Energy Harvesting Solutions for Wireless Lighting

By: Dr. Jeff C. Andle

Explore how Gemns™ technology enables feature-rich wireless switches for advanced lighting—from color control to brightness adjustment—without batteries or data cables.

Contents

Executive Summary

There is a growing demand for wireless switches and controls, especially with advanced lighting solutions. On one hand, color and brightness controls are too complex for traditional wall switches and on the other hand, wired switches would require placing data cables into the walls. Wireless controls allow a diverse array of controls to be installed with minimal effort.

This trend has contributed to the ever-expanding volume of discarded batteries year over year. Energy harvesting solutions, combined with low energy radio protocols, offer a solution to the battery refuse crisis.

Recently presented solutions by Gemns™ allow more complex and feature-rich solutions. In addition to allowing two-way communication (command acknowledgements can be received), the surplus of energy harvested by these devices enables more feature-rich and user-friendly solutions.

Introduction

The first wireless remote control appears to be a side function of the Zenith Flash-Matic, invented by Eugene Polley in 1955, although some sources cite Nikola Tesla's remote-controlled boat at Madison Square Garden in 1898 and Leonardo Torres' Telekino in 1903. Still Zenith's Flash-Matic optical remote and the 1956 Zenith Space Command ultrasonic remote are the first commercial units. Lutron claims that the 9189 RanaX was the first remote control dimmer switch and that 1990's NeTwork was the first remotely controlled home lighting center. Since then, millions of remotes and many millions of batteries have been disposed increasing with the sharp increase in products due to the Internet of Things.

"Popular protocols include ZigBee, DALI's wireless extension, Xbee, EnOcean, Bluetooth, Bluetooth LE and the Synapse Network Appliance Protocol (SNAP). In July 2017, Bluetooth announced Bluetooth Mesh. A number of systems are also offered that use proprietary protocols, many of which are similar to ZigBee. The wireless controls can be integrated with wired lighting and building automation systems using either gateways or by sharing a common protocol." [1] The push for interoperability favors Bluetooth, Zigbee, and Thread. Higher security systems might use Z-wave and internet-based systems might use Matter (and Matter over Thread).

Bluetooth, Zigbee, and Thread have low energy protocol extensions (more on this later) that allow controls to operate from less than a millijoule (mJ) of energy. By contrast, a typical 2032 coin cell battery stores more than 2 kilojoules. This could seem like the equivalent of 1 million or more presses, but the battery powered transmitters draw sleep current even when no button is pressed. Energy harvesting buttons that are designed for over a million presses can reliably operate with no maintenance: obviating the need for several - potentially tens of - battery changes. These low energy protocols allowed, first EnOcean, and then several other kinetic energy harvesting solutions, to offer batteryless, wireless solutions.

Technology Overview

WePower Technologies' Gemns™ solutions offer several switch formats capable of providing over 4 mJ of energy per activation. These can be miniaturized to sub-mJ or scaled up to well over 10 mJ. In the G-100, a linear press of a button harvests just over 4 mJ of energy. The G200 is a rotary-based harvester but can be activated linearly or angularly by a gear. It is the most flexible solution and has been demonstrated in limit switches, door opening and closure switches, rocker switches, and other related formats with useful energy approaching 4.5 mJ. The G300 is an integrated rotary-based harvester in a slide switch format with over 3 mJ harvested.

The actuation converts the force and travel of your finger into kinetic energy of a freely moving generator magnet within a coil. Opposing stationary magnets keep the free magnet in oscillatory motion until the coil extracts the energy. The G100 and G200 have between 7 and 9 mJ of raw energy that could be delivered to a resistive load. Rectifying, storing, and regulating this raw energy into useful circuit power at, for example, 1.8 to 3.3V, comes at an efficiency-cost tradeoff. Lower cost solutions can deliver just over 2 mJ while more optimized solutions can reach 4.5 mJ or more when powering a 1.8V~3.3V circuit at between 5 and 30 mA. Peak currents of at least 50 mA for tens of milliseconds are attainable and reasonable efficiency down to 1 mA average currents are attainable (e.g. potentially 2 seconds at 1.8V/1 mA).

Applications will typically employ a System-on-Chip (SoC) containing a processor being powered by the Energy Harvester. A typical power profile might see ~3 mA

[1] https://lightingcontrolsassociation.org/2018/03/23/introduction-to-wireless-lighting-controls/

load through cold boot and setup (e.g. 20-40 ms at 3.8 mW or 0.076~0.152 mJ), followed by cycles of sleep, transmit, and receive. Sleep power can be on the order of 10 μW without the low frequency crystal oscillator, at which point the losses in the harvester dominate. Assuming a sleep power for the system of about 80 μW including capacitor leakage and quiescent currents, 2 mJ would be the equivalent of 25 seconds of sleep time. Transmit powers up to 8 dBm or more are possible at under 60 mW (e.g. 30 mA at 1.8V) and 33 ms of transmit time are possible with 2 mJ. In battery-free systems, it is RX/receiving that poses considerable energy burden - not because the receiver power is high, but because the time at which a response will be received can be hard to identify, the receiver must be on for extended periods of time. Typical receiver powers are under 20 μW, but with tens of hundreds of milliseconds of uncertainty a single receive could consume 2 mJ at 100 ms.

In context, 0.15 mJ is enough for highly optimized Zigbee Green Power Device (GPD) or BLE beacon transmitters at 0-4 dBm transmit power. One mJ is enough for a standard Zephyr cold boot through to BLE pairing. With 4 mJ, Zigbee GPD and BLE beacon transmitters are able to send tens (often more than 30) repeats of a message at 8 dBm while triplicate repeats are considered sufficient redundancy. These harvesters can spare 2-3 mJ to operate auxiliary sensors, such as slide potentiometers, resistive touch pads, or even cap-sense touch pads. There are a number of ways to use such controls.

In all the controls, the kinetic motion of the generator must be used to create energy. It takes about 20-50 ms from starting the motion to attain peak useable power. MCU cold boots of 10-30 ms from initial voltage rise are typical of low energy chips and protocol boot times can add under 10 ms (e.g. Zigbee GPD and BLE beacon) to around 120 ms (e.g. Z-Wave) to this.

A control could have one or more slide controls (e.g., a single brightness or three separate R/G/B brightness sliders) and a send button or an ON (sends slide values)/OFF rocker. During protocol startup, the slide positions may be read and encoded as data for the packet.

A control could have one or more virtual touch buttons. Pressing anywhere on the button surface could activate the sensor, which could use capacitive or resistive touch sensors to determine which virtual button was pressed. The code for that button command would be embedded in the protocol packet and sent.

A control could use a rocker switch based on the G200 or G300 with polarity detection to determine the direction of the motion.

Key Features & Benefits

Gemns harvesters offer a robust solution, proven to millions of activations, with much higher energy output than existing solutions (2-8 mJ vs 0.12-1 mJ) and can support user friendly slide and touch sensor controls.

The increased available energy allows using rapid application development (less optimized firmware) and more secure and robust wireless protocols and potentially allows receiving an acknowledgement. A common annoyance with some low-cost remote controls is that they send a large number of packets repeats rather than listening for an acknowledgement. While most protocols can handle this, occasionally a single press can toggle a light on, off, and even back on.

Gemns energy harvesters are compatible in form factor with existing battery-free and battery powered controls, making the conversion process painless. By converting battery powered controls to Gemns harvesting controllers, each controller can eliminate several, potentially tens of batteries form entering the waste stream as well as eliminating the annoyance of needing a new battery and not having one on hand.

Case Studies

Rocker switch

WePower Technologies demonstrated a Zigbee GPD rocker (ON/OFF) switch based on the G200 generator at CES 2025. The rocker plate activated a +/- 170-degree windup and release of the G200 rotor, which then oscillated back to the rest position as the energy is extracted. The damped sinusoidal output starts positive for the ON direction and starts negative for the OFF direction. The waveform is rectified and pumped to a storage capacitor, which in turn feeds a 1.8V DC-DC load regulator.

This switch used the button press pairing system typical of battery-free GPD switches. Alternate designs could have a USB-C receptacle or other standard means of commissioning under temporary power.

The demo used a high-performance harvester circuit that extracted about 4 mJ and was able to provide sufficient energy to the EFR32MG22E to send as many as 30 repeats of the ON or OFF command. In practice, a lower cost and less efficient circuit could be used as the number of retransmissions should be limited to between 3 and 5. In fact, with 30 transmissions the demo exhibited glitches that have been seen in battery powered remote controls for some light and fan products where a single button press does (a) nothing, (b) the intended, e.g. ON, operation, (c) momentary ON then OFF, and occasionally (d) ON/OFF/ON. It is a simple matter for the transmitter firmware to limit the number of transmissions with a 1-2 mJ harvester system. For the CES demo, the unit stopped at 10 transmissions and then expended the remaining energy and still exhibited all four behaviors. Alternately, the 4 mJ harvester could allow a more reliable switch that listened for the acknowledgment and then stopped transmitting.

Single or multi-slide switch

WePower Technologies is presently designing prototype slide controls for dimmer and color applications. A single slide and rocker system could send OFF commands for the OFF direction of the rocker and BRIGHTNESS (xx%) for the ON rocker direction where the brightness would be determined by reading the slider position. Two slider systems could send brightness and color temperature, and three slide systems could send tailored color values for the ON direction.

Multi-button models could control multiple lights, with single toggle buttons per light or paired on/off buttons per light. This offers an economy of a single electronics package serving as the harvester and transmitter for multiple buttons and allows significant space savings as a single wall unit can provide multiple functions. Using a single transmitter to control many lights reduces the purchase cost and installation effort while combining functions can reduce clutter form multiple switch panels on a wall, offering a cleaner aesthetic.

Toggle switches

The G100 Industrial Pushbutton is but one example of a toggle switch. Simple push buttons serve as toggle switches for lighting. Directing multiple toggle switches to the same group of smart lights replaces traditional three-way and four-way switch configurations to control that set of lights without the complicated wiring between the switches.

Conclusion

Gemns energy harvesting generators and associate harvesting circuits have shown more than a 5-fold improvement in harvested, regulated energy from existing, sub-mJ, battery-free switches. This allows simpler application development, use of more robust protocols, and addition of a richer set of control features.

In some applications, it might even be possible to flash an indicator light (a few mW) or briefly sound a small piezo buzzer (tens of mW) on receipt of an acknowledgement from the system to provide feedback.