Keywords: 4-20mA current control loop, PLC, PIXI, ADCs, DACs, Current sense amplifiers.

APPLICATION NOTE 6221

PIXI MAX11300 4-20MA CURRENT CONTROL LOOP TRANSMITTER

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Abstract: This application note reviews the operation of the 4–20mA current control loop transmission standard, and the application of the MAX11300 20-Port Programmable Mixed-Signal I/O with 12-Bit Analog to Digital Converter (ADC), 12-Bit Digital to Analog Converter (DAC), Analog Switches, and GPIO to measure -40°C to +70°C temperature range with less than 0.6% accuracy as the preferred choice of the transmitter.

Introduction

Temperature is one of the most widely measured parameters in industrial process control and automation, and 4–20mA current control loop is perhaps the most common analog transmission standard used in industry for transmitting the data from remote sensors to a programmable logic controller (PLC) in a central control center over a twisted-pair cable. This application note reviews the operation of this transmission standard, its advantages, and the application of the MAX11300 20-Port Programmable Mixed-Signal I/O with 12-Bit Analog-to-Digital Converter (ADC), 12-Bit Digital-to-Analog Converter (DAC), Analog Switches, and GPIO to measure -40°C to +70°C temperature range with less than 0.6% accuracy as the preferred choice of the transmitter in this 4–20mA control loop.

Detailed Description

In two-wire 4–20mA control loops, the transmitters are typically used to convert various process signals such as flow, temperature, pressure, etc., to 4–20mA DC current for transmitting the signal over a long distance up to 2km with little or no loss of signal as shown in **Figure 1**.

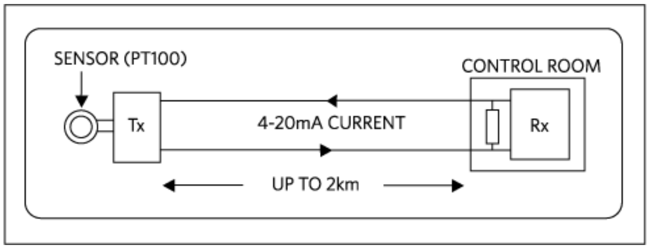

Figure 1. Block Diagram of a typical 4–20mA current control loop.

In Figure 1, current supplied from the power supply flows through the wire to the 4–20mA transmitter, which is not only the source of current, but also regulates the flow and magnitude of the current through the control loop. The current allowed by the transmitter is called the loop current which is proportional to the parameter that is being measured. The loop current flows back to the controller through the electrical wire, then flows through the receiver resistor to ground and returns to the power supply. The current flowing through receiver produces a voltage that is easily measured by an analog input of a controller or monitoring device such as the MAX11300. For a 250Ω-resistor load as used in this demo board, the voltage is 1VDC at 4mA and 5VDC when the current in the loop is 20mA. 4mA current minimum is chosen so that when 0mA current is measured, it means the control loop is broken, alerting the controller of a potential problem.

The advantages of the 4–20mA current control loop are that the accuracy of the signal is not affected by the voltage drop in the loop since, unlike voltage, current remains constant through an electrical conductor as long as the power-supply voltage is greater than the total voltage drop in the loop and that the current is immune to noise.

Power Supply:

For 4–20mA current control loops with 2-wire transmitters, common power supply voltages are 12, 15, 24, and 36 VDC. Power supplies for 2-wire transmitters must always be DC voltage because the magnitude of the current flow represents the signal level that is being transmitted. If AC voltage were used in the loop, the magnitude of current would be continuously changing, making it difficult to distinguish the signal levels being transmitted. The DC voltage must be set to a level that is greater than the sum of the minimum voltage required to operate the Transmitter, the resistor load loss, V_{RL}, and for long transmission distances, the V_{RW} drop in the wire as shown in the equivalent circuit in **Figure 2**.

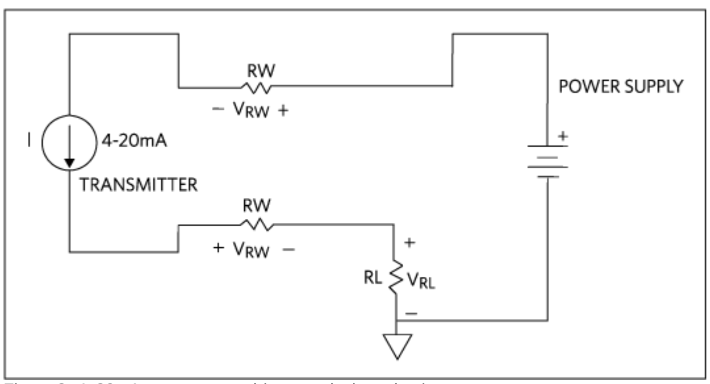

Figure 2. 4–20mA current control loop equivalent circuit.

The Current Control Loop Wire, RW

Current flowing through an electrical wire creates a voltage drop due to the resistance in the wire, which is proportional to the length and the wire gauge and is expressed in Ohms per 1,000 feet. This voltage drop is expressed as V_{RW} in Figure 2.

Transmitter

This is the essential device used to convert a real-world physical property such as temperature from a sensor like the resistance temperature detector (RTD) PT100 into an electrical current over the control loop electrical wire, regulating the flow of current in the current loop. There can be only one transmitter output in any current loop. The level of loop current is adjusted by the transmitter to be proportional to the actual sensor input signal. An important distinction is that the transmitted signal is not the current in the loop, but rather the sensor signal it represents. The transmitter typically uses 4mA output to represent the calibrated zero input and 20mA output to depict the calibrated full-scale input signal.

The Load Resistor, RL

It is much easier to measure voltage than it is to measure current in a closed loop circuit. Ergo, many current loop circuits use a load resistor, RL, to convert the current into voltage. In Figure 2, RL is a 250Ω precision resistor used in this demo board. The current flowing through RL produces a voltage that is easily measured by an analog input of a controller such as the integrated analog to digital converter (ADC) in the MAX11300 device. For the 250Ω-resistor, the voltage is 1VDC at 4mA of loop current and 5VDC when the flow of current in the loop is 20mA. The most common RL in a 4–20mA loop is 250Ω; however, depending on application, resistances of 100Ω to 750Ω can be used.

MAX11300 4–20mA Transmitter

The MAX11300 integrates a PIXI™, 12-bit, multichannel, ADC and a 12-bit, multichan-nel, buffered DAC in a single integrated circuit. This device offers 20 mixed-signal high-voltage, bipolar ports, which are configurable as an ADC analog input, a DAC analog output, a general-purpose input (GPI), a general-purpose output (GPO), or an analog switch terminal. The MAX11300 provides highly flexible hardware configuration for 12-bit mixed-signal applications. The device is best suited for applications that demand a mixture of analog and digital functions such as this 4–20mA current control loop.

Figure 3 is the block diagram of the MAX11300 PT100 RTD to 4–20mA current control loop transmitter. The daughter board consists of the analog front end input sensor RTD PT100 and ultra-precision, low-noise, zero-drift operational amplifier MAX44248. The basic operation of this sensor block is to measure the temperature, which is then amplified by the MAX44248 IC and converted into 4–20mA current by the DACs in the MAX11300 device.

The variation in temperature creates a change in galvanic resistance of the wheatstone bridge, due to change in the resistivity of the RTD element. As the temperature ranges from -40°C to +70°C, an approximately 6mV differential dynamic voltage range is observed across the wheatstone bridge to input 1 and input 2 of the 510x amplifiers.

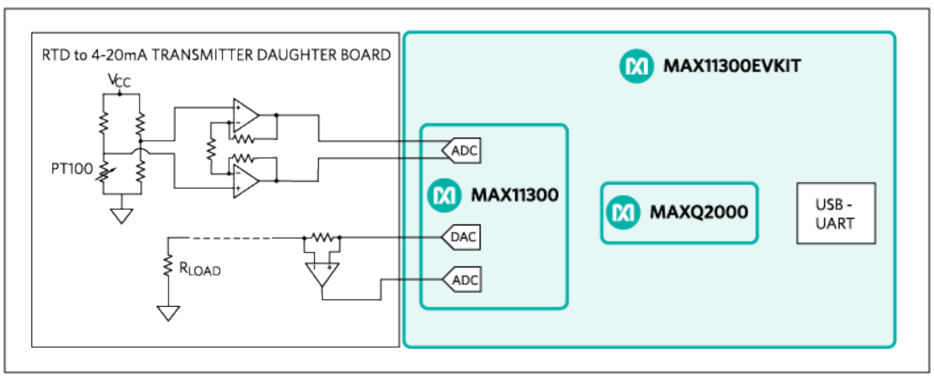

Figure 3. MAX11300 PT100 RTD to 4–20mA transmitter block diagram.

The gain stage is used to amplify very minor differential voltage arising from the wheatstone bridge. Jumpers J4 and J5 provide options to use the amplifier stage or bypass it. When used, the differential voltage is gained 510 times by using the MAX44248 before digitized by the ADC of MAX11300 device. A dual amplifier stage (MAX44248) is used as a 510x differential amplifier. The gain can be changed by changing the resistors, R30 and R31, to match the desired signal range from the wheatstone bridge, maintaining proper input signal range and output swing from the amplifiers driving the differential ADC of the MAX11300 IC. See **Figure 4** for analog front-end circuit. The complete schematics of the RTD to 4–20mA board and the MAX11300EVKIT are available online at www.maximintegrated.com.

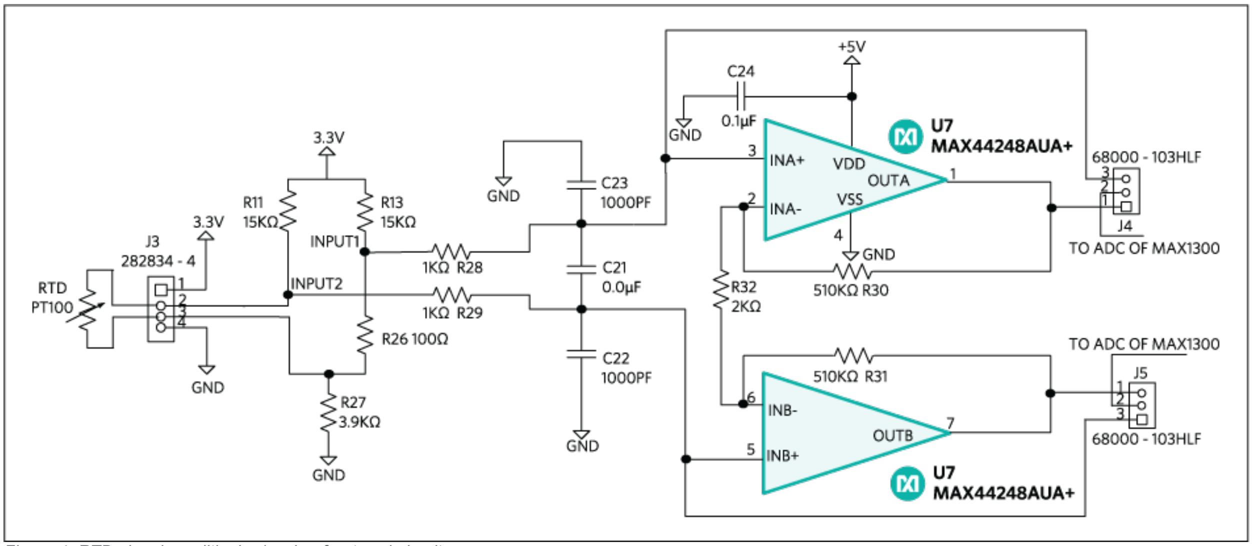

Figure 4. RTD signal conditioning/analog front end circuit.

The MAXQ2000 microcontroller calibrates the temperature and maps the voltages corresponding to the temperature readings that the PT100 translates to the differential ADC, which in turn-commands the configured DAC to provide the needed current. This transmitted current can also be accurately measured by the configured ADC in the MAX11300 device.

For each RTD to 4–20mA transmitter, 4 ports are needed to configure as 1 current transmitter DAC, 1 differential input ADC, and 1 single-ended ADC to measure the transmitted current. Ergo, up to 5 RTD transmitters can be implemented with a single MAX11300 alone, saving board space and cost significantly.

Evaluation of PIXI MAX11300 4–20mA Current Control Loop

To evaluate the PIXI MAX11300 4–20mA Current Control Loop application, the following evaluation kits and test instruments are required.

1. The MAX11300/MAX11301/MAX11311/MAX11312 RTD to 4–20mA Transmitter board
2. MAX11300 EV Kit
3. RTD Fluke 724 calibrator used as PT100 sensor
4. An amp-meter

Step by step instructions

1. Connect the J2 connector of the MAX11300EVKIT board to the J1 connector of the MAX11300/MAX11301/MAX11311/MAX11312 RTD to 4–20mA Transmitter board as shown in **Figure 5**.

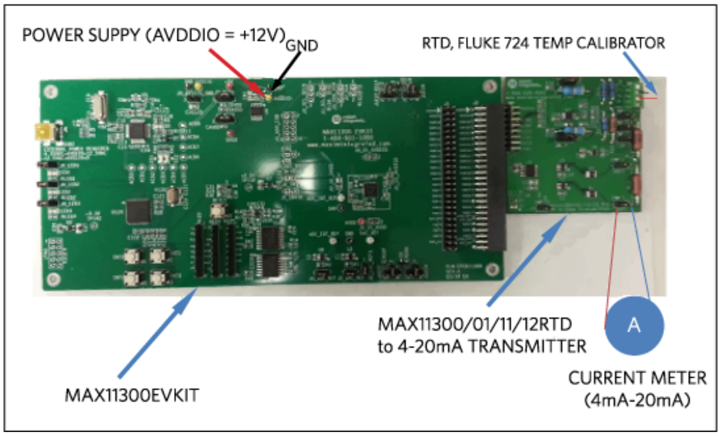

Figure 5. MAX11300EVKIT connected to the RTD to 4–20mA transmitter.

2. With the power supply off, connect +12V power supply to “AVDDIO” and ground to “GND” connectors of the MAX11300EVKIT.
3. Connect a current meter to the “AMP1” jumper of the MAX11300/MAX11301/MAX11311/MAX11312 RTD to 4–20mA board.
4. Connect RTD Fluke 724 temperature calibrator to pins J3-2 (IN+) and J3-3 (IN-) of the MAX11300/MAX11301/MAX11311/MAX11312 RTD to 4–20mA board. Press the RTD button on the Fluke 724 to select PT100.
5. Download the most recent version of the MAX11300EVKIT software GUI, MAX11300EVKitSetupV1.2.zip, at http://www.maximintegrated.com/en/design/tools/applications/evkit-software/index.mvp/id/1171. Save the software to a temporary folder and decompress the ZIP file.
6. Install and run the software GUI.
7. Turn on the power supply.
8. Run the Configuration Software and configure the registers as shown in **Figure 6**. In this exercise, ports 18 and 19 are used to configure the differential ADC connected to the amplifiers from the RTD to 4–20mA board. Port 17 is configured as the transmitter DAC, and the transmitted current measuring ADC is configured at port 16.

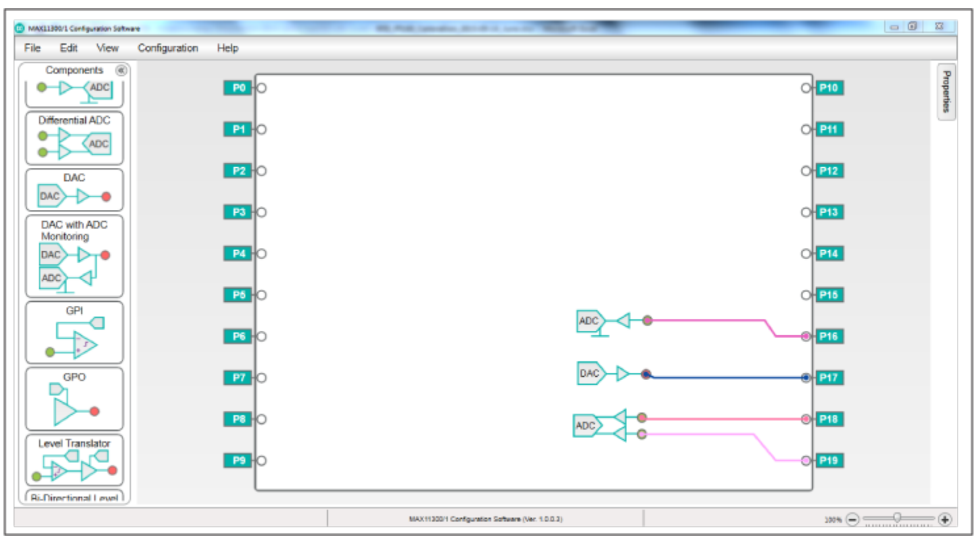

Figure 6. MAX11300 control loop registers configuration.

9. To generate the configuration registers file, select File > Generate Registers and save the file as “MAX11300 Register RTD-4–20mA.csv.”
10. In the MAX11300EVKIT software main menu, select File > Load Configuration to load the configuration registers file “MAX11300Register RTD-4–20mA.csv” as shown in **Figure 7**.

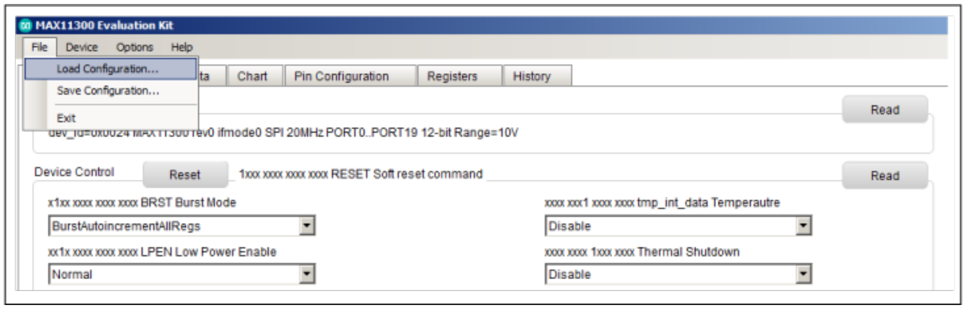

Figure 7. Loading configuration registers.

11. Select Option > Control Loop and "4–20mA Loop Drive PORT17, Sense PORT16, Ref PORT18" from the drop-down menu as depicted in **Figure 8**.

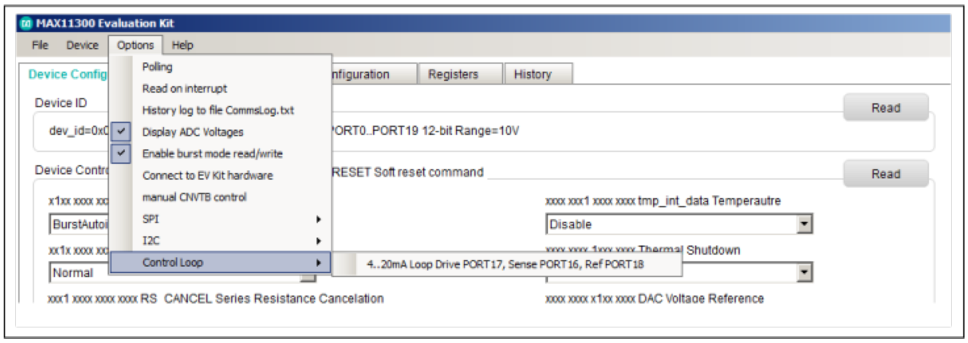

Figure 8. Control loop selection.

12. To perform calibration, select Option > Control Loop and "Calibrate 4–20mA Loop Port17, 16, 18" from the drop-down menu as depicted in **Figure 9**.

    A new pop-up window now appears as shown in **Figure 10**.

    A. Enter "17" to the "PLC Shunt (current meter) Resistance" box.
    B. Press the "Drive 4mA" button. Observe and record the current value displayed on the current meter to the "measured current" box.
    C. Similarly, press the "Drive 20mA" button. Again, observe and record the current value displayed on the current meter to the "measured current" box.

    If the measured current is lower than the expected value, increase the number in the "PLC Shunt (current meter) Resistance" box and repeat the calibration steps B and C above. Then click "OK" to continue.

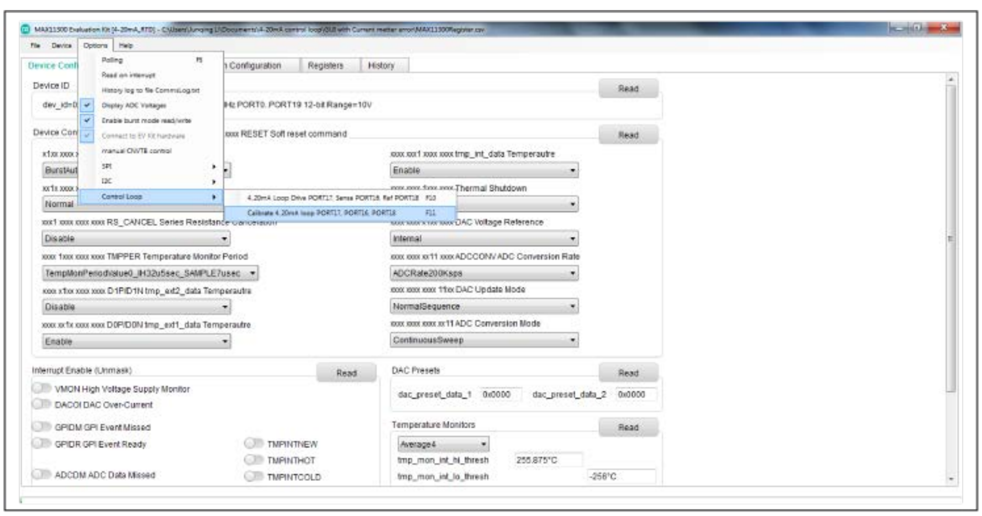

Figure 9. Calibration option.

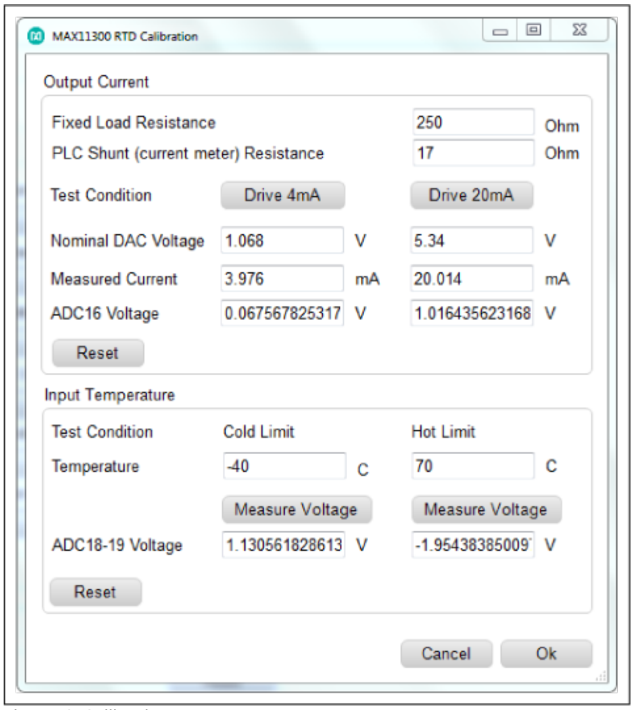

Figure 10. Calibration menu

13. Select "Options" and "Polling" from the drop-down menu to start testing. See **Figure 11**.

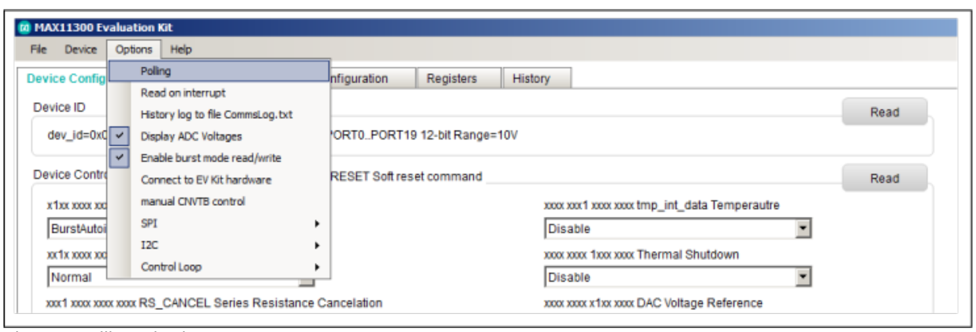

Figure 11. Polling selection.

14. Select "Data" to view test results as shown in **Figure 12**.

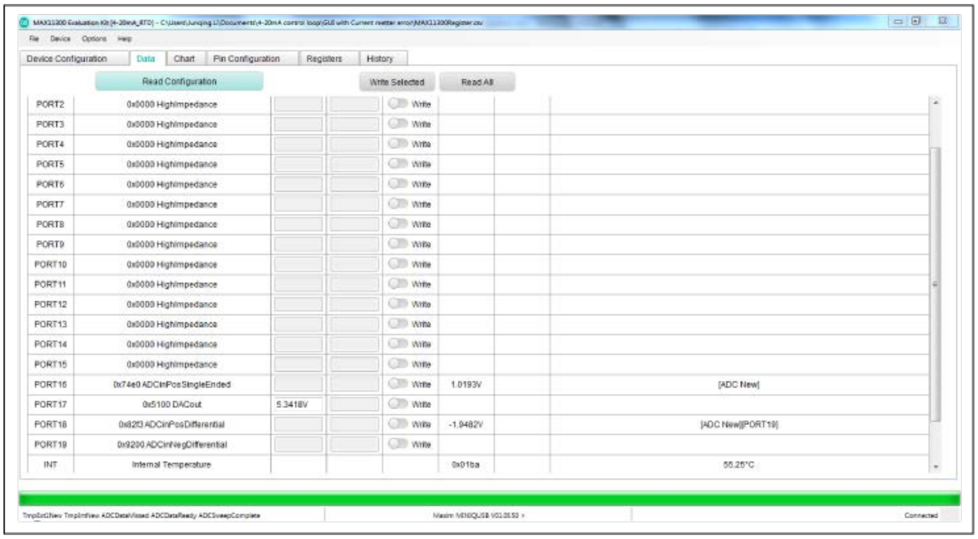

Figure 12. Viewing data

Figure 12. Viewing data results.

15. Adjust the arrow button on the Fluke 724 to set the temperature to -40°C. Observe that the current display on the amp-meter is 4mA.
16. Similarly, adjust the arrow button on the Fluke 724 to set the temperature to +70°C. Observe that the current display on the amp-meter is 20mA.

Test Results

The 4–20mA vs. RTD temperature plot is shown in **Figure 13**.

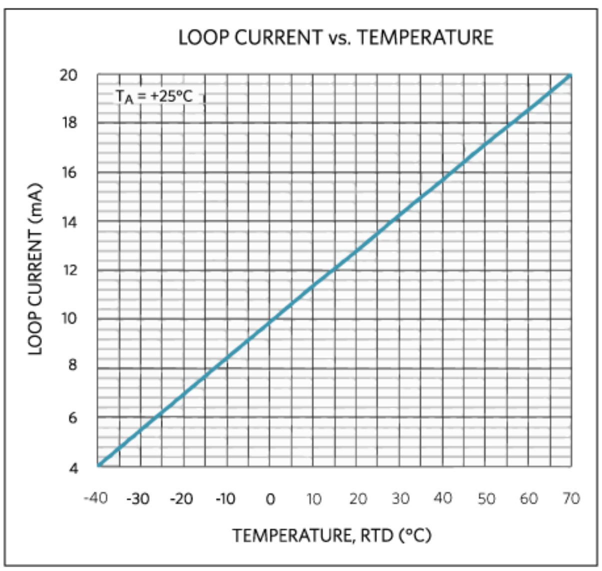

Figure 13. 4–20mA Loop Current vs. RTD Temperature.

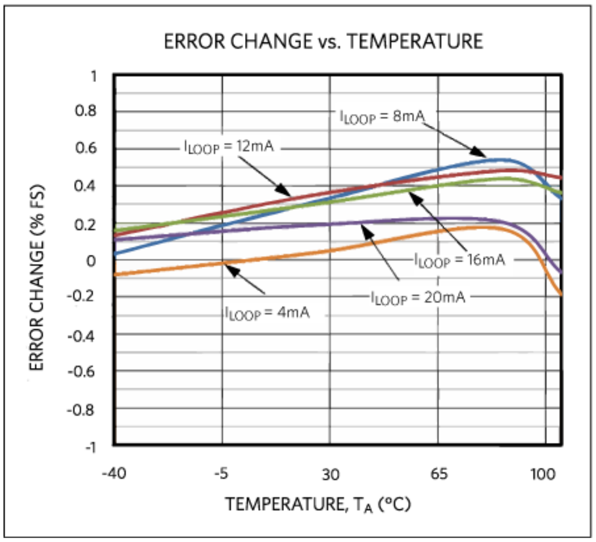

Figure 14. Error Change vs. Temperature

Conclusion

With 12-Bit DAC Outputs capable of delivering 25mA minimum current, the PIXI MAX11300 is a great device for the 4–20mA current control loop transmitter. In addition, up to 5 transmitters can be implemented using a single device since the MAX11300 has a total of 20 ports, but only 4 ports are required to design a transmitter. The test results have shown that the error change is less than 0.6% over the entire 4–20mA loop current range and ambient temperature from -40°C to +105°C.

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Related Parts		
MAX11300	PIXI, 20-Port Programmable Mixed-Signal I/O with 12-Bit ADC, 12-Bit DAC, Analog Switches, and GPIO	Free Samples
MAX44248	36V, Precision, Low-Power, 90μA, Single/Quad/Dual Op Amps	Free Samples
MAXQ2000	Low-Power LCD Microcontroller	

More Information
For Technical Support: https://www.maximintegrated.com/en/support
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