Harnessing wasted energy in 4- to 20-mA current-loop systems

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A 4- to 20-mA current-loop signal is frequently used in industrial environments to transmit measurements across long distances, such as the temperature of a process or the pressure in a tank. This type of signaling is preferred because of its simplicity, noise immunity, safety, and ability to traverse great lengths without data corruption. These current loops are also low-power systems, since relatively low currents transmit the data. Previously, whatever power was not used or lost in the signal transmission was merely dissipated in the transmitter; but now, with modern integrated circuits, even this small amount of power can be harnessed to support necessary functions in these systems.

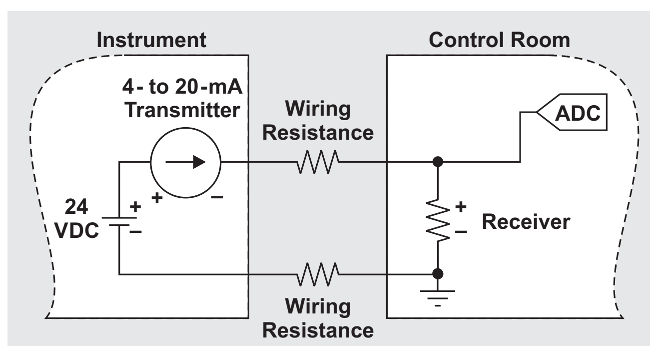
The basics of 4- to 20-mA current-loop systems

Figure 1 shows a typical 4- to 20-mA current-loop system. A semiregulated 24-VDC source provides power to the current loop and to the transmitter element. The transmitter measures the signal of interest (such as temperature, pressure, and many others) and outputs a 4- to 20-mA current that is proportional to that signal. This current passes through the wiring to a receiver system. There, the current develops a voltage across a resistor that is read by an analog-to-digital converter (ADC) and then further processed. The loop is completed with a connection back to the voltage source that powers the loop.

These current loops provide several benefits in industrial applications:

- The current loops are simple circuits requiring only a crude power supply; a transmitter to make the measurement and source the current; a wire; and a receiver circuit. The power supply needs to provide only enough voltage to overcome the various voltage drops in the system; any excess loop voltage is just dropped across the transmitter. Due to the low current, this is only a small amount of power, which creates little heat.
- The current loop contains only one loop for current flow. Therefore, from Kirchhoff's current law, the current through all the elements in the loop is equal. This provides high noise immunity, which is critical in industrial environments.
- Safety is provided since the lowest signal level is 4 mA. If something in the loop is broken or becomes disconnected, the receiver reads no current, which demonstrates a fault instead of the lowest signal level.
- As long as the power-supply voltage is high enough to overcome system voltage drops, the desired current representing the measured signal is maintained by the transmitter. Thus, smaller wire gauges with their higher voltage drops and lower cost are used for the interconnections, requiring only an increase to the supply voltage. Most importantly, the relatively large voltage drops permitted across the wiring allow a large amount of wire to be used. This allows physical separation of the instrument being measured and the control room that processes the measurement, providing safety to those in the control room.

Figure 1. Basic 4- to 20-mA current-loop system



Basic system improvement

The excess loop voltage that would otherwise be dropped across the transmitter can be harnessed and used to provide power to the receiver circuitry. Figure 2 shows a power supply inserted into the current loop. This power supply is located in the control room with the receiver circuitry it powers—efficiently converting the excess loop voltage to useful output power.

Since the receiver resistor is no longer ground-referenced, a level-shift circuit is likely necessary to interface with the data converter's input. This very simple circuit is provided by any high-side current-shunt monitor, such as the Texas Instruments (TI) INA138. These devices measure very small sense-resistor voltage drops at a common-mode voltage, thus lowering the necessary voltage drop across the receiver resistor. This allows more voltage for the power supply to harness, reducing the amount of wasted energy.

The power supply typically provides a regulated 3.3 V to power this level shifter, the data converter, and any other low-power devices in the control room. Examples of these devices are a microprocessor from TI's MSP430™ platform to review the incoming data and make decisions, and possibly a low-power RF device from TI's CC430 family to wirelessly transmit the data to other locations. A wireless transmitter is particularly useful if its cost is offset by savings from not having to buy and install the wire required for a particularly lengthy current loop. These devices must use very low power due to the limited amount of excess energy harnessed from the current loop.

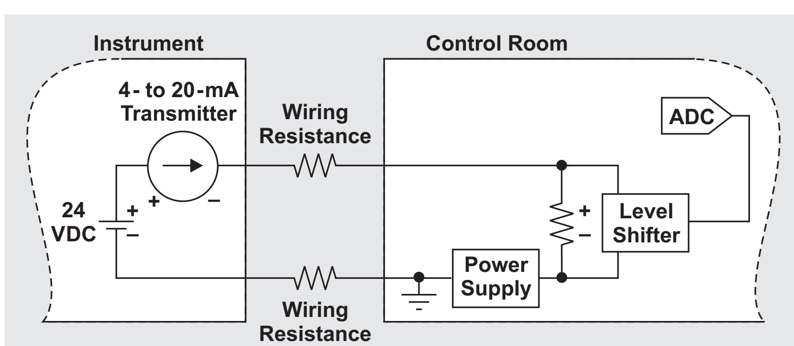
Finally, the power supply must be able to operate with such a low-power source—4 mA being the minimum current, and 20 mA being the most it ever gets. Since the voltage generated by this current is the excess voltage in the loop, the power supply must accept a wide input-voltage range and still provide a regulated output. What is more difficult for the power supply is starting up the system from such a current-limited source. Typically, a higher output power is required during start-up to charge up the output capacitors and provide the load with its start-up current. This can be much higher than what the system consumes in normal operation. If the power supply attempts to provide this higher power during start-up, its input power can exceed what the current loop provides. If this happens, the voltage into the power supply drops until the power supply turns off. Then, its input voltage rises again until it turns back on and repeats the process. Such start-up oscillations are a difficult challenge to be overcome when the power supply runs from such small amounts of input power.

Energy-harnessing solution

As just described, the energy-harnessing power supply must have a wide input-voltage range, be able to operate on a very small amount of input power, and avoid start-up oscillations when powered from current-limited sources. TI's TPS62125 is such a power supply, because it operates from a 3- to 17-V input, requires only 11 µA to operate, and has a programmable enable threshold voltage with adjustable hysteresis. The circuit recommended in the TPS62125 datasheet is used with three small modifications:

1. A 15-V Zener diode is added on the input to the device to protect it in cases where the excess loop voltage applied to it exceeds its 17-V rating. If a lower-voltage current-loop system is used, this diode may not be necessary. A Zener diode that clamps at a maximum of 15.6 V gives good results.
2. Bulk capacitance is added on the input to the device to store enough energy for start-up and load changes. Depending on the load's power demands during start-up, this capacitor may not be needed at all. A total of about 200 µF provides a smooth start-up for the example load, which draws 50 mA at 3.3 V for 30 ms at start-up, and 10 mA once started. The bulk capacitance also provides stored energy for periodic higher power demands that might occur, such as for measuring a temperature, taking a reading with the data converter, or transmitting the data via an antenna.

Figure 2. Harnessing excess loop voltage in 4- to 20-mA current loops



3. The device's enable threshold voltage is adjusted such that the device turns on when its voltage reaches 12 V. The device is programmed to turn off if its input drops down to 4 V. Once enabled, the device efficiently converts the harnessed energy to its 3.3-V output.

For an example power-supply solution, 4 V was chosen as the turn-off voltage in order to provide the required headroom of input voltage to output voltage, allowing the device to keep the 3.3-V output regulated. A turn-on voltage of 12 V was chosen for system considerations. It was assumed that the 24-V source varied between 18 and 30 V and that the voltage dropped in the current-loop sum to a maximum of 6 V, leaving a minimum of 12 V applied to the device under worst-case conditions. Thus, 12 V was chosen as the point at which to start the power supply, since it is the minimum voltage that would ever be applied to the device. Also, 12 V achieved sufficient separation between the turn-on and turn-off voltages such that the power supply started into its higher-powered load without start-up oscillations.

The described power-supply solution starts up from and runs off of TI's XTR111, a 4- to 20-mA current-loop transmitter delivering less than 4 mA at all times. Figure 3 shows this solution's start-up. Once the transmitter is enabled, it begins sourcing current, which raises the input voltage to the 12-V turn-on point of the power supply. The power supply's output voltage ramps up into regulation and immediately supplies the load's start-up current of 50 mA. This slightly reduces the input voltage of the power supply, but the supply keeps regulating the output voltage because of its wide voltage range and bulk input capacitor. After the 30-ms duration of the load's start-up power draw, the load current reduces to a steady-state, 10-mA level. The input voltage rises further and is clamped by the Zener diode at a safe 15-V level. As already noted, the current provided by the current loop remains below 4 mA at all times.

Figure 4 shows a close-up version of Figure 3. The power supply draws stored energy from the bulk capacitor to supply the start-up load current's demands, while the current loop provides less than 4 mA at all times. Drawing this energy reduces the input voltage by about 2 V, which is acceptable for this power supply.

Figure 3. Start-up of energy-harnessing power supply

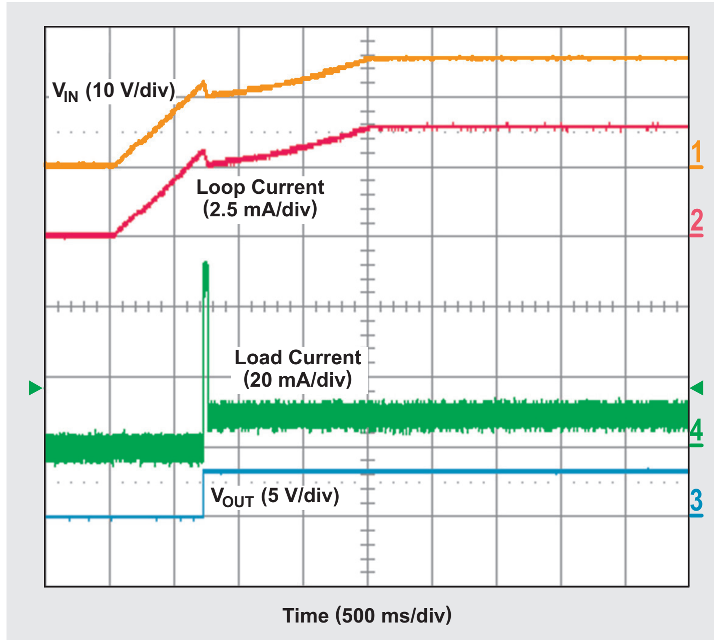
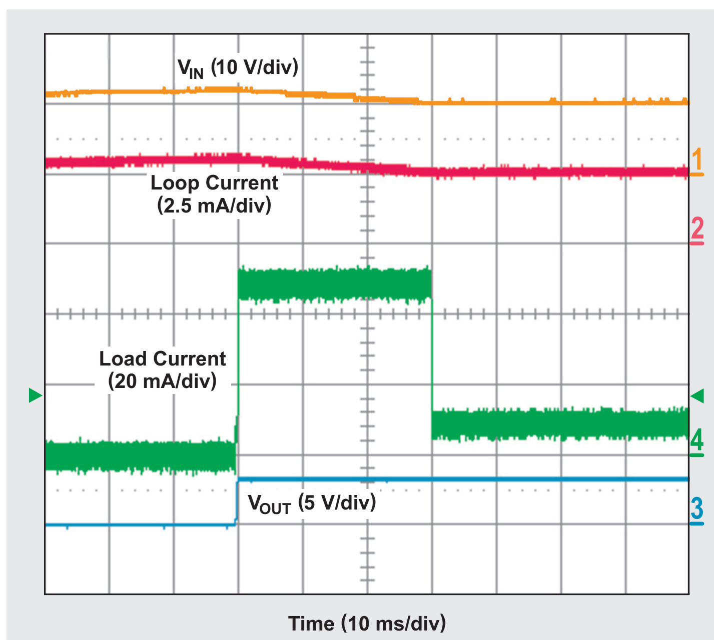


Figure 4. Energy-harnessing power supply providing load's start-up current



Finally, the energy-harnessing power supply stores enough energy in the bulk capacitor and operates over a wide enough input-voltage range to supply continuous pulses of power to the load. Figure 5 shows the supply providing 20 mA to the load for a duration of 100 ms every second, with the supply's output voltage remaining regulated.

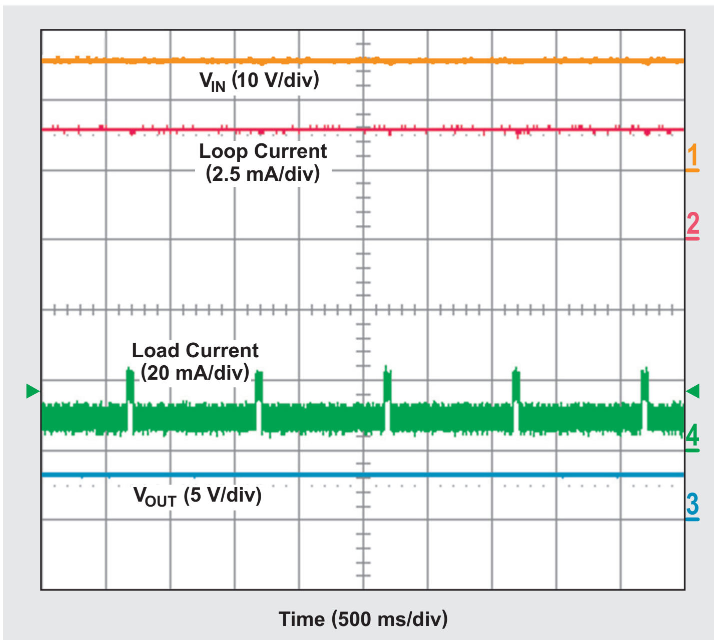
Conclusion

In 4- to 20-mA current-loop systems, energy that otherwise would be wasted can be harnessed for useful purposes. This energy powers data converters and microprocessors that the control room needs to process the incoming data from the current loop, but it can also power low-power RF transmitters that extend the application possibilities of 4- to 20-mA current loops, as well as potentially save costs in such systems by reducing the amount of wire required. A power supply that has a wide input-voltage range, operates on very small amounts of power, and starts from current-limited sources without oscillations enables the energy to be harnessed and the continued usefulness of these systems.

Related Web sites

power.ti.com
www.ti.com/cc430
www.ti.com/msp430
www.ti.com/product/*partnumber*
Replace *partnumber* with INA138, TPS62125, or XTR111

Figure 5. Energy-harnessing power supply providing power pulses to the load



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