The SCARLET™ ARRAY FOR HIGH POWER GEO SATELLITES

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ABSTRACT

The GEO satellite market is demanding increasingly capable spacecraft which, in turn, drives commercial spacecraft manufacturers to require significantly higher power solar arrays. As satellite capability increases the demand for high power array systems which are both cost and performance competitive becomes more crucial. Conventional rigid panel planar arrays, although suitable in the past, negatively impact spacecraft competitiveness for these new applications. The Solar Concentrator Array with Refractive Linear Element Technology (SCARLET™) represents an economically attractive solution for meeting these new high power requirements. When compared to conventional planar arrays, Scarlet™ provides substantially lower cost and higher deployed stiffness, competitive mass, better producibility, and affordable use of high efficiency multijunction cells. This paper compares cost/performance characteristics of the Scarlet™ array to conventional planar arrays for high power GEO spacecraft applications. High power Scarlet™ array configurations are described, and inherent spacecraft and array level cost/performance benefits are presented.

INTRODUCTION

As satellite and solar array capability increase, the demand for higher power array systems which are both cost and performance competitive is becoming more crucial. Recent projections from leading GEO spacecraft manufactures indicate that solar array power requirements will climb from the 8-10 kW ranges of today to 15-20 kW with five years, and up to 30 kW within the next decade.[1] To meet these new aggressive applications requires consideration of an alternative array technology which minimizes performance/cost impacts at the spacecraft level.

The Solar Concentrator Array with Refractive Linear Element Technology (Scarlet), Figure 1, offers an attractive solution for meeting these new high power requirements. When compared to conventional planar arrays, Scarlet provides substantially lower cost, competitive mass, higher deployed stiffness, better producibility, and affordable use of high efficiency multijunction cells.

To assess the benefits of the Scarlet solar array, when compared to conventional systems for high power GEO spacecraft applications, a trade study evaluation was performed. Parameters considered include array and spacecraft system level cost, mass, and deployed stiffness. It will be shown that Scarlet represents a low-risk, high-payoff, solution for high power GEO applications when compared to conventional rigid panel array systems.

Figure 1
Scarlet DS-1 Solar Array

GEO ARRAY BACKGROUND

Conventional rigid honeycomb, multi-panel planar arrays have long been the array of choice for GEO spacecraft applications. The rigid multi-panel design leverages successful past flight heritage and, as such, is ideally suited for conservative/risk sensitive applications. Panel materials, photovoltaics, and mechanism subsystems have evolved over the years to produce array level end-of-life specific powers between 40-50 W/kg. These systems have performed admirably since their inception. The basic structural platforms have maintained an ability to provide GEO spacecraft manufacturers with power growth capability to meet today's end-of-life power needs of 8-10 kW.

Due to the enormous demand for increased GEO spacecraft capability, satellite manufacturers are aggressively developing next generation spacecraft designs which operate larger more efficient payloads and empty improved systems for radiating waste heat. As such, these enhanced spacecraft configurations both require and can thermally tolerate higher power generating capabilities. As power systems grow beyond 10 kW, and up to 20-30 kW, the limitations of conventional array technologies are becoming apparent. In general, a conventional system adapted for a higher power application becomes larger, heavier, or significantly more expensive. This results in notable performance and/or costs for the GEO spacecraft producer.

A number of modifications can be incorporated to adapt a conventional array for a high power application. The most common approach is a simple changeout of photovoltaics to a higher efficiency cell, such as high efficiency Silicon, GaAs/Ge, or more expensive multijunction $GaInP_2$/GaAs/Ge. Incorporation of such advanced photovoltaics does increase specific power, but carries with it a significant increase in array cost.

Another technique for increasing power is to incorporate additional panels onto each wing. Unfortunately, this adaptation poses many structural and spacecraft attitude control system concerns. Adding panels to a wing increases kinematic complexity which affects deployment authority and reliability. A suitable qualification program is generally required to minimize risk of the modified design.

As a wing becomes longer its deployed stiffness degrades approximately as the cube of its length. Therefore, the longer the wing the greater the burden it places on a spacecraft's ability to efficiently perform attitude and control maneuvers. Additionally, some spacecraft attitude and control system designs actually limit the number of panels that can be deployed. This deficiency may drive a system designer to consider completely alternative wing configurations which position the array center of gravity closer to the spacecraft to enable more precise spacecraft attitude and control response.

Many of the above modifications are being considered by commercial spacecraft manufacturers as a short-term solution to increase power. However, in the limit, increased spacecraft power requirements will drive designers to greater cell areal efficiency which, in turn will drive array costs up, counter to the demands of a highly competitive commercial marketplace.

Therefore, as spacecraft power needs increase, competitive pressures will tend to drive array selection from conventional approaches towards new highly efficient array technologies, such as Scarlet, which can cost-effectively employ the required high areal efficiency photovoltaics.

ANALYTICAL SCOPE

Scarlet and conventional GaAs/Ge planar array systems for GEO spacecraft applications were configured and analyzed for powers ranging from 8-20 kW EOL. Array system level costs and mass properties were calculated for each array type and configuration. Depending upon the array's mass, an additional cost savings/penalty valued at ±$58,000/kg was applied to each configuration accordingly to determine a spacecraft system level cost.[2] Finite element models were used to determine the deployed first mode fundamental frequency for each array type and size. Array costs were calculated for each system based upon pricing for a 250shipset (50-wings) multiple-buy procurement over a 5-year duration. Array costs for the conventional GaAs/Ge planar systems are based on actual costs from numerous industry sources (commercial and government) which have been substantiated through several current buyers.

SCARLET GEO ARRAY DESCRIPTION

The Scarlet array modeled in this analysis was configured especially for GEO spacecraft applications. These systems accommodate conventional single-axis sun tracking (±24° solstice seasons) with standard alpha pointing tolerances of ±3°. Additionally, these Scarlet system include an outboard facing planar panel to provide stowed power and on-orbit tumble recovery power. Descriptions of Scarlet subsystems and hardware can be found in the provided references.[3&4]

The Scarlet GEO array, shown in Figure 2, is a hybrid configuration in which each wing is composed of multiple Scarlet panels with an integrated outboard conventional planar panel. Panel size and number of tiedown points are consistent with typical GEO array systems.

Figure 2
GEO Scarlet Solar Array

The Scarlet optics and cell modules are similar to, and based on, the New Millennium DS1 Scarlet II flight design (Figure 3). Structural platforms modeled in this analysis included both a standard substrate design, which yields conventional stowed packing efficiencies, and a modified substrate design, which produces a significantly reduced stowed stack height. Each structural platform type incorporates locking shear-tie features which effectively couple the lens frame and cell substrate elements together to produce a deployed section with appreciable structural depth and greater deployed stiffness.

The Scarlet cell options modeled include both GaAs/Ge and multijunction GaInP2/GaAs/Ge. Despite the commercial cost-sensitive perspective of this analysis, multijunction GaInP2/GaAs/Ge cells were included since the Scarlet system enables an affordable implementation unlike typical planar arrays. Because fewer and smaller cells are required by Scarlet the cost impacts and cell yield concerns with employing advanced photovoltaics becomes negligible. Additionally, under Scarlet's ~7.5 X concentration, cell shunt defects become less significant allowing low performing 1.0 AM0 shunt-defected multijunction cells to be utilized rather than scrapped, further increasing yield which translates into reduced cost. The outboard planar panel can be populated with a variety of cell options, but for this analysis proven, high-efficiency silicon photovoltaics were modeled.

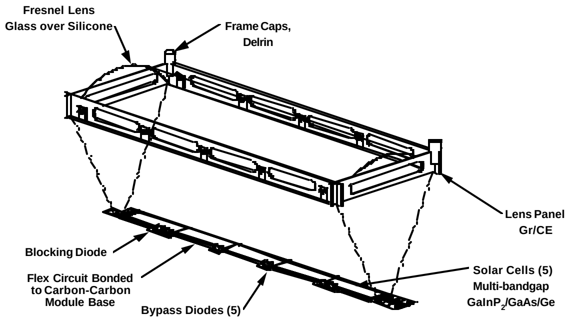

Figure 3
Scarlet Cell/Optics Module

CONVENTIONAL GEO ARRAY DESCRIPTION

To model the performance of a conventional high power array system for this trade study an approximately 49 W/kg (EOL at 15-years equinox) ABLE PUMA™ system was configured with four to seven panels per wing for powers up to 20 kW. The array was populated with 19% efficient single-junction GaAs/Ge solar cells. State-of-the-art multijunction GaAs/Ge solar cells were not considered for conventional arrays in this analysis because of their excessive costs and limited availability.

ANALYSIS RESULTS

Scarlet conventional planar array analysis results for specific power, deployed stiffness, array level costs, and spacecraft system level costs are discussed in the following paragraphs.

Specific power as a function of EOL power for each array system and configuration are shown in Figure 4. The data in Figure 4 indicates that the Scarlet system provides better specific power than the conventional planar array at all power levels. Understandably, Scarlet's economical use of advanced multijunction photovoltaics provides higher specific powers than the GaAs/Ge. The highest specific power was achieved with the Scarlet modified substrate design populated with multijunction cells.

Scarlet and conventional planar array analysis results for deployed first mode frequency are shown in Figure 5. Typically, a suitable deployed first mode requirement for GEO spacecraft ranges between 0.05 to 0.1 Hz, depending upon bus attitude control system capability.

Figure 4
Specific Power Comparison

Deployed stiffness of the Scarlet designs are significantly higher compared to conventional planar arrays (Figure 5). This is because Scarlet uses an innovative coupling between the lens frame and cell substrate panel which increase the sectional moment of inertia to produce a significantly stiffer deployed structure. As shown in Figure 5, the Scarlet designs meet the deployed stiffness requirements by a large margin and will not impact existing spacecraft attitude and control systems for higher power arrays. In contrast, the conventional planar array drops below 0.05 Hz deployed first mode for systems larger than ~11 kW EOL. The lower deployed stiffness of the conventional planar array will impact the spacecraft/attitude control system Scarlet's higher stiffness will save significant fuel weight and cost over mission life.

Figure 5
Deployed Stiffness Comparison

Array level cost savings for a Scarlet system when compared to a GaAs/Ge planar array over a 25-shipset procurement are depicted in Figure 6. The curves clearly show that conventional GaAs/Ge planar designs are not cost competitive when compared to Scarlet. As an example, a 15 kW EOL Scarlet system produces an array level cost savings between $9M to $10M per spacecraft. In some cases, this cost savings represents a 10% reduction in overall spacecraft cost.

Figure 6
Array Level Cost Savings with Scarlet

Spacecraft level cost savings for a Scarlet system when compared to a GaAs/Ge planar array over a 25-shipset procurement are depicted in Figure 7. The spacecraft level cost savings curves account for array level costs and an applied mass savings/penalty valued at ±$58,000 per kg, adjusted appropriately depending on a system's mass.2 The curves displayed in Figure 7 clearly show that conventional GaAs/Ge planar designs are not cost competitive when compared to Scarlet, at any power range. Again, as an example, a 15 kW EOL Scarlet system produces a spacecraft level cost savings between ~$11M to $13M per spacecraft.

CONCLUSIONS

Conventional GaAs/Ge planar solar arrays are not cost or performance competitive for high power GEO spacecraft applications when compared to Scarlet systems. Conventional planar systems exhibit significant cost, mass, and deployed stiffness impacts to the spacecraft which significantly affect overall system performance and cost competitiveness. Scarlet systems provide an attractive alternative for meeting these aggressive high power requirements. When compared to conventional GaAs/Ge planar arrays, Scarlet systems provide substantial cost savings on the order of ~$9M to $10M at the array level, and ~$11M to $13M at the spacecraft level, for a 15 kW EOL application. Additionally, Scarlet systems have superior specific power ranging up to 67 W/kg EOL. Scarlet also provides a significantly higher deployed stiffness which mitigates the impacts to an existing spacecraft attitude and control system. Scarlet provides more cost-effective power growth accommodation by the implementation of the modified substrate design which produces an extremely high stowed packing density. Unlike other concentrator designs, Scarlet's innovative linear Fresnel optics can accommodate standard single-axis tracking systems which eliminates the impacts to existing bus designs. Scarlet's unique hybrid configuration which incorporates an outboard facing planar panel provides mission dependent stowed transfer orbit and deployed tumbling anomaly power. Finally, because of Scarlet's ~7.5 X concentration the currently impacted solar cell manufacturing base is leveraged because fewer and smaller cells are required. Risk mitigation through ongoing programs and ABLE IR&D activities facilitate Scarlet's implementation as a low risk high payoff array solution for high power GEO spacecraft applications.

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