Loop-powered 4- to 20-mA transmitter circuit

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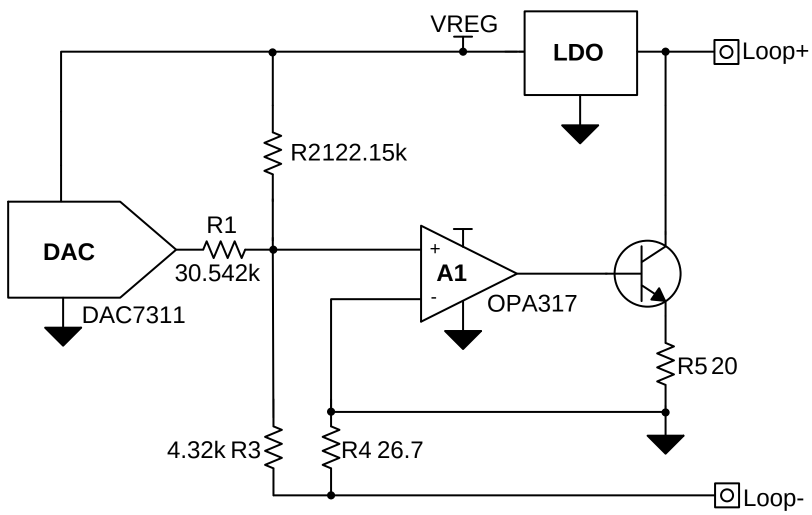
Design Goals

Loop Supply Voltage	DAC Output Voltage	Output Current	Error
12V–36V	0V–3V	4mA–20mA	<1% FSR

Design Description

The loop powered current transmitter regulates the current in series loop consisting of the power supply, transmitter, and load resistance. The active circuitry in the transmitter derives power from the loop current, meaning the current consumption of all devices must be less than the zero-scale current, which can be as low as 3.5mA in some applications. A regulator steps down the loop voltage to supply the DAC, op amp and additional circuitry. The op amp biases the transistor to regulate the current flowing from Loop+ to Loop-. The circuit is commonly used in 2-wire field sensor-transmitters such as Flow Transmitters, Level Transmitters, Pressure Transmitters, and Temperature Transmitters.



Design Notes

1. Select a single channel DAC with the required resolution and accuracy for the application. Use an op amp with low offset and low drift to minimize error.
2. Select a low power DAC, op amp, and voltage regulator to ensure a total sensor-transmitter quiescent current of less than 4mA.
3. Minimize current flow through R1, R2, and R3 by selecting a large ratio of R3/R4 to minimize thermal drift of the resistors.
4. Use precision low drift resistors for R1-R4, R7-R8 to minimize error.
5. Use a voltage regulator with a wide input voltage range and low dropout voltage to allow for a wide range of loop supply voltages.

Design Steps

The output current transfer function is:

$$I_{OUT} = \left(\frac{V_{DAC}}{R1} + \frac{V_{REG}}{R2}\right)\left(\frac{R3}{R4} + 1\right)$$

1. Select a large ratio of R3/R4:

$$\frac{R3}{R4} = \frac{4.32k\Omega}{26.7\Omega}$$

2. Calculate R2 based on the zero-scale current (4mA), regulator voltage, and gain ratio (R3/R4).

$$R2 = \frac{V_{REG}}{I_{OUT,ZS}}\left(\frac{R3}{R4} + 1\right) = \frac{3V}{4mA}\left(\frac{4.32k\Omega}{26.7\Omega} + 1\right) = 122.10k\Omega$$

3. Calculate R1 to set the full-scale current based on the full-scale DAC voltage and current span of 16mA.

$$R1 = \frac{V_{DAC,FS}}{I_{OUT,SPAN}}\left(\frac{R3}{R4} + 1\right) = \frac{3V}{16mA}\left(\frac{4.32k\Omega}{26.7\Omega} + 1\right) = 30.524k\Omega$$

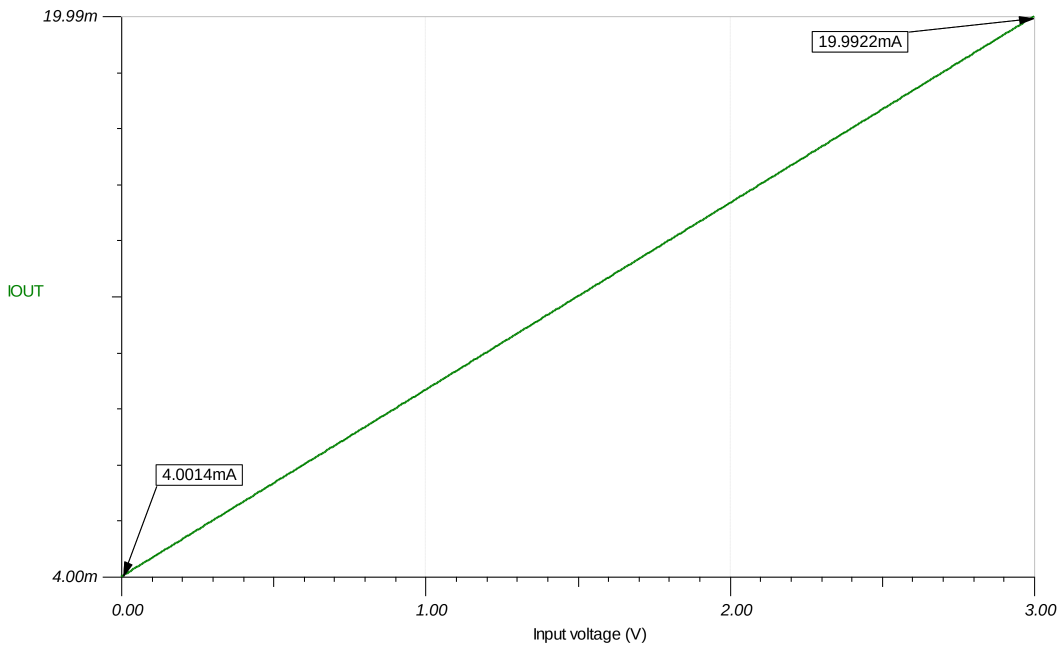
4. Calculate the zero-scale output current based on the chosen resistance values.

$$I_{OUT,ZS} = \frac{V_{REG}}{R2}\left(\frac{R3}{R4} + 1\right) = \frac{3V}{122.15k\Omega}\left(\frac{4.32k\Omega}{26.7\Omega} + 1\right) = 3.9983mA$$

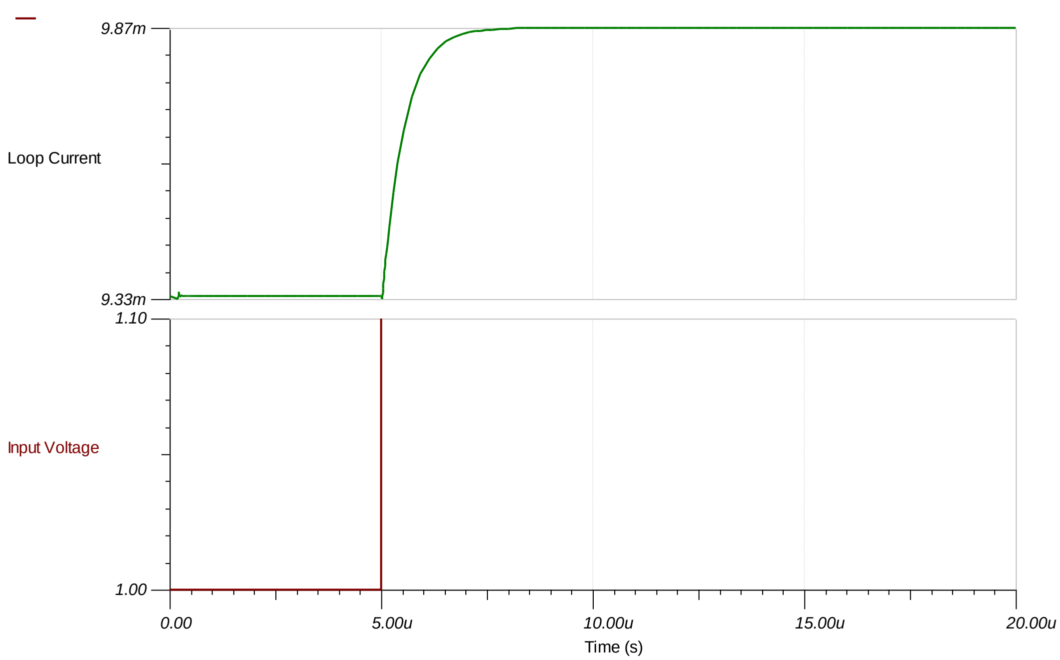
5. Calculate the full-scale current based on the chosen resistor values.

$$I_{OUT,FS} = \left(\frac{V_{DAC}}{R1} + \frac{V_{REG}}{R2}\right)\left(\frac{R3}{R4} + 1\right) = \left(\frac{3V}{30.542k\Omega} + \frac{3V}{122.15k\Omega}\right)\left(\frac{4.32k\Omega}{26.7\Omega} + 1\right) = 19.9891mA$$

DC Transfer Characteristic



Small Signal Step Response



Devices

Device	Key Features	Link	Other Possible Devices
DACs			
DAC7311	12-bit resolution, single channel, ultra-low power, 1 LSB INL, SPI, 2V to 5.5V supply	http://www.ti.com/product/DAC7311	http://www.ti.com/dacs
DAC8560	16-bit resolution, single channel, internal reference, low power, 4 LSB INL, SPI, 2V to 5.5V supply	http://www.ti.com/product/DAC8411	http://www.ti.com/dacs
DAC8830	16-bit resolution, single channel, ultra-low power, unbuffered output, 1 LSB INL, SPI, 2.7V to 5.5V supply	http://www.ti.com/product/DAC8830	http://www.ti.com/dacs
DAC161S997	16-bit, 4-20mA current output, 100uA supply current, SPI, 2.7V to 3.3V supply	http://www.ti.com/product/DAC161S997	http://www.ti.com/dacs
Amplifiers			
TLV9001	Low-Power, 0.4mV Offset, Rail-to-Rail I/O, 1.8V to 5.5V supply	http://www.ti.com/product/TLV9001	http://www.ti.com/opamps
OPA317	Zero-Drift, Low-Offset, Rail-to-Rail I/O, 35uA supply current max, 2.5V to 5.5V supply	http://www.ti.com/product/OPA317	http://www.ti.com/opamps
OPA333	microPower, Zero-Drift, Low Offset, Rail-to-Rail I/O, 1.8V to 5.5V supply	http://www.ti.com/product/OPA333	http://www.ti.com/opamps

Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Links to Key Files

TI Designs TIPD158, Low Cost Loop-Powered 4-20mA Transmitter EMC/EMI Tested Reference Design

TI Designs TIDA-00648, 4-20mA Current Loop Transmitter Reference Design

TI Designs TIDA-01504, Highly-Accurate, Loop-Powered, 4mA to 20mA Field Transmitter with HART Modem Reference Design

Source Files for *Loop-Powered 4- to 20-mA Transmitter* – http://www.ti.com/lit/zip/slac782.

For direct support from TI Engineers use the E2E community:

e2e.ti.com

Other Links:

Precision DAC Learning Center

http://www.ti.com/data-converters/dac-circuit/precision/overview.html