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IN THIS ISSUE:

- IIoT
- Medical
- Rail
- EMC

Ethernet at the edge of industrial networks

Contents

Regulars

Cover supplied by Microchip Technology. More on pages 6-7

Features

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Optically-isolated analogue output module for a 0-5V to 4-20mA signal converter

By Professor Murat Uzam, Department of Electrical and Electronics Engineering, Yozgat Bozok University, Turkey

In this series of articles about signal coverters, this month we will present the seventh – and last in the series – output module, this time for a 0-5V to 4-20mA converter that provides current from 4-20mA and requires two DC power supplies: +12V and isolated +12V.

Figure 1 shows the module, which connects to the DAC output of a 5V microcontroller; see Figure 2. This circuit contains the Positive Unipolar Photovoltaic Isolation Amplifier 3 (PUPIA3), which we covered before, with an HCNR201 high-linearity analogue optocoupler providing photovoltaic isolation. The circuit's input (to the left of HCNR201) is isolated from its output. Due to the limited current drive capability, the buffer amplifier (a voltage follower) LM358P-1A is used on the DAC output, whose output is connected to the input of PUPIA3. Here, PUPIA3 consists of:

1. Input: R1, R2, LM358P-1B;
2. HCNR201;
3. Output: P1, R3, C3, LM358P-2A.

Provided that the input voltage of the PUPIA3 is limited by $0.00V \leq V_{IN} \leq 5.00V$, its output voltage will also be limited between 0.00V and 5.00V. The output of PUPIA3 is connected to the non-inverting input terminal of the buffer amplifier LM358P-2B.

Design based on XTR116

This design is based on the XTR116 from Texas Instruments, a precision current output converter that feeds 4-20mA signals over an industry-standard current loop. It provides accurate current scaling and output current limit functions.

XTR116 operates over an extended industrial temperature range (-40°C to +85°C), offers low quiescent current (200µA), 5V regulator for external circuits, V_{REF} for sensor excitation (4.096V), low span error (0.05%), low nonlinearity error (0.003%) and a wide loop supply range (7.5-36V). Applications include 2-wire, 4-20mA current loop transmitters, industrial process control, test systems compatible with Hart modems, current amplifiers, voltage-to-current amplifiers, and more.

The XTR116 is found in most PLCs at the heart of modern automation products. It is the least expensive 4-20mA current loop output IC and it is very accurate.

The XTR116 is a two-wire current transmitter, where its input signal (pin 2) controls the output current. A portion of this current flows into the V+ power supply, pin 7. The remaining current flows in the external transistor, BD139.

The XTR116 is a current-input device with a gain of 100; i.e., $I_{OUT} = 100 \bullet I_{IN}$. The input voltage at the I_{IN} pin is zero (referred to the I_{RET} pin). A voltage input is created with an external input resistor (P1 + R1).

Common full-scale input voltages range from upward of 1V; full-scale inputs greater than 0.5V are recommended to minimise the effects of offset voltage and drift of the internal operational wamplifier A1.

The XTR116 is designed to use an external transistor to avoid on-chip thermal-induced errors. Transistor BD139 conducts the majority of the full-scale output current. Power dissipation in this transistor can approach 0.8W with high loop voltage (40V) and 20mA output current.

The XTR116 provides accurate, linear output up to 25mA. Internal circuitry limits the output current to approximately 32mA, to protect the transmitter and loop power/measurement circuitry.
The XTR116 low compliance voltage rating (7.5V) allows the use of various voltage protection methods without compromising the operating range. A diode bridge circuit, obtained by using 1N4148 diodes, allows normal operation, even when the voltage connection lines are reversed. The bridge causes a two diode drop loss (approximately 1.4V) in loop supply voltage, which results in a compliance voltage of about 9V – suitable for most applications.

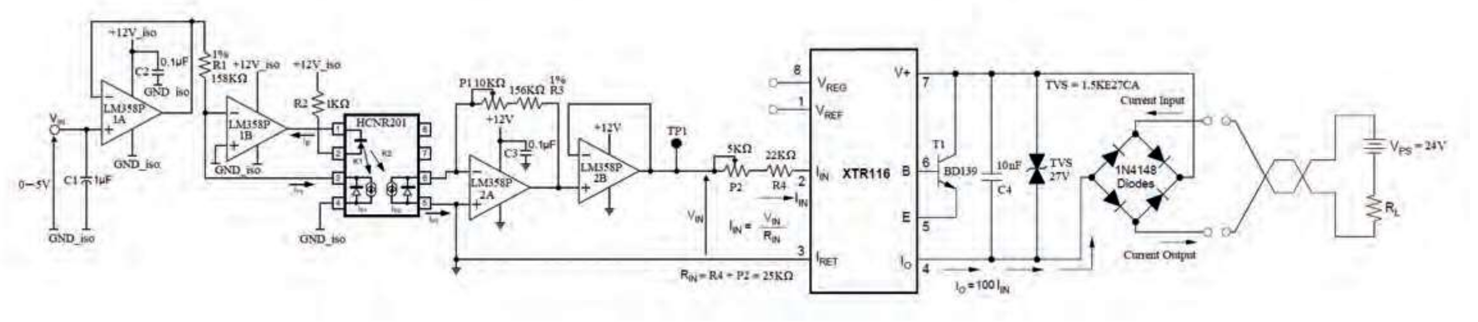

Figure 1: The output module of the optically-isolated 0-5V to 4-20mA signal converter

V_{IN}(V)	I_{OUT} (mA)
5.00	20
..	..
4.75	19
..	..
4.50	18
..	..
4.25	17
..	..
4.00	16
..	..
3.75	15
..	..
3.50	14
..	..
3.25	13
..	..
3.00	12
..	..
2.75	11
..	..
2.50	10
..	..
2.25	9
..	..
2.00	8
..	..
1.50	6
..	..
1.25	5
..	..
1.00	4
..	..
0.75	3
..	..
0.50	2
..	..
0.25	1
..	..
0.00	0.00

Table 1: Modules 1 and 2 example voltages, assuming $0.00V \leq V_{IN} \leq 5.00V$

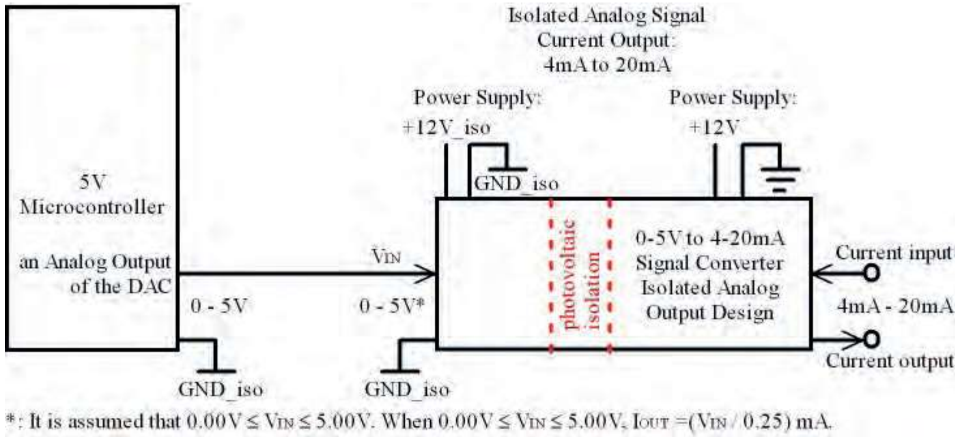

Figure 2: The module's connections

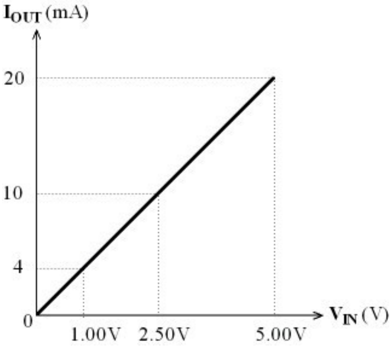

Figure 3: I_{OUT} vs V_{IN} for the module

Remote connections to current transmitters can sometimes be subjected to voltage surges. Therefore, it is prudent to limit the maximum surge voltage applied to the XTR116 as low as practically possible. A 27V TVS (Transient Voltage Suppressor) is used to filter and suppress any transients coming from the current input and output terminals.

A 27V TVS is chosen for a 24V external power supply V_{PS}. For $V_{PS} \geq 24V$, this TVS must be replaced with an appropriate one. For example, when V_{PS} = 36V, a 39V TVS must be used.

Setup and calibration

Here we assumed that V_{IN} is taken from the DAC output of a 5V microcontroller with $0.00V \leq V_{IN} \leq 5.00V$. When $0.00V \leq V_{IN} \leq 5.00V$, $I_{OUT} = (V_{IN}/0.25)$mA. Input voltage range V_{IN} = 0-5.00V and therefore output current range I_{OUT} = 0-20mA; see Figure 3.

Table 1 provides some example input voltages and output currents for this signal converter module, with its prototype circuit board shown in Figure 4.

To calibrate it, do the following:

1. V_{PS} = 24V and R_L = 250Ω.
2. Set V_{IN} to +5.00V and, then, by adjusting P1 make V_{TP1} = +5.00V.
3. By adjusting P2 make sure that when V_{IN} = 0.00V, V_{RL} = 0.00V and, also, when V_{IN} = +5.00V, V_{RL} = +5.00V. EW

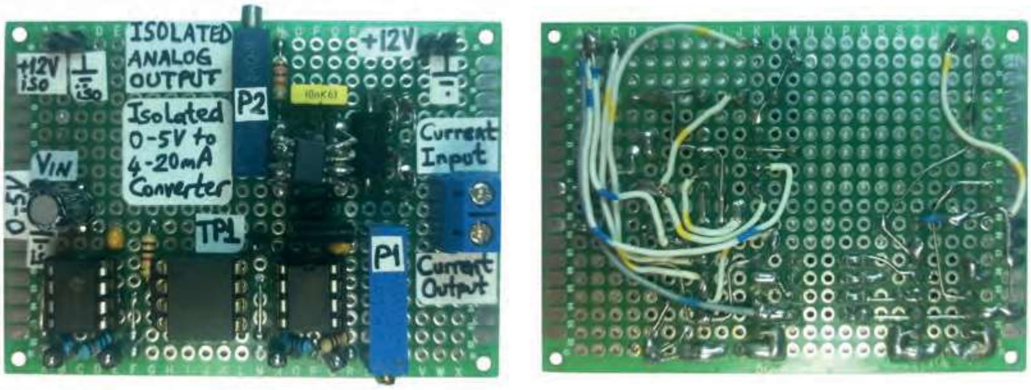

Figure 4: The module's prototype circuit board