Antenna Integration and Selection

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The single most important factor in designing a radio-based product – be it GPS, cellular or an ISM-band device – is the antenna plan. Not just the antenna itself, but the whole plan. What kinds of antennas make sense for the product based on size, weight, expected performance in the desired use cases and required agency approvals? When it comes to antennas, everything matters. Where you put the antenna in the product relative to Printed Circuit Board (PCB) ground planes, batteries, wiring harnesses, the color of the enclosure and of course meat all affect the antenna in different ways.

How do you judge what is or is not a good antenna? This gets complicated because the performance of the antenna in free space only tells you how good the antenna could be. What you are always working with is the actual implementation. There are a few key metrics:

• **Antenna Efficiency**: This is the percentage of energy radiated versus not radiated. This is typically an integrated measurement swept over a sphere around the antenna.
• **Radiation Pattern** (Fig. 1): All antennas have a radiation pattern. The ideal point antenna, an isotropic radiator, has a perfect spherical pattern. Dipoles and monopoles have a toroidal pattern where the antenna pokes through the hole in the middle. The pattern is a 3D map describing what direction the RF energy is radiating relative to the antenna.

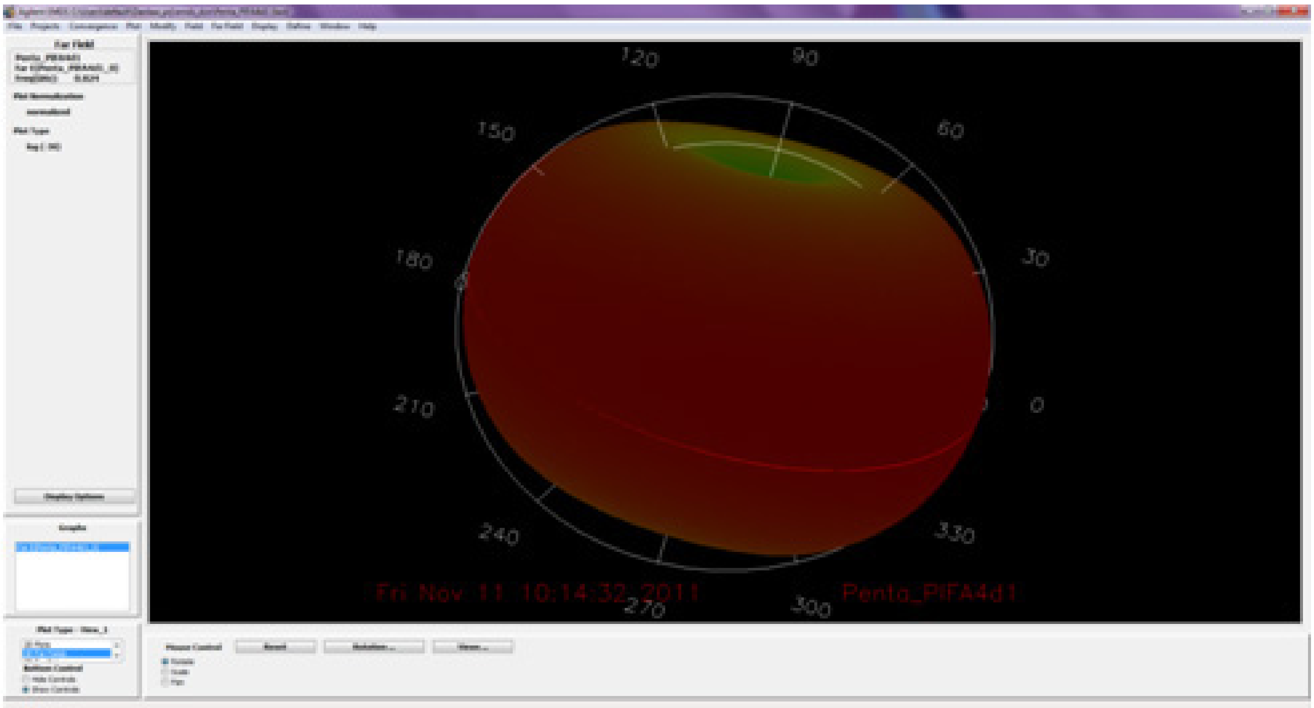

Figure 1. The 3D radiation pattern is from a penta-band 3G cellular antenna simulation operating at 824MHz. The donut pattern is a textbook monopole/dipole response. This radiation pattern is omni-directional which supports cellular link reliability.

• **Gain**: Gain is usually a product of directivity, the antenna is designed to radiate in a particular radiation pattern doing a better job in that preferred direction than others. Gain is seldom a good measurement criterion for small antennas.
• **Return Loss** (Fig. 2): AKA S11, this is how much energy is reflected back from the antenna versus the amount put into the antenna. It’s related to Standing Wave Ratio.

Figure 2. The return loss plot is from a penta-band 3G cellular antenna simulation. The device has a small ground plane which decreases the impedance bandwidth. The desired frequency ranges are 824-960MHz (GSM850/GSM900), 1710-1990MHz (GSM1800/GSM1900) and 2110-2170MHz (UMTS).

What to look for
The bigger the better. The best antenna options take up space one way or another and that space is related to the frequency the antenna is design for. There is no cheating here, the smaller the antenna the poorer the efficiency and bandwidth. If I could still buy a cell phone with a pull-out antenna I would because they just work better. As your frequency of operation goes up, you will be able to make the antenna smaller for a given level of efficiency. This is an important factor in low power license-free radio products – 433MHz RKE solutions can be very cheap but the antenna efficiency in a small package isn't good. 2.4GHz can yield a much better antenna efficiency but there are other reasons 2.4GHz may not be a good choice.

At a very basic level, unless you're doing a custom antenna design you want to choose an antenna that fits your product. If the antenna is supposed to be along a PCB edge with a ground plane behind it, you have to use it that way. If the antenna is supposed to extend out away from the ground plane, you have to use it that way. Off the shelf antennas are designed to be used a certain way relative to the ground plane and feed point. They are almost never designed to have a battery right next to them or a metal enclosure alongside them. If you don't use the antenna exactly the way it was intended, your performance will be worse than the manufacturer's stated numbers. Often MUCH worse.

How good is good enough?
Generally, when dealing with small devices we figure a 5-7dB return loss is good enough. Obviously you need to have that much return loss over the entire band of operation. The goal is to have the vast majority of F energy go into the antenna and

not get reflected back to the transmitter and wasted as heat. If S11 isn't good, you don't have a chance at good radiated efficiency. If S11 is acceptable, then you measure radiated efficiency. This obviously needs specialized equipment. Antenna vendors like Taoglas have this sort of equipment and there are 3rd party test labs like Satimo that can do it as well.

As a general rule of thumb, the net radiated efficiency should be at least 10 percent or it's really hard to call it an antenna. Sometimes you can't get even that good of net radiated efficiency because of device size versus frequency used. 150MHz in a wrist watch for instance doesn't lead to a very efficient antenna. The better your antenna works, the greater the perceived range of your product and the lower the chance you'll get grief from marketing about range.

There are some situations where efficiency is dictated to you, mainly in cellular products. The carriers spent a lot of money on their networks, and they don't want customers complaining about their networks because your product's antenna doesn't work properly. So for cellular antennas, it's not uncommon to have 35 percent as an enforced minimum efficiency. For some carriers, this requirement can be as high as 50 percent depending on the product.

What should I use?
The best antenna you can. In most cases you'll want an omnidirectional antenna. If you can, your best choice is a high quality antenna mounted a few feet away from any electronics or obstructions with good quality coax cable running to an RF connector on the product. The next best option is a terminal antenna that screws directly onto the device. Beware though – if your device doesn't have a ground plane similar to what the terminal antenna was designed for you can have performance problems.

Internal options are also available. DigiKey carries small connectorized antennas made of flex and rigid materials. These are good options for a plastic enclosure where you can meet the minimum spacing between where the antenna is mounted and any part of a ground plane. This includes batteries as well as the PCB.

The next best option after that is a placed antenna soldered to the PCB. The PCB as mentioned before must be explicitly designed to mimic the development board of the chosen antenna as closely as possible and nothing can be placed near the antenna like batteries, wiring harnesses, etc.

The last option is a ceramic chip antenna. These aren't really antennas; they're the driven element in an antenna formed by the part and the ground plane around it. Again these antennas must be used exactly as show on the development board or there is little chance for acceptable performance.

Custom antennas
Design your mechanicals around your antenna, or you will eventually design your antenna around your mechanicals. If your physical space is limited or the mechanical details of your device are already defined and you can't use an off the shelf antenna the way it was designed, a custom antenna is your only option for

acceptable performance.

There are two main reasons to develop a custom antenna versus an off-the-shelf antenna. The first is performance. A custom antenna is by definition designed around the mechanicals and physical details of your product and will yield the best possible performance in the space available. The second reason is cost. Most custom antennas can be printed on the PCB or as a stamped metal part. In both cases the per-unit cost of the antenna is usually very small in comparison to the cost of an off-the-shelf antenna. There are development costs for the custom antenna, but if you're building a large enough quantity of devices, the custom antenna can save a lot of money.

Every device and application is different and there are hundreds of antenna choices. Sometimes the choice is obvious, but oftentimes your options are limited and even those options aren't necessarily good ones. Antenna selection is a specialized area, so when it doubt consult an expert. An expert can guide you in choosing and qualifying antenna choices and ensuring you're product is successful.

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