Application Brief

High-Performance 16-bit PWM to 4- to 20-mA DAC for Field Transmitters

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The loop-powered, 4- to 20-mA output field-transmitter is the industry de facto standard for process automation. Pulse Width Modulation (PWM) to 4-to 20-mA conversion is used in field transmitters for different reasons including simplicity, robustness, and cost optimization. New applications demand higher resolution, lower noise, and lower power implementation of the loop transmitter which represent a challenge for the PWM approach.

This technical note shows the implementation methodology and test results of PWM to 4- to 20-mA loop circuit.

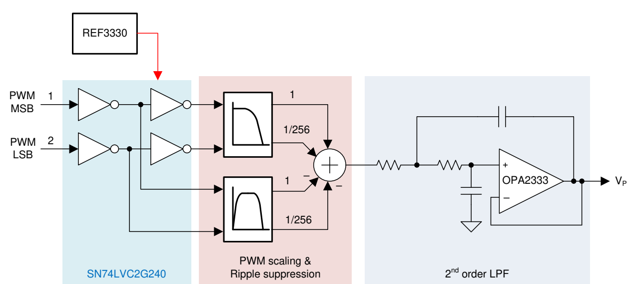

Figure 1. PWM to Voltage Converter

As Figure 1-1 shows, the input signals are two PWMs from any microcontroller like the MSP430. A ripple suppression circuit which sums positive and filtered inverted signals generated by the logic buffer SN74LVC2G240 relaxes filter requirements. Two PWM signals are used to represent MSBs (8 bits) and LSBs (8 bits) with LSB PWM scaled by $1/2^8$.

Ripple suppression with a simple low-pass filter acts as second-order low-pass filter (LPF). Another second-order active LPF based on the zero drift OPA2333 device ensures the resulting voltage signal (V_P) ripple is below noise floor. Due variation in ambient temperature of the field transmitter, power supply variation can be a big factor for output errors. Powering both inverters and op amp by a stable reference like REF3330 as power supply ensures gain errors are kept to a minimum. The REF33xx family has an output current of 5 mA which is enough for our application, where a maximum of 100 µA is required.

The generated voltage (V_P) is converted to loop current by a current transmitter (see Figure 1-2) using the other op amp in the OPA2333 dual package.

The loop circuit supports HART signal injection through capacitive coupling.

The complete circuit is powered by the loop power supply, typically at a 24-V level. The loop power is converted to a lower level by the TPS7A16-Q1 LDO with a current limiter stage in front to limit inrush current.

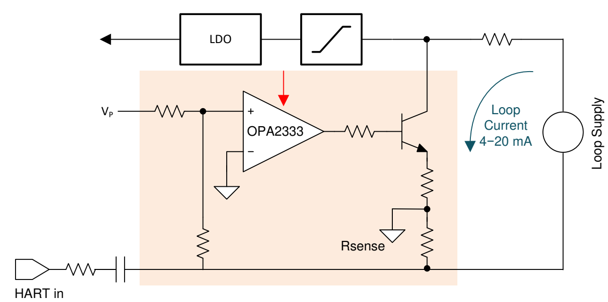

Figure 2. Voltage-to-Loop Current Converter

Test Setup

Figure 1-3 shows a board of the described circuit within its test setup.

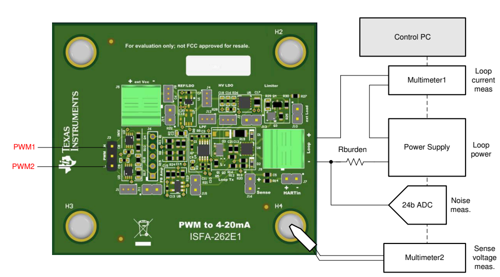

Figure 3. PWM to 4- to 20-mA Test Setup

Test Results

The design achieves both low gain error and low offset error, low current consumption, and low output current noise. Table 1 shows a summary of the test results. Offset and gain errors over temperature are shown in Figure 1-4 and Figure 1-5, respectively. Figure 1-6 shows the current consumption over temperature for different output current levels. Figure 1-7 shows the current RMS noise versus temperature for different current levels.

Table 1-1. Key Tested Specification

Parameter	Specifications and Features
Loop supply voltage	9.66-V to 32-V
Loop current range	40 µA to 24.075 mA
Resolution	16 bits
Current consumption	< 100 µA
Temperature range	–40 to 125°C
Bandwidth	600 Hz
Settling time	3 ms with 4- to 20-mA step
Offset error	–6.66 µA to 5.02 µA @ 4 mA
Offset error tempco	5.84 ppm FS/°C
Gain error	–0.18 to 0.08% FS @ 20 mA
Hart input gain	1.1 mA/V @ 1.2 kHz, 1 Vpp
	1.3 mA/V @ 2.2 kHz, 1Vpp
DNL over temperature range	–4 to 4 LSBs

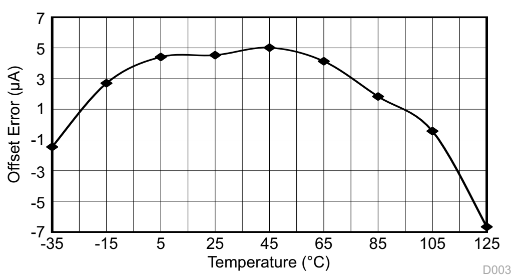

Figure 4. Offset Error Over Temperature

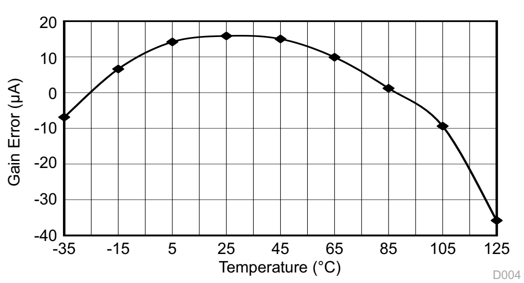

Figure 5. Gain Error Over Temperature

The temperature sweep is done from –35°C to 125°C with a 20°C step. The maximum offset error is 6.66 µA and maximum gain error is –35.8 µA at 125 °C which is below 0.18% FS.

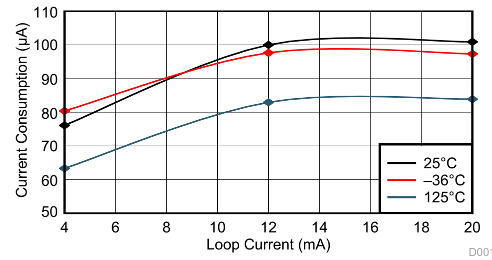

Figure 6. Current Consumption Over Temperature

The maximum current consumption is around 100 µA which allows for more current available for the transmitter circuit.

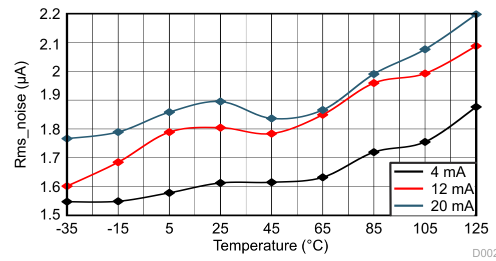

Figure 7. RMS Noise (6.5-kHz BW) Over Temperature

The noise measurement over 6.5-kHz bandwidth shows the increasing noise with the higher temperature and larger loop current with worst case of 2.2 µA at 20 mA and 125°C.

Conclusion

Using the PWM technique to generate 4- to 20-mA signals in sensor transmitters can achieve high resolution and high accuracy when adopting techniques like buffering the PWM signals with voltage reference-powered gates, using the two path technique, and using active ripple suppression. The implementation presented features fast settling time with very low power consumption.

Table 1-2. Alternative Parts

Amplifier	Offset Voltage	I_Q	Bandwidth
OPA2333	10 µV	17 µA	0.35 MHz
TLV2333	15 µV	17 µA	0.35 MHz

References

1. Texas Instruments, *Small Form Factor, 2-Wire, 4- to 20-mA Current-Loop, RTD Temperature Transmitter Reference Design*

2. Texas Instruments, *Highly Accurate, Loop-Powered, 4- to 20-mA Field Transmitter With HART Modem Reference Design*

3. Texas Instruments, *PWM DAC Using MSP430 High-Resolution Time Application Report*