Analog Engineer's Circuit

Loop-Powered 4mA to 20mA Transmitter Circuit

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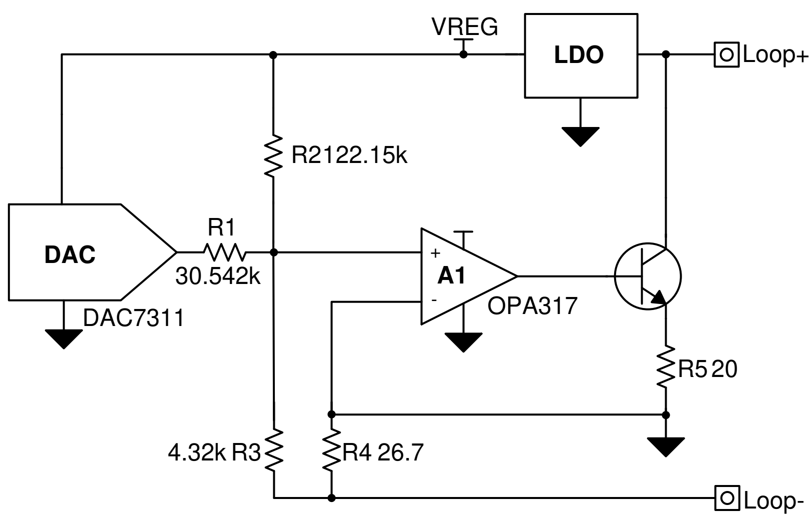
Design Goals

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 establish 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.

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

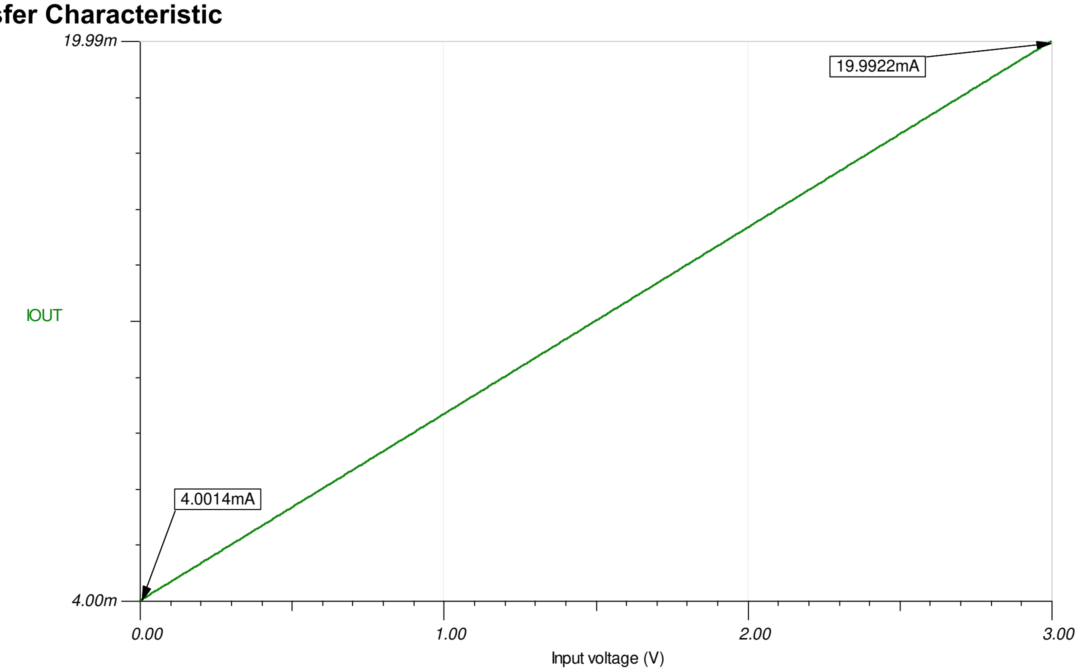
4. Calculate the zero-scale output current based on the chosen resistance values.

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

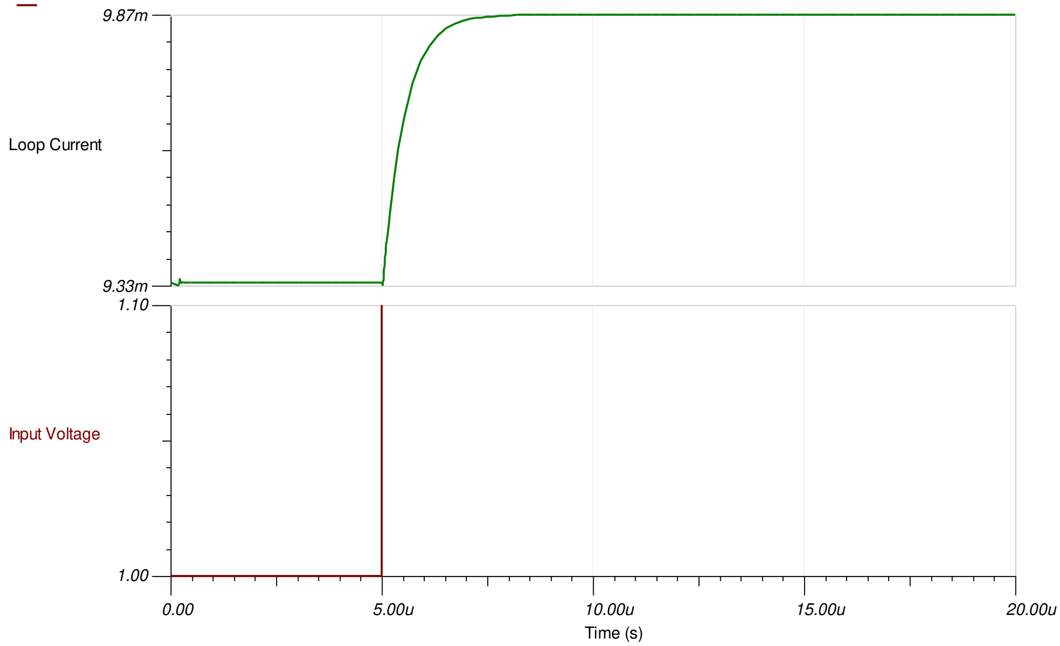
5. Calculate the full-scale current based on the chosen resistor values.

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

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	12-bit, single-channel, ultra-low power DAC in 6-pin SC70 package for battery powered applications	Precision DACs (≤10 MSPS)
DAC8560	16-bit resolution, single channel, internal reference, low power, 4 LSB INL, SPI, 2V to 5.5V supply	16bit, Single Channel, 80uA, 2.0V-5.5V DAC in SC70 Package	Precision DACs (≤10 MSPS)
DAC8830	16-bit resolution, single channel, ultra-low power, unbuffered output, 1 LSB INL, SPI, 2.7V to 5.5V supply	16-bit, single-channel, ultra-low power, voltage output DAC	Precision DACs (≤10 MSPS)
DAC161S997	16-bit, 4-20mA current output, 100uA supply current, SPI, 2.7V to 3.3V supply	16-Bit Precision DAC With Internal Reference and 4mA-to-20mA Current Loop Drive	Precision DACs (≤10 MSPS)
Amplifiers			
TLV9001	Low-Power, 0.4mV Offset, Rail-to-Rail I/O, 1.8V to 5.5V supply	One-channel, 1-MHz rail-to-rail input and output 1.8-V to 5.5-V operational amplifier	Operational amplifiers (op amps)
OPA317	Zero-Drift, Low-Offset, Rail-to-Rail I/O, 35uA supply current max, 2.5V to 5.5V supply	Low Offset, Rail-to-Rail I/O Operational Amplifier	Operational amplifiers (op amps)
OPA333	microPower, Zero-Drift, Low Offset, Rail-to-Rail I/O, 1.8V to 5.5V supply	Micropower, 1.8-V, 17-µA zero-drift CMOS precision operational amplifier	Operational amplifiers (op amps)

Links to Key Files

Texas Instruments, *Low Cost Loop-Powered 4-20mA Transmitter EMC/EMI Tested*, TIPD158 reference design

Texas Instruments, *4-20mA Current Loop Transmitter*, TIDA-00648 reference design

Texas Instruments, *Highly-Accurate, Loop-Powered, 4mA to 20mA Field Transmitter with HART® Modem*, TIDA-01504 reference design

Texas Instruments, source files for SLAA866, SLAC782 software support

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