White Paper

Low-Power Sensing

Energy-efficient power solutions

Abstract

Increasing system functionality in portable electronic systems has traditionally occurred at the expense of higher power consumption and shorter battery life. Sensors designed for low-power consumption at both the device and system levels can reverse this trend while providing additional functionalities that delight users. With its micro-electromechanical systems (MEMS) sensor, MCU and sophisticated power management technologies, Freescale Semiconductor can help users address the ongoing issue of increasing functionality without sacrificing battery life. This white paper will describe three approaches that benefit different applications.

Table of Contents

Impact of Power Consumption on Portable Products

The power consumption of a battery-powered portable product has a direct relationship to feature content and battery size that allows suppliers of smartphones and other portable devices to differentiate their products. For example, table 1 shows battery life versus battery size and average current draw (power consumption) for four popular smartphones based on recent testing [1, 2, 3]. The current consumption is strictly a calculation based on I_{ave} = battery size/battery life. Improved battery life occurs with either a larger battery, lower current-consuming components and low-current strategy, or a combination. It is worth noting that the smartphone with the largest battery did not have the highest current draw and, even with a large feature set, it had the longest life. In contrast, the smartphone with the smallest battery had the lowest battery life and the lowest current draw.

Average Current Consumption for Smartphones

Smartphone	Battery Life[1] Hours	Battery Size (mAh)	Current (Ave) (mA)
Motorola DROID RAZR MAXX	14.88	3300	222
Motorola DROID RAZR HD	9.62	2530	263
Samsung Galaxy S® III	9.40	2100	223
Motorola DROID 4	9.08	1785	197

[1] According to CNET testing

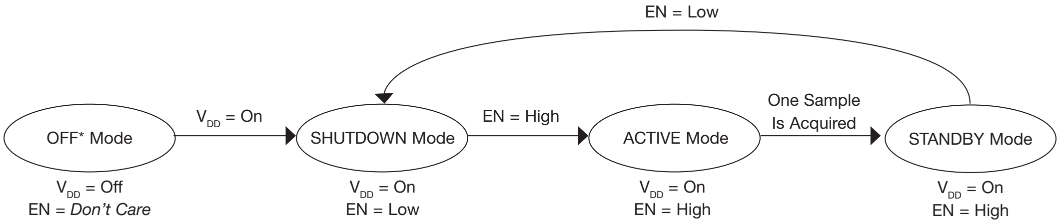
Table 1: Battery life, battery size and current consumption comparison for four smartphones

One of the power-saving techniques enabled by sensors is placing the smartphone in a very low-power mode based on user inactivity. The inactivity is detected through motion sensing by the accelerometer that also provides the screen rotation function. In addition to this system power-saving function, design of the sensor can contribute to reduced power consumption at the sensor and system level. Freescale has established three different design approaches to provide design flexibility for customers looking to achieve specific design goals for their products.

Achieving the Lowest Sensor Power Consumption

The first, and perhaps most direct, approach to a low power consumption design targets the sensor itself. The sensor can have one or more lower power states such as a shutdown mode and an extremely low-power operating mode. In many instances, this type of sensor's operation is directly controlled by the system designer in the end application. As a result, it provides many power consumption advantages.

MMA865xFC Accelerometer Digital Logic



*OFF mode can be entered from any state by removing the power

Figure 1: The operating modes of a sensor design with extremely low power consumption enable system designers to achieve specific design goals

An example of this design approach is an ultra-low-power tilt sensor. As shown in figure 1, the **MMA8491Q** accelerometer starts completely off (V_{DD} = 0) in the OFF mode. Whenever a measurement is required, the sensor is power cycled. When a reading is made, the sensor can be turned on for a millisecond every minute and essentially consume no power. The extreme low-power capabilities of the MMA8491Q reduce the low data rate current consumption to less than 400 nA per Hz. To minimize the amount of time the sensor is on for a reading, it has an ultra-fast data output time of about 700 µs.

The advantage of this design approach is readily apparent in environments with very low duty cycle requirements and a long time between samples. In appropriate situations, it is the option with lowest power consumption on the market. Applications where this strategy applies include industrial and supply chain monitoring where the sensor only needs to be powered on when the product is moving and not when it is in the warehouse.

Smart Sensing for Low Power Consumption

A second method for achieving low power uses integrated digital logic in the sensor design. Frequently called “smart sensing,” the added digital capability can be used to enable the sensor to perform its own internal power management. This approach has been used in accelerometers, pressure sensors and magnetometers.

An accelerometer with integrated digital logic is an example of how lower power considerations can be taken to the next level. With added logic, the sensor performs its own internal power management and data can be sampled as required. Beyond simple shaking of the device to power it on or off, more complex tasks such as double taps or a rotational shake with the direction of rotation initiating one command versus another allow the sensor to initiate a variety of useful functions.

MMA865xFC Accelerometer Four Operating Modes

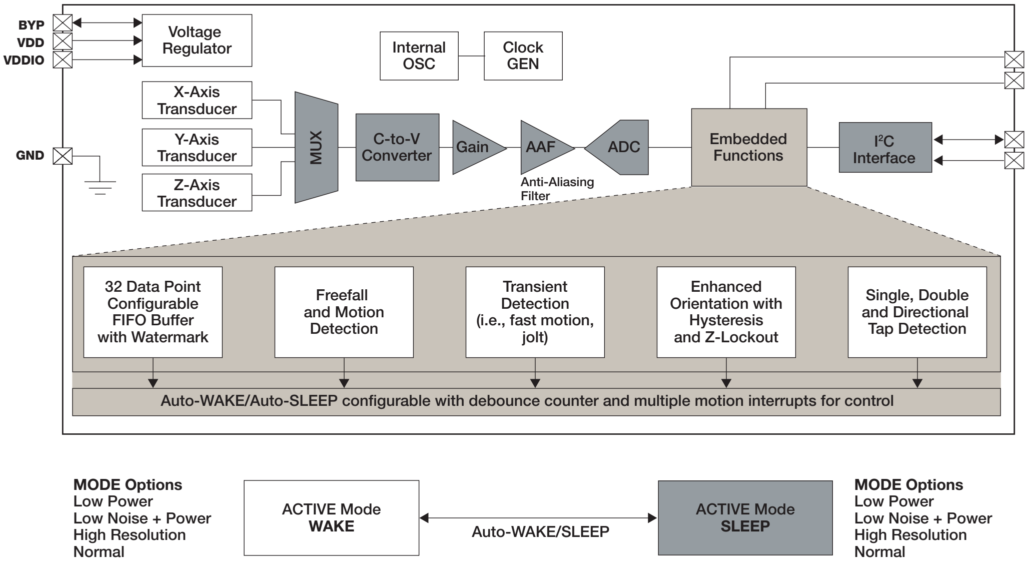


Figure 2: MMA865xFC accelerometer digital logic (Figure 1) and four operating modes (above)

The main applications for this low-power sensing approach are end products where portrait/landscape detection is desired, such as cell phones or tablet computers. An accelerometer with this capability can provide the desired functionality as well as sophisticated power management for minimum power consumption. One example is the **MMA865xFC** accelerometer that consumes only 6 μA in the lowest power mode, as shown in figure 2.

In this case, the sensor itself draws the power dictated by its design. The sensor's embedded logic detects events and notifies an external MPU over interrupt lines using an I^{2}C interface. Unlike the first low-power method that has no power consumption at its lowest level, this sensor has a baseline power consumption of 6 μA, so it can automatically power itself on. With a higher frequency of use, a device with more internal intelligence eventually becomes more efficient.

Another example of integrated technology for reducing power consumption is the accelerometer's smart first in, first out (FIFO) buffer. An 8-bit or 12-bit configurable 32-sample FIFO allows buffering of the data so a host system can power on the sensor and read the data at a slower rate. As a result, the device can be kept in a lower power state more of the time, achieving lower power consumption for itself and lower duty cycle operation for the primary system whose power consumption can be hundreds or even a thousand times higher than the accelerometer's power consumption. By reducing the primary system's power on time by a mere 0.5 %, the system consumes less power even though the accelerometer consumes more power. The system-level advantages more than compensate for the slightly higher power consumption in the sensor.

The smart sensing for low power methodology has also been employed in pressure sensor design. For example, the **MPL3115A2** pressure sensor, a featured Freescale Energy-Efficient Product Solution, has very low power consumption and smart features, and requires zero external data processing since it converts the data to the format required by the MCU. Processing the sensor data locally reduces communications with the host processor and minimizes MCU usage. Consuming only 8 µA in its highest speed mode (oversample = 1), the sensor has two interrupts for auto-wake, minimum/maximum threshold detection and autonomous data acquisition. In addition to performing internal computations, the pressure sensor has a programmable output rate, a FIFO buffer and internal settings for low power similar to the MMA865xFC accelerometer. These capabilities are very useful in mobile devices, medical and security applications.

One final example of the smart sensor approach to minimizing power consumption is a magnetometer. The **MAG3110** magnetometer for E-compass applications has an I^{2}C serial interface and is capable of measuring local magnetic fields up to 10 Gauss with output data rates (ODR) up to 80 Hz. These output data rates correspond to sample intervals from 12 ms to several seconds. I^{2}C communications can occur in both standby and active operating modes. In standby mode, the typical current consumption is only 2 µA. Power consumption at the maximum ODR of 80 Hz is typically 900 µA but this can be reduced to 17.2 µA at an ODR of 1.25 Hz and even further to 8.6 µA at a sub 1 Hz ODRs. With its integrated signal processing and control capabilities, the magnetometer can offload the computations from an external MCU and minimize the communications as well to provide further system power reduction.

Integrated MCU/Sensor Operation

In the third design approach for low-power sensing, the sensor utilizes the local computing capability of an MCU. This functionality can be achieved in the same package or simply by taking into account the joint/system-level operations of these two components.

Termed “local compute capability,” this system-level methodology can offload sensor-based (and other) computations from the system application processor even further than the second low-power approach. For example, for a primary system that uses 100 to 1000 times as much power, a local MCU that can perform the required computations (and allow the other processor to go into a lower power mode) delivers a significant power savings at the system level, resulting in savings that justify adding the smaller MCU. Unlike the second case that provided interrupt capability for basic functions such as portrait/landscape transition, a FIFO buffer or similar functions, in this last case, all of the computations can be performed internally providing the full capability of a sensor hub.

This design methodology can implement very complicated filtering systems such as Kalman filters where significant computing capability and power consumption would normally be required from the host processor. Examples include the **MMA9550L** sensing platform, a featured Freescale Energy-Efficient Product Solution, and other platforms in this family. In addition to the integrated MCU, sensing software also provides additional capabilities to reduce power consumption. (Note: The MMA9550L has insufficient resources for Kalman filtering.)

A typical application or use case is a pedometer that must always be on to obtain the required amount of data to calculate the number of steps, distance and other values on a continuous basis. This type of capability cannot be integrated with a cell phone without significantly decreasing battery life since the phone would essentially always have to be on. In contrast, the local compute method has much lower power consumption than the primary computing system in the phone. This makes the pedometer a viable application and avoids battery life as a limiting factor. A free or low-cost downloaded app that counts steps using the phone's integrated accelerometer costs battery life for the cell phone. This same functionality built into the phone using an integrated sensor hub could provide the pedometer capability while the phone's primary processor and display are powered off.

The MMA9550L consumes only 2 µA in STOPNC mode with internal clocks disabled. Table 2 shows the current consumption for this and the two other operating modes.

MMA955xL Accelerometer Current Consumption

Characteristic	Symbol	Condition(s)	Min	Typ	Max	Unit
Supply current in STOP_{NC} mode	$I_{DD\text{-}SNC}$	Internal clocks disabled	–	2	–	µA
Supply current in STOP_{SC} mode	$I_{DD\text{-}SSC}$	Internal clock in slow-speed mode	–	15	–	µA
Supply current in RUN mode[2]	$I_{DD\text{-}R}$	Internal clock in fast mode	–	3.1	–	mA

[1] All conditions at nominal supply: $V_{DD} = V_{DDA} = 1.8$ V

[2] Total current with the analog section active, 16 bits ADC resolution selected, MAC unit used and all peripheral clocks enabled.

Table 2: Supply current characteristics[1] of the MMA955xL accelerometer in three operating modes

A tire pressure monitoring system (TPMS), such as the **MPXY8xxx**, is a pressure sensor example of the third case. With its integrated pressure sensor and MCU as well as an accelerometer and radio frequency (RF) transmitter, the computing is performed locally to save power by minimizing communications with and computations by the primary system. The data has to be transmitted wirelessly using minimal power for the sensing node to have sufficient battery life without increasing the battery size and, as a result, the total system cost. Tables 3, 4 and 5 show the impact of power consumption in different modes for the MCU during measurements and RF transmissions.

MCU Power Consumption in TPMS

Characteristic	Symbol	Min	Typ	Max	Unit
Standby Supply Current (V_{DD} = 3 V, T_A = 25 °C)					
Stop1 mode, LFR, LVD and TR all off	I_{STDBY}	–	0.36	0.9	µA
Adder for LFR (continuous ON, any mode)	I_{STDBY}	–	93	112	µA
Adder for temperature restart (TR)	I_{STDBY}	–	10	20	µA
Stop4 mode, LFR, LVD and TR all off	I_{STDBY}	–	73	95	µA
Standby Supply Current (V_{DD} = 3 V, T_A = 125 °C)					
Stop1 mode, LFR, LVD and TR all off	I_{STDBY}	–	9	19.5	µA
Adder for LFR (continuous ON, any mode)	I_{STDBY}	–	80	112	µA
Adder for temperature restart (TR)	I_{STDBY}	–	10	20	µA
Stop4 mode, LFR, LVD and TR all off	I_{STDBY}	–	95	140	µA
MCU Operating Current (V_{DD} = 3 V, T_A = 25 °C)					
0.5 MHz f_{BUS}, BUSCLKS1 = 1, BUSCLKS0 = 1	I_{DD}	–	0.68	0.8	mA
1 MHz f_{BUS}, BUSCLKS1 = 1, BUSCLKS0 = 0	I_{DD}	–	0.94	1.1	mA
2 MHz f_{BUS}, BUSCLKS1 = 0, BUSCLKS0 = 1	I_{DD}	–	1.46	1.7	mA
4 MHz f_{BUS}, BUSCLKS1 = 0, BUSCLKS0 = 0	I_{DD}	–	2.50	2.9	mA

$V_{DD} \leq 3.6$, T_A = 0 °C to 70 °C unless otherwise specified.

Table 3: Power consumption of the MCU in the TPMS

Power Consumption of Measurements in TPMS

V	Characteristic	Symbol	Min	Typ	Max	Unit
	Pressure and Temperature Measurement[1]					
C	Sensor measurement time[2]	t_{PM}	–	3.3	–	mSec
C	Peak current (V_{DD} = 3.3 V)[3]	I_P	–	4.0	–	mA
C	Total power consumption	Q_P	–	6.28	7.3	µA-sec
	Acceleration Measurement (X- or Z-Axis)[4]					
C	Sensor measurement time (LP Filter ON)[2]	t_{AM}	–	3.82	–	mSec
C	Peak current (V_{DD} = 3.3 V)[3]	IA	–	3.4	–	mA
C	Total power consumption (LP Filter ON)	Q_A	–	3.77	4.5	µA-sec
	Temperature Measurement					
C	Sensor measurement time[2]	t_{TM}	–	1.13	–	mSec
C	Peak current (V_{DD} = 3.3 V)[3]	IT	–	3.4	–	mA
C	Total power consumption	Q_T	–	1.17	1.4	µA-sec
	Voltage Measurement					
C	Sensor measurement time[2]	t_{VM}	–	0.26	–	mSec
C	Peak current (V_{DD} = 3.3 V)[3]	IV	–	3.4	–	mA
C	Total power consumption	Q_V	–	0.35	0.8	µA-sec

$2.3 \leq V_{DD} \leq 3.3$, T_A = –40 °C to +125 °C unless otherwise specified.

NOTES:

[1] Fully compensated pressure and temperature reading using the PCOMP routine with an average of eight readings. Power consumption can be reduced if readings are uncompensated.

[2] Measurement times dependent on clock tolerances.

[3] Peak currents measured using external network shown in Figure 17-5 (in the ~~MPXY8xxx~~ **data sheet**) with R_{BATT} equal to zero ohms.

[4] Fully compensated acceleration reading using the ACOMP firmware routine with single reading and the 500 Hz low-pass filter active. Power consumption can be reduced if readings are uncompensated.

Table 4: Power consumption of measurements in the TPMS

RF Transmission in TPMS

V	Characteristic	Symbol	Min	Typ	Max	Unit
	RF Transmission Supply Current, T_A = 25 °C					
	V_{DD} = 2.1 V, PWR4:0 = 01110					
C	Data 1, FSK or ASK	I_{DD}	–	7.82	8.45	mA
C	Data 0, ASK, Xtal oscillator, VCO, PLL only	I_{DD}	–	TBD	TBD	mA
	V_{DD} = 2.5 V, PWR4:0 = 01110					
C	Data 1, FSK or ASK	I_{DD}	–	8.25	8.90	mA
C	Data 0, ASK, Xtal oscillator, VCO, PLL only	I_{DD}	–	TBD	TBD	mA
	V_{DD} = 3.0 V, PWR4:0 = 01011					
P	Data 1, FSK or ASK	I_{DD}	–	8.53	9.20	mA
C	Data 0, ASK, Xtal oscillator, VCO, PLL only	I_{DD}	–	TBD	TBD	mA
	V_{DD} = 3.3 V, PWR4:0 = 01011					
C	Data 1, FSK or ASK	I_{DD}	–	8.80	9.50	mA
C	Data 0, ASK, Xtal oscillator, VCO, PLL only	I_{DD}	–	TBD	TBD	mA

$2.1 \leq V_{DD} \leq 3.6$, T_A = –40 °C to +125 °C unless otherwise specified.

Target power output 5 dBm using dynamic RF power correction firmware routine.

Table 5: Power consumption of the RF transmission (at 315 MHz carrier frequency) in the TPMS

With a typical lowest power consumption of 0.36 µA in Stop1 mode to a maximum of 9.5 mA during RF transmission, the tables illustrate the importance of minimizing the use of higher power consumption modes to obtain maximum battery life of the sensors mounted at each tire in the TPMS.

Based on the level of digital control, the three low-power management strategies provide users alternatives for minimizing power consumption and optimizing battery life.

Table 6 shows a comparison of the techniques using accelerometer, pressure sensor and magnetometer values from each product's data sheet. When sensor measurements require more complex computing, offloading the main processor that methods 2 and 3 enable provides substantially greater system-level power consumption savings.

Accelerometer, Pressure Sensor and Magnetometer

Type	Power Reduction Method	Example Sensor Product	Sensor Type	Lowest Current Consumption	Level of Digital Control
1	Lowest sensor power consumption	MMA8491Q	Accelerometer	400 nA at 1 Hz sample rate	Low
2	Smart sensing with integrated digital logic	MMA865xFC	Accelerometer	6 μa in lowest power mode	Medium
3	Integrated MCU/ sensor operation	MMA9550	Accelerometer	2 μa in STOPnc mode with internal clocks disabled	High
2	Smart Sensing with integrated digital logic	MPL3115A2	Pressure	8 μa in highest speed mode (oversample = 1)	Medium
2	Smart Sensing with integrated digital logic	MAG3110	Magnetometer	8.6 μa in active/2 μa in standby	Medium
3	Integrated MCU/ sensor operation	~~MPXY8xxx~~	Pressure	0.36 μa in Stop1 mode	High

Table 6: Comparison of three power-saving approaches/methodologies

Tools Supporting Each Low-Power Method

In addition to reducing users' development effort and time to market as well as system power consumption, Freescale development kits show how to take advantage of Freescale-developed software. They allow users to more readily develop their own code to achieve the lowest power for a specific application.

Low-Power Method 1

For this customer-implemented and managed power consumption technique, there are several tools (as well as data sheets, application notes and more) to help achieve low power consumption. Specific reference designs include:

- **Electronic tamper detection** smart meter reference design
- **Kinetis KM3x MCU single-phase** metering reference design
- **Kinetis KM3x MCU two-phase** metering reference design

All reference designs use the MMA8491Q tilt sensor.

The **DEMOMMA8491** standalone demo is an easy-to-use tool that contains two boards. The breakout board has a sample device and the demo board can be positioned for tilt detection. The DEMOMMA8491 accelerometer evaluation kit application note (**AN4292**) explains how to use this kit.

The **LFSTBEB8491** Sensor Toolbox accelerometer development board contains an MMA8491Q accelerometer daughter card. The **LFSTBEB8491** quick start guide provides additional support for this tool.

Low-Power Method 2

The **MMA865xFC** Sensor Toolbox user guide for the MMA865xFC Sensor Toolbox accelerometer kit provides users the hardware and software for the demonstration and evaluation of the MMA865xFC accelerometers.

LFSTBEB865X Sensor Toolbox boards for MMA865xFC accelerometers contain MMA8652FC and MMA8653FC accelerometer daughter cards and the sensor interface board.

The **DEMOSTBMPL3115A2** Sensor Toolbox MPL3115A2 development kit includes the USB communication board, the interface board and the pressure sensor evaluation board for the MPL3115A2 pressure sensor. An example of the breadth in design support tools is shown in figure 3.

Sensor Toolbox Development Kit Boards

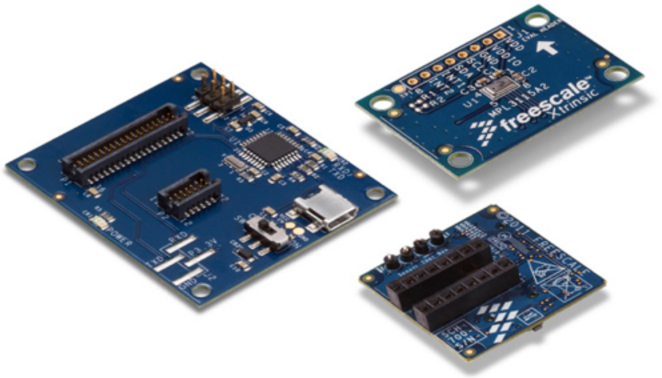


Figure 3: USB communication board, interface board and pressure sensor evaluation board for the DEMOSTBMPL3115A2 Sensor Toolbox kit

The **LFSTBEB3110** development kit enables users to develop both accelerometer and MAG3110 magnetometer designs.

The **RD4247MAG3110** is a complete kit containing three PCBs: MAG3110 magnetometer and MMA8451 accelerometer daughter cards, sensor interface board and LFSTBUSB communication board for running the Freescale Sensor Toolbox PC software.

Low-Power Method 3

KITMMA955xLEVM Sensor Toolbox for smart sensing platform is a complete kit (including software) with no additional boards or components required. KITMMA9550LEVM and KITMMA9551LEVM evaluation kits for the MMA955xL devices demonstrate the common accelerometer user cases and provide access to device-specific features. The **MMA9550L and MMA9551L** Sensor Toolbox user guide explains how to use the evaluation kits.

The ~~MPXY8xxx~~ design reference manual provides complete information including firmware function examples and application source code for the ~~MPXY8xxx~~ TPMS solution.

The **RDFXWIN8USB** is a 12-axis sensor reference platform for Windows® 8 that greatly simplifies the implementation of local compute capability and the resulting power consumption savings for applications such as sensor fusion for motion control.

Conclusions

To satisfy the requirements of a broad range of customers with varied use cases, Freescale has established three different methodologies for low-power sensing. These approaches were developed through the combined efforts of application experts in our sensor organization and other divisions. With these three distinct approaches, engineers can think differently about low-power operation and achieve their system design goals in an expedient manner based on having Freescale as a technology partner and utilizing the tools Freescale has developed to support the three low-power strategies.

A few of the ideas that have already been developed and implemented were presented. However, there are several other concepts that Freescale experts are working on for future implementation. These ideas address the requirements that customers have defined and some that we have discovered based on our extensive capabilities in sensors, MCUs, power management and RF technologies. Contact us for more details.

Energy-Efficient Solutions Program

The Energy-Efficient Solutions program and mark highlight Freescale products that excel in effective implementation of energy-efficient technologies or deliver market-leading performance in the application spaces they are designed to address. Freescale's energy-efficient product solutions include microcontrollers, processors, sensors, digital signal controllers and system basis chips optimized for high performance within the constrained energy budgets of their target applications. Our solutions enable automotive, industrial, consumer and networking applications and are truly energy efficient by design. For more information, visit **freescale.com/energyefficiency**.

Energy Efficient Solutions™
by Freescale

References

1. Smartphones with long battery life (roundup)

2. Cell phone battery life charts

3. How we test: Cell phones and smartphones

For more information about Freescale low-power sensors, visit freescale.com/sensors