WHITEPAPER

# Antenna Design for Small Bluetooth Devices

Three Expert Rules to Minimize Device Size with a SiP Module Without Compromising RF Efficiency

By Pasi Rahikkala and Mikko Nurmimaki | 2023

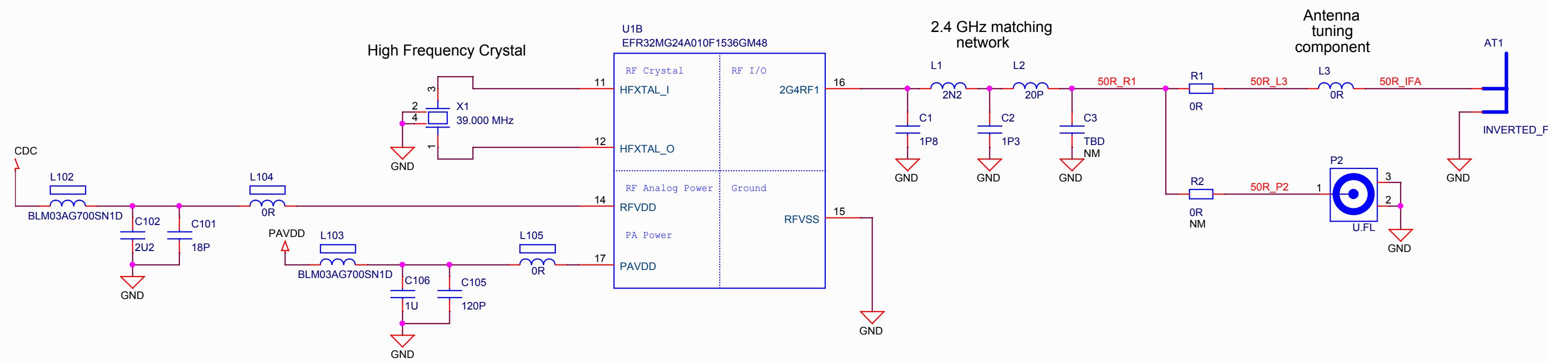

SILICON LABS | Bluetooth®

# Designing Small Bluetooth IoT Devices

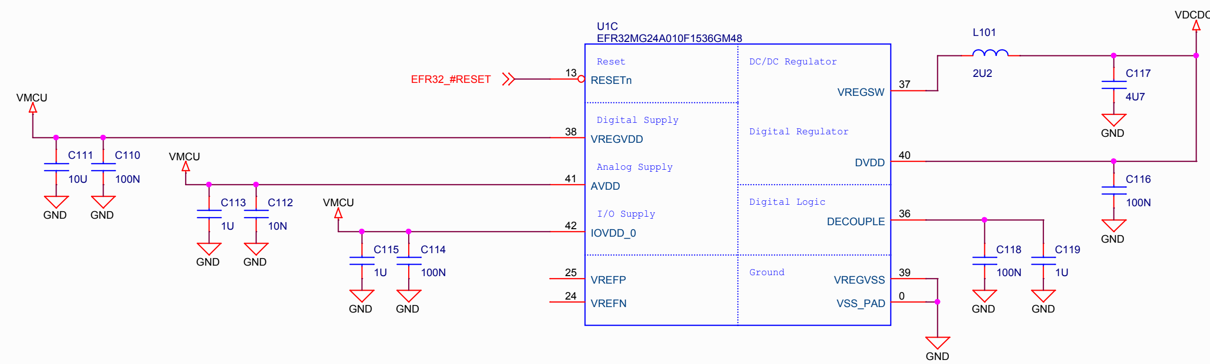
Size is critical for many Bluetooth IoT devices, such as medical devices and wearables. Consumers simply prefer to buy products with a small size and sleek design. On the other hand, due to the nature of some medical and health applications, many devices can only be functional in tiny form factors, forcing the designers to push the envelope when minimizing their device dimensions.

Size is the reason why many manufacturers choose a System-in-Package (SiP) module for Bluetooth instead of a System-on-Chip (SoC). SiP modules integrate more than 20 critical components, such as decoupling capacitors, DCDC components, crystal, RF matching, and harmonic filtering in a tiny footprint of a few millimeters, enabling device makers to reduce their PCB size radically. Additionally, SiP modules come with worldwide RF certifications, accelerating development time significantly.

### Antenna & Radio Interface




### Power & Decoupling

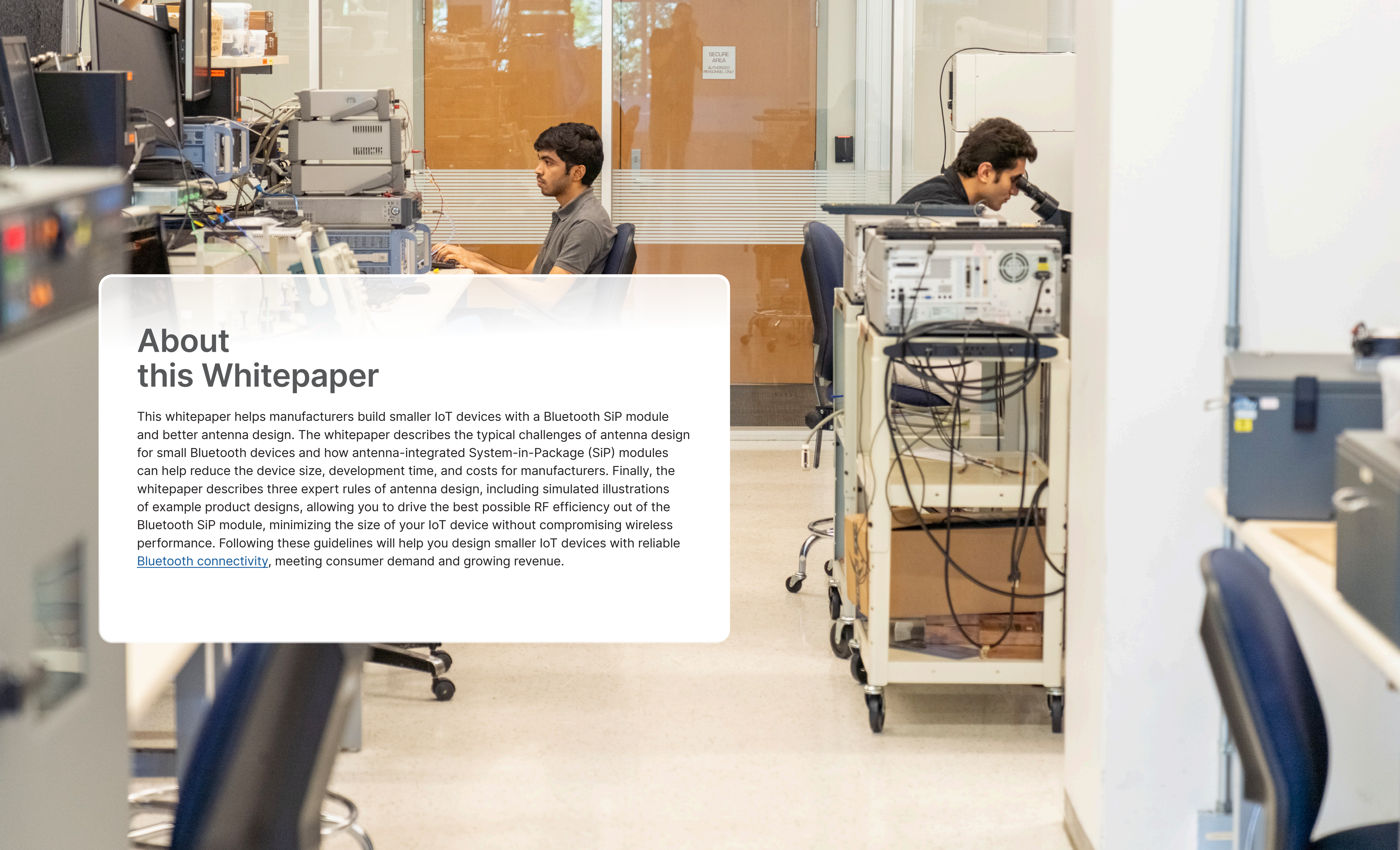



*The Silicon Labs BGM240S Bluetooth SiP module integrates 20+ critical components, which otherwise would have to be mounted on the IoT device's PCB, into a footprint of just 7 × 7 mm. The above diagram shows a reference design for those components, illustrating the sheer saving of PCB footprint, design effort, and BoM costs for the device manufacturer.*

However, if you want to build a small Bluetooth device with reliable wireless performance, simply mounting a Bluetooth SiP module on your PCB is not enough; it requires careful antenna design.

Efficient wireless performance is a combination of countless interdependent physical, electromagnetic, and mechanical variables – even the tiniest details and variations affect each other. As a designer, you cannot shrink device dimensions without reserving ample space for the antenna and respecting the clearance requirements. You must also choose the materials carefully, considering how their electromagnetic characteristics impact radio signals. Also, the mechanics of the device must be designed according to the theories of radio propagation. Yet you typically have only limited time reserved for product development, and the costs must not break the bank.

In conclusion, antenna design for small IoT devices can be challenging. On the one hand, you want to obey the consumers' demands for ever smaller sizes, sleeker designs, and cheaper prices to maximize sales. On the other hand, you cannot bend the laws of physics and electromagnetics by cramming suboptimal antenna design into a too tight product casing.

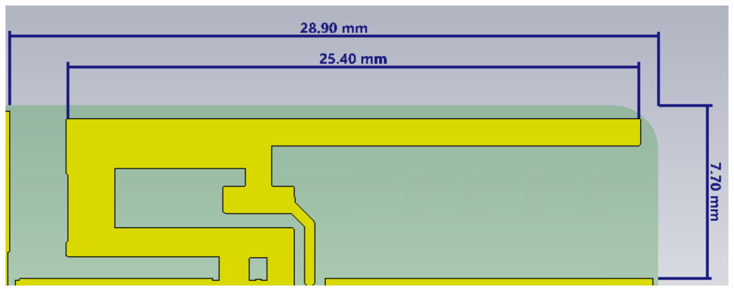


# About this Whitepaper

This whitepaper helps manufacturers build smaller IoT devices with a Bluetooth SiP module and better antenna design. The whitepaper describes the typical challenges of antenna design for small Bluetooth devices and how antenna-integrated System-in-Package (SiP) modules can help reduce the device size, development time, and costs for manufacturers. Finally, the whitepaper describes three expert rules of antenna design, including simulated illustrations of example product designs, allowing you to drive the best possible RF efficiency out of the Bluetooth SiP module, minimizing the size of your IoT device without compromising wireless performance. Following these guidelines will help you design smaller IoT devices with reliable Bluetooth connectivity, meeting consumer demand and growing revenue.

## PCB Antennas

The printed circuit board (PCB) trace antennas, such as inverted-F, are popular in IoT due to their low Bill of Material (BOM) costs. However, PCB antennas require a lot of space, generally in the range of 25 × 15 mm, ultimately making the IoT devices enormous.




## Chip Antennas

Chip antennas simplify design and enable smaller product sizes. Typically, the actual radiator is not the chip antenna itself, but the ground plane. Thus, the efficiency of a chip antenna is strongly affected by the size and shape of the PCB board they are mounted on. Different chip antennas are designed to work in different installations. One antenna might deliver the best efficiency at a corner of a PCB while another antenna works best at the edge of a PCB. It is important to follow the manufacturers design guidelines to the letter when designing with a chip antenna and select an optimal antenna type for each device and installation scenario.

## Antenna Length

The smaller the IoT device, the more compromises antenna designers must make. By theory, the smaller the area allowed for the antenna, the lower the efficiency of the RF performance.

Devices less than 10 mm per side can deliver a Bluetooth range of approximately 10 meters with a mobile phone, which is acceptable for most personal IoT devices.

However, with the device dimensions closer to 20 mm per side, the RF efficiency increases significantly, delivering a range of 20-40 meters over Bluetooth.

When the device dimensions reach 40 mm per side, the optimum efficiency of several antennas tuned with the ground plane size reaches maximum performance. The distance between two identical Bluetooth devices can be even 60-400 meters.

Depending on the application and target size, a designer needs to consider the antenna performance and efficiency in relation to PCB size because most of the chip antennas use the PCB ground plane as part of the antenna configuration. In addition, the placement of the antenna or SiP module, including the clearance areas and grounding, are important aspects of the design.

## External Antennas

According to Silicon Labs market data, almost 50 percent of IoT 2.4 GHz customers evaluate the feasibility of an external antenna. However, only 10 percent of these designs are actually deployed, and 90 percent of the customers choose a SiP module with a built-in chip antenna. What is the reason behind this? Firstly, the mechanics of an external antenna are not design-friendly and can break easily if the device is dropped. An external antenna increases the IoT device's BOM and assembly costs significantly. When comparing the efficiencies of a well-designed chip antenna and an external antenna, there is no benefit in using an external antenna unless the housing of the device is metallic and forms a Faraday cage preventing the RF signals from penetrating the device.

## Antenna Housing

With chip antennas, the mechanics and housing of the IoT device play a key role in antenna detuning. The RF radiation is affected by the proximity of the materials when it bursts out of the antenna. The antenna touching metal or plastic causes detuning. For this reason, the antenna must be separated from physical contact with plastic or metal. Sensitivity to detuning varies from one type of antenna to another. Monopole antennas are more sensitive than ground-coupled antennas.

## SiP Modules with an Integrated Antenna

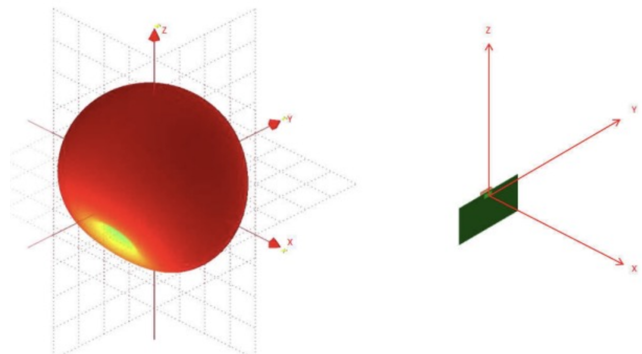
Silicon Labs' System in Package (SiP) modules are a compact, fast, cost-efficient, and designer-friendly solution for developing small IoT devices. By integrating several components typically needed for IoT devices into a tiny footprint, SiP modules are a fast track to reducing the device size for many manufacturers.

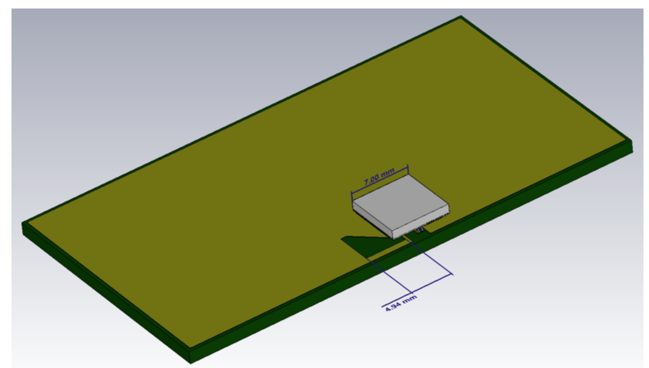
Silicon Labs' BGM220S and BGM240S Bluetooth SiP modules integrate more than 20 critical passive components and crystals, freeing you from RF-related design worries if layout guidelines are followed. The SiP modules have worldwide RF certifications to accelerate your time-to-market radically.

One of the most significant benefits of Silicon Labs' SiP modules, such as BGM220S and BGM240S, is that the antenna is integrated inside the module substrate, preventing detuning, even in the proximity of the housing and mechanics. Thanks to this robust antenna architecture, a SiP module can be placed near the product housing, eliminating the need for the total 3-dimensional clearance area reducing the IoT device size without compromising antenna efficiency.

With a SiP module, you can achieve the same optimal RF performance as with a custom-designed antenna to minimize the size of your IoT device without compromising antenna performance.

Unlike competing modules, BGM240S also provides an option to externally optimize the antenna impedance matching for host boards of any size and shape, making it possible to achieve the best possible RF range in all scenarios. BGM220S and BGM240S also provide an option to route a 50-ohm trace from the modules' RF pads to a planar PCB antenna, should an external antenna be needed for the best possible RF range.





***The radiation efficiency of BGM240S is up to -1.4dB, which is practically as high as what is achievable with small Bluetooth antennas.***

### Two Bluetooth SiP Modules for Small IoT Devices

BGM220S is designed for the smallest design footprint for Bluetooth Low Energy. Its 6 × 6 mm size and small antenna clearance areas offer a complete ultra-compact Bluetooth implementation. BGM220S SiP module is the world's smallest (when considering the clearance needs with end product housing) Bluetooth solution, featuring an ARM Cortex®-M33 MCU core, 512 kB flash and 32 kB RAM, the industry-leading power consumption of 3.4 mA TX current, and an integrated antenna on the SiP module's substrate.

BGM240S with a size of 7 × 7 mm is an ideal solution for small and advanced Bluetooth IoT devices. With key features like an ARM Cortex-M33, 10 dBm output power, low current consumption, and the highest PSA Certification Level 3 security, you can create robust and energy-efficient applications while securing end-user privacy. The large memory of up to 1536 Flash (kB) and 256 RAM (kB) and 32 GPIO provide maximum resources while leaving room for growth.

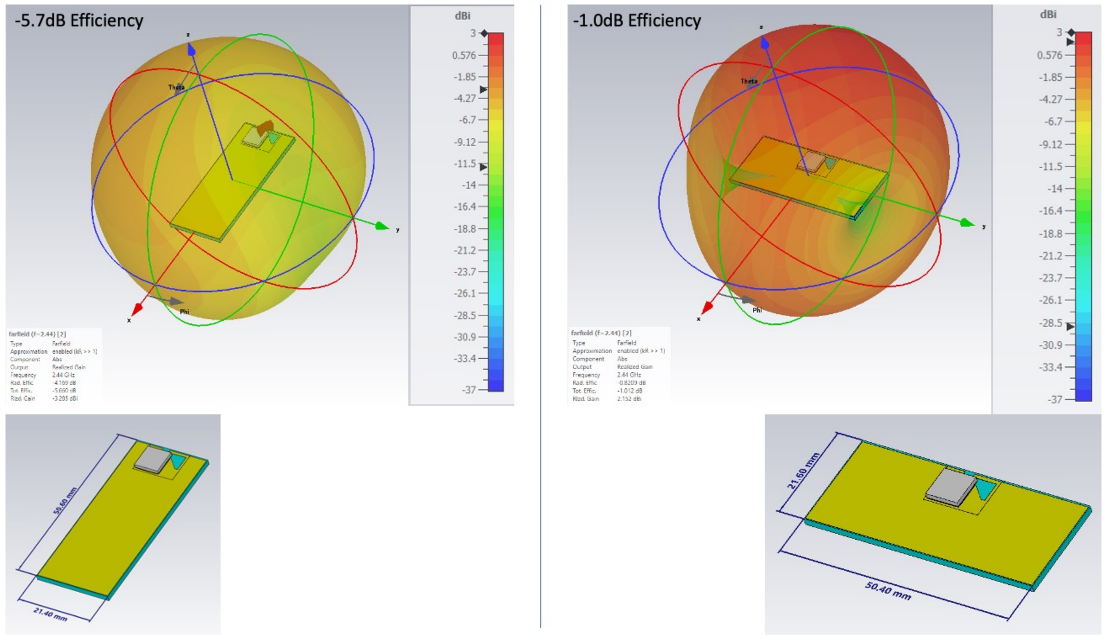
# Three Expert Rules of Antenna Design for Bluetooth Devices

To drive the most RF performance from your Silicon Labs antenna-integrated SiP module, follow these three expert rules. It allows you to reduce the device size without compromising antenna efficiency.

## 1. Placement

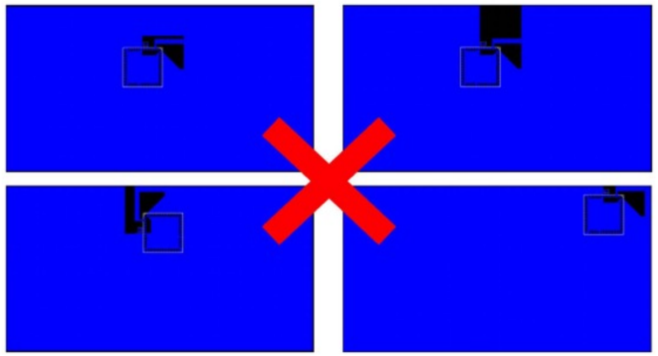
Suboptimal placement of the SiP module is one of the most common design mistakes that can deteriorate the antenna efficiency of your IoT device. Two PCB boards of the same dimensions and size can have significant differences in the antenna efficiency depending on how the SiP modules are placed.

The simulation example below shows a suboptimal placement of the SiP module, reducing antenna efficiency radically (-5.7 dB) compared to an optimal placement, which delivers an exceptionally high efficiency of -1.0 dB.

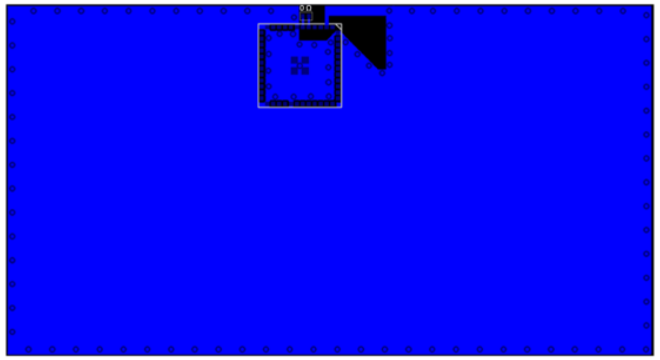



***Left: SiP module placed on the short edge of a narrow PCB reducing antenna efficiency. Right: The SiP module is placed on the long edge of a narrow PCB delivering exceptional antenna efficiency.***

By following Silicon Labs' guidelines for how to place the SiP module on the PCB, you can increase the antenna efficiency and achieve better Bluetooth connectivity.



**Examples of suboptimal layouts.**

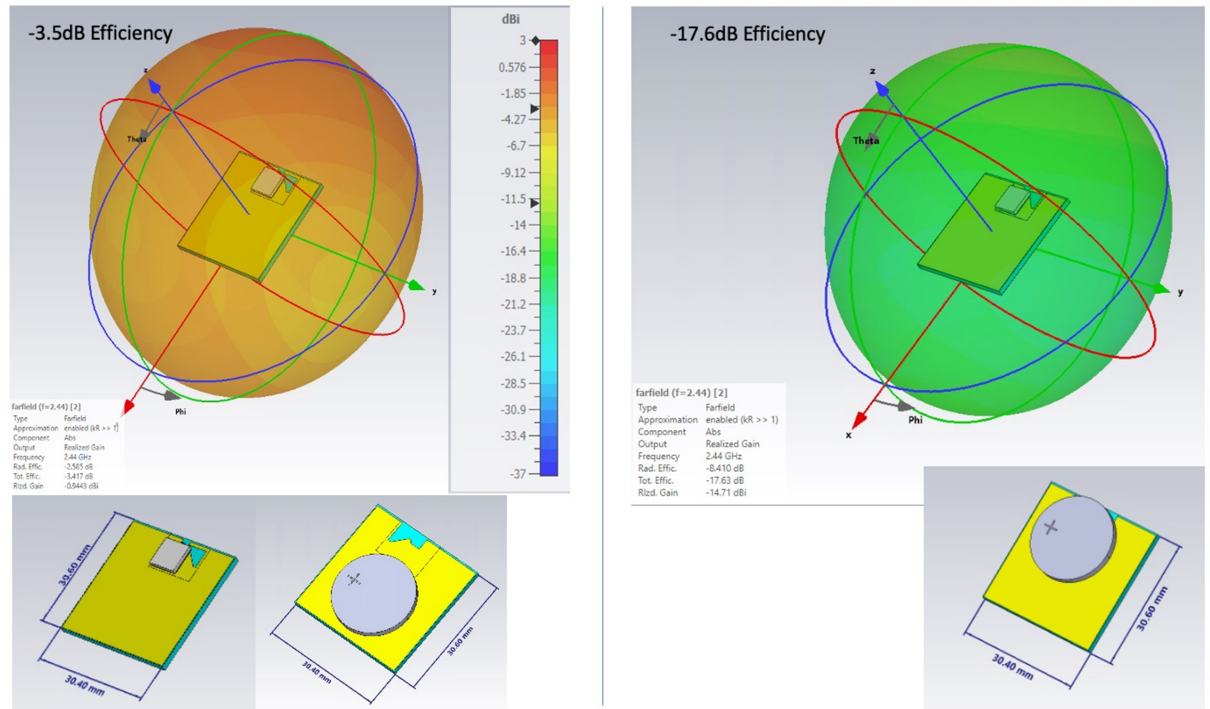


**Recommended layout.**

## 2. Clearance

Every designer knows that the manufacturer's clearance area guidelines must be respected to achieve optimal antenna efficiency, even though it can increase the device size significantly. The same rule applies to the SiP modules with an integrated antenna. However, a less known fact, and a common antenna design mistake, is, that while the PCB surface is kept free of components within the clearance area, a metallic part such as a coin cell battery is placed underneath the clearance area.

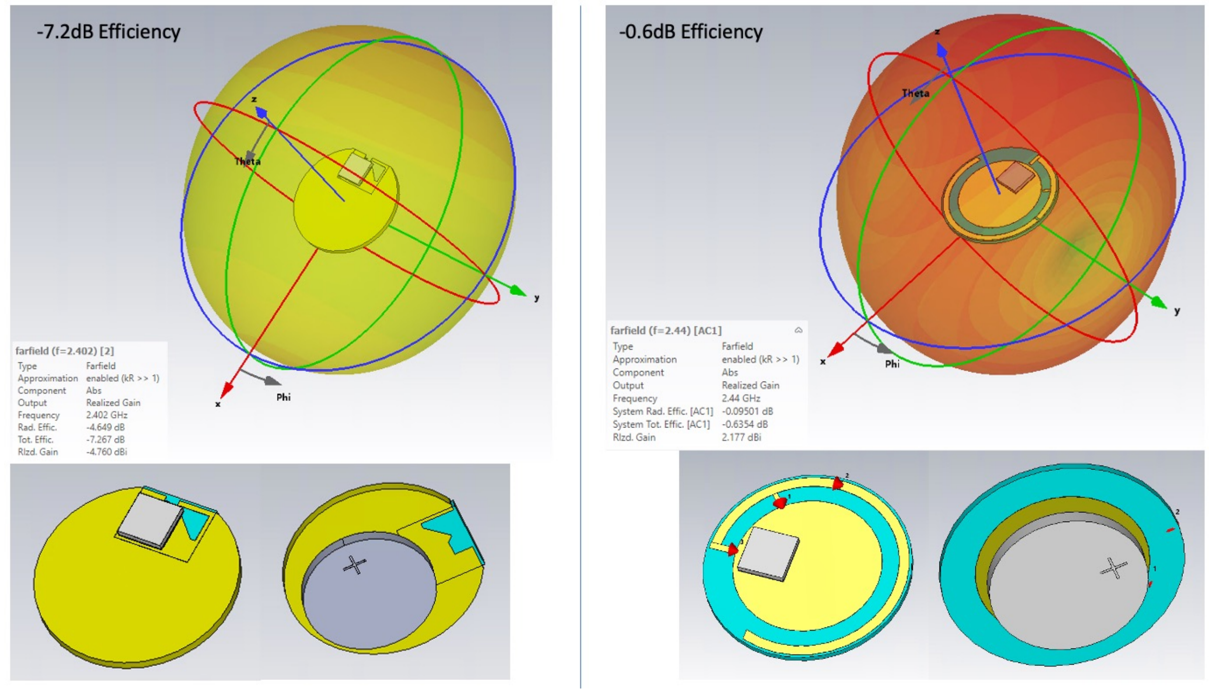
The simulation visualization below compares an antenna design where this rule was violated, and a (metallic) coin cell battery was placed underneath the clearance area, resulting in an inferior antenna efficiency of -17.6 dB. An alternative design that respects the clearance area (even underneath the PCB) delivers remarkably higher efficiency, -3.5 dB.




***Left: The clearance area is respected, delivering optimal efficiency. Right: A metallic part (coin cell) placed underneath the clearance area, deteriorating antenna efficiency.***

## 3. Custom-designed Antenna

Small IoT devices are particularly challenging for designers because the antenna integrated with the SiP module uses an edge of the PCB for emitting radiation. However, if the edges are too short, optimal antenna efficiency cannot be achieved. In these cases, the internal antenna of the SiP module is not viable, and you must consider an external custom-designed antenna integrated into the housing of your IoT device and connect it to the Bluetooth SiP module via e.g., a U.FI connector.




***Left: An internal antenna used in a device that is too small to cater to the layout guidelines, reducing RF efficiency. Right: A custom-designed external antenna optimized for the extremely small size, delivering outstanding RF efficiency.***

## About the Authors

Pasi Rahikkala is a Senior System Engineer at Silicon Labs, focusing on antenna and RF design. Rahikkala has 17 years of wireless engineering experience from global tech companies. Rahikkala holds several patents in antennas for wireless modules.

Mikko Nurmimaki is a Senior Marketing Manager at Silicon Labs, focusing on smart home, medical, and wearables application segments. Nurmimaki has 20 years of marketing experience with several world-leading tech brands in the wireless industry.

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