# Six Hidden Costs in a Wireless SoC Design

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**So you want to save money by using a system-on-a-chip (SoC) in your wireless IoT design? What you don't know about dropping a wireless SoC onto the board could delay your product. If you're trying to decide between using a wireless SoC or a wireless module, be sure you know the tradeoffs. In this whitepaper, we explore the often overlooked elements of deciding between a module or an SoC.**

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## So You Want to Save Money With a Wireless SoC?

When trying to save money by using a wireless SoC, two options present themselves:

First, using a wireless SoC on the product printed circuit board (PCB). This is typically smaller and cheaper than a wireless module but designing with it may include hidden costs. Second, using a wireless module with an SoC inside. A majority of the design is already done, including a fully-characterized PCB with RF optimization and antenna layout, shielding, timing components (crystals), the SoC's supporting bill of materials (BOM), regulatory approvals, and standards certifications. But they are generally more expensive than the SoC and needed bill of material.

So, which one is the easier and more cost-effective option? The answer changes depending on the product, the designer, time-to-market, and so on. Furthermore, the best option changes with volume.

*In 2019, Silicon Labs launched its first Series 2 Products. The - EFR32xG21xx SoC and xGM210xx module. These are ideal devices for for IoT devices requiring long range connections in home or industrial environments. This whitepaper will compare the benefits and costs for these two devices.*

- BGM210P a Wireless Bluetooth module pricing $2.99 in 300,000-unit quantities (based on typical pricing at time of print)
- EFR32BG21 Bluetooth SoC pricing $1.11  in 300,000-unit quantities (based on typical pricing at time of print)

## Breakeven Analysis

Modules cost more than their SoC equivalent, but many companies use them extensively. Why? And what's the breakeven volume for selecting between one option and the other? Here's a high-level cost comparison of wireless modules versus a wireless SoC.

| Cost Category (for a single product) | Wireless Module | Wireless SoC |
|---|---|---|
| **Board design effort (antenna, layout, match, PCB, debug)** | Low | High |
| **Resource and lab equipment costs** | Low | High |
| **Regulatory certification costs** | Low | High |
| **Standards certifications costs** | Low | Med |
| **Time to market risks** | Low | High |
| **300K typical pricing (in our intro/example above)** | $2.99 each | $1.11 each |

### Breakeven Assumptions

1. Flat $2.99 wireless module pricing between 10K-300K annual volumes.
2. Flat $1.11 for equivalent wireless SoC pricing between 10K-300K annual volumes.
3. Flat $0.55 for SoC corresponding bill of materials (BOM) and manufacturing test costs.
    a. Actual BOMs vary between suppliers and even different versions of the same SoC.
    b. The test cost per manufactured device is estimated to be $0.05.
4. Gross Margin (in your product) = $4.98 or 40% above module price.
5. SoC typically requires six months of extra development time due to more complexity in design, certification and regulatory approvals. Assuming an engineer's salary is ~$100K/year, this would cost $50K.
6. Given the above, the annual breakeven volume falls between 500K-1,300K units when we include the time to market and of lost revenues (see Appendix 1 for more details). When removing the time to market aspect, ie. the lost revenues from the calculation, the breakeven is between 100k-200k units.

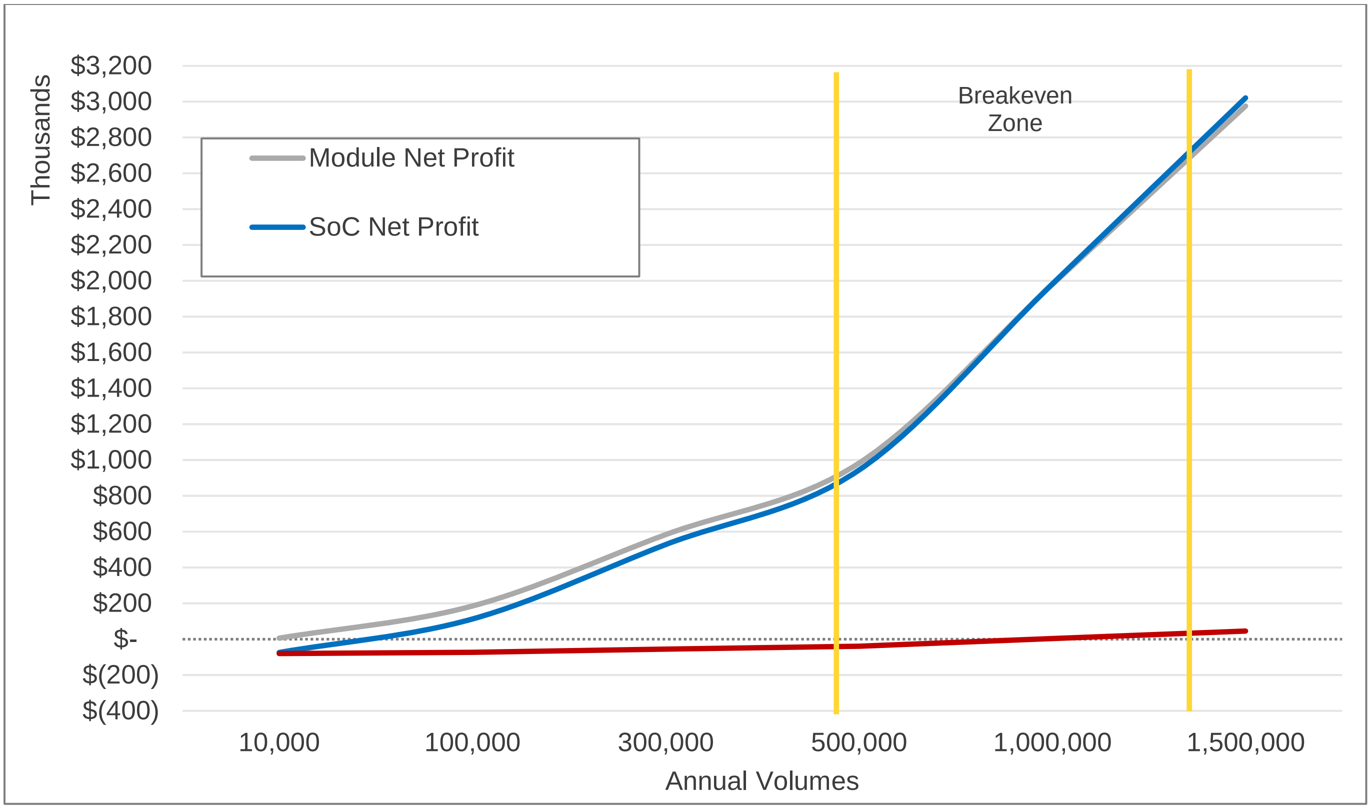


Figure 1: Breakeven Example for Using a Wireless Module Versus Wireless SoC

This breakeven figure may seem high, but even at these volumes, it still may not justify using an SoC, as the benefits of wireless modules are strong. For example, several high volume global products, such as bestselling mobile devices selling hundreds of millions of units per year, use wireless modules. Why? Modules can offer superior miniaturization and full global certifications with affordable comparable component costs. Typically the extra work of SoCs is not made up in profit.

So why is the breakeven point spread into such a wide scale of volumes? Because modules remove unknown risks that come with using a wireless SoC, and unknown risks are by definition hard to quantify in dollars or weeks.

Miniaturization of IoT design is difficult and expensive (costs of miniaturization is not included in this analysis). This is especially valid for “system-in-package” (SiP) modules, such as BGM13S, where the “bare die” is integrated into the substrate with all necessary RF components offering superior size and performance. Module benefits are even more obvious for applications where size is a critical design factor – where using the SiP modules may be the only option. Learn more about the SiP module benefits in the Silicon Labs “Miniaturizing IoT Designs” whitepaper.

## Hidden Cost #1: RF Engineers and Design

An RF engineer is required for an SoC design. Or, at a minimum, access to RF engineering expertise from the SoC supplier. RF engineers can be expensive. Glassdoor.com estimates an RF engineer’s salary is $80-125K/year, unloaded, which does not account for overhead (office space, benefits, etc.). In the U.S., this typically adds about 33% on top of the salary.

Hiring an RF engineer = $80-125K/year + 33% overhead = $100-200K/year.

## RF Application Notes – Not Always as Easy as 1, 2, 3

SoC suppliers provide application notes. The Silicon Labs application note, AN930, helps provide guidance for RF layout, including recommended antennas, traces, board material, and matching networks to maximize performance while minimizing cost and footprint.

However, since every design is different, the recommendations are always–*always*–hard to get exactly right. In fact, industry experts will attest that it is very common for product designers to follow an application note's recommendations "exactly" and still have performance issues compared to the datasheet specifications and/or product expectations.

Module companies charge more for their products partly because they are already RF-optimized within a small footprint and low BOM. The whole "system" can be placed on the end product board as a single component in one simple step.

| RF Performance Factor | Potential RF Impact |
|---|---|
| **Antenna type, supplier, and placement** | Antenna placement, type, material composition, manufacturer, and cost can change signal gain to the matching network resulting in mismatch and poor performance. |
| **Antenna trace shape and length** | Minor variations in length and shape can change the expected signal energy and therefore the recommended matching network. |
| **Board manufacturer** | Differing distances or insulation material between layers, PCB via materials, trace widths, screw holes, etc. can have effects. |
| **Component suppliers** | At RF frequencies, different suppliers' components can behave differently through tolerance differences in manufacture and result in different performance. This can result when designers use "the ones they have on the shelf" versus the recommended supplier or save a few pennies with a cheaper alternative. |
| **Component types** | Different component technologies can affect received power and voltage (e.g., wire-wound resistor vs. thin film). |
| **Plastics and screw location** | Screw placement can have coupling effects for both radiated and received energy. |
| **Battery location** | Battery location and technology can affect signal power. A charging battery can cause unknown adverse effects. |
| **Display location** | Like batteries, displays can create both electrical and RF interference. |

## Hidden Cost #2: Lab Equipment and Facilities

RF engineering requires special equipment, software, and facilities to debug RF designs.

| Lab Equipment | Cost to Own | Cost to Rent/Day |
|---|---|---|
| **Calibrated traceable gain horn antenna** | ~$2,500 | |
| **Bi-conical antenna** | ~$2,000 | |
| **3D positioner** | ~$2,000 | |
| **Spectrum analyzer** | ~$6,000 | Included in a single day rental at test facilities. This is generally $1,000-$3,000/day. |
| **Wireless testing software with desired modulation** | ~$1,500 | |
| **RF isolated, anechoic room (5m x 5m)** | ~$20,000 | |
| **Wireless standard emulator, sniffer, and debug** | ~$20,000 | |

## Hidden Cost #3: PCB Layout and Antenna Selection

How hard can it be? Many engineers believe it should be easy to follow an application note for layout. While that can be true in many cases, antenna application notes are often complex. AN930, *the Silicon Labs EFR32 2.4 GHz antenna application layout guidelines*, provides some good examples of the nuances involved. It's designed to provide detailed RF parameters for the layout, to help customers get close to a "perfect" layout on their first try.

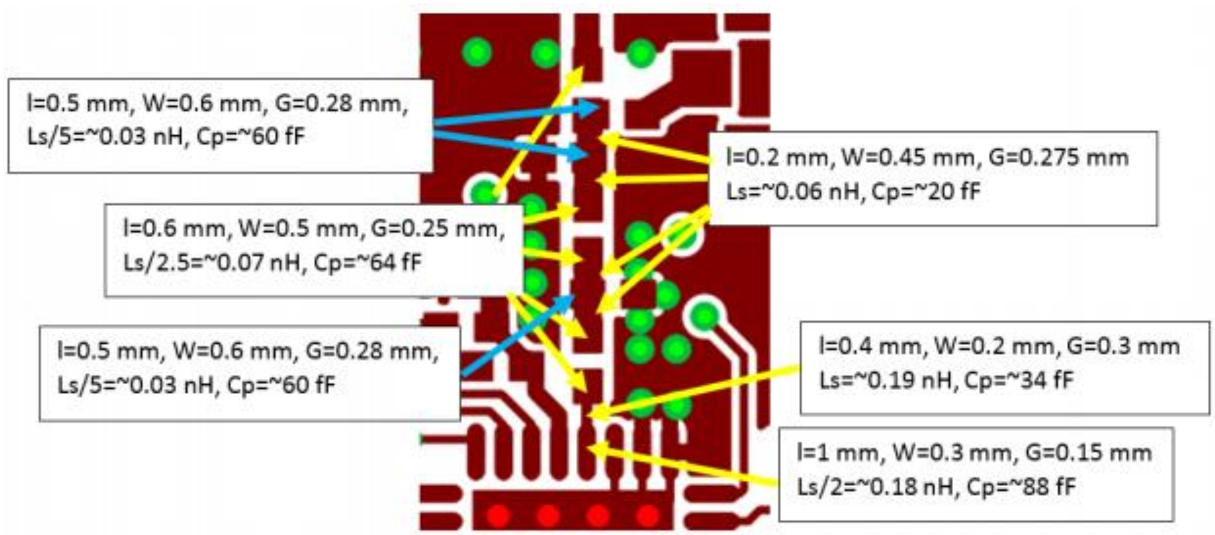


Figure 2: Image from AN930 on Estimation of PCB Layout Parasitics

But the PCB will *always* need tweaks to optimize antenna performance. These take time – a few days to determine what needs to be tweaked and several weeks to turn the board at a local PCB manufacturer. Two weeks, done multiple times, adds up quickly when a typical development can take 16 to 20 weeks. As mentioned before, wireless modules can generally be successfully placed on a product board with very simple guidelines. It is still necessary to test a design's RF performance, but with a module, it will likely be much more predictable.

## Hidden Cost #4: Regulatory Approvals and Wireless Standard Certifications

Products that operate in the unlicensed frequency bands require regulatory “type approvals.” Many may also require a wireless standard certification, such as Bluetooth, Wi-Fi and Zigbee before they can be marketed.

Some wireless modules come pre-certified for type approval and wireless standards. Adding them to a product brings these approvals and certifications along, although the product designer must apply for membership in the standards bodies and conduct some product-level regulatory testing. Wireless SoCs do not carry product type approvals or pre-certifications, though may still be subject to alliance certifications (Zigbee, Wi-Fi- Bluetooth).

| Certifying Body | Estimated Cost | Certification Costs Included in Module Price | Certification Costs Included in SoC Price |
|---|---|---|---|
| FCC | ~$7,900 | Yes | No |
| ISEDC (Canada) | ~$7,900 | Yes | No |
| ETSI/CE (Europe) | ~$7,900 | Yes; some limited end product testing/re-testing required | No |
| South Korea | ~$4,500 | Yes | No |
| Japan | ~$8,500 | Yes | No |
| Bluetooth | ~$8,000 | Yes; additional membership fee required | Some additional membership fee required |
| Zigbee | ~$4,000 | Yes, additional membership fee required | No; additional membership fee required |

### Typical Certification Costs

Regulatory testing costs and type approvals vary by country. Some countries will accept others’ approvals. For example, The United States FCC Part 15 approvals and paperwork are accepted by Canada without the need for further testing, but require separate application, approval and certification work.

Every wireless standard requires certification and paid membership in the standards body. Each certification body is independent and will not accept others’ certifications. There are consulting companies for the approval and certification processes. They understand exactly what’s required, how to test, how to correctly complete reports and when an approval or certification is required. Appendix 3 provides a list of certifying bodies, guidelines, estimated costs and consulting companies.

One aspect to also consider is changing RF regulatory requirements. When using a wireless module, this issue is solved by the module manufacturer. Changing RF regulations can be very complicated to manage for a company that does not focus on these items as their main business, especially when the product portfolio consists of tens of SoC based designs. Changes in RF regulatory certifications result in several hundreds of thousands of dollars of unexpected costs, as the supplier needs to do re-tests for all of its IoT devices; these costs are minimum when using pre-certified wireless modules.

Certification of a product, based on SoC design, can become a budget nightmare, but also lead to unwanted product performance issues. The typical issue in SoC based IoT design, is the radio transmit output power related. When designs are completed and the device is taken to RF regulatory testing, it does not pass the RF certification tests with given TX powers due various reasons. This is very typical for an IoT device – and what needed to be done, is not welcome - the actual radio performance (TX power) is knock down to compensate the issues in RF regulatory testing or the actual design would needed to be tweaked. If the choice is to lower the actual TX power, this is leading on poor link budget, ie less RF range eventually leading higher transmit power and issue on connection range. All the mentioned issues can lead into several months of unbudgeted work / costs. When using wireless modules, lot of this burned is taken away with very careful RF design of the module and well documented layout guidelines for maximum RF performance. Also leading to managed RF regulatory budget. Read more about the regulatory certifications in AN1048.

## Hidden Cost #5: Reduced Product Revenue from Time-to-Market Delays

One of the biggest hidden “costs” in using a wireless SoC versus a module is the risk of missing the market window due to incremental time to design it in, test it, debug it, type approve it and certify it.

Every day the product is not on the market is a day of lost revenue. This can range from a few weeks to a few months. Removing risk of time to market is a key reason why some very large volume companies still use modules even though they cost more.

## Hidden Cost #6: Supply Management and Assurance

For companies with low-volume production runs, modules can mitigate supply risk. A module supplier bargains for SoC supply on behalf of its entire customer base. Therefore, they consolidate demand and insulate small companies from potential line-down situations if there is a shortage of SoCs. Sourcing a single module is also simpler than sourcing all the components to put an SoC on the board.

## Moving from Wireless Modules to Wireless SoCs

When a company using modules decides to move to wireless SoCs, the question becomes how to reuse the software they have developed with the module. Module companies generally provide a software application programming interface (API) for their modules. This provides their customers with an easy-to-use API that allows them to transition between different modules for different SoC versions and/or wireless standards. The Silicon Labs developer experience for wireless SoCs and modules is the same, allowing customers to move their application among these devices.

## Single Source for Wireless Modules and SoCs

Some suppliers sell both modules and SoCs. As such they may support a more seamless software migration between modules and SoCs, using the same development tools for both. This provides the advantage of de-risking the initial product development and achieving faster time to market, but still allowing for a future cost reduction without changing software. Silicon Labs is an example of such a company. The company has a heritage of pioneering RF innovations and a long history of working with module companies. Silicon Labs acquired several strategic module providers over the years and is specialized in designing, certifying, supporting and manufacturing wireless IoT modules. Silicon Labs is a one-stop-shop for both wireless SoCs and wireless modules, delivering common software, stacks, support and development tools.

## Conclusion

The decision whether or not to use a wireless module or wireless SoC has a high degree of associated complexity that depends on volume, time to market urgency, risk tolerance and available resources. By choosing a single supplier who can deliver both modules and SoCs while protecting software investment, the migration from module to SoC is simplified, if and when the breakeven analysis warrants the move.

## Appendix 1: Breakeven Calculations for Figure 1

| Requirement | SoC Costs | Module Costs |
|---|---|---|
| Wireless standards body certification (single) | $(4,000) | - |
| Wireless memberships (single) | $(4,000) | $(4,000) |
| Reg. approvals (U.S., IC, EU, Korea, Japan) and mgmt.. for 5 years | $(51,800) | $(5,000) |
| Lab equipment or rental for development (3 months prorated for SoC dev) | $(15,000) | $(5,000 |
| RF expertise (3 months for SoC design and debug) | $(20,000) | - |
| RF, dev, cert & govt approval cost | $(94,800) | $(14,000) |
| SoC time-to-market vs. module (3-6 months) | 3 | |

| Cost Type | 250KU Pricing |
|---|---|
| Module cost (BGM210P, 10dB, fully certified) | $2,99 |
| SoC cost (EFR32BG21, QFN32, 10dB, 512kB Flash) | $1,11 |
| SoC BOM and manufacturing RF test cost | $0,55 |
| SoC total cost | $1,66 |
| SoC savings vs. module | $1,33 |
| Product retail ASP wireless premium @40% GM on module price | $4,98 |

| Annual Volumes | 10,000 | 100,000 | 300,000 | 500,000 | 1,000,000 | 1,500,000 |
|---|---|---|---|---|---|---|
| Total revenue | $49,833 | $498,333 | $1,495,000 | $2,491,667 | $4,983,333 | $7,475,000 |
| Module dev costs | $(14,000) | $(14,000) | $(14,000) | $(14,000) | $(14,000) | $(14,000) |
| Module costs | $(29,900) | $(299,000) | $(897,000) | $(1,495,000) | $(2,990,000) | $(4,485,000) |
| Module net profit | $5,933 | $185,333 | $584,000 | $982,667 | $1,979,333 | $2,976,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **SoC dev costs** | $(94,800) | $(94,800) | $(94,800) | $(94,800) | $(94,800) | $(94,800) |
| **SoC time-to-market lost revenue** | $(12,458) | $(124,583) | $(373,750) | $(622,917) | $(1,245,833) | $(1,868,750) |
| **SoC + BOM costs** | $(16,600) | $(166,000) | $(498,000) | $(830,000) | $(1,660,000) | $(2,490,000) |
| **SoC net profit** | $(74,025) | $112,950 | $528,450 | $943,950 | $1,982,700 | $3,021,450 |
| **Breakeven (SoC profit + module profit)** | $(79,958) | $(72,383) | $(55,500) | $(38,717) | $3,367 | $45,450 |

## Appendix 2: Costs of Designing a Wireless SoC onto a Product Board and Going to Production

<table>
<tr><th>Cost Category</th><th>Module Cost</th><th>Confidence Level (%)? Comment?</th><th>SoC Cost</th><th>Confidence Level (%)? Comment</th></tr>
<tr><td>Selecting antenna</td><td>Zero</td><td>100%</td><td>Medium</td><td>50% - The supplier likely has a list of recommended antennas. Even so, picking one with confidence requires careful analysis.</td></tr>
<tr><td>Laying out antenna</td><td>Low</td><td rowspan="3">90% - As an all-in-one system, a module is hard to mess up. However, there may be restraints on module placement and “keep-out zones” that could get messed up. It’s also likely that the module package probably includes shielding to account for these eventualities, so the probability of these issues is really low.</td><td>High</td><td rowspan="2">90% - Very high likelihood of trial-error-tweak-repeat cycle. Even highly experienced RF engineers spend weeks optimizing antennas for Rx/Tx performance and low BOM cost. This includes rigorous attention to keep-out zones, effectively isolated inductive loops, component selection and placement, etc. There is also likely a need for RF expertise, lab equipment and an RF-isolated testing environment.</td></tr>
<tr><td>Optimizing antenna layout</td><td>Low</td><td>High</td></tr>
<tr><td>Reducing interference to antenna inputs</td><td>Low</td><td>High</td><td>90% - Very high likelihood of coupled noise into RF front end from unanticipated and/or unintentional radiators.</td></tr>
<tr><td>Reducing interference to antenna</td><td>Low</td><td></td><td>Medium</td><td>50% - Very likely that sub-optimal layouts will degrade output performance; unintentional</td></tr>
</table>

| | | | | |
|---|---|---|---|---|
| **output power** | | | | interferors will also degrade output power. |
| **Pinout complexity** | Standard | Module companies mask SoC pinout changes by accommodating them in an unchanging module footprint. | Standard | SoC pinouts may change between alpha and production silicon. Likewise, they may change with subsequent releases. |
| **Software complexity** | Low/Medium | 50% - It's likely that module companies have an "SoC abstraction layer" development software and API. It varies from supplier to supplier. | Low/Medium | 50% - Depending on the SoC company's design philosophy, their software APIs may be super easy or super hard. It varies from supplier to supplier. |
| **Regulatory certifications** | None/Low | 100% - Modules can come pre-certified for various wireless standard. There may be some product-level certifications required that the module supplier cannot provide, driving some incremental cost. | High | 100% - Each product must be certified in each desired regulatory region and for each supported wireless standard. This is a time consuming and expensive task and not always successful the first time resulting in re-dos. |

## Appendix 3: Regulatory and Wireless Standards Certification Cost Estimates

| **Type** | **Certification Body** | **Link / Comment** | **Estimated Costs** | **Module Applies (Yes/No)** |
|---|---|---|---|---|
| Regulatory | Regulatory U.S. FCC, Parts 15B and 15C for unlicensed radios | https://en.wikipedia.org/wiki/Title_47_CFR_Part_15<br>This page provides an easy-to-read guide. | ~$7,900 | Yes for Part 15B |
| Regulatory | Industrie Canada (IC) | http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01698.html<br>Guidelines for testing:<br>http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01130.html | ~$7,900 | Yes |

| | | | | |
|---|---|---|---|---|
| | | FCC Part 15 certification applies for IC certifications with written reports stating cross-country compliance. | | |
| Regulatory | Europe ETSI and CE (Covers Europe, Africa, Middle East and parts of Asia) | http://www.etsi.org/standards/looking-for-an-etsi-standard/list-of-harmonised-standards<br>EN 300 328, EN 301 489, and EN 60950 are all important for unlicensed radios. | ~$7,900 | Yes |
| Regulatory | South Korea | http://rra.go.kr/eng2/cas/introduction.jsp | ~$4,500 | Yes |
| Regulatory | Japan MIC / Telec | http://www.tele.soumu.go.jp/e/sys/equ/tech/ | ~$8,600 | Yes |
| Regulatory | Sub-GHz / Proprietary wireless | Generally only require regulatory compliance. | | Yes |
| Bluetooth | Membership fees | https://www.bluetooth.org/en-us/members/membership-benefits | $0 - $8,000 (or higher) | No |
| Bluetooth | Qualification overview | https://www.bluetooth.org/en-us/test-qualification/qualification-overview | | Yes |
| Bluetooth | Qualification fees overview | https://www.bluetooth.org/en-us/test-qualification/qualification-overview/fees | $4,000 - $8,000 | Yes |
| Bluetooth | Qualification FAQs | https://www.bluetooth.org/en-us/test-qualification/qualification-overview/listing-process-updates | | |
| Zigbee | Membership fees | http://www.zigbee.org/zigbeealliance/join/#levels<br>http://www.zigbee.org/Join/HowtoJoin.aspx<br>http://www.zigbee.org/Join/MembershipFAQ.aspx | $4,000 - $9,000 (or higher) | No |
| Zigbee | Qualification overview | http://www.zigbee.org/zigbee-for-developers/zigbeecertified/ | | Yes |
| Zigbee | Qualification fees overview | Per test house | ~$4,000 | Yes |
| Zigbee | Qualification FAQs | https://docs.zigbee.org/zigbee-docs/dcn/05/docs-05-3594-04-0zqg-zigbee-certification-testing-faq.pdf | | |

**Helpful sites:**

- Northwest EMC: http://www.nwemc.com/

- TUV: http://www.tuv.com/en/corporate/business_customers/product_testing_3/product_testing.html
- NTS: https://www.nts.com/services/certification_services
- 7Layers: http://www.7layers.com/#!/type-approval/