Analogue output module for a 0-5V to 4-20mA signal converter

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This series of columns is dedicated to a project involving thirteen analogue input modules and seven analogue output modules to connect to the ADC/DAC channels of a 5V microcontroller.

This month we present the last article in the series, which discusses the seventh analogue output module for a 0-5V to 4-20mA signal converter that provides current output from 4-20mA and requires a +12V DC power. Figure 1 shows the module's circuit diagram, with its connections shown in Figure 2.

In this design, we've 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} = 0.00V to 5.00V, therefore output current range I_{OUT} = 0-20mA. The relationship between V_{IN} and I_{OUT} is shown in Figure 3.

The design

This design is based on the cheap yet very accurate XTR116 device from Texas Instruments (TI), a precision current output converter designed to transmit 4-20mA signals over an industry-standard current loop. It provides accurate current scaling and output current limit functions.

The XTR116 is specified for operation over an extended industrial temperature range of –40°C to +85°C. Its features include a low quiescent current of 200μA, a 5V regulator for external circuits, V_{REF} for sensor excitation of 4.096V, low span error of 0.05%, low nonlinearity error of 0.003% and a wide loop supply range of 7.5-36V. XTR116 applications include 2-wire, 4-20mA current loop transmitter, smart transmitter, industrial process control, test systems compatible with HART modems, current amplifiers and voltage-to-current amplifiers, among others. The XTR116 can be found in most automation product PLCs.

Due to its limited current drive capability, the buffer amplifier (voltage follower) LM358P-A is used on the DAC output. The XTR116 is a two-wire current transmitter, with its input signal (pin 2) controlling the output current. A portion of this current flows into the V+ power supply (pin 7), with the remainder flowing into BD139.

The XTR116 is a current-input device with gain of 100. A current flowing into pin 2 produces $I_O = 100 \bullet I_{IN}$. The input voltage at the I_{IN} pin is zero (referred to the I_{RET} pin). A voltage input is obtained from an external input resistor $P_1 + R_1$, as shown in Figure 1. Common full-scale input voltages range from 1V upward. Full-scale inputs greater than 0.5V are recommended to minimise the effect of offset voltage and drift of the internal operational amplifier A1.

The external 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 is designed to use an external transistor to avoid on-chip thermal-induced errors. It also provides accurate, linear output up to 25mA. Internal circuitry limits the output current to approximately 32mA to protect the transmitter and loop power/measurement circuit. The XTR116's low-compliance voltage rating of 7.5V allows the use of various voltage protection methods without compromising the operating range.

A diode bridge circuit made of 1N4148 diodes allows normal operation even when the voltage connection polarity is reversed. The bridge causes a two-diode drop of approximately 1.4V in the loop supply voltage, resulting in a compliance voltage of approximately 9V, satisfactory for most applications.

Limitations

Remote connections to current transmitters can sometimes be subject to voltage surges. It is prudent to minimise the surge voltage applied to the XTR116 as much as practical. 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 to match the 24V external supply V_{PS}. For $V_{PS} \leq 24V$ this TVS must be replaced accordingly. For example, for V_{PS} = 36V, a 39V TVS must be used.

Table 1 provides some input voltages and output currents for this analogue output module, with its prototype circuit board show in in Figure 4.

To calibrate the circuit, choose the following: V_{PS} = 24V and R_L = 250Ω. Adjust P_1 to ensure that when V_{IN} = 0.00V, V_{RL} = 0.00V and, also, when V_{IN} = +5.00V, V_{RL} = +5.00V. EW

V_{IN}(V)	V_{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: Input voltage and output currents for the analogue output module for a 0-5V to 4-20mA signal converter, assuming 0.00V ≤ V_{IN} ≤ 5.00V

Figure 1: Circuit diagram of an analogue output module for a 0-5V to 4-20mA signal converter

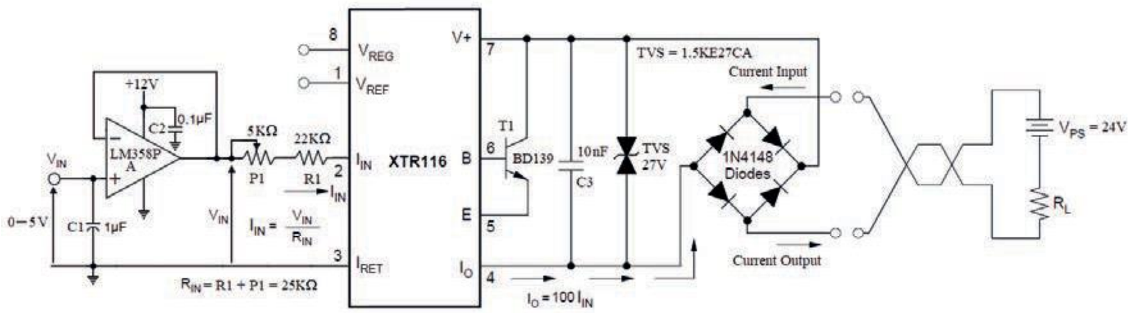

Figure 2: Analogue output module for a 0-5V to 4-20mA signal converter connections to a 5V microcontroller

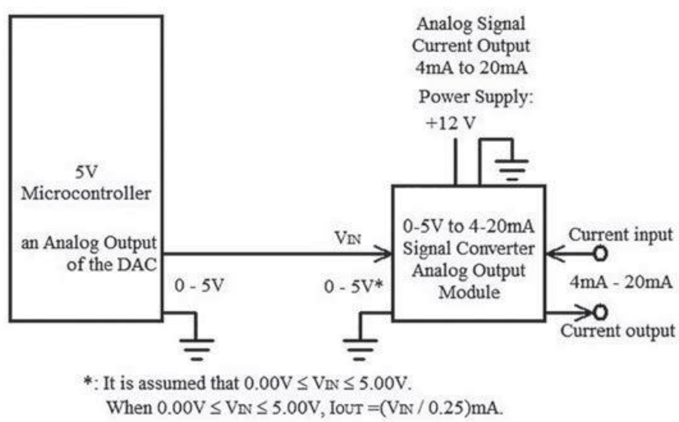

Figure 3: I_{OUT} vs V_{IN} for the module shown in Figure 1

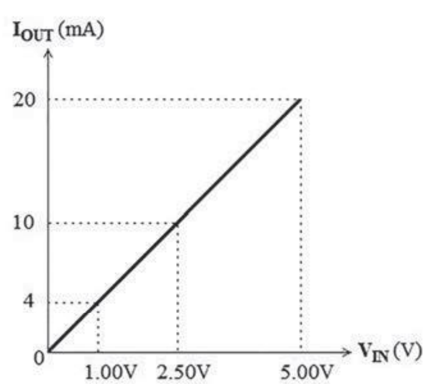

Figure 4: Prototype circuit board of the analogue output module for a 0-5V to 4-20mA signal converter