Performance Expectations for Reduced-Size Antennas

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This month's tutorial article presents a summary of the advantages and limitations of electrically-small antennas like those used in many wireless devices

Every device that transmits and/or receives radio signals needs an antenna. When that device has a small size or limited space for a classic resonant antenna, various techniques are used to implement reduced-size antennas. Those techniques may include inductive or capacitive loading, meandered or spiral construction, high dielectric constant materials to slow down wave propagation, and embedded structures incorporated into the packaging. Each of these methods imposes some type of limitation when compared to monopole, dipole, or resonant loop antennas. This tutorial looks at the key limitations of small antennas, with the intention of illustrating what level of performance can be expected from the various design options.

VSWR Bandwidth

A good impedance match is needed for efficiently transferring power into, and extracting power from an antenna. Compared to the "natural" radiation resistance of a monopole (36 ohms) and a dipole (72 ohms), the radiation resistance of reduced size antennas will be much lower.

As an illustration, the radiation resistance of a small dipole is [1],

$$R_{Rad} = 20\left(\frac{\pi L}{\lambda}\right)^2$$

where L/λ is simply the dipole length in wavelengths. Using this equation, a dipole that is one-third of normal $\lambda/2$ size will have $L/\lambda = 0.167$ and $R_{Rad} = 5.5$ ohms. The feedpoint impedance will be $5.5 - jX$, where X is a large capacitance, as high as 1500 ohms in the case of thin dipole. This $5.5 - j1500$ ohm impedance must be matched to the system impedance, typically 50 ohms.

Small loops and monopoles have similarly low radiation resistance with high reactance. Matching to highly reactive loads is inherently narrow bandwidth, since the magnitude of the reactance changes rapidly with frequency. Achieving a broader bandwidth match requires either complex networks or the introduction of lossy components.

The use of meandered lines, spirals, fractal patterns effectively distribute the required inductance over the length of the antenna, and can result in higher radiation resistance and lower loss matching networks. However, they require more space to implement.

Efficiency

In the above example, the initial task of creating a non-reactive feedpoint requires cancelling the capacitive reactance with an inductor of 1500 ohms reactance. In practice, such an inductor will have a Q no greater than 100, usually less, and thus will also have a series resistance of 15 ohms or more. With the inductor in place, the system will see 20.5 ohms (or greater) resistive impedance, of which 15 ohms is loss. Small loops and monopoles have similar problems with losses when attempting to match their low radiation resistance.

The analytical work of Harrington, reviewed in [2], shows that efficiency is reduced as antennas become smaller, even with lossless matching. These losses are primarily resistive losses in the antenna's conducting material, which become greater with lower radiation resistance. In practice, however, most loss will be due to lossy matching components.

Proximity Effects

The environment surrounding a small antenna will have a large effect on its performance. Small antennas used on portable, handheld devices will be subject to changing orientations and widely varying proximity to conducting and dielectric materials. These will all affect the radiation pattern, and the interactions may affect the impedance, as well, resulting in less efficient power transfer. These changes in polarization and signal strength must be accounted for when analyzing the total path loss of the system the portable device will be used with.

In addition, the operating environment may have nearby shielding and reflecting surfaces, such as vehicles, buildings, furnishings, and other objects. These things can block the desired signal path, or magnify the multipath characteristics inherent to portable device communications. Although these larger-scale objects do not interact directly with the antenna, they alter the final radiation pattern.

Some Antenna Examples

Small antenna design is a compromise among gain, efficiency, bandwidth and occupied volume. Some types that address these tradeoffs in different ways are described below.

Bent and folded antennas—bent monopoles, including the inverted-F, folded patch antennas, and a wide range of meandered structures may be used. They may be implemented as two- or three-dimensional structures. In general, the highest radiation resistance for a given occupied volume will be achieved with a moderate amount of “meandering.” The four-arm spiral appears to be the most efficient 3-D structure [3].

Lumped Element Loading—Chip capacitors or inductors may be used to provide the necessary reactance to create an electrically small antenna with a non-reactive feed impedance.

Dielectric Loading—With lower velocity of propagation, antennas constructed on dielectric materials are smaller than their free-space counterparts. Strip or inverted-F antennas on ceramic substrates are popular for handheld wireless devices. Circular or rectangular stacked patch antennas are often used for circularly-polarized Global Positioning System antennas.

Electromagnetic Bandgap (EBG) Ground Planes—EBGs are low-height structures comprising many small-size antenna-like elements with capacitive top-loading surfaces that approximate a flat substrate. Because these structures are resonant, they present a high impedance at their tops. This effectively isolates the surface from the primary antenna that is installed above. With no surface waves, the “ground plane” has greatly reduced interaction with the antenna, allowing it to perform in a manner approximating its free space performance. This is a narrowband solution, although varactor diodes can be integrated to provide tuning.

Many other structures are possible. Readers are encouraged to review the References and other sources.

References

1. D. Miron, *Small Antenna Design*, Newnes, an imprint of Elsevier, 2006.

2. J. Volakis, C.-C. Chen, K. Fujimoto, Small Antennas, McGraw-Hill 2010.

3. S. R. Best, “The radiation properties of of electrically small folded spherical helix antennas,” *IEEE Trans. on Antennas and Propagation*, vol. 52, April 2004, pp. 953-960.