 above.

As a final comment for those dying to find out just how power efficient *Bluetooth* low energy and the CC2540 is, the following example is a battery lifetime estimate for our CC2540DK-MINI key fob running on a 230 mAh coin cell battery with a connection interval (reporting rate) of 1 second.

Using the information discussed above for the 1 second reporting interval we find that we have a total connection event time of 2348 us, an average current draw during the connection event of 10.65 mA, and an average current draw during sleep of 0.026 mA, resulting in an expected battery lifetime of 7,920 hours, or approximately 330 days. For a device that is communicating at an interval of 1 data event per second and operating on a very small coin cell, we can see that *Bluetooth* low energy has truly lived up to its name.