ADVANCED RING ANTENNA FOR VEHICULAR COMMUNICATIONS

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ABSTRACT

Reliable communication of telemetry and command data to and from various vehicles, including rockets, missiles, and aircraft, is of critical importance for many systems. This paper presents an antenna system mounted on a cylindrical vehicle that provides a tight control of phase variation in far field within wide field of view. The antenna system overcomes limitations from earlier designs, including need for increasing data demands, spectrum scarcity, and spectrally efficient modulation.

INTRODUCTION

State of the art missiles and rockets generate a significant amount of telemetry data, necessitating wider radio frequency (RF) bandwidths for transmission. The available RF spectrum for telemetry is limited and shared by multiple users. Spectrally efficient modulation schemes like Shaped-Offset Quaternary Phase Shift Keying (SOQPSK) reduce bandwidth requirements; however, these schemes are more sensitive to phase variations. Further, GPS often used to measure vehicle position and velocity, relies on the less robust Bi-Phase Shift Keying (BPSK) modulation, making it even more susceptible to phase changes. Large phase variations can lower the carrier-to-noise ratio (C/No) and cause the GPS receiver to lose signal lock. Vehicle spinning adds to the potential causes of signal fading impacting reliability and throughput of communication channels. Antenna design having phase and magnitude coverage requirements in mind may help to alleviate the above-mentioned challenges and improve robustness of communication significantly.

Traditionally antenna designs are tuned to have a given field of view in terms of amplitude coverage ignoring phase variation. For example, a two-element antenna with a combining network may have nulls in radiation patterns, leading to signal fading in certain directions. This antenna solution has both amplitude and phase variation in the field of view. Coverage can be improved by quickly switching the antennas and doing signal post-processing in software [1]. It requires having a computational power on-board of the vehicle and development of advanced algorithms. The discussed in this paper wrap around antenna solutions control amplitude and phase variation around the vehicle, which significantly simplifies on-board transceiver and improves robustness of the system in general at the same time.

Wrap around solutions for small diameter platforms in terms of wavelength have been reported in open literature [2,3]; however, bigger platforms rise practical implementation challenges in terms of analysis, fabrication, and test. This paper is focused on full coverage antenna solutions for large platforms of many wavelengths in diameter with constant phase around the axes of a vehicle (Figure 1).

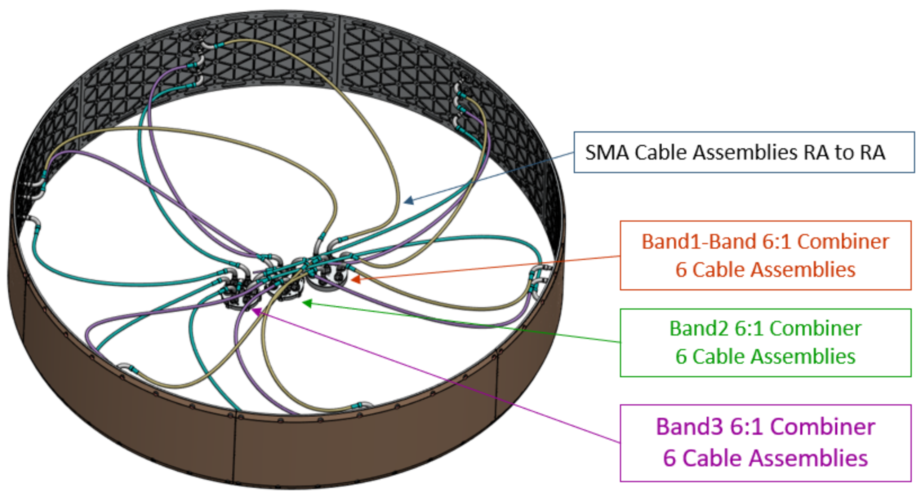

Figure 1. Ring wrap-around antenna split into 6 segments.

TWO-ELEMENT ANTENNA

A straightforward method to improve the field of view of an antenna system is to use multiple antennas each covering its own sector of view. The simplest antenna array has two elements (Figure 2). Typically no switching between the antennas is used, and the radio signal is combined by a combiner/splitter. Due to a phase difference between the two signals, the individual patterns can be combined destructively at certain directions resulting in pattern nulls. (Figure 3, CP) shows a far field radiation pattern in a pitch plane. The pitch plane, also known as the H-plane or azimuth plane, refers to a plane perpendicular to the array's boresight direction and containing the antenna elements. As can be seen from the plot, some undesirable nulls are found around +/-90 deg for circularly polarized (CP) antenna elements with the same polarization sense.

The next level of coverage improvement is to use a polarization diversity to improve the coverage. If a system allows, two orthogonally polarized antennas have an improved coverage at the cost of 3 dB polarization loss. For instance, ground antenna radiates CP and the vehicle utilizes linearly polarized (LP) antennas. In this case, co-polarized pattern (co-pol) of one antenna is combined with cross-polarized pattern (cross-pol) of the second antenna. Since cross-pol is typically much weaker than co-pol, cross-pol makes much smaller contribution to the combined pattern, so the pattern is similar to a superposition of two individual patterns without phase considered (Figure 3, LP). Despite significantly improved coverage, the combined pattern still has some variation of amplitude. Besides, phase variation is still difficult to control with this approach.

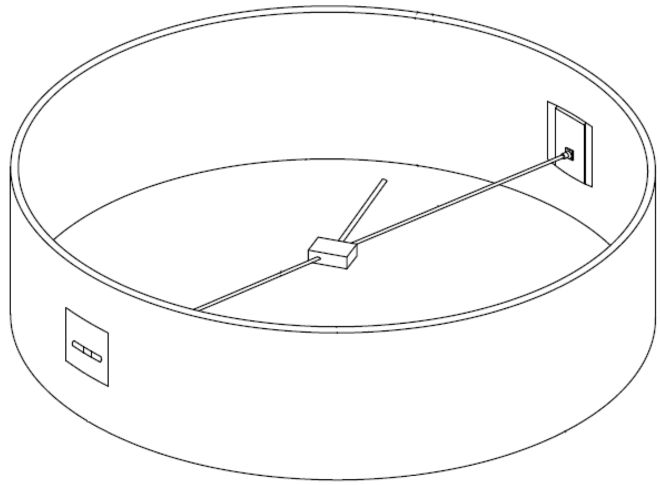

Figure 2. Two-element array of an electrically large cylindrical platform of a few tens of wavelength.

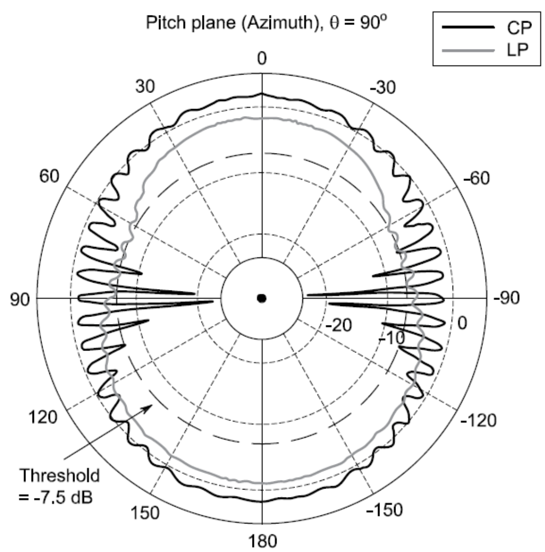

Figure 3. Radiation pattern of two element array in a pitch plane, also known as the H-plane or azimuth plane.

RING ANTENNA

Design of the ring antenna considered in this paper is based on a mode 0 circular antenna array approach, when all the elements are excited / combined with the same magnitude and phase, and the distance between the elements is less than half wavelength. Figure 4 shows dependence of amplitude and phase variations as the number of antenna array increases. For the given geometry, the number of elements should be more than a threshold to be able to keep the amplitude and phase variation at minimal. Note that minimizing the phase variation may require more elements compared to the number of elements needed to minimize amplitude variation.

Because of a low air drag requirement, the antenna is implemented as a printed circuit board. If there is an aperture size requirement limiting the space available for the aperture and beam forming network (BFN), the BFN can be moved behind the aperture (Figure 5). The BFN provides the required excitation coefficients, thus assisting in shaping the beam pattern, resulting in clearer and more reliable communication. The splitting / combining ratio should support the mode 0 of the circular array. In the shown case, each BFN supports 1 to 8 split.

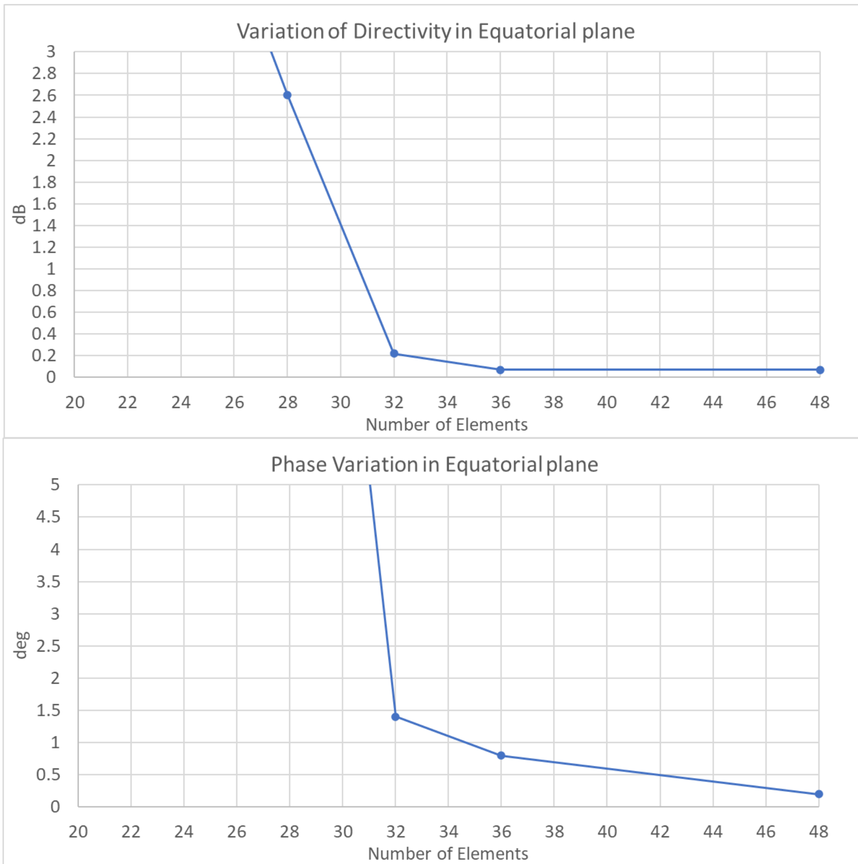

Figure 4. Example of variation of amplitude (top) and phase (bottom) depending on a number of array elements in a circular array.

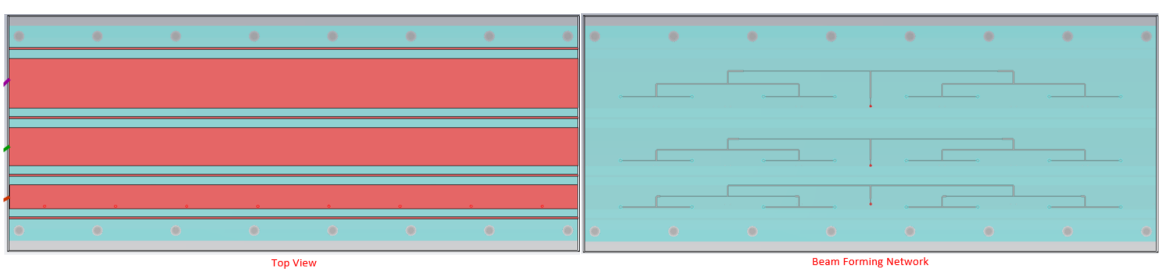

Figure 5. Three band ring Antenna Top, and bottom views.

Because of the large vehicle size, the array is split into sectors. The sectors are recombined with coaxial combiner, such that the ring antenna fully encompasses the vehicle. Figure 1 shows an antenna with six segments of the ring antennas. With six sectors with 8 feeding point each, the antenna is equivalent to a 48-element circular array ensuring that amplitude and phase variation in far field is minimal (Figure 4). Figure 6 shows the azimuth and elevation plane plots for the ring antenna. As can be seen in the plot the azimuth is nearly perfect, while the elevation plot has nulls occurring at the nose and tail of the vehicle. This significantly improves amplitude and phase coverage as compared to the two-element array. Table 1 shows typical specifications and how the two-element array and the ring antenna meet these requirements.

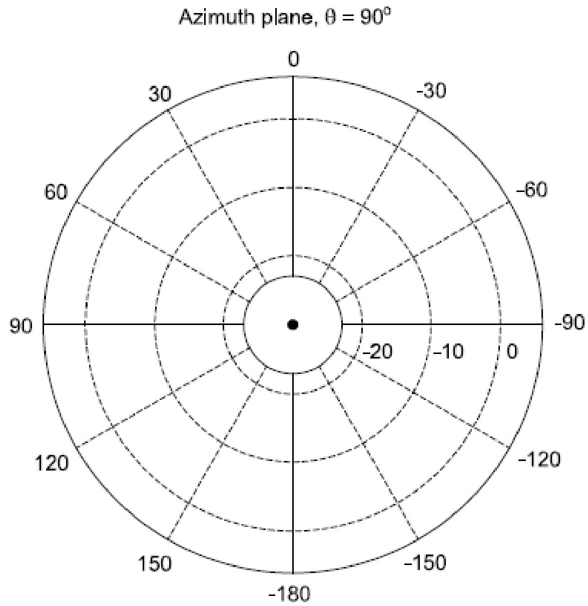

Figure 6. Ring antenna azimuth and elevation plane plots.

Table 1 Comparison of two-element array and ring antenna.

Parameter	Required	Two-element array antenna	Ring antenna structure
Gain	-7.5 dB / 85% over 4π	86.8%	100%
Variation (dB) in Azimuth Plane	2 dB/deg, 85%, θ = 25° to 155°	92.8%	100%
Variation (deg) in Azimuth Plane	20°/deg, 85%, θ = 25° to 155°	84%	100%
Variation (dB) in Elevation Plane	2 dB/deg, 85%, θ = 25° to 155°	98.4%	100%
Variation (deg) in Elevation Plane	20°/deg, 85%, θ = 25° to 155°	96.1%	95%

Other considerations are needed to be kept in mind are weight, power handling, discharging paths, manufacturing tolerances.

CONCLUSIONS

Communication between an aerial vehicle, like missile or rocket, may benefit from having minimal amplitude and phase variation in the field of view. If this requirement is kept in mind, antenna system may simplify on-board processing requirements and improve reliability of the communication channel at the same time. This paper presents an example of a ring antenna for a large vehicle and discusses may consideration that should be taken into account during design.

REFERENCES

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