

How to Optimize Building and Home Automation Designs for Energy Efficiency



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Introduction

One of the most important design considerations when developing any building automation product is energy efficiency. Some new wireless smart sensors have the capability of operating for more than five years on a single coin-cell battery; others can last as long as 10 years or more. In this white paper, I'll discuss various advances with respect to energy efficiency in building automation.

Let's begin by looking at how nanopowered integrated circuits (ICs) are helping increase functionality and decrease power consumption; recent advances have made low-power, long-life operation a reality. The average current draw of a nanopower device is measurable in nanoamperes (nA), or one-billionth of an amp. A standard CR2032 coin-cell battery used in a remote wireless smart building sensor can provide about 2,100 nA in a 10-year period.

Nanopower components introduced to the mass market over the past two years require less than half the current of their immediate predecessors. Because designers need to reserve less design space for batteries and power supplies, they can build much smaller products. These advances also make it easier and safer to retrofit existing residential, commercial and industrial spaces with sensors and smart devices. Because these devices can run for several years on a commodity-grade battery, electrical wiring is not necessary, and there is no need to budget routine maintenance for battery replacement.

The rapid growth of Internet of Things-related applications within building automation puts a spotlight on the tremendous potential to improve safety and efficiency with embedded sensors that can detect faults on the individual components of much larger systems, or to monitor human well-being and comfort through millimeter-wave radar.

Energy efficiency in building automation: considerations, importance and future trends

Energy efficiency involves many considerations for design engineers, who must balance not only

features and battery-life expectations, but also the average current consumption of each device on the board, and how to obtain an accurate steady-state consumption model for the design. Many engineers have become very clever in how they implement certain features on a design in order to save as much power as possible, thus increasing overall efficiency.

Energy efficiency isn't just for battery-operated devices, but almost any line-powered system as well. For example, in the heating, ventilation and air-conditioning (HVAC) industry, the U.S. Department of Energy (DOE) established more stringent regulations for minimum efficiency ratings called a seasonal energy-efficiency ratio. These regulations in turn resulted in a swift shift away from permanent split capacitor motors to electronically commutated motors, which most manufacturers now offer as a standard feature in newer HVAC equipment.

Figure 1 on the following page compares both types of motors.

Although the consumer bears the initial cost of these more expensive motors, electronically commutated motors actually increase energy efficiency so drastically that the technology pays for itself quickly according to the DOE, saving Americans more than

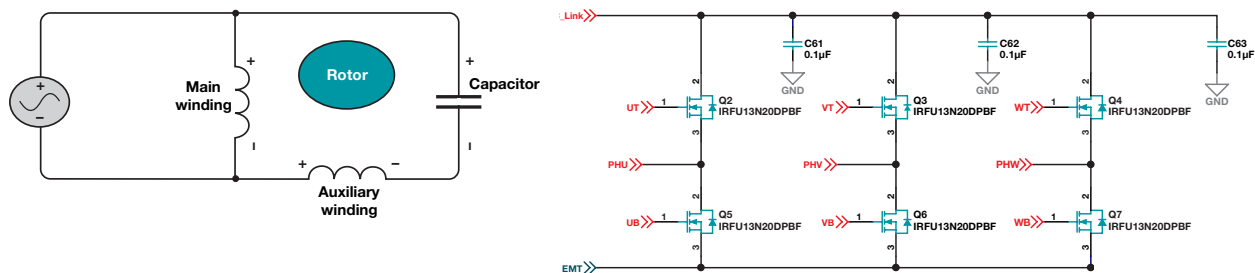


Figure 1. A permanent split capacitor motor vs. an electronically commutated motor.

\$9 billion in home electricity bills through 2030. TI's [Electronically Commutated Motor Reference Design for HVAC Blowers with Low BOM](#)

[Cost](#) is a good starting point for a high-efficiency electronically commutated motor design.

Looking specifically at one of the most prevalent battery-powered application areas within building automation—building security—there are countless examples of this trend in ultra-low-power product designs and energy efficiency. As shown in **Figure 2**, the security and video surveillance market is predicted to grow about 5 percent from 2013 to 2023 (Source – Omdia, Industrial Semiconductor Market Tracker, 2020*). With this growth, there will be an inevitable push to optimize the efficiency of security and video surveillance devices. In larger spaces as well as older buildings, it is much more

cost-effective to have battery-powered sensors, rather than relying on line power that may or may not be there.

The increased focus on energy efficiency has led to an increase in battery life, enabling remote sensors in buildings or homes to relay real-time environmental data and sensor conditions for a much longer duration than previously obtainable – and to do so without requiring line power.

Energy-efficient devices to address engineering design challenges

In building security applications, Hall-effect sensors can detect magnetic field changes using low-cost magnets placed on a door or window. Using two DRV5055 sensors together, as in the DRV5055 angle evaluation module, enables two-dimensional

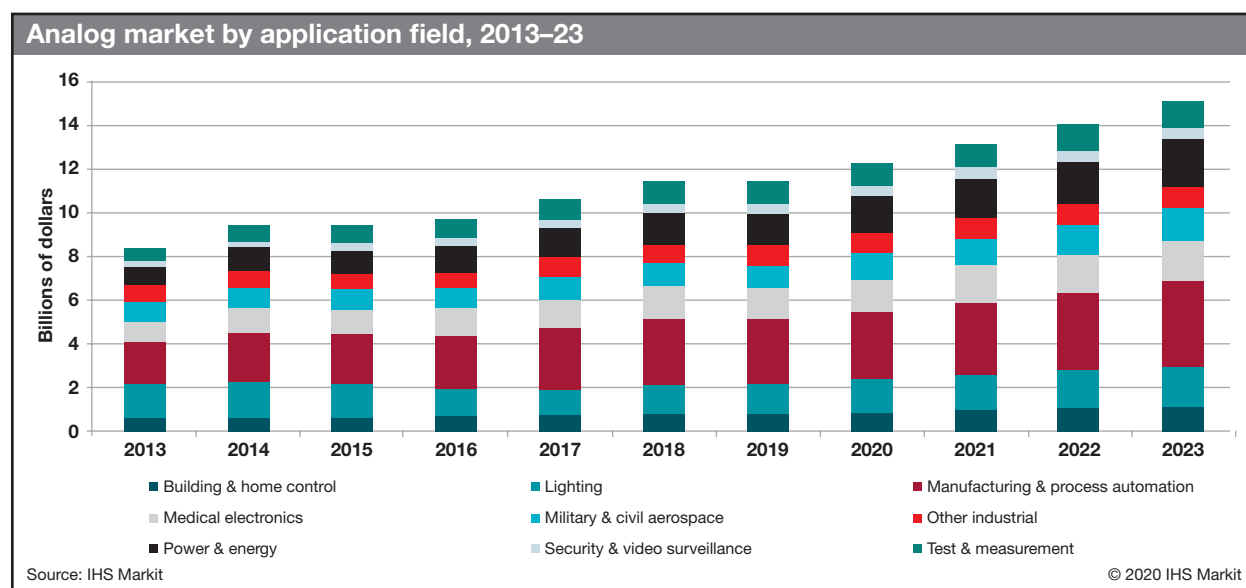


Figure 2. Omdia, Industrial Semiconductor Market Tracker. Results are not an endorsement of Texas Instruments. Any reliance on these results is at the third-party's own risk.

position detection. With this advanced sensing method, depending on the calibration method and number of calibration points used, a high accuracy of $<1^\circ$ can be achieved but the current consumption can be on the higher side (~ 12 mA typical), so to minimize the power consumption, you can use an ultra-low-power Hall-effect switch as a first-pass detection method for magnetic field movement.

Employing a setup such as the one shown in **Figure 3** to detect the rotational angle of a door-closer swing arm, an additional nanopowered hall effect sensor, a DRV5032 wakes up the more power-demanding DRV5055 sensors, only consuming additional power once movement is detected, instead of always being on. Using the Hall-effect switch in conjunction with an ultra-low-power load switch removes the power source from the DRV5055 sensors until they are actually needed for angle sensing.

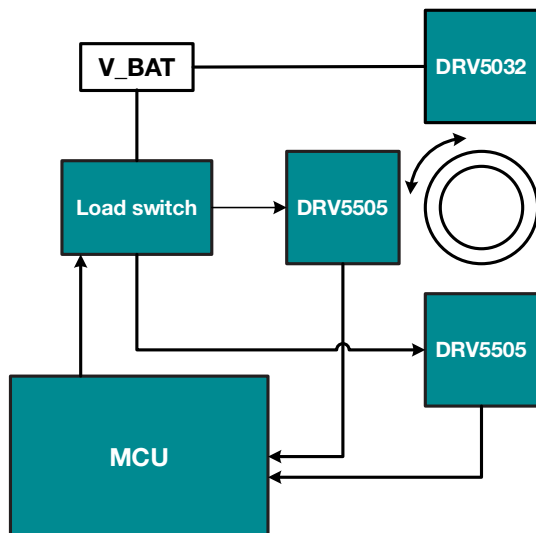


Figure 3. An energy-efficient door-position sensing block diagram.

Figure 4 shows another low-power energy-efficient application using the 320-nA TLV8802 operational amplifier as the signal chain for a passive infrared sensor. The TLV8802 is a good fit for cost-sensitive systems with battery-powered devices.

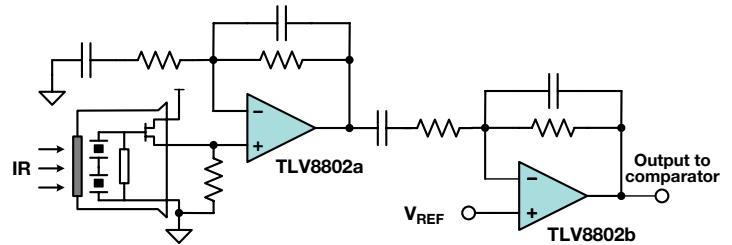


Figure 4. A low-power PIR sensor analog front end.

PIR applications require an amplified and filtered signal at the output of the PIR sensor, so that the signal amplitudes going into the subsequent stages of the signal chain are large enough to provide useful information. Typical signal levels at the output of a PIR sensor are in the microvolt range for detecting the motion of distant objects, which exemplifies the need for amplification. The filtering function is necessary in order to limit the noise bandwidth of the system before reaching the input to the window comparator. The filtering function also sets limits for the minimum and maximum speeds at which the system will detect movement.

Another way to optimize a design for energy efficiency is to use a combination of a nanotimer and a load switch to power down higher-power-consuming devices or even the microcontroller (MCU) to a deeper state of sleep.

Figure 5 on the following page is a schematic of a simple low-power wireless environmental sensor for both residential and commercial environments.

In Figure 5, the TPL5111 is used as a periodic wake up or enable signal for the TPS22860, which powers the HDC2080 once the TPS22860 is enabled. This circuit also has the DONE pin tied to a general-purpose input/output pin of the SimpleLink™ MCU to power down the HDC2080 once processing is completed. Once the nanotimer turns off the load switch, the power from the HDC2080 is removed, which results in significant energy savings. It is possible to set the TPL5111 to a wide range of times, potentially saving even more power when the polling rate is set to a high delay value.

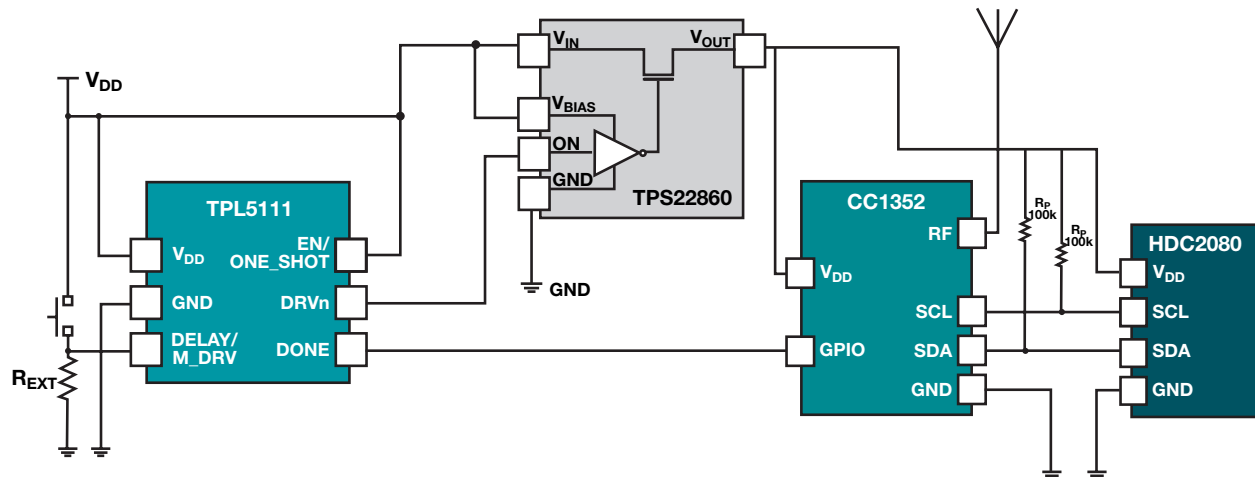


Figure 5. A wireless environmental sensor with a nanotimer and load switch.

Energy harvesting in building automation

Much of the current wave of ultra-low-power innovation is based around coin-cell battery designs that have previously been unchanged for decades, but these components can draw from sources in the environment, such as light (photovoltaic), motion or wireless RF energy. Energy harvesting can drastically increase energy efficiency by providing additional power to a device. And when combined with ultra-low-power devices and energy-efficient designing, you can increase the lifetime of remote building sensors by as much as several years. A supercapacitor, used in conjunction with or as a replacement for coin-cell batteries in low-power devices, stores harvested energy for use by the device. Unlike single-use batteries, supercapacitors recharge rapidly.

Energy harvesting application: door handle

An action as simple as the turning of a door handle can harvest additional energy for a smart lock. When used in conjunction with a motor, the shaft of the motor can be integrated with a reduction gear

that will translate a slow door handle turn to a higher rpm rotation of the motor acting as a generator to produce energy, which can then be rectified and conditioned for supercapacitor energy storage.

Figure 6 shows a potential setup to test this energy harvesting method using a dynamometer and a coupler for the door handle.

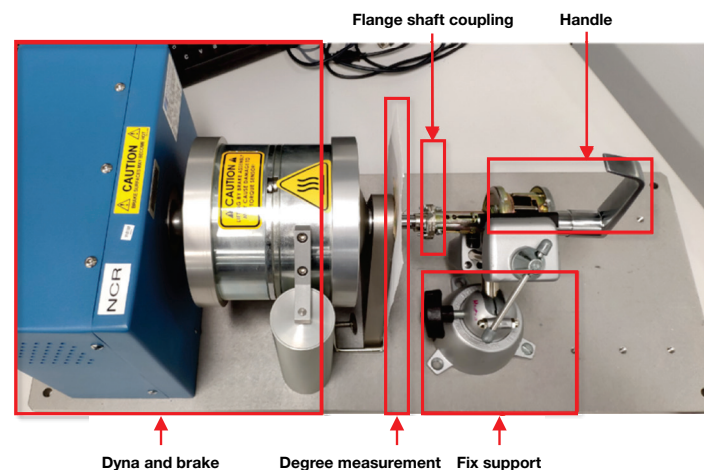


Figure 6. Door handle energy harvesting test setup.

Figure 7 on the following page shows the complete power path for converting the rotational motion of a door handle to stored energy. The power path

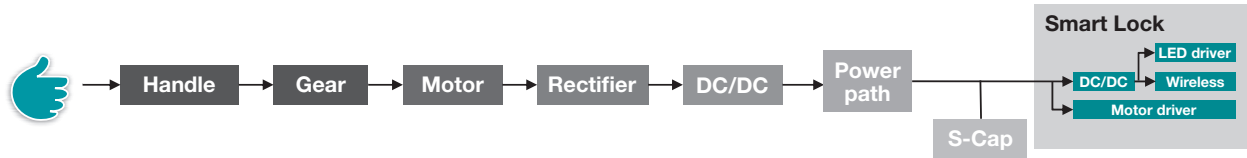


Figure 7. Door handle energy harvesting power-path example.

includes two load switches that relieve the load on the battery when the energy on the supercapacitor becomes high enough to supply system power, or to provide an energy source for battery charging.

The DRV8847 dual H-bridge motor drive harvests the energy from the generator motor. Figure 8 illustrates the output power from this power architecture.

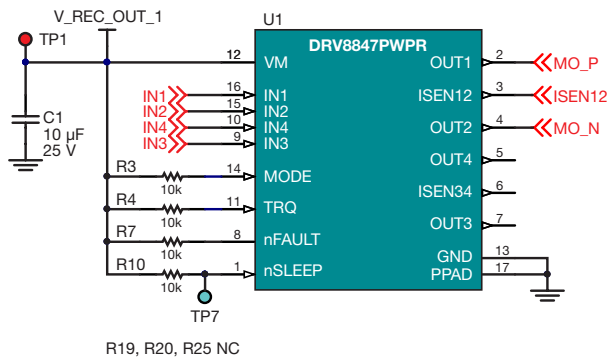


Figure 8. Using the DRV8847 for rectification.

There are many other TI products and designs that meet the industry demands of energy harvesting, such as the [Energy Harvesting for Wireless Switch Power Reference Design](#), which leverages a zero-frequency energy harvesting switch to generate energy from a button press. Another good example is the [Energy Harvesting Ambient Light and Environment Sensor Node for Sub-1GHz Networks Reference Design](#), which has two integrated solar cells capable of providing additional energy to the system through photovoltaic

harvesting. Figure 9 below shows the output of this energy harvesting door handle and the active rectification of the motor output.

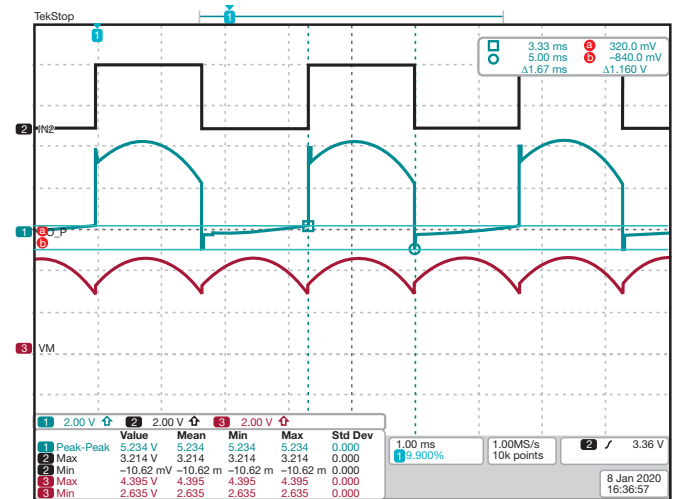


Figure 9. Output voltages for an energy harvesting door handle.

An example of an energy-efficient design

One of the centerpieces of a smart home design is a smart lock, capable of accepting commands wirelessly from authorized users, tracking passages, and operating the lock without manual intervention. But smart locks can't gain the mainstream acceptance of standard lock-and-key mechanisms if battery life and maintenance are constantly interfering with expected operations. Energy-efficient design and energy harvesting can help stretch the life of electronic smart locks by years.

Consider an advanced smart lock in which it is possible to verify that the deadbolt is in the door jamb and the door is fully closed. Rotating the deadbolt latch as the user turns the latch to extend the deadbolt from the inside generates a small amount of energy that can be harvested for deadbolt position verification later when the door is locked remotely. Obviously this is only one proposed method; many others are also possible. **Figure 10** below illustrates the block diagram for this particular method.

On the door-jamb side is a simple insert that can be mounted behind the deadbolt plate. Internal to these contacts is a unique resistance value that provides a voltage drop across the contacts. You can use an operational amplifier to compare this voltage, or for even better accuracy and tamper mitigation, use an ultra-low-power analog-to-digital converter to measure the output voltage.

Once the MCU verifies the output value, it removes the power to the load via the load switch to minimize consumption (≤ 2 nA in shutdown mode). Due to the passive nature of the peripherals, this design is very efficient and provides an additional intrusion and tampering safety feature for the smart lock at very little additional cost.

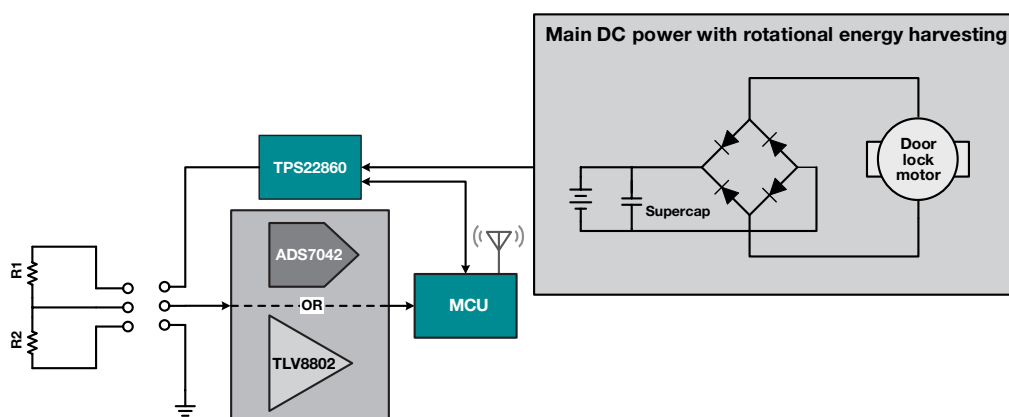


Figure 10. Example block diagram of a deadbolt position sensor with energy harvesting.

Figure 11 provides a more detailed overview of the deadbolt position sensing application.

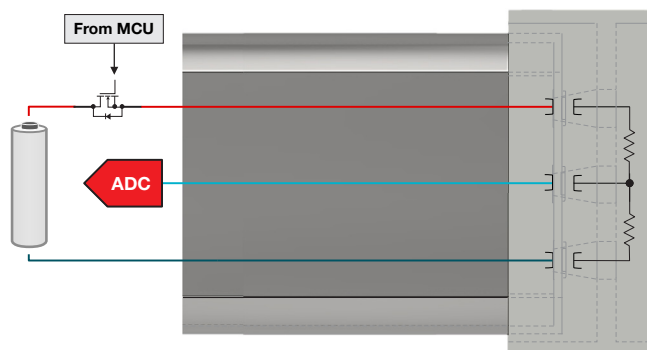


Figure 11. Deadbolt position sensing.

Conclusion

For new technology to displace a proven, lower-tech incumbent, it typically needs to be significantly better and create no major burdens. Ultra-low-power advances answer these challenges by improving convenience and by delivering sophisticated technology with virtually zero maintenance.

With reliable data insights and computing power that can be trusted for years, ultra-low-power technology is reshaping expectations of where, how and how long smart devices can be deployed. The

ripple effects of these innovations will carry on long after the first wave of batteries are finally replaced.

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