How to Build a
Smart LED Bulb Design

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Introduction

Light bulbs are so common that we practically take them for granted. But for as common as they are, their utility hasn't changed much until lately. LED bulbs aren't exactly a new technology, but only recently have we been able to realize the full scope of their benefits, including significant energy savings and extended lifetimes. Adding connected functionality further enables an LED bulb to do a lot more than just convert energy into light. A bulb can also become an access point for other devices on the network, serving as a backbone for transferring data throughout the home. As a result, smart LEDs bring an added layer of convenience, intelligence, and data analytics as well as opening the door to a widespread reduction in power consumption, operating expense, and environmental issues associated with battery-powered portable products.

From a developer perspective, however, LEDs are not simple devices. In this whitepaper, we review some industry norms for designing smart LED bulbs, explain the process for selecting the right wireless protocols, and provide you with information on how to get started with development.

Characteristics and Features that Drive Hardware Requirements

Light bulbs have always been subject to industry requirements regarding characteristics such as physical size and how they connect to a power source. But some regulations are specific to LEDs, including energy efficiency and light output. LEDs come in a wide range of sizes, shapes, fittings, and even opacity - or how easily you can see the internal components. All of these variables can impact your design, so they are important to consider during the planning process. Additionally, the light output type and effect will determine how the LEDs are driven, which influences the feature requirements for your wireless SoC or module.

The actual hardware implementation depends on your approach. For example, you can add intelligence to an existing bulb, or you can design a smart LED bulb from scratch. LED light bulbs have an electronic ballast that usually includes a power management IC (PMIC) and discrete high-voltage components. The electronic ballast typically drives the LEDs with a constant current to achieve consistent brightness regardless of input voltage or temperature variations. The PMIC auxiliary supply can also power an MCU, wireless system-on-a-chip (SoC), or an RF module. One thing to keep in mind is that the SoC or module generally requires a 3 V supply, and these auxiliary power supplies can be poorly regulated. As a result, it may be necessary to add a linear regulator to supply a more stable, or possibly a lower, voltage.

On/Off Switch and Light Dimming

Other considerations for your LED are power switching and dimness control. Disabling the PMIC isn't a real option here because this will also disable the auxiliary supply. One method is to add a MOSFET between the LED cathode and ground for the MCU to switch or dim the LED. However, this technique presents issues if the PMIC was originally designed for a constant load. The next generation of smart LED bulbs will include ballast electronics with PMICs designed specifically for small bulbs and an always-on, well-regulated current supply. This functionality will enable LED intensity control without requiring extra components.

Features for the Wireless SoC

A **pulse width modulator**, or PWM, makes it possible to control the brightness of a string of LEDs. Timers are the base component for the PWM, and how many you need will depend on how you drive the LEDs and how many LED strings you have. For example, a bulb that allows you to switch between warm, neutral, and cool light will have both a warm and a cool light LED string. If you're building a colored bulb, then you'll need to control the RGB LEDs, and in these cases, you might find it helpful to have two or three PWMs. The ability to measure temperature is also useful because high-lumen bulbs tend to get hot. LED and wireless SoC reliability can be extended by monitoring temperature and dimming the LEDs to limit heat generation. Therefore, it's a good practice to have a **chip temperature sensor** on the wireless SoC so it can measure its temperature directly. You will also need enough **memory** to be able to support over-the-air (OTA) updates. This memory can be internal to the SoC or externally connected via a serial interface. These OTA updates allow you to future-proof existing designs by adding features and fixing issues as they arise.

A **radio engine** with support for different protocols provides the flexibility to decide which protocol is the best fit. The use of standards-based protocols helps enable interactivity with common consumer products, including voice assistants, smartphones, and tablets, without the need for additional networking infrastructure. Some smart LED bulb designs may require **multiprotocol connectivity**. For example, set up from a mobile handset using Bluetooth and then control and operation with a Zigbee-based network. We'll discuss multiprotocol support in detail later in this paper.

Space Constraints with LED Bulb Design

Bulbs come in a variety of shapes and sizes, which can cause some unique challenges. All the components need to fit into very specific form factors. The type of ballast used and its rating will determine how much space is available for the connectivity solution, and adding a second connectivity PCB or module can provide some flexibility here. Size and physical orientation affect two other important factors: heating and RF performance. The amount of heat generated by the bulb depends on the output of the lumens. This heat is primarily from power electronics and LEDs. Though cool to the touch, LEDs generate heat due to the inefficiency in which semiconductors produce light. However, LEDs are becoming more efficient, and choosing LEDs with higher lumens per watt, or luminous efficacy, will help. Keep in mind that different colors have different efficacy. For example, an RGB bulb set to red will run hotter than the same bulb with the output color set to blue or green. Electronic power efficiency is also a focus area, and the trade-off is that more efficient components are typically higher cost. Heat sinks and potting compounds provide a means of dissipating heat, but impact on the RF performance must be considered. Material contact with an antenna will impact its tuning and the value of the S11 parameter. The S11 or input reflection coefficient is a measure of how much power is reflected from the antenna with 0 dB, meaning all power is reflected and nothing is radiated.

The location of the antenna can also be different in each bulb. What might be a good location for one design may not be for another. For example, one bulb type might not physically accommodate the connector board in the same location. An MR16 is different than an A19, and the higher illumination output of the A19 might not have space for a cut-out in the LED metal PCB due to the layout required for the LEDs. Even if you use a cut-out in the PCB, you need to be careful that the protruding antenna doesn't create a shadow or influence the light output in an adverse way.

Industry Requirements

Product requirements and constraints provide one set of specifications that we need to adhere to, and the industry requirements generate additional guidance. One key specification relates to energy efficiency. The bulb may not always be on, but it is seldom powered off. Standards such as The Environmental Protection Agency's Energy Star Program and California Energy Commission's Title 20 Appliance Efficiency Program have strict requirements for standby, or vampire, current. Energy efficiency requirements also differ by region, and these can change over time. The EU, for example, is updating its legislation in 2021 to establish eco-design requirements on light sources.

The chart below illustrates how California Title 20 generates specific requirements for wireless connectivity. Based on the standby power and the typical efficiency that the power stage can provide, we're left with a requirement to average about 40 mW, or approximately 12-15 mA at 3.3 V. The average power consumption will depend on how much time the device spends in different modes and how often the radio is in use. Wireless SoC consumption will also vary by ambient temperature. There are other regulatory requirements specific to bulbs. For example, EU regulations include requirements for the startup time of less than 500 milliseconds per bulb. That time needs to include the power stage warm-up and the firmware initialization. We need to make sure that the way we add intelligence doesn't negatively impact these criteria.

Test	Setting	Notes
Tx:	10dBm	PA with 3.3V
Tx Duty Cycle:	<1%	Typical network maintenance
Network:	2 nodes	Router sample application
Test duration:	60 minutes	
Temperatures:	25°C / 45°C / 75°C / 85°C	Ambient temperature
Test	**Title 20**	**Measured**
25°C	12mA	**10.26mA**
85°C	12mA	**11.38mA**

Figure 1: California Title 20

We should also distinguish between wireless regulatory certifications and standard certifications. Each region worldwide has its own set of regulatory requirements when it comes to wireless emitters. These regulations primarily ensure two things: first, to see if the product operates as intended in its intended environment. Factors that go into this category include sensitivity, adjacent or co-channel selectivity, and blocking. Second, the regulation ensures that the RF product does not disturb other electronic or RF devices. Standards-based certifications vary by conformance to the standard and ensure interoperability. These certifications also allow the use of licensed IP and technology and the logos and marketing rights for special interest groups.

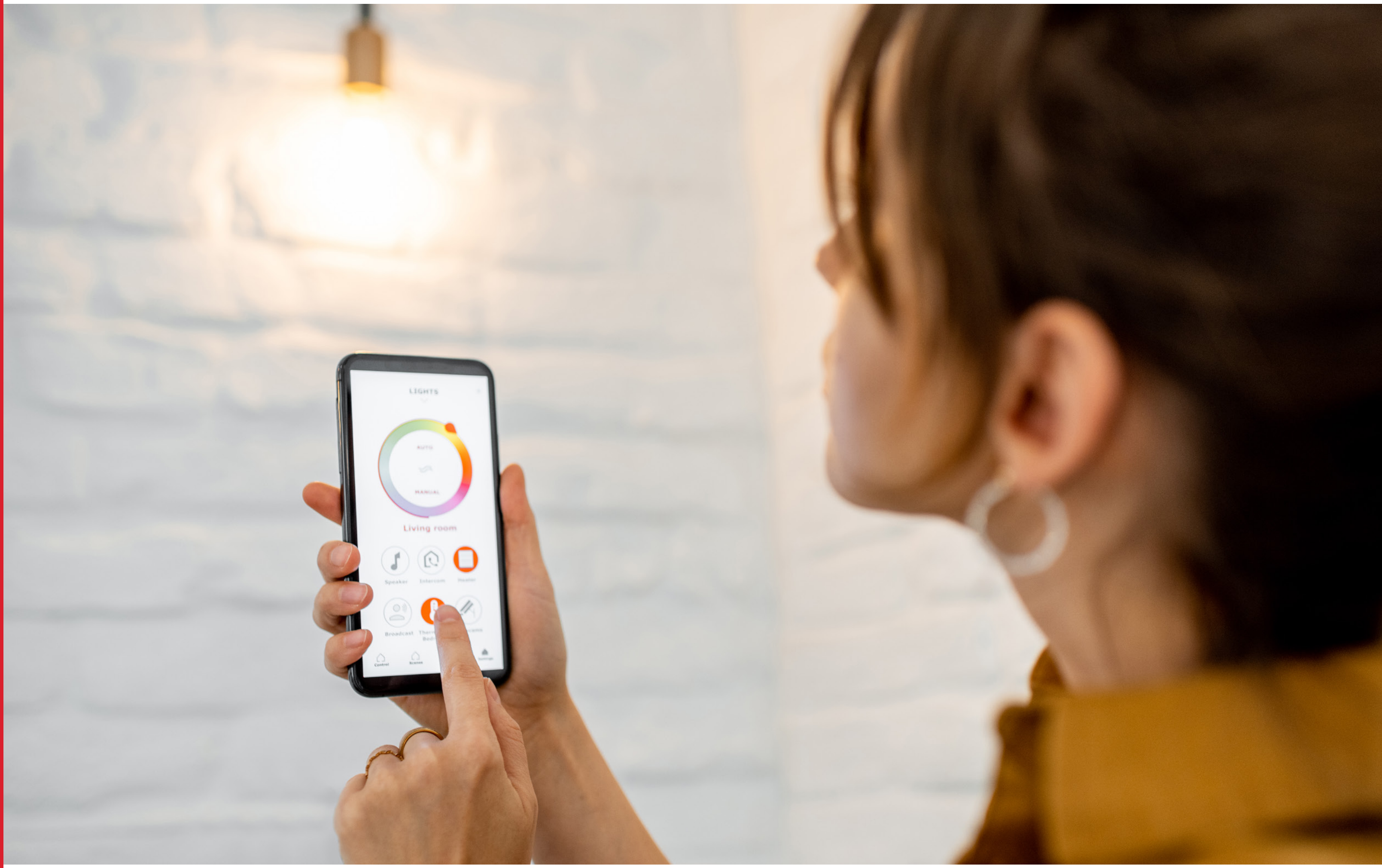
Choosing the Right Protocol for Your Wireless LED Bulb

Lighting is a powerful environmental factor that influences large portions of our day-to-day lives. With connectivity, we enable more capabilities that make our lighting solutions more convenient and intelligent. In choosing the right connectivity protocol, consider what frequency bands to use and whether to go with a standards-based or proprietary protocol.

Frequency bands, in general, work well if the connectivity requirements include far reach or penetrating surfaces like walls. If this is the case, sub-GHz protocols are often the best fit. However, keep in mind there is no global frequency standard for sub-GHz. 2.4 GHz is a global standard and allows for higher bandwidths but has a shorter range. Many connected bulbs operate in the 2.4 GHz frequency band, and most use standards-based short-range wireless protocols such as Zigbee, Bluetooth, Bluetooth Mesh. In many homes, users will already have installed an ecosystem that uses a hub or a gateway for devices on their network. If your wireless LED bulb needs to work with that connected ecosystem, you'll need to use a supportive protocol. There are also regional differences in the popularity of the protocols. Zigbee, for example, has a strong presence in North America and Europe, while Bluetooth and Bluetooth Low Energy are popular in Asia.

Dynamic Multiprotocol

Each networking protocol has its advantages but having a solution that isn't tied to a specific protocol means you don't have to commit to just one. For example, if a consumer buys a light bulb that runs Zigbee exclusively, then they need to be sure they are connecting it to a Zigbee network. But if a device has multiprotocol support, then the user doesn't have to know what kind of network they connect to. Adding dynamic multiprotocol capabilities to a device makes it possible for the product to speak more than one protocol language.



Getting Started with your Smart LED Bulb Design

Adding wireless connectivity to a bulb can be a difficult task for a developer with minimal RF expertise. Pre-certified wireless modules are a good way to simplify this task. A wireless module is designed to provide an all-inclusive plug-and-play solution that integrates the key components a developer needs to complete the connectivity portion of an LED bulb design. Using a wireless module in an LED bulb design also means you don't need to worry about managing multiple RF components. It also results in freeing up engineering resources to focus on other parts of the design. You can also accelerate your go-to-market time by not having to go through the many regulatory approvals.

At Silicon Labs, we offer a range of module solutions based on our Wireless Gecko devices evaluating high-temperatures module options for LED bulb applications up to 125 °C, we propose you use Silicon Labs solutions that are designed and built for the unique needs of smart LED bulbs like the Bluetooth Low Energy EFR32BG21 Module.