Circuits from the Lab

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Devices Connected/Referenced	
AD8657	18V, Precision, Micropower CMOS Rail-to-Rail I/O Dual Operational Amplifier
ADR125	Precision, Micropower LDO Voltage Reference in TSOT
AD5621	2.7 V to 5.5 V, <100 μA, 12-Bit *nano*DAC, SPI Interface

Less Than 200 μA, Low Power, 4 mA-to-20 mA, Process Control Current Loop

CIRCUIT FUNCTION AND BENEFITS

The circuit in Figure 1 is a 4 mA-to-20 mA current loop transmitter for communication between a process control system and its actuator. Besides being cost effective, this circuit offers the industry's lowest power solution. The 4 mA-to-20 mA current loop has been used extensively in programmable logic controllers (PLCs) and distributed control systems (DCS's), with digital or analog inputs and outputs. Current loop interfaces are usually preferred because they offer the most cost effective approach to long distance noise immune data transmission. The combination of the low power AD8657 dual op amp, AD5621 DAC, and ADR125 reference allows more power budget for higher power devices, such as microcontrollers and digital isolators. The circuit output is 0 mA to 20 mA of current. The 4 mA to 20 mA range is usually mapped to represent the input control range from the DAC or microcontroller, while the output current range of 0 mA to 4 mA is often used to diagnose fault conditions.

The 12-bit, 5 V AD5621 requires 75 μA typical supply current. The AD8657 is a rail-to-rail input/output dual op amp and is one of the lowest power amplifiers currently available in the industry (22 μA over the full supply voltage and input common-mode range) with high operating voltage of up to 18 V. The ADR125 precision micropower 5 V band gap reference requires only 95 μA. Together, these three devices consume a typical supply current of 192 μA.

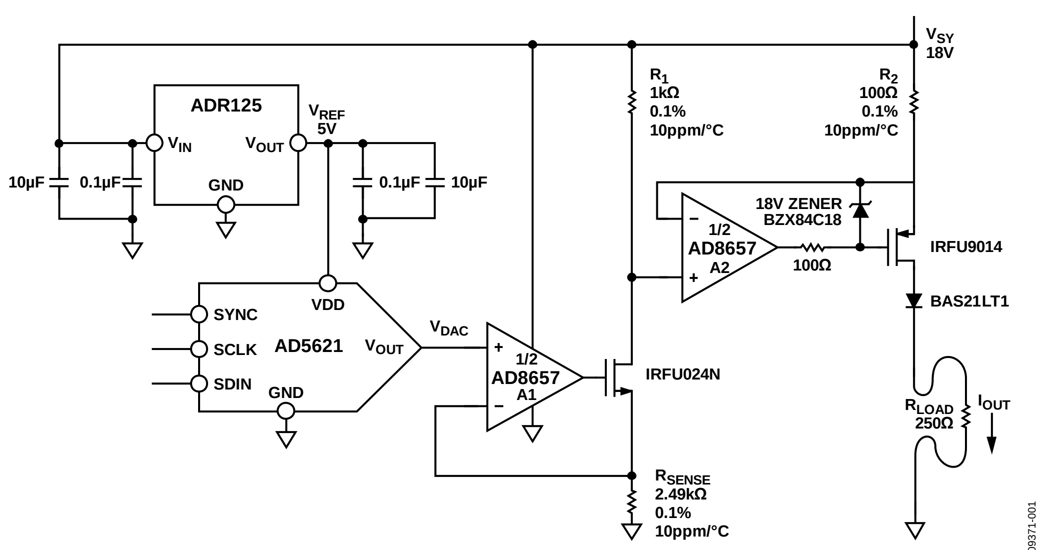

Figure 1. Low Power 4 mA-to-20 mA Process Control Current Loop (Simplified Schematic: All Connections and Decoupling Not Shown)

Rev. 0
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CIRCUIT DESCRIPTION

For industrial and process control modules, 4 mA-to-20 mA current loop transmitters are used as a means of communication between the control unit and the actuator. Located at the control unit, the 12-bit AD5621 DAC produces an output voltage, V_{DAC}, between 0 V and 5 V as a function of the input code. The code is set via an SPI interface. The ideal relationship between the input code and output voltage is given by

$$V_{DAC} = V_{REF} \times (D/2^{12}) \quad (1)$$

where:

V_{REF} is the output of ADR125 and the power supply to the AD5621.

D is the decimal equivalent of the binary code that is loaded to the AD5621.

The DAC output voltage sets the current flowing through the sense resistor, R_{SENSE}, where

$$I_{SENSE} = V_{DAC}/R_{SENSE} \quad (2)$$

The current through R_{SENSE} varies from 0 mA to 2 mA as a function of V_{DAC}. This current develops a voltage across R1 and sets the voltage at the noninverting input of the AD8657 amplifier (A2). The A2 AD8657 closes the loop and brings the inverting input voltage to the same voltage as the noninverting input. Therefore, the current flowing through R1 is mirrored by a factor of 10 to R2. This is represented by Equation 3.

$$I_{OUT} = I_{R2} = (V_{DAC}/R_{SENSE}) \times (R1/R2) \quad (3)$$

With V_{DAC} ranging from 0 V to 5 V, the circuit generates a current output from 0 mA to 20 mA.

The AD5621 is a 12-bit DAC from the *nano*DAC family and operates from the 5 V output voltage of the ADR125 reference. It has an on-chip precision output buffer that is capable of swinging from rail-to-rail, thus allowing a high dynamic output range. With a supply voltage of 5 V, AD5621 consumes a typical 75 µA of supply current.

In addition, this circuit solution requires a rail-to-rail input amplifier. The AD8657 dual op amp is an excellent choice, with low power and rail-to-rail features. The op amp operates with a typical supply current of 22 µA over the specified supply voltage and input common-mode voltage. It also offers excellent noise and bandwidth per unit of current. The AD8657 is one of the lowest power amplifiers that operates on supplies of up to 18 V.

The ADR125 is a precision, micropower, low dropout (LDO) voltage reference. With an 18 V input voltage, quiescent current is only 95 µA, typical. An LDO voltage reference is preferred because more voltage drop can be tolerated across the loop wires from the control unit to the actuators. The ADR125 requires a small 0.1 µF capacitor at its output for stability. An additional 0.1 µF to 10 µF capacitor in parallel can improve load transient response. Input capacitors, though not required, are recommended. A 1 µF to 10 µF capacitor on the input improves transient response if there is a sudden supply voltage change. An additional 0.1 µF capacitor in parallel also helps reduce noise from the supply.

Bypass capacitors (not shown in Figure 1) are required. In this case, a 10 µF tantalum capacitor in parallel with a 0.1 µF ceramic capacitor should be placed on each power pin of each dual op amp. Details of proper decoupling techniques can be found in Tutorial MT-101.

The circuit solution outputs 0 mA to 20 mA of current. Figure 2 shows the measured output current from the circuit into the 250 Ω load resistor. Figure 3 shows the output current error plot.

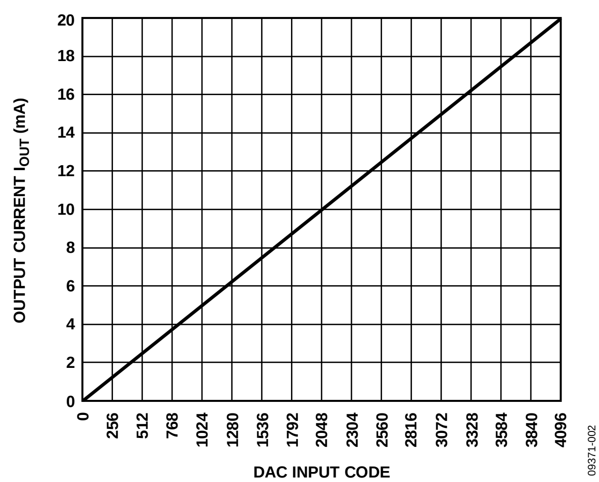

Figure 2. 0 mA to 20 mA Output Current

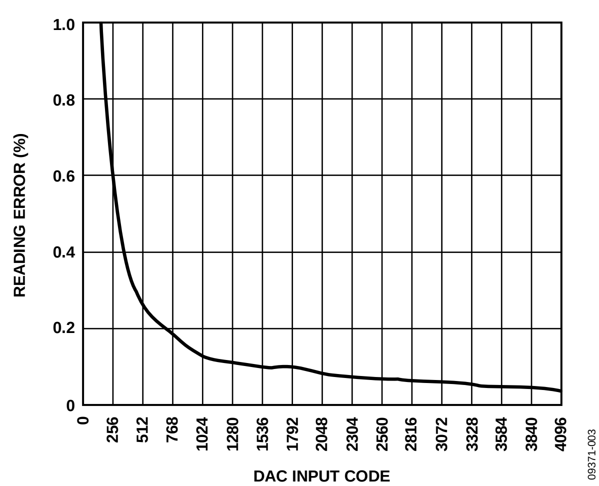

Figure 3. Output Current Error Plot

COMMON VARIATIONS

For a 14-bit or 16-bit resolution solution, consider the AD5641 or AD5662, respectively. The 16 V CMOS ADA4665-2 op amp is another option to replace the AD8657. It is more cost effective and has lower voltage noise at the expense of a higher supply current.

When selecting amplifiers for this application, always make sure that the input common-mode voltage range and the supply voltage are not exceeded.

For a higher supply voltages, consider the ADR02 voltage reference, which can operate on supply voltages of up to 36 V.

LEARN MORE

AN-202 Application Note, *An IC Amplifier User's Guide to Decoupling, Grounding, and Making Things Go Right for a Change,* Analog Devices.

AN-345 Application Note, *Grounding for Low- and High-Frequency Circuits*, Analog Devices.

AN-347 Application Note, *Shielding and Guarding: How to Exclude Interference-Type Noise,* Analog Devices.

Colm Slattery, Derrick Hartmann, and Li Ke, "PLC Evaluation Board Simplifies Design of Industrial Process Control Systems," *Analog Dialogue* (April 2009).

Jung, Walt. *Op Amp Applications*, Analog Devices. Also available as *Op Amp Applications Handbook*, Elsevier.

Kester, Walt. 2005. *The Data Conversion Handbook*. Chapters 3 and 7. Analog Devices.

MT-015 Tutorial, *Basic DAC Architectures II: Binary DACs*. Analog Devices.

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND."* Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*. Analog Devices.

Voltage Reference Wizard Design Tool.

Data Sheets

AD8657 Data Sheet

ADR125 Data Sheet

AD5621 Data Sheet

AD5641 Data Sheet

AD5662 Data Sheet

ADA4665-2 Data Sheet

ADR02 Data Sheet

REVISION HISTORY

12/10—Revision 0: Initial Version

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