Application Note

PIR Motion Detection With MSPM0

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ABSTRACT

Motion detection is valuable in many battery powered building automation applications, from basic security sensors to fully interactive camera systems. These systems rely on accurate, low power motion detection to maximize battery life by keeping powerful processors and wireless radios shut down when not needed. This design provides a low power, high-performance, and very cost competitive motion detection solution using an analog passive infrared (PIR) motion sensor and the MSPM0L1306. The MSPM0L1306 has integrated operational amplifiers (OPAs) and digital to analog convertors (DACs). The OPAs can provide the PIR sensor's entire signal chain, integrated inside the MSPM0. The OPAs are software configurable, allowing the signal chain to be easily adjusted for higher sensitivity and range, digital feedback loops, and optimized for low-power performance. This application note addresses ultra-low power, high-performance PIR design theory and test results using the MSPM0L1306.

Demo code mentioned in this document can be found in the MSPM0 SDK.

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1 PIR Design Description

1.1 PIR Sensor

There are several different types of sensors that can be used to detect basic motion, but the most common solution for the last decade has probably been using PIR sensors. PIR sensors are based on Wien's displacement law, which states that black-body radiation curve for different temperature will peak at different wavelengths that are inversely proportional to the temperature. Basically, if you monitor the infrared spectrum, objects of different temperature will radiate different levels of energy. Figure 1-1 shows what you see in images taken with infrared camera.

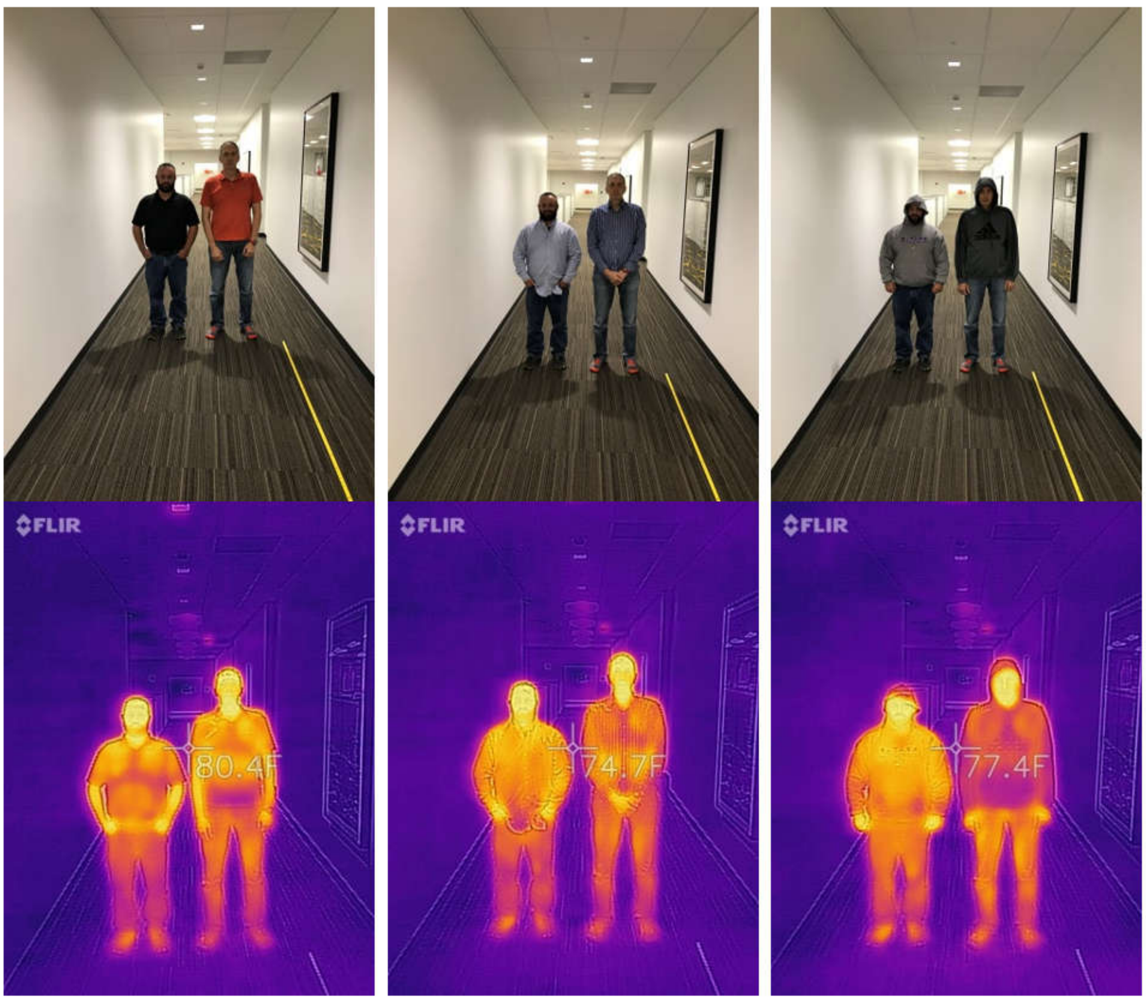

Figure 1-1. Infrared Photos

PIR motion detectors are passive sensors that used to detect general motion of people or animals. Instead of all the pixels seen in the IR images above, the PIR motion detectors typically generally only have only two sensing elements, as seen in Figure 1-2. These two sensing elements will be physically offset from each other, giving each of them slightly different fields of view (FOV). Each sensor will respond to general changes in temperature in its FOV. Only two sensors may sound limiting, but analyzing the combined signal from both sensor elements can provide a decent amount of information to be captured.

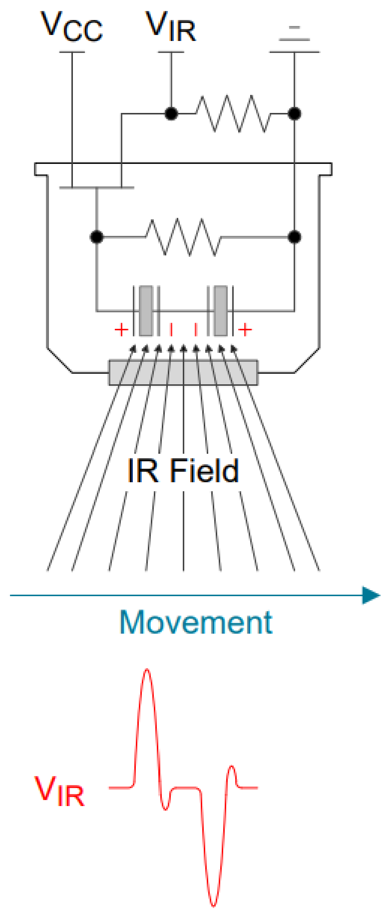

Figure 1-2. PIR Motion Sensor Illustration

As a person moves across both fields of view, the sensor will output a wave form from the sensing elements as the person passes from one sensor elements FOV through the next one. This waveform can be seen in Figure 1-3. As seen in Figure 1-3(a), The direction of this signal can tell us the direction of motion. In Figure 1-3(b). The amplitude of the signal can indicate the distance of the object or possibly the size of the individual/animal. Finally, in 3C, the speed of motion will also affect the speed of the waveform seen. In a given hallway, a walking person will have a different signature than a running person. An adult will have a different signature than that of a child or pet.

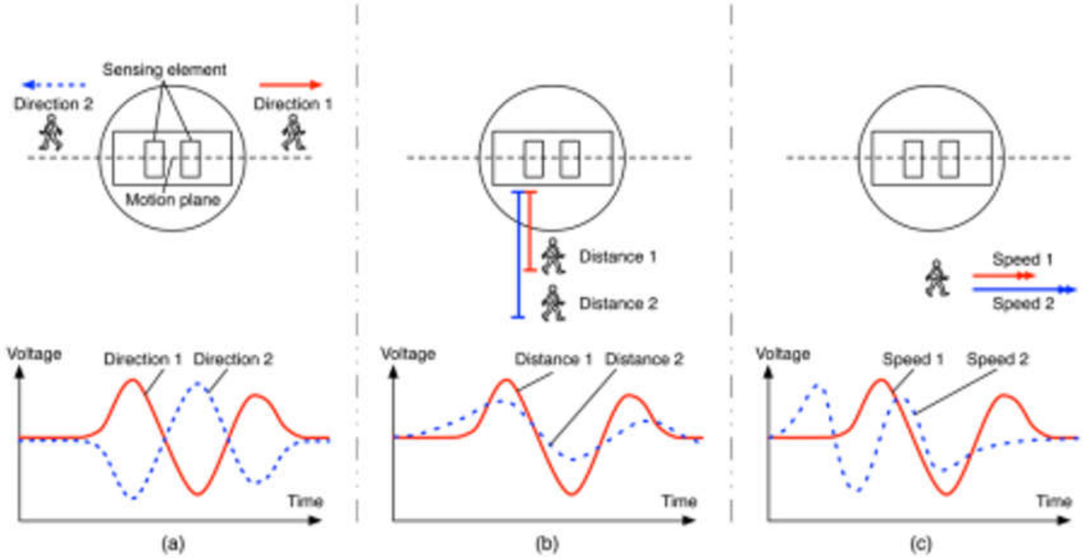

Figure 1-3. PIR Sensor Output Signal

There are usually two main specifications that are chosen when designing a motion detector for a specific application, maximum range and minimum motion speed. Generally, PIR motion detectors try to detect up to 10-12 meters and the motion frequency range is usually .7 Hz to 30 Hz. The exact performance needed for the application will affect how sensitive the system will need to be, from signal conditioning but also in software thresholding. The further away you want to monitor, the smaller the amplitude of the signals and the lower the signal to noise ratio. Typical signal levels at the output of a PIR sensor are in the micro-volt range for motion of distant objects, so it is necessary to amplify and filter the signal. The lower the minimum speed, the harder it will be to slowly slip past the monitor but the system will be more susceptible it to false triggers from environmental variation.

False detections are very undesirable, especially in battery powered applications. Typically the PIR Motion detection is monitoring while an application is in a low power mode. False detections will wake the rest of the system or trigger false alarms. This risk vs the sensitivity stated above must be weighed when designing a system. Traditionally a PIR's signal chain was designed with a specific use case in mind and designed with a fixed gain and bandwith in hardware, which means it had a fixed detection distance and speed. Fortunately, using the MSPM0L1306 the signal chain can be integrated so that it can actually be configured via software offering much greater flexibility without changing anything in hardware.

Finally, there are both analog and digital PIR sensors on the market. The digital sensors have their signal chain and detection algorithms integrated in them. They are easier to integrate into applications, but usually come with a significant added cost that makes them unsuitable for low cost applications. This document focuses on analog PIR sensors as they reduce overall system cost and can easily be integrated with the built-in OPAs.

1.2 PIR Signal Chain

1.2.1 Traditional Motion Detection Signal Chain Design

Figure 1-4 illustrates the traditional PIR motion detector signal chain. The signal from the PIR sensor is fed through a series of gain band-pass filters, that usually include DC blocking caps, and then fed to a set of comparators for low and high side waveform detection, acting as a window comparator.

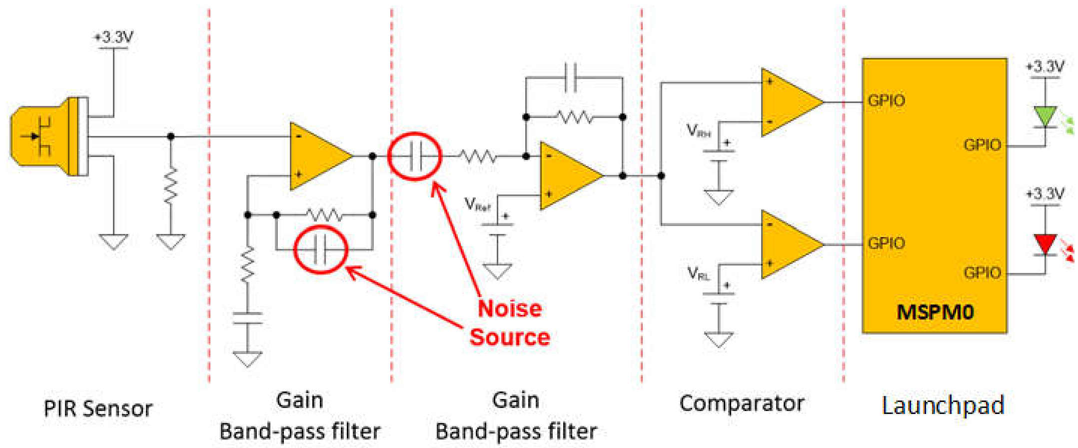

Figure 1-4. Traditional PIR Signal Chain

As mentioned in the introduction, this signal chain is fixed and limited. For the band-pass filters, the gain and cutoff frequencies are configured specifically for a particular detection range and motion speed. Typical cutoff frequencies are around .7 – 30Hz and overall signal gain may be as high as 1000x.

Another downside of this signal chain we found during our investigation, is that these DC filter caps actually end up being very large noise sources for the signal chain. Ceramic surface mount capacitors are usually made of barium titanate, which has a piezoelectric effect, meaning any noise or vibration actually generates small noise signals on the caps. Tantalum capacitors at such low frequencies can also introduce noise onto the signal. Coupling this noise with up to 1000x gain in the signal chain can return a very poor signal to noise ratio. In Figure 1-5, the signal from a PIR sensor was fed into the above signal chain and a capacitor free signal chain using the MSP in parallel. It is much easier to see the motion signal with the capacitor free circuit.

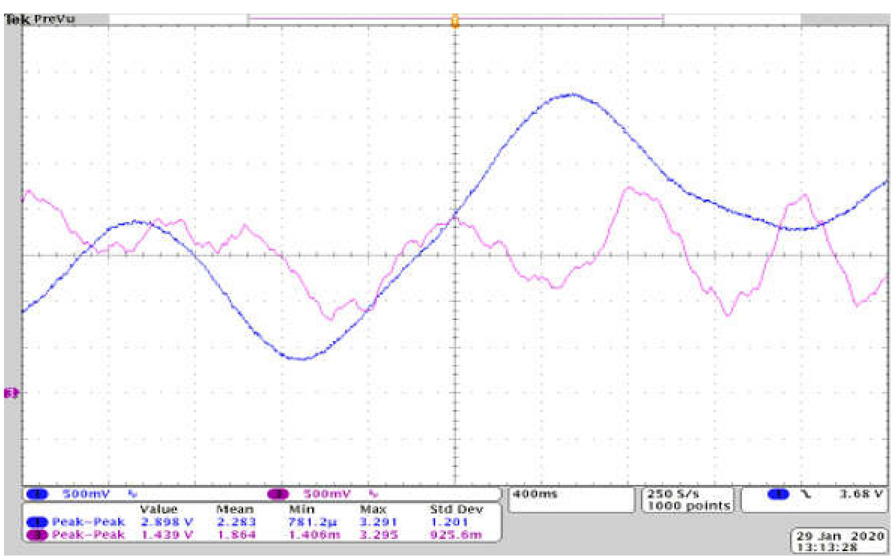

Figure 1-5. Traditional vs Capacitor-Free Signal Chain

1.2.2 Capacitor-Free Signal Chain Design

Figure 1-6 shows a simplified version of our capacitor-less signal chain. The signal chain now is mostly purely buffering and gain stages. To remove DC blocking capacitors in the traditional circuit that were adding noise to the system, the stages are being biased using DACs. Instead of using comparators, the signals are fed into an analog-to-digital converter (ADC) which enables a feedback loop for the DAC for tracking changes to environment and ambient temperature and allows digital filtering of the signal.

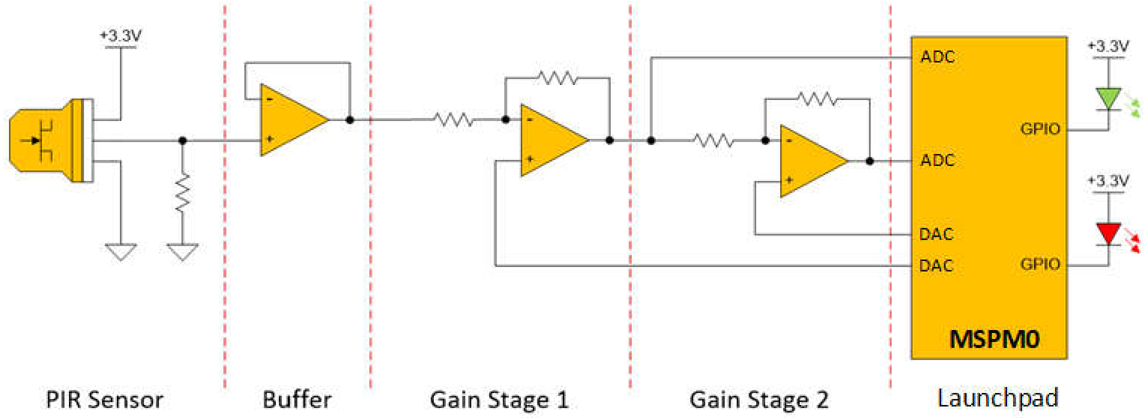

Figure 1-6. Capacitor Free Signal-Chain

The biggest benefit of the MSPM0 solution is that this entire signal chain is integrated into the MCU and is software configurable. The MSPM0L1306 is the most cost effective solution and it includes two operational amplifiers (OPAs). Each of these OPA's are zero-drift, zero-crossover chopper opamps with configurable gain from 1-32x. The MSPM0L1306 also includes one 8-bit reference DAC which is used to bias one stage for the signal chain. For the second stage, a PWM DAC was created using the general purpose amp (GPAMP) and a timer output channel.Figure 1-7 illustrates the improved interface to the PIR sensor leveraging the full signal chain inside the MSPM0L1306. The OPAs can be chained together inside the chip, connected directly to the ADC, and can be shutdown/power-cycled for lowest possible sleep currents.

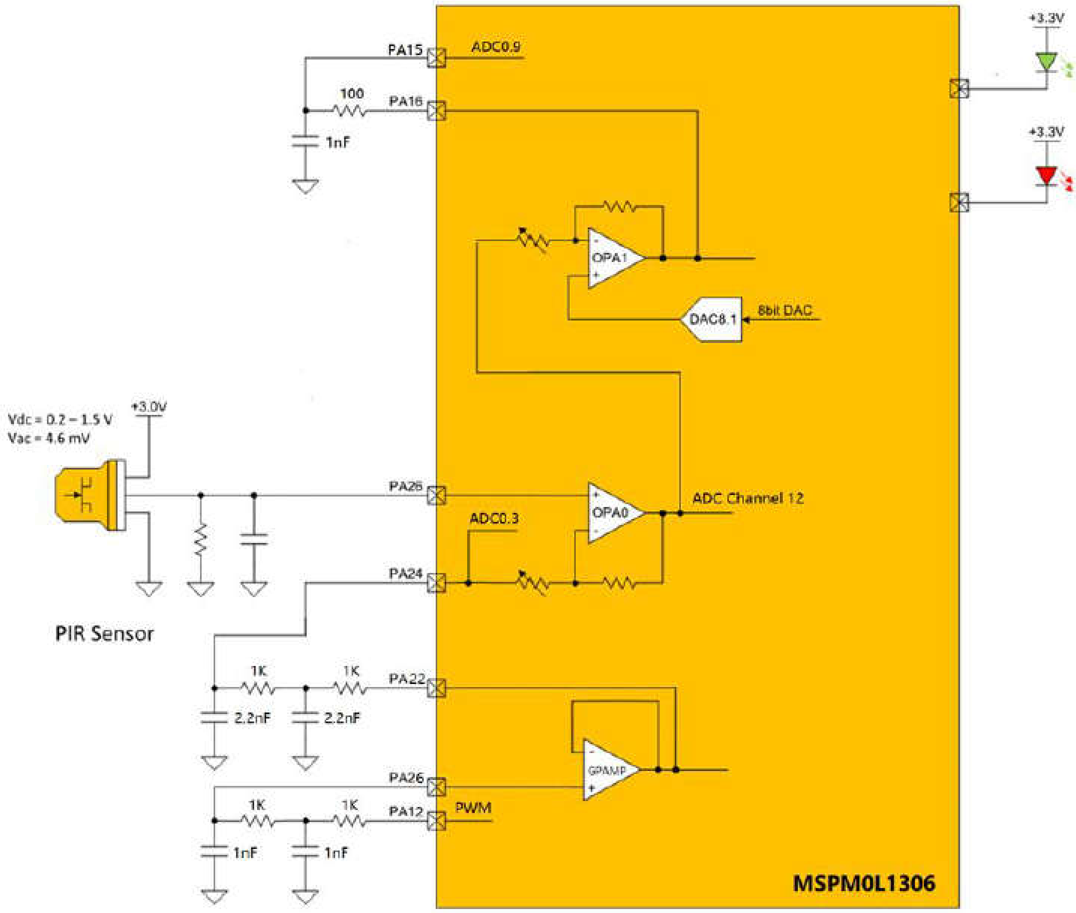

Figure 1-7. PIR Signal-Chain Integrated into MSPM0L1306

2 Hardware and Schematic

2.1 MSPM0L1306

The main MCU leveraged to enable this innovative PIR Motion Detector Design is the MSPM0L1306. The MSPM0L1306 is part of MSP's highly-integrated, ultra-low-power 32-bit MSPM0 MCU family based on the enhanced Arm® Cortex®-M0+ core platform operating at up to 32-MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from -40°C to 125°C, and operate with supply voltages ranging from 1.62 V to 3.6 V.

The MSPM0L134x and MSPM0L130x devices provide up to 64KB embedded flash program memory with up to 4KB SRAM. These MCUs incorporate a high-speed on-chip oscillator with an accuracy up to ±1.2%, eliminating the need for an external crystal. Additional features include a 3-channel DMA, 16- and 32-bit CRC accelerator, and a variety of high-performance analog peripherals such as one 12-bit 1.68-MSPS ADC with configurable internal voltage reference, one high-speed comparator with built-in reference DAC, two zero-drift zero-crossover operational amplifiers with programmable gain, one general-purpose amplifier, and an on-chip temperature sensor. These devices also offer intelligent digital peripherals such as four 16-bit general purpose timers, one windowed watchdog timer, and a variety of communication peripherals including two universal asynchronous receiver/transmitter (UARTs), one serial peripheral interface (SPI), and two inter-integrated circuits (I2Cs). These communication peripherals offer protocol support for LIN, IrDA, DALI, Manchester, Smart Card, SMBus, and PMBus.

- Core
  - Arm 32-bit Cortex-M0+ CPU, frequency up to 32 MHz
- Memories
  - Up to 64KB of flash
  - Up to 4KB of SRAM
- High-performance analog peripherals
  - One 12-bit 1.68-Msps analog-to-digital converter (ADC)
  - Two zero-drift, zero-crossover chopper operational amplifiers (OPA)
    - Integrated programmable gain stage (1-32x)
  - One general-purpose amplifier (GPAMP)
  - One high-speed comparator (COMP) with 8-bit reference DAC
  - Programmable analog connections between ADC, OPAs, COMP, and DAC
- Optimized low-power modes
  - RUN: 71 µA/MHz (CoreMark)
  - STANDBY: 1.0 µA with 32 kHz 16-bit timer running, SRAM/registers fully retained, and 32 MHz clock wakeup in 3.2 µs
  - SHUTDOWN: 61 nA with IO wakeup capability
- Clock system
  - Internal 4- to 32-MHz oscillator with ±1.2% accuracy (SYSOSC)

MSPM0L134x and MSPM0L130x MCUs are supported by an extensive hardware and software ecosystem, including Launchpad Development kits, the MSPM0 Software Development Kit (SDK), which is available as a component of the TI Resource Explorer. MSPM0 MCUs are also supported by extensive online collateral, training with MSPM0 Academy, and online support through the TI E2E™ support forums.

2.2 MSPM0 PIR Boosterpack

The MSPM0 PIR Boosterpack is not orderable, but the schematics are provided below. Figure 2-1 shows the PIR Boosterpack on the MSPM0L Launchpad.

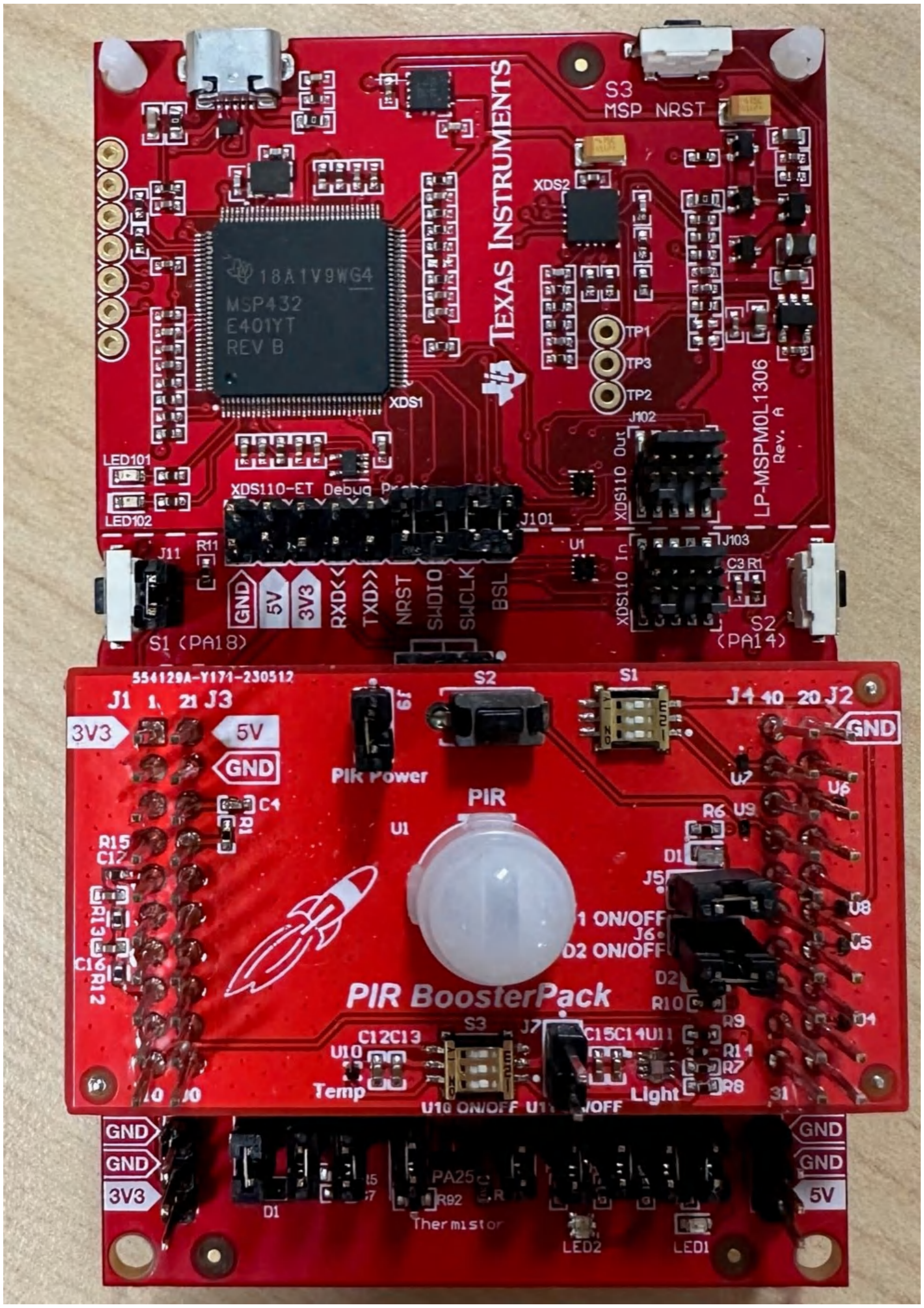

Figure 2-1. MSPM0 Launchpad and PIR Boosterpack

2.2.1 Schematic

Figure 2-2 shows the schematics for the prototype board that were built as a proof of concept and to provide the example performance data found in this document.

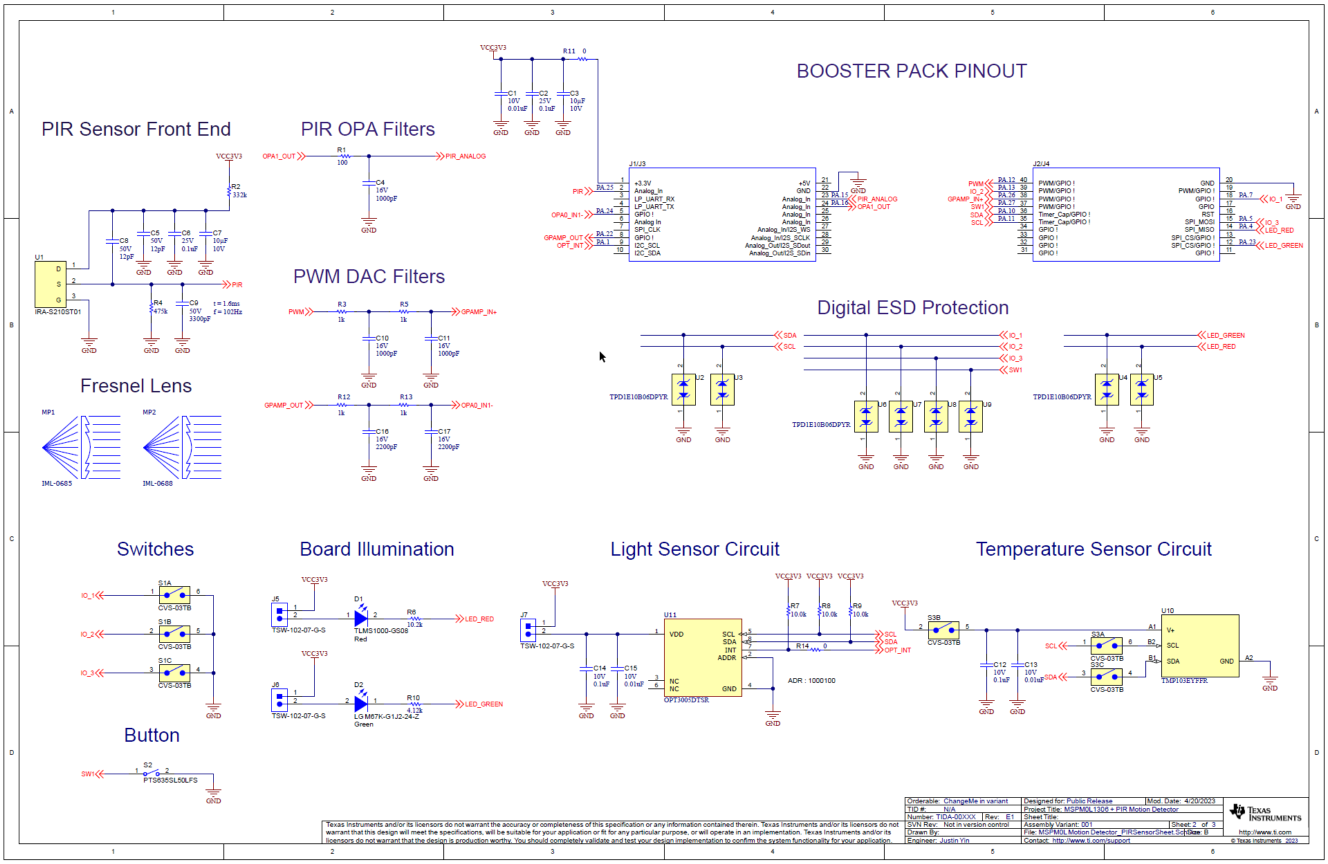

Figure 2-2. M0L PIR Boosterpack Schematic

3 Software

Software is a powerful piece of the MSPM0 PIR Motion Detector. As mentioned, the software controls the analog signal chain and feedback loops. The signal is also being sampled via the ADC, which allows digital filter techniques to be applied to the detection and feedback loops. This application note includes source code for the PIR motion detection demo. This demo software is intended to accelerate the development of a PIR solution using MSPM0L1306 MCU, but this software is only a part of a complete system and is intended to be used only as a reference.

3.1 Software Architecture

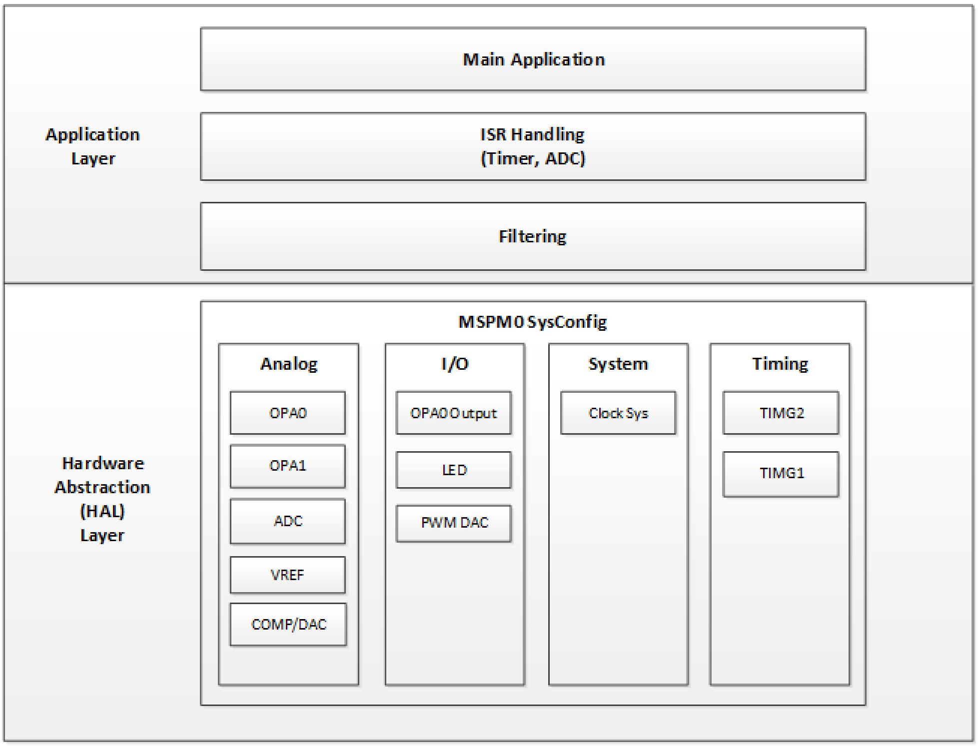

Figure 3-1. Software Architecture

The software was architected in two layers:

- The application layer implements the main functionality, with a default configuration, and handles the initialization and processing of the data.
- The HAL layer provides hardware-abstraction to interface with different peripherals of the MSPM0L1306. The pheripherals in the HAL are configured and initialized using

  SysConfig for a easily customizable solution.

3.2 Software Flow Chart

Figure 3-2 shows a flow chart of the software's overall behavior. The demo software wakes up and performs this full loop 20 times a second. The measurement takes approximately 90 µs and another 40-60 µs for simple data processing. The other 99.5% of the time, the analog is shut down and the MSPM0 is sleeping in Standby mode drawing ~1 uA. This flow chart is explained somewhat further in the power profile section.

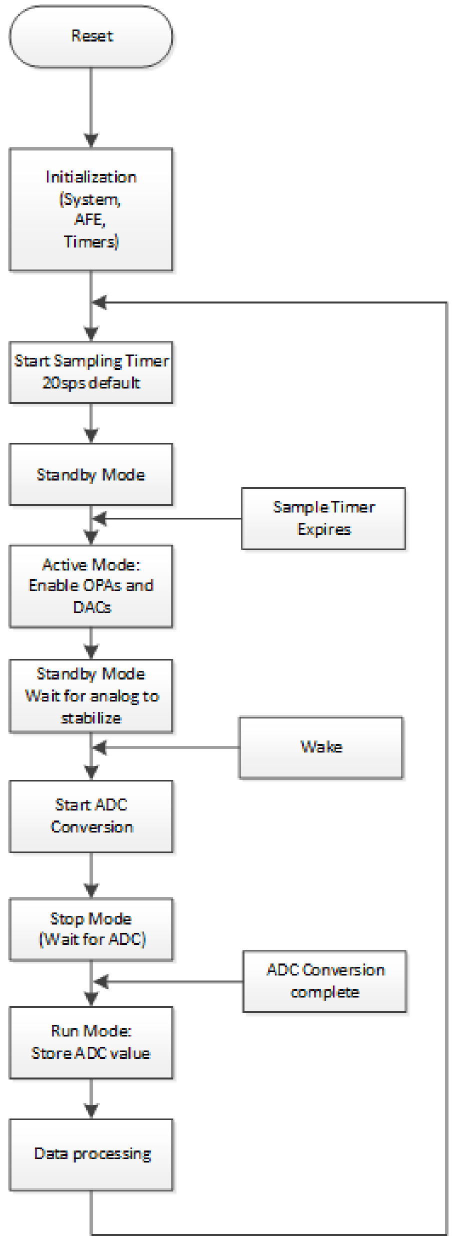

Figure 3-2. Software Flow Chart

3.3 Data Processing

3.3.1 Digital Signal Conditioning

3.3.2 Low-Pass Filter for Temperature Drift

Figure 3-3 shows what the PIR signal looks like over time as the ambient temperature and the PIR sensor body temperature are fluctuating. There is no motion detect events here, just the signal drifting. A digital low-pass, moving average filter is applied in software to the collected data samples. Based on this moving average filter, the DACs are adjusted to compensate for this baseline trend over time and this removes most of the DC component of the signal. This allows you to achieve a higher dynamic range from the MSPM0's 12-bit ADC since the signal chain is actively being compensated for the ambient temperature, it keeps the signal centered within the ADC measurement range. The software can use both the ADC's reading and the current DAC compensation values to determine the absolute digital output code.

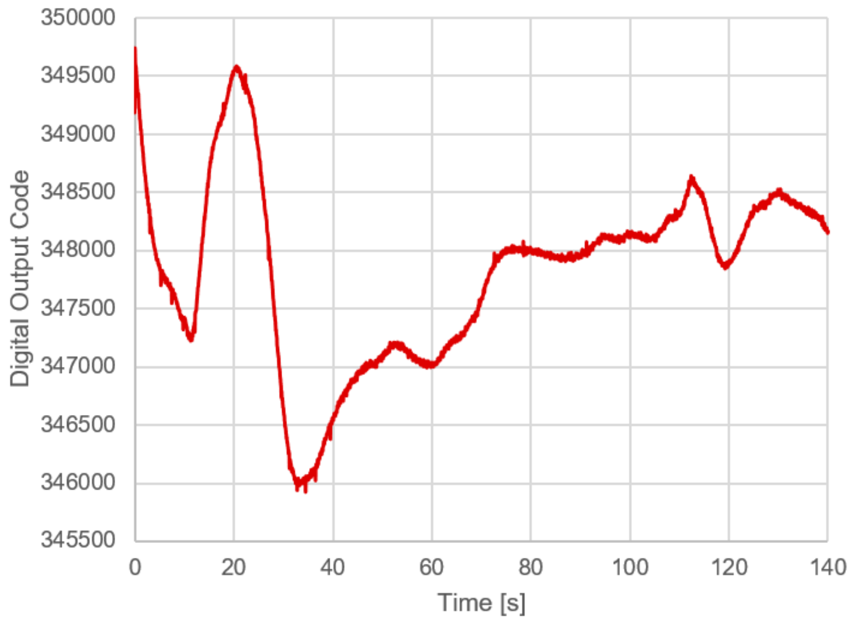

Figure 3-3. PIR Sensor Signal Drift Over Time

3.3.3 Spikes and Noise

If you zoom in on the data waveform, you will see that the signal is still quite noisy. The more noise that can be removed, the better the signal to noise ratio will be. The signal chain has already been improved to reduce the noise, but because you are sampling the signal with an ADC, it is possible to perform additional data processing on the signal. For the software, this noise is characterized as two different types: spikes and ripples.

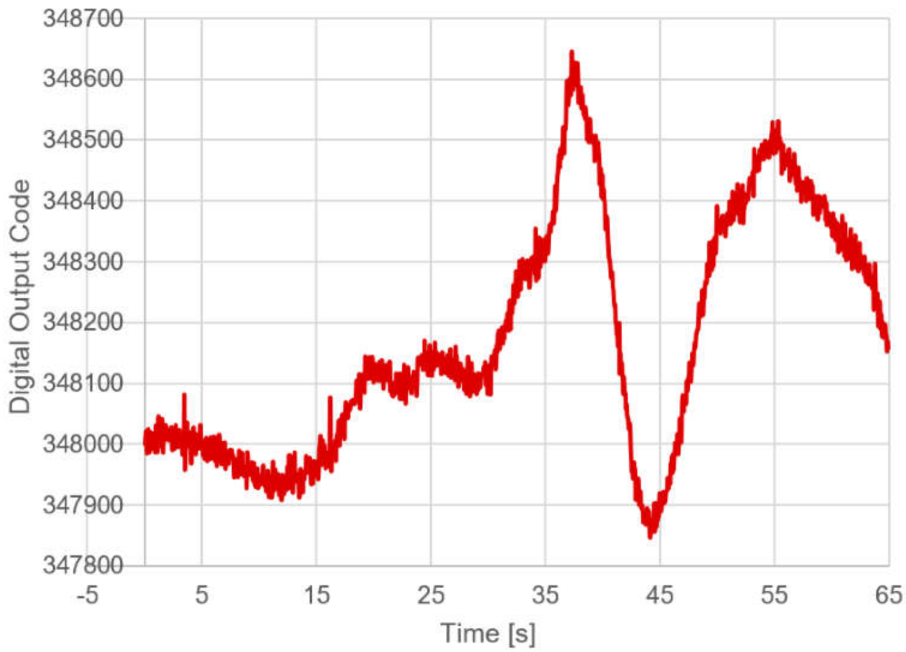

Figure 3-4. PIR Sensor Signal Zoomed In

Figure 3-5 shows two fairly large, random high-frequency spikes in the data. The samples are run though a "de-spiking" function that attempts to identify and remove these spikes and improve performance. This function basically looks at the last several samples captured in a window, and removes maximum and minimum values and therefore smoothing out any extreme "spikes" seen in the data.

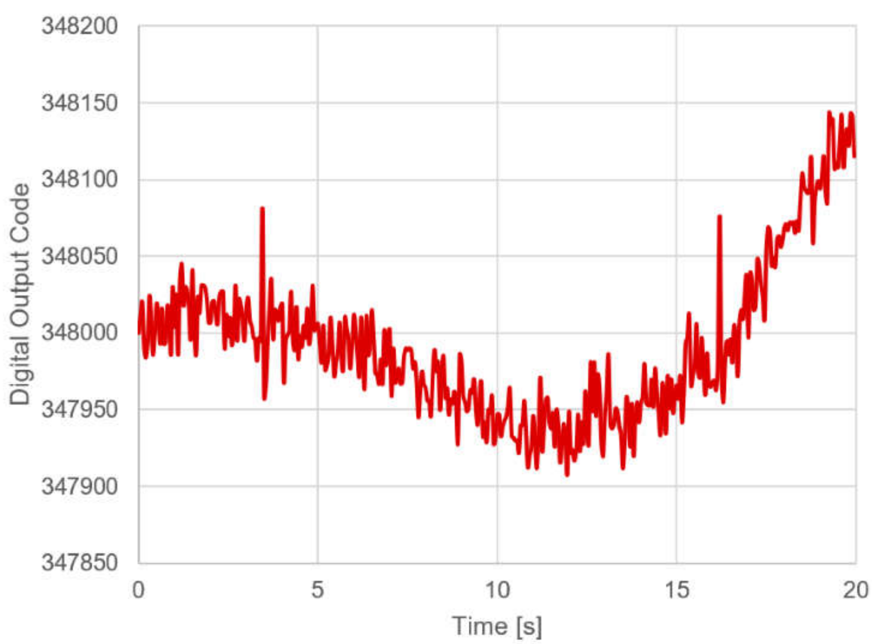

Figure 3-5. PIR Signal Spikes

Figure 3-6 shows ripples and white noise. There is a place holder for a“de-rippling” function, but the current example software has not implemented this. All the data below was captured without it.

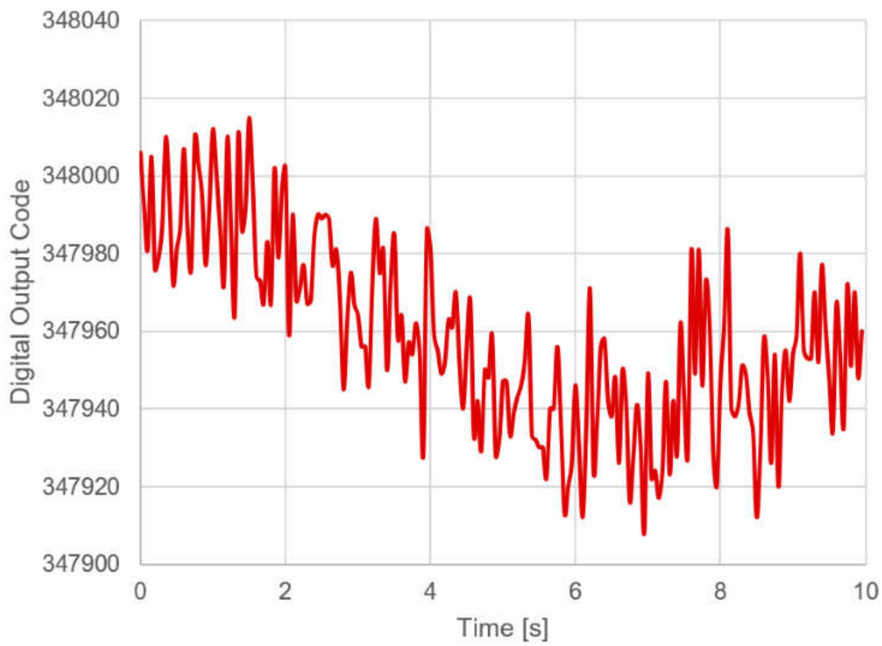

Figure 3-6. PIR Signal Ripples/Noise

3.3.4 Motion Detection Function

To detect if there has been motion, the software sends the latest sample to a signal analysis function after it has been run through the filtering functions. This function uses previous samples in an exponential moving average filter. This filter is used to output a reference level. There are a few more functions that then compare the sample to this reference output from the moving average filter. If the delta between these two samples becomes large enough and faster enough, then it decides that motion has been detected. This is the main place in software where the overall behavior and sensitivity of the solution can be tuned.

4 Results

4.1 Power Profile and Current Consumption

The software flow is what ultimately controls the system's power profile. Figure 4-1 shows some timing and signal captures on an oscilloscope and has been annotated to explain where you are in the software flowchart. It takes ~90 µs to wake-up from Standby, enable the analog, wait for it and the measurement signal to stabilize, and complete the ADC conversations. The Blue trace is the output of the PWM DAC needed on the MSPM0L13xx solution and discussed in Section 1.2. The yellow trace is our measurement signal from the end of the PIR signal chain and you can see it stabilize right as the ADC conversation starts. After the measurement, the analog is shut off and the data processing is done. Then the MCU goes to Standby for ~50 ms.

Ultimately, this solution has been measured to **average ~12 µA when running at 20 SPS**. This power measurement includes the MSPM0L1306, the integrated signal chain, and also the power for the PIR sensor.

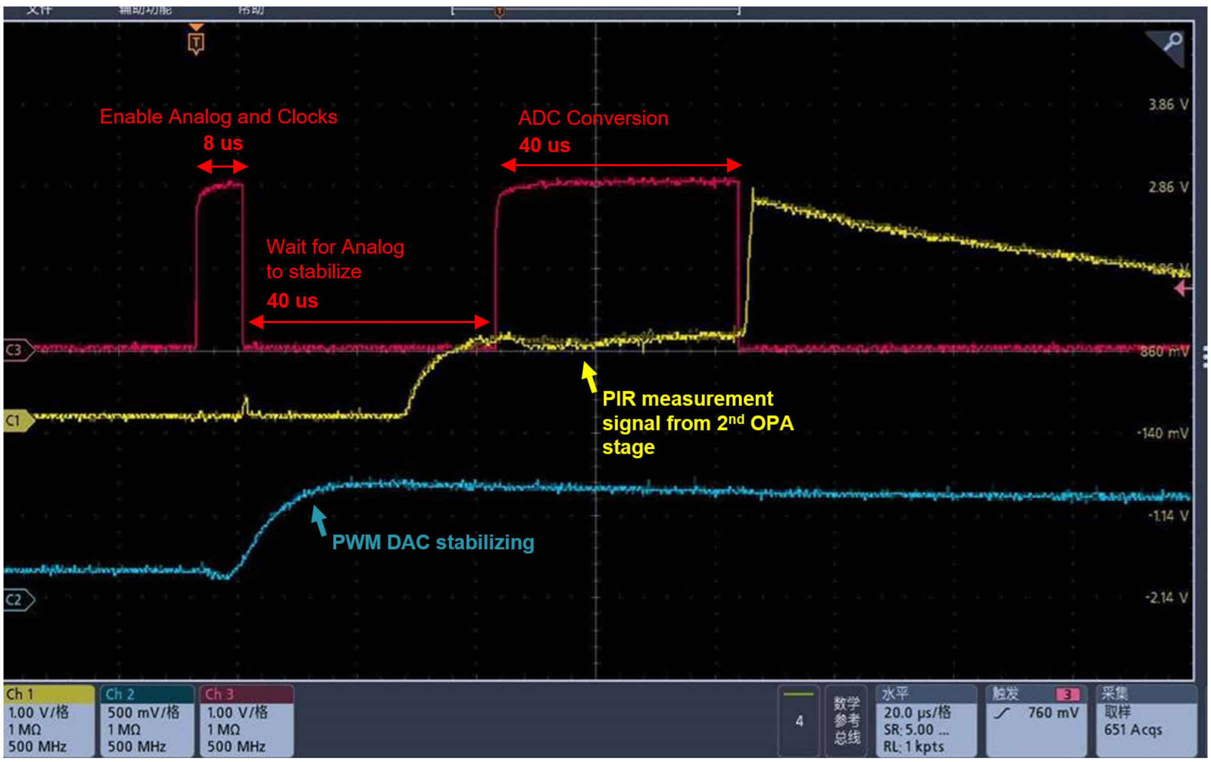

Figure 4-1. Power Profile of MSPM0L13xx PIR Demo Software

4.2 Detection Performance

In order to test the range of the MSPM0 PIR motion detector, the device was positioned at the end of a hallway on a tripod. An adult would walk side-to-side at set distances at approximately 1 m/s, and the resulting absolute value of the signal would be analyzed. The threshold for the digital output code to detect motion was set to 30. The motion detector could reliably detect motion at the beginning 5 m range, and could detect with less sensitivity out to 9 m under the set test conditions. These result could be further optimized with further software development and possibly the use of different PIR lenses.

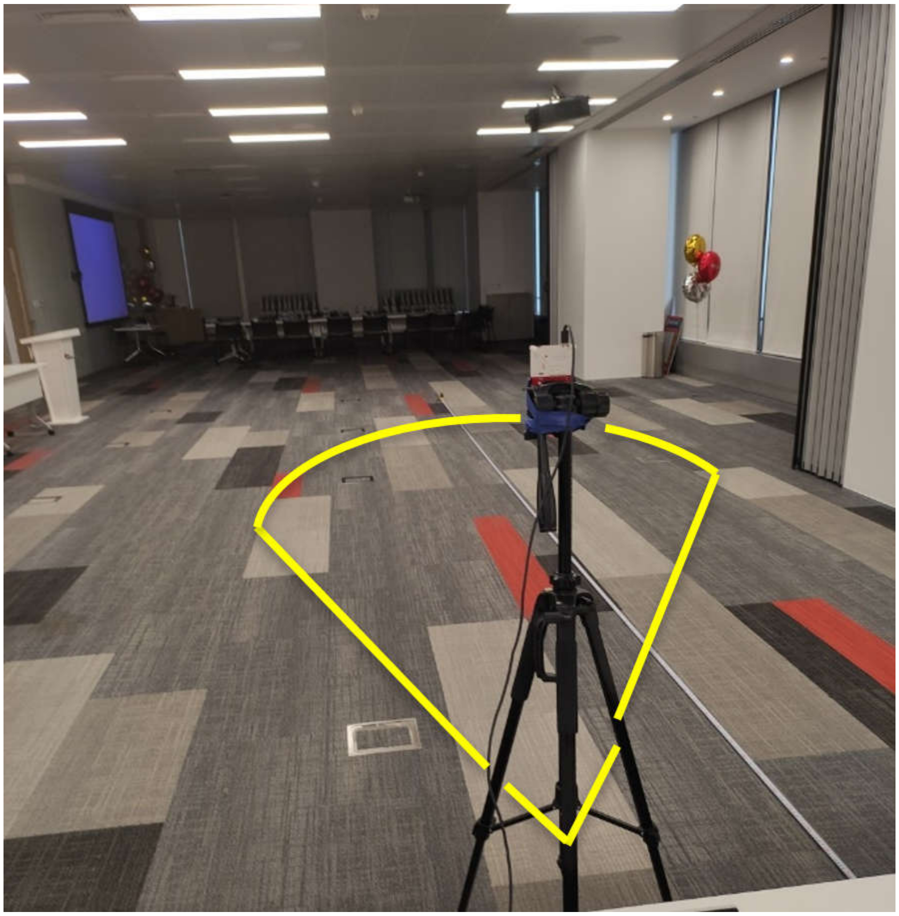

Figure 4-2. MSPM0 PIR Motion Test Setup Example

4.2.1 Distance: 5 meters (16.4 ft)

Motion events are clearly detected, with spikes passing well above the set software threshold.

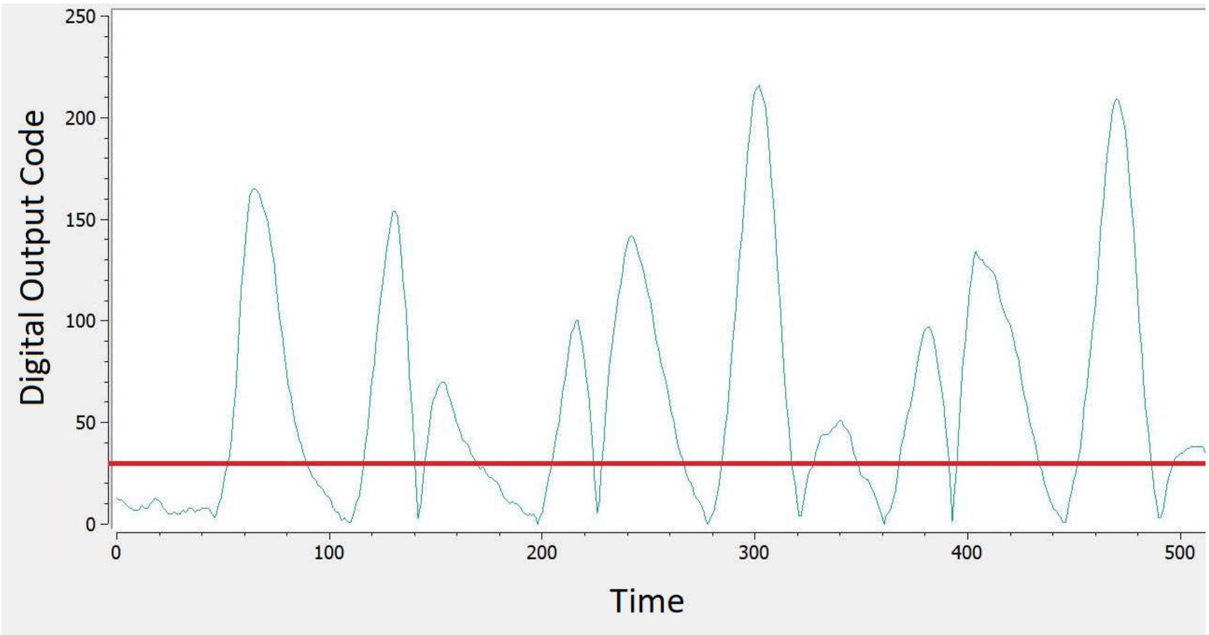

Figure 4-3. Adult at 5 m (16.4ft), speed 1 m/s

4.2.2 Distance: 9 meters (29.5 ft)

Motion events are clearly detected, with spikes passing well above the set software threshold.

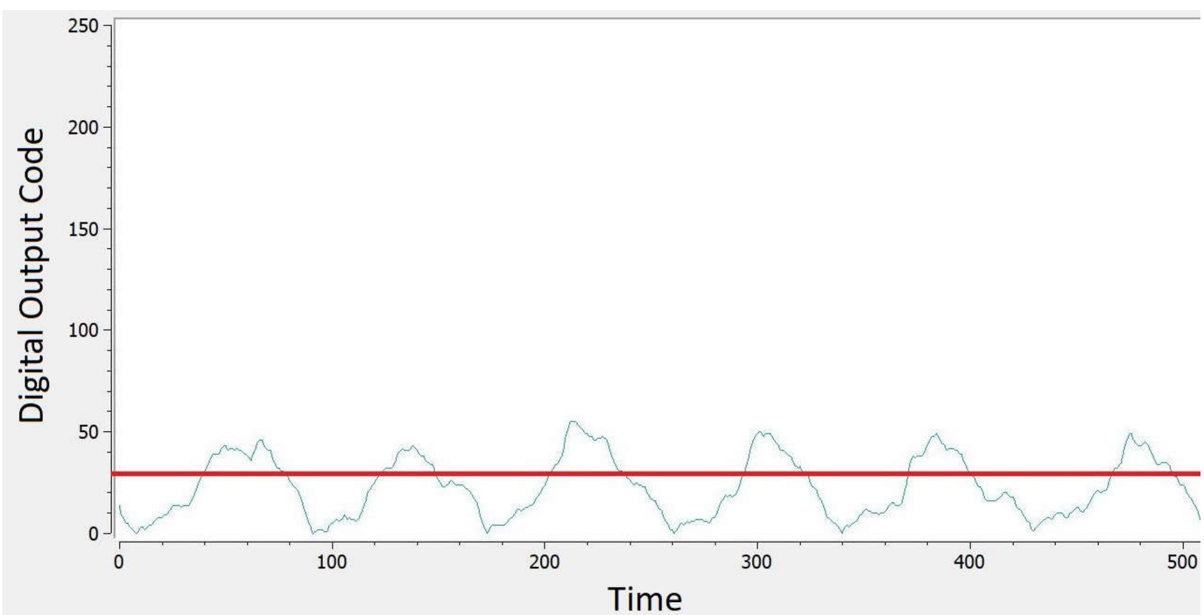

Figure 4-4. Adult at 9 m (29.5 ft), speed 1 m/s

4.2.3 Distance: 10 meters (32.8 ft)

At 10 m, motion events barely reach the required threshold, and motion detection becomes sporadic.

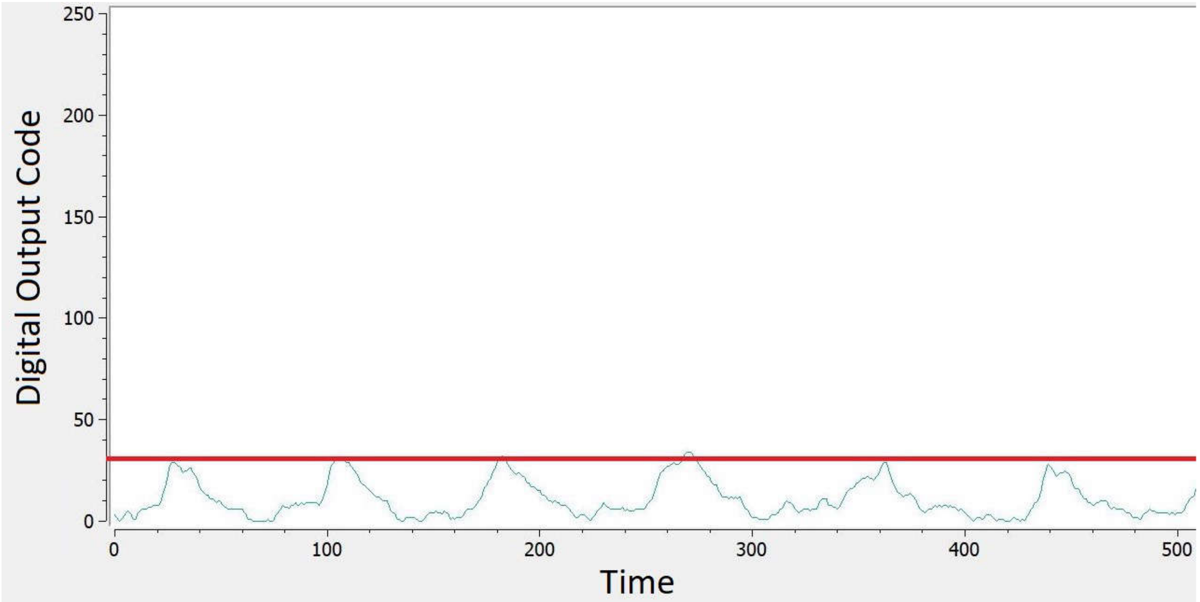

Figure 4-5. Adult at 36.5 ft (11.1 m), speed 1 m/s

5 Summary

PIR Motion detectors have remained mostly unchanged for the last decade but finally new, updated solutions are possible by leveraging devices like the MSPM0L1306 with advanced analog integration. The MSPM0 PIR Motion Detector offers a completely fresh and competitive solution to motion detection applications. The integrated capacitorless signal chain offers great performance and flexibility, with the ability to detect motion out to 9-10 meters. The solution provides significant BOM savings and board simplification with integrated OPAs and an analog PIR sensor. Finally, the software controlled AFE also allows for a very low power solution, with approximately 12 µA average current at 20 SPS.

To get started, order an MSPM0L1306 Launchpad and download the example project.

6 References

- Texas Instruments: *MSPM0L130x Mixed-Signal Microcontrollers Data Sheet*
- Texas Instruments: *MSPM0 L-Series 32-MHz Microcontrollers Technical Reference Manual*
- Texas Instruments: *Ultra-Low-Power Wireless PIR Motion Detector for Cost- Optimized Systems Reference Design*
- MSPM0L1306 LaunchPad™ development kit

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265