Battery Life Calculation for an Ultra Low-Power Wireless Optical Mouse

Application Note 5243

Introduction

In wireless applications the battery life is an essential indication of the power management efficiency. Choice of low-power devices obviously is a must. Good hardware and firmware design also contributes significantly.

The ADNS-3040 Optical Mouse sensor is specifically designed for wireless mouse applications. It incorporates sophisticated power-management architecture including multi-level of sleep modes. The sensor manages these modes automatically freeing the system controller and firmware. Additionally the system controller can force the sensor into entering the various sleep modes thus further accelerates power savings.

This application note details the design considerations with the ADNS-3040 to achieve better than six months of operating life with two AA alkaline batteries.

Reference Design Considerations

The ADNS-3040 is an ultra low-power optical navigation sensor. It has a new, low-power architecture and automatic power management modes, making it ideal for battery-and power-sensitive applications such as cordless input devices. In addition to low-power consumption during active mode its multi-level rest modes enable the ADNS-3040 to claim the title for the world lowest-power navigation sensor.

The ADNS-3040 is capable of high-speed motion detection—up to 20 inch-per-second (ips) and 8 G. In addition, it has an on-chip oscillator and LED driver to minimize external components. Some key specifications in terms of power consumption:

Typical values at 25° C, V_{DD} = 2.6V.

Note that in Rest3 mode the ADNS-3040 consumes typically 30 µA. It manages the various operating modes based on motion history. The Motion Detect output (pin 5) is designed as a priority interrupt to alert the system controller that there is motion. This interrupt-driven architecture allows the system controller to enter its own Sleep Mode without having to constantly poll the sensor for motion. By choosing the appropriate low-power system components an optical mouse can achieve better than six months of battery life based on this architecture. Texas Instrument's MSP 430 micro-controller is chosen for its low power. In this reference design the MSP430 operates in two modes: Active (1 mA @ 4 MHz) and Deep Sleep (0.1 µA). A key benefit of the MSP430 is that even in Deep Sleep it can be awaken to fully operational in 6 µs.

Parameter	Symbol	Typ.	Max.	Units	Notes
DC Supply Current in various modes	I_{DD_RUN}	2.9	10	mA	Average current, including LED current. No load on MISO, MOTION.
	I_{DD_REST1}	0.5	1.8	mA	
	I_{DD_REST2}	0.1	0.4	mA	
	I_{DD_REST3}	0.03	0.15	mA	

For detailed MSP430 features and operation please refer to Texas Instrument for their application notes.

For wireless applications there are several popular RF technologies commonly used for mice: 27 MHz and 2.4 GHz. This reference design employs a mother board/daughter board approach so that different RF section can easily be interfaced to the microcontroller.

For the 27 MHz transmitter a circuit which was developed for a previous reference design is reused. It consists of several bipolar transistors and a crystal. The high-frequency carrier signal is modulated by the digitally encoded data using a FSK modulation technique. The transmitter circuit is powered only during transmission of mouse data. Otherwise the microcontroller turns off the supply current to the circuit.

The Nordic nRF2402 operating in the ShockBurst™ mode is used for the 2.4 GHz transmitter. Motion data is sent to the nRF2402 via the 4-wire SPI at full 1Mb/s rate to minimize the transmitter active-time thus conserving battery power. For detailed operation and capability of the nRF2402 please refer to Nordic Semiconductor data sheet and application notes.

Every effort is made to ensure there is no unnecessary current consumption. The microcontroller and its firmware play a major role in helping the reference design mouse to achieve the low-power performance. For example the microcontroller manages directly the optical scroll wheel. The microcontroller pulses the scroll wheel LED to turn it on for 40 µs every 2 µs. The overall LED duty cycle is only 2% thus the average current is low. In addition the microcontroller samples the scroll wheel status only during Active mode.

Power-Management Modes

For power savings, the navigation LED is not continuously on. The ADNS-3040 flashes the LED only when needed. The SmartSpeed feature self-adjusts the frame rate for optimum performance. As the ADNS-3040 enters progressively the various Rest modes the flashing of the navigation LED slows down accordingly.

The ADNS-3040 has three power-saving modes. Each mode has a different motion detection period, affecting response time to mouse motion (Response Time). The sensor automatically changes to the appropriate mode, depending on the time since the last reported motion (Downshift Time). The parameters of each mode are shown in the table below.

Mode	Response Time (nominal)	Downshift Time (nominal)
Rest 1	16.5 ms	237 ms
Rest 2	82 ms	8.4 s
Rest 3	410 ms	504 s

In addition the ADNS-3040 can be forced into Rest modes with Register 0x11 by setting the RESTEN bits. However, Forced Rest has a long wakeup time and should not be used for power management during normal mouse motion.

The MSP430 can operate in 5 low power modes (LPM0 to LPM4), LPM4 being the deepest sleep (with RAM retention) drawing only 0.1 µA. While in LPM4, the CPU, peripherals, and all internal & external clocks are completely shut off. Only an external interrupt can wake up the MSP430 from its DEEP SLEEP mode in less than 6 µsec. Once an external interrupt is detected, the CPU can be switched on and perform the necessary processing for sensor motion detection, button clicks, and scroll wheel movement. When the CPU is in ACTIVE mode, it only draws 250 µA for every 1 MHz. In this reference design the CPU runs @ 4 MHz with 1 mA.

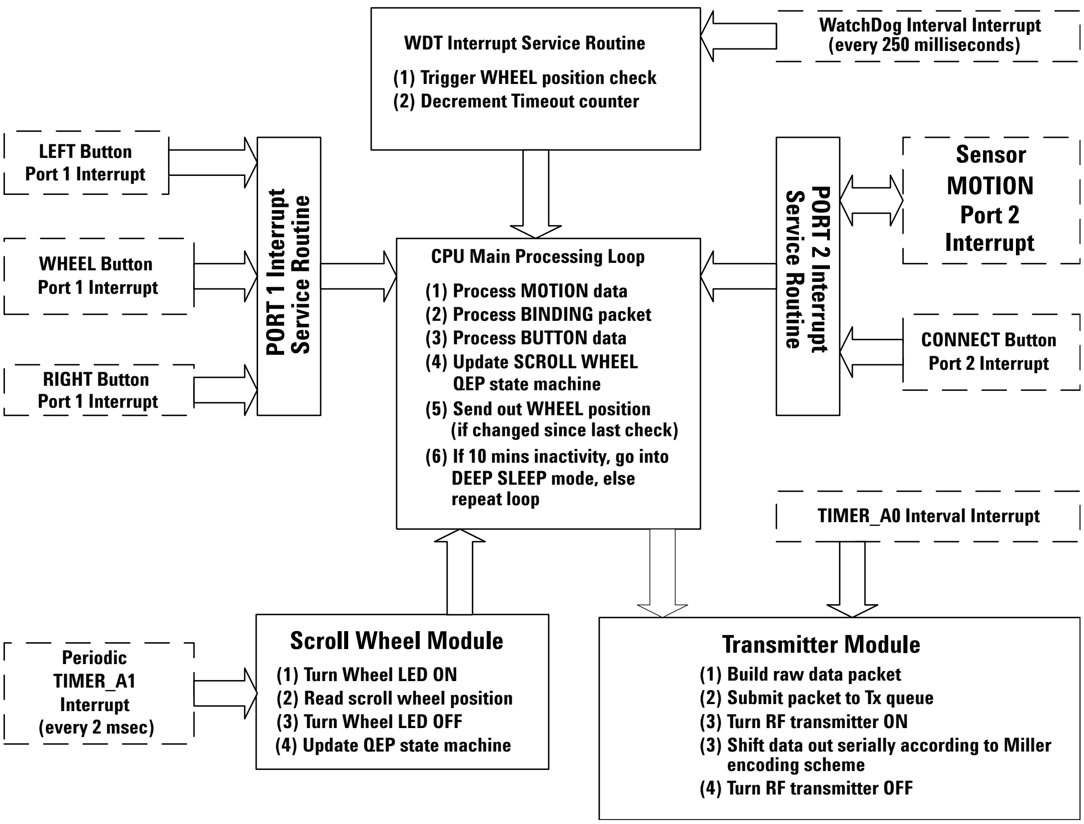

Figure 1. Reference Design Mouse Software Architecture.

Battery Life Calculation

Predicting battery life is not a simple task. There are many factors to consider. As mentioned before, selecting low-power system components is a good start. Careful circuit implementation will help to reduce/eliminate unnecessary current drain. Clever firmware maximizes the benefits of the low-power environment. Choice of optical or mechanical scroll wheel will affect both the hardware and software design. In addition, the LED for the optical scroll wheel can be pulsed at different rates within the different operating modes thus affecting the overall power consumption. And lastly and literally, depends on how you drive, your mileage will vary. A casual user with only email and web surfing will enjoy better battery life then a serious gamer who exercises the mouse constantly.

The measured power consumption for this reference design with a 2.4 GHz transmitter daughter card is shown in Table 1. There are several observations:

Battery voltage is not constant. As energy is consumed the battery voltage drops. In this reference design the dc-dc converter operates with alkaline battery voltage as low as 0.8V. The two AA-alkaline batteries are in parallel.

Current drawn by the mouse from the battery is not constant. As battery voltage decreases the current drawn by the circuit from the battery increases. This is particularly important. The mouse draws a typical amount of current, I_{MOUSE} from V_{DD} (output of the dc-dc converter). The following expression describes the relationship between I_{MOUSE} and I_{BATT} where I_{BATT} is the current the battery supplies:

$$I_{BATT} = I_{MOUSE} * \frac{V_{DD}}{V_{BATT}} \quad \text{or}$$

$$I_{BATT} * V_{BATT} = I_{MOUSE} * V_{DD}$$

Where V_{BATT} is the battery voltage.

In Active Mode the average power consumed by the mouse is constant. The input power to the converter ($I_{BATT} * V_{BATT}$) approximately equals to the output power of the converter ($I_{MOUSE} * V_{DD}$) ignoring the converter efficiency. The data is collected by manually moving the mouse in continuous, circular (clockwise or counter-clockwise) or figure-eight motion for one minute, followed by one minute of no motion. This motion profile is used so that the measurement process can be replicated easily. The advanced power-saving design of the ADNS-3040 adjusts itself to keep up with the motion. The vigorousness of the motion is subjective, however, and it can affect the average power consumed.

In Sleep Mode the variation in the dc-dc converter efficiency is a source for the slight discrepancy in the average power consumed. Efficiency of a dc-dc converter typically varies with input voltage, output voltage and load current. In a typical optical mouse design, including this reference design, the dc-dc converter is designed for a fixed output voltage. However, as shown in Table 1 the input voltage and load current vary throughout the battery life cycle affecting the dc-dc converter's efficiency.

After the last reported motion, the ADNS-3040 enters its Rest Modes. Upon reaching 504 seconds (slightly over 8 minutes) the sensor would enter Rest3 Mode. The Sleep-Mode power consumption data is then collected after the ADNS-3040 has entered the Rest3 Mode.

Table 1. Measured Typical Power Consumption at Various Battery Voltages

	V_{Batt}	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	Unit
	# of readings	356	357	356	359	358	360	356	355	
	Min	474.16	408.84	366.39	338.22	307.01	281.24	249.65	219.58	µA
Active	Max	30.12	24.41	22.47	20.15	18.41	16.81	15.47	13.00	mA
	Avg	13.59	11.87	10.65	9.58	8.85	7.96	7.26	6.68	mA
	Avg PWR	10.87	10.68	10.65	10.54	10.62	10.35	10.16	10.02	mW
	# of readings	1907	4318	3193	8089	1548	15223	4998	11727	
	Min	67.34	60.28	47.76	44.20	37.14	29.56	26.91	22.70	µA
Sleep Mode [2]	Max	289.32	263.43	226.78	213.50	187.87	177.51	162.10	149.00	µA
	Avg	164.84	151.36	127.75	117.57	103.56	97.86	86.50	77.35	µA
	Avg PWR	131.87	136.22	127.75	129.33	124.27	127.22	121.10	116.03	µW

Notes:

1. Test surface used: Avago Reference Surface B – Gray Standard (Strathmore 400 Artagain Steel gray UPC 12017-44607)
2. 10 minutes after Active

The current data is collected using an Avago 6 $^1/_2$ digit multimeter model 34401A. The meter is set to the range with the lowest input resistance (< 1Ω). The meter automatically collects the minimum, the maximum and calculates the average current over the collection period. This technique captures the rapid decline of the average current since the ADNS-3040 enters the first Sleep mode (Rest1) approximately $^1/_4$ second immediately after active motion. Furthermore the data collection is cumulative. The accuracy of the calculated average current increases as the measurement period is increased.

User Model

Battery life will vary depending on how the mouse is used. As part of the ADNS-3040 development process to studying the mouse-usage pattern Avago developed and installed software in the office environment to capture mouse usage statistics. The office user environment includes engineering, finance, technical writing, administrative assistance, etc. Figure 2 below summarizes the findings. Over 90% of the time the mouse is in Rest Mode and specifically 85% of the time the mouse is in its most power-saving mode: Rest3. Under 5% of the time the mouse is active. The study took place over 4 seven-day weeks, 8 hours/day, 5 work days/week; with 2 idle days/week. The mouse is in RUN mode when it is actively moving, including any pauses up to 0.25 second in duration. REST1 includes those motion activities with pauses between 0.25 and 10 seconds. Similarly, the mouse is in REST3 when the pause exceeds 600 seconds (10 minutes). Different surfaces were used by the different users in the data collection to represent a spectrum of scenarios.

Based on this Office User Model we can reasonably predict the battery life in the office users' environment. The typical capacity of a regular AA alkaline battery is 2560 mAh. With two AA batteries the capacity increases to 5120 mAh.

As a first order of estimate we can use the mean battery voltage of 1.15 V. Referring to Table 1 the total operating current is the sum of the Active and Sleep Modes currents @ 1.15 V:

$928 \text{ mA} * 5\% + 0.107 \text{ mA} * 95\% = 0.57 \text{ mA}$

The battery life equals:

$$\frac{5.120\text{mAh}}{0.57\text{ mA}} = 9051 \text{ hours} = \frac{9051 \text{ hrs}}{24 \text{ hrs/day}} =$$

$$377 \text{ days} = \frac{377 \text{ days}}{30 \text{ days/mo}} = 12.5 \text{ months}$$

Applying the user's model and the battery life calculation method to a computer-controlled motion stage, the reference design was evaluated for battery life. The software developed for the computer-controlled motion stage employs significantly more sophisticated scenarios. One of the challenges in deciding what the motion profiles should look like was how to apply the user model data. The approach taken was to first look at the motion. The motion was broken down by velocity/acceleration distribution, motion time and motion distance. This data suggests there should be five motion profiles based on the velocity/acceleration distribution. To apply the pause data the operational mode percentages were used and mapped onto the velocity distribution. A sixth profile (Sleep time) was created to capture the very long pause times (minutes and hours). The software will execute the first five motion profiles and then lastly the Sleep profile. Each of the profile simulates user action such as rapid, multiple button clicks, scroll wheel, mouse motion and sleep. In addition, the type of pauses, (refer to Figure 2) and their associated Wake-up times are all mapped into the operational percentages. Table 2 summarizes the Motion profiles.

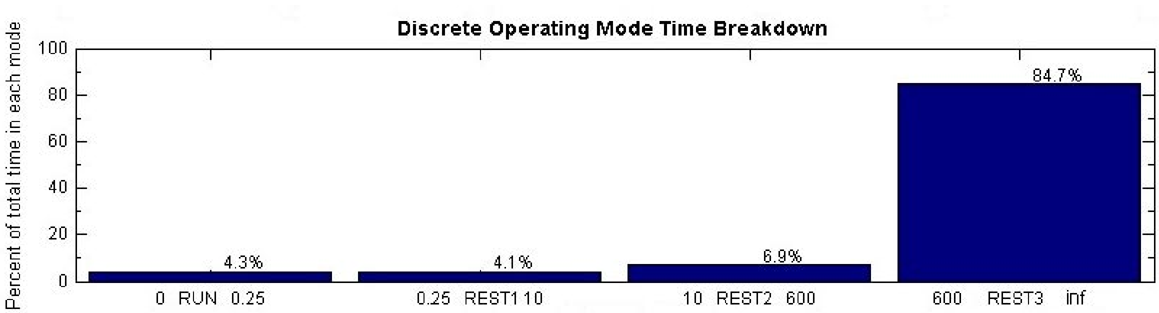

Figure 2. Discrete Operating Mode Time Breakdown - second.

Compared to the simplistic, manual approach which resulted with a battery life of 12.5 months; the motion stage collects significantly more number of data points through automation. Over one million readings are taken over a nineteen hours period. The computer-control motion is extremely sophisticated and emulates the office users far more closely. Also note that the surfaces used in the two tests are different. The grey steel (Avago Reference Surface B) is expected to cause higher power consumption stemming from the ADNS-3040 operating at slower frame rate. This serves to illustrate yet another factor needs to be taken into consideration when predicting battery life.

Conclusion

The total system battery life is a combination of careful component utilization and clever firmware implementation.

The ADNS-3040 is an ultra low-power navigation sensor. Its advanced, sophisticated power-saving algorism enables mice with careful design to achieve exceedingly long battery life. Together with its 20 ips and 8 G tracking performance the ADNS-3040 is one of the best optical mouse sensors available today.

Low-power, high performance system components such as the MSP430 microcontroller is essential to compliment the ADNS-3040. Its multi-level Sleep-Mode, fast wake-up time and interrupt-driven architecture is ideal. Although the Bootstrap Loader (BTL) function is not utilized here it proves to be a valuable cost-saving feature in the laser-mouse design with the ADNS-6030.

Table 2. Motion Profile Description

Profile	Distance (in)	Velocity (ips)	Acceleration (G)	Button/Z-wheel (clicks)	Pause Time (seconds)	Repetitions
1	63	1.0	1	1,355	1,328	12
2	63	1.5	1	1,355	447	4
3	48	2.0	1	1,023	180	2
4	42	3.0	1	903	159	2
5	2.4	25.0	6	51	4	5
6	0	0	0	0	65,100	1

Table 3. Reference Design Mouse Power Consumption (Motion Stage Based)
Test surface: white paper

Profile Name	# of readings	Test time (Hour)	Avg current (mA)
Profile 1	42084	0.8052	5.0971
Profile 2	12456	0.2441	5.3430
Profile 3	4688	0.0911	4.9859
Profile 4	3951	0.0765	4.8705
Profile 5	348	0.0071	6.5472
Profile 6	1000727	18.3083	0.0713
Total	**1,064,254**	**19.3083**	**0.3734**

Average battery life: 2 x 2560 mAh/0.3734 mA = 571 days (19 months)

Appendix

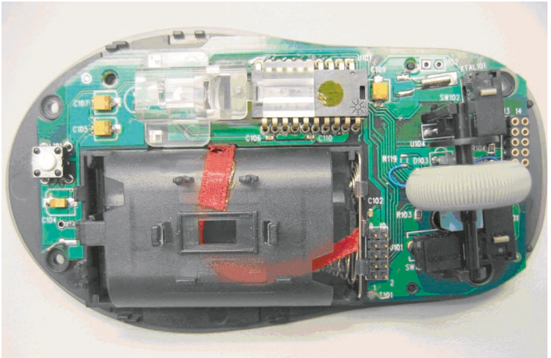

Figure 3. ADNS-3040 Reference Design Mouse Main PCB.

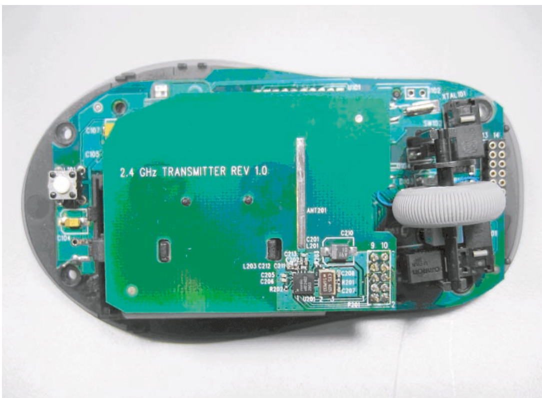

Figure 4. Reference Design Mouse with 2.4 GHz Transmitter Daughter Card.

For product information and a complete list of distributors, please go to our web site:
www.avagotech.com

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