Chip or Module "Cookbook" for BLE designs

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Bluetooth LE has been around for a while now. Today, many company's providing BLE chipsets and even more module suppliers can be found in the market.

Most R&D engineers and managers came across the question: using a BLE module or designing-in the chip? As a fully independent Design House we have helped many customers with that question. In the following document we will dig into details to find pros and cons of both solutions, based on real projects and numbers. Finally we will provide a "cookbook" to help you making a decision easier in your next BLE design.

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1. Introduction

Integrating Bluetooth Low Energy technology in products always leads to the question: ***«How many devices do I have to sell to go for a design-in development?»***

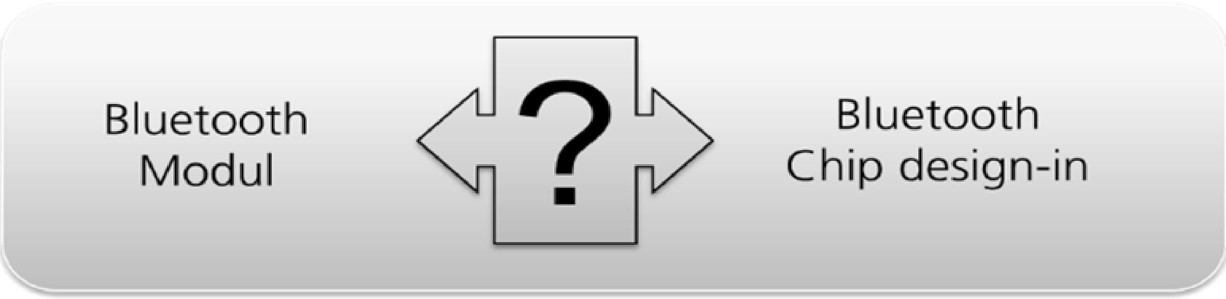
The following paper will reflect both roads – using a BLE module or doing a chip design-in approach – and ends with a simple to use "cookbook" that simplifies your decision making process.

2. Decision Drivers

There are many factors influencing this decision, but 90% will be based on the 4 major factors:

- Product quantities
- Module and/or single component prices
- Your skills in RF design
- Countries to be delivered that allow modular RF approval

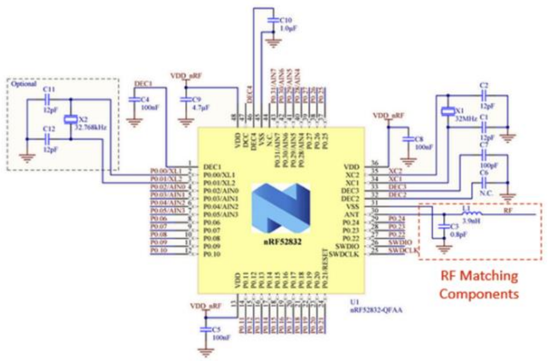
Reliable product quantity estimations are essential, especially because the component prices are highly quantity related. To integrate a BLE module into an existing design does not require very high RF design skills. Nevertheless, when doing a design-in solution, it is highly advised to buy in the needed RF skills if they are not available in your company.



3. Doing your own BLE design

Compared to earlier days, a single chip Bluetooth integration is very simple. You will get a lot of support from chipset suppliers like reference layouts, reference circuit designs for the antenna path and also examples of PCB antennas. In fact, it is simple to make your own design by copying what the chipset suppliers provides. It also helps that there are not many components any more besides the RF chip, typically just some crystals, power supply and the antenna matching network.

Here is a sample of a Nordic nRF52 chipset schematics that shows the simplicity of a modern Bluetooth RF design:



Nordic RF Design (Ref. nRF52 Nordic data sheet)

Such a design will work well, even the antenna performance will be reasonable, if you stick to what you get from the chipset supplier and if an antenna matching is done. Though, a well working design does not give you any guarantee that your design is good enough to properly work once integrated in your host system. A good working design does also not give you any hint on RF side affects you might generate like spurious emissions, out of band emissions or blocking issues. All this will pop up once you start with type approval tests, which is often pretty late in your project.

A good advice is to plan some RF pre-measurements in a very early project stage to reduce the risk of having an RF issues close to project end. The following pre-measurements are advised to be done:

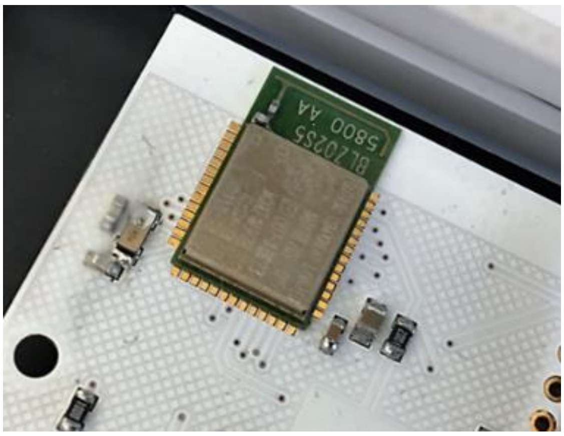
- Spurious emissions up to 4th harmonic
- Out of Band emissions (based on EN 300 328)
- TX power, antenna gain and optionally a 3D antenna radiation pattern
- EMC immunity tests

With the results of these measurements, you already have a very good idea about the performance of your design and possible issues for the upcoming type approvals.

Summarized: doing a RF design based on a modern BLE chipset is a lot easier that it was a few years ago and the risk of fatal RF issues can be managed by doing the right pre-measurements at an early project stage. It also helps to have an experienced Bluetooth expert at hand which can help if things get tricky.

4. Module based design example

The first example to be described is a module based design for a German premium lighting market. The product quantities are approximately 5/k per year and the product shall be delivered in the US, Canada and in several Countries around Europe.



Integration of a Fujitsu Bluetooth LE module

Hardware Design

The hardware design of this product will need 2 prototype rounds. When using a module, the second prototype can already be used for all the pre-measurements needed to be done. After the second prototype, usually a pilot series with typically 50-100 pieces will be produced to verify the production process and the test equipment. All type approvals can be done with the pilot series samples as well. The hardware design of a module based development contains the following tasks:

- First Electronic Design
  - Component sourcing
  - Module positioning for best Antenna performance
  - Schematics and PCB Layout
  - Sample Assembly
- HW verification (Shortcuts, Voltage, Current, Temperature, ..)
- RF Pre-Measurement (Spurious, AoB, immunity,)
- Second Electronic Design
  - Improve Schematics and PCB Layout
  - Sample Assembly
- HW verification, environmental checks, documentation
- Produce pilot series in fab (used also for approvals)
- Produce mass production devices

Firmware Design

The firmware design in BLE products usually start with setting up the software environment provided by the Chipset supplier (e.g. using the SDK). This contains of a Bluetooth Host and Controller stack, which will be provided as binary code or software library. Most chipset providers also share sample code for Bluetooth services or profiles, some of them even provide qualified services and profile with a QDID (Qualified Design ID) which can be used for the product listing at the Bluetooth SIG. Despite of some very common profiles/services like DIS (Device Information Service) or BAS (Battery Service), most applications are based on proprietary services on top of GATT. At least the own proprietary service has to be developed in the project, together with additional features like bootloaders, firmware update over the air, extensions for testing in the factory or in the approval lab, handling of additional peripheral components, and so on. Summarized we have the following software tasks for a module based firmware design:

- Setup project and software environment (IDE, compiler, build server, code management tool, ..)
- Define Software design and architecture
- Build basic firmware to do the hardware verification (ESD, RF Test, DTM, ..)
- Provide some firmware upgrade possibility (e.g. over the air)
- Define and specify Bluetooth Profiles and Services
- Implement, test and continuously improve firmware
- Setup unit test framework und build unit tests to be added in the build process
- Add necessary production test extension
- Finalize and release firmware (build version, tag, system test, ..)

Type Approval

The right selection of type approvals is fully dependent on the application the module is built in. The only thing which all they have in common is that you need to have a Bluetooth Qualified and listed product and you must always do RF type approvals. As the resource air is not endless and therefore precious, nearly every Country is handling the RF approval separately. One exception is the CE

RF approval which is valid for most European Countries. Even if module suppliers will tell you a different story, it is important to know that an RF type approval on a module can only be used as full certification, if a so called "modular approval" is possible in the specific Country. The best example of a modular approval comes with the FCC approval, which is valid for the US and Canada. A modular approval allows you - with some restrictions - 100% re-use of the RF approval made for the stand alone RF module. If modular approval is not possible, which is actually the case for most Countries in the world, you will need to go through RF type approval with your Bluetooth enabled RF product. Summarized: using a module only reduces type approval cost for your end product if the module supplier has made a modular type approval which you can use.

Type approval tasks in our example module based projects are:

- Use pilot production samples or last prototypes for approval test
- Choose approval lab with Bluetooth experience
- Prepare samples (for RF, EMC, safety test)
- Prepare documentation/tools for approval lab
  - RF -> continuous sending pattern
  - EMC/ESD -> module status
  - verification possibility
  - Documentation for Safety (printed label, …)
- Send an engineer to assist approval staff in lab
- Test's
  - RF -> EN 300 328 for EU/CE (FCC for USA/CA due to modular approval not needed)
  - EMC -> EN 301 489-1/-17 EU/CE
  - Safety -> EN 60950 (or better suited standard for your product)

Production

As the Bluetooth module come as pre-tested component, you have little risk on production side to integrate it. You have to make sure that all soldering is done properly and as test the RF link. You might just setup a simple Bluetooth Link to make sure that the module is working properly in your design. To do this, usually some extensions in the firmware have to be made and you also need a way to bring the firmware image of your module firmware into the module.

The following tasks come up with the production when using a module:

- Specification of production concept
- Firmware Image programming possibility
- Software extensions in Test tools and module firmware for performing the tests and optional self-test
- Factory reset capability in module to remove pairings
- Build testing equipment for RF Link test, IO's which are in use, current consumption of module
- Possible extensions to program production process or configuration data in module (module firmware and tools)

Cost Calculation Module based design

To compare a module base solution with a Chip design-in solution, we also need to talk about workload and cost. Thus we have an example calculation for a module based and mid complex Bluetooth low energy project.

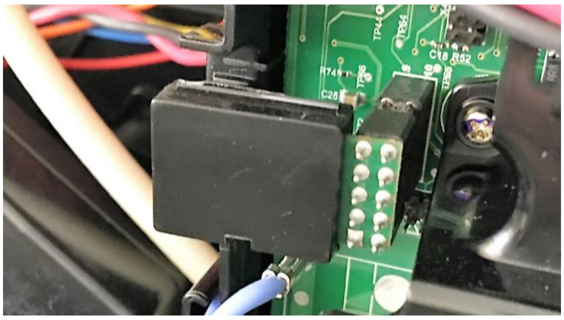
Task	Cost EUR
First Electronic Design, First Samples	11'520.00
HW Verification / RF Pre-Measurements	3'200.00
Second Electronic Design, Second Samples	4'480.00
HW Verification, RF Testing, Environmental testing	3'200.00
Support for pilot production	1'920.00
Support for MP	1'280.00
Firmware Development	28'800.00
Preparation and assistance in Approval Lab	1'920.00
Fab Concept for testing and module programming	1'920.00
Build Test and Program Equipment, FW extensions	3'200.00
Management/Overhead 10% of project cost	6'144.00
System Test/End Test	3'200.00
Sample Cost (First, Second, Pilot Production)	3'000.00
Lab Cost Pre-Measurements	3'000.00
Approval Cost EN (RF, EMC, Safety)	7'500.00
Approval Cost FCC (US/CA)	-
Bluetooth Listing	7'100.00
Total Cost	91'384.00

Cost overview for module base design

As the task and cost overview shows, the full project development cost for this module based example is around 91k EUR.

5. Chip design-in example

To compare the two approaches, the second example is a Chip design-in solution for an OEM kitchen appliance provider. He has several customers worldwide and a huge variety of machine PCBs where Bluetooth needs to be integrated. To have this flexibility, the use of a module is a must. Because of the high quantities and some special requirements on the module, an own dedicated module was built. Quantity of the products are 200k/year and the production plant is located in China.



Very low cost module design (design-in approach)

As the basic task for a module or Chip design-in project are identical, we will only focus on the additional work that has to be done for a Chip design-in solution.

Hardware Design Differences

The hardware design of a chip design-in solution will require 1 or 2 more prototype rounds. You also have to think of the kind of antenna you are going to use and you need to do an RF proven PCB layout for the module. Also care has to be taken to the PCB supplier that will be chosen. For RF designs, it is essential that the PCB supplier produces the PCB as your RF Engineer requests it with respect to materials used and layer stacking. It is also very important to get a PCB supplier which will always deliver the same PCB quality, not changing anything during product life cycle.

These are the additional task to be done when doing a Bluetooth Chip design-in:

- At least 1-2 additional HW loops with prototypes
- Choosing an antenna design
- Preparation for conducted testing (Bluetooth RF Conformance)
- PCB layout must be designed for RF requirements
- Taking care of PCB material, stacking and production quality
- Antenna tuning needed
- Much more RF pre-testing required in test lab

Software Design Differences

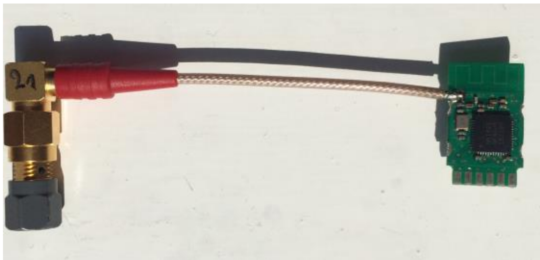
Compared with a module base solution, the firmware of a Chip design-in solution is more or less identical. There might be some more functionality required for testing, because a Chip design-in solution needs deeper testing than a buy in module.

Additional tasks for the software development in our example are:

- More test features needed for factory tests
- DTM access needed for Bluetooth RF Conformance test

Approval Differences

Type approval definitely differs between a buy in module and an own RF design, but not so much. For the Bluetooth Qualification, a separate Bluetooth RF Conformance test needs to be done. Such a test guaranties that the requirements on the Physical Layer in a Bluetooth product is still met and interoperability is given. A Bluetooth RF conformance test in the lab requires to access the DTM (Direct Test Mode) Interface, which is a Bluetooth standardized interface over USB, RS232 or UART. And it also requires to contact your Antenna output conducted, with disconnected on board antenna.



Cable mounting for conducted RF tests

Compared to a buy in Module which comes with modular type approvals, these modular type approvals have to be done with your own design. Usually this is the case with the FCC type approvals for the US and Canada. In case you do not have an FCC or Canadian IC ID yet, you also need to request such IDs first. Many Countries require that you have representative in the Country of Approval, so does Canada. In case you do not have a representative in the Countries you are requesting the approval, many approval labs will be able to provide you such a representative.

Here is the list of the additional tasks to be done for our Chip design-in example compared to the module design:

- Also conducted samples needed for approval
- Bluetooth RF Conformance test needed
- Approval ID to be requested (FCC ID, CA ID, …)
- FCC RF test and approval for USA/CA needed
- Separate RF approval for **each** additional Countries on the list

Production

Compared to a pre-produced and pre-tested Bluetooth module, you need much more effort in testing at factory level. It must be verified that the module does perform in a certain range (minimum RF sending power, minimum RX sensitivity). Even better is to make sure that no unwanted emissions are sent out by your design. To do this properly, it is advised to perform all of these tests in a RF shielded environment.

Tasks to be done in our example:

- Testing needed in shielded environment (own antenna path)
- Special test equipment need to be built

RF test fixture for testing 10 modules in parallel

Cost Calculation for a Chip design-in project

To compare this approach with a module base solution, we put together a list with task that will show you the additional cost with respect to the development. We still talk about a mid complex Bluetooth low energy project.

Task	Cost EUR
Total Cost module approach	91'384.00
Additional complexity (Layout/Antenna/...)	2'560.00
Third Electronic Design, First Samples	4'480.00
HW Verification / RF Pre-Measurements	1'920.00
Forth Electronic Design, Second Samples	2'560.00
HW Verification, RF Testing, Environmental testing	1'920.00
Antenna Tuning / sample preparation approval	2'560.00
Additional Test Features in FW for Fab / DTM access	4'480.00
Additional work Fab Concept, Fab Tool development	6'400.00
Additional Management/Overhead 10% of project cost	2'688.00
Additional sample cost	2'000.00
Fab Equipment (Shielded Box, RF Tester)	7'000.00
Additional Lab Cost Pre-Measurement	3'000.00
Bluetooth RF Conformance	5'000.00
Cost FCC Test and US/CA Approval, local representative needed	7'500.00
Cost Test and Approval Japan	5'500.00
Cost Test and Approval 5 additional countries (7500/country)	37'500.00
Total Cost	**188'452.00**

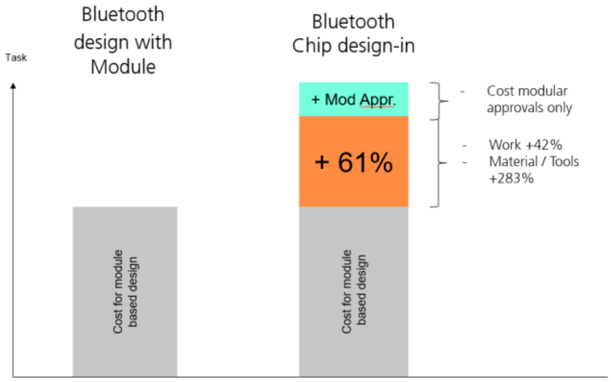
Cost for a design-in solution

Total project cost for the above Chip design-in example is 188k EUR.

6. Cost calculation comparison

Now we want to compare the project development cost for a module based solution to a Chip design-in solution. To have a fair comparison, the following is given:

- Calculation based on the 2 above examples
- Mid complex Bluetooth product (2 services, 1 profile supported, some peripheral devices to handle)
- Normal antenna design (PCB or ceramic antenna)
- Bluetooth Listing will be done (RF conformance test included)



Cost comparison (design-in / module)

	Module based	Chip design-in based	Upcost [€]	Upcost [%]
Overall project cost	91'384.00 €	188'452.00 €	97'068.00 €	106%
Cost work only	70'784.00 €	100'352.00 €	29'568.00 €	42%
Material and Lab cost	6'000.00 €	23'000.00 €	17'000.00 €	283%
Project cost without approvals	76'784.00 €	123'352.00 €	46'568.00 €	61%

7. Cookbook – The "arendi" Formula

$$Q_m = \frac{(DC * 0.61) + MAC}{MP - CP}$$

DC (Development Cost for module design)
MP (Module Price)
CP (Component Price for design-in components)
Qm (Product minimal quantity)
MAC (Cost of all modular Approvals which are provided by the module)

Formula applied to example I

DC = 76'784€
MP = 5.4€
CP = 2.9€
MAC = 7'500€ (FCC)

$$Qm = \frac{(76'784€ * 0.61) + 7'500€}{5.4€ - 2.9€}$$

-> Qm = **21'735** Product minimal quantity

The estimated quantities for the module based example was 5k per year which is far below the calculated minimum quantity.

Formula applied to example II

DC = 76'784€
MP = 3.9€
CP = 1.3€
MAC = 13'000€ (FCC+JP)

$$Qm = \frac{(76'784€ * 0.61) + 13'000€}{3.9€ - 1.3€}$$

-> Q_m = **23'014** Product minimal quantity

The estimated quantities for the Chip design-in example was 200k/year. This is far above of the calculated minimal quantity.

8. Summary

Going with a BLE module…

- reduces project risk
- speeds up your project
- simplifies Bluetooth Qualification/Listing process
- simplifies production process
- can be done with very little RF expertise
- often does **not** simplify type approvals (only helps with modular approvals)

A BLE Chip design-in solution…

- can be done with low risk if some RF experience is available
- can be done with reasonable effort and up-cost
- does not require huge quantities to be the economically better choice

Thomas Rupp, October 2016