Low-I_Q synchronous buck converter enables intelligent field-sensor applications

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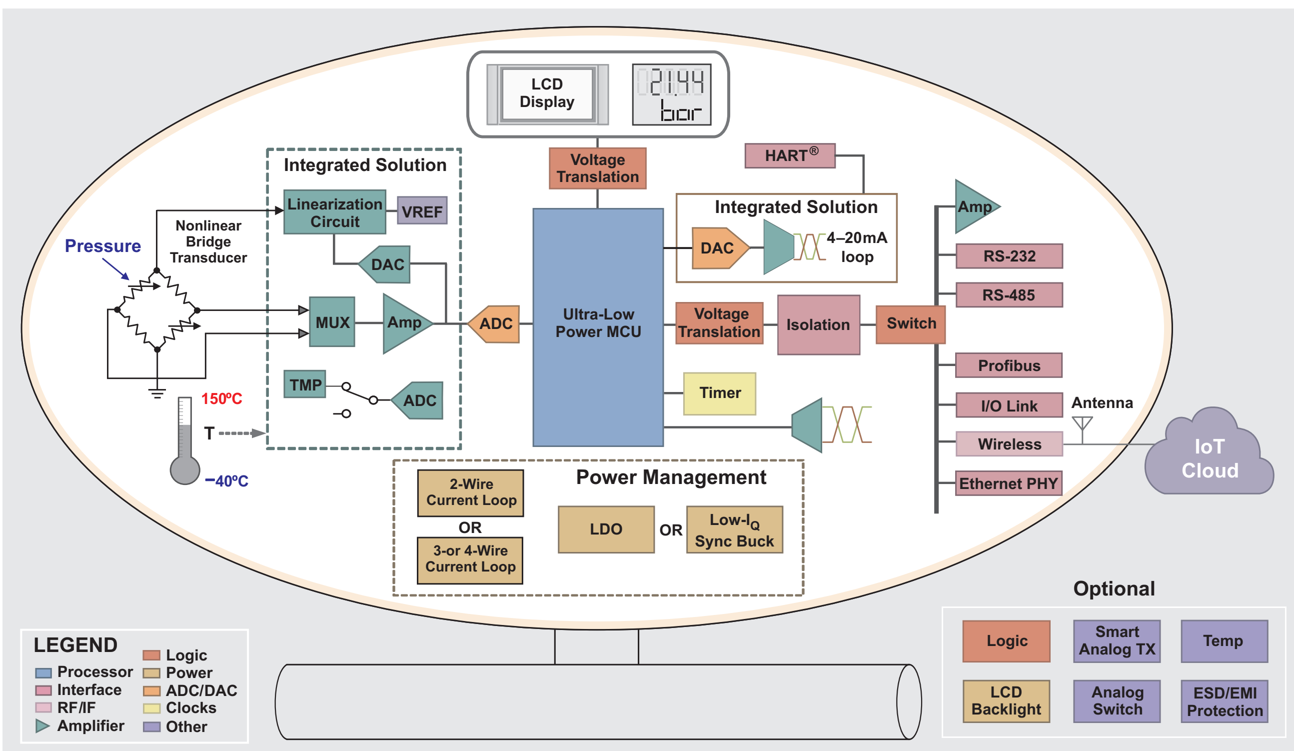
Introduction

There are several dimensions to the functionality of field-sensor transmitters used in industrial automation and control equipment to measure temperature, pressure, flow, level, and many other process variables. To provide some perspective, Figure 1 is a block diagram of a pressure-sensor transmitter. Included are a quarter-bridge strain-gauge transducer, microcontroller (MCU), data converters, input amplifiers, output drivers, isolators, display unit, connectivity options and power management. The primary challenge of sensing in industrial environments is the ability to condition low-amplitude signal levels from sensors in the presence of high noise and large surge voltages.[1]

The input signal from the pressure-sensor transducer needs to be converted to a precise electrical representation and transmitted from the field via a robust interface to a central control unit. An example of such an interface is the traditional two-wire, 4–20-mA current loop that remains a popular choice for long-distance communication in noisy industrial environments. The analog loop communicates the sensed primary variable (PV) in addition to supplying power to the transmitter circuit, as long as a minimum loop-current threshold is not exceeded.[2]

Figure 1. Strain-gauge pressure transmitter in a factory monitoring application



Intelligent sensor systems with high current demand

While the MCU and data converters of a fundamental sensor-transmitter circuit are typically optimized for low operating current as shown in Figure 2, the feature set and increased functionality of high-performance sensor applications lead to increased current demand. Such intelligent sensor systems may not be able to meet typical under-scale current thresholds or zero-scale level of 4 mA as required by the 4–20-mA current loop. For example, a programmable digital-to-analog converter (DAC) and loop driver, such as the DAC161S997, has a default ERROR_LOW current threshold of 3.375 mA. Currents below this level are used as a diagnostic failure information range.[3]

To increase the available power for a loop-powered sensor transmitter, a high-voltage switching DC/DC converter with high efficiency provides an inherent current-multiplication feature not possible with a classic low-dropout (LDO) linear regulator.

An increased current budget, in excess of a 3.375-mA low-alarm setting, offers developers of intelligent sensing applications the agility to deploy new capabilities. Following are several examples.

1. Input-isolated transmitters

Input-isolated sensor transmitters require a galvanically-isolated power rail from the loop supply to power the sensor. The sensor typically communicates across the isolation barrier via serial peripheral interface (SPI) through a digital isolator. Both the digital isolator and the isolated power stage need relatively high current and the system still requires an analog-to-digital converter (ADC), MCU and a DAC, all within the sub-4-mA current budget. An increased current resource from a supply also lets multichannel digital isolators operate with higher-speed digital signals.

2. High-performance MCUs

Sensor output linearization is an essential task to meet accuracy specifications. In general, high-performance MCUs are required to perform complex calculations and deliver different levels of computational capabilities. This opens up a range of MCU options that involve processor speed, memory, connectivity, peripherals, and power optimization.

3. Calibration and advanced diagnostics

Device status information, calibration and diagnostic coverage also increases current demand. For instance, the HART® protocol operates by superimposing a 1-mA peak-to-peak signal on top of the DC current level of the 4–20-mA loop.[4] Also, WirelessHART® adapters access and wirelessly communicate diagnostic information. These adapters also use power drawn from the wired-transmitter current loop.[5]

4. Multivariable sensing

Many applications sense two or more (primary and non-primary) process variables.[6] Often, the primary variable is dependent on one or more secondary variables. For example, mass flow transmitters for natural gas and steam applications sense differential pressure (raw flow) combined with process static pressure and temperature measurements for compensated mass flow readings. Monitoring non-primary variables may be advantageous if one or more of the variables is especially important to the safety or quality of the process.

Figure 2. Top-level hardware architecture of loop-powered temperature transmitter

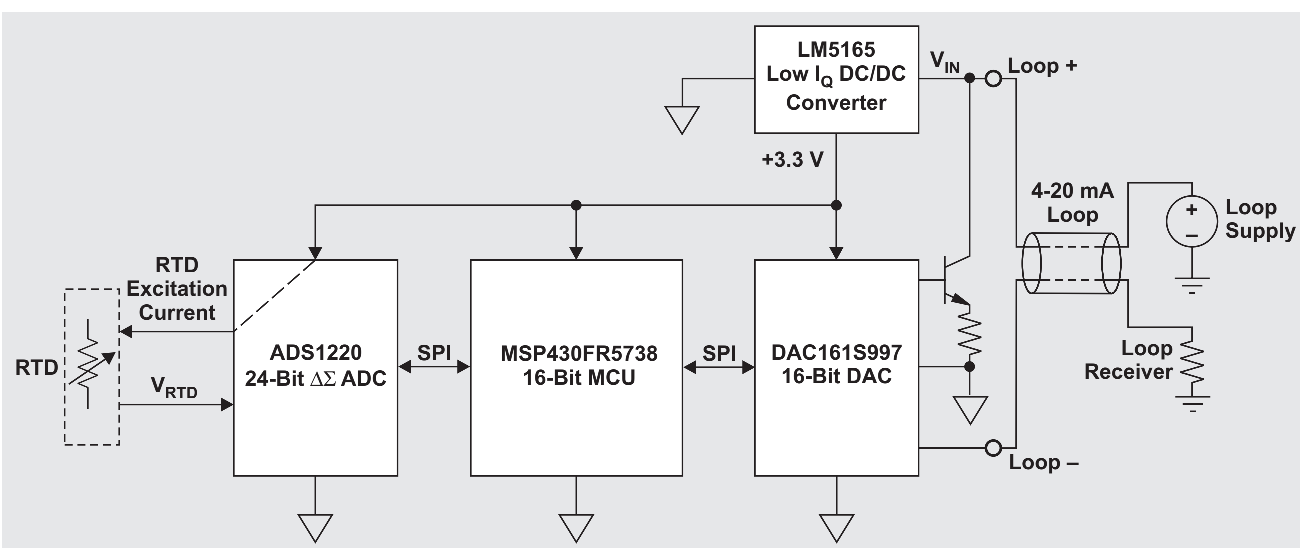
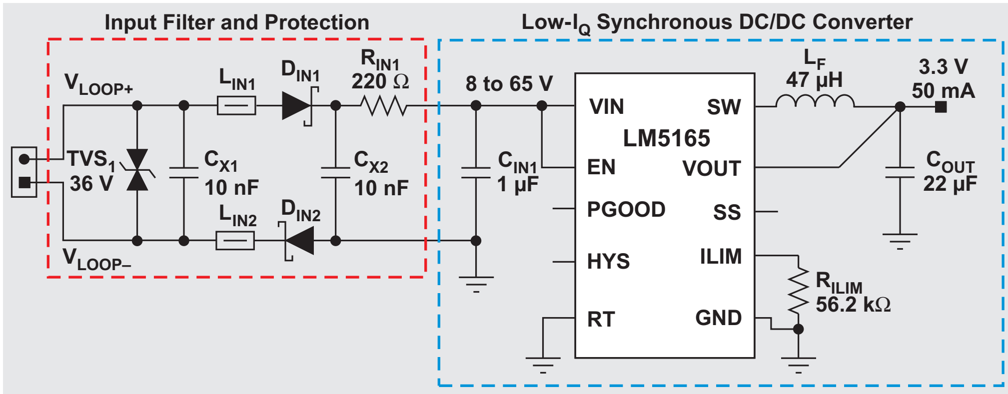


Figure 3. Low-I_Q synchronous buck converter includes input filter and protection circuit



5. Remote display and interface

Some two-wire transmitters have the ability to display information or take user input from an operator interface panel. The remote display unit and sensor transmitter may consume greater than 4 mA, depending on the complexity of the display.

6. Low-impedance bridges with high excitation currents

Common bridge impedances for strain and pressure sensors range from 120 Ω to 10 kΩ. The 120-Ω bridge consumes 40 mA of current with a 5-V supply. Some solutions use resistors in series with the bridge to increase bridge impedance and reduce current consumption at the expense of sensor output sensitivity. Having a larger current budget facilitates a higher sensor output that reduces the gain requirement of the analog front end (AFE).

Powering sensors with a high-efficiency buck converter

A synchronous buck converter must reliably power the sensor circuit, even during minimum input-power conditions when the transmitter is operating at its compliance voltage, typically 10 V or lower. This corresponds to the voltage between the Loop+ and Loop– terminals (Figure 2). Ultra-high efficiency within a 1- to 20-mA range of output current is thus imperative. Additionally, to deal with supply transient voltages such as those described in the IEC 61000-4 suite of tests, a DC/DC solution with a wide range for the input voltage (wide V_{IN}) offers an outsized voltage rating and operating margin.[7, 8]

The LM5165 is an example of a synchronous buck converter that produces a tightly-regulated output, even in volatile voltage environments. This 150-mA monolithic step-down solution has high efficiency and ultra-low quiescent current, I_Q. Operating from a 20:1 wide-V_{IN} range and capable of sustaining repetitive 65-V surges, this buck converter's output voltage is immune to large and noisy voltage swings at the input. Such transient immunity is critical in sensor applications where high reliability and extended product life cycles are compulsory.

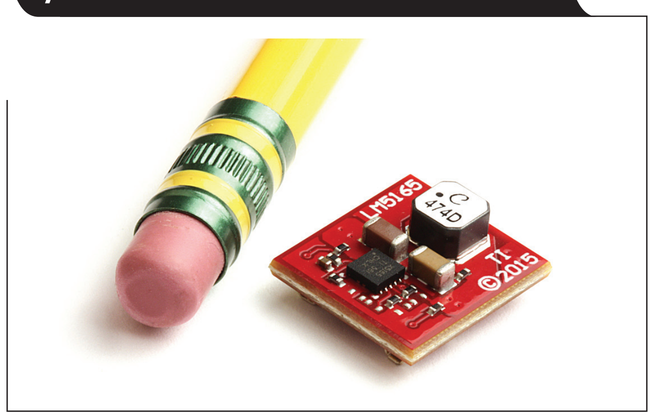
Figure 3 shows a converter schematic when configured with minimum component count. An input filter that includes reverse polarity and surge protection was added to achieve IEC 61000-4 compliance.

Provided in a compact 3- × 3-mm, WSON-10 package with integrated power MOSFETs, the LM5165 is extremely easy to use and it requires no components for loop compensation. The 3.3-V and 5-V fixed-output versions need only a filter inductor and two capacitors for operation and an adjustable set point is configured with just two 0402 feedback resistors.

Robust, reliable buck-converter implementation

Figure 4 shows a high-density converter implementation. Integrating the feedback resistors for the fixed-output versions allows the use of high values of resistance. This integration achieves a lower no-load supply current without compromising noise performance. The design minimizes system-generated noise because the high-impedance divider is integrated and proper layout practices were used to shield the sensitive nets from any system- or converter-level noise sources.[9]

Figure 4. Implementation of a high-density synchronous buck converter



Various features incorporated for enhanced reliability and safety include an internally-fixed or externally-adjustable output soft-start (SS), and precision enable with customizable hysteresis for programmable line under-voltage lockout (UVLO). Other features included are thermal shutdown with automatic recovery and an open-drain PGOOD indicator for sequencing and fault reporting. The device's cycle-by-cycle, peak-current-limit threshold provides inherent fault protection from output overload and short circuits. Moreover, the device is easily configured to reduce its peak current limit such that smaller inductors and capacitors are viable for high-density, lower-current applications.

Input UVLO configuration

The precision enable input supports adjustable input UVLO with hysteresis, which can be programmed independently via the HYS pin for application-specific power-up and power-down requirements. An external logic signal can be used to drive the EN input to toggle the output on and off and for system sequencing or protection. Sensor applications in particular can benefit from using a resistor divider from V_{IN} to EN to establish precision input-voltage turn-on and turn-off levels. The HYS pin in tandem with the EN setting is used to increase the UVLO voltage hysteresis as needed to prevent unwanted UVLO triggering due to noisy loop voltage, high source impedance due to long loop wiring, or high-voltage coupling in harsh operating environments.

Achieving high efficiency with large step-down ratios

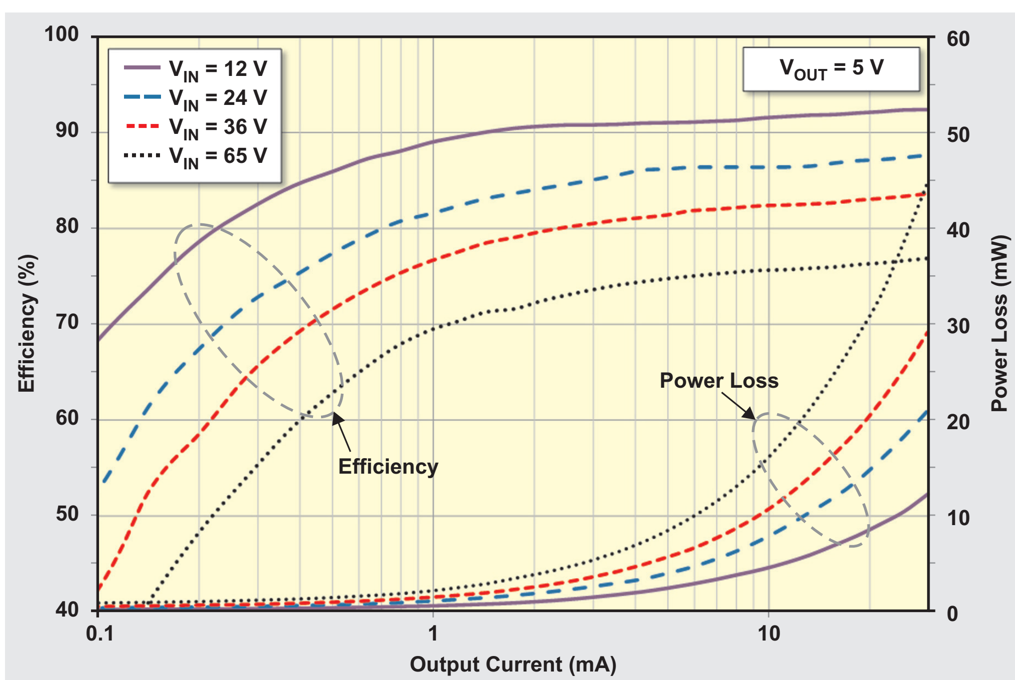
Unlike a high-voltage LDO, a synchronous buck converter does not incur a large power loss or increase in junction temperature as a result of the voltage difference between V_{IN} and V_{OUT}. Maintaining a low increase in junction temperature above ambient is paramount for reliable power solutions.

High efficiency is achieved at light loads by virtue of low I_Q in both sleep and active operating modes, in addition to the diode emulation and pulse-skipping to reduce switching activity and minimize switching power losses. High efficiency also continues at heavier loads through optimized switching of the integrated power MOSFETs. Figure 5 shows a relatively constant efficiency profile over the critical operating region when the load current is between 1 mA and 30 mA.

Conclusion

With the increasing demand for intelligently-connected sensing in applications such as industrial process control and analytics, home/building automation, healthcare/medical, smart metering and many others, wired and wireless connectivity enable a new level of scalability. Reliable buck converters with wide V_{IN} capability, high efficiency, small form factor and high immunity to line transients are finding increasing relevance to power these applications. Within the context of high density 4–20-mA loop-powered sensor nodes, the total bias current is limited to 3.6 mA or lower.

Figure 5. Typical efficiency performance of a buck converter



The total current budget must be sufficient to power all functional blocks of the transmitter: sensor interface and excitation, linearization method (MCU), galvanic barrier jump (if needed), 4–20-mA loop driver, and so forth. The solution presented was an integrated and robust DC/DC buck converter that has ultra-high efficiency across wide supply-voltage and load-current ranges. The resulting compact solution was achieved with minimal design effort.

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Related Web sites

Product information:
LM5165
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