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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 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 250 Ω 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 250 Ω -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 250 Ω ; however, depending on application, resistances of 100 Ω to 750 Ω 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.
- 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.

File Device Options Help		
Load Configuration	a Chart Pin Configuration Registers History	
Exit Evit Dev_Id=0x00241MPX1T3001ev	v0 ifmode0 SPI 20MHz PORT0_PORT19 12-bit Range=10V	Read
Keset	1xxx xxxx xxxx RESET Soft reset command	Read
x1xx xxxx xxxx xxxx BRST Burst		Read
Keset		Read
x1xx xxxx xxxx BRST Burst	Mode xxxx 1 xxxx xxx1 xxxx xxxx tmp_int_data Temperautre Disable	Read

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.

le Device Op	tions Help		
evice Config	Poling	nfiguration Registers History	
Device ID	Read on interrupt		
Jevice ID	History log to file CommsLog.txt		Read
dev_id=0x0 🗸	Display ADC Voltages	ORT0PORT19 12-bit Range=10V	
Image: Second	Enable burst mode read/write		
Device Contro	Connect to EV Kit hardware	RESET Soft reset command	Read
x1xx xxxx xxx	manual CNVTB control	x000x x00x1 x000x tmp_int_data Temperautre	
BurstAutoi	SPI 🔸	Disable	
	12C		
Normal	Control Loop	420mA Loop Drive PORT17, Sense PORT16, Ref PORT18	

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.

Device Options Help				
Poling Poling	Configuration Registers	History		
Pead on interrupt History log to the Commilliog tot			Read	
dev_kdm0 V Display ADC Vallages	Ha PORTO PORTIN 12-bit Ran	e=10v		
Crable burt mode read/wrbs				
evice Con Connect to EV Richardware	xxx RESET Soft reset command	(Read	
x1xx xxxx a manual CNVTB control	2 2	xxxx.xxx1 xxxx tmg_int_data Temperautre		
BurstAut		Enable	•	
xx1x xxxx x	4.20mA Loop Drive PORTL1 Set	now now flow now Thermal Shutdown		
Normal	Calibrate 4 20mA Issep PORTLT			
xxx1 xxxx xxxx RS_CANCEL Series Res		wax wax wax wax DAC Voltage Reference		
Disable		Internal		
x000 1x00 x000 x000 TMPPER Temperature M		800 800 xx11 xxx ADCCONV ADC Conversion Ra	ate	
TempMonPeriod/alue0_H32u5sec_SAM		ADCRate200Ksps		
xoox x1xx xxxx xxxx D1PID1N tmp_ext2_data	Temperautra	1000 1000 1000 The DAC Update Mode		
Disable	•	NormalSequence		
xxxx xx fx xxxx xxxx D0P/D0N tmp_ext1_data	Temperautre	8000 8000 8000 30 11 ADC Conversion Mode	-	
Enable	•	ContinuousSweep	<u>n</u>	
errupt Enable (Unmask)	R	ad DAC Presets	Read	
VMON High Voltage Supply Monitor		dac_preset_data_1 0x0000 dac_prese	at_data_2_0x0000	
DACOI DAC Over-Current				
BPIDM GPI Event Missed		Temperature Monitors	Read	
B GPIDR GPI Event Ready	CON TMPINTNEW	Average4 • tmp_mon_int_hi_thresh 255.875°C		
ADCOM ADC Data Missed	Call IMPINIPICI	tmp_mon_int_to_threah	-258°C	

Figure 9. Calibration option.

Fixed Load Resistance	•		250	Ohn
PLC Shunt (current me	eter) Resistance		17	Ohn
Test Condition	Drive 4mA		Drive 20mA	
Nominal DAC Voltage	1.068	v	5.34	v
Measured Current	3.976	mA	20.014	mA
ADC16 Voltage	0.067567825317	v	1.016435623168	v
Reset				
nput Temperature				
Test Condition	Cold Limit		Hot Limit	
Temperature	-40	С	70	С
	Measure Voltag	je	Measure Voltag	e
ADC18-19 Voltage	1.130561828613	v	-1.95438385009	v
Reset				
	1.130561828613	v	-1.95438385009	v

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

File Device Options	Help		
Device Config	ling	nfiguration Registers History	
	ead on interrupt		
Device ID His	story log to file CommsLog.txt		Read
dev_id=0x0 🗸 Dis	splay ADC Voltages	ORT0PORT19 12-bit Range=10V	
V En	able burst mode read/write		
Device Contro Co	onnect to EV Kit hardware	RESET Soft reset command	Read
x1xx xxxx xxx ma	anual CNVTB control	x000x x00x1 x000x x000x tmp_int_data Temperautre	
BurstAutoi	PI +	Disable	
12	c +	xxxx xxxx 1xxx xxxx Thermal Shutdown	
Cc	ontrol Loop +		
Normal		Disable	

- Figure 11. Polling selection.
- 14. Select "Data" to view test results as shown in Figure 12.

evice Configuration	Data Chart Pin Confl	guration Registers	s History			
	Read Configuration		Write Selected	Read All		
PORT2	0x0000 Highimpedance	1/	CD With			12
PORT3	0x0000 Highimpedance		CIP Write			
PORT3 PORT4	0x0000 Highimpedance		C Witte			
			Con write			1
PORT5	0x0000 Highimpedance		Con withe			
PORT6	0x0000 HighImpedance					
PORT7	0x0000 HighImpedance		OT Witte			
PORTB	0x0000 Highimpedance		CID Witte			
PORTR	0x0000 Highimpedance		CID Willia			
PORT10	0x0000 Highimpedance		COD Write			
PORT11	0x0000 HighImpedance		Call Write			
PORT12	0x0000 Highimpedance		CIP Write			
PORT13	0x0000 Highimpedance		CIP Witho			
PORT14	0x0000 Highimpedance	L [2	CID with			
PORT15	0x0000 Highimpedance		C wine			
PORT16	0x74e0 ADCInPosSingleEnded		CIII Withe	1.0193V	[ADC New]	
PORT17	0x5100 DACout	5.3418V	O Wille			
PORT18	0x82t3 ADCinPosDifferential		CID Wille	-1.94827	(ADC New((PORT10)	
PORT19	0x9200 ADCIniNegDifferential		COD WITH			
INT	Internal Temperature			0x01ba	68.26°C	+

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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MAX11300 PIXI, 20-Port Programmable Mixed-Signal I/O with 12-Bit ADC, 12-Bit DAC, Analog Free Samples MAX44248 36V, Precision, Low-Power, 90µA, Single/Quad/Dual Op Amps Free Samples MAXQ2000 Low-Power LCD Microcontroller Free Samples	Related Parts		
	MAX11300		Free Samples
MAX02000 Low-Power LCD Microcontroller	MAX44248	36V, Precision, Low-Power, 90µA, Single/Quad/Dual Op Amps	Free Samples
	MAXQ2000	Low-Power LCD Microcontroller	

More Information

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