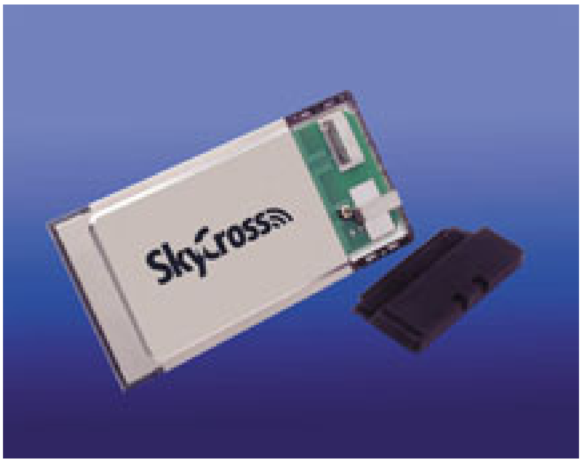
Stretching the Limit of Embedded Antenna Design

New design techniques allow engineers to stretch the limit of embedded antenna design.

By Kerry Greer, SkyCross, Inc.
As the wireless industry starts to mature, the successful introduction of new products has been linked to the capability to build smaller devices that perform more tasks. Today, cell phones fit within the palm of your hand and can send text messages and browse the Internet. They were not always this size. Who can remember the Wireless Stone Age (why do you think they called the first cell phones bricks?). Those early models only provided voice connectivity. Today, functional combinations of digital voice, Internet data and PDA organizers are fast becoming the standard for wireless devices. But this never-ending pace of functionality integration places incredible demands on the very component that makes a wireless device &quotwireless&quot&#151 the antenna.

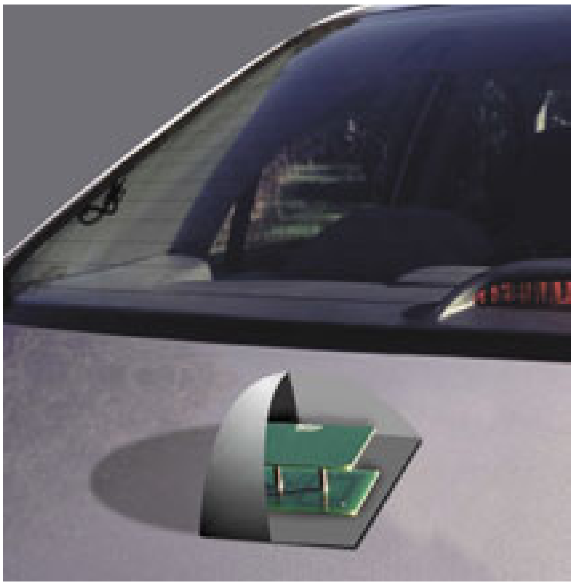
Antenna size has for the most part shrunk in correspondence with the evolution of wireless technology. This is evident when you compare the 4- and 5-inch whip antennas found on early phone models to 1-inch &quotstubbies&quot and &quotnubs&quot of today.
But, there are practical limits on how small you can build an antenna while still maintaining a minimum level of performance. Can an antenna be built so small that it is embedded into a wireless device and unseen, yet still perform as well as an external antenna? The answer is yes, but as we shall see it takes new design techniques and new antenna structures to keep pace with the corresponding advances in silicon, batteries and displays.



Antenna Physics

Consumers do not (and should not have to) understand antenna theory. Unfortunately, most wireless device design engineers do not understand it either. An antenna is fundamentally a transmission line that transforms information from electrical energy (current and voltage) into electromagnetic energy (RF waves). The length of this line is inversely proportional to the frequency of transmission. Therefore, as new wireless applications in the past moved up in the frequency spectrum (Commercial Radio, Broadcast Television, Analog Cellular, Digital PCS, Wireless Data), their antennas correspondingly decreased in size. As an example, a 1/4-wave 4-inch analog cellular &quotwhip&quot antenna at 800 MHz becomes a 1.5-inch digital PCS &quotstubby&quot antenna at 1900 MHz.

As mentioned, an antenna converts electrical energy into electromagnetic energy. These electromagnetic waves now propagate in all directions away from the antenna (during transmit). But how does this occur? Maxwell first described a detailed mathematical description of this process in 1865. Loosely speaking, this transformation takes place anywhere an electric current traveling through a conductor changes its velocity (speed and/or direction). Consequently, antennas come in all forms of curved, bent and folded metal shapes designed to induce this change in the electric current's velocity and thereby induce radiation. Furthermore, a time-varying electric current (such as a sinusoidal signal) has by definition alternating current flow and therefore produces radiation from even a length of straight copper wire. When the length of wire is chosen as an integer multiple of the frequency of oscillation, standing voltage and current waves are set up in this wire maximizing the change in current velocity and thereby maximizing the radiation or RF waves from the wire. This is the basis for traditional monopole antennas.



More practically, when a particular antenna design is being considered for a wireless application, it is peak power or average power of the waveform that is of interest to antenna engineers. The current and voltage on the transmission line act like waves on a pond and can be reflected back from the antenna terminals, so that only a portion of the applied power is available to the antenna for broadcast as electromagnetic waves. The amount of power reflected is determined by how well the antenna is &quotmatched&quot to the transmission line. A &quotperfectly matched&quot antenna accepts all of the available power on the line and reflects little or no power. Most real antennas are not perfectly matched and accept a fraction of the power available only over a small frequency range or bandwidth. These are called &quotnarrowband antennas&quot. Outside the bandwidth, narrowband antennas accept little of the available power and are &quotinefficient radiators&quot. The percentage of power that is radiated by the antenna is known as its efficiency. Efficiency (along with size) is the key parameter used today when comparing different antenna technologies for use in wireless devices.

External Antennas

The common dipole has long been recognized as an efficient radiator (when cut to the appropriate frequency length). It is made from bending the end of an open circuit two-wire transmission line into a 'T' shape, where the top of the 'T' is the radiating section of the antenna. The length of the top is lambda (λ), the wavelength of the signal. But this results in half of the wire sticking above the device and half below &#151 not very attractive to a wireless device designer. Consequently, the monopole antenna was developed to consist of half of the dipole (length = λ/2) mounted over a ground plane. This configuration results in a good radiating element with a desirable omnidirectional or toroid type beam pattern. Monopoles are implemented using λ/4 length. They are the antennas of choice for wireless device designers implementing an external antenna.

As noted, at a 1/4-wavelength the PCS frequency of 1900 MHz is still about 1.5 inches long. As the consumer market evolves wireless devices are getting smaller and demand is growing for internal antenna designs that still meet external monopole performance.

Internal (Embedded) Antennas

Antennas are slowly becoming more integral as new antenna technology becomes available. Today there are four leading antenna architectures that are commonly used in embedded applications: microstrip, patch, Planar Inverted 'F' Antenna (PIFA) and Meander Line Antenna (MLA).

Microstrip lines are an extension of the monopole, only laying it down on a two-dimensional surface. It can be easily fabricated by etching a copper strip of 1/2- or 1/4-wavelength onto the radio circuit board. While very inexpensive to make, its performance is limited to the extent that surrounding metallic sections of the circuit board (such as the underlying groundplane) severely interfere with its radiation efficiency. Furthermore, it is a single-frequency solution and most wireless devices today implement more than one mode of communication, usually in different frequency bands.

Patch antennas have been around for a long time and are a good choice for a system that requires a beam pattern focused in a certain direction. Patches are fabricated out of square or round copper clad on the top surface of a circuit board. Their radiation beam is normal to the surface of the board, resulting in a unidirectional &quotmushroom&quot or &quotinverted cone&quot pattern. Also inexpensive to manufacture, they are somewhat narrow in bandwidth. They are typically used in single frequency applications requiring the directed beam pattern, such as a GPS receiver or a wall-mounted access point.

The PIFA antenna literally looks like the letter 'F' lying on its side with the two shorter sections providing feed and ground points and the 'tail' providing the radiating surface. PIFAs make good embedded antennas in that they exhibit a somewhat omnidirectional pattern and can be made to radiate in more than one frequency band. But, their efficiency is only average and it can be difficult to properly match the device to the transmitting circuitry at both operating frequencies.

The MLA is a new type of radiating element, made from a combination of a loop antenna and frequency tuning meander lines. Unlike the previous examples, the electrical length of the MLA is made up mostly by the delay characteristic of the meanderline rather than the length of the radiating structure itself. This results in an antenna that is more efficient for its size than many competitive antennas used in wireless applications. In addition, MLAs can be designed to exhibit broadband capabilities that allow operation on several frequency bands, such as AMPS, PCS, and GPS bands simultaneously. However, initial MLA designs are slightly more expensive than the previous antenna options.

Embedded Antenna Design Issues

Regardless of which embedded antenna technology is used, there is always a challenge to integrate the antenna into the device and still produce the optimal or desired beam pattern relative to the orientation of usage. A problem of this today is the PDA. Consider that PDAs are really used in two different operating modes: held in the hand about chest-high at a 45 degree elevation, and flat on the desk at 0 degree elevation. While this may seem to be a trivial difference, it really calls for two different antenna designs. Going back to the monopole cell phone antenna, its radiation pattern is directed in a &quotring&quot or &quotdonut&quot shape around the axis of the antenna. It therefore works best when oriented straight up and down. Laying it on the desk distorts its pattern and wastes power in useless directions, such as up in the sky versus focused on the horizon (towards cell towers).

Even with all the current advances in embedded antenna technology, they alone are not sufficient to keep up with consumer demand for smaller, more powerful, longer lasting battery and multiple functioning devices. In addition, the recent mandate by the FCC for cellular phone position location is bringing GPS integration into wireless devices faster than technology will allow. There is an ongoing push in the wireless industry to maximize communication system performance with respect to capacity for high data rate 2.5G and 3G systems and to decrease &quotcoverage holes&quot in current systems.

In order to address these complicated and difficult challenges, new techniques are under evaluation to further advance wireless device performance. Among these, antenna diversity is now being considered for use on the handheld/consumer side of the communications link to improve handset Signal-to-Noise Ratio (SNR) as well as addressing the device orientation problem outlined above.

Mobile Device Antenna Diversity

Antenna diversity has been used in wireless communication systems for many years. Cell towers routinely deploy two antennas on the uplink (receive path back to the tower) to mitigate the effects of multipath in a desired signal. These systems are complex and have been limited to base station applications.

In general, diversity combining is analogous to the concept that &quottwo eyes are better than one&quot&#151 meaning that a single antenna does not always &quotsee&quot its intended signal, even though the radio may be well inside minimum communications range. Anyone who listens to the car radio while driving in a downtown urban environment has experienced a momentary dropout or fading of the radio station at the stoplight. Clearly the car is in range of the radio tower, yet no signal is received. This phenomenon is called signal fading and is the result of multiple signals from different paths canceling at the receiver antenna. This is much like the case of multiple pebbles being thrown into a pond simultaneously, where it can be observed that there are regions where the water appears undisturbed. What is different in the mobile signal environment is that the nulls are not fixed in space and also vary in time. This is because the environment is non-stationary &#151 the user is moving and so is the environment.

It is well known in signal processing that there are actually not one but five different types of diversity that can be used to increase signal reception: spatial, temporal (time), polarization, frequency, and pattern (angle). Of these, only spatial, polarization and pattern make for a practical implementation in wireless antenna systems.

Spatial diversity is the most widely implemented form of diversity combining. Referring to the car radio example above, the temporary loss of a radio signal at a stoplight is due to multipath interference. As the radio signal propagates through the urban landscape, the signal bounces off buildings and other structures. This scatters the signal in many directions, producing multiple copies of the signal.

As the radio is tuned to the specific frequency of interest, it receives all these copies of the signal together. Since reflected signals traverse a farther distance path from tower to radio than a direct signal, the multiple signals are no longer in phase with each other. In fact, they are now in random phase. Multiple signals that are in-phase will add to reception, while signals out of phase will cancel each other. As a result, the multiple signals will periodically cancel each other and reception is lost.

Spatial diversity mitigates this by using two similar receive antennas separated by a fixed number of wavelengths. Given that the multipath interference is localized to a specific location (such as antenna #1), antenna #2 will not suffer the same degradation. The separation spacing is chosen specifically to maximize the reception of antenna #2 when antenna #1 is at minimum. Therefore, in the simplest implementation, the radio simply switches to whichever antenna is currently receiving the strongest signal. More complex systems utilize different forms of signal combining based on weighting according to the signal-to-noise ratio of each of the received signals (Maximal Ratio Combining) or according to equal weighting (Equal gain Combining). In either case the signals are co-phased and summed.

Pattern diversity (or angle diversity) is conceptually easy to understand. Antennas come in all shapes and sizes. Part of this variety is due to the desired beam pattern they produce. For example, large parabolic dish antennas produce a very high gain beam pattern that is narrowly focused in one particular direction (usually pointed toward a geosynchronous satellite in space). If the antenna is not perfectly aligned, the signal drops. This is a form of pattern diversity in which the transmitter (the satellite) and the receiver (the dish) are fixed in position.

In cellular or WLAN systems however, the mobile unit is not fixed in position. In fact, the adoption of WLAN systems is predicated on mobility, allowing the user to connect his/her laptop from anywhere (i.e. any angle, including straight above). So conceptually, the mobile unit would best be configured with a hemispherical antenna allowing connection in any direction above the horizontal plane of the device. The problem comes from the fact that it is not easy to design an antenna with a complete hemispherical pattern, especially one that has positive gain throughout the entire hemisphere of interest.

The third type of diversity combining that can be used to increase wireless system performance is polarization. Polarization is a naturally occurring consequence of electromagnetic waves bouncing off some surface. In fact, polarized sunglasses make use of this fact when blocking sunlight glare off of water. Sunlight is naturally polarized both horizontally and vertically. As sunbeams hit the water surface, the water absorbs the vertically polarized beams and the horizontally polarized beams are reflected. Polarized sunglasses are built then to block horizontally-polarized reflected light only, resulting in a filter for glare off the water while still passing other light sources.

Electromagnetic waves in free space travel in a direction that is perpendicular to the direction(s) of oscillation of their associated electric and magnetic fields. For example, if an RF wave is traveling in the z-direction, the electric field could be oscillating in either (or both) the x- and/or y-directions (referred to as the horizontal and vertical directions). As this wave encounters other structures, it bounces off and produces multiple copies as detailed above in the spatial diversity section. However, in addition to the now random phase of the multiple received signals, the reflected signals exhibit changed polarization. Therefore, both a horizontally- and vertically-polarized receiver system is optimal for wireless systems.

All these diversity options require the implementation of (at least) two separate antennas on the wireless device. This would of course be seen as a &quotset back&quot in terms of wireless device evolution &#151 even though the wireless link actually would be much more robust. One solution currently being proposed to implement diversity is to have one external antenna and one hidden internal antenna. This device would look similar in appearance to the existing stubby antenna models of today, with the second antenna hidden inside.

Conclusion

Engineers have begun leveraging advanced technology, such as the MLA to create nearly invisible antenna solutions that reduce the size of devices and significantly improve frequency bandwidth performance. In addition, these antennas are being developed to achieve higher gain, and provide better directional control over emissions, while still allowing for embedded applications. This is a complex design problem, and wireless device manufacturers are realizing that antenna design and integration issues must be addressed at the beginning of the wireless device design cycle. Otherwise, waiting to the end of the cycle only results in the gangly, obtrusive appendix so prevalent in designs today.

Kerry Greer is Vice President of Engineering at SkyCross, Inc. headquartered in Melbourne, FL. For additional information please contact Mr. Greer at kerry.greer@skycross.com or visit www.skycross.com.