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Optically-isolated input modules for a -10V to +10V to 0-5V signal converter

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

In this month's column we will cover two optically-isolated analogue input modules for a −10V to +10V to 0-5V signal converter, with DC input voltages varying between −12V and +12V, powered by +5.00V, +6.26V, −12V, +12V, +12V (isolated) for module 1 and −12V, +12V and +12V (isolated) for module 2.

Module 1

Figure 1 shows the −10V - +10V to 0-5V signal converter for use with the ADC input of a 5V microcontroller; its connections are shown in Figure 2. The circuit is based on the Positive Unipolar Photovoltaic Isolation Amplifier 1 (PUPIA1 – explained in a previous month), with an HCNR201 high-linearity analogue optocoupler for photovoltaic isolation. The circuit's output is isolated from V_{IN}.

This design is used to level-shift the bipolar −10V - +10V analogue input signals to provide a unipolar 0-5V signal. The transfer function is obtained from:

$$V_{OUT} = \left(\frac{\frac{R1.R3}{R1+R3}}{R2 + \frac{R1.R3}{R1+R3}} \right) V_{IN} + \left(\frac{\frac{R2.R3}{R2+R3}}{R1 + \frac{R2.R3}{R2+R3}} \right) 5$$

Since R2 = R3, R1 = ½ R2,

$$V_{OUT} = \left(\frac{1}{4} \right) V_{IN} + \left(\frac{1}{2} \right) 5 = \frac{V_{IN} + 10}{4}$$

V_{IN} can be subjected to electric surge or electrostatic discharge on the external terminal connections, but adding a transient voltage suppressor (TVS) gives it good protection. A ferrite bead is connected in series with the input path to add isolation and decoupling from high-frequency transient noises. External Schottky diodes protect the operational amplifier. Even when internal ESD protection diodes are present, using external diodes lowers noise and offsets errors. Dual series Schottky barrier diodes D1 and D2 divert any overcurrent to the positive or negative power supply.

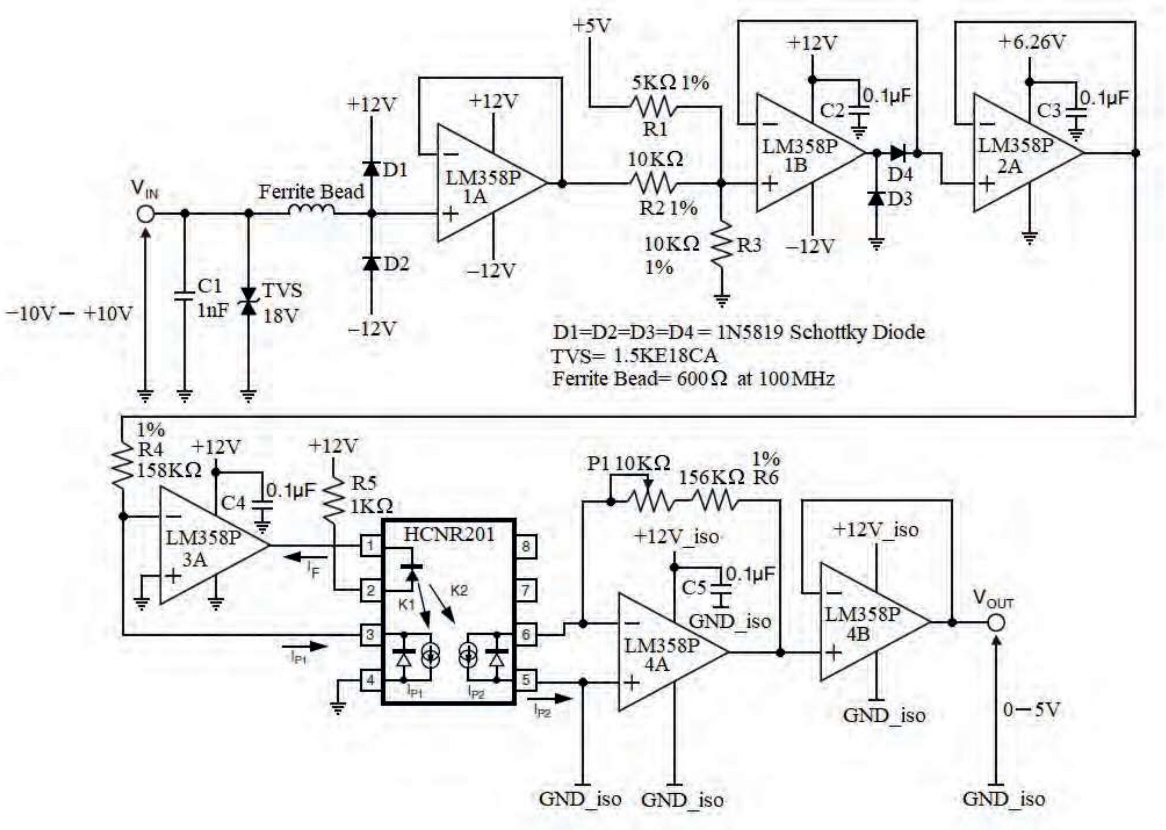

Figure 1: -10V - +10V to 0-5V signal converter – module 1

The operational amplifier LM358P-1A, with bipolar supply voltages, provides a high input impedance and is connected as a buffer amplifier (voltage follower).

Diodes D3 and D4 ensure that when $-12.00V \le V_{IN} < -10.00V$, $V_{OUT} = 0.00V$. The operational amplifier LM358P-2A, with a +6.26V supply voltage, acts as a voltage limiter and is connected as a buffer amplifier. Its output is connected to the input of PUPIA1, limited by LM358P-1A.

Here, PUPIA1 consists of:

1. Input section: R4, R5, C4, LM358P-3A;
2. HCNR201 high-linearity analogue optocoupler.;
3. Output section: P1, R6, C5, LM358P-4A.

In this design, the circuit's input is powered by +5.00V, +6.26V, −12V and −12V. Likewise, the circuit's output is powered by +12V isolated from the input. The output of the PUPIA1 is connected to the non-inverting input terminal of the buffer amplifier LM358P-4B, obtaining V_{OUT}.

We assume V_{IN} is = −12V to +12V. When $-12.00V \le V_{IN} < -10.00V$, $V_{OUT} = 0.00V$. When $-10.00V \le V_{IN} \le +10.00V$, $V_{OUT} = (V_{IN} + 10V) / 4$. When $+10.01V \le V_{IN} \le +12V$, V_{OUT} will be a value from 5.01V to 5.07V, due to LM358P-2A. See V_{OUT} vs V_{IN} in Figure 3, with some examples in Table 1.

For proper operation make R2 = R3, R1 = ½R2 and +5V = +5.00V.

To calibrate the setup, set V_{IN} to +10.00V and adjust P1 to bring V_{OUT} to +5.00V.

Module 2

Figures 5, 6 and 7 show the optically-isolated analogue input module 2 with its connections to the ADC port of a 5V microcontroller. As before, this circuit is also PUPIA1-based, with a high-linearity analogue optocoupler (HCNR201) providing photovoltaic isolation.

This design is used to level-shift the bipolar −10V - +10V analogue voltage signal to provide a unipolar input of 0-5V.

The transfer function is obtained from the following:

$$V_{OUT} = \left(\frac{\frac{R1.R3}{R1+R3}}{R2 + \frac{R1.R3}{R1+R3}} \right) V_{IN} + \left(\frac{\frac{R2.R3}{R2+R3}}{R1 + \frac{R2.R3}{R2+R3}} \right) 5$$

Since R2 = R3, R1 = ½ R2,

$$V_{OUT} = \left(\frac{1}{4}\right) V_{IN} + \left(\frac{1}{2}\right) 5 = \frac{V_{IN} + 10}{4}$$

R7, D5 (10V zener diode) and C6 provide a 10.00V reference voltage from +12V. This 10.00V is divided with R8 and R9 to obtain +5.00V, which can source current to 20mA.

Likewise, the 10.00V reference voltage is also divided by using R10 and R11 to obtain a +6.26V reference voltage. Next, the 5V is connected to the non-inverting input of the buffer amplifier LM358P-3B, whose output is fixed at 5V, sourcing current to 20mA.

V_{IN} can be subjected to electric surge or electrostatic discharge on the external terminal connections; the TVS (transient voltage suppressor) protects it. Dual series

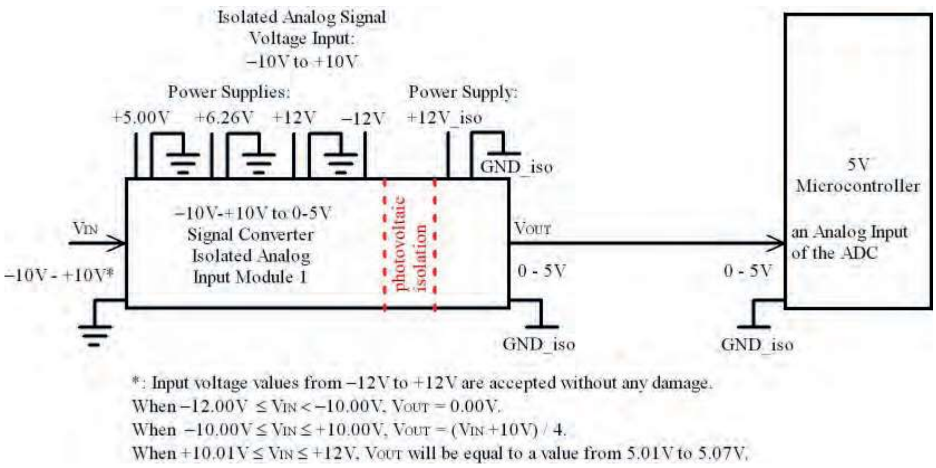

Figure 2: Function generator signals when none of the outputs are connected to a load

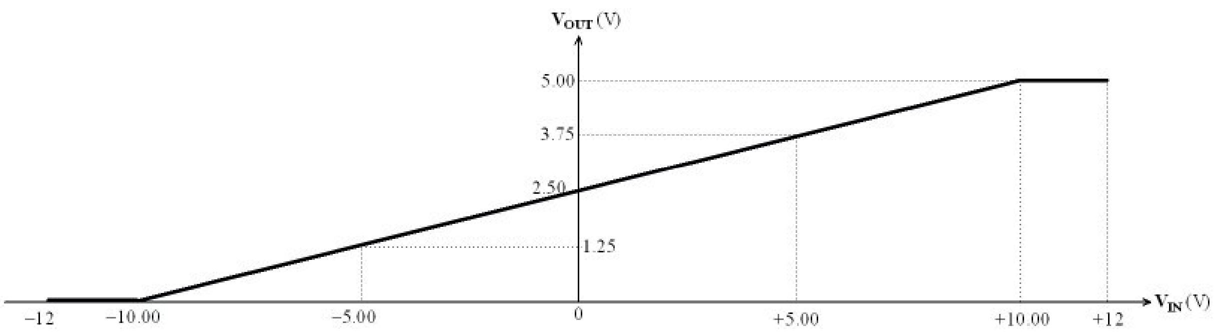

Figure 3: V_{OUT} vs. V_{IN} relationship for modules 1 and 2

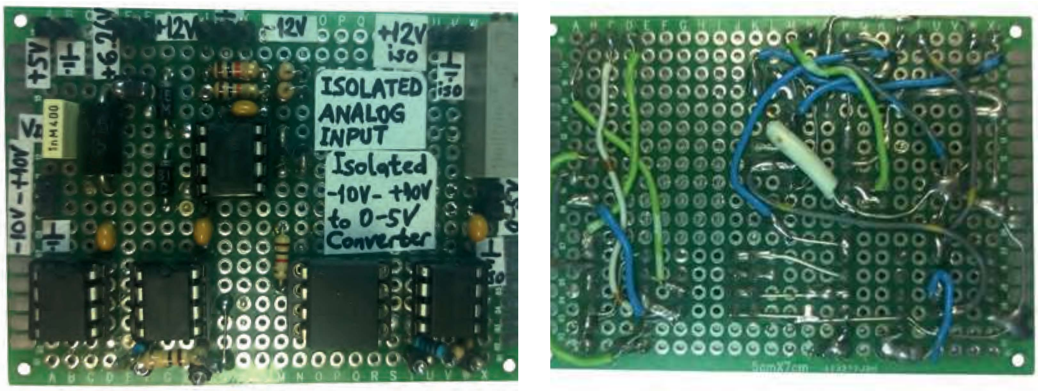

Figure 4: Module 1's prototype circuit board

V_{IN}(V)	V_{OUT}(V)
+12.00	5.0X
..	5.0X
+11.00	5.0X
..	5.0X
+10.00	5.00
..	..
+9.00	4.75
..	..
+8.00	4.50
..	..
+7.00	4.25
..	..
+6.00	4.00
..	..
+5.00	3.75
..	..
+4.00	3.50
..	..
+2.00	3.00
..	..
0.00	2.50
..	..
−1.00	2.25
..	..
−3.00	1.75
..	..
−4.00	1.50
..	..
−5.00	1.25
..	..
−6.00	1.00
..	..
−7.00	0.75
..	..
−8.00	0.50
..	..
−9.00	0.25
..	..
−10.00	0.00
..	..
−11.00	0.00
..	..
−12.00	0.00

Table 1: Example input and output voltages for modules 1 and 2 (5.0X: a value from 5.01V to 5.07V)

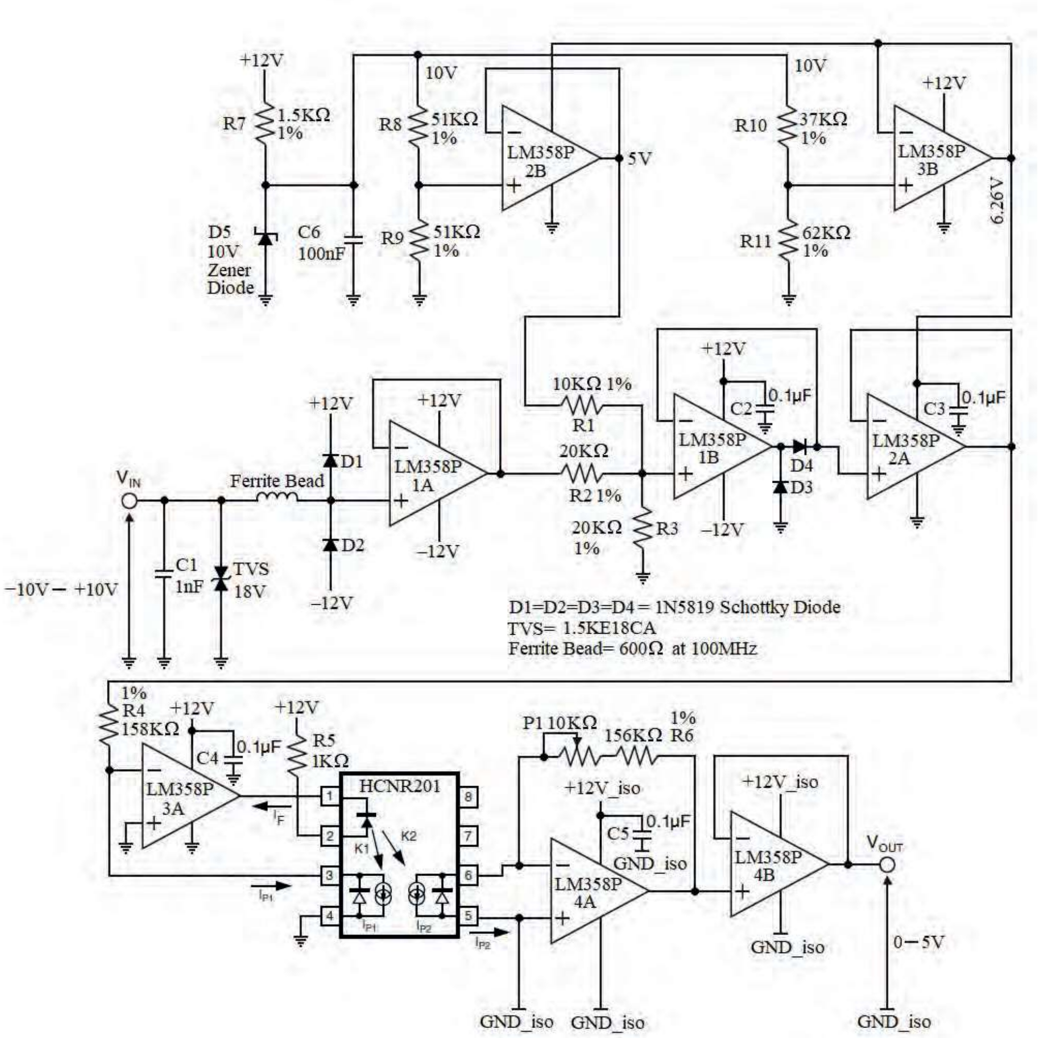

Figure 5: Module 2

Schottky barrier diodes D1 and D2 divert any overcurrent to the positive or negative power supply.

The operational amplifier LM358P-1A, with bipolar supply voltages, provides a high input impedance and is connected as a buffer amplifier (voltage follower). Diodes D3 and D4 ensure that when −12.00V ≤ V_{IN} < −10.00V, V_{OUT} = 0.00V. The operational amplifier LM358P-2A, with a +6.26V supply voltage, acts as a voltage limiter and is connected as a buffer amplifier.

LM358P-2A's output is connected to PUPIA1's input, which limits the input voltage. PUPIA1 consists of:

1. Input section: R4, R5, C4, LM358P-3A;
2. HCNR201 high-linearity analogue optocoupler;
3. Output section: P1, R6, C5, LM358P-4A.

The input and output are powered by isolated +12V. It is assumed that V_{IN} = −12V to +12V. When −12.00V ≤ V_{IN} < −10.00V, V_{OUT} = 0.00V. When −10.00V ≤ V_{IN} ≤ +10.00V, V_{OUT} = (V_{IN} +10V) / 4. When +10.01V ≤ V_{IN} ≤ +12V, V_{OUT} will be a value from 5.01V to 5.07V, because of LM358P-2A; see Figure 3 and Table 1.

For proper operation make R2 = R3, R1 = ½ R2, R8 = R9, and R11/(R10+R11) = 62.62%. EW

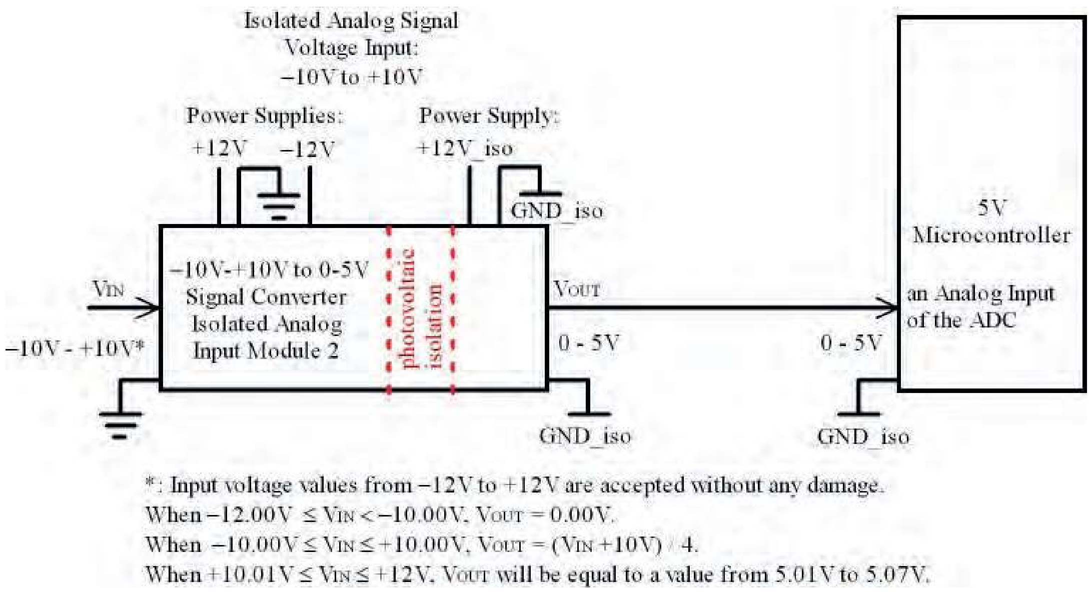

Figure 6: Module 2's connections

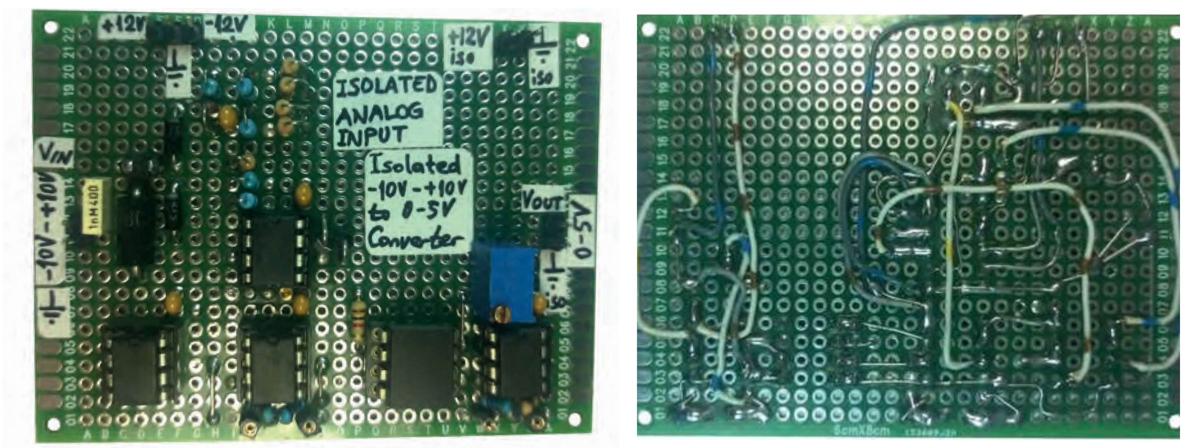

Figure 7: Module 2's prototype circuit board