
Overview

This reference design demonstrates how to use Zilog's ZMOTION® Occupancy Detection solution in a PIR-based motion detector module. It also shows how to implement additional hardware and software functions such as a serial interface and configuring the detector using potentiometers.

The ZMOTION Detection Module II (ZDMII) provides an integrated and flexible solution for Passive Infrared (PIR)-based motion detection applications. It includes the Z8FS040 MCU combined with a selection of lenses to fit a range of occupancy detection applications.

The Z8FS040 MCU ships preprogrammed with motion detection software algorithms that comprise the ZMOTION Engine. These algorithms run in the background while control and status of the Engine is accessed through a software Application Programmer Interface (API). Optimized API settings are provided that match the Engine operation to each of the lens and pyroelectric sensor combinations provided.

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- **Note:** The source code file associated with this application note, [RD0026-SC01.zip](#), is available free for download from the Zilog website. This source code has been tested with version 5.0.0 of ZDSII for Z8 Encore! XP MCUs. Subsequent releases of ZDSII may require you to modify the code supplied with this reference design.
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Features

The key features of this reference design are:

- Complete board-level motion detection design supporting the following five lens types:
 - NCL-10IL (7 meter wall mount, wide angle) installed
 - NCL-10S (12 meter wall mount, corridor, directional)
 - NCL-9(26) (5 meter wall/ceiling mount, 2:1 diameter-to-height coverage ratio)
 - NCL-3R (ceiling mount, 1.8:1 diameter-to-height coverage ratio)
 - NCL-3B (3 meter wall mount, wide angle)
- Employs a low-cost RE200B dual-element pyroelectric sensor
- Low-cost modular design
- Serial and hardware configuration modes

- Automatic temperature compensation
- Standard 8-pin 0.100" header interface

Front and back views of the ZMOTION Detection Module II are shown in Figures 1 and 2, respectively.



Figure 1. ZMOTION Detection Module II: Front

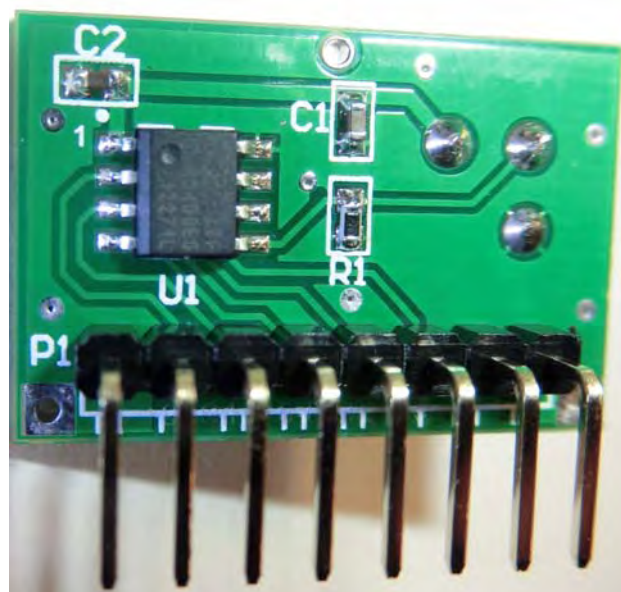


Figure 2. ZMOTION Detection Module II: Back

Discussion

The use of Passive Infrared (PIR)-based motion detectors has been prevalent in lighting control, energy management, and general occupancy detection applications for a number of years. Despite this popularity, the traditional design architectures of motion detection devices, and their inherent limitations, have not significantly changed since their inception. Zilog's ZMOTION Occupancy Detection Solution employs an architecture that provides a significant advantage over previous approaches, delivering a dramatic improvement in both sensitivity and stability over traditional motion detection designs.

Traditional Design Architecture

The traditional motion detector design uses a pyroelectric sensing element combined with a Fresnel or similar-type lens to direct the infrared energy emitted from a target as it moves across the sensor's detection area. As this focused energy moves across the sensing elements of the pyroelectric sensor, it generates a voltage with a frequency component ranging from 0.1 Hz to 10 Hz. The amplitude of this signal is relative to the difference in temperature between the target and its surrounding environment (ambient temperature) and is typically in the range of 1 m VP-P to 2 m VP-P. It also contains a large high-frequency noise component and a DC offset of 400 mV to 1,800 mV that will change with temperature and aging; this offset can even vary between devices.

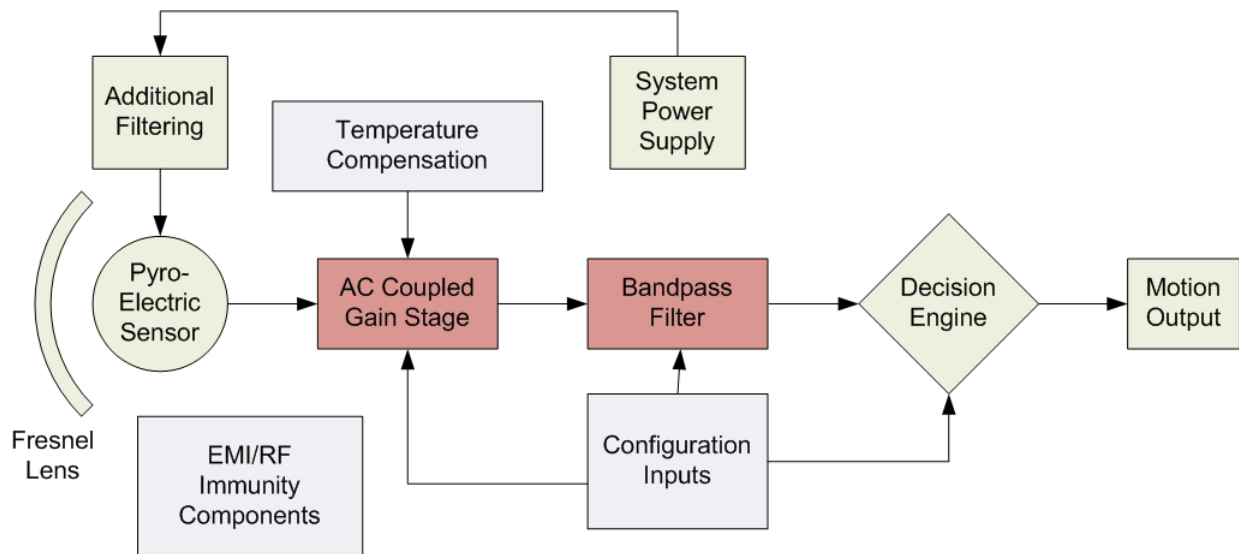


Figure 3. Traditional Design Architecture

To create a signal that is usable by either discrete components or a microcontroller, the output signal from the sensor is typically followed by an AC-coupled gain stage (~72 db), combined with a bandpass filter, which reduces the high-frequency noise content and strips the DC offset. This decision stage is responsible for extracting the signature of human motion from the resulting signal. The most common approaches to type of signal

filtering are the *rate of rise* and *time above amplitude* methodologies. The *time above amplitude* method can be implemented with a simple window comparator, in which the two signal inputs are phase-delayed from each other. Although there are several drawbacks to either of these methods – the most significantly drawback being its susceptibility to false detections – it is commonly used in low-cost motion detectors.

More commonly, however, motion detectors intended for occupancy applications use a microcontroller to perform decision analysis. A microcontroller can combine multiple detection methods to produce a more stable motion detector. However, this combination approach still does not address the root issues causing false detections: high-gain circuit elements and an extremely modified sensor signal. By filtering the signal, useful information that is sometimes critical to making a reliable decision is removed. Because of the low-frequency filtering required by traditional architectures, signal discontinuities caused by external electrical factors (mainly EMI and ESD) can create a signature that is indiscernible from valid motion-creating false events. The high-gain stage simply compounds the problem and increases a traditional design’s susceptibility.

ZMOTION Design Architecture

In the ZMOTION Occupancy and Motion Detection Architecture shown in Figure 4, the pyroelectric sensor is interfaced directly to the Z8FS040 MCU without any AC coupling, gain, or filtering. As a result, the MCU is allowed to work with a true, unmodified signal to gauge the real-time effects caused by shifts in DC offset, transience, and other nonmotion-based signal changes. No temperature compensation is required, thereby resulting in a lower-component-count design.

The ZMOTION Detection Module II Reference Design is based on this architecture, and is described in more detail throughout the remainder of this document.

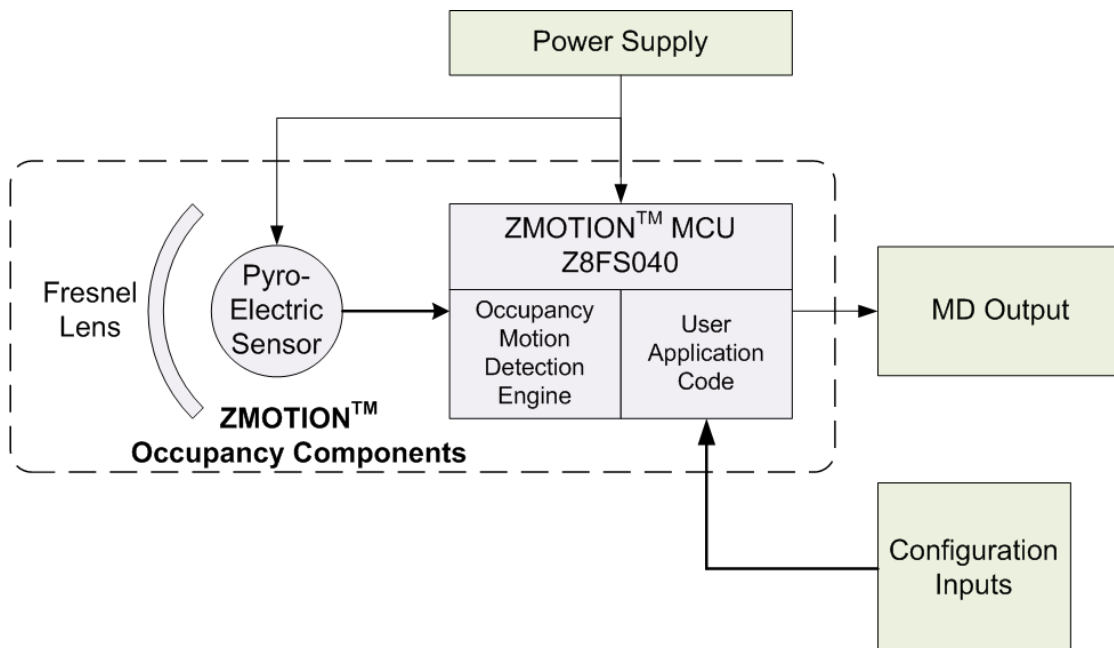


Figure 4. ZMOTION Design Architecture

Theory of Operation

The ZMOTION Detection Module II Reference Design is based on the Z8FS040 MCU, which includes the ZMOTION motion-detection algorithms preprogrammed in Flash memory; 4 KB of memory is available for application code. This ZMOTION software runs from the ADC end of the conversion interrupt, and provides status updates to the application through the API registers. To learn more about the Z8FS040 MCU's API registers, refer to the [ZMOTION Detection and Control Product Specification \(PS0285\)](#).

The block diagram in Figure 5 shows all peripherals included with the Z8FS040 MCU that are available to the application.

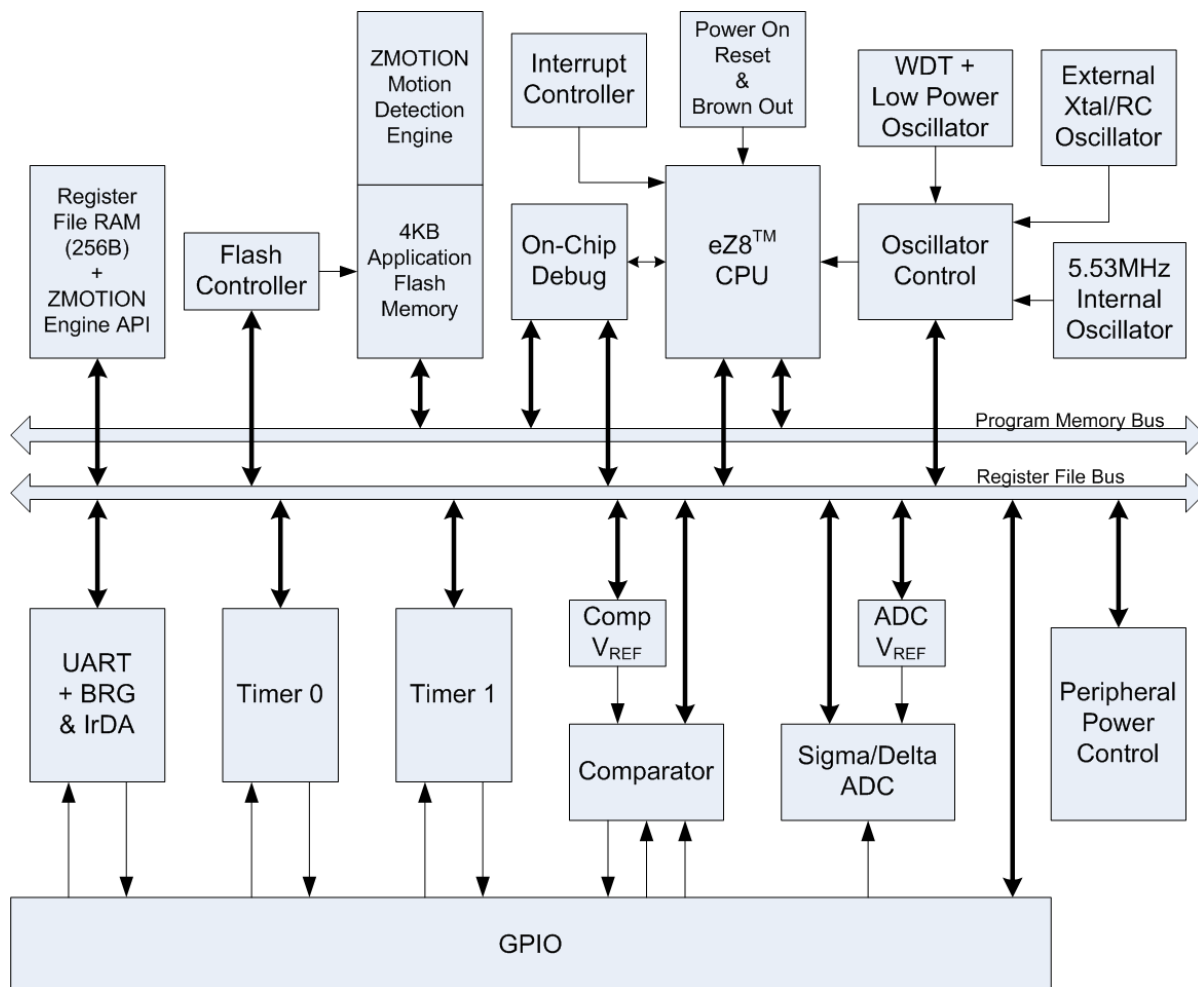


Figure 5. Z8FS040 MCU Block Diagram

The motion detection algorithms take advantage of the Z8FS040 MCU's on-chip Sigma/Delta ADC when operated in Differential Mode. The pyroelectric sensor is connected directly to the positive ADC input, with the 1 V ADC V_{REF} connected to the negative

input of the ADC. This connection creates a $\pm 1\text{ V}$ range for the pyroelectric sensor input. Although specified for 10-bit accuracy, the Sigma/Delta ADC features a 16-bit result register, in which one bit is used for overflow indication and another bit is used for sign. The ZMOTION Engine oversamples and averages the pyroelectric sensor's signal input and provides 15 bits of resolution. Because the software algorithms of the ZMOTION Engine are tuned to detect changes and rates of changes in the pyroelectric sensor signal, absolute accuracy is not necessary. By oversampling and averaging the signal input, constructed sample values have a $\pm 16,384$ -count range, which provides a usable resolution of $61\ \mu\text{V}$ per count.

Hardware Architecture

The ZMOTION Detection Module II (ZDMII) Reference Design is based on the 8-pin Z8FS040 MCU. All functions related to the operation of the detector are handled by the MCU. The reference design is supported by the ZDMII Development Board, which includes additional hardware to demonstrate the advanced features of the Module.

In Figure 6, all external connections to the Module are made through the 8-pin row header.

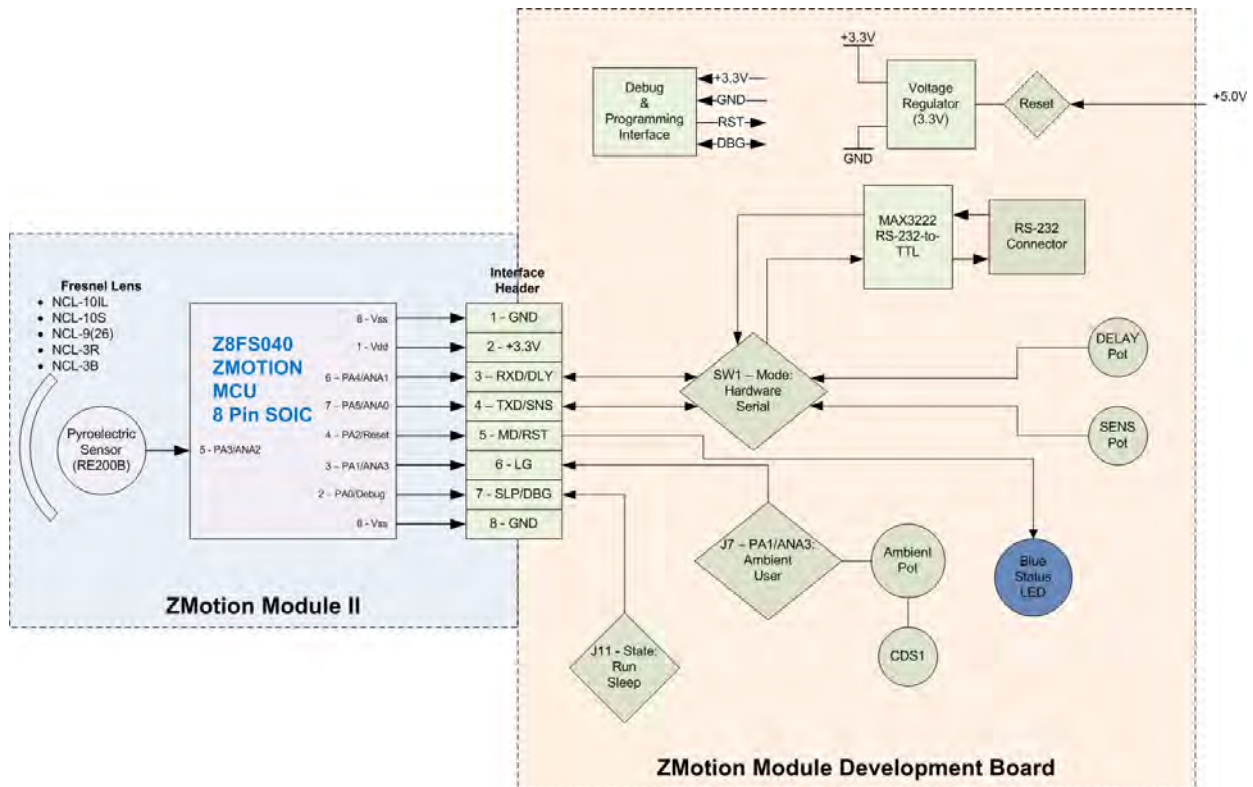


Figure 6. ZDMII Block Diagram

The Module is designed to support standard clip-on lenses, which available from Zilog and other suppliers. The reference design ships with the NCL-10IL lens installed; a 7-meter, 90° wide-angle lens. The Module’s printed circuit board is composed of a two-layer FR4 material using 1 oz. copper with gold plating.

I/O Map

An I/O map of the Z8FS040 MCU is shown in Table 1.

Table 1. ZDMII Z8FS040 MCU I/O Map

Pin #	Pin Name	Type	Function	Comments
1	V _{DD}	V _{DD}	Power	2.8V to 3.6V.
8	V _{SS}	V _{SS}	Ground	
2	DBG (PA0)	Digital I/O	Sleep/Debug	Needs 10K PU for Debug.
4	Reset (PA2)	Digital I/O	MD/Reset	10K PU for Reset.
5	ANA2 (PA3)	Analog I/P	Pyro Signal (ANA2)	–
3	ANA3 (PA1)	Analog I/P	Light Gate (ANA3)	–
7	TXD0/ANA0 (PA5)	Digital O/P	UART Tx/Sensitivity Potentiometer	–
6	RXD0/ANA1 (PA4)	Digital I/P	UART Rx/Delay Potentiometer	–

Software Architecture

The [RD0026-SC01.zip](#) source code file included with this reference design includes a project file named `ZMotion_App.zdsproj` which is built using Zilog Developer Studio II (ZDSII) for Z8 Encore! XP version 5.0.0. The `RD0026-SC01.zip` source code file contains standard ZDSII support files, standard ZMOTION support files, and custom application files; these files are briefly described in this section.

Source Files

main.c. A custom application source code file that implements the major functions of the software.

ePIR_API.c. A standard ZMOTION support file required for all ZMOTION projects. This file reserves space in RAM for the ZMOTION API registers, and defines the API register names.

startupPIR.asm. A standard ZMOTION support file required for all ZMOTION projects. This file provides all necessary environment initializations after reset, and replaces the standard `startups.asm` or `startup1.asm` file.

Header Files

ePIR_API.h. A standard ZMOTION support file required for all ZMOTION projects. This file provides bit definitions for all API registers.

Main.h. A custom application file that includes project definitions and defaults for the `main.c` file.

eZ8.h. A standard ZDSII support file that brings in all other MCU-specific support files.

API_INIT_ZDM2.h. A standard ZMOTION API configuration file for ZDMII with an RE200B pyroelectric sensor. This file is compatible with several lenses without requiring additional modification.

Project Configurations

The following two ZDSII project configurations are defined for ZDMII:

ZDM_Release. This configuration is used to produce a final build for production.

ZDM_Debug. This configuration used to produce a copy that can be used for in-circuit debugging.

The application consists of a main loop and two interrupt sources: ADC and Timer 0. Halt Mode is used in the main loop, causing it to be executed once after either interrupt. The ADC interrupt passes control to the ZMOTION Engine, which performs all motion detection processing, updates the API, and then returns to the calling function. The ADC is run in Continuous Mode, so this interrupt occurs once every 256 system clocks (about once every 46.2 μ s). The Timer 0 interrupt runs once every 100ms and controls all software timers used in the main loop. It also sets the required one-second time base bit in the API and updates the status of the MD output.

See [Appendix B. Flow Charts](#) on page 18 to review a top-level code flow for this reference design.

Equipment Used

Each of the following items is included with the ZMOTION Detection Module II Reference Design.

- ZMOTION Detection Module II
- ZMOTION Development Board
- ZDSII – Z8 Encore! v5.0.0
- Selection of lenses
- 5V DC power supply
- USB SmartCable
- Serial cable

Installation and Operation

This section describes how to connect and operate the ZDMII Module with the ZDMII Development Board.

Establishing Connections

All connections to the ZDMII Module are made through the P1 interface header, which inserts into J4 on the ZDMII Development Board, as indicated in Figure 7.

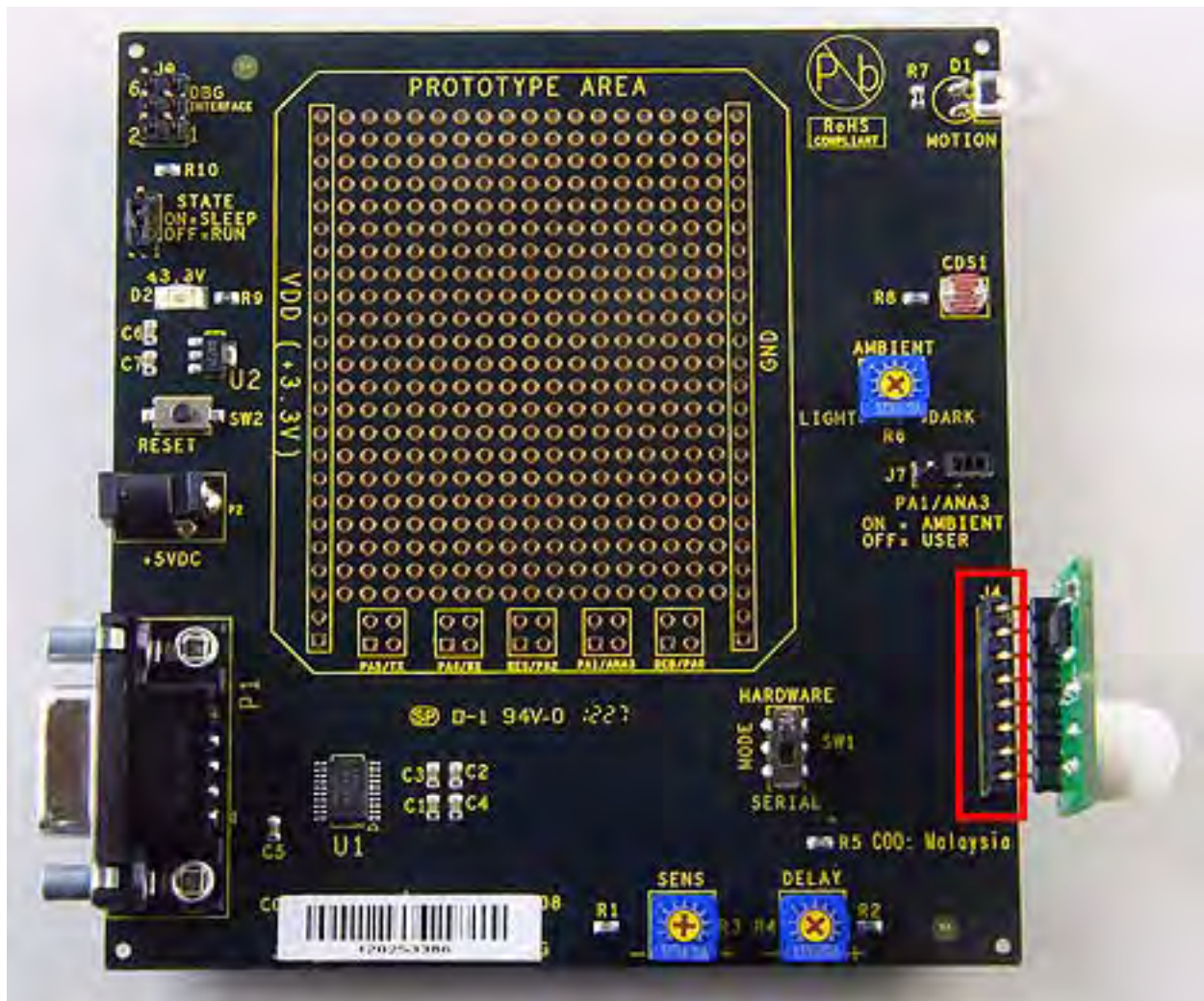


Figure 7. The Location of J4 on the ZDMII Development Board

The ZDMII Development Board provides additional hardware to support the two operating modes of the Module, Serial Mode and Hardware Mode; these modes are selectable with SW1. Details about the connections for each mode are shown in Table 2.

Table 2. ZDMII Development Board Signal Connections

Pin	Name	Connection on the ZDMII Development Board	Comments
1	V _{SS}	GND	
2	V _{DD}	+3.3V	
3	RXD/DLY	Serial: Receive Data out from RS-232 chip U1 Hardware: Delay Potentiometer R4	Selected by SW1.
4	TXD/SNS	Serial: Transmit Data to RS-232 chip U1 Hardware: Sensitivity Potentiometer R3	Selected by SW1.
5	MD/RST	Motion Detected LED D1	Configurable as MD or Reset in Serial Mode.
6	LG	Ambient Light Sensor CDS1	Connected via J7.
7	SLP/DBG	State jumper J11	Debug interface pin.
8	V _{SS}	GND	

Setting the Jumpers

Four jumpers are provided on the ZDMII Development Board to allow control and evaluation of certain features of the ZDMII; Table 3 lists the settings for these jumpers.

Table 3. Jumper Settings

Jumper	Function	Installed	Removed
J7	CDS	Ambient, PA1 connected to CDS1	User, PA1 not connected to CDS1.
J11	State	Sleep, MCU in Stop Mode	Run, MCU active.

Selecting an Interface Mode

The ZDMII Module determines the interface mode by sampling the voltage level on PA5 during the power up sequence. If the voltage on the pin is below 2.0V, the Module will select hardware interface mode. If the voltage is above 2.0V the Module will select Serial Interface Mode.

Operating In Hardware Mode

To select Hardware Mode, place SW1 in the **Hardware** position and apply power to the ZDMII Development Board. The Module can be configured through the trim pots, which are labeled **Sens**, **Delay**, and **Ambient**.

The Sensitivity trim potentiometer, **Sens**, adjusts the motion sensitivity of the Module. Turning this pot in the + direction increases the Module's sensitivity; turning this pot in the – direction makes it less sensitive.

The Delay trim potentiometer, **Delay**, adjusts how long the MD output will remain active after a motion event. Turning this pot in the + direction increases this delay; turning the pot in the – direction makes the delay shorter.

The Ambient trim potentiometer, **Ambient**, adjusts the threshold for ambient light sensing. Turning this pot towards **Light** increases the threshold (e.g., it activates the MD output even when a room is already brightly illuminated); turning the pot towards **Dark** lowers the threshold (e.g., it activates MD only when a room is dark).

Operating In Serial Mode

To select Serial Mode, place SW1 in the **Serial** position and apply power to the ZDMII Development Board. The Module can be configured through the serial interface. This serial interface is asynchronous, and is configured to the following settings:

- 9600bps
- No parity
- 8 data bits
- 1 stop bit
- No flow control

The serial interface operates via a host/client relationship in which the Module is the client. Commands are sent from the host, and the Module responds with the requested information or a confirmation. All commands sent to ZDMII are in ASCII character format; however, the data sent to and from the Module may be in ASCII or decimal formats; these formats are selectable by the host. The ASCII character format allows for easier reading when using a terminal emulation program (e.g., HyperTerminal) to interface with the Module.

Three types of command structures are accepted by ZDMII; each is described in this section:

- Read commands
- Write commands
- Confirmation commands

Read commands are used to request information from the ZDMII, and are sent from the host. The Module responds with the requested data. The command structure of these read commands is shown in Figure 4.

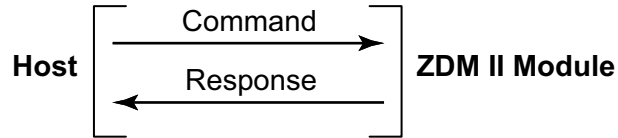


Table 4. Read Command Structure

Write commands are used to update the configuration of ZDMII, and are sent from the host. The Module responds with the current value as an acknowledgment. The host then sends the new data, and the Module responds with an ACK. The command structure of these write commands is shown in Figure 5.

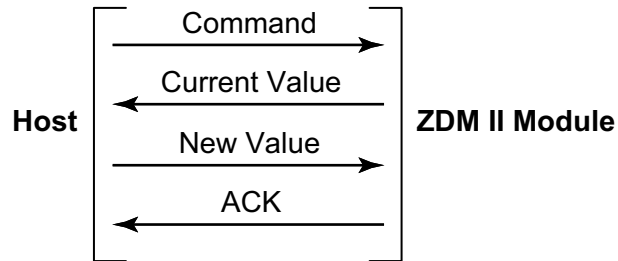


Table 5. Write Command Structure

Certain commands require a specific sequence of characters to be sent to prevent accidental initiation. These commands require a 4-character confirmation sequence. After a command requiring confirmation is received, the device returns an ACK. The command structure of these confirmation commands is shown in Figure 6.

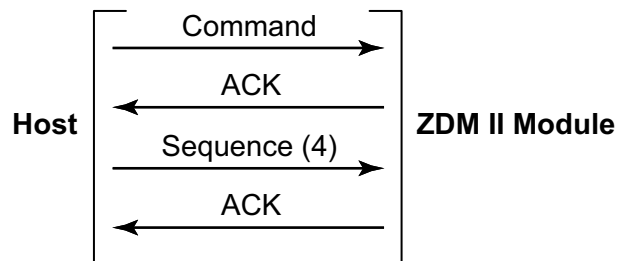







Table 6. Confirmation Command Structure

Details about these and other commands can be found in the [ZMOTION Detection Module II Product Specification \(PS0305\)](#).

Changing Lenses

This reference design is preprogrammed to support all of the lenses included in the ZMOTION Detection Module II Evaluation Kit. To change lenses on the ZDMII Module, gently pull the installed lens to remove it from the pyroelectric sensor. Install the new lens so that the tab on the sensor lines up with the correct slot on the lens. Table 7 indicates the location of the tab for each lens in the Kit.

Table 7. Tab Location For Each Lens

Lens	Image with Position Indicator	Lens	Image with Position Indicator
NCL-10IL		NCL-3R	
NCL-10S		NCL-3B	
NCL-9(26)			

Walk Test

To perform a basic walk test using the ZDMII Module installed on the ZDMII Development Board, place SW1 in Hardware Mode, and supply power to the ZDMII Development Board. When using the NCL-10IL lens, place the Board on a horizontal surface at a height of 1.2m (4'). Set the **Sens** potentiometer to the desired sensitivity, and set the **Delay** potentiometer to Minimum (-).

When power is applied, the detector will undergo a warm-up period to allow the pyroelectric sensor to stabilize. This period will take approximately 30 seconds. During this time, the status LED will remain off. After this warm-up period is complete, the status LED will turn on when motion is detected.

Visual diagrams showing the results of walk tests for each lens are presented in [Appendix C. Walk Test Results](#) on page 21.

Stability Test Results

Stability tests were performed in a small indoor room for a period of five days. Five ZDMII detectors were mounted at a height of four feet using each of the provided lenses. The room temperature varied from 18°C to 22°C.

Table 8 lists the test conditions. As a result of these tests, no false detections were recorded.

Table 8. Stability Test Conditions

Test	Condition
Room Dimensions	5' x 4'
Temperature variation	18°C to 22°C
Mounting	Vertical at 4'
Time period	5 days
Number of units	6

Summary

The ZMOTION Detection Module II Reference Design demonstrates how to use Zilog's ZMOTION Occupancy Detection solution in a PIR-based motion detector module design that meets and exceeds industry expectations. The stability and walk tests show that how even a non-optimized setup (open-air PCB) is capable of providing reliable consistent performance. The flexibility of the Z8FS040 MCU allows additional features such as Serial interface and configurability features to be added with minimal additional components.

The five lenses included with the reference design demonstrate the ease with which a full product family can be created based off the initial design - without changes to hardware or software.

Specifications

Table 9 lists the electrical and detection characteristics of the ZDMII Module hardware and reflects all available data as a result of testing prior to qualification and characterization. As such, the data presented in Table 9 are subject to change.

Table 9. ZMOTION Detection Module II Reference Design Specifications

Item	Specification
Detection Method	Dual-Element PIR
Power Input	2.8V to 3.3V
Current Consumption:	
Run Mode	~8mA
Sleep Mode	~350µA
Detection Range:	
NCL-10IL	7 meters (wall mount)
NCL-10S	12 meters (wall mount)
NCL-9(26)	5 meters (wall), 2:1 ratio (ceiling)
NCL-3R	2:1 ratio (ceiling mount)
NCL-3B	3 meters (wall mount)
Motion Detected Output Active Time	Configurable
MD Output Type	TTL active low signal
Power on Warm up Time	Approximately 30 seconds
Dimensions (W x H x D; with NCL-10IL)	25.5mm x 16.7mm x 17.6mm

Ordering Information

The ZMOTION Detection Module II Reference Design can be purchased from the Zilog Store – simply click the Store Product ID listed in Table 10. As with all Zilog development kits, the ZMOTION Detection Module II Evaluation Kit is available through Zilog’s distributors. To order the ZMOTION Detection Module II Evaluation Kit, please contact your nearest [Zilog sales representative](#).

Table 10. ZMOTION Detection Module II Ordering Information

Part Number	Description	Store Product ID
ZEPIR000103ZRDG	ZMOTION Detection Module II Reference Design	RD10021

Related Documentation

The documents associated with the ZMOTION Detection Module II Reference Design are listed in Table 11. Each of these documents can be obtained from the Zilog website by clicking the link associated with its Document Number.

Table 11. ZMOTION Detection Module II Reference Design Documentation

Document ID	Document Title
RD0026	This ZMOTION Detection Module II Reference Design document
RD0026-SC01	Source code for the ZMOTION Detection Module II Reference Design
PS0305	ZMOTION Detection Module II Product Specification
UM0260	ZMOTION Detection Module II Evaluation Kit User Manual
PS0285	ZMOTION Detection and Control Product Specification
PS0228	F082A Series Product Specification
PS0286	ZMOTION Lens and Pyroelectric Sensor Product Guide
WP0017	ZMOTION - A New PIR Motion Detection Architecture White Paper
WP0018	ZMOTION Detection Lens and Pyro Sensor Configuration Guide
WP0018-SC01	Application Library for the ZMOTION Detection Lens and Pyro Sensor Configuration Guide

Appendix A. Schematic Diagrams

Figure 8 displays a schematic diagram of the ZMOTION Detection Module II Reference Design.

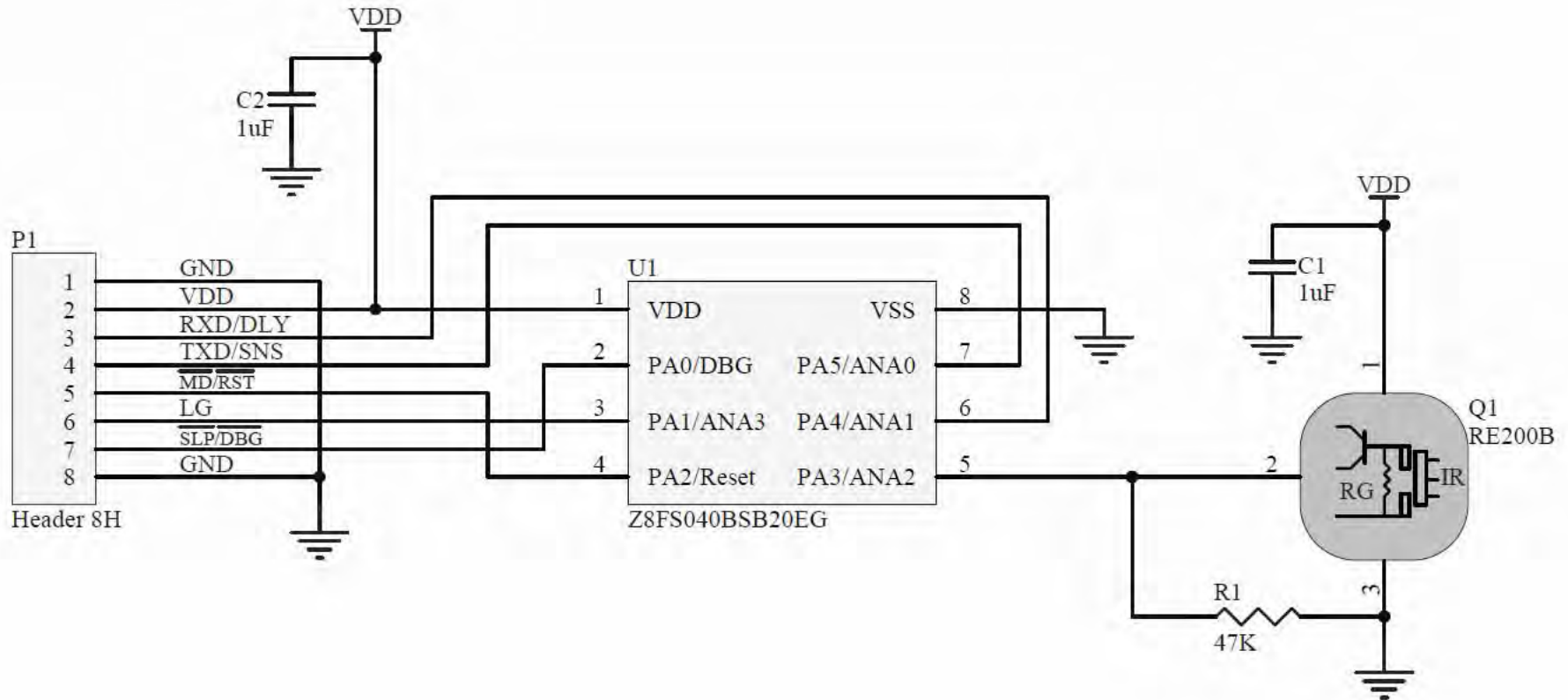


Figure 8. Walk Test Results for NCL-10IL Lens

Appendix B. Flow Charts

Figure 9 presents a top-level code flow for the ZMOTION Detection Module II Reference Design.

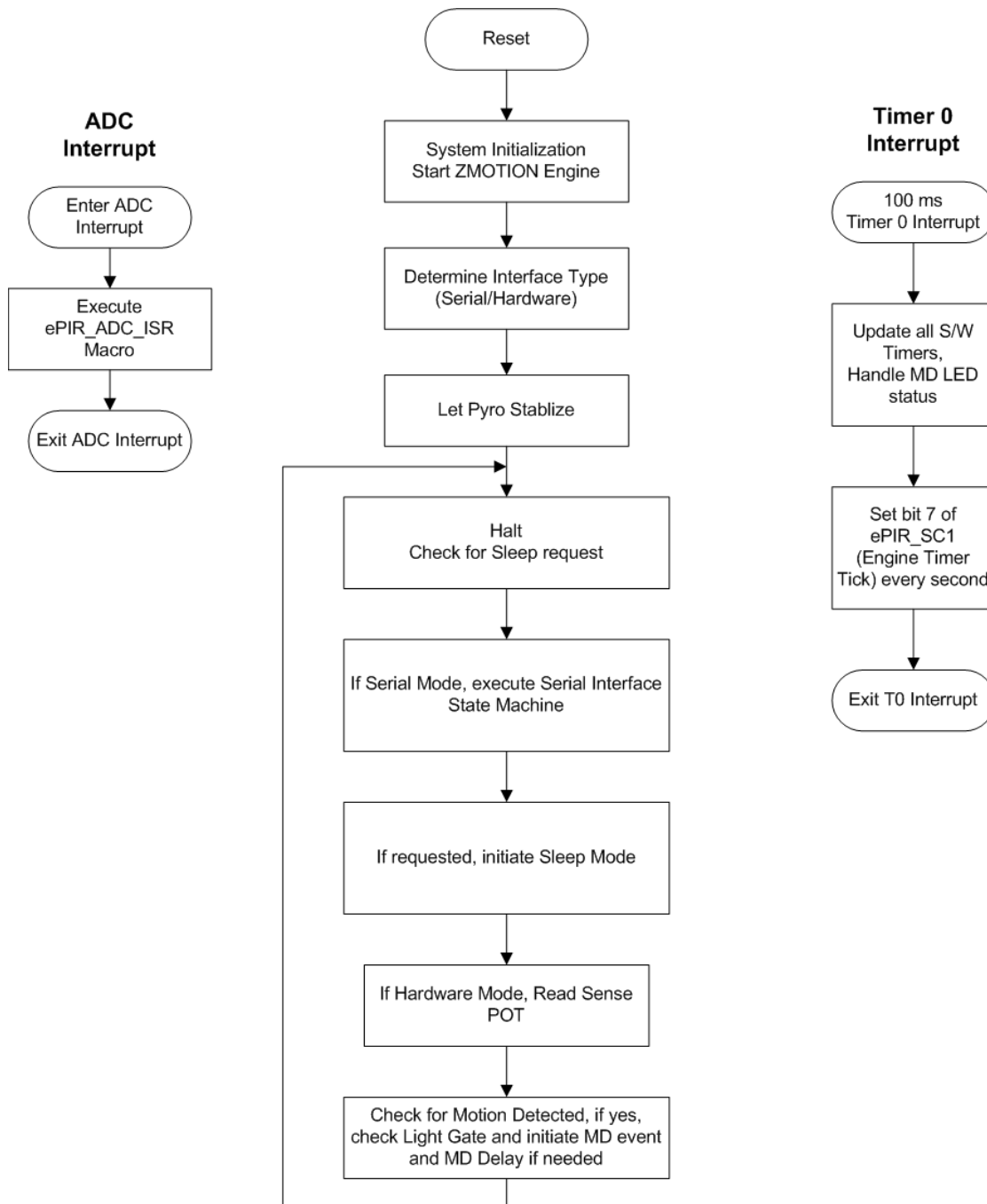


Figure 9. ZDMII Software Flow: Top Level

Figure 10 shows the flow of the main application loop.

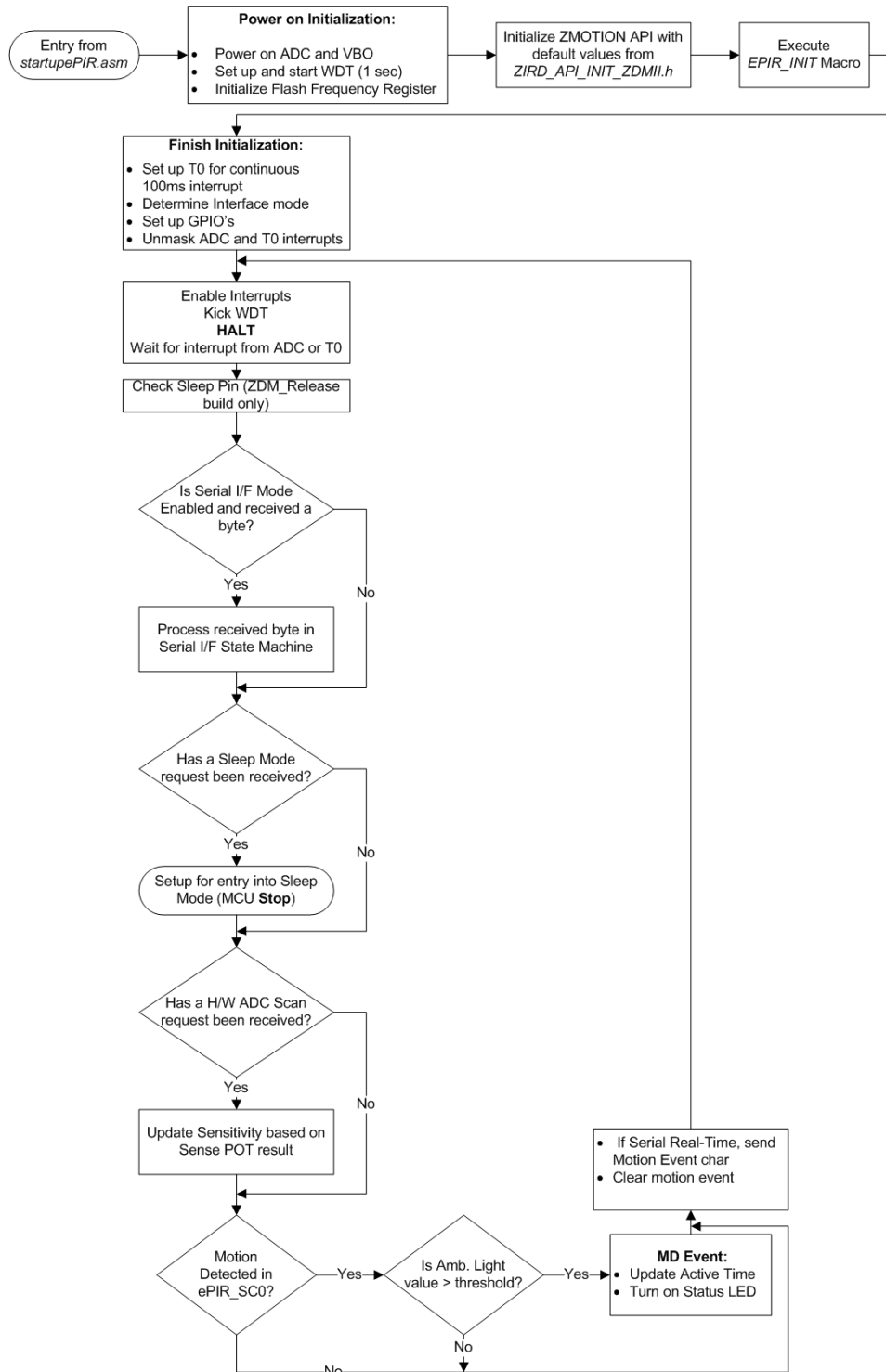


Figure 10. Software Flow: Main Application

The Serial Interface is handled as a command-based state machine, with two levels of processing. If a command requires additional received data, it is transferred into the second level to complete the task. Figure 11 shows the flow of the Serial Interface state machine.

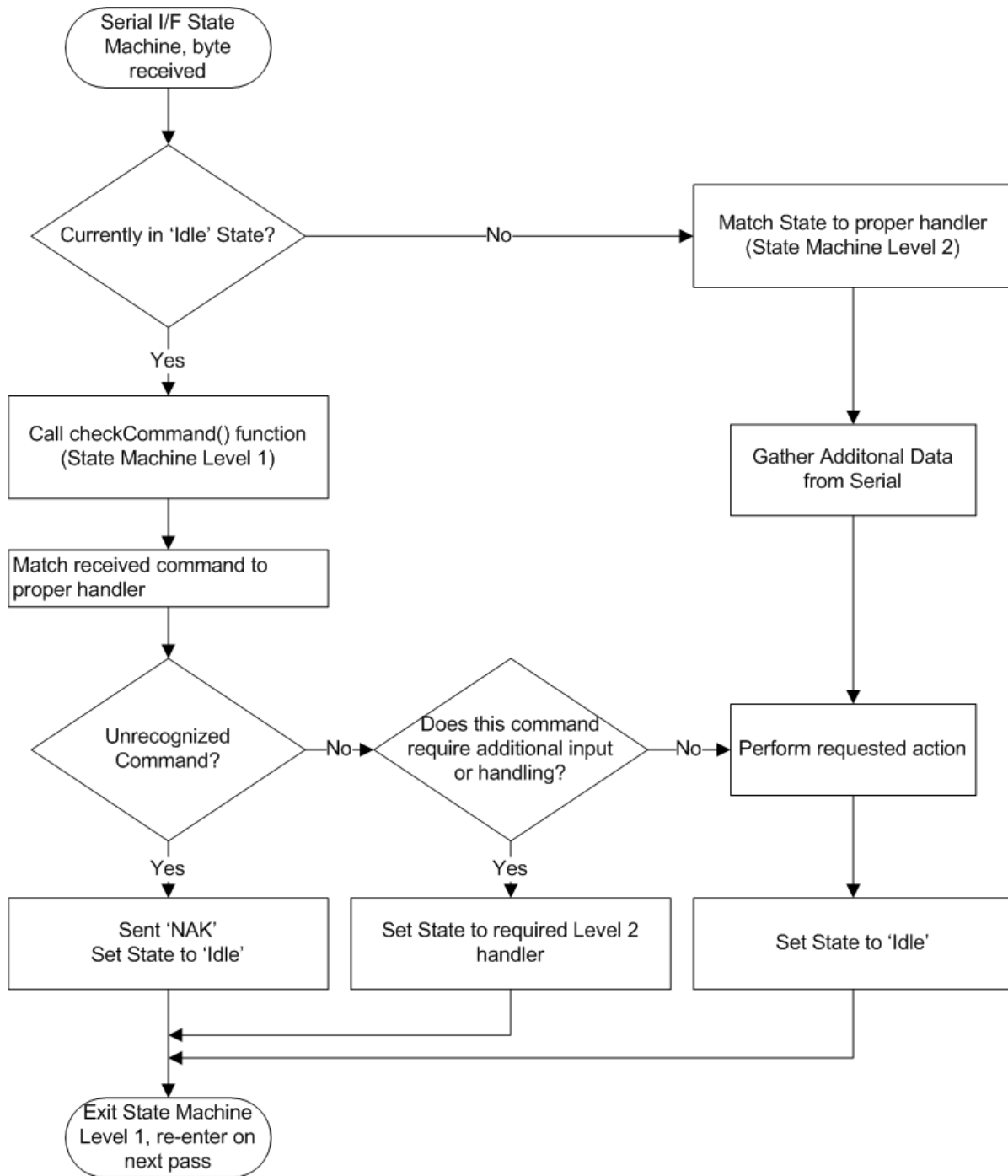


Figure 11. Software Flow: Serial Interface State Machine

Appendix C. Walk Test Results

Figures 12 through 16 present the results of walk tests for each of the five lenses used in this reference design. For the sake of simplicity, the walk test plots for wall-mount lenses show half of the total pattern.

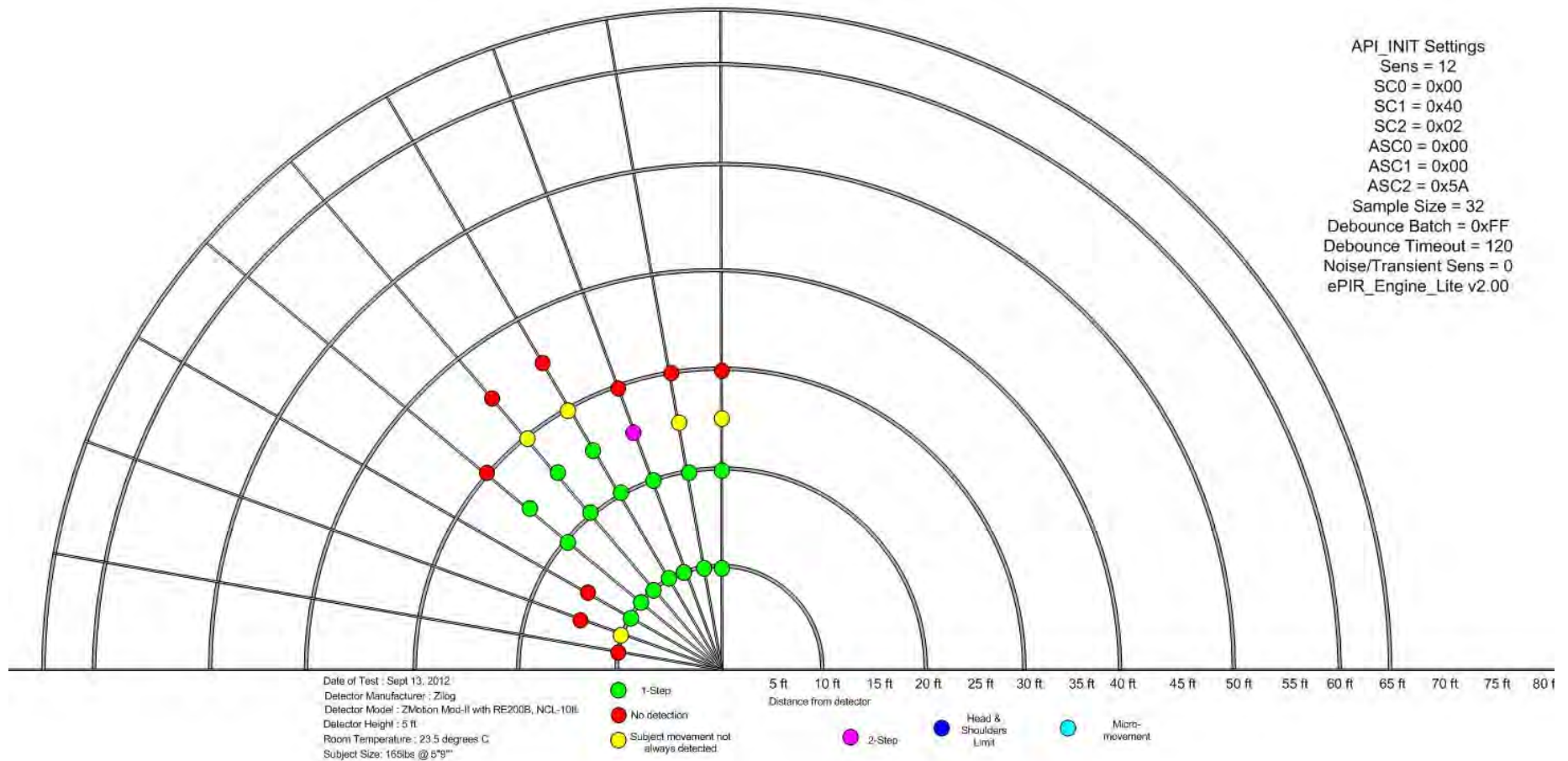


Figure 12. Walk Test Results for NCL-101L Lens

API_INIT Settings

Sens = 12
 SC0 = 0x00
 SC1 = 0x40
 SC2 = 0x01
 ASC0 = 0x00
 ASC1 = 0x00
 ASC2 = 0x5A
 Sample Size = 32
 Debounce Batch = 0xFF
 Debounce Timeout = 120
 Noise/Transient Sens = 0
 ePIR_Engine_Lite v2.00

Note: Micro-Movement test has Extended
 Detection = Level 3

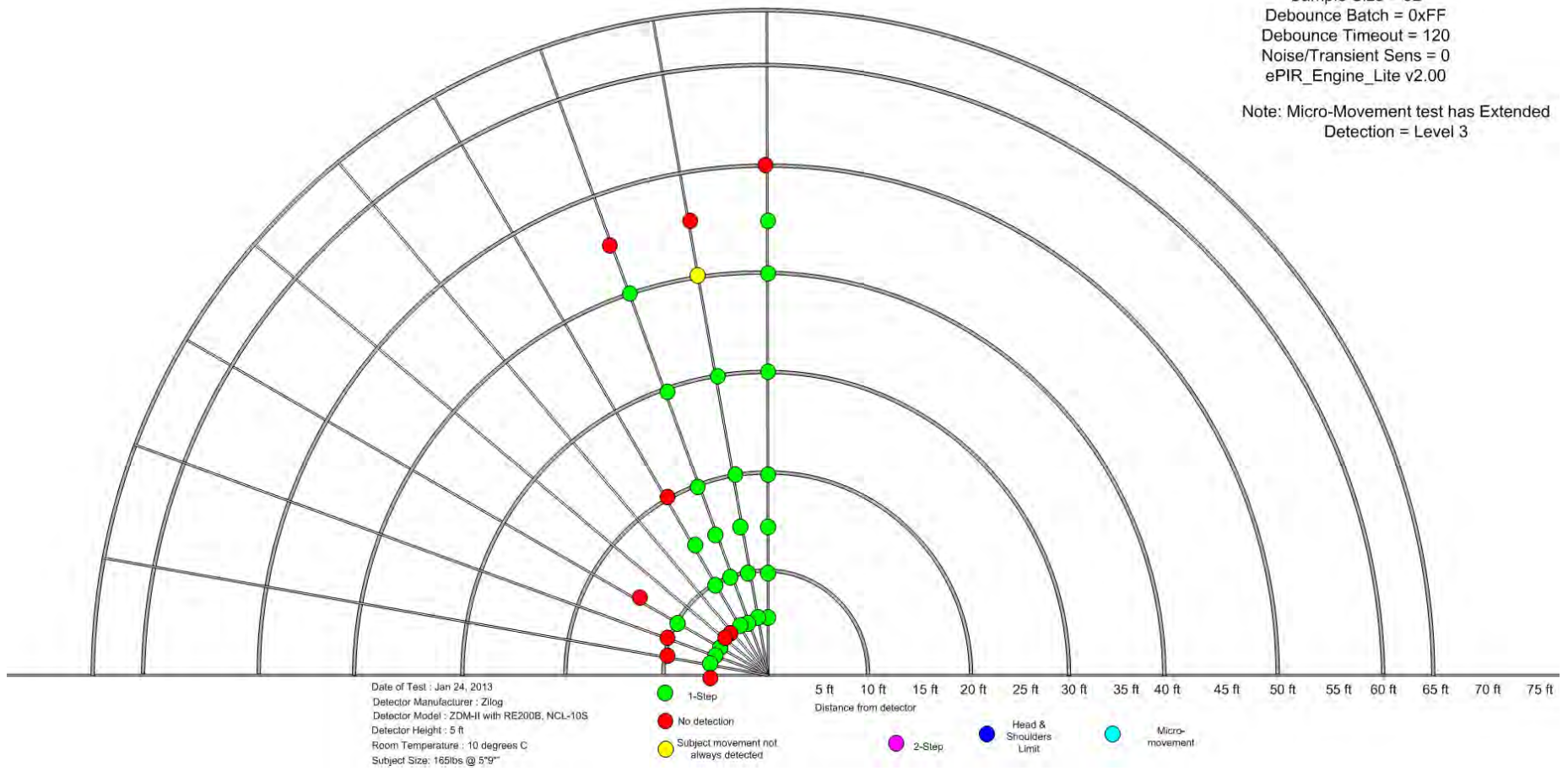


Figure 13. Walk Test Results for NCL-10S Lens

API_INIT Settings

Sens = 12
 SC0 = 0x00
 SC1 = 0x40
 SC2 = 0x01
 ASC0 = 0x00
 ASC1 = 0x00
 ASC2 = 0x5A
 Sample Size = 32
 Debounce Batch = 0xFF
 Debounce Timeout = 120
 Noise/Transient Sens = 0
 ePIR_Engine_Lite v2.00

Note: Micro-Movement test has Extended
 Detection = Level 3

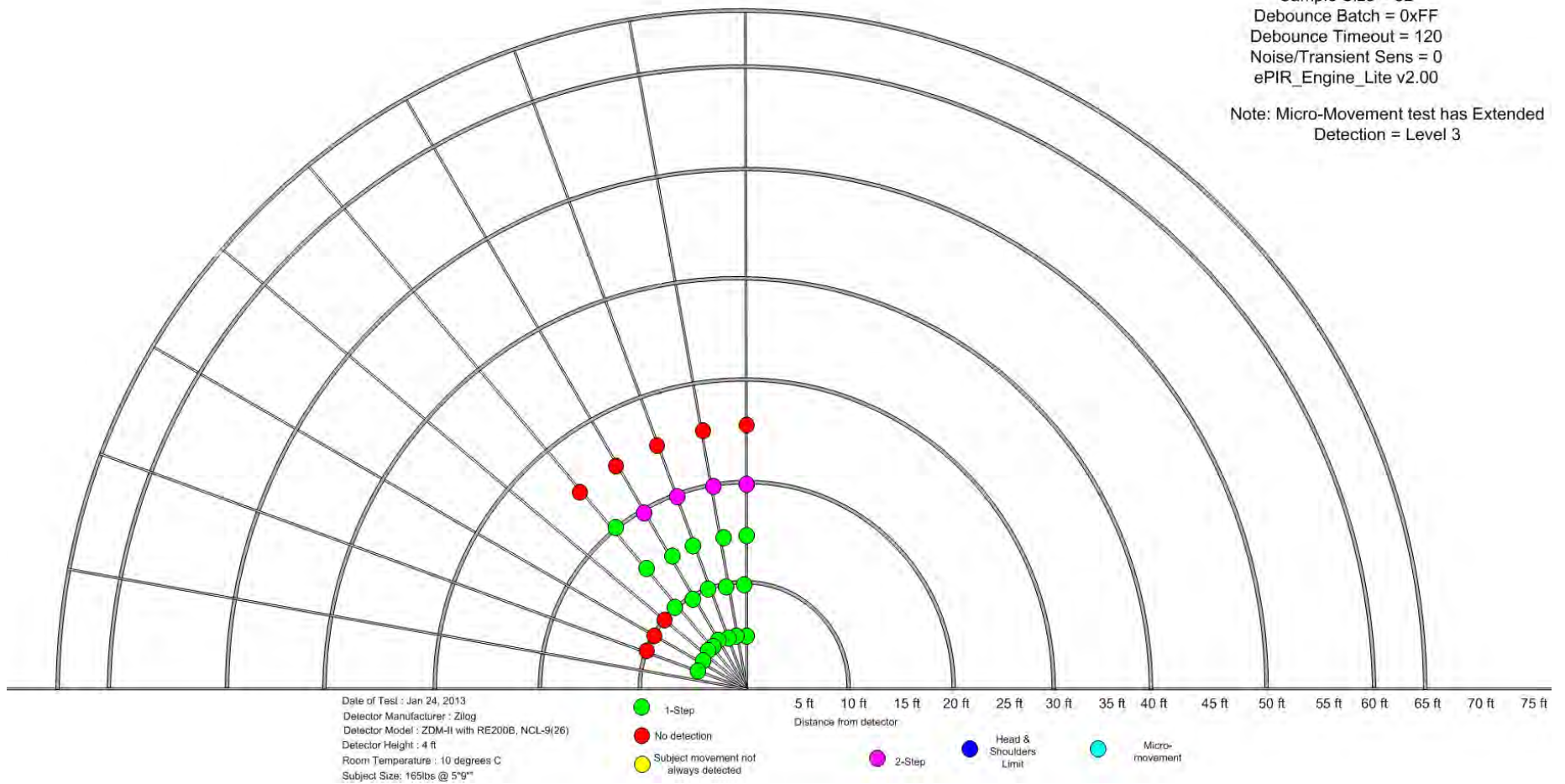


Figure 14. Walk Test Results for NCL-9(26) Lens

Date of Test : Jan 24, 2013
 Detector Manufacturer : Zilog
 Detector Model : ZDM-II with RE-200B, NCL-3R
 Detector Height : 8 ft
 Room Temperature : 10 degrees C
 Line Radius: 3 ft increments
 Note: Radial walk along 3ft radius
 increments. 15 degree per event.
 (ex. move from 90 to 105 degrees).

API_INIT Settings
 Sens = 12
 SC0 = 0x00
 SC1 = 0x40
 SC2 = 0x01
 ASC0 = 0x00
 ASC1 = 0x00
 ASC2 = 0x5A
 Sample Size = 32
 Debounce Batch = 0xFF
 Debounce Timeout = 120
 Noise/Transient Sens = 0
 ePIR_Engine_Lite v2.00

- 1-Step
- No detection
- Subject movement not always detected
- 2-Step
- Micro-movement

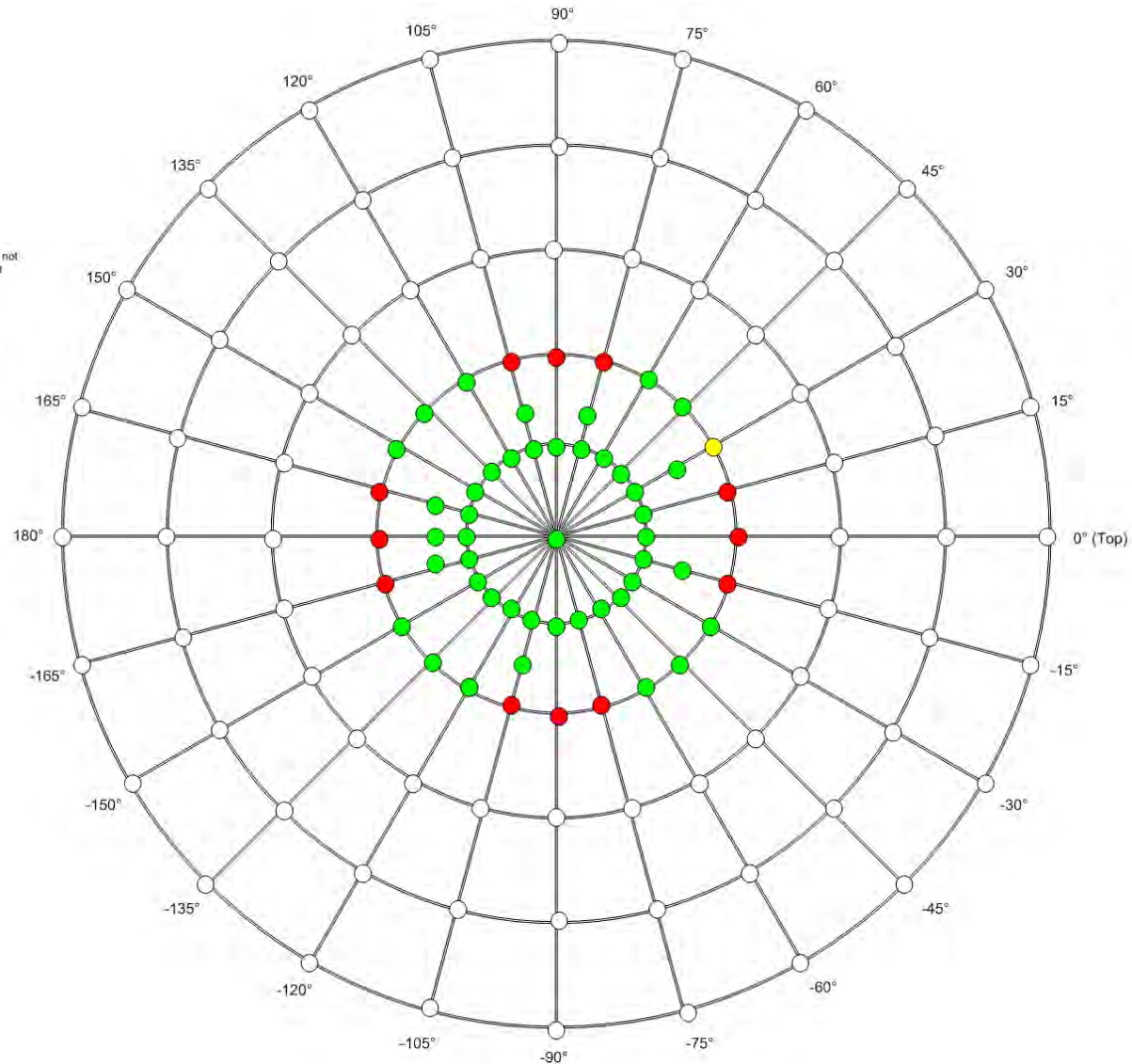


Figure 15. Walk Test Results for NCL-3R Lens

API_INIT Settings
 Sens = 12
 SC0 = 0x00
 SC1 = 0x40
 SC2 = 0x01
 ASC0 = 0x00
 ASC1 = 0x00
 ASC2 = 0x5A
 Sample Size = 32
 Debounce Batch = 0xFF
 Debounce Timeout = 120
 Noise/Transient Sens = 0
 ePIR_Engine_Lite v2.00

Note: Micro-Movement test has Extended
 Detection = Level 3

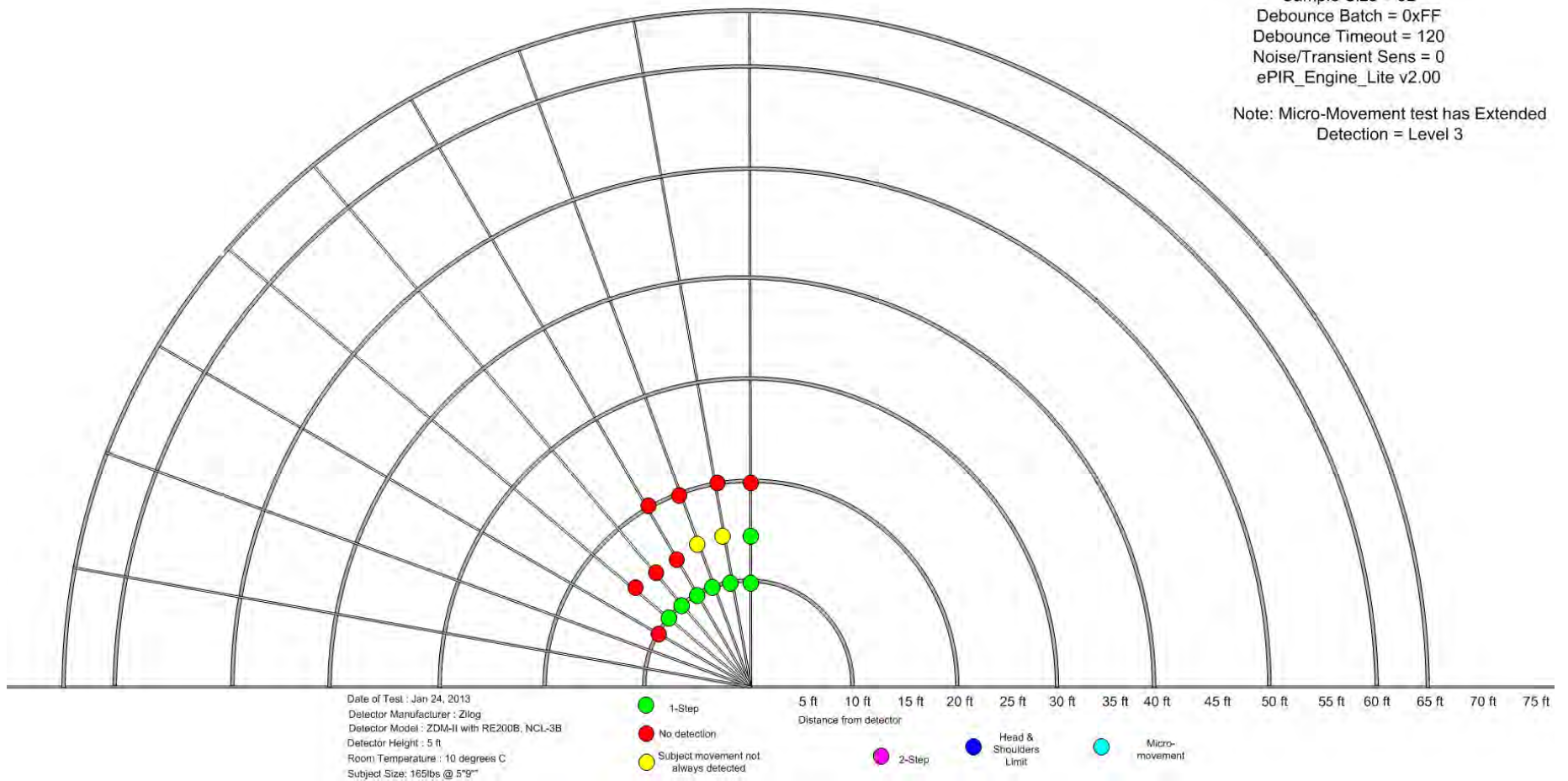


Figure 16. Walk Test Results for NCL-3B Lens

Appendix D. Parts List

The parts required for building this ZMOTION Detection Module II reference design are listed in Table 12. The components shown in red are available from Zilog.

Table 12. ZMOTION Detection Module II Reference Design PCB Parts List

#	Qty	Description	Designator	Manufacturer	Mfg. Part Number	Footprint
1	2	CAP 1µF 16V 0603	C1, C2	Murata	GRM188F51C105ZA01D	0603
2	1	Header, 8-Pin, Right Angle	P1	3M	929550-01-08-EU	HDR1X8H
3	1	Pyro Dual Gen Purpose	Q1	Zilog/Nicera	ZRE200BP/RE200B-P	TO-5 (3 PIN)
4	1	RES 47K 1% 0603	R1	Panasonic	ERJ-3GEYJ473V	0603
5	1	ZMOTION MCU 4K Flash S08N	U1	Zilog	Z8FS040BSB20EG	S08N
6	1	Lens, Clip-On 90° Wide Angle	Lens	Zilog/Nicera	ZNCL10IL/NCL-10IL	

Customer Support

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