How to overcome RF design challenges

A practical guide for engineers, project owners, and decision makers

Radiofrequency (RF) systems are the backbone of modern wireless communication, supporting a wide range of applications from smart meters, industrial sensors, and tracking devices to building automation, medical equipment, and consumer electronics, including wearables, smartphones, Wi-Fi equipment, and smart-home devices.

Yet RF design is often perceived as a “dark art” – complex, risky, hard to debug, and prone to errors. Moreover, mistakes can remain undiscovered until late in the project when changes are expensive.

Fortunately, today’s product design teams have many options that can save bringing-up RF circuits from first principles. Wireless modules and wireless microcontroller system-in-package devices simplify and accelerate the most fundamental aspects of designing RF communication systems. These devices, supported with ready-to-use software, development boards, tools, and reference designs, help teams target industry standards such as Bluetooth, NB-IoT, LoRaWAN, Zigbee, Thread, wM-Bus, and Mioty. They can also be used with proprietary protocols like KNX RF and others.

While these devices abstract OEMs’ engineering teams from many complex RF design challenges, success demands attention to details such as impedance matching, circuit layout, and antenna selection and placement. Because constraints such as power consumption, physical size, and bill-of-materials (BOM) are typically extremely tight, careful attention here can deliver a competitive edge in the marketplace.

To help understand how to use these modules to quickly build systems that meet wireless specifications, pass certification testing, and deliver a competitive edge in the marketplace, this paper explains:

- What an RF system is and how it works (at a high level, no deep math required).
- Key performance metrics (sensitivity, selectivity, link budget, antenna efficiency) and why they matter to range, reliability, and battery life.
- Where RF design impacts business metrics:
  - Time-to-market
  - Certification risk (ETSI, regulatory)
  - BOM cost and margin
  - Power consumption and battery life
  - Product quality and field returns

The paper presents real design examples showing that small adjustments can lower BOM costs and reduce circuit footprint, while also achieving better current consumption and longer battery life.

Current and future RF trends are discussed, including sub-GHz, Bluetooth® LE, multi-protocol connectivity, and ecosystem support.

Readers will also learn how STMicroelectronics helps reduce RF design risk with integrated transceivers, reference designs, tools, and ecosystem partners.

This document is written for:

- RF engineers, providing a structured technical framework.
- Project managers, helping understand RF-related risks, tradeoffs, and milestones.
- Executives and financial roles, showing how RF choices translate into business value and total cost of ownership (TCO) advantage.

What is an RF system, and why it matters for your product

An RF system enables wireless communication between a transmitter (point A) and a receiver (point B) through an antenna, using electromagnetic waves. In practice, these connections may be point-to-point connections between individual devices, point-to-multipoint connections designed to distribute or aggregate data, or networked connections between peer devices. This paper focuses only on optimizing the performance of RF front-end circuitry and not the topology, which is managed at a higher level.

An RF design is successful when the message decoded at the receiver matches the transmitted message within an acceptable error rate (e.g., one wrong bit per hundred packets), under real-world conditions and regulatory constraints. Real-world conditions can include challenges such as interfering or blocking signals, as well as effects like multipath and attenuation. These can result from atmospheric conditions such as airborne water droplets, buildings, trees, and other objects in the environment that reflect, scatter, and absorb signal energy.

Regulatory constraints tend to be focused on maximizing availability of the licensed RF spectrum for as many users as possible. The principle constraints tend to place limits on maximum transmitted power and use of bandwidth, as well as mandating efficient use of the allocated radio spectrum.

Within this, there is scope for the system to be more successful, or less, depending on the components and circuit designs and the skill of the engineering team in bringing them together. The underlying challenge is to ensure that the circuit will convert the highest possible proportion of the electrical energy supplied into RF energy radiated from the antenna.

Transmitter priorities

Matching the impedances of the antenna and amplifier is critical to create resonance and thereby maximize the transfer of signal energy from one to the other. This applies both in the transmitting and the receiving circuits and is influenced by the component values and parasitic effects of the electrical connections.

When building a system using a radio module, which is the typical approach in modern wireless equipment design, managing the signal path lengths, circuit layout, and component selection to ensure optimal matching is the key challenge that determines success, as we shall see later in the examples section.

Getting this matching right creates an efficient system capable of radiating signals throughout the desired area using the minimum electrical energy. In a battery-powered device, this may lead to longer recharge or replacement intervals. On the other hand, if extreme space constraints apply, the more successful design may be the one capable of operating for an acceptable duration, with a smaller battery.

The receiver

It takes two to tango, as they say. Hence, the receiver also requires careful design to capture and convert the RF signal energy efficiently into electrical signals corresponding to the original message; the digital packets presented for transmission. As is the case with the transmitter, impedance matching between the antenna and receiving circuit is crucial.

There are two additional important metrics of receiver performance: sensitivity and selectivity. Sensitivity expresses the lowest signal strength the receiver system can detect. High sensitivity in the receiver can allow lower transmitter power or longer communication range. Selectivity expresses the receiver system’s ability to exclude RF signals and noise at frequencies outside the desired receiving range and is achieved by filtering. Bandpass filters are typically used to select signals within the target frequency band and reject out-of-band blockers and adjacent-band signals.

Signs of success

A well-implemented RF system can deliver longer range and larger coverage area than a less careful design, while operating within regulatory limits – particularly the maximum allowable transmitted radio power. Similarly, a well-implemented system can experience a lower error rate, minimizing demands from the receive side for the transmitter to resend data. Users can experience this as faster pairing between Bluetooth devices, faster completion of data exchanges, and smoother audio through wireless headphones.

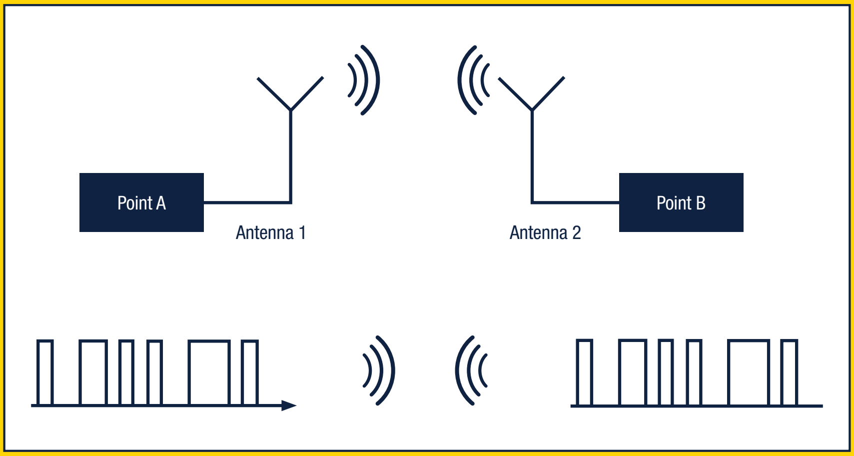
These superior user experiences create the perception of greater end-product quality and can drive better product reviews while building customer loyalty.

For the business, this directly translates into:

- Coverage and range: number of devices per gateway, installation flexibility, customer experience.
- Reliability and robustness: fewer re-transmissions, less support, higher perceived quality.
- Battery life and maintenance cost: centerpiece for IoT and remote devices.
- Compliance and certification: ability to sell and deploy in target markets without delays.

Note that this paper concentrates solely on the RF system circuitry, excluding aspects such as application-level processing, protocol handling, and baseband signal conditioning.

CORE ELEMENTS OF AN RF SYSTEM



Transmitter

- Creates an analog baseband signal from digital data.
- Modulates and converts it to radio frequency.
- Amplifies, matches, and filters the signal before radiation.

Receiver

- Amplifies the typically weak received signal.
- Filters and down-converts it back to baseband.
- Converts to digital form for decoding.

Antenna

- In transmit mode: converts electrical energy from the transmitter into electromagnetic energy radiated into the surrounding space.
- In receive mode: converts electromagnetic energy back into electrical signals.
- Antenna efficiency and impedance matching between the antenna and transmitter or receiver directly affect range and power consumption.

Transceiver

- A single component that integrates both transmitter and receiver.
- Uses a frequency synthesizer (local oscillator + reference clock) shared by TX/RX.
- In ST platforms, this is implemented with simplified, highly integrated architectures that reduce BOM and design complexity.

Key RF concepts for engineers and managers

Receiver sensitivity and selectivity

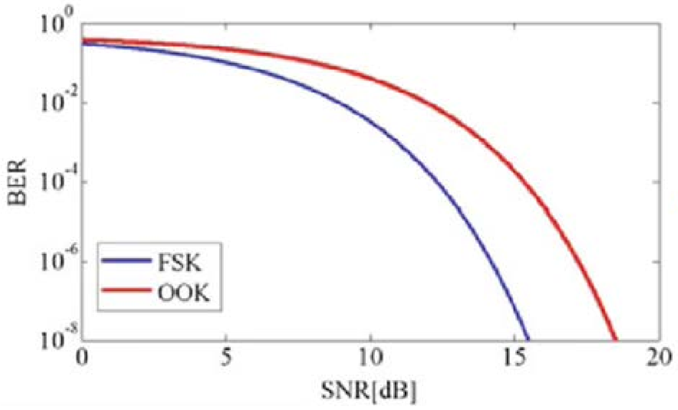
Sensitivity is the minimum input power at which the receiver can correctly decode data, with acceptably few errors, or bit error rate (BER). A typical maximum BER is 0.1%, or 10^{-3}, as stated in ETSI documents. Receiver sensitivity is quoted in dBm.

The RF signal power reaching the receiver input depends on the energy captured from the air by the antenna. This, in turn, depends on the distance from the transmitting antenna and the power and pattern of the radiated RF signal, as well as the channel conditions. Hence, receiver sensitivity is a key factor determining the communication range of the system and the transmitter battery life. The RF signal power reaching the receiver antenna also depends on the effectiveness of the matching network between the antenna and receiver.

Moreover, the input signal power needed to achieve the target BER depends on the quantity of noise and jitter in the receiver system. Low noise in the receiver is directly related to the quality of the design, including the circuit layout, as well as the components used.

Choosing a module that is known to be well designed and efficient, with adequate sensitivity for the target application, is often preferred over designing a receiver in-house. Bringing up a receiver or transmitter in-house requires deep RF design expertise.

The required power also depends on the signal modulation format; in particular, the signal-to-noise ratio (SNR) needed to achieve the target BER. The diagram below compares frequency shift keying (FSK) and on-off keying (OOK) modulation formats, showing that FSK modulation can achieve a given BER with less signal power or in the presence of greater noise. Hence, FSK is considered to be more robust than OOK.



Business impact

Better sensitivity means:

- Longer range or fewer gateways and repeaters.
- More robust communication in noisy or obstructed environments.
- Potentially lower transmitter power for the same range, resulting in longer battery life.

POWER IN DBM: THE “CURRENCY” OF RF

Engineers use dBm (literally: decibels relative to one milliwatt) to express power on a logarithmic scale, which makes gains and losses easy to add or subtract.

Example:

- Amplifier output power measured at antenna input: 16 dBm
- Antenna loss: 3 dB
- Radiated power: 16 dBm – 3 dB = 13 dBm

Power in dBm is an absolute value referenced to 1 mW, where 0 dBm = 1 mW while +10 dBm = 10 mW and -10 dBm = 0.1 mW.

On the other hand, dB is a relative term. In the example above, the antenna loss of 3 dB is not dependent on any value of input power. Similarly, the gain of an amplifier (ratio of output to input power) is expressed in dB, while the measured power of the output signal would be stated in dBm.

WHY IT MATTERS FOR NON-ENGINEERS

In practical terms, every dB lost through inefficiency in the RF system translates into reduced communication range or shortened battery life. Improving the system performance by +1 or +2 dB is difficult and costly. On the other hand, 3–4 dB can be easily lost, especially if the antenna or matching are poor.

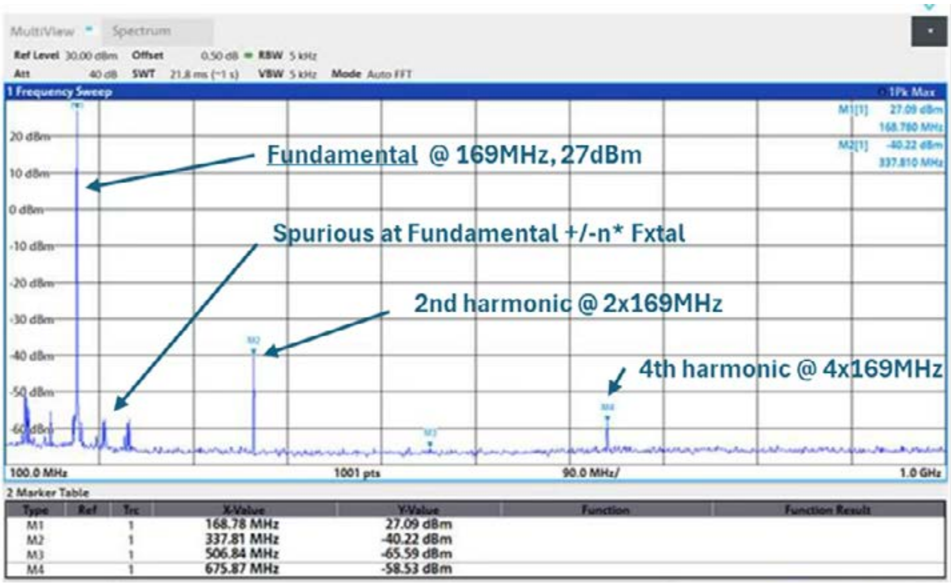
Selectivity measures how well the receiver performs in the presence of strong interferers. These may be signals in adjacent channels at nearby frequencies, or out-of-band blockers. Regulatory documents such as ETSI, Wireless M-Bus, and others define categories based on selectivity for critical applications, such as medical systems and metering.

Business impact

- Poor selectivity leaves a receiver vulnerable to interference problems, since out-of-band signals are less attenuated. And can result in packet loss, unpredictable field behavior, and excessive support calls.
- Good selectivity, on the other hand, can deliver predictable performance even in crowded RF bands such as 2.4 GHz and sub-GHz ISM frequencies.

Transmitter output power and harmonics

A transmitter is characterized by the fundamental output power, which refers to the wanted signal, as well as spurious emissions including, intermodulation products and harmonics at multiples of the carrier frequency. Regulations impose strict limits on spurious emissions.



Ref Level 30.00 dBm Offset 0.50 dB RBW 5 kHz
Att 40 dB SWT 21.8 ms (~1 s) VBW 5 kHz Mode Auto FFT

M1[1] 27.09 dBm 168.780 MHz
M2[1] -40.22 dBm 337.810 MHz

Fundamental @ 169MHz, 27dBm

Spurious at Fundamental +/-n* Fxtal

2nd harmonic @ 2x169MHz

4th harmonic @ 4x169MHz

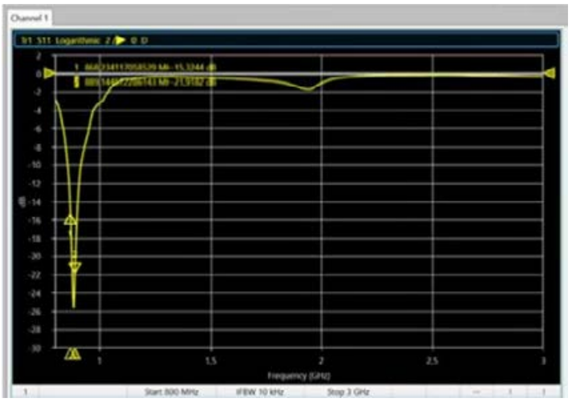
2 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	168.78 MHz	27.09 dBm		
M2		1	337.81 MHz	-40.22 dBm		
M3		1	506.84 MHz	-65.59 dBm		
M4		1	675.87 MHz	-58.53 dBm		

Why this matters to management & finance

Passing certification according to applicable standards, such as ETSI, FCC, and others, depends on the levels of spurious signals detected. Over-filtering can increase both BOM cost and insertion losses, translating into reduced output power. On the other hand, under-filtering risks failing compliance, causing redesigns, delays, and extra redesign cycles in the laboratory.

The Antenna



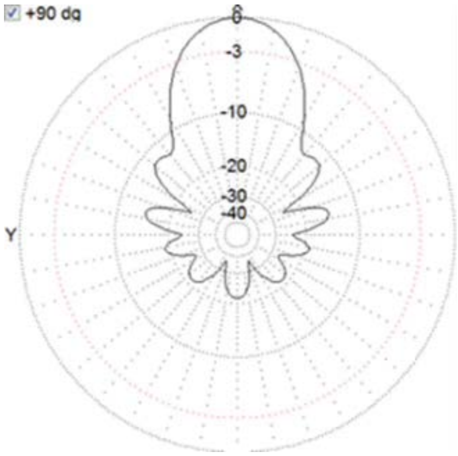
The importance of the antenna is often overlooked. As a precision RF component, the antenna has critical characteristics, including its resonant frequency and bandwidth. The resonant frequency must be tuned to the operating RF band with minimal loss.

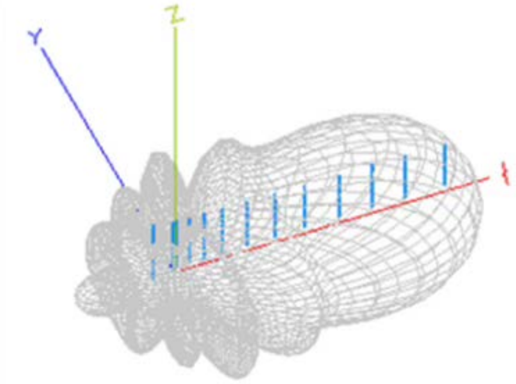
The antenna impedance is often not naturally 50 Ω, which is the typical impedance of the connected transmitter or receiver. This is one of the main reasons an RF system will require a matching network. Another key parameter is the return loss, which indicates how much power is reflected instead of radiated from the antenna. The return loss is also referred to as the scattering parameter, S11, which compares the energy entering and leaving the port.

Moreover, directivity, efficiency, and gain are important characteristics that directly affect the antenna’s effectiveness.

Directivity refers to the orientation or shape of the radiation pattern in space. The radiated energy is distributed throughout this entire volume. A highly directional antenna can produce a strong signal within a narrowly defined space, while a broader radiation pattern can allow more uniform coverage throughout the surrounding space.

Efficiency quantifies the proportion of power input to the antenna that is actually radiated. The gain is a composite of directivity and efficiency, referenced to a standard antenna.





Choosing an off-the-shelf antenna is typical. Selection is constrained by factors such as the physical size of the end product and whether the antenna can be mounted externally or must be contained within the enclosure. The connections to the antenna, which may be PCB traces or a cable, must be considered as part of impedance matching, and a clearance area is required if the antenna is mounted on the PCB.

Antenna selection and positioning warrant careful consideration, and several iterations may be needed to optimize performance. Simulation tools are available in the market to help with this.

For the business

- A poorly tuned antenna can waste 3–6 dB or more, equivalent to cutting range by half or more, or significantly shortening battery lifetime by demanding more energy for extra power to overcome the loss.
- Antenna and matching are often the easiest and most cost-effective aspects to adjust in order to improve product performance without changing silicon.

RF link budget

Calculating the RF link budget lets engineers understand the system's real-world range, aggregating all gains and losses between the transmitter and receiver. These include signal energy lost in the electrical system between the transmitter output and the transmitting antenna, between the receiving antenna and the receiver electronics, and the channel in between (ideally, this is free space but there can be obstructions such as buildings, structures such as walls, and various objects including the human body that can absorb or deflect the signal energy).

If power in dBm is the currency of RF, the link budget determines the system's maximum allowable "spend" for the transmitted signal to reach the receiver input with enough power remaining to exceed the sensitivity threshold.

If:

- P_{tx} : Transmitter power
- G_{tx}, G_{rx} : TX/RX antenna gains
- FSPL : Free Space Path Loss
- P_{rx} : Power at receiver input
- S : Receiver sensitivity

Then communication is possible if:

$$P_{rx} = P_{tx} + G_{tx} - \mathrm{FSPL} + G_{rx} > S$$

The link budget is often defined as:

$$\text{Link budget} = P_{tx} - S + G_{tx} + G_{rx}$$

Using this and the FSPL formula, one can estimate the maximum theoretical range in free space, then adjust for realistic conditions. Clearly, this must be an approximation, as the conditions will differ depending on the environment: in built-up urban areas, inside buildings, or a device such as a smartphone or keyfob operating while in a pocket or bag.

Example: Impact of RF link budget degradation

For a given line-of-sight scenario

RF link budget degradation	Typical distance (LoS)
0 dB (baseline)	7.1 km
–1 dB	6.4 km
–2 dB	5.9 km
–3 dB	5.4 km
–6 dB	4.1 km
–10 dB	2.8 km

Interpretation for non-engineers

- Losing 3–6 dB can easily happen due to a poor antenna or bad filtering and can reduce the potential coverage by as much as half.
- Optimizing the system design to improve the link budget by even 1–2 dB is difficult and may call for increased transmitter power or a higher-performing transceiver. Changes like these can increase system power consumption and add to the bill of materials. Expensive engineering changes, such as adjustments to the circuit-board layout, may be required, which can be costly and introduce unwanted delays if discovered late in the project.

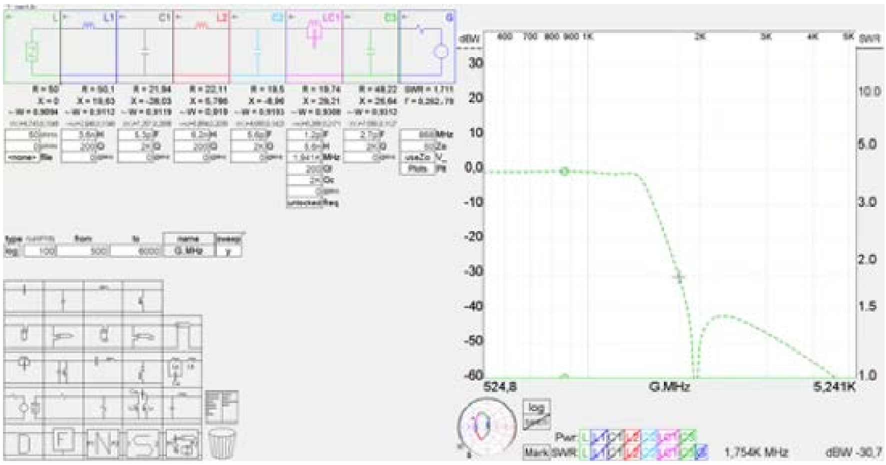
Impedance matching and filtering: where RF designs win or lose

Impedance adaptation between RF blocks (transceiver ⟷ matching network ⟷ antenna) is essential. If the respective impedances of the transceiver and antenna are different, a proportion of the signal energy moving between the two will be reflected, causing losses and distortion. Impedance matching is therefore needed:

- To maximize power transfer.
- To filter undesired signals (low-pass, high-pass, band-pass, notches).
- To balance:
  - Output power.
  - Spurious suppression.
  - Receiver sensitivity.

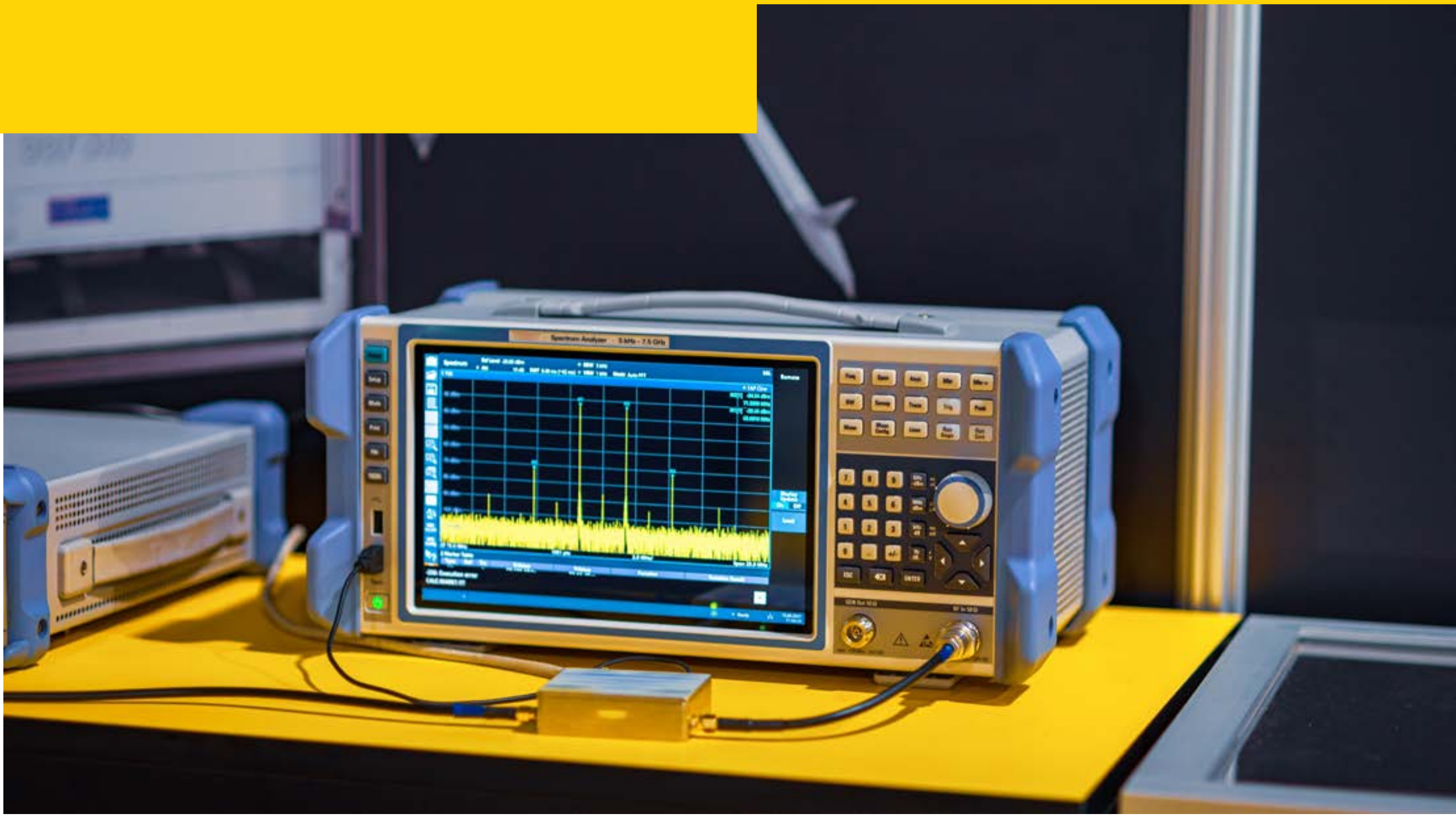
Matching and filtering calls for a network of components, comprising inductors (typically nH values) and capacitors (typically pF values). Each of these components has tolerances and quality factor (Q) that must be borne in mind when designing. Broadly speaking, wirewound inductors have high Q and good RF performance and are relatively expensive, while multilayer inductors are cheaper with lower Q and greater losses.

ST's RF ecosystem provides tools such as Smith-chart-based matching calculators and reference designs to help users choose appropriate topologies and values.



In addition, ST has a portfolio of chip-scale devices (baluns) for antenna matching that are pre-optimized for use with specific modules and STM32 wireless microcontrollers. They are fabricated on a non-conductive glass substrate using proprietary integrated passive device (IPD) technology. These devices simplify circuit design, have a greatly reduced footprint compared to a network of discrete components, and can reduce the bill of materials.

Real-world examples



ST's RF experts can directly assist customers by providing engineering advice that can deliver savings and meet system performance goals through RF optimization.

Sub-GHz BOM optimization: fewer components, better output power

Scenario

Sub-GHz radio systems can offer relatively long range, sometimes several hundred meters or over a kilometer, and operate in unlicensed frequency bands. They are frequently used in outdoor applications, such as weather sensors, traffic sensors, soil monitors, animal health monitors, and remote garage door openers. The **STM32WL3 wireless microcontrollers** are ideal for these applications.

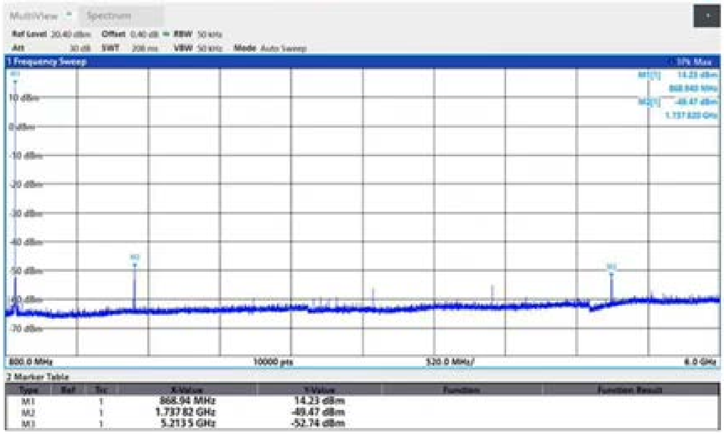
A customer developing a sub-GHz radio system sought improvements to reduce the number and cost of filtering components in the transmitter, to lower the overall BOM cost and reduce the PCB area, while still meeting harmonic rejection requirements.

Using two series LC low-pass cells, one LC notch filter, and one final shunt capacitor, the customer's design achieves >20 dB margin on the 2nd harmonic. Simulation shows >30 dB attenuation on the 2nd harmonic, indicating a strong design that safely surpasses certification requirements. However, the design uses wire-wound inductors that have high Q and are relatively expensive.

To adjust the design for lower BOM cost while ensuring certifiable performance, the team was able to remove one series LC cell, switch from wire-wound to lower-cost multilayer inductors, and re-tune remaining components.

With better than 12 dB margin over the RF standard limit, the design remains comfortably compliant. Removing the LC cell lowered insertion loss, leading to a +1 dB measured increase in output power. The changes achieved the desired goal, lowering BOM cost and reducing PCB area.

Original BOM

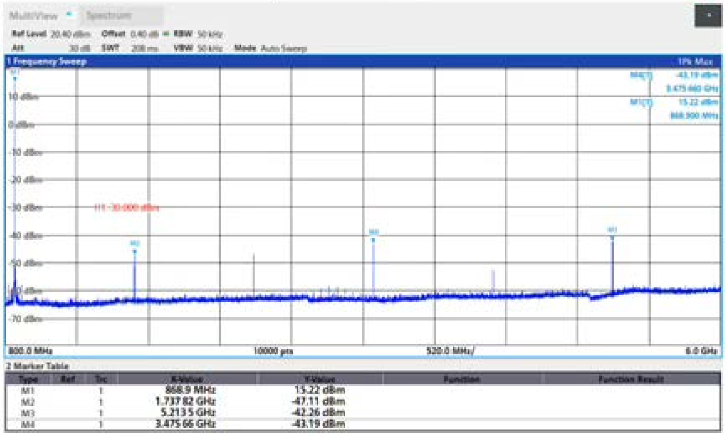


Ref Level 20.40 dBm Offset 0.40 dB ● RBW 50 kHz
Att 30 dB SWT 208 ms VBW 50 kHz Mode Auto Sweep

2 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	868.94 MHz	14.23 dBm		
M2		1	1.737 82 GHz	-49.47 dBm		
M3		1	5.213 5 GHz	-52.74 dBm		

Optimized BOM



Ref Level 20.40 dBm Offset 0.40 dB ● RBW 50 kHz
Att 30 dB SWT 208 ms VBW 50 kHz Mode Auto Sweep

2 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	868.9 MHz	15.22 dBm		
M2		1	1.737 82 GHz	-47.11 dBm		
M3		1	5.213 5 GHz	-42.26 dBm		
M4		1	3.475 66 GHz	-43.19 dBm		

Business takeaway

Leveraging simulation and ST reference architectures can:

- Cut component count.
- Preserve regulatory margin.
- Improve performance.
- Reduce total product cost.

Bluetooth LE Current consumption optimization: longer battery life via antenna tuning

Scenario

Devices like wearables, trackers, hearing aids, smart home devices, and many others must offer Bluetooth LE connectivity to let users interact through their smartphones. This is important because a smartphone app is the universally expected interface for setting up the device, routine interactions like viewing the dashboard, connecting to the cloud, and updating firmware. In devices like these, the battery runtime is often among the main selection criteria for end users, as a longer recharge interval promises greater convenience and portability.

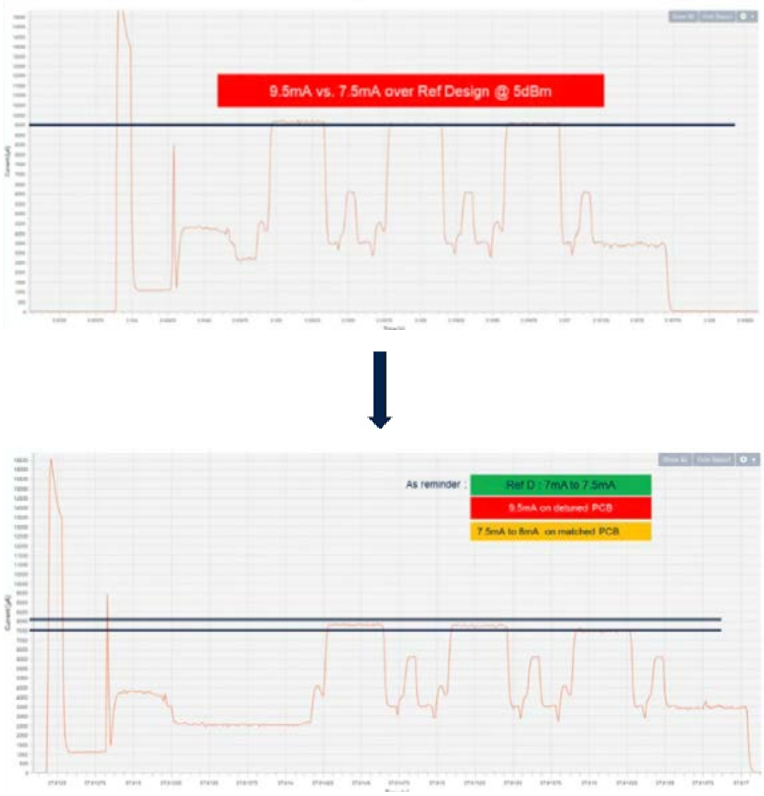
ST's **STM32WB0 integrated wireless MCU** contains a 2.4 GHz radio transceiver and Arm® Cortex®-M0+ microcontroller in the same package. Certified for Bluetooth LE, the wireless MCU features a compact, energy-efficient design and has best-in-class power consumption suited to energy-sensitive wireless applications.

An ST customer developing a new wireless product with Bluetooth LE running on the STM32WB0 sought to extend the runtime by significantly reducing the system power demand. To help achieve this, ST engineers began by investigating the current consumption in transmit mode. Tests showed the current to be about 9.5 mA, whereas ST's reference design had shown transmit current of about 7.5 mA under similar operating conditions. ST's own experience therefore showed that reducing the transmit current by approximately 25% should be possible.

Remedial work began by focusing attention on the customer's PCB, and the antenna and matching network in particular. Measuring S11 at the antenna input with the customer's original inductor-capacitor (L-C) matching network highlighted a large mismatch between the antenna resonance and the Bluetooth LE frequency band.

The team re-tuned the antenna matching (L, C) components, bringing the antenna resonance into the Bluetooth LE band. The changes improved both the effective radiation and the return loss.

This work successfully reduced the transmit current to a value similar to that seen in ST's reference design. Also, the battery life improved to fulfill the original expectations. This was achieved without making any changes to the Bluetooth LE transceiver chip or the board layout. The only adjustments were to the values of passive components in the matching network.



Business takeaway

- Antenna and matching are key levers for battery life and RF performance.
- Fine-tuning and optimization, guided by ST's experienced support teams, can deliver double-digit savings in current consumption without redesigning the entire product.

Sub-GHz BOM re-tuning to pass RF certification

Scenario

Sometimes, although a proven reference design may already be available, other constraints may prevent product developers from reusing the design exactly.

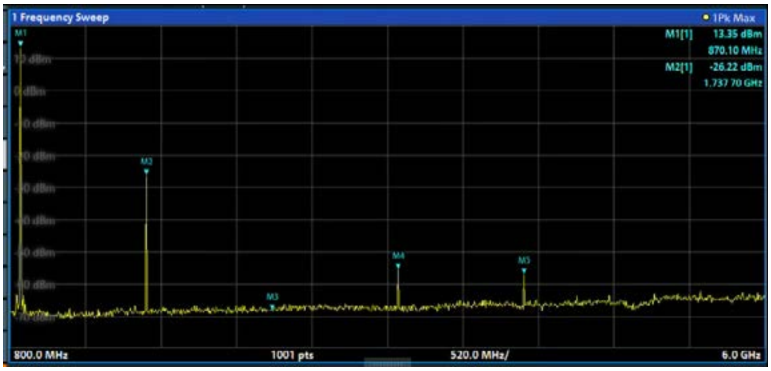
One ST customer had produced a design using an exotic PCB stack-up that differed significantly from the recommended reference design and produced unwanted effects in the RF system. In particular, the difference in the PCB parasitic capacitances caused antenna de-tuning.

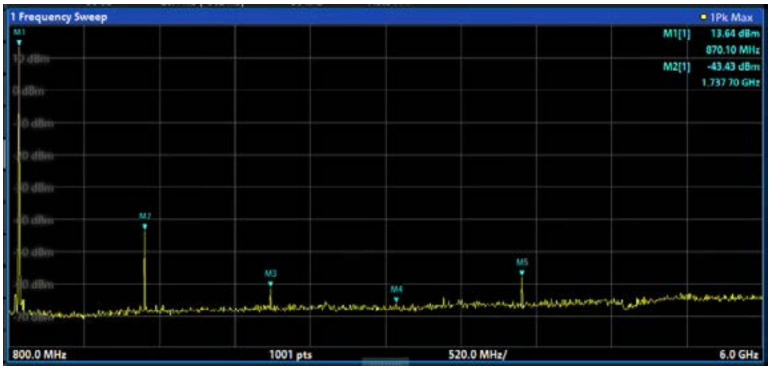
Measurements on the original system showed the RF output power to be lower than expected and the 2nd harmonic to be above the allowable maximum of -30 dBm according to ETSI specifications.

Specifically, the output power was 13.3 dBm and the 2nd harmonic was about -26 dBm. In comparison, ST's reference design demonstrated output power of 14 dBm with a 2nd harmonic below -40 dBm. This is well within the ETSI limit.

Investigation focused on optimizing component values in the transmit chain to compensate for the difference in parasitic capacitance between the customer PCB and the reference design. ST designed a notch filter to attenuate the 2nd and 3rd harmonics, adjusting L-C values to optimally center the filter's frequency response. Subsequent validation checked the impact on both output power and all harmonic levels up to 6 GHz.

This brought the 2nd harmonic within specified limits, with a generous margin of more than 10 dB, and aligned the performance of the customer's design with the ST reference design. Testing showed zero unintended effects on other harmonic frequencies.

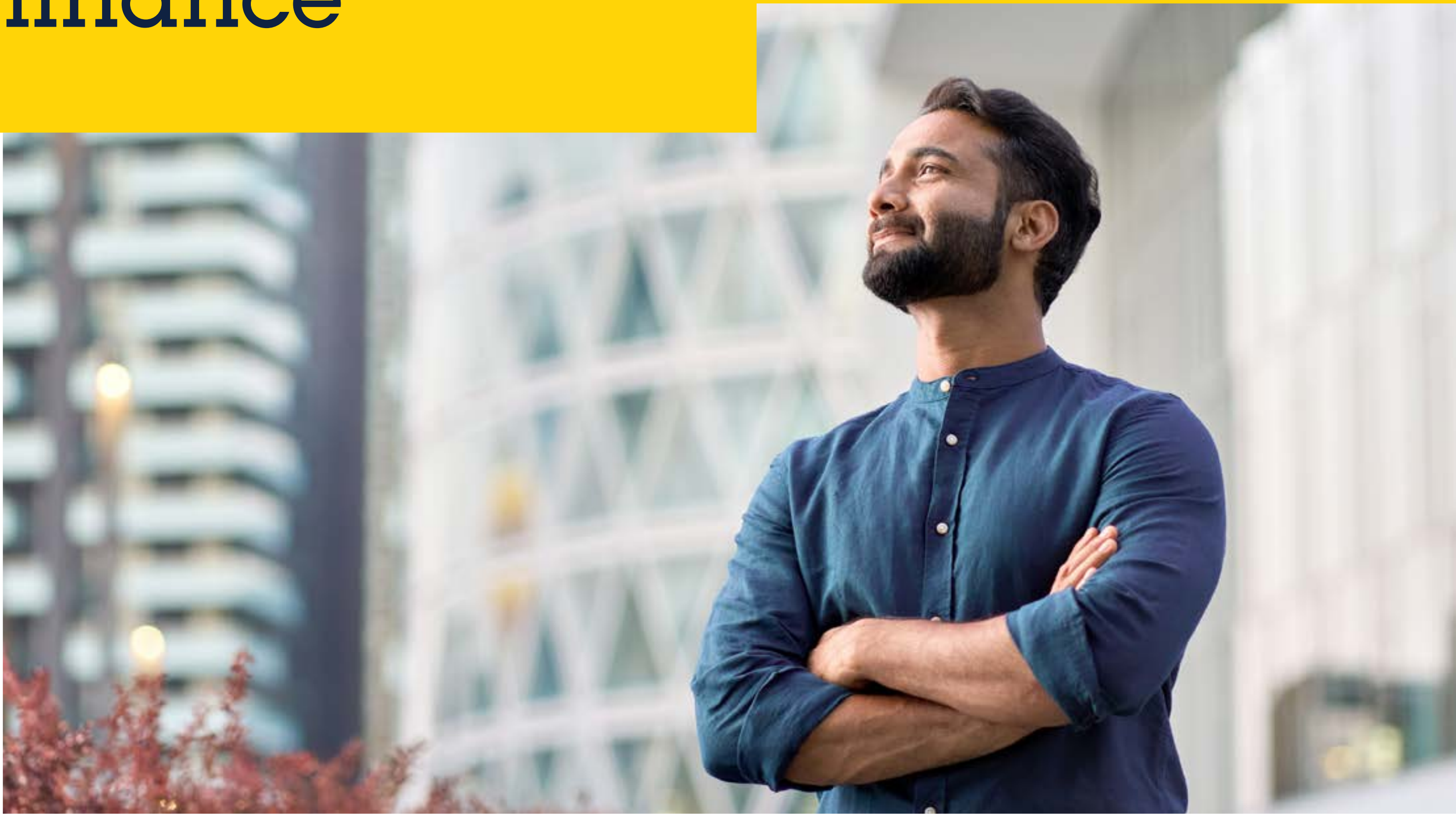




Business takeaway

- The customer's PCB became fully compliant with applicable ETSI RF standards.
- BOM re-tuning saved time and money by:
  - Retaining the customer's originally desired PCB structure.
  - Accelerating final certification at official test house.

Why RF design matters to project managers, CEOs, and finance



Time-to-market and project risk

Poor RF design often surfaces late when design changes can be expensive to implement and can introduce delays.

In the test house

Ideally, certification testing should validate the design, confirming that all requirements have been met and that a certificate can be awarded. An appointment with an independent test house is expensive, and sub-standard results are unwelcome at this stage.

However, testing is rigorous – of course – and will reveal any aspects where the product fails to conform. The tests may discover spurious effects, excessive harmonics, or out-of-band emissions from the transmitter, or inadequate selectivity or sensitivity in the receiver.

Going “back to the lab” to investigate and fix the causes is a serious setback. The cure may be relatively straightforward, such as adjusting the values of filtering or matching components. On the other hand, changes to the layout may involve re-spinning the PCB, which is expensive and time-consuming.

Then the product must be re-presented for testing, which can involve a long wait time for a new appointment and, of course, extra fees.

Failing in field trials

Problems such as insufficient range or interference issues may become apparent during field trials. Field-ready hardware is expensive to produce, much closer to the finished product than a laboratory model. Deploying engineers for field activity is also expensive.

Failure in the customers' hands

Discovering fundamental design issues during certification and testing activities is inconvenient, expensive to remedy, and can result in launch delays and lost sales. However, the consequences are even greater if a problem only comes to light when the product is in the hands of customers. If use of the equipment in a harsh environment or demanding scenario exposes issues here, the expense associated with re-engineering can be small compared to the potential permanent loss of that customer and broader reputational damage.

Mitigation

While modules and system-in-package devices effectively streamline wireless system design, the layout, PCB design, and component values demand careful scrutiny and can involve multiple trial-and-error cycles to perfect.

ST's reference designs are produced through the same approach and embody solutions to the same design challenges the OEM teams would face. A sensible approach is to leverage ST's investment by reusing the reference design accurately without modification. This can save considerable time and effort to solve avoidable issues later in the project, as shown through the examples in section 3:

- Start with proven ST reference designs and evaluation boards.
- Use ST's recommended layout, matching networks, and BOMs.
- Engage ST's FAEs or partners early for design reviews.

Total cost of ownership (TCO)

The Sub-GHz and Bluetooth LE examples described in the previous section show that careful RF optimization can reduce BOM without compromising compliance and improve performance, resulting in higher customer satisfaction.

Proper optimization of the RF circuitry can influence multiple factors affecting the overall cost of ownership:

- BOM cost in terms of the type and number of passives, including inductors, capacitors, and filters, as well as the choice of antenna.
- Manufacturing complexity can be reduced through optimization that minimizes demand for individually adjusting and calibrating each unit in the production area.
- Optimal power efficiency and component selection can ensure operating costs are low, reducing the frequency of battery replacements and other maintenance visits.
- Products that perform strongly in the field deliver savings through reduced customer returns and warranty obligations, as well as enhancing brand reputation.

Strategic positioning

Well-engineered RF designs can become competitive differentiators that win sales and long-term customer loyalty by offering advantages such as longer-range, more reliable links, smaller batteries, and a larger operating envelope with longer recharge or replacement intervals.

ST platforms, such as wireless modules and microcontrollers that can combine connectivity with application processing, let design teams achieve higher integration. This can simplify adding extra high-value features and secure edge processing to protect end users, delivering a competitive advantage, while also facilitating over-the-air firmware updates, thereby simplifying long-term support.

ST's RF ecosystem: today and tomorrow

ST provides a broad set of RF devices that are highly integrated and ready to use, giving users a choice of variants supporting popular industry-standard and proprietary wireless technologies:

- Transceivers and multi-protocol radios including **proprietary Sub-1 GHz products**, **Bluetooth LE application processors**, and **Bluetooth LE network co-processors**
- **STM32 MCUs with integrated wireless connectivity**
- Power management, secure elements, sensing ICs, and **RF integrated passive devices** are all supported within the development ecosystem, helping complete system design and enable broader application-level functions."

Architecturally, ST RF platforms let users take advantage of simplified and optimized RF front-ends and implement critical aspects that can be complex and time-consuming for OEM design teams to accomplish. For example, the devices provide integrated frequency synthesizers based on robust reference clocks (XTAL, TCXO), ensuring accurate RF channels.

In addition, ST reference designs come with validated RF layouts, pre-tuned matching networks, pre-compiled BOM, and certification-ready performance.

Development ecosystem

To lower RF entry barriers, ST and its ecosystem offer:

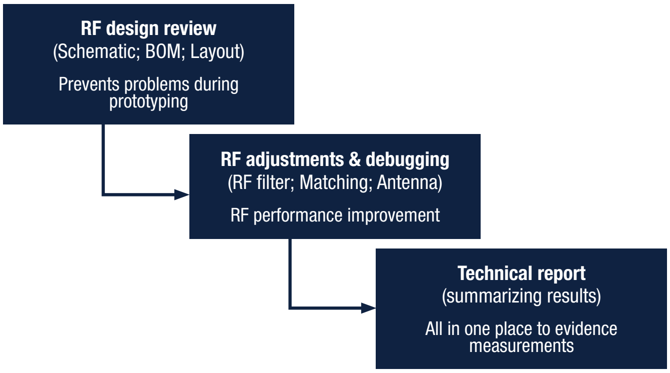
- **Evaluation boards & reference designs**
  - Sub-GHz modules and boards.
  - BLE and multi-protocol boards.
- **Design tools and software**
  - Configuration tools for RF parameters.
  - Example applications and code libraries.
- **Application notes and guidelines**
  - Antenna design and matching.
  - Layout recommendations.
  - Certification guidance.
- **Support & partners**
  - FAEs supporting architecture and RF decisions.
  - Third-party partners for antenna design, certification prep, and RF consulting.

Using this ecosystem, customers can accelerate prototype development, freeze the design quickly, pass certification testing efficiently, and move into mass production.

ST support process

Of course, ST provides support for product developers using these platforms, with assistance accessible throughout all phases of the project. Support services cover preliminary discussions to determine performance requirements, all the way to pre-certification.

The three-step structure illustrated here helps to visualize the support for customers' workflows, from RF architecture choice, hardware reviews (schematics / layout), RF bring-up, and a complete technical report to summarize the results.



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Or contact your local ST representative: **https://www.st.com/content/st_com/en/contact-us.html**

Current trends in RF design

Sub-GHz LPWAN & metering

Benefiting from long-range and low power consumption, sub-GHz wireless is often preferred for remote smart metering, industrial monitoring, and infrastructure. Key strengths include ultra-low power consumption, high sensitivity, and robust selectivity.

Bluetooth Low Energy (Bluetooth LE) everywhere

With attributes such as long range and low power, mesh-networking, advertising, and localization capabilities, Bluetooth LE is becoming ubiquitous for consumer devices as well as industrial beacons and tags.

Thanks to broad deployment and ease of use, Bluetooth LE is also a convenient protocol for commissioning and configuring devices such as smart bulbs.

Multi-protocol and multi-radio systems

Emerging products increasingly require multiple radios, for example, Bluetooth LE with everything, combined Bluetooth LE and Wi-Fi gateways, dual-interface sub-GHz / Bluetooth LE industrial sensing hubs. This trend is driving demands for integrated front-end devices and demands careful antenna placement and matching.

Higher integration and smaller form factors

Packing more features and boosting performance, within a small space, is a perennial demand. ST's RF modules, System-in-Package (SiP) devices, and System-on-Chip (SoC) ICs reduce design complexity and footprint, and accelerate time to market.

PCB space is at a premium, requiring careful layout of antennas and matching components with creative integration strategies where possible.

Sustainability and ultra-long battery life

Today's concerns about safe battery disposal and operating costs, particularly for large IoT projects, mean devices are increasingly expected to operate for 5–10 years on a single battery. Efficient RF design, ensuring correct impedance matching and antenna selection to maximize the value of every milliamp and every dB.

Future directions

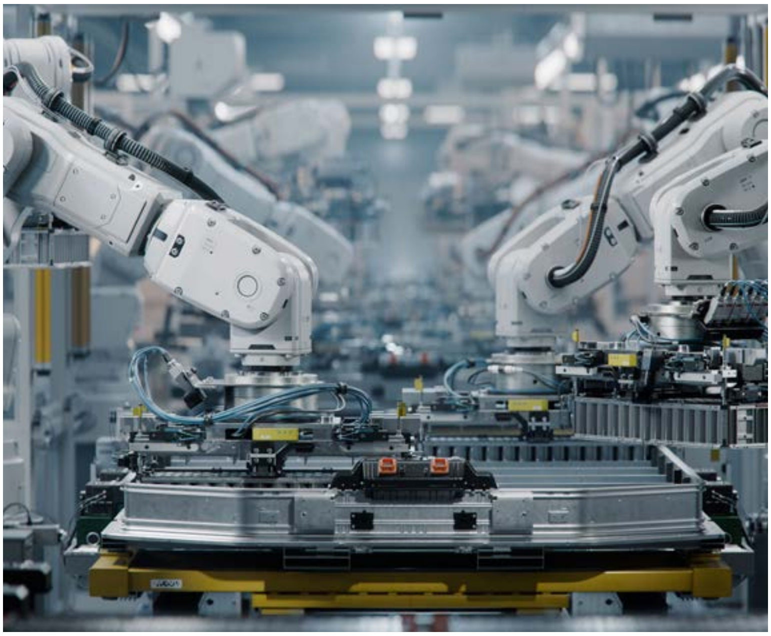
Looking forward, RF design will increasingly focus on more intelligent radios that feature flexibility through adaptive data rates and dynamic power control to save energy while preserving link quality.

In addition, ongoing simplification of RF design will assist non-RF experts, including pre-certified modules and enhanced reference designs where RF decisions are largely pre-made. Design automation, including more powerful tools for simulation and auto-optimization to accelerate matching and layout validation.

Another trend is towards tighter integration with security and edge AI, to ensure state-of-the-art industry-grade protection for IoT, industrial, and medical applications.

ST is investing in the road ahead with:

- New generations of RF-enabled MCUs and SoCs.
- Software frameworks and tools.
- Closer integration with partner ecosystems.



Practical recommendations

For RF engineers

- Start from ST reference designs and do not change RF layout without a clear plan and verification.
- Use ST's recommended BOM and antenna matching as a baseline, then fine-tune with proper RF measurements (S11, radiation pattern, conducted tests).
- Simulate filters and matching networks to avoid over- or under-design.
- Validate early with pre-compliance testing to avoid late surprises.

For project managers

- Allocate explicit milestones for:
  - RF architecture review (with ST or partner).
  - Antenna/matching tuning.
  - Pre-certification testing.
- Treat antenna design and PCB layout as critical path items, not as "just mechanical details".
- Plan for at least one iteration based on RF measurements.

For executives and finance

- Recognize RF design as:
  - A differentiator that can yield greater range, robustness, and battery life for market advantage.
  - A risk due to the mandatory requirement for certification, where success first time is not guaranteed, and the possibility of use in the field to expose shortcomings in performance or reliability. These risks can be mitigated by leveraging ST's ecosystem.
- Balance:
  - Component cost vs. performance (cheap passives can cost more in performance and certification risk).
  - Time-to-market vs. thorough RF validation.
- Consider ST's integrated transceivers and reference designs to:
  - Reduce RF engineering effort.
  - Shorten schedule.
  - Lower TCO over the product life.

CONCLUSION

RF design is known to be challenging and demands extensive technical expertise to bring up a system from first principles. Small decisions in transmitter power, receiver sensitivity, filtering, and especially antenna matching can dramatically affect:

- Range and reliability.
- Power consumption and battery life.
- BOM cost and certification success.

Creating a suitable specification for a system that will perform well in a wide range of environments, which can be approximated but not controlled, calls for informed engineering judgement. While the maximum transmitter power is often limited by radio-authority regulations, achieving the required receiver sensitivity demands low-noise design skills.

A modular approach is more typical, taking advantage of solutions such as ST's pre-validated and pre-certified wireless MCUs and modules, and supporting ecosystem including reference designs, simulation and measurement tools, and software. Note, however, that proper antenna selection and positioning, optimized circuit layout, and correctly calculated filtering and impedance matching between the antenna and transceiver are always essential.

Face-to-face support is also available, and the opportunity to connect with ST online design communities.

By leveraging these resources, design teams with a strong grasp of the fundamentals can overcome RF design challenges, reduce project risk, and deliver differentiated connected products – on time and on budget.

Ready to move forward?

For support, contact our team of experts free of charge: **https://my.st.com/ols**

Or reach out to your local ST representative: **https://www.st.com/content/st_com/en/contact-us.html**

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