The right antenna makes GPS work

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Global Positioning System is becoming the next ubiquitous utility for all manner of communications devices, from cell phones and police radios to PDAs, automobiles, and laptops. Beyond the marketing implications of knowing where the user is, GPS adds a critical location dimension to public safety devices like the TETRA band radios used in Europe by police, fire, and other public safety workers. As the popularity of incorporating location information as a utility increases, system designers are lulled into a false sense of security at the ease of integrating GPS into a device—GPS poses some difficult engineering challenges. Unlike most voice communications services with comparatively luxurious power budgets, GPS is an ultra-low-power, line-of-sight satellite communications service with signals buried below the noise floor. GPS engine designers have made great strides in squeezing the highest level of performance out of the most difficult reception circumstances, however the contribution of the antenna to the GPS system cannot be ignored in making a reliable, robust GPS system. The consuming public just wants a GPS system, designed to operate out in the open air, to work in all environments, no matter how harsh.

A good case in point is the SAVOX Track-Mate GPS module for the Nokia THR800 TETRA-band radio. This module plugs into the bottom of a handheld radio in such a way that in the talk position the user's hand is in close proximity to the GPS antenna. Receivers with conventional GPS antennas would have a very difficult time acquiring and maintaining GPS lock in such an arrangement due to near field interaction with the user's hand and the variability with which the user orients the radio in use. The Sarantel GeoHelix GPS antenna embedded in the SAVOX Track-Mate solved the difficult problems faced by designers of GPS systems that are required to work under difficult circumstances—the right antenna does indeed make a difference.

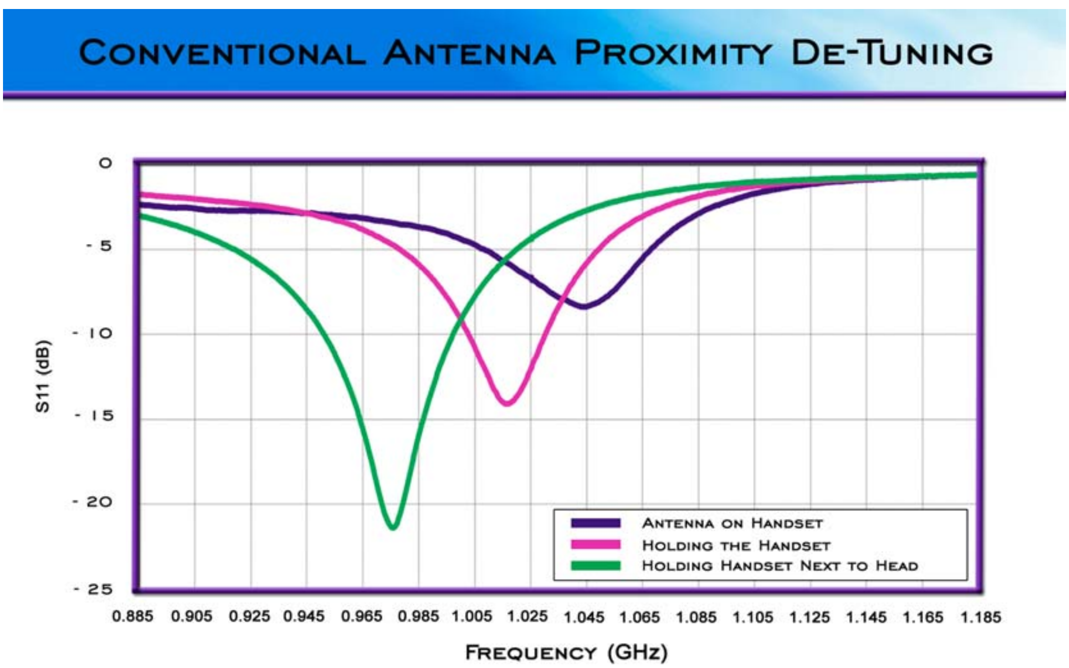
Size (usually) matters

In antenna science, size matters. Bigger antennas give better reception.

$$\frac{\text{Gain} \bullet \text{Bandwidth}}{\text{Volume}} = \text{a constant}$$

Therefore, as volume increases, gain and bandwidth increase in concert. To achieve higher gain from a smaller volume, bandwidth must decrease. Or, for a higher bandwidth application, gain must decrease if volume remains fixed. This simple fact poses many difficulties for RF designers under constant pressure to shrink the size of radio devices. As a result, the most common antenna solution chosen for small, handheld radios is a monopole antenna with a single-ended feed system. Such an antenna uses the volume of the handset as a resonator, increasing the apparent size of the antenna from the visible stub or whip to the effective size of the entire handset. Problem solved? Not really.

Using the entire handset as the effective resonating body means the antenna designer is never sure how long the antenna needs to be to resonate at the correct frequency. Small alterations in the design of the handset or antenna ground plane change the resonating length of the antenna system. Worse yet, the user becomes a part of the resonating system when holding the handset because human beings are largely made of electricity-conducting, salty water. Grasping the handset changes the effective size of the resonant system by an amount that varies by the great diversity of the size of people's hands! The only apparent solution for the RF designer is to choose an antenna with wide enough bandwidth to cover the service requirements plus a considerable band at the margin to handle all the variable in-use effects. Of course, wider bandwidth impacts gain according to the [(gain • bandwidth) / volume] formula, particularly at the margins. The problem can be seen very clearly in an S_{11} plot of a conventional GSM900 antenna measured in free space, hand-held, and held near a phantom head, resulting in a dramatic frequency and match shift.

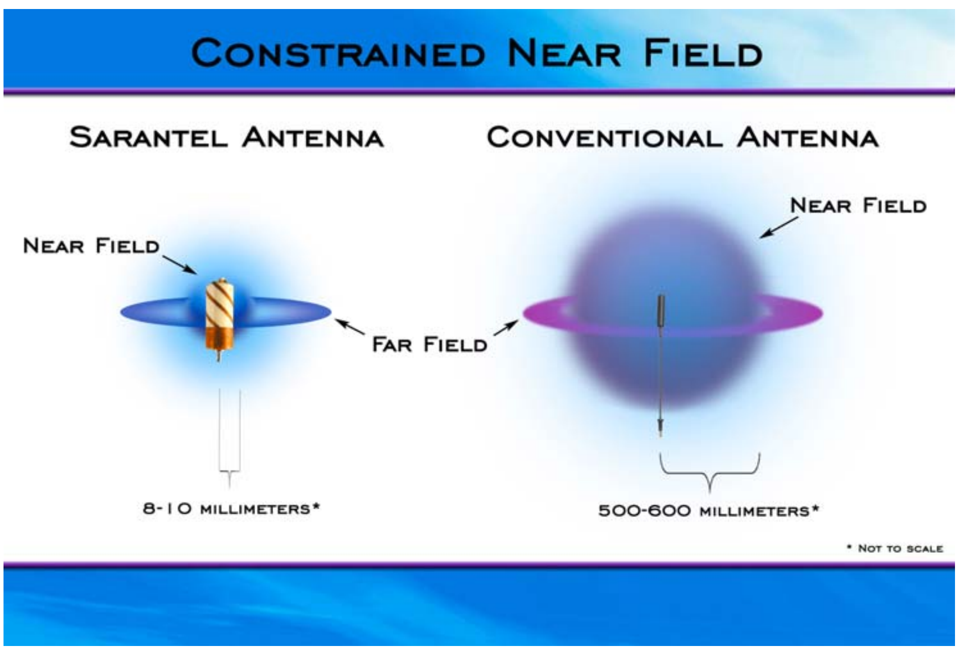


What then is the designer to do? In the case of conventional antennas, the solution is a painstaking trial-and-error process in which the antenna design becomes an integral part of the radio design.

The human sponge

The tuning effect of human tissues on a conventional antenna becomes much more critical in a GPS context. All antennas create a "near field" reservoir that stores resonant energy in the air surrounding the antenna. It is this field that resonates to form the "far field" transmission or reception pattern of the antenna. It is of paramount importance for the RF designer to understand the extent of the near field volume because objects entering that volume will de-tune the antenna or reduce its radiating efficiency. When a material of higher permittivity than air (e_r = 1) enters the near field, it will store electrical field energy with a density that is directly related to the material's relative permittivity. If the material is also lossy, it acts like a sponge, absorbing the energy from the near field. That absorbed energy is no longer available to the radio.

Near field interaction with human tissues severely complicates the design of small, portable wireless devices with GPS. It is a conventional rule of thumb that the radius of the near field region is approximately three wavelengths (in the absence of dielectric loading, which we'll look at later). For a GPS antenna with a wavelength of 19 cm, the rule of thumb yields a near field over a meter across! At $e_r \approx 40$, human tissues have a much higher permittivity than air, therefore tuning and energy loss ramifications of sharing near field energy with the human body are highly significant. In mobile voice communications, signal levels are high enough to suffer a large loss of efficiency and still provide adequate performance. However, because the signal levels involved in GPS are quite low, the hit to efficiency suffered when the user's hand or head enters the near field can often be quite enough to prevent the receiver from getting enough signal to reliably obtain or maintain a location fix.

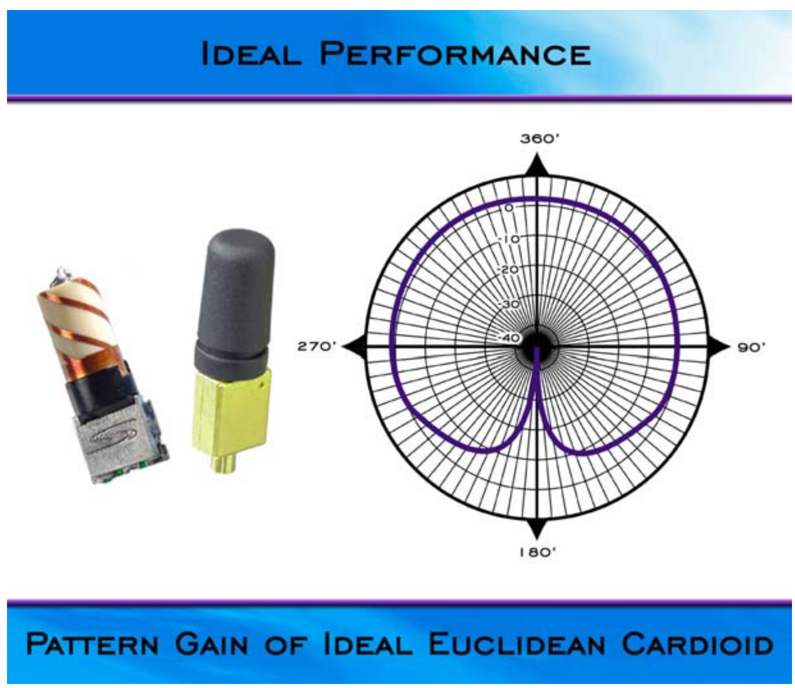


Therefore, three significant challenges remain to be solved before a robust GPS solution can be offered in small, handheld devices that are intended to be used in close proximity to a human being: 1) The antenna must be small enough for the device to accommodate it; 2) the antenna must be large enough to provide an adequate service without using the volume of the radio as part of the resonating system; and 3) the antenna must remain efficient even when held in the user's hand or near the user's head.

Fit and forget the antenna

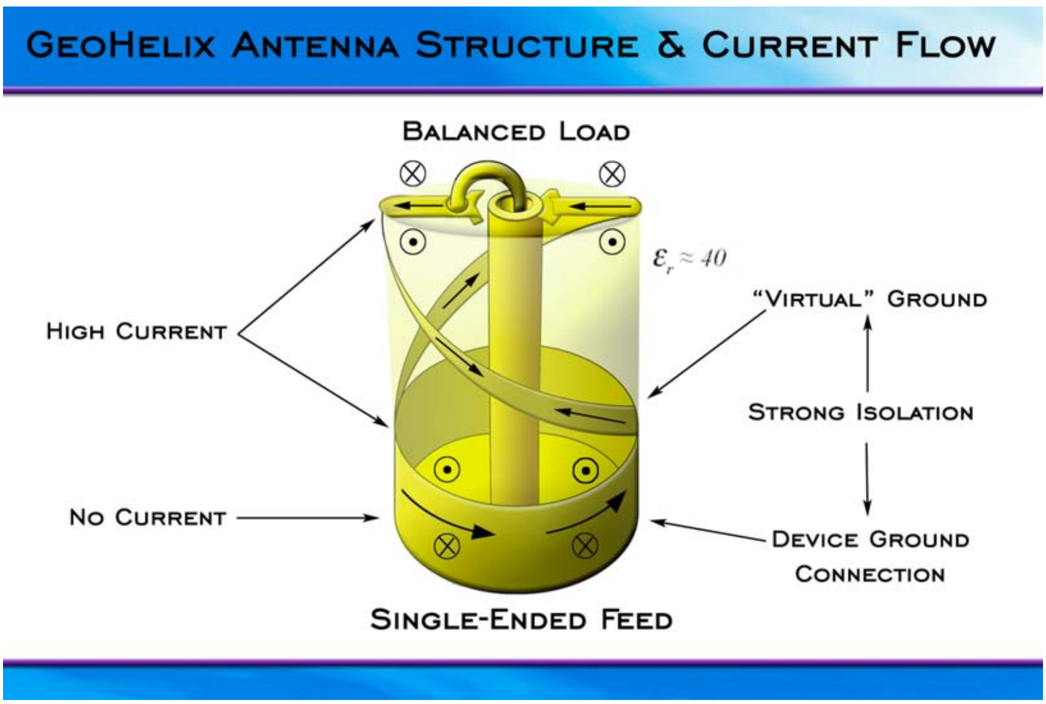
To thoroughly address these challenge, an antenna would have to resonate in isolation from the radio on which it is mounted. This infers that it would have to be balanced so that it does not resonate against or couple with a ground plane. Further, it would have to be constructed in such a way that the user's hand, head, or body doesn't interact with the near field. An antenna that accomplishes these goals would be very stable in frequency regardless of the size of the radio or how the radio was being used, and would offer higher in-use efficiency than conventional antennas. The designer could fit the antenna to the radio and forget about it, much like a digital component. Sarantel's GeoHelix GPS antennas have these properties, and provide other features that make them ideal for many GPS applications.

The GeoHelix GPS antenna employs a structure known as the quadrifilar helix, a well-understood double loop structure long used in satellite communications because of its excellent circular polarization properties. The quadrifilar helix forms a spinning dipole across two orthogonally phased loops, creating a far field pattern that is cardioid in shape with broad beamwidth and a null pointing toward the bottom of the antenna. Such a pattern is ideal for satellite reception because satellites transmit from above the horizon yet spend most of their viewable orbit in lower angles from the viewpoint of the user—imagine watching an airplane approach you from the horizon; it would appear to move slowly as it came over the horizon, then pick up speed rapidly as it approached higher angles of view and passed over your head, then slow down again as it approached the opposite horizon. The cardioid pattern of a quadrifilar helix offers lower peak gain than more directional antenna styles, but has better low elevation performance.

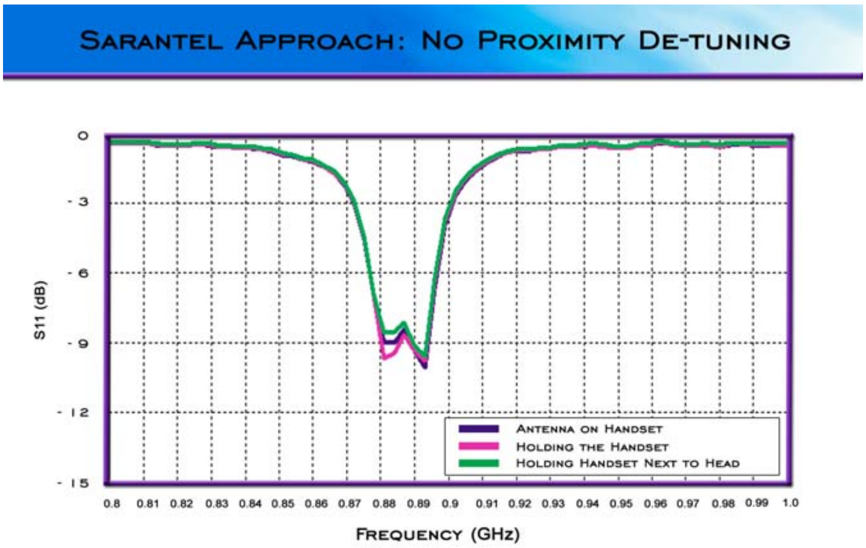


Sarantel's embodiment of the quadrifilar helix adds two unique elements: 1) Dielectric loading; and 2) addition of a balun to achieve a balanced load from a single-ended feed. Dielectric loading addresses one of the size concerns discussed previously by shrinking the antenna element into a size that can easily be accommodated in a smaller, handheld GPS receiver system. Further, by loading the antenna with a ceramic material of high permittivity ($e_r \approx 40$), the near field region is shrunk to a small volume not much larger than the antenna itself. As a result, in normal use the hand or head of the user does not approach the denser energy regions of the near field, yielding efficiencies that are unaffected by the mode of use. By itself, however, dielectric loading does not accomplish all of the stated goals. Other styles of GPS antenna, like patch antennas, use dielectric material with related near field effects. However, these antennas fail to prevent human tissue interaction with the antenna because they must resonate against a ground plane, leading to changes in resonant volume when the user grasps the device.

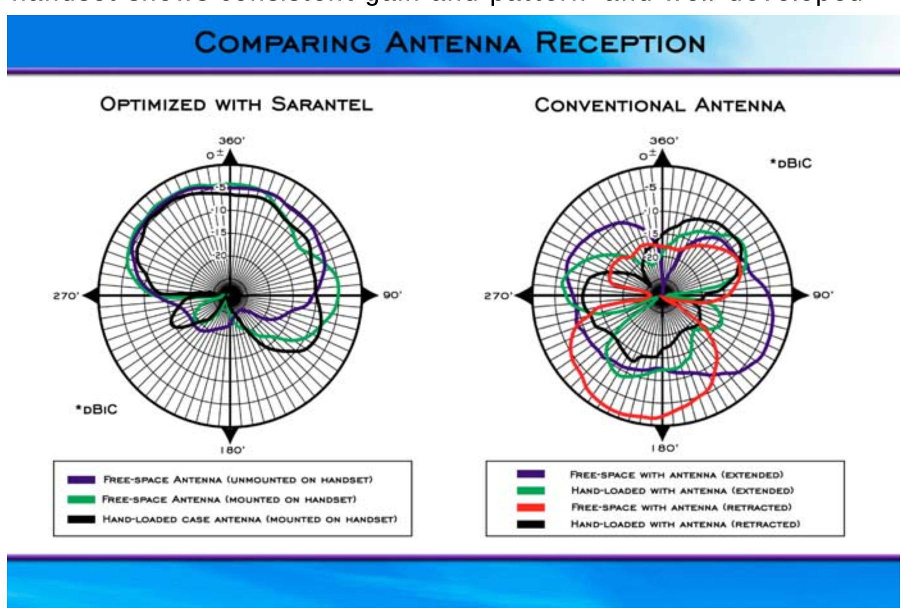
Sarantel introduces a balun to the quadrifilar helix structure to address the remaining problems of near field interaction and proximity effects. Currents fed from the conductor travel around the helices and along the rim of the balun, creating a virtual ground at its rim. This virtual ground is very strongly isolated from the actual ground at the base of the antenna where the antenna makes a physical connection to the ground of the radio such that there is no electrical path coupling the two grounds. As a result, the GeoHelix antenna is also strongly isolated from the box, a necessity for creating antennas that resonate in isolation from the device. Going back to the [(gain • bandwidth) / volume] equation, volume is fixed by the antenna alone, leaving only gain and bandwidth as variables. All other things being equal, bandwidth of ceramic antennas tends to be narrow, thus over a small band one would expect higher gain. For the GPS application, fractional bandwidth is indeed quite small (≈ 0.2%), thus the gain performance of the GeoHelix is excellent for its volume.



The key measure of an antenna's efficacy for a given application is to put it to the test as a user would operate the device. Too often antennas are specified for a particular peak gain or efficiency *as measured in free space*, while we have demonstrated that conventional antennas perform quite differently when they are actually deployed on a radio with a user holding the device. An antenna that truly achieves isolation from the radio would necessarily have a smaller volume, thus be expected to have lower free-space efficiency, but that efficiency would not be expected to change when the antenna is mounted on the radio or held by the user. The first test would be frequency stability, which can be demonstrated by a GSM900 antenna built on the Sarantel platform. In stark comparison to the conventional antenna, Sarantel's antenna shows remarkable frequency stability between handset-mounted, handheld, and held near the head use positions.



The other critical test of the antenna's efficacy would be to measure the antenna's gain and pattern under different use positions. The graphic shows measurements taken with a conventional GPS antenna on a commercial handset, where the antenna is using the entire handset as the resonating volume. Much of the antenna's gain is pointed down, and the antenna in all use positions shows little hint of circular polarization. Sarantel's GeoHelix antenna mounted on the same handset shows consistent gain and pattern–and well-developed circular polarization–regardless of the use position. Despite the volume advantage the conventional antenna has over the GeoHelix antenna, the GeoHelix antenna provides measurably superior performance.



Practical Measures

In the end, however, the measure of an antenna's performance does not come in a chamber or at the end of a test set. Robust, reliable performance is measured on products in use in difficult environments. The SAVOX Track-Mate GPS module presented a challenge for getting good performance from the antenna because it plugs into the bottom of a handheld radio in such a way that the user's hand in talk position is very close to the GPS antenna. Near field interaction between the user's hand and a conventional GPS antenna would have a strong proximity de-tuning effect on the antenna, making a position fix very difficult to achieve and maintain. We have shown the Sarantel GeoHelix antenna to be immune from such near field de-tuning effects. In addition, the Track-Mate is mounted on a handheld radio that is rarely oriented at an optimum angle for GPS signal acquisition. The variability with which the user orients the radio contraindicates the use of directional antennas. Planar-style antennas (for example, patch antennas) common to GPS devices would be very difficult to orient in this device since it does not present a facet that has a fixed orientation parallel to the ground. The Sarantel GeoHelix antenna provides a broad reception pattern that is greatly tolerant of variable orientation by the user.

The SAVOX Track-Mate provides one example of an application where antenna selection appropriate to the intended use of the device is absolutely critical. The GeoHelix GPS antenna provides robust and stable performance over all modes of use, with an optimum reception pattern for the service, in the smallest volume possible. Because of its isolation from the handset, the GeoHelix antenna achieves a unique position among RF components: The designer can fit it to the radio and then forget about it. Sometimes, public demands seem contradictory: smaller size and better performance. Sarantel is developing antennas that optimize the [(gain • bandwidth) / volume] equation so designers can focus their efforts on squeezing the greatest possible performance out of radios that are ever decreasing in size.

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