When Deployable Spacecraft Antennas Don’t

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***Abstract*—The objective of this paper is to explore possibilities for continued use of certain deployable spacecraft antennas when full deployment fails. Four (4) deployables are used as examples, including 1) a reflectarray, 2) a parabolic reflector, 3) a loop, and 4) a set of 4 monopoles. The measure of “continued usability” in each case is relative antenna gain as a function of partial deployment. Note, types (and levels) of partial deployment presented here are strictly hypothetical. Also, discussions of actual deployment mechanisms are considered outside the scope of this paper.**

I. INTRODUCTION

During design of any spacecraft (SC), anything that doesn’t fit within the launch vehicle payload volume must be either eliminated or “collapsed” into something that does fit. One example is a large solar cell array, and another is a large antenna. Still another deployable is a long boom. The “deployment” of these collapsed entities must occur after separation from the launch vehicle.

The focus of this paper is on the deployable antennas and, more specifically, in their continued usability in the face of partial deployments. This study examines 4 deployable antenna types for gain loss when partial deployments occur. Our thrust here is to determine possibilities for continued usability in the face of partial deployment. Note, all states of partial deployment considered here are hypothetical and no deployment mechanisms or failure modes are discussed.

II. BACKGROUND

Communication (COMM) between Earth and any SC (or between SC) generally takes two forms, sometimes simultaneously; 1) the uplink of commands and 2) the downlink of data. In either case, the objective is successful transfer of the maximum information (bits) in the shortest possible time (seconds). This defines a maximum data rate (DR) that *statistically* promises successful transfer of a certain number of bits, on a given link, in a specific time, with equal or fewer than some number of (bit) errors. These last two properties define a link bit error rate (BER).

Directly related to COMM DR and BER is signal to noise ratio (SNR); when SNR goes up, DR goes up, for a given BER. The relevance of this to this study is that if antenna gain increases, so does SNR, and the same can also be said for non-COMM applications such as radar and radiometry; as gain increases, so does the sensitivity of the instrument.

This study will focus, specifically, on maximum antenna gain when deployment is partially successful. Our reference will be the gain of the same antenna, fully deployed. Although we expect the antenna’s pattern, impedance, and polarization to also change with partial deployment, here we tabulate only maximum “effective” gain; “effective” includes all of the above.

III. DEPLOYABLE ANTENNA EXAMPLES

The 4 deployable SC antenna examples include 1) an X-band reflectarray for COMM, 2) an L-band parabolic reflector for radar and radiometry, 3) a UHF low-medium gain loop for COMM and 4) a set of 4 separated low gain UHF monopoles for COMM.

A. Microwave Deployable Antennas

1) *X-band Reflectarray*

This antenna is a flat panel reflectarray formed by 3 subpanels, plus an offset lip-out patch array feed. The 3 coplanar subpanels emulate a parabolic reflector. Figure 1 shows the stowed and deployed antenna and feed on a JPL mockup of the MarCO 6U CubeSat [1]. This configuration is expected to fly in the near future.

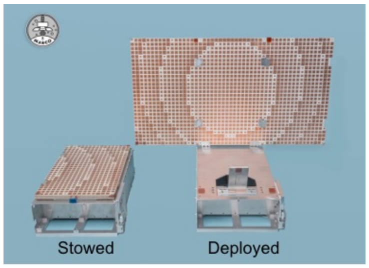

Figure 1. MarCO X-band Reflectarray Mockup

The following tabulation compares simulated maximum (RCP) gain for a simple truncated parabolic reflector (for the fully deployed case) to 2 cases using reduced (projected) areas to represent partial foldout deployments.

Deployment Degradation (deg. angular foldout)	Boresight Gain (dBic)
180 (full deployment - flat)	24.4
150 (180-30)	23.7
120 (180-60)	19.7

2) *L-band Metalized Mesh Reflector*

Figure 2 shows a sequence of deployment stages of this parabolic reflector. Fully deployed, the reflector surface is a 6 m diameter metalized mesh supported by the accordion-like structure. The reflector plus its focal point feed are major components of an L-band soil moisture radiometer and an L-band high resolution radar. Note, this design is currently flying in a 685 km near-polar Earth orbit on the SMAP satellite [2].

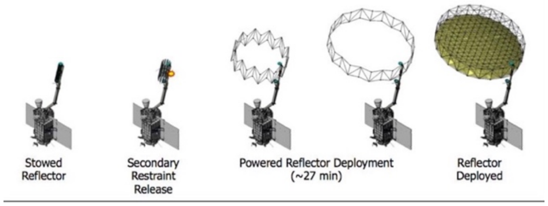

Figure 2. Deployable L-band Parabolic Reflector

The following tabulation compares calculated boresight gains for the fully deployed reflector to gains with 3 levels of "idealized" partial deployment causing 3, 6 and 9 cm "wrinkles" of the parabolic surface and commensurate reductions in reflector diameter.

Deployment Degradation (RMS cm)	Boresight Gain (dBi)
0 (fully deployed)	37.1
3	36.2
6	33.0
9	31.0

B. UHF Deployable Antennas

1) UHF Low-Medium Gain Loop

This antenna scheme was designed to give a broadside unidirectional beam using a bidirectional dual fed 1λ loop in front of a reflecting ground plane. Figure 3 shows a simple mockup of the "printed" loop, in the deployed and stowed states. This design [3] is also expected to fly on MarCO in the near future.

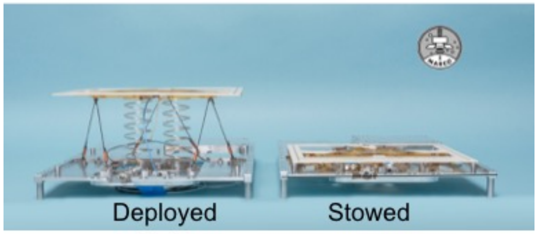

Figure 3. MarCO Deployable UHF Loop Mockup

The following data compare calculated boresight RCP gain for the fully deployed loop over the reflecting surface (the broad side of a 6U model) to the gain for the same loop at 2 levels of partial deployment (tipped 10 and 20 deg.).

Deployment Degradation (tilt degrees)	Max Gain (dBic)
0 (no tilt)	6.2
10	6.1
20	4.7

2) Low Gain ~¼λ Monopoles

Figure 4 (from a CAD model) shows four deployable ~¼λ monopoles on one end of a 2U CubeSat. The monopoles deploy shortly after the SC leaves its CubeSat deployer. This CubeSat, the California State University Northridge CSUNSat1 [4], is currently in orbit doing science in collaboration with JPL.

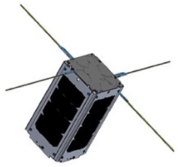

Figure 4. CSUNSat1 with 4 UHF Monopoles

The following data compare the calculated (lin-pol) tumble average gain for the 4-element case, to calculated tumble averages for deployment missing 1, 2, and 3 elements (monopoles).

Deployment Degradation	Tumble Average Gain (dBi)
None (all 4 elements present)	-2.1
1 missing	-2.3
2 missing	-2.7
3 missing	-2.9

IV. CONCLUSIONS

This paper has presented gain degradations for 4 different deployable spacecraft antennas over a range of hypothetical, non-catastrophic partial deployments. While these gain results are not surprising, what is surprising is that deployable antenna gain (i.e., SNR) reductions due to mal-deployments don't seem to be considered in early design trade studies, i.e., for setting some important SC requirements, such as COMM channel wavelength, transmitter power, and SC attitude control (or not), to mention only a few. The obvious conclusion from these results is that under certain conditions, even a partially deployed antenna could be useful. Another likely (though not surprising) conclusion is that partial deployments would be more deleterious the higher the frequency. Final comment: More exploration of this concept might even be considered part of risk reduction.

AKNOWLEDGEMENT

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