Application Note

Battery powered applications using the 500 Series Z-Wave Single Chip

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1 ABBREVIATIONS

Abbreviation	Explanation
ADC	Analog to Digital Converter
API	Application Programming Interface
GND	Ground
GPIO	General Purpose Input Output
LDO	Low Drop Out
LSB	Least Significant Bit
POR	Power On Reset
SMPS	Switched Mode Power Supply

2 INTRODUCTION

2.1 Purpose

The purpose of this application note is to describe what to consider when developing a battery driven application. How to use the ADC of the 500 Series Z-Wave Single Chip as a battery monitor; how the battery monitor works and what to consider when using a battery monitor.

2.2 Audience and prerequisites

The application note is written for developers working with the 500 Series Z-Wave Single Chip in battery operated applications or applications where knowledge of the supply voltage is of importance.

3 BATTERY SUPPLIED APPLICATIONS IN GENERAL

Remotely placed sensors, mobile applications, remote controls etc. are all examples of applications where the usage of batteries as power source for the application is the only feasible option.

When thinking of a battery as a power source, one might consider it as being a stable power source in terms of noise and ripple. This is true, but it is not stable in terms of power capacity. Depending on the type of battery used, the voltage across the battery is very dependent of the load current, and this fact may be critical.

Consider an application supplied by 2 AA-type batteries connected in series. Initially, the voltage across the batteries will be app. 3V (1.5V each). This voltage will drop over time, and it will eventually drop below the reset threshold of the 500 Series Z-Wave Single Chip, which is below 2.3V. The time it will take before this happens depends on the type of battery used and the power consumption of the application. The graph below shows an example of a discharge curve for an alkaline battery versus load resistance:

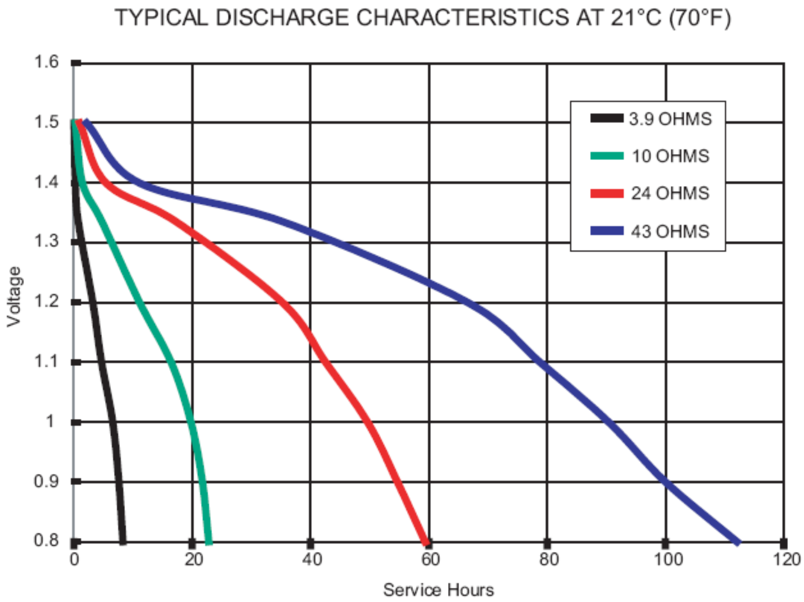


Figure 1, Example of discharge curve (Duracell®, Coppertop MN1500)

Please refer to the technical information supplied by the battery vendors for actual discharge curves.

From Figure 1, two important relationships between voltage across the battery and the usage of the battery can be derived. First, if the power-load of the battery is constant, the voltage across the battery will drop over time. Second, if the power-load increases instantaneous, this too will lead to a voltage drop across the battery.

This is very important to take into account when designing a battery driven application. If it is left to the user to change the batteries when the application stops to work, the application will most likely end up disturbing the entire Z-Wave network before the batteries are due to change. The explanation is as follows:

During the execution of a battery driven application, at least 4 different power consumption levels are seen:

1. Power-down power consumption, when the application awaits action.

2. Active power consumption, when the application is active but does not receive/listen for or transmit Z-Wave frames.

3. Receive power consumption. The power consumption used during listening for and receiving Z-Wave frames.

4. Transmit power consumption. The power consumption used during transmission of Z-Wave frames.

The current drawn by the 500 Series Z-Wave Single Chip alone during each of the 4 phases are :

Power phase	Current consumption (typically)
1, Power-down	Few uA
2. Active	> 15 mA
3. Receive	> 32 mA
4. Transmit	> 34 mA

Right after insertion of new batteries into the application, a change from one power-state to another will not cause any critical voltage-drops across the batteries. But, this changes as the batteries discharges. The more worn out the batteries are, the more sensitive they are to changes in the load current. And, at a given point in time, the following will happen:

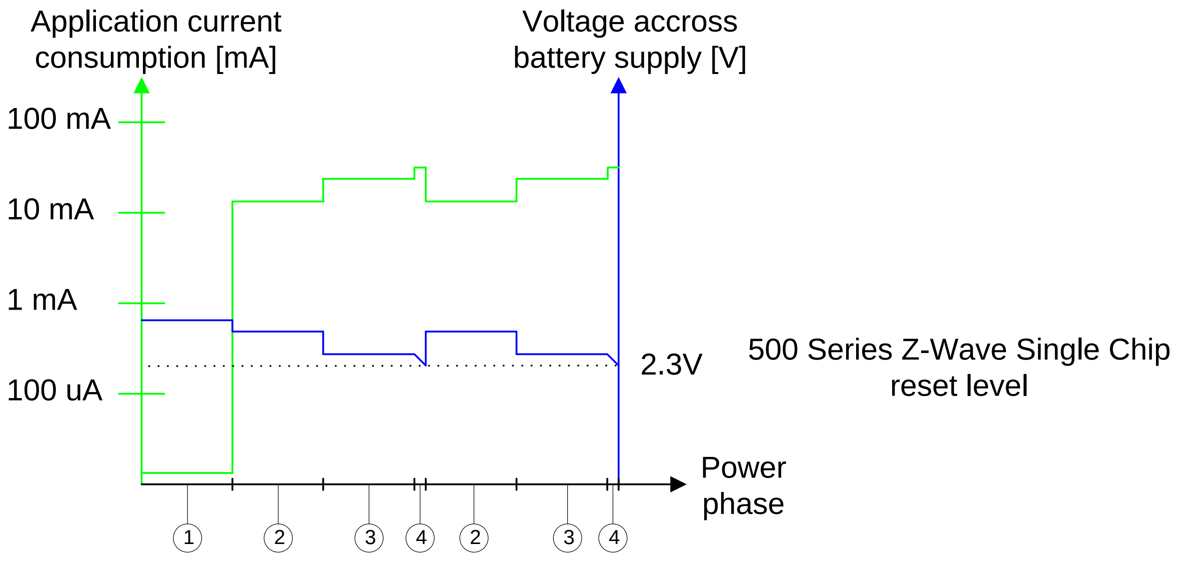


Figure 2, Power supply voltage vs. application execution

The voltage across the batteries has over time been drained to just above the 500 Series Z-Wave Single Chip reset threshold level when the application is in power down. When the application wakes up, an instant increase in current consumption causes the voltage to drop, but not below the reset threshold. The application starts to listen for Z-Wave frames, receives a frame, and starts to transmit an acknowledge Z-Wave frame. This increase in current consumption causes the voltage to drop below the 500 Series Z-Wave Single Chip reset threshold, which aborts the transmissions, and forces a reset of the application. Depending on how the application is written, the application might start to transmit again, causing a new reset of the application etc. The result of the weak batteries is that the application does not work properly, and it may continuously transmit interrupted Z-Wave frames. This could result in RF-noise on the Z-Wave channel. In worst case scenarios, this might lead to a Z-Wave network with poor performance due to the interference which is introduced by the application with weak batteries.

In order to prevent disruptive performance due to weak batteries, ***all battery powered applications should be equipped with some sort of battery monitor circuit*** for three reasons :

1. To inform the user of the application about the current battery status.
2. To prevent unwanted behavior of the application due to weak batteries.
3. To prevent the batteries of the application to be discharged to a level where battery leakage may occur.

The rest of this application note describes two different ways to perform the battery monitoring.

4 BATTERY MONITORING IN GENERAL

Basically, monitoring the supply voltage of the 500 Series Z-Wave Single Chip enables an application to give a warning to the user of the application if the supply voltage gets close to the reset threshold of the 500 Series Z-Wave Single Chip. If the application is battery driven, monitoring the power supply gives a status of the battery capacity, and the application can warn the user when it is time to change the batteries before the application starts to malfunction due to an inadequate supply voltage.

Supply monitoring using the 500 Series Z-Wave Single Chip can be performed in two ways, either using the internal battery monitor circuit, or building an external circuit and then use the build-in ADC. The internal battery monitor circuit enables battery monitoring without requiring external components resulting in the cheapest and simplest solution. Due to component-to-component spread of the internal reference voltage in the ADC used to perform the battery monitor, the best result of internal battery monitoring is obtained if some sort of calibration is incorporated.

This application note describes how to perform both internal and external battery / supply monitoring.

Internal monitoring is possible if no voltage regulators (e.g. LDOs or SMPSs) are between the 500 Series Z-Wave Single Chip and the power source. If the power source is regulated, an external supply monitor circuit must be used.

The chapter below describes the usage of the built-in battery monitor. The next chapter describes the precautions to take if using an external battery monitor circuit.

5 INTERNAL BATTERY MONITOR

Monitoring the supply voltage without usage of external circuit is possible when using the ADC in the 500 Series Z-Wave Single Chip as a battery monitor.

But, it is only possible to estimate the remaining battery power if the power supply of the 500 Series Z-Wave Single Chip is unregulated. ***I.e. if the power supply of the 500 Series Z-Wave Single Chip is derived using a LDO or a switched mode power supply, one cannot use the build-in battery monitor mode of the ADC***, as the voltage level will not reflect the status of the batteries.

If, however, e.g. 2 AA batteries are used as power supply for the 500 Series Z-Wave Single Chip, and the 2 batteries are connected in series and used directly as power supply, then the build-in battery mode of the ADC is a way to measure the supply voltage.

When using the ADC as a battery monitor, a measurement of an internal band-gab reference voltage is performed with the internal supply voltage as upper reference and the internal GND as lower reference. The ADC conversion result can be calculated to:

Equation 1, conversion result in battery monitor mode

$$ADC_{result\_8\_bit} = \frac{V_{BG}}{\frac{V_{DD}}{2^8}}, V_{BG} \equiv 1.23V \qquad ADC_{result\_12\_bit} = \frac{V_{BG}}{\frac{V_{DD}}{2^{12}}}, V_{BG} \equiv 1.23V$$

As seen, ADC_{result} and V_{DD} are inversely proportional. The lower supply voltage the higher the ADC conversion result. The relationship is illustrated in Figure 3:

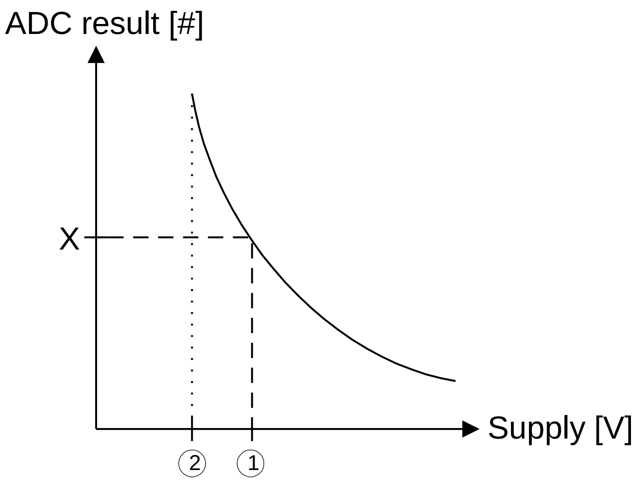


Figure 3, relationship between ADC result and supply voltage

As seen on Figure 3, two points are marked on the X-axis (the supply axis). Point 1 is where the user of the application should be notified about a low supply level, point 2 is where the supply level gets lower than the reset level, resulting in a reset of the 500 Series Z-Wave Single Chip.

Since the band-gab voltage is an internally generated voltage, it has a variation from chip to chip and over temperature.

The band-gab voltage is used in both the POR circuit and in the battery monitor circuit. There is however one big difference, and that is, that the band-gab voltage is used directly by the POR circuit, but buffered in the battery monitor circuit. This means, that there is a correlation between the reference voltage for the

POR circuit and the reference voltage to the battery monitor circuit, but not a 100% correlation. This is due to the fact, that gain error and offset error in the buffer amplifier will influence the voltage used for the battery monitor and this has no impact on the POR circuit.

When setting the warning level for the battery monitor, the X in Figure 3, one has to take the above mentioned uncertainties into account and make sure, that the battery warning level is not set too close to the POR limit.

According to the data sheet, the POR level is guaranteed to happen happens when the voltage drops below 2.3V. According to the data sheet, the band-gab reference for the ADC varies between 1.2V and 1.3V. With such variations, a calibration scheme during application production is advised in order to be able to set a reasonable warning level.

Apart from the internal reference voltages, the battery monitor warning level also depends on the shape of the battery discharge curve. If the discharge curve is flat, that is, if the batteries can be drained without a significant voltage drop, it is possible to select a relatively small difference between the battery warning level and the reset threshold. If, however, the discharge curve is steep, a larger distance between battery warning level and the reset threshold has to be selected.

Note : One should consider performing the battery measurement while the application uses the most power, e.g. during transmission of Z-Wave frames. This will give the most true picture of the state of the batteries.

5.1 Code implementation

Using the battery monitor of the 500 Series Z-Wave Single Chip is part of the regular Z-Wave API code. In order to enable the battery monitor, please refer to the Z-Wave programmers guide [1].

6 EXTERNAL BATTERY MONITOR

If the supply for the 500 Series Z-Wave Single Chip is regulated using a LDO / SMPS for step down in cases where the unregulated voltage is > $V_{supply\ 500\ Series\ Z\text{-}Wave\ Single\ Chip\ max}$ or an SMPS for step up in cases where the unregulated voltage is < $V_{supply\ 500\ Series\ Z\text{-}Wave\ Single\ Chip\ min}$, great care must be taken when designing the battery monitor circuit.

At first, no voltages on any pins on the 500 Series Z-Wave Single Chip may exceed the absolute maximum ratings of the chip. Secondly, no pins may be subjected to any voltages exceeding 0.3V above $V_{DD\ Chip}$. This implies that a circuit like the one shown in Figure 4 is an illegal circuit if V_{DD} is above $V_{DD\ Chip}$:

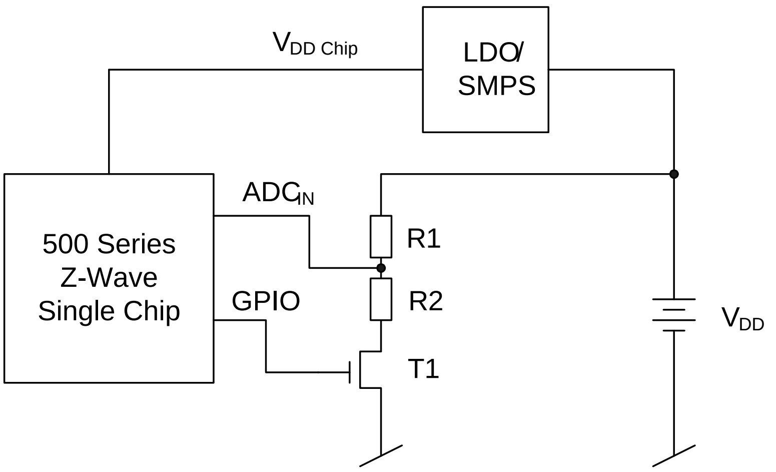


Figure 4, wrong implementation of external battery monitor circuit

The reason is as follows: During power up, all GPIO's are configured as inputs with pull-up resistors. The transistor T1 is thus turned on, and the voltage on ADC_{in} equals a voltage division between the resistors R1, R2 and $R_{T1\ ON}$. If R1 and R2 are selected correctly, the voltage at the pin ADC_{in} is < $V_{DD\ Chip}$. But, in order to save power, T1 is turned off when no battery monitoring is needed, and the voltage on ADC_{in} will be equal to V_{DD}, possibly violating the absolute maximum ratings but surely violating $ADC_{IN} > V_{DD\ Chip} + 0.3V$.

If an external battery monitor circuit is to be implemented, it should in principle work like shown in Figure 5:

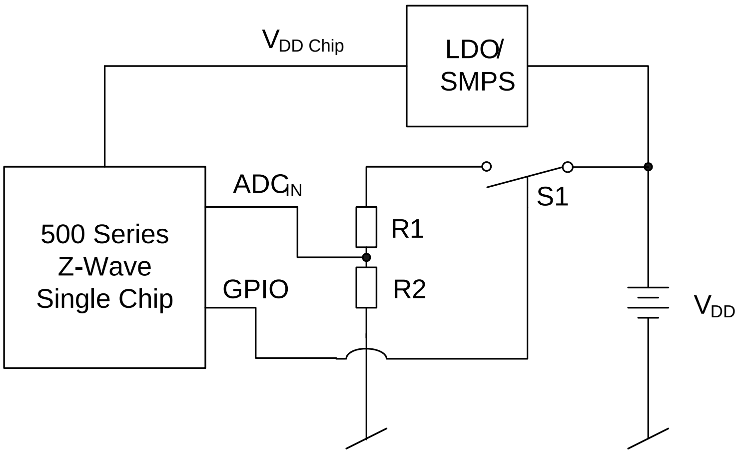


Figure 5, correct implementation of external monitor circuit

The difference between the circuits in Figure 4 and Figure 5 is that when the switch S1 is closed, the voltage applied to ADC_{IN} is divided by R1 and R2. If R1 and R2 are correctly dimensioned, the voltage will not exceed $V_{DD\ Chip}$ regardless of the state of S1.

Regardless of how an external battery monitor circuit is build, the pins of the 500 Series Z-Wave Single Chip may not be subjected to voltages larger than $V_{DD\ Chip}$ + 0.3V.

7 GENERAL CONSIDERATIONS

7.1 Type of batteries to use

The most important, when selecting the battery type to an application, is not the battery type itself, but is to choose the type of battery that suits the needs of the application.

It is the internal resistance (ir) of a battery that influences the stability of the voltage towards rapid changes in current drain. The ir is dependent of the rate of discharge, the temperature and the chemistry of the battery (for further information, the application note: http://data.energizer.com/PDFs/BatteryIR.pdf is recommended).

Battery types with a large ir will give an initially large voltage drop if the current drain increases rapidly. This applies e.g. for the alkaline batteries, where the ir for e.g. Energizer E91 has an ir ranging from 150 – 300 milliohms.

Battery types with a lower ir will give an initially lower voltage drop at rapid current drains. This applies e.g. for advanced Li/FeS_2 batteries, where the ir for e.g. Energizer EA91 has an ir ranging from 90 - 150 milliohms.

The type of battery to choose for a battery driven application depends on the type of power supply of the application. If the batteries are used unregulated, then high capacity and good load performance is paramount. If a SMPS is used, then batteries with high capacity but poor load variation may be acceptable, since the SMPS compensates for the poor load variation performance.

7.2 Speed of battery monitor measurements

If speed is of importance, an 8 bit conversion may be considered as an alternative to a 12 bit conversion. Firstly, 8 bit conversions are twice as fast as 12-bit conversions, and secondly, depending on margins in the design, it may not be necessary with a 12 bit representation of the battery voltage level. If 8 bits are enough, both speed and code space is gained using the low resolution.

7.3 Timing of battery monitor measurements

In order to get a realistic view of the battery status, it is very important to perform the measurement during maximum load of the batteries. If this is not possible, include a margin for supply variation due to load variation when calculating the battery monitor level. Even a small series resistance in the supply lines may result in a load dependent supply variation big enough that it has to be taken into account when calculation the warning threshold.

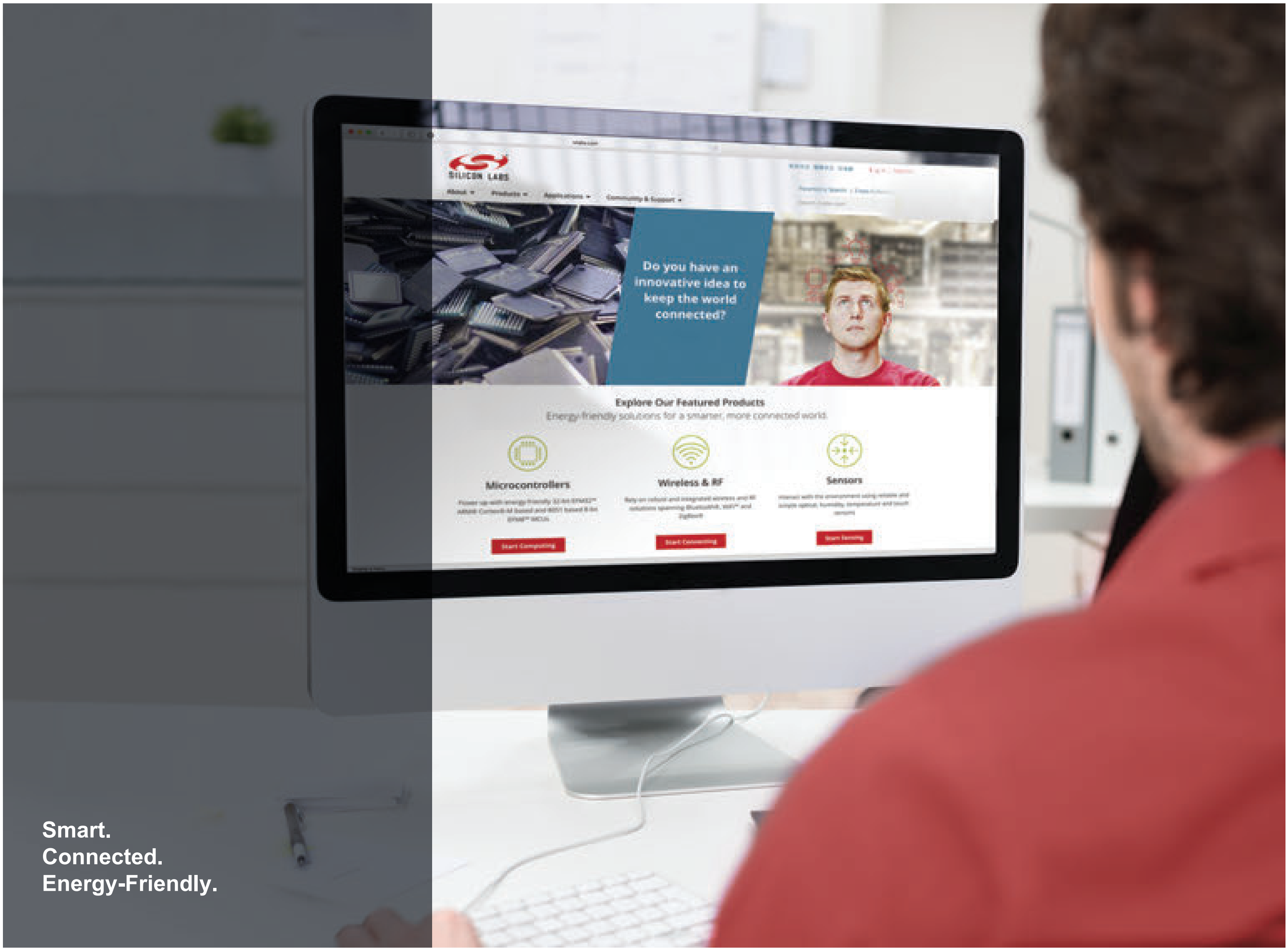
When performing an internal battery monitor measurement, the ADC cannot measure on other signals simultaneously. If an input to the ADC has to be monitored constantly, then performing a battery monitor measurement will interrupt the constant measurement for the duration of the supply measurement. When only using the ADC for internal battery monitoring, the state of the IO’s will not be influenced.

7.4 Calibration

Due to component-to-component variation in the internal band-gab voltage used during internal battery monitoring, its advised to calibrate the battery monitor during production of the application. If calibration is omitted, one should design the battery monitor system in a way that tolerates the variations.

REFERENCES

[1] Silicon Labs, INS12308, Instruction, Z-Wave 500 Series Appl. Prg. Guide v6.50.01 (Beta1)



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