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Designing Your First Wireless Product

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If you are new to wireless this paper should serve as a roadmap for your first development.

Wireless system design is known for being somewhat of a black art with good product performance and timely development often being difficult to achieve. For this reason many companies use pre-approved radio modules or integrated radio ICs. These are good strategies, but still require care and a good knowledge of radio systems in order to achieve good performance.

Developing a wireless product requires the R&D team to address a wide array of technical issues with the major areas of concern being:

- System design
- Achieving system performance
- Passing regulatory tests

The risk of each of these three areas can be reduced by augmenting your R&D team with experienced wireless design consultants [1].

WIRELESS SYSTEM DESIGN

Wireless system design is largely about matching user requirements with radio transmission behavior, legal limitations and implementation practicalities. A wide range of things effect wireless performance with even plastic type and color having an impact. While there are many small issues to contend with, the major questions one needs to answer are covered in this section.

Prior to implementing your design you need to know the following answers:

<u>What is your radio environment capable of supporting in terms of data rate and distance?</u>

Every environment has a different interference behavior. Different kinds of locations (urban, suburban, industrial) will produce different levels of interference in the commonly used radio bands. Such interference will limit data rates and distance and influence on-air protocols, architecture and system operation.

[1] The author has spent much of his life designing wireless systems. Please see the contact information at the end of this whitepaper to arrange for an initial free consultation.

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The expected RF signal attenuation will determine the radio performance targets required to meet the application's needs. Different building types cause different RF signal attenuation. Metallic coated windows, concrete walls, and metal floors behave much differently than wooden houses or open-air environments. It is worth noting that open-air environments are not usually as benign from a radio perspective as they first appear. Ground reflections, tree absorption and other effects reduce performance.

A review of the radio propagation and interference environment will start with a scenario analysis, then a literature review followed by a link budget analysis. On-site tests and/or simulation may be required in some difficult or novel environments.

<u>What radio technology and frequency band should you choose?</u>

Historically each radio system was a custom designed system that closely matched its propagation environment and application. Today, with so many available off-the-shelf standard solutions and the relentless pressures of time and price one rarely does full custom radio designs anymore.

Today's design problem is one of selecting from an increasing array of standards and offerings and assessing which compromises are acceptable, which are not, and which platform will carry your product forward into the future with the least amount of redesign. The input to this kind of decision includes the following factors:

1. Wireless technology considerations (bit rate, error performance, frequency, etc).
2. Software development considerations (OS, libraries, tools, etc).
3. Business considerations (price, supply chain, product line continuity, etc).

<u>Does the candidate wireless platform have the capability needed?</u>

Some low cost modules and chip sets have marginal radio performance, especially in terms of transmit power and receiver performance. A review of a radio platform can result in the following recommendations:

1. Acceptable as is
2. Augmentation of the transmitter required
3. Augmentation of the receiver required
4. Both augmentation of the transmitter and the receiver
5. Additional filtering at RF or elsewhere
6. Radio found to be unacceptable

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Meeting price and performance can often be met by tackling different aspects of a design. For example one can vary transmit power, receiver performance and data rates to arrive at similar radio link availabilities but at different price points.

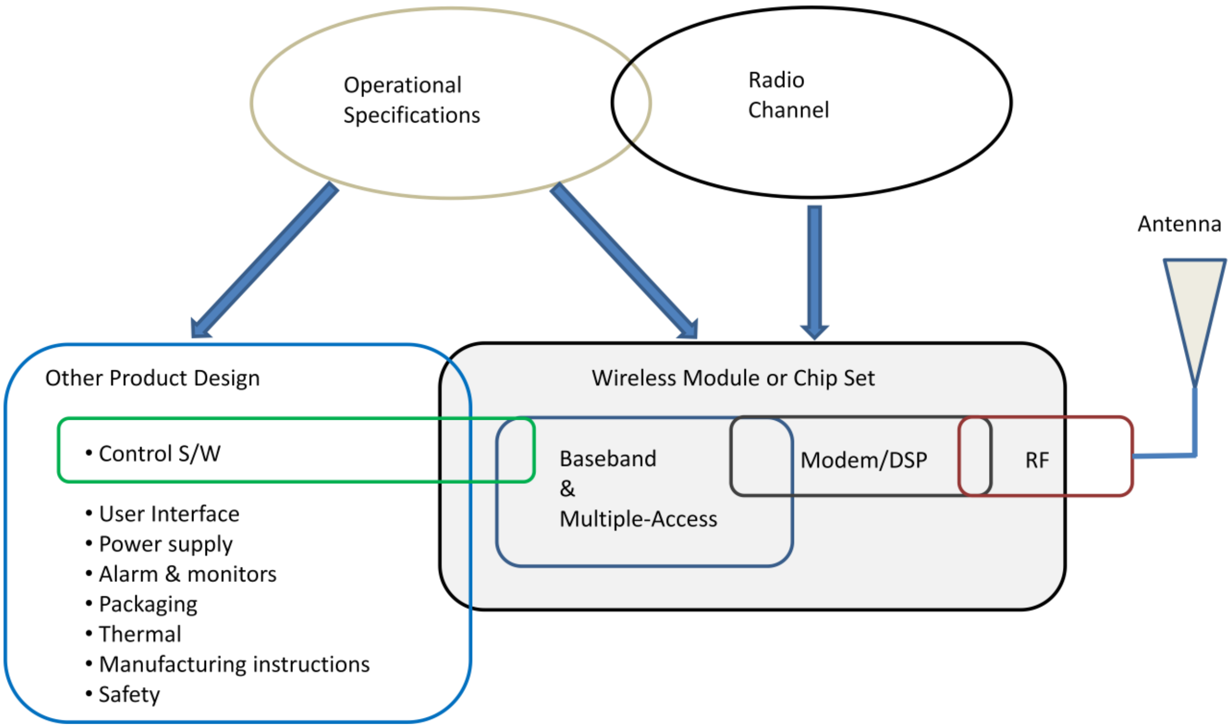

Figure 1 - Product Design and the Wireless Module

Figure 1 shows the portion of a typical product design that the radio module addresses. Using such modules and chip sets there is still plenty of room for your R&D team to add value and novelty.

<u>What antenna behavior and design is required to meet your application's needs?</u>

Device orientation and the propagation environment will affect the antenna choice. A review will identify an appropriate antenna type (folded metal, PCB, wire, inverted-F, dipole, etc.) or recommend a custom design.

The need for a custom design is often the result of unusual multi-band operation, a small or irregular size or unusual mounting requirements (for example adjacent to a large metal surface). Custom antennas may result in more testing time and expense (see below on Regulatory Requirements).

<u>What power requirements will the system need?</u>

Power limitations often affect RF technology choices, communication throughput and system

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protocol choices and behavior. Support for sleep modes is often required in wireless systems adding to system complexity and potentially affecting system response time.

Transmitting typically requires much more energy than receiving. It is not unusual to make a wireless system asymmetric in operation so that if one end has access to wall power it performs the more complex processing and modem functions to conserve power at the battery powered end of the link.

Does my radio system require diversity?

Radio systems are statistical in nature. In order to combat outages we often add an alternative radio path that is independent from the primary path in order to increase system reliability. The nature of this diversity path depends on the propagation environment and other elements and limitations of the system design.

There are different kinds of diversity schemes including, time, space, angle, polarization and frequency. Each can be effective depending upon the radio channel characteristics, and system limitations such as size, channel bandwidth and cost. Many chip sets and modules provide a basic switched antenna receive diversity scheme which will provide significant benefit if the second path is largely uncorrelated or negatively correlated from the primary path.

A well designed diversity system will greatly improve radio performance so one should always plan for its addition, even if it has to come later as a product revision.

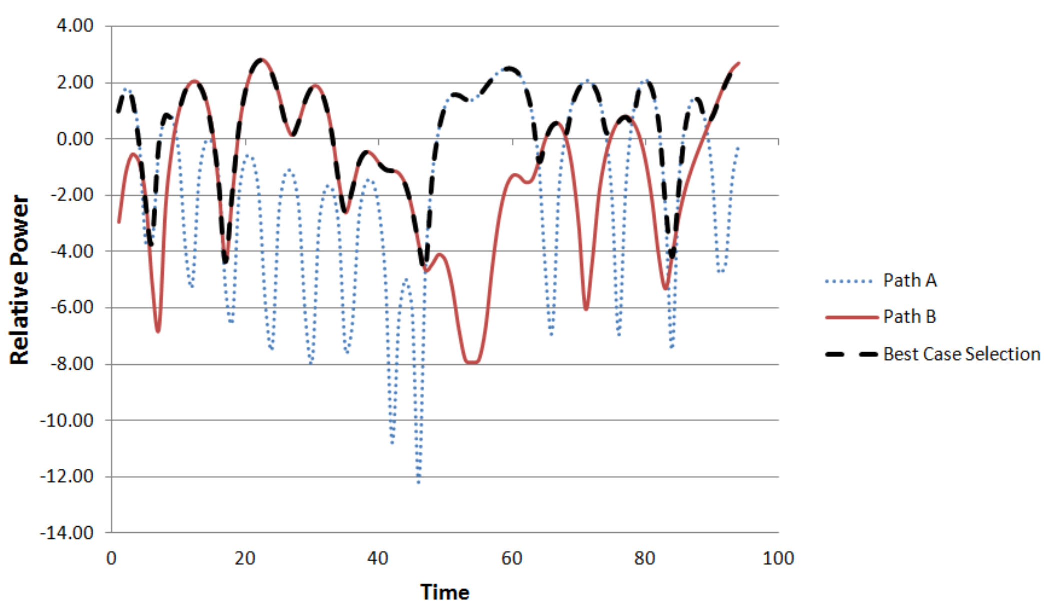

Figure 2 - Diversity Example Showing Improved Signal Level

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What regulatory approvals does the system need?

A pre-approved radio module's approval will not be valid in certain situations. Antenna selection, other integrated wireless devices and packaging can all effect this grant. If the grant is not valid then additional testing and cost will be incurred.

Other questions we must assess are what safety tests must each device in a system pass? (See below on Regulatory Requirements.) Such requirements need to be thoroughly understood during the design phase. Failure to think this through can result in:

1) A product that is expensive to test

2) A product that cannot be tested to prove it is legal

3) A product that needs significant redesign in order to pass testing.

4) A product that is not legal

ACHIEVING THE DESIRED SYSTEM PERFORMANCE

A poorly working short-range wireless system will rarely be a profitable product. When a wireless system does not connect, or does not stay connected, your customer support lines will get multiple calls and your company a bad reputation. The surest way to minimize your radio related support calls is to provide a well performing radio link. To deliver a high performance product one needs to address the following:

Verify that your radio is transmitting as much power as is legally permitted.

Getting to the maximum legal power (or the design target) is almost always desirable. One needs to verify that other parameters are also within limits (e.g. phase noise). Signal level incompatibility, matching circuit design and antenna issues can result in less output power than desired or result in excessive signal harmonics (and a regulatory failure).

Verify that your receiver is working as close as practical to the manufacturer's specifications.

This begins by knowing your radio link performance. Many companies new to wireless cannot tell you how much radio path loss they can tolerate before their system fails. You need to know this figure of merit (called System Gain) for both engineering and marketing purposes.

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For a host of reasons the system performance will rarely meet the radio module (chip set) specifications until the product has been refined. These refinements will touch many aspects of the product design including power supply, PCB layout, component selection, RF matching, antenna, grounding and packaging.

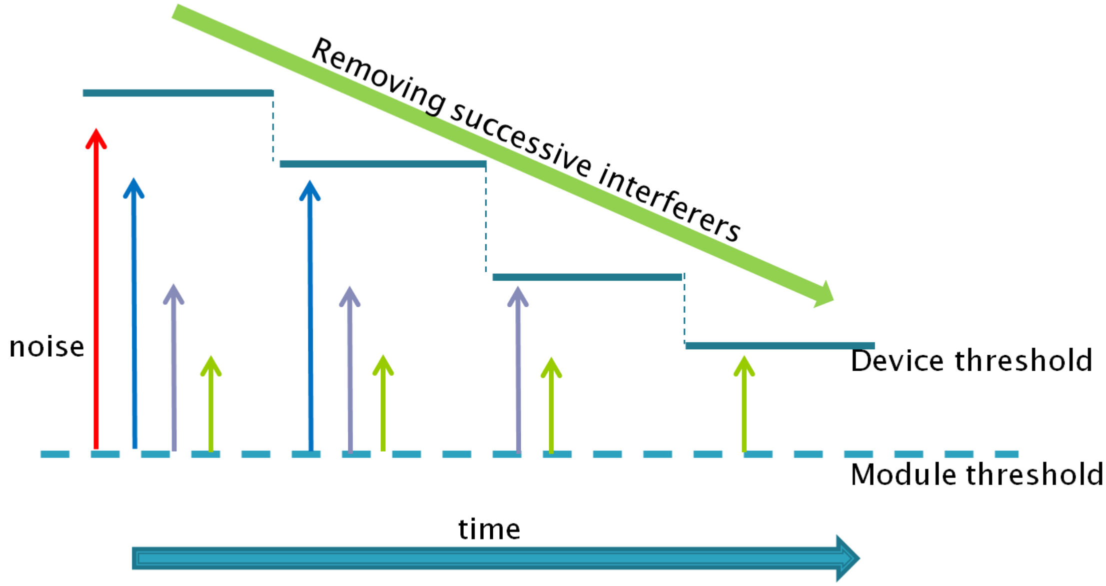

Figure 3 – System Performance Improvement Progresses from Large Issues to Small

The performance refinement process can be difficult and slow. The reason is that one needs to find and resolve issues in their approximate order of impact. What appears to not be an issue when the product is 20 dB from the receiver performance specification can become the dominant factor when the device is only 6 dB from spec. Achieving good radio performance requires staff with RF experience - or a lot of patience.

<u>Verify that the higher layer protocols operate properly in an impaired radio environment.</u>

It is typical that most software and firmware will be tested in nominal radio conditions. In the field this will often not be the case and will result in hard to duplicate bugs. Such intermittent bugs create customer and designer frustration.

To test the overall product performance in poor radio conditions one needs a test environment with controllable radio impairments (in a selectable direction) and used in a disciplined manner. Those new to wireless will find the creation of such a test environment difficult as they discover the limits of cables, enclosures, attenuators and other components. The practical reality is that getting signal attenuations greater than 80 or 90 dB is challenging in a lab environment.

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Other elements to consider in the test environment are dealing with the outside interferers such as cellular, WiFi, aeronautical and other industrial and commercial systems. You may need shielded enclosures or a screen room in some situations. A rural test location is a plus.

REGULATORY REQUIREMENTS

Wireless systems need to meet both unintentional and intentional emissions regulations (and EMI susceptibility regulations for use in Europe). Intentional radiation tests are more complex and expensive than the usual unintentional conducted and radiation tests for a digital device (e.g. FCC 15).

A carefully thought through EMC test plan needs to be developed during the design cycle so that the necessary operating modes and special configurations are available when entering the EMC certification lab.

Intentional Radiation Compliance

If the product uses a pre-approved module and a production antenna with suitable specifications then intentional radiation approval may be only a paperwork exercise. A review of the published antenna specifications and product architecture will typically suffice to enable your EMC test lab to prepare the necessary paperwork.

If however, you are using a custom antenna or have multiple radios in the design then the approval process will be more complex. If the design has only one radio, but uses an antenna outside the scope of the module's regulatory approval grant then antenna performance testing will need to be done. If the gain is too high then a full recertification will need to be done.

Unintentional Radiation Compliance

Like all digital devices a wireless device needs to be tested for unintentional conducted and radiated emissions. Wireless systems can be more complex to test than wired devices. The challenge arises because the regulations require that the device under test be operating in a normal mode when it is tested. You need to consider anything that can affect the amount of EMI coming from the device such as transmit power, interface activity, power supply input voltages, radio transmission activity, etc.

Note that passing FCC 15 may still leave you 40 to 50 dB short of having a well-performing radio.

Human Safety

If your device is normally used near a human being then it needs to be certified for the RF it sends into the human body. This kind of certification is a mix of EMI test lab measurements and calculations. For

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intermittent devices (almost all wireless devices) a measurement and calculation of the maximum duty cycle will sometimes be needed in order to establish compliance with the required limits.

CONCLUSION

Developing a wireless product requires the R&D team to address a wide array of technical issues with the major areas of concern being:

- System design
- Achieving system performance
- Passing regulatory tests

If you are new to wireless this whitepaper should serve as a roadmap so that you know what questions to ask, what activities to plan for and when you may wish to get outside help.

To save R&D time and expense on your wireless development contact Lee at Tech-Knows.

ABOUT THE AUTHOR

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Mr. Vishloff is the principal engineer in a wireless consultancy working in the areas of cellular-based M2M solutions, short-range wireless products and EMC Consulting. He has over 30 years of experience in wireless systems and product design. Lee has a degree in Electrical Engineering from the University of British Columbia and completed his management education at Simon Fraser University and the AEA/Stanford Executive Institute. He is a Professional Engineer, Senior Member of the IEEE and an IEEE Certified Wireless Communication Professional.

He is a regular contributor to the IEEE Communications Society training program, teaching several courses in wireless technology.