

# Antenna Design Challenges for New-Generation Nano Satellites

David Farr and Bill Henderson
*Haigh-Farr, Bedford, N.H.*

The commercialization of space is well underway with companies such as SpaceX, Boeing, ULA and Orbital Sciences developing and providing launch vehicles and spacecraft being used by both government entities, as well as private, commercial customers. Large satellites are being launched from these vehicles and while they are still of prime interest because of shear capacity, depth of functions and expected service life, a new generation of compact satellites and launch vehicles are being developed that allow the academic and commercial sectors to produce useful science at significantly lower cost and with shorter realization times.

NASA is also contributing to this movement, as it has produced the Nanosatellite Launch Adapter System (NLAS) enabling small satellites to be launched as secondary payloads on major launch vehicles. Meeting size and space restrictions for small satellite devices presents engineering challenges to deliver the desired performance capabilities within these confines. A major area of concern is the availability of reliable communications to and from Earth, as well as between other compact satellites launched as a group. The antennas required to do so are, of course, a key element of the analysis of this problem. This article will explore the issues considering both where we are now and what we believe will be the future, and will evaluate the challenges facing standardization of the satellite's infrastructure and communication capabilities with a focus on antennas.

When looking at developing antennas for the compact satellite market, there are two areas that pose significant challenges: the actual physical size of the satellites, and the size and weight restrictions of the launch vehicle. Delivering a robust antenna that can fulfill the mission and survive the harsh environment of space within these size and weight constraints is the goal. The small satellites themselves offer much smaller surface area for antenna placement. Miniaturized or small satellites are of low mass and small in size, usually less than 1,100 lbs. While all such satellites can be referred to as small satellites, different classifications are used to categorize them based on size, with the largest ones being a mini-satellite (220 to 1,100 lbs.), micro-satellite (22 to 220 lbs.) and nano-satellite (2.2 to 22 lbs.); down to as small as a pico-satellite (0.22 to 2.2 lbs.) and femto-satellite (3.5 oz.). For purposes of this discussion we will focus on nano, micro and mini-satellites, or a weight range of 2.2 to 1,100 lbs.

The key to success in this emerging market for antenna companies, is taking their well-proven space-qualified designs and manufacturing techniques for costly, high-end satellite solutions, where size and weight are not the limiting factors; and miniaturizing them to fit the new compact satellites and achieving a commercial-off-the-shelf (COTS) price point. Equally important, however, remains performance. Achieving a balance between these competing goals is a challenge. Performance in particular has several considerations. The designer needs to consider not only the antenna itself and the degradation to performance through miniaturization, but the nature of the structure the antenna is mounted on. This is always an important consideration for Telemetry, Tracking and Control (TT&C) antennas, which are typically low gain operating in L- or S-Band. Also, many low Earth orbit satellites utilize GPS receive antennas. The performance of all of these antennas can be strongly affected by the size and shape of the ground-plane and the presence of other nearby objects. The ground-plane in this case is the satellite which, given its reduced size, is often less than ideal. Using computer modeling and calculating the pattern with the antenna mounted on an electromagnetic solid model of the satellite is a key design step discussed later.

One of the major benefits of small satellites is the reduced cost for entry into space. Educational institutions, as well as small businesses with great ideas but limited resources have not been afforded the opportunity to participate in this market until now. The cost to build and launch the satellite along with high insurance expense has left this market unattainable to all but a few in the past. With a more affordable price point and easier access, this market is poised to show significant growth over the next five to seven years. According to a MarketsandMarkets report (March 2014), the nano and micro-satellite market is estimated to grow from $702.4 million in 2014 to $1887.1 million in 2019 with the commercial sector being the largest contributor by 2019. The payloads may encompass such things as general weather observations, text-messaging backhaul, science experiments or still-photo reconnaissance, and may be tailored for specific applications from basic to complex. The cost associated with each type of payload will vary. The more complicated the payload requirements the more expensive the satellite and its component parts, including the antenna.

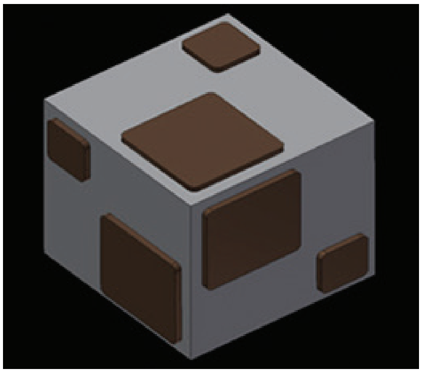


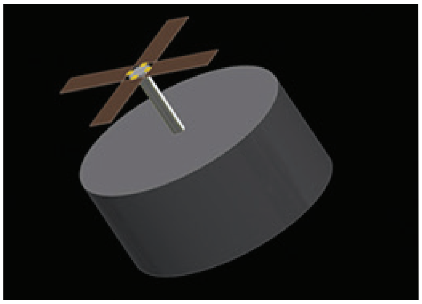
*Fig. 1 Conformal antennas on a CubeSat (1U).*

## THE SHAPE OF THINGS TO COME

Given launch container limitations, such as those imposed by an NLAS, there are two basic antenna designs for small satellites that may be utilized: conformal and deployable. There is a significant need for rugged conformal antenna designs that are shaped to naturally mate with the flat, cylindrical or conical surfaces of the satellite with little or no protrusion. ***Figure 1*** is a representation of mounted conformal GPS and S-Band antennas. Each type of antenna individually provides hemispherical coverage and when installed in pairs, connected through a power divider/combiner, will yield spherical coverage. The two can also be connected through a switchable divider/combiner to initially provide spherical coverage during insertion, and then hemispherical coverage when operational and aligned properly. Using only hemispherical coverage will provide increased gain, which is always desirable.

There are also requirements for deployable antennas. In this application, the antenna lies flat on the satellite so it will not interfere with the required launch dimensions. When it is released into orbit the antenna's radiators are deployed and locked in place. While there are several configurations for deployable antennas, a basic version is shown deployed in ***Figure 2***.

Each of these approaches requires advanced design and manufacturing capabilities, while staying within a COTS target price point. Some may believe that standardization of antenna requirements is the solution,



▲ *Fig. 2 Deployed antenna elements on a cylindrical satellite.*

which would result in lower costs, but it would also be extremely challenging since each satellite will present with varying electrical and environmental requirements to meet the demands of the particular mission. In addition, this would require collaboration between many organizations in a competitive environment, which is unlikely, so the concept of true standardization is challenging. The world of micro and mini-satellites require designs that are specific or highly tailored to optimize antenna performance given the size, limited placement options and other objects that need to be placed close to the antenna, so standardization will be even tougher on these platforms.

## LAUNCH VEHICLE ANTENNA DESIGNS

Hand-in-hand with the discussion of smaller satellites is consideration of the method to put them into orbit. These new small satellites can be deployed in both traditional ground rocket launch vehicles (i.e., Atlas, Delta, Falcon-9) and non-traditional small, dedicated launch vehicles (both ground and sub-orbital air launch). Currently, there are a number of NASA and DARPA awards to companies that are bringing this new launch technology to market. These new, dedicated nano-launch vehicles require antenna performance schemes similar to the traditional large launch vehicles, including UHF Flight Termination, C-Band Transponder, GPS Metric Tracking and S-Band Telemetry. The ultimate challenge is meeting size and weight restrictions while providing higher gain. Higher gain helps when using a lower-power configuration, which in turn, helps reduce vehicle battery draw and thus, can help reduce battery weight and size.

A traditional launch vehicle is right now a one-time-use method of launching a main payload, and in some cases will also carry along several smaller satellite packages, "piggybacked," for the ride. As a result, the insertion of the smaller satellites might be less than desirable since they are not the primary payload. Since these new, smaller launch vehicles are dedicated to the smaller satellite market, they ensure the satellite will be put into the preferred orbit. These smaller satellites may prove to be considerably more productive and relied upon since the mission profile will be known with certainty.

## SYSTEM PERFORMANCE

One of the tasks facing both the satellite and antenna companies is optimizing performance of these systems once they are in space. Simulation or modeling of the antenna mounted on the satellite is an integral part of initial antenna design activities. This is especially important with smaller satellites, where, as previously mentioned, the reduced size of the satellite imposes considerable limitations on antenna performance (reduced ground plane), placement and size. Haigh-Farr combines its expertise in antenna design with unique software tools and techniques to simulate the performance of antennas in real-world environments. When antennas are placed in a working environment, such as on the body of a satellite, the proximity of metallic and dielectric structures will affect its radiation pattern. The resulting change in the coverage may adversely affect the performance of the communication link. In order to avoid costly and time-consuming trial-and-error methods to fix these problems, computer modeling is used to optimize the performance of the antenna in its actual environment. Early in the design cycle, simulation may be used to change the shape and spacing of structures to further optimize antenna performance.

To further highlight the impact of vehicle geometry, the radiation patterns of a Wraparound™ antenna were calculated when mounted, first on a smooth cylinder, then with strategically shaped and placed fins near the antenna. The patterns for both cases are shown in ***Figure 3***. While this is certainly a dramatic case, it is not out of the realm of possibility. It is our ex-

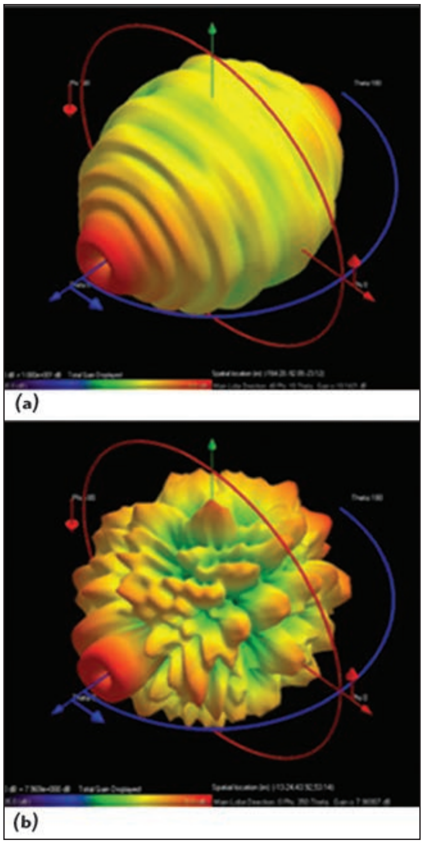



*Fig. 3 Antenna pattern on a smooth cylinder no fins (a) and on a smooth cylinder with strategically placed fins (b).*

perience that these types of parasitic structures can have a dramatic effect on pattern characteristics.

Simulation tools are also used to optimize the performance of an antenna in the presence of other antennas. When multiple antennas are placed in close proximity to one another, the radiation pattern of each antenna is distorted from its ideal. In this scenario, modeling is used to alter electrical, mechanical and spacing parameters of the antennas to mitigate, or at least minimize, the effect of nearby antennas. The analytical techniques used provide far field gain performance of complex antenna configurations and/or complex vehicle geometry (including effects of solar panels, protruding sensors, other antennas, etc.). ***Figure 4*** is another example of computer modeling.

## MAKING CONNECTIONS

The growth of the small satellite market, while very exciting and far reaching, must conform to the laws of physics – as the physical size gets smaller, a conformal antenna that might work with one application may need to migrate over to a deployable antenna for another. As a case in point, the nano-satellite is particularly challenging when the mission needs UHF capabilities. A conformal antenna may not work for this satellite class because the satellite can be substantially smaller than the wavelength at UHF, thus, unable to support the necessary physical size of the antenna. Switching to a small UHF deployable antenna that folds for launch and opens up once inserted into orbit is the best current solution.

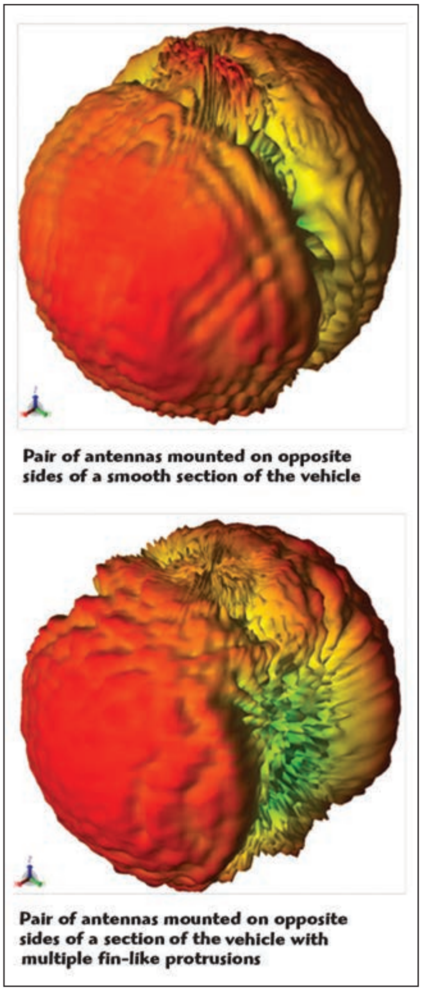



*Fig. 4 Simulated performance of a pair of antennas on a launch vehicle.*

It is common to use circularly polarized antennas, since it eliminates the need to align the polarization of the transmit and receive antennas. This is not the case with linearly polarized antennas, which must be perfectly aligned in order to avoid loss of signal due to polarization mismatch. Circular Polarization (CP) however, often presents implementation challenges, especially at low frequencies, since the antenna is typically larger than its linear counterpart.

Finally, the use of the antenna must be considered when determining coverage (i.e., directional or omnidirectional). As previously discussed, TT&C antennas are typically low gain antennas with broad antenna patterns. For data link antennas, which tend to be directional but not necessarily, the choice of antenna architecture is driven by a complex interplay among many system level considerations including performance, cost (both recurring and non-recurring) and regulatory issues. Key factors determining the performance needs of the satellite antenna are propagation loss, required data rates and spectral efficiency, along with the nature of the ground antenna.

Consider two extreme examples: a UHF antenna in a low Earth orbit and a Ka-Band satellite in geostationary orbit. When both free space loss and weather related attenuation are considered, the total difference in propagation loss between the two scenarios can be 80 dB or more. For the Ka-Band Satcom application, high gain, directional antennas are always necessary. However, the low propagation loss at UHF implies that for some applications low-gain (omni-directional or hemispherical coverage) antennas can be employed for both the space and ground antennas. The omni-directional antenna has obvious advantages with regard to equipment costs, especially for applications with a mobile earth terminal. However, greater antenna gain enables higher data rates and better spectral efficiency (more bits/sec of data per Hz of bandwidth), which translates to lower operating costs.

These kinds of performance and cost tradeoffs are important factors to consider for all Satcom applications. In the realm of conventional large satellites, these tradeoffs have led in part to the fact that currently most high data rate satellite applications utilize high gain antennas on geostationary satellites, while low Earth orbit communication satellites have been utilized more for lower data rate (and greater cost per bit) applications. It is fair to say that the trade space for small satellites has only begun to be explored and the implications for large scale deployment of small satellite based communication systems is not fully understood.

Another important aspect of this will be employing new methods to share the spectrum with the current satellite infrastructure. Optimizing the performance of the current satellite antennas to the needs of future small satellite-based systems will be one key to their success. It should be noted that in the past, deployment of new types of satellite-based communication systems (e.g. those employing VSATs or mobile ground terminals) have often required working around the existing infrastructure that was optimized for different applications. The low cost and rapid deployment that is possible with small satellites should facilitate avoiding some of the associated pitfalls.

## CONCLUSION

A viable commercial market is enabling innovative companies to carry multiple payloads with clusters of small/nano satellites that are affordable and yield quick access to space for everything from intelligence, surveillance and reconnaissance, to planetary science and internet backhaul. Large clusters are possible, however, as these small satellites are less expensive and can be replaced frequently with technological advances and shorter life cycles (some between 90 to 180 days). Data from both individual and clustered satellites can be sent to multiple ground stations and processed very quickly, enabling, for example, updated images during natural disasters or battle ground assessments for combat situations. This capability will open new commercial, scientific and military monitoring that will benefit the industry in a multitude of ways, making it possible to design and produce a working satellite at lower costs.

As the market continues to explore and expand the small satellite trend, the antenna technology will continue to cater to the broader availability of these smaller satellites. Specific mission requirements will vary. The complexity of the payloads will also change depending on the specific application. The common theme will be transmitting video, pictures, voice and data to large, fixed ground stations or mobile receivers. Even though these are desired to be at COTS prices, they still need to be built with well-proven materials and methods of fabrication to withstand the extremely harsh thermal, shock and vibration environments from launch to orbit. It would be catastrophic if the antennas did not perform after launch, since in most cases this would render the mission a total failure. While balancing these competing interests is the challenge, in the end the integrity of the mission must be the forefront consideration. ■

**David Farr** *received his degree in electrical engineering with honors from Northeastern University. He joined Haigh-Farr in 1984 and has been responsible for the design and development of several circularly and linearly polarized antennas, arrays, and directional antennas for high performance missile use utilizing both traditional methods, as well as innovative software providing advanced design capabilities. He has worked his way through the ranks of the company serving as program manager on numerous high-level programs and now serves as Haigh-Farr's CEO. He has developed and implemented electromagnetic microwave measurement techniques, conducted radiation pattern measurements utilizing scaled model measurement techniques as well as simulation software packages, and has been responsible for environmental qualification of several designs.*

**Bill Henderson** *received his PhD in Condensed Matter Physics from Rutgers University in 1996 and his bachelor's degree in physics and math from the State University of New York in 1988. He has a wealth of antenna design, analysis and test experience from positions as lead RF engineer with both ThinKom Solutions and Raytheon. In addition to his engineering design and analysis experience he has served in the role of program lead engineer overseeing and managing staff engineers to bring designs from conception to execution.*