Low-EMI buck converter powers a multivariable sensor transmitter with BLE connectivity

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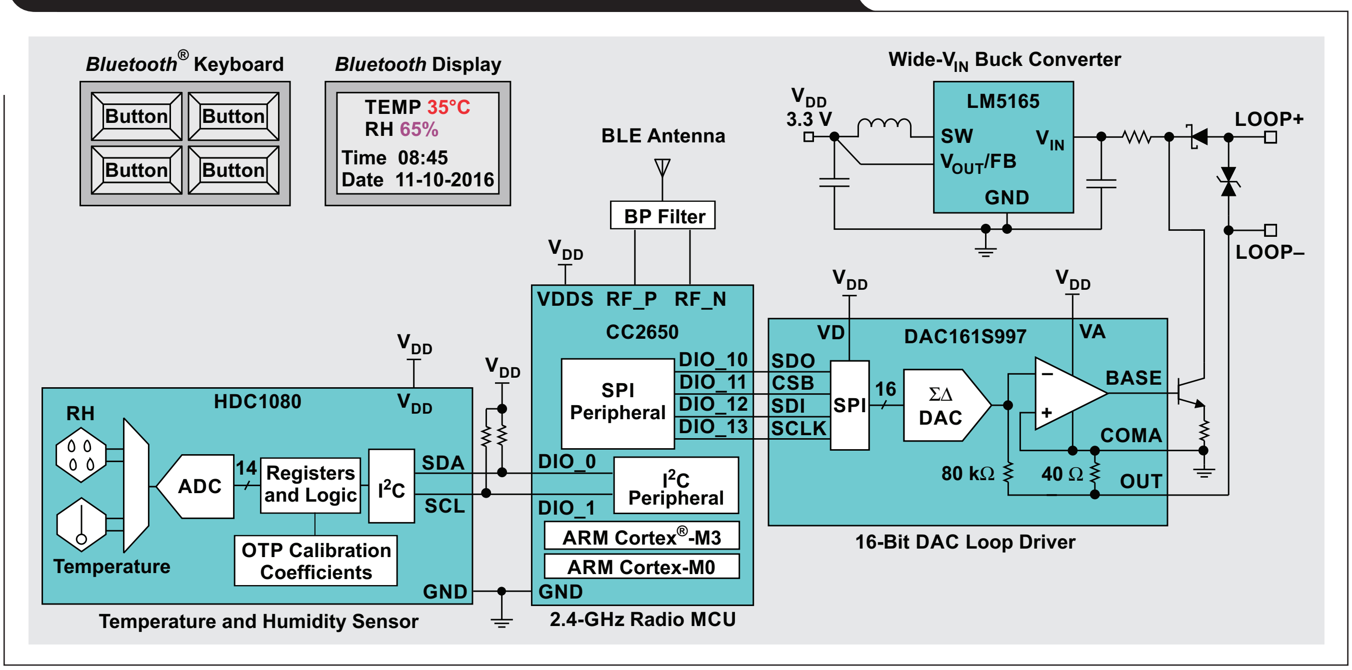
Introduction

Field-sensor transmitters used in applications for industrial automation, process control, actuator control, and home/building automation are used to measure temperature, pressure, displacement, proximity, and many other variables. The sensor electronics includes the sensor analog front end (AFE), a low-power microcontroller (MCU), high-precision data converters [both analog-to-digital converters (ADCs) and digital-to-analog converters (DACs)], input amplifiers, output drivers, and perhaps isolation. The sensor transmitter must communicate the sensed parameter data efficiently and reliably to a data aggregation point—for example, a host programmable logic controller (PLC) within a factory-automation environment.

There are several options available for both wired and wireless connectivity that have enabled developers of intelligent-sensor designs to deploy advanced functionality and features such as multivariable sensing,[1-3] remote calibration, and advanced system-level diagnostic capabilities. Illustrated in Figure 1 is a block diagram of a multivariable sensor transmitter that measures relative humidity (RH) and temperature.[1] Specific applications include demand-controlled ventilation (DCV) systems, smart thermostats and room monitors, fire-safety systems, refrigerators, printers, white goods, and medical devices. The system uses *Bluetooth*® Low Energy (BLE) to broadcast to nearby *Bluetooth*-enabled peripherals. Optimized for low electromagnetic interference (EMI), a synchronous buck converter with wide input-voltage range (wide V_{IN}) provides a low-noise 3.3-V supply rail for the sensor, MCU and DAC loop driver.[4]

Figure 1. Transmitter system for temperature and humidity sensor



Wired sensor interfaces

An example of a commonly-used interface with wired communication is the traditional 4- to 20-mA analog current loop that remains a very popular solution for long-distance, one-way communication in noisy industrial environments. Illustrated in Figure 2 is the basic current-loop architecture, the convenience being that power is also derived from this two-wire connection as long as a minimum loop-current threshold is not exceeded.[4]

Important considerations are involved to program and have bidirectional communication with remote sensor nodes, and have them operate reliably for long periods of time on low power. To exploit the full potential of digital field devices while retaining the traditional 4- to 20-mA loop circuit, the HART® protocol offers a complementary mode of communication.[2] It not only delivers additional sensor data but also supplementary information in the form of remote diagnostics, system troubleshooting, or preemptive maintenance where it can be used to enhance the safety integrity level (SIL) rating of a system.

Aside from the 4- to 20-mA analog loop and other wired industrial protocols such as RS-232 and RS-485, IO-Link (standardized as IEC 61131-9) is an increasingly popular and cost-effective digital interface that uses a three-wire connection for linking sensors and actuators in industrial automation and control environments.[3] IO-Link lines, L+ and L–, designate the 24-V supply and GND lines, respectively, and C/Q is a bidirectional-data signal line. However, IO-Link's point-to-point communication is limited to a maximum distance of 20 meters.

Wireless sensor interfaces

Wireless-connectivity options can be demarcated by frequency band into sub-1 GHz for long-range and 2.4 GHz for short-range communications. For example, the utility-grid developers of a smart-metering system might decide that the longer signaling range of a sub-1-GHz wireless protocol is best suited to their application. Meanwhile, intelligent-sensor applications with low-power and shorter-range requirements may expand functionality with BLE or ZigBee® implementations to provide features such as beaconing, over-the-air updates, smart commissioning, remote displays, and more.

Figure 2. Sensor transmitter with two-wire, 4- to 20-mA loop for signal transfer back to a PLC host

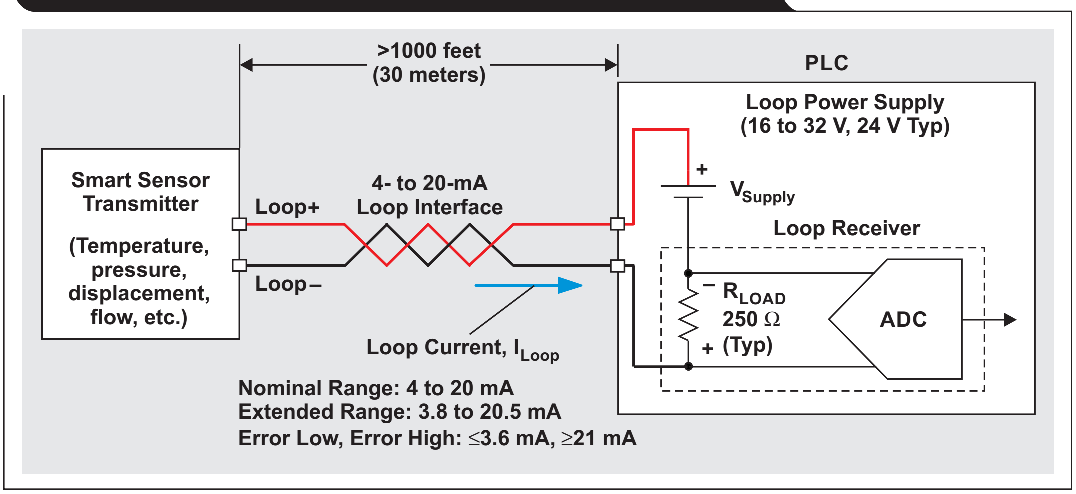
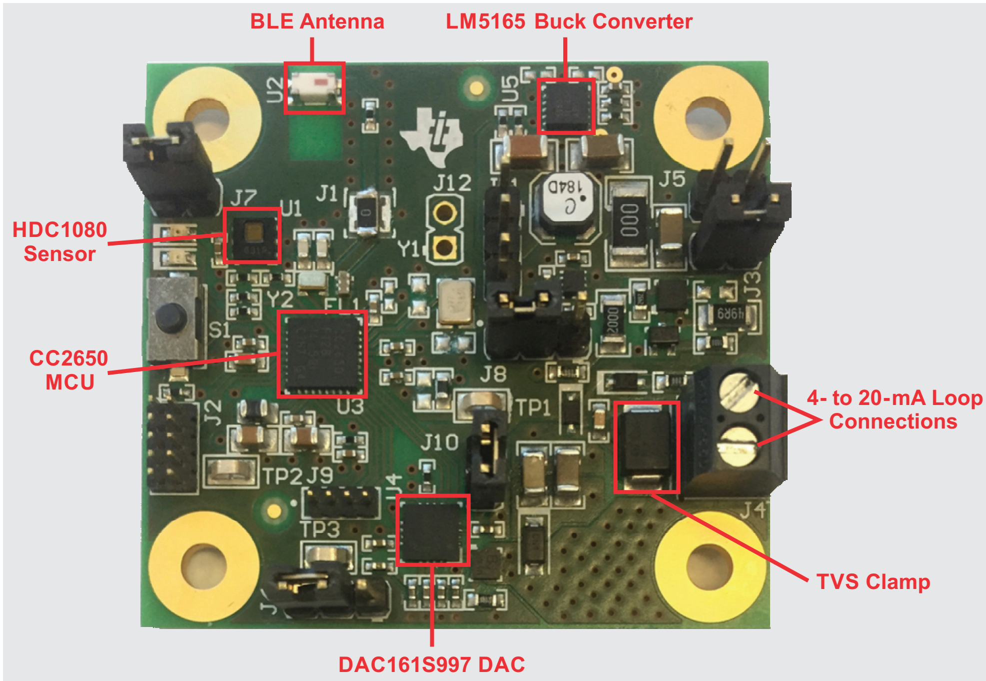


Figure 3. Practical implementation of a two-variable sensor transmitter with BLE connectivity



Loop-powered sensor transmitter with BLE connectivity

Based on the system shown in Figure 1, Figure 3 shows a practical implementation of a temperature and relative-humidity sensing, sensor transmitter with 4- to 20-mA wired and BLE wireless connectivity.[1] The solution size is 45 mm by 45 mm on a single-sided, 4-layer FR4 PCB. The essential circuit components are detailed in Table 1.

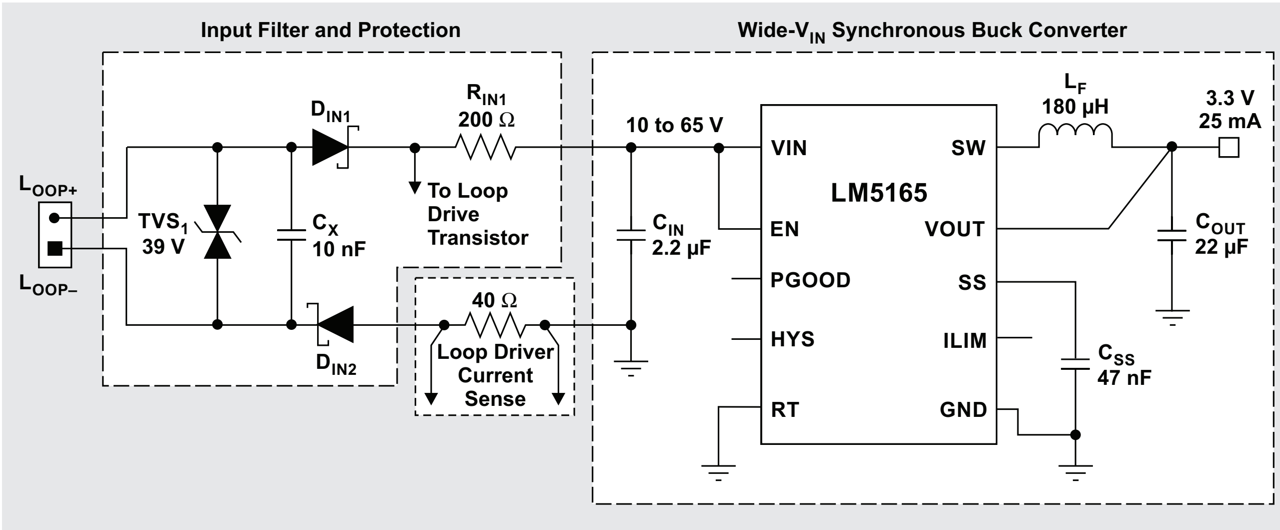
Optimized for micropower applications, the CC2650 MCU is uniquely flexible as it can be dynamically configured in both hardware and software to support one of several different 2.4-GHz radio standards, allowing communication with both ZigBee- and *Bluetooth*-based devices. BLE is the protocol of choice in this implementation, given its low power consumption, the availability of a full-featured *Bluetooth*-4.2-certified software stack,[5] and a wide ecosystem of devices.

Meanwhile, the HDC1080 humidity and temperature sensor uses an I^2C interface to the MCU and is factory calibrated to provide measurement accuracies of ±2% and ±0.2°C for RH and temperature, respectively. The MCU in turn communicates over a SPI interface with a DAC161S997 loop driver to send humidity data with 16-bit resolution over a 4- to 20-mA loop. 0% and 100% RH correspond to loop currents of 4 mA and 20 mA, respectively.

Table 1. Essential components of the loop-powered sensor transmitter with BLE

Component	Part Number	Package, Size (mm)
Wide-V_{IN}, low-I_Q synchronous buck converter	LM5165	VSON-10, 3.0 × 3.0 × 0.9
Digital humidity and temperature sensor	HDC1080	PWSON-6, 3.0 × 3.0 × 0.8
Multi-standard, 2.4-GHz, ultra-low-power wireless MCU	CC2650	VQFN-32, 4.0 × 4.0 × 0.9
16-bit, SPI-programmable DAC for 4- to 20-mA loops	DAC161S997	WQFN-16, 4.0 × 4.0 × 0.8
SMD antenna, 2.45 GHz	2450AT18D0100	1206, 3.2 × 1.6 × 1.2
39-V bidirectional TVS diode	SM6T39CA	SMB, 5.6 × 3.95 × 2.45

Figure 4. Wide-V_{IN} synchronous buck converter that includes components for EMC



Loop-powered buck converter

To increase the available supply current for an advanced, loop-powered sensor transmitter in excess of the 3.6 mA maximally available from the 4- to 20-mA loop, a DC/DC converter with high efficiency provides an inherent current-multiplication feature not possible with a traditional LDO regulator. A high-efficiency synchronous buck converter, such as the LM5165 from TI, optimized for a load-current range of 1 mA to 25 mA is a good choice.[4] Figure 4 shows the converter schematic with a switching frequency of approximately 220 kHz at nominal 24-VDC input. The power solution is easy to use, requiring no loop compensation components, and the 3.3-V fixed-output version requires only an inductor and two capacitors for operation.

Various features integrated for reduced size and enhanced reliability include a cycle-by-cycle current limit, an internally-fixed or externally-adjustable output soft-start (SS), precision enable with customizable hysteresis for programmable line undervoltage lockout (UVLO), and an open-drain PGOOD indicator for sequencing and fault reporting.

EMC performance

Electromagnetic compatibility (EMC) is a key consideration in any electronics product development and critical for systems integration. Table 2 lists several important EMC standards and suggested test levels for sensor applications.

Table 2. EMI/EMC standards and test levels typically required for sensor applications

Standard	Description	Test Level
IEC 55022/CISPR 22	Conducted emissions (CE)	Class B
IEC 61000-4-2	Electrostatic discharge (ESD)	8 kV contact, 15 kV air
IEC 61000-4-3	Electromagnetic (EM) fields	30 V/m, 80 MHz to 1 GHz
IEC 61000-4-4	Electrical fast transient (EFT) / Burst	1 kV
IEC 61000-4-5	Surge	±1 kV/42 Ω/24 A
IEC 61000-4-6	Conducted disturbance induced by RF fields	10 V/m, 150 kHz to 80 MHz
IEC 61000-4-9	Pulsed magnetic fields	100 A/m peak

The input filter in Figure 4 includes Schottky diodes for input reverse-polarity protection and a transient-voltage suppressor (TVS) diode for surge protection. A resistor in series with the converter input, designated R_{IN}, is typical for circuits with a 4- to 20-mA current loop. It not only provides damped EMI filtering, input-ripple attenuation and inrush protection, but also contributes to small-signal stability of the current loop. A loop current-sense resistor of 40 Ω is shown explicitly in the schematic even though it is typically integrated into the loop driver (Figure 1).

Low noise and EMI

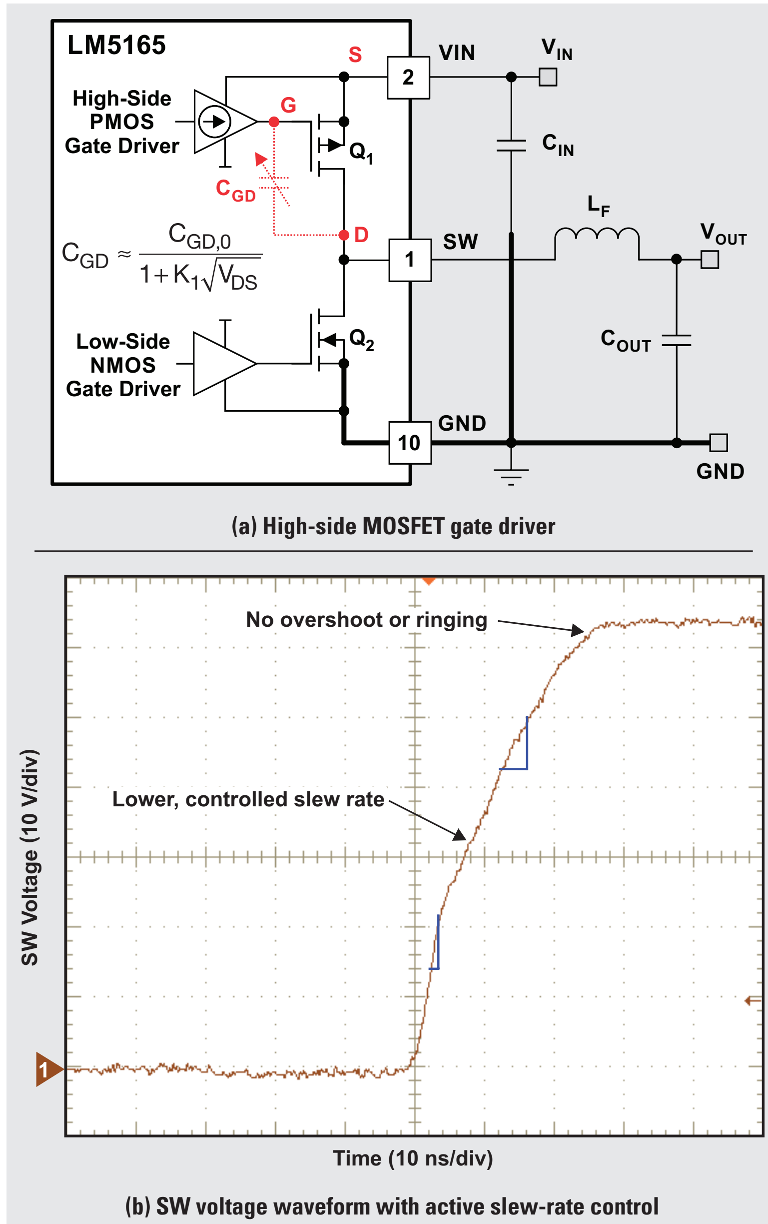
System-level conformance to EMI regulatory specifications is an increasingly-important power-solution benchmark and a crucial milestone in a product's design cycle. For high-density sensor designs in particular, there is little space available for EMI filtering. Moreover, the imperative is that the switching power converter should not affect the sensor's functionality.

The LM5165 buck converter incorporates two features to minimize its EMI signature. First, an integrated active-slew-rate control of the switch-node (SW) voltage transition lowers both conducted and radiated EMI. As shown in Figure 5, the current-source gate driver discharges the high-side MOSFET's non-linear gate-drain capacitance, C_{GD}, so that the SW-voltage overshoot and ringing are eliminated. The capacitance of C_{GD} increases as the V_{DS} voltage decreases, corresponding to the increases in SW voltage. Also, the current-source gate driver tunes the slew-rate profile of the SW voltage as it swings from GND to V_{IN} during the turn-on transition of Q_1. The result is a low-noise turn-on transition for Q_1, eliminating SW-voltage overshoot and ringing.

Second, the LM5165's PFM control mode uses a boundary conduction mode of switching to allow a lossless and soft turn-on transition for the high-side MOSFET. The turn-on of the high-side MOSFET occurs at zero inductor current, thus eliminating reverse recovery losses related to conduction of the low-side MOSFET's body diode.

The cumulative benefits of these switching techniques are increased reliability and robustness owing to lower voltage and current stress, and increased margin for input-voltage transients. There is also more tolerance to non-optimized board layouts, and easier EMI filtering, particularly in the more challenging high-frequency band above 30 MHz.[7] Based on the CISPR-25 class-5 EMI test setup and limits, Figure 6 on the following page shows the conducted emissions plot from 30 MHz to 108 MHz for the converter shown in Figure 4.

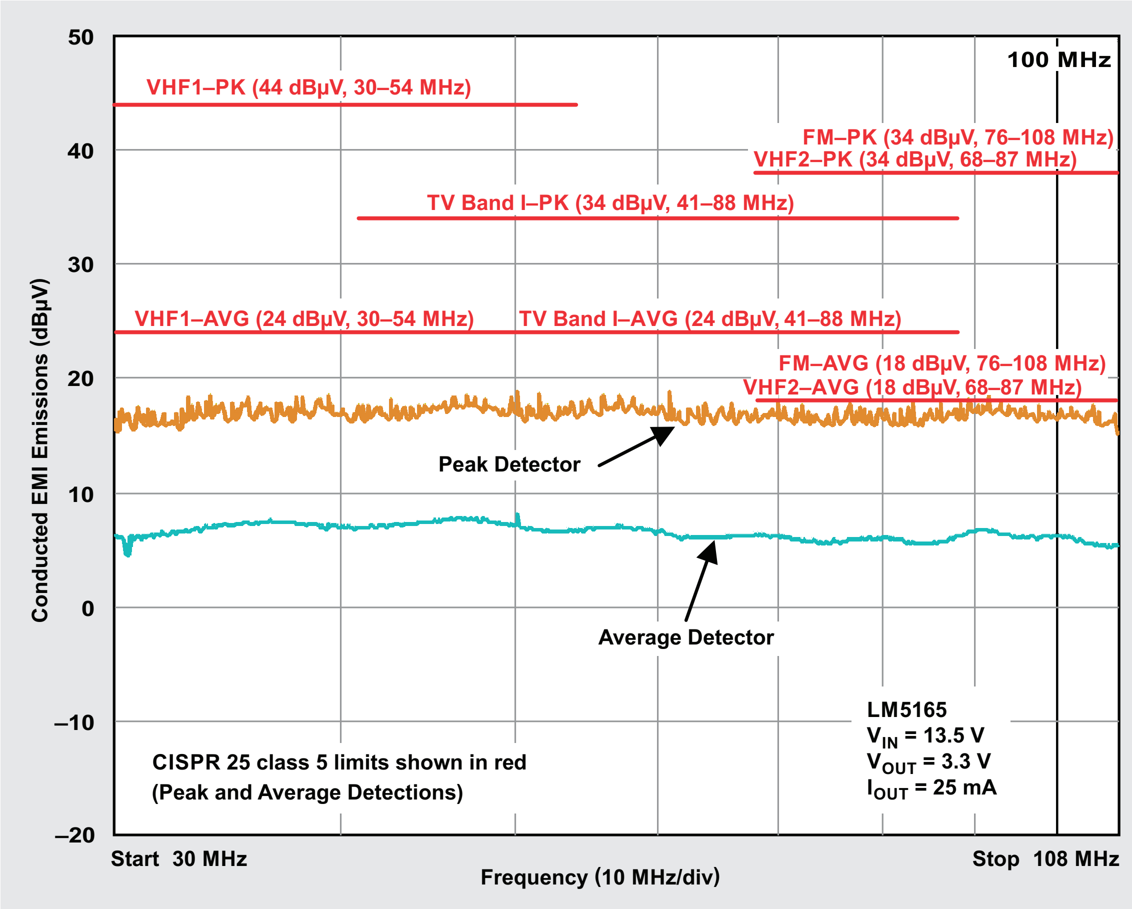
Figure 5. Solution to minimize EMI signature



(a) High-side MOSFET gate driver

(b) SW voltage waveform with active slew-rate control

Figure 6. Conducted EMI performance from 30 to 108 MHz (no external filter)



Conclusion

DC/DC converters for powering smart sensor-transmitter nodes in noisy industrial environments have distinctive requirements such as high efficiency, wide V_{IN}, low I_Q, small form factor, robust EMC performance, and low noise. This article presented a transmitter design with BLE connectivity for a multivariable sensor. The LM5165 wide-V_{IN} synchronous buck converter offers a compact power solution with low EMI that can reduce time-to-market and total solution cost.

References

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Related Web sites

Product information:
LM5165, HDC1080, CC2650, DAC161S997

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