±10V or ±20mA 4-Channel Universal Analog Input Using the MAX11270

MAXREFDES1246

Introduction

The MAXREFDES1246 is a 4-channel universal analog input that measures voltage or current signals. Each channel can be configured for voltage input at -10V to 10V or current input at -20mA to 20mA. A 24V power supply can be switched out to power an external 2-wire, 3-wire, or 4-wire sensor.

The MAXREFDES1246 provides a complete system solution for industry voltage and current measurement. The analog front end (AFE) includes Beyond-the-Rails™ analog switches, and operational amplifiers are used to achieve voltage/current input selection and signal conditions. The 24-bit MAX11270 analog-to-digital converter (ADC) is the heart of the system and achieves highly accurate measurement.

The microcontroller communicates with MAX11270 and MAX7317 10-port I/O expander to control the AFE and accept ADC conversion results. The 24V field input power supply is isolated with the AFE and with the microcontroller, which is powered by a USB power supply. This isolated design enhances system robustness in harsh industry applications.

The MAXREFDES1246 also integrates five Beyond-the-Rails SPDT analog switches (MAX14763), a dual Beyond-the-Rails 4:1 analog multiplexer (MAX14778), two ultra-precision, low-noise op amps (MAX44251), 2.75kV$_{RMS}$ data isolators (MAX14930 and MAX14932), a STM32F1 microcontroller, a microprocessor supervisory circuit (MAX6730), a FTDI USB-UART bridge, a high-efficiency iso-buck DC-DC converter (MAX17681), and isolated/regulated +5V and +3.3V power rails (two MAX16910s) and a -5V power rail (MAX1697). The entire system typically operates at less than 500mW and fits into a 5cm x 10.6cm space. While targeted for industrial PLC applications, the MAXREFDES1246 can be used in any application that requires high-accuracy analog-to-digital conversion.

Other features include:

- High accuracy measurement
- -10V to +10V voltage inputs
- -20mA to 20mA current inputs
- Four channels
- Each channel can be configured as voltage or current input
- 24V input protection
- Isolated power and data
- Board calibration
- Connector provides 24V output
- 24V output enable or disable

Hardware Specification

The MAXREFDES1246 features 4-channel analog input that supports voltage or current input signals with isolated power and data. The MAXREFDES1246 includes four sections: power supply, AFE, ADC, and microcontroller.

The power supply section generates all the power rails used in the AFE and ADC. The power is isolated with a 24V input. The AFE transfers the input signal to meet the ADC input range. A high precision 24-bit ADC converter converts the analog input to digital signals that are read by the microcontroller. The microcontroller is isolated with the AFE by the digital isolator. Table 1 shows an overview of the design specification.

Table 1. Design Specification

PARAMETER	SYMBOL	MIN	MAX
Power Supply	V_{CC}	20V	36V
Supply Current	I_{CC}	20mA	25mA
Voltage Input	V_{IN}	-15V	15V
Current Input	I_{IN}	-20mA	20mA
Input Current Clamp	I_{CLAMP}	-27mA	27mA
24V Output Current	I_{24VO}		1.25A

Notes:

1. The power supply input current increases with the power supply voltage due to on-board protection.

2. The maximum 24V output current depends on the input 24V power supply but is no larger than 1.25A.

3. The reference design targets a voltage input range of -10V to +10V, but it can handle inputs of up to -15V to +15V. Maxim® does not guarantee the accuracy of measurements taken with voltage inputs that are out of the design's target range.

Designed–Built–Tested

This document describes the hardware and firmware. It provides a detailed system design, especially for the AFE. This reference design has been built and tested, details of which follow later in this document.

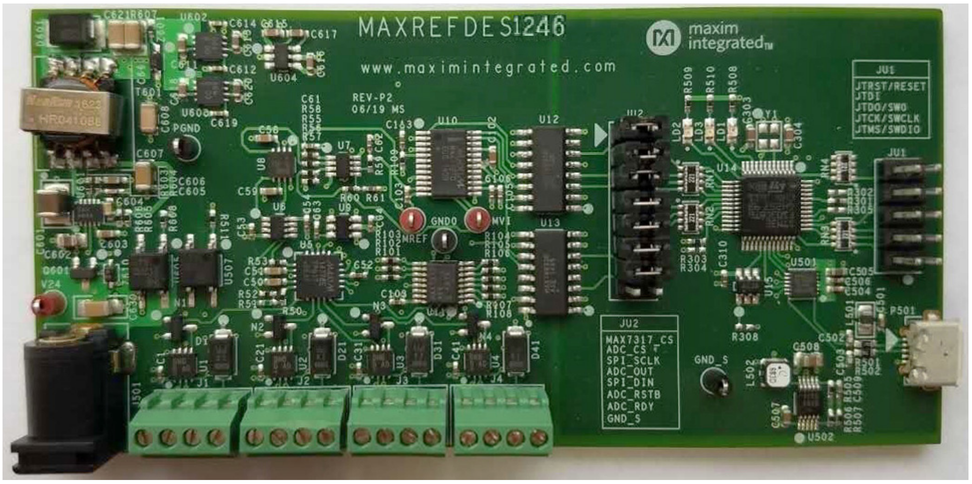

Figure 1. MAXREFDES1246 hardware.

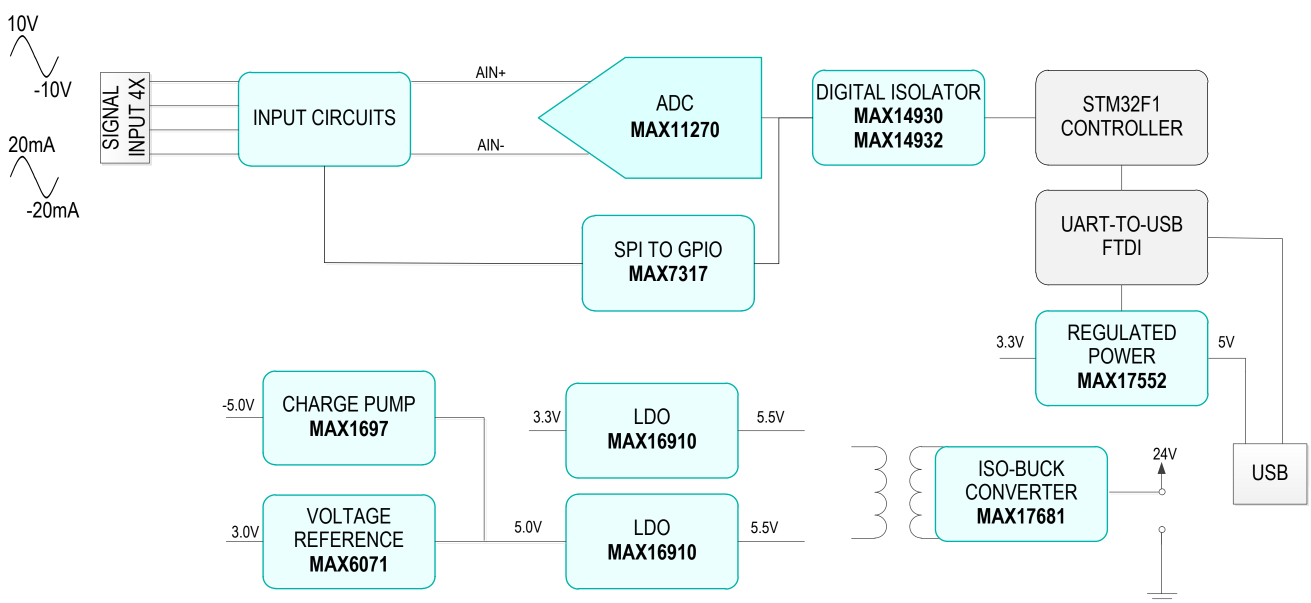

Figure2. MAXREFDES1246 block diagram.

Design Procedure

Step 1: Analog Front End Design

An analog switch is required for selecting the input, which can be configured for current or for voltage. When the input is configured for current, a sense resistor is used to convert the input from current to voltage. When the input is configured for voltage, high input impedance (commonly > 100kΩ) is required. Because the input voltage can be up to ±10V, the power supply voltage of the analog switch should be larger than 10V for positive and less than -10V for negative. In these cases, the design should include a power supply of 10V or larger and -10V or less to power the switch. However, the MAXREFDES1246 uses Beyond-the-Rails switches, which support inputs of -25V to +25V with only a 5V power supply. The ±10V power supply is not necessary, so this reduces design complexity.

The input section is the same for all four channels. The channels are connected to the MAX14778, which selects the input type. For voltage inputs, the four inputs use one voltage divider, which simplifies calibration by requiring calibration on only one channel and applying the calibration results to all other channels. However, for current input, each channel has its own sense resistor, so for highly accurate measurement, calibration on each channel is required.

For more details about the AFE, see the *Detailed Description Of Hardware* section.

Step 2: ADC and Reference Selection

To meet highly accurate measurement requirements, select the MAX11270 24-bit, 130dB SNR, delta-sigma ADC. In bypass mode, the MAX11270 can achieve 16.9 bits of noise-free resolution at 1ksps data rate. For a voltage reference of 3V, the noise-free resolution in bipolar mode is calculated as follows:

$$\left(\frac{3V}{2^{16.9}}\right) \times 2 = 49\mu V$$

For an input current of ±20mA, the sense resistor is 100Ω, so 1μA of current generates 100μV of voltage. A noise-free resolution of 49μV ensures accurate measurements as low as 1μA.

The MAX11270 is a single-channel ADC that measures four channels of input. The ADC requires a switch on each channel for measurement and must work in single-cycle conversion mode. The maximum sample rate for single-cycle conversion mode is 1.6ksps. An additional delay time is required for switching from one channel to another and waiting for input voltage stability at the ADC input.

An input voltage of ±10V or an input current of ±20mA is conditioned to ±2V and then scaled to feed into ADC input. However, for some applications, a certain margin is required to detect the fault condition. For the MAXREFDES1246, select the MAX6071A 3V voltage reference as the ADC reference. The MAX6071 is a highly accurate voltage reference with 0.04% initial accuracy and a 6ppm/°C maximum temperature coefficient.

Step 3: Power Supply Design

The system is powered by a 24V field power supply. Field power supplies are commonly used in applications deployed in harsh environments with significant noise that can negatively impact the accuracy of measurements. The analog section requires a very stable power supply to ensure highly accurate measurement. So the design incorporates the MAX17681 iso-buck DC-DC converter, which generates an isolated 5.5V power supply, and two MAX16910 low-cost LDOs generate +5V and +3.3V for analog switches, an operational amplifier, reference, and the ADC.

To ensure that the operational amplifier can work properly at zero input, a negative power supply is also required. The charge pump MAX1697 is used to generate a -5V rail for the operational amplifier.

Step 4: Protection Design

The ON Semiconductor® MMBT3904 and Zener diode DDZ24ASF from Diodes Incorporated form a voltage regulator that can prevent high-voltage transient pulses of up to 65V at the power supply input from causing damage to the device. The MAX14763 integrated ±2500V HMB ESD and ±750V CDM ESD, 24V TVS on each input channel can increase the protection and clamp the input to approximately 24V when the input is larger than 24V.

Overcurrent protection is achieved by using the Infineon® BSS159N on-current inputs. This protection is required to avoid damage when the input current is too large. On high-voltage inputs, overcurrent is required for when the channel is incorrectly configured for the input current. In the event of overcurrent, the current generates a voltage through the sense resistor to limit the input current. For more details about the connection, see the reference design schematic.

Step 5: Digital Isolation Design

The microcontroller configures the ADC or reads the ADC conversion result through the serial peripheral interface (SPI). The channel selection setting and on-board 24V power supply switch are controlled by digital signals. To save the digital isolator, select the MAX7317 SPI-to-GPIO expander. The MAX7317 can expand to up to ten GPIO ports and is controlled by an SPI. The MAX7317 and MAX11270 ADC share the same SPI to reduce isolation channels. Only one MAX14930B and one MAX14932B are required to achieve the digital isolation for the microcontroller and analog sections.

The MAX14930B/MAX14932B are 4-channel, $2.75kV_{RMS}$ digital isolators that support a data rate of up to 25Mbps. A low propagation delay allows the device to support high-speed SPI communication isolation.

Step 6: Microcontroller Design

The on-board microcontroller is used to evaluate the performance of the universal analog input. The MAX17552 DC-DC converter generates the 3.3V power supply to power the microcontroller, and the MAX17552 input is from a USB port.

The MAX6730A watchdog monitor device monitors the microcontroller to ensure it works properly. It has an open drain output, a long initial watchdog time-out period (35s min), and a short time-out period (1.12s) after the first valid WDI transition. The long initial watchdog time-out provides enough time to initialize the system after power-up.

The purpose of this reference design is to demonstrate the front-end performance and accuracy of ADC measurements. Because the reference design is meant only for testing in the lab, it does not use the MAX6730A watchdog monitor. In real-world industrial applications, however, the watchdog is required.

If customers want to provide their own firmware to control the system, they can remove the jumpers on JU2 and connect the external SPI and GPIO to JU2. This allows them to easily evaluate the universal analog input with different microcontrollers or their own firmware.

Step 7: 24V and GND On-board Power Supply Switch

For the 4mA-to-20mA current transmitter sensor, the on-board 24V voltage can switch out to a power sensor. The 24V and GND switch are PhotoMOS® from Panasonic®. The 24V power supply GND and signal input GND are isolated when the GND switch is open. The 24V switch and GND switch can be controlled individually.

The 2-wire and 3-wire sensors must close the 24V and GND switch. The 4-wire sensor must close the 24V switch and leave the GND switch open. The sensor connection is listed in Figure 3.

Detailed Description Of Hardware

The MAXREFDES1246 reference design has 4-channel analog input with isolated power and data. It supports voltage and current inputs as shown in Figure 3. Each input circuitry utilizes the digital controlled analog switches (MAX14763) to make the appropriate electrical connections for different types of input signals.

Figure 4 shows the AFE which converts the input voltage or current to an acceptable ADC range.

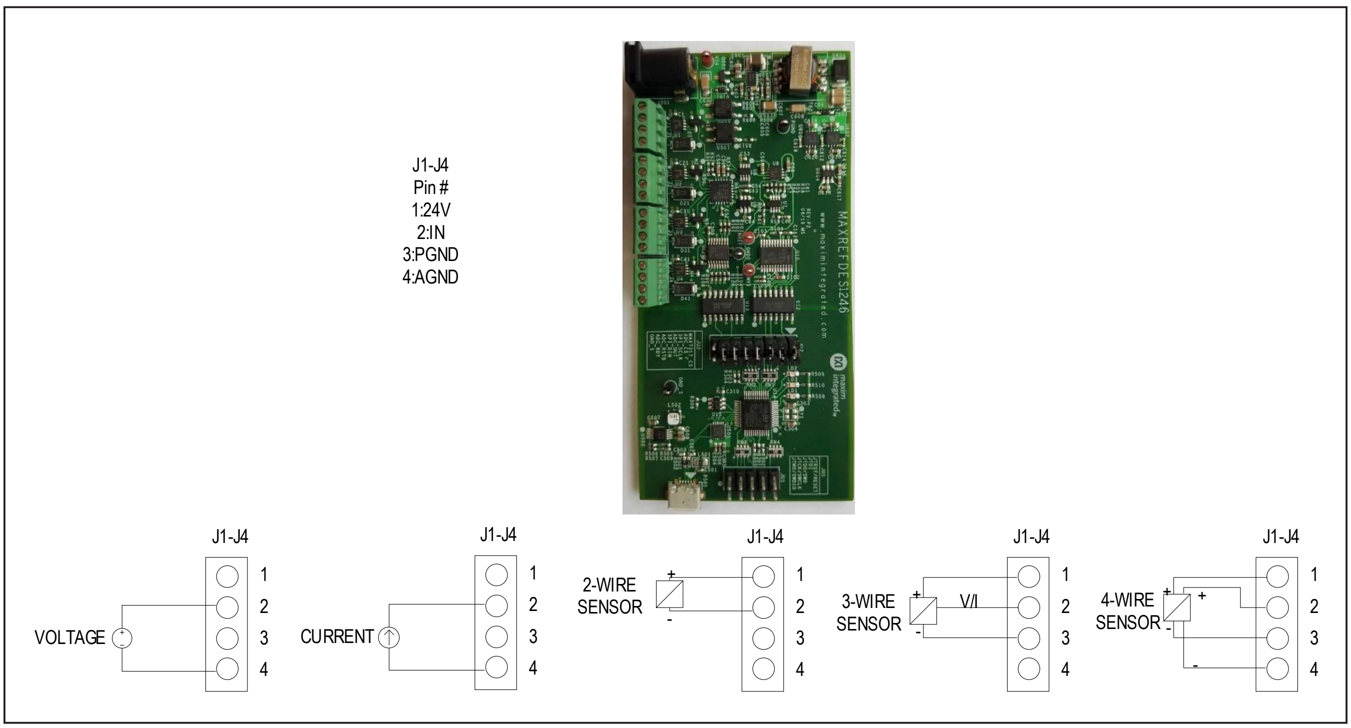

Figure 3. MAXREFDES1246 input configuration.

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Panasonic is a registered trademark and registered service mark of Panasonic Corporation.

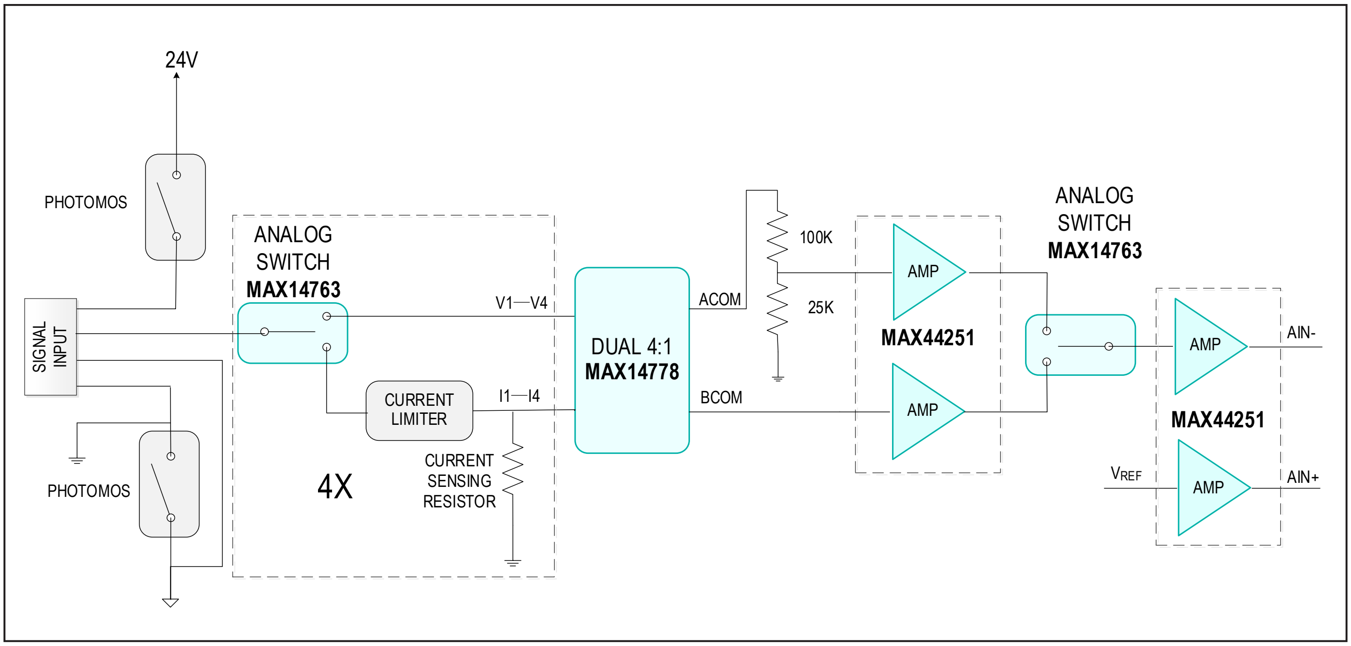

Figure4. MAXREFDES1246 input circuit block.

Voltage Input

The input is configured for voltages when the MAX14763 SEL is set LOW. The input voltage is routed to the MAX14778 to select the channel to be measured. A voltage divider (4:1) divides the MAX14778 ACOM output voltage. The MAX44251 ultra-precision amplifier buffers the divider voltage. Because the MAX44251's input bias current is 200pA and the offset is 7µV, the high-resistance voltage divider does not decrease the accuracy. The buffered voltage is routed to another MAX14763, which selects whether to measure the voltage or current to the ADC. The MAX14763 output voltage (V_{COM}) is fed into a differential amplifier. The output of the differential amplifier is calculated as follows:

$$V_{MVI} = \frac{1}{2} \times (V_{REF} - V_{COM})$$

The ADC input voltage is the differential voltage of V_{MREF} and V_{MVI}, where V_{MREF} is V_{REF} divided by 2 and buffered out, as shown by the following equation:

$$V_{MREF} - V_{MVI} = \frac{1}{2} \times V_{REF} - \frac{1}{2} \times (V_{REF} - V_{COM}) = \frac{1}{2} \times V_{COM}$$

V_{COM} is 1/5 of the input voltage, so the ADC measured voltage is 1/10 of the input voltage. Because all four voltage input channels share the same voltage divider, only one channel needs to be calibrated and its results then apply to all other channels. This greatly simplifies the calibration process.

Current Input

The input is configured for current when the MAX14763 SEL is set HIGH. The input current flows through the sense resistor to generate a voltage. Each current input channel has overcurrent protection, which limits the input current to approximately ±22mA, if the input current is out of this range. Overcurrent protection helps to ensure the integrity of the internal circuit when the input current is too large or when there is high voltage because the input is incorrectly configured as current.

The input voltage (V_I) is routed to the MAX14778 and switches to the BCOM output. The BCOM output voltage is buffered with the MAX44251 and through the MAX14763 to a differential amplifier. The differential amplifier output is calculated as (V_{REF}-V_I)/2. The ADC input voltage is the differential voltage of V_{REF}/2 and (V_{REF}-V_I)/2, as shown by the following equation:

$$\frac{V_{REF}}{2} - \frac{(V_{REF} - V_I)}{2} = \frac{V_I}{2}$$

Because V_I = I x R_{SENSE}, R_{SENSE} is a known resistor and I = V_I/R_{SENSE}. The ADC measures the V_I, and the input current value can then be calculated. Each channel has an R_{SENSE}, so perform a current input calibration on each channel and select a 0.1% accuracy R_{SENSE} resistor and low temperature drift for better performance.

Control and Measurement

Control and measurement of the input current and voltage for each channel selection uses logic-level control.

All the control signals are from the MAX7317 SPI-to-GPIO expander. The MAX7317 and MAX11270 ADC share the same SPI.

The MAX11270 ADC is a 24-bit delta-sigma ADC with low power and high SNR that can measure input accurately. The ADC's reference input is driven by a high-precision voltage reference (MAX6071A), with 0.04% initial accuracy and a 6ppm/°C maximum temperature coefficient. The ADC conversion results can be read out through an SPI interface, which is isolated with the STM32F103 microcontroller by using the MAX14930 and MAX14932 4-channel 2.75kV$_{RMS}$ digital isolators. The on-board STM32 microcontroller controls all operations. Customers can provide their own SPI by removing the shunt on JU2 and connecting their own SPI to the system. This can help them evaluate the AFE performance with their own firmware.

Power

The AFE is powered by an external 24V input power supply. The iso-buck MAX17681 generates an isolated 5.5V power supply. Two MAX16910 LDOs generate +5V and +3.3V rails from a +5.5V power supply. The MAX1697 charge pump also generates a -5V power rail from +5V input.

The system incorporates two on-board PhotoMOS relays to support 2-wire, 3-wire, and 4-wire sensors. One PhotoMOS can switch on/off the 24V input voltage to the connector in order to power the external sensor. The other PhotoMOS can switch on/off the 24V input power supply GND and AFE GND.

The MAX17552 step-down DC-DC converter converts the +5V supply from the USB to +3.3V and powers the STM32 microcontroller and FTDI USB-UART bridge. Three LEDs can be used as indicators for system operation.

Detailed Description of Firmware

The MAXREFDES1246 uses the on-board STM32F1 microcontroller to control the analog switch and communicate with the ADC. The user reads the sampled data through a terminal program, allowing analysis on any third party software. The user can also perform system calibrations through a terminal program. The simple process flow is shown in Figure 5. The firmware is written in C using the IAR tool.

The firmware accepts channel set, calibration, sampling and debug commands, and communication with a PC through a standard terminal program by way of a virtual COM port. The complete source code is provided to speed up customer development. Code documentation can be found in the corresponding firmware platform files.

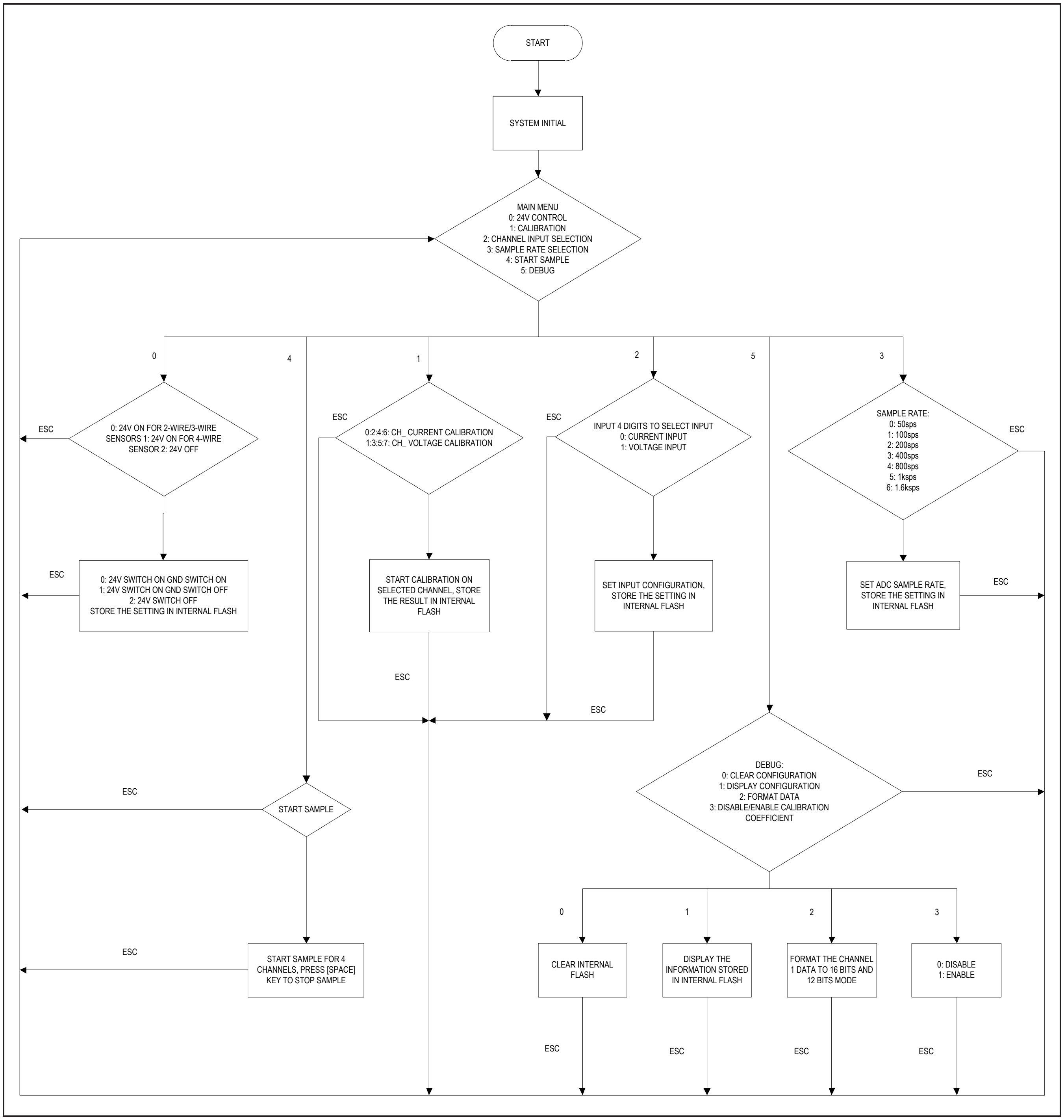

Figure 5. MAXREFDES1246 firmware flowchart.

Design Resources

Download the complete set of **Design Resources** including schematics, bill of materials, PCB layout, and test files.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	8/19	Initial release	—