Airborne Antenna Considerations for C-Band Telemetry Systems

Co-Authors:
David Farr- Chief Executive Officer
Dr. William Henderson- Chief Technology Officer

Haigh-Farr, Inc., 43 Harvey Rd, Bedford NH 03110 USA

Abstract: The changeover of many test ranges from S-band to C-band telemetry implies the need to modify or replace current systems. Several antenna-related issues need to be considered in to order facilitate a smooth transition to C-band. Amongst these are changes in vehicle-induced pattern degradation, the effect on increased propagation loss on link budgets, and the potential need for multi-band antennas that also support legacy systems during the transition. This Paper discusses these issues for both existing telemetry systems modified for C-band and for new systems. Conformal and non-conformal antennas will be addressed in this discussion.

Keywords: Conformal Antennas, C-Band, Telemetry, Multi-band antennas

Introduction

It is fairly well known within the aerospace community that telemetry is moving from the traditional L-band and S-band frequency ranges up to C-band. It is widely understood that the reason for this push to C-band is two-fold. First, traditional L and S-band frequency bands have been greatly reduced through re-allocation for a variety of reasons by different markets and second, bandwidth required for most applications has seen exponential growth. This exponential growth has not only been seen in military applications but in civilian aerospace platforms as well.

This paper focuses primarily on airborne antenna considerations resulting from moving to the higher C-band region specifically two types of airborne antennas—conformal and non-conformal.

Conformal antennas come in a variety of different shapes, sizes and configurations from discrete radiators such as a Flexislot™ (Figure 1) or a Patch antenna (Figure 2) to arrays such as a Wraparound™ (Figure 3). The Flexislot™ or Patch style antennas provide hemispherical coverage while the Wraparound™ provides Omnispherical.

Figure 1 –Flexislot™ Antenna

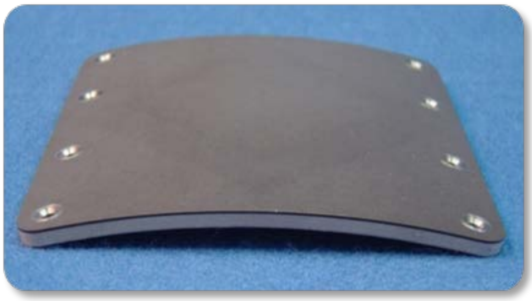

Figure 2 – Patch Antenna

Figure 3 –Wraparound™ Antenna

In telemetry applications, it is usually desirable to cover as much of the radiation sphere as possible to ensure data is received during an abnormal event. This is why the Wraparound™ configuration is often the optimal solution. There are times, however, where it is not feasible to use a Wraparound™, for example, when there are obstructions on the vehicle that will prevent the utilization of the full circumference or when the vehicle geometry is non-circular or physically so large that a Wraparound™ is simply not possible. As discussed below, the use of discrete elements on large geometries is but one consideration that must be taken into account in this transition to C-band telemetry.

Antenna Construction

For Wraparounds™ there are two construction techniques, namely microstrip (Figure 4) and stripline (Figure 5). Microstrip has typically been the more popular and generally works well for L-band and S-band. The circuitry used to feed the multiple elements of a microstrip Wraparound™ is unshielded. The feed is reasonable in size at S-band or L-band, however, when the frequency is increased 2.5 times; this is no longer the case. Unlike the resonant patch, which decreases in size with an increase of frequency, the feed network is nearly invariant with frequency. So, at C-band the feed network is physically large as compared to individual patches. It is common for high field areas to exist on the feed network itself (Figure 6) and given that the feed network on a microstrip design is unshielded, spurious radiation will occur. The radiation pattern is no longer strictly a result of the energy coming from the individual patches, but is also a function of this parasitic or spurious radiation from the feed network. This can result in a very messy radiation pattern (Figure 7). While there are certain design techniques that can be used to reduce the amount of this spurious radiation, it is still unshielded. Stripline construction is fully shielded and radiates through a series of slots cut out in the ground plane and can be superior in terms of radiation characteristics (Figure 8). Control of the pattern shape is one of the most important parts of antenna design.

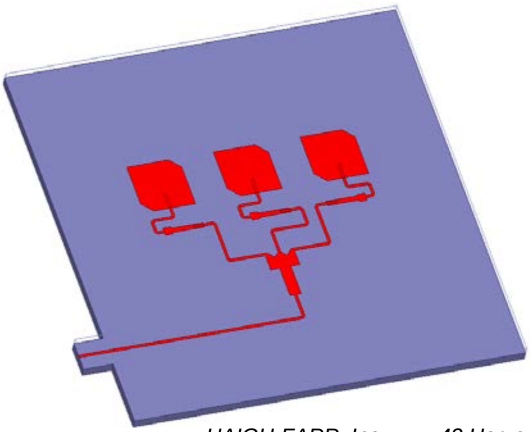

Figure 4 – Typical Microstrip Circuit

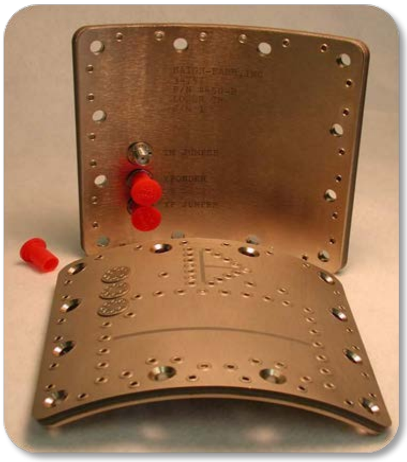

Figure 5 – Example of Stripline (Circuitry is Shielded)

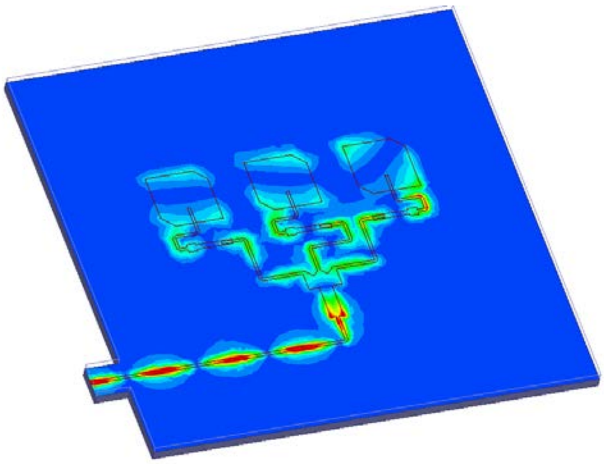

Figure 6 – Microstrip Circuit with Fields

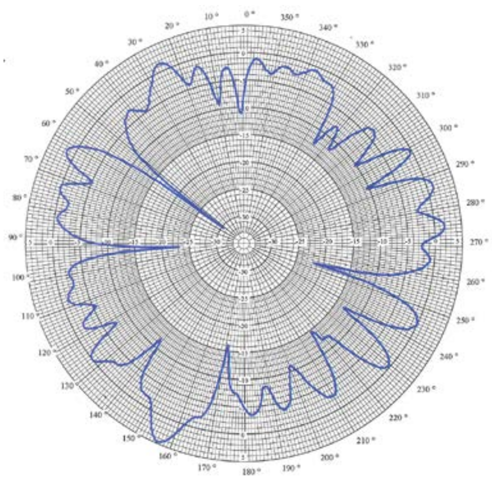

Figure 7 – Radiation Pattern of Microstrip C-Band Wraparound™ Antenna

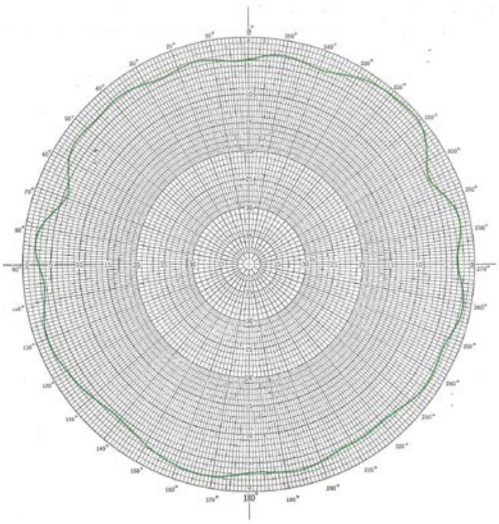

Figure 8 – Radiation Pattern of Stripline C-Band Wraparound™ Antenna

Vehicle Influence on Radiation Pattern Characteristics

Antennas that provide Omni-coverage induce surface currents on the ground plane (vehicle). When these surface currents hit a discontinuity such as a wing, fin or ground plane edge they can radiate. The resulting antenna pattern is then not only due to the contribution from the antenna elements directly, but also the contribution of these additional sources. This can be demonstrated by mounting a hemispherical radiator on a cylinder of 1 meter in diameter. The elevation pattern (with defined ends) contains a ripple (Figure 9) while the roll plane (without defined ends) is smooth (Figure 10). While the changes shown here are not necessarily detrimental, it demonstrates that ground plane or vehicle effects need to be considered.

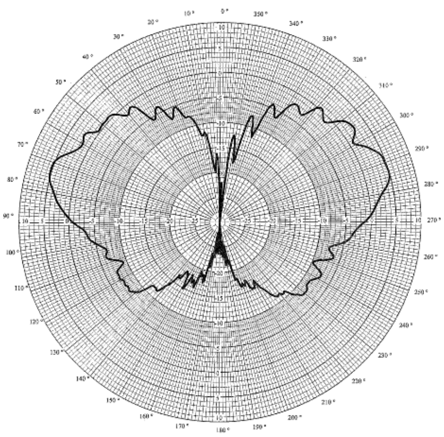

Figure 9 – Pitch Plane Pattern of an Omni on a Cylinder

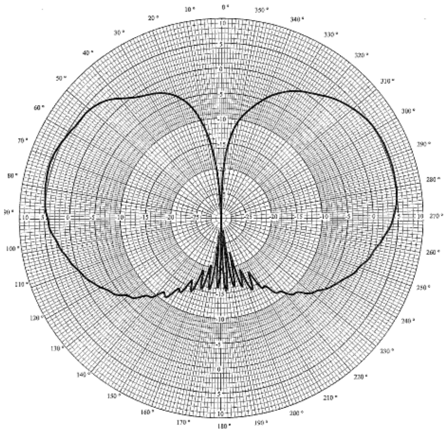

Figure 10 - Roll Plane Pattern of an Omni on a Cylinder

To further highlight the impact vehicle geometry can have, the radiation patterns of a Wraparound™ 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 given in Figures 11 and 12 respectively. While this is certainly a dramatic case, it is not out of the realm of possibility. It is the author's experience that these types of parasitic structures can have a dramatic effect on pattern characteristics and the pattern needs to be considered up front through simulations of the antenna on the vehicle geometry. This will help optimize the antenna design and/or location of the antenna on the vehicle before it is too late.

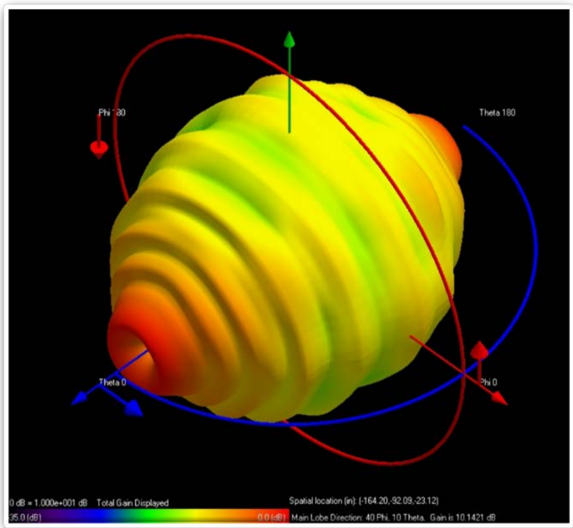

Figure 11 – Smooth Cylinder No Fins

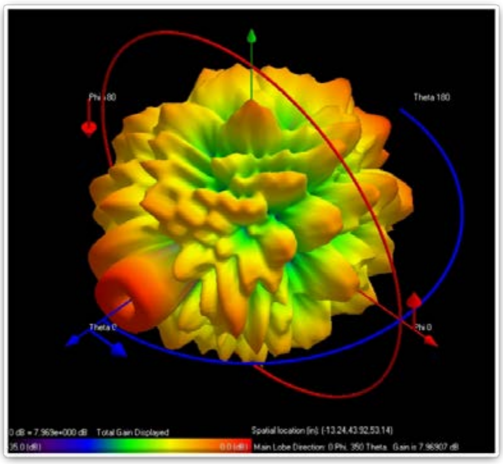

Figure 12 – Smooth Cylinder With Strategically Placed Fins

While the effect vehicle geometry has needs to be considered regardless of what frequency you are using, it becomes even more important as frequency increases since fins, wings or other parasitic structures are electrically larger at C-band than at L or S-band.

Optimal Number of Elements To Use

When a full array such as a Wraparound™ cannot be used, it is widely thought that more is better - this is certainly not the case as is shown in the following examples.

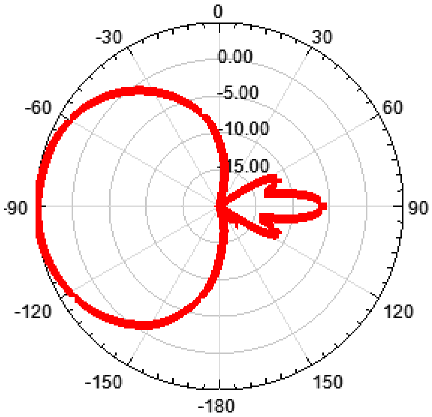

Figure 13 – Single Element

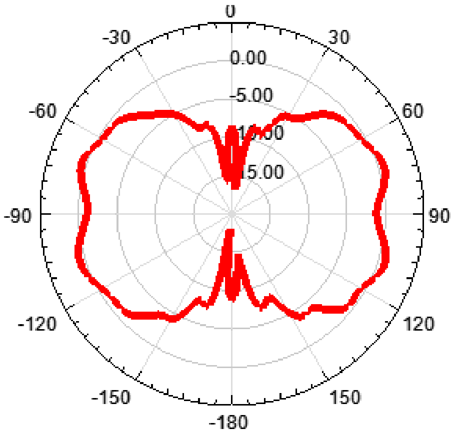

Figure 14 – Two Elements

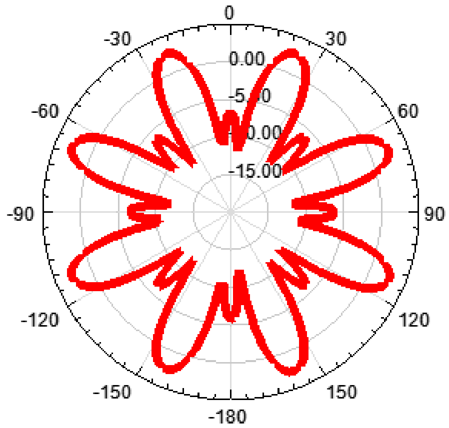

Figure 15 – Eight Elements

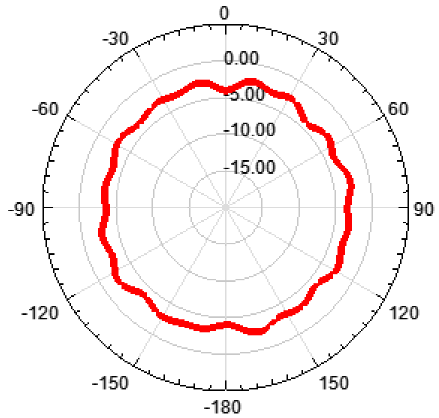

Figure 16 – Optimal Number of Elements Wraparound™

We start with a single element (Figure 13) and two hemispherical radiators on a cylinder, 180° apart (Figure 14). With the exception of the area directly above and below pattern coverage is reasonably good. Adding additional elements results in a precipitous drop in pattern coverage, which can clearly be seen in the 8 element case (Figure 15). Rather wide, deep nulls result. Eventually there are enough elements added to achieve the optimal number of elements and an omni-spherical pattern is obtained. This is the Wraparound™ configuration (Figure 16).

As discussed above, it is not always possible to utilize a full circumference Wraparound™ and so, the next best thing is almost always the two element case Certainly two S-band elements will have far fewer nulls as compared to two C-band elements on the same diameter cylinder. There are limitations on the number of elements that can be utilized for a given configuration.

Positive Effects of Moving to C-Band

Due to the small wavelength, C-Band antennas can be made considerably smaller and lighter than their L and S-band counterparts. In addition, not only does the bandwidth grow proportionally with frequency, but percent bandwidth is actually greater. This means that if you have 100 MHz at S-band you will have more than 250 MHz at C-Band, most likely in the order of 300 to even 400 MHz with the same type of design, just scaled up in frequency.

Link Budget Considerations

Not directly related to the airborne antennas, but certainly important enough from a system standpoint are the effects on link budget when changing from S-band to C-band. The following briefly discuss effects on typical link budget parameters.

Free Space Propagation Loss: There will be a link degradation of approximately 7 dB. Since the free space propagation loss is given by:

$$10 \log (4\pi d^2/\lambda^2) \quad [1]$$

The difference in propagation loss at two different frequencies is equal to:

$$20 \log(f_2/f_1) \quad [2]$$

Precipitation: The loss due to precipitation will certainly vary with rain intensity, however, you can reasonably expect to realize an additional 2 dB degradation at C-band over S-Band in moderate rain.

Cable Loss: Typically with airborne applications, especially with small missiles, it is desired to use the smallest and most lightweight cables possible. If we take a look at a relatively large cable, RG-142 for example, the additional loss associated with 5 GHz vs 2 GHz can be in the order of .5 to 2 dB depending on the cable length.

Transmitter Efficiency: The transmitter power amplifier tends to be less efficient at C-band so we can add anywhere from 0 to 3 dB degradation attributed to the transmitter as compared to use at S-band.

Total Degradation Delta: Considering all of the above items can result in a total degradation in link of between 7.5 to 14 dB when comparing C-band to S-band. While this is not meant to take a hard look at any specific link, it is brought to the attention of the reader as another consideration that should not be overlooked. While it is not the intention to discuss ground antennas, it should also be noted that certainly an increase in ground antenna gain can make up some of these differences in link degradation. This does, however, result in a much narrower beam which can cause some tracking issues if not handled correctly.

Transition Antennas

While the transition to C-band is taking place, certain areas are still utilizing L-band and S-band. It is, therefore, highly desirable to have an antenna that will handle all three, L, S and C-band as using a one antenna solution simplifies system change over.

Monopole and dipole antennas naturally provide multi-band performance with regard to VSWR, however, only the lowest frequency band provides the desired radiation pattern as illustrated in Figure 17. A common mistake observed by the author is utilizing the VSWR solely to evaluate antenna performance. To get the full picture, radiation patterns must also be considered.

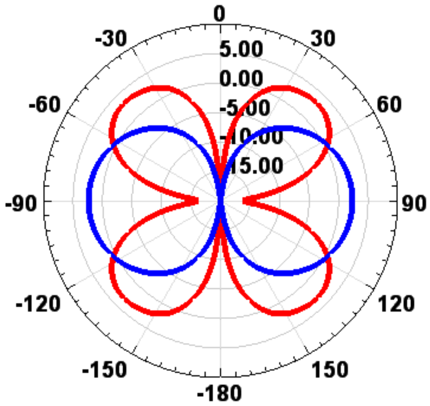

Figure 17 – Broadband Response of a Dipole

Figure 18 – Pattern Optimized Tri-Band Antenna

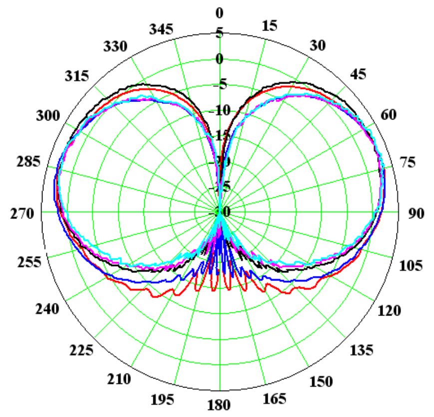

Figure 19 – Patterns of Optimized Antenna

There are antennas specifically designed to maintain radiation pattern characteristics over frequency. An example is shown in Figure 18. The radiation patterns of this antenna are essentially invariant as a function of frequency (Figure 19). The minor differences observed are actually caused by the ground plane changing in electrical size as we go from 1.4 to 5.25 MHz. The VSWR of this antenna is well under 2:1 over all of the telemetry bands as indicated by the yellow hi-lighted areas (Figure 20).

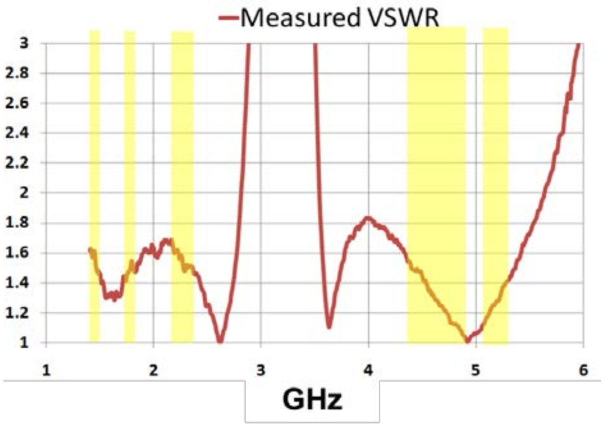

Figure 20 – VSWR of Optimized Antenna

Conformal Multi-Band Antennas

There are several ways that both S-band and C-band or all three (L, S and C-band) can be achieved in a conformal design. Certainly, the simplest is to have a dual-band antenna with two distinct arrays within the same physical package and two distinct connectors as shown in the block diagram (Figure 21).

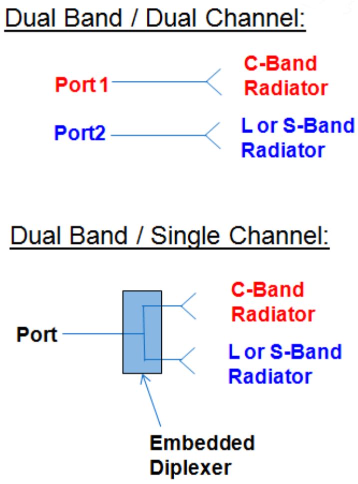

Figure 21 – Conformal Multi-Band Antenna Block Diagram

This would result in possibly having to change to the correct RF connector (band) before use. An alternate approach embeds a diplexer inside a conformal antenna we have L or S-band radiators for the legacy system and C-band radiators included which are all fed through the embedded diplexer. This results in a single port design. It is also possible to do this with a tri-band configuration L, S and C-band.

Given that the C-band, L-band and S-band radiators are optimized for their respective bands, pattern characteristics would be the same, there would be no degradation. This multi-band conformal antenna would require additional space over the legacy L or S-band antennas. In some cases it may not be feasible to change the vehicle geometry to accept this larger antenna, but a C-band antenna can always be packaged to replace the lower frequency legacy units.

Conclusion

There are several antenna considerations when changing from the legacy bands to C-Band for telemetry. Choosing the wrong construction type, number of elements and/or placement can have a major impact on overall performance. While all of the effects cannot be fully mitigated, in most cases performance can be optimized which will result in a successful link.