The Case for Commercially Hosted Space Situational Awareness Payloads

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ABSTRACT

Space Situational Awareness (SSA) in the Geosynchronous Earth Orbit (GEO) belt presents unique challenges, and given the national importance and high value of GEO satellites, is increasingly critical as space becomes more congested and contested. SSA capabilities can serve as an effective deterrent against potential adversaries if they provide accurate, timely, and persistent information and are resilient to the threat environment. This paper will demonstrate how simple optical SSA payloads hosted on GEO commercial and government satellites can complement the SSA mission and data provided by Space-Based Space Surveillance (SBSS) and the Geosynchronous Space Situational Awareness Program (GSSAP), as well as ground based sensors. GSSAP is built by Orbital Sciences Corporation and launched on July 28, 2014. Analysis performed for this paper will show how GEO hosted SSA payloads, working in combination with SBSS and GSSAP, can increase persistence and timely coverage of high value assets in the GEO belt. The potential to further increase GEO object identification and tracking accuracy by integrating SSA data from multiple sources across different viewing angles including GEO hosted SSA sources will be addressed. Hosting SSA payloads on GEO platforms also increases SSA mission architecture resiliency as more sensors are distributed across multiple platforms including commercial platforms. This distributed architecture presents a challenging target for an adversary to attempt to degrade or disable. We will present a viable concept of operations to show how data from hosted SSA sensors could be integrated with SBSS and GSSAP data to present a comprehensive and more accurate data set to users. Lastly, we will present an acquisition approach using commercial practices and building on lessons learned from the Commercially Hosted Infrared Payload (CHIRP) to demonstrate the affordability of GEO hosted SSA payloads.

1. TODAY'S CHALLENGES AND OPPORTUNTIES

The concept of hosting optical SSA payloads on commercial satellites is not new. Many concepts have been proposed in the past, from simple to the elaborate sensors, and a variety of system architectures with wide-ranging objectives. Since hosted SSA payloads were originally proposed, the threat environment has continued to change and evolve which creates an ever-increasing need for the deterrence and resilience provided by hosted SSA payloads. Additionally, recent technology developments such as Orbital's Secondary Payload Interface (SPI) and improvements in low cost sensor capabilities provide for a decrease in the total system costs. Lastly, policy initiatives to encourage Department of Defense (DoD) partnerships with industry and increased use of commercial hosting further support hosted SSA payload approaches. These factors combine to form a case for hosting SSA payloads on commercial satellites in GEO which is more compelling than ever.

The National Security Space Strategy Unclassified Summary, dated January 2011, documents the fact that space has become more contested, as well as congested and competitive. It states that

> "Today space systems and their supporting infrastructure face a range of man-made threats that may deny, degrade, deceive, disrupt, or destroy assets. Potential adversaries are seeking to exploit perceived space vulnerabilities. As more nations and non-state actors develop counter space capabilities over the next decade, threats to U.S. space systems and challenges to the stability and security of the space environment will increase. Irresponsible acts against space systems could have implications beyond the space domain, disrupting worldwide services upon which the civil and commercial sectors depend." [1]

Considering the growing threat to U.S. space systems, the National Security Space Strategy goes on to identify five U.S. objectives for the strategy, including the objective to "prevent and deter aggression against U.S. space infrastructure that supports U.S. national security." [1] How to best deter a potential adversary is a complex subject and differing theories abound. But in the most simplistic terms, the cost of an actor's actions must outweigh the benefit. Applying this to a space conflict, the price paid for attempting to degrade or disable another system can be either in the monetary cost and effort to develop and field effective offensive systems, or in the cost incurred due to military, economic, or diplomatic reactions to the act of aggression.

SSA is fundamental to supporting either view of deterrence theory. SSA products can provide information necessary to take counter steps at the system or enterprise level, which decreases the aggressor's benefit and, at the same time, drive the aggressor to develop more complex and costly systems. Perhaps more importantly, SSA products enable one to attribute an action to a particular aggressor. Based on this attribution, other instruments of national power, such as economic actions, can be employed to increase the cost of the action for the aggressor.

Recent statements from General William Shelton, USAF, appear to confirm the value of SSA for deterrence. In April of 2014, General Shelton, Commander of Air Force Space Command, publicly announced the pending launch of the Geosynchronous Space Situational Awareness Program (GSSAP), built by Orbital Sciences Corporation and launched in July 2014. The AFSPC Fact Sheet states the mission of GSSAP is to "collect space situational awareness data allowing for more accurate tracking and characterization of man-made orbiting objects." Data from GSSAP will uniquely contribute to timely and accurate orbital predictions, enhancing our knowledge of the geosynchronous orbit environment, and further enabling space flight safety to include satellite collision avoidance." [2] When asked by Aerospace America why the Air Force had decided to publicly acknowledge GSSAP, General Shelton responded that "It was a desire to indicate that we, in fact, were watching what was going on in geosynchronous orbit – watching very closely. And hopefully it will have deterrent and dissuasion impact."[3]

As the threat continues to evolve, the need to provide SSA sufficient to deter an advisory grows accordingly. Commercially hosted payloads, enabled by technology developments, policy initiatives, and new contracting mechanisms, can contribute to the existing architecture to provide additional deterrence while also improving the resiliency, accuracy, and timeliness of the current architecture.

The SSA mission area is ideally suited for hosted payloads due to the availability of commercial satellites in the orbit of interest and the relatively small size, weight, and power required of simple optical SSA sensors. The National Space Transportation Policy encourages the DoD to explore the use of hosted payloads [4], and the Air Force's Space and Missiles Systems Center just awarded an Indefinite Delivery/Indefinite Quantity contract for Hosted Payloads to multiple bidders, including Orbital Sciences. The commercially hosted payload arena is rapidly expanding, and hosted SSA payloads are well-suited to take advantage of these capabilities and opportunities.

A review of upcoming anticipated GEO commercial communication satellite opportunities shows there are a number of opportunities which would provide suitable viewing positions of High Value Assets. Now is the right time to leverage commercially hosted SSA payloads.

2. A RESILIENT AND AFFORDABLE ARCHITECTURE FOR DETERRENCE

SBSS and GSSAP together provide good coverage of the GEO belt. However, adding a commercially hosted layer to the architecture could provide a significant measure of deterrence while also improving the accuracy of the architecture's tracking observations. Simple optical sensors hosted on commercial platforms specifically selected for their viewing angles and proximity to High Value Assets (HVA) could provide continuous, persistent surveillance of Resident Space Objects (RSOs) in the vicinity of the HVA. If a change is detected, timely warning can be provided to the Joint Space Operations Center (JSpOC), which can then take appropriate action to include defensive actions and/or tasking other assets. Continuous surveillance and change detection within the vicinity of the HVA would be the primary mission of commercially hosted SSA payloads.

The persistence provided by the hosted payload could serve as a strong deterrent against a potential adversary. Consider an analogy to home security. The police force is constantly monitoring the entire community looking for bad actors. In GEO, this role is fulfilled by existing SSA assets. For an extra measure of protection, a house may have cameras constantly monitoring the home, and likely a sign indicating the presence of a security system. A thief will be deterred from entering the home that he knows is being watched. If the home security system detects something unusual, the police force can be called in to take a closer look, and similarly, a commercially hosted sensor could notify the Joint Space Operations Center (JSpOC) of suspicious activity.

Commercially hosted SSA payloads also provide a resilient layer to the SSA mission area architecture. In the event of hostile action, system failures, or acquisition delays, which create a gap in capability, commercially hosted payloads can continue to provide SSA data in the vicinity of the high value assets. If existing systems are task-saturated, hosted SSA payloads can off-load some of the tasking burden. While the commercially hosted sensors may not provide the same coverage as the Air Force dedicated space based SSA assets and do not serve as a replacement for them, they could provide dedicated and persistent SSA coverage of high value assets in the case of loss of data from the Air Force assets.

Fig. 1a demonstrates the concept for a resilient GEO SSA architecture. In this example, an HVA and two nearby RSOs (denoted at T-1 and T-2) are being tracked by SBSS, a dedicated Low Earth Orbit (LEO) sensor in a zero inclined orbit, a Ground Based Electro-Optical Deep Space Surveillance (GEODSS) site in New Mexico (NM), and two GEO hosted SSA payloads (denoted as CHSSAP_E and CHSSAP_W). In this scenario, all sensors are tracking the HVA and RSOs. Fig. 1b shows a similar sensor, but in a theoretical scenario in which a swell in the South Atlantic Anomaly degrades the LEO-based assets, the GEODSS site in NM is in daylight, and one of the GEO hosted payloads exceeds solar phase angle limitations. Despite this very challenging scenario, the architecture is still able to maintain coverage of the HVA and RSOs with the remaining GEO hosted payload.

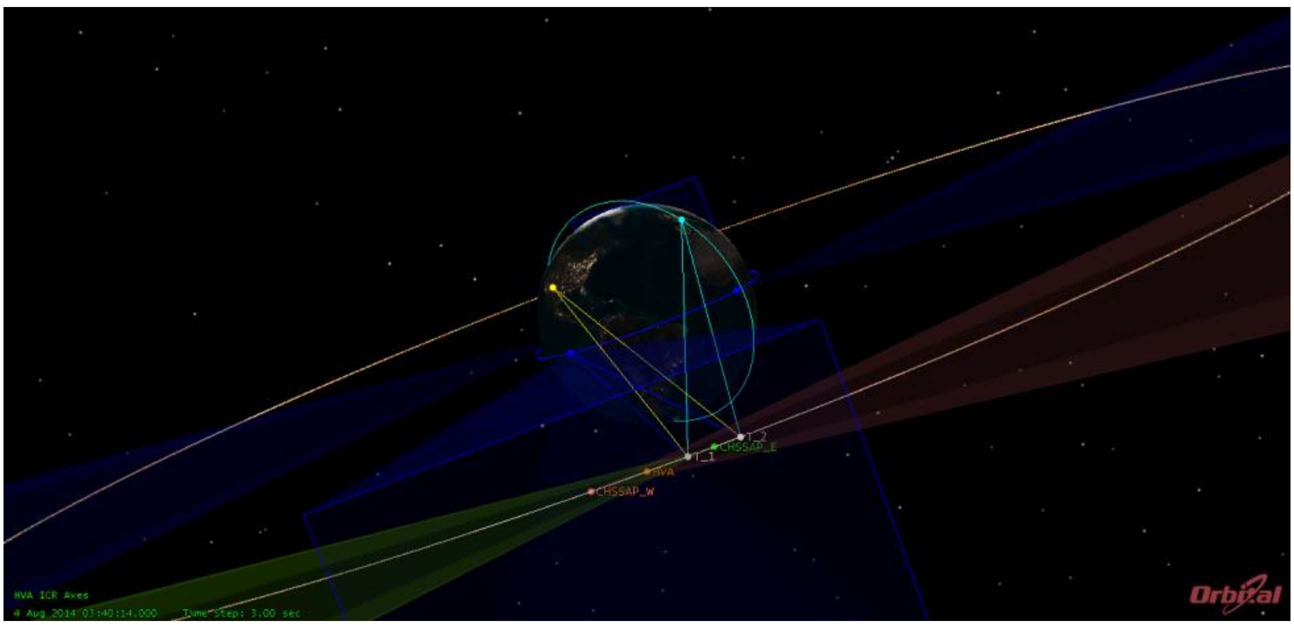


Fig. 1a. Resilient GEO SSA Architecture for Deterrence – All Sensors Tracking

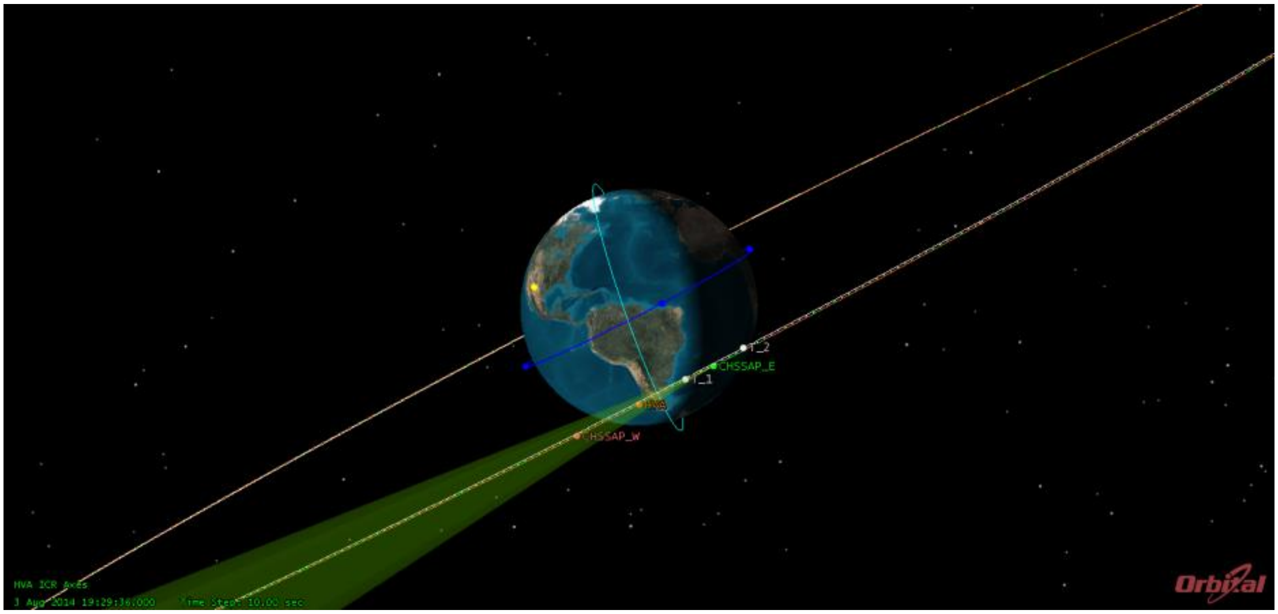


Fig. 1b. Resilient GEO SSA Architecture for Deterrence – Worst-Case Tracking

To be an effective deterrent, an SSA system must be persistent and timely. Persistence is necessary to preclude an adversary from taking advantage of gaps in coverage. Timeliness is required to enable counter actions. Commercially hosted SSA payloads achieve persistence by using staring sensors in close proximity to the HVA. By never looking away, an adversary is denied the advantage of surprise. Hosted SSA payloads provide timely data delivery by leveraging the commercial communications networks. Security of the SSA data products is maintained by using NSA-approved Type 1 Communications Security (COMSEC) equipment for payload commanding and data handling.

3. SYSTEM PERFORMANCE

Commercially hosted SSA payloads provide a number of benefits in addition to resiliency and deterrence. Data collected from commercially hosted payloads can be integrated with other data sources to provide increased accuracy in orbit determination of RSOs as well as continuous surveillance of target objects.

The mission utility of hosted SSA payloads is a function of sensor resolution, platform position knowledge, and metric observation generation rate. Since the heritage of most proposed hosted SSA sensors includes off-the-shelf star tracker components, the base resolution and sensitivity of the optics and Charged Couple Device (CCD) are on the order of several arc-seconds. Subsequent image processing, centroiding and registration of images against the star field can significantly increase the performance of the sensor with 1-sigma measurement uncertainty approaching 1 arc-second. Through calibrations, any misalignments or attitude errors with the host spacecraft can be compensated for with any remaining offsets manifesting as a bias in the resulting solution. Precision knowledge of the host platform's position in inertial space is key to the process in that any error in the host sensor's location directly translates into a similar magnitude error in any observed targets. State-of-the-art position knowledge for geostationary vehicles ranges from 10-100m. Lastly, the quantity and quality of observations generated and processed are limited only by the onboard processing and storage capabilities of the sensor and/or the available downlink bandwidth available to the hosted SSA sensor.

To illustrate the utility and performance of a surrogate hosted SSA sensor, assume a nominal performing modified star tracker with 5 arc-second resolution and a limiting visual magnitude of 9 to preclude advanced star field maps. For this example, whether the data is processed onboard or centroids are sent to the ground is of no consequence, but it is assumed that metric observations consisting of angle measurements are generated at a 1 pps rate. The hosting platform is assumed to be within 3 degrees longitude east of the HVA. Fig. 2 shows the worst-case phase angle for a commercially hosted SSA payload and Fig. 3 shows the resulting performance of the surrogate sensor against a specular and a diffuse sphere in terms of visual magnitude.

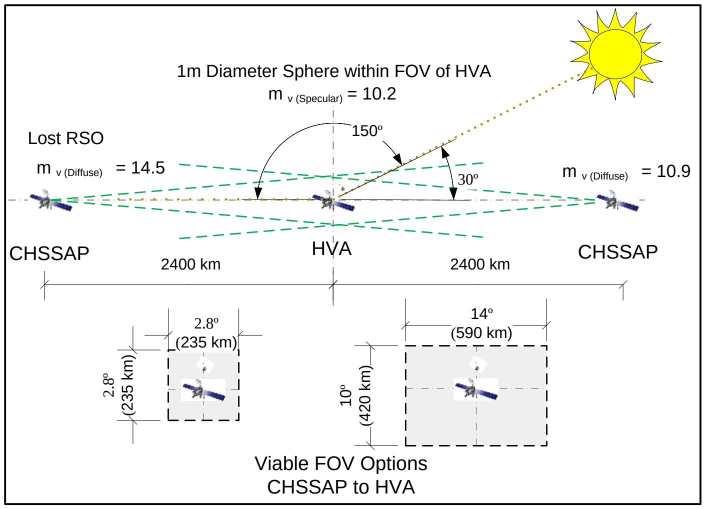


Fig. 2. Worst-Case Phase Angle for CHSSAP on Left

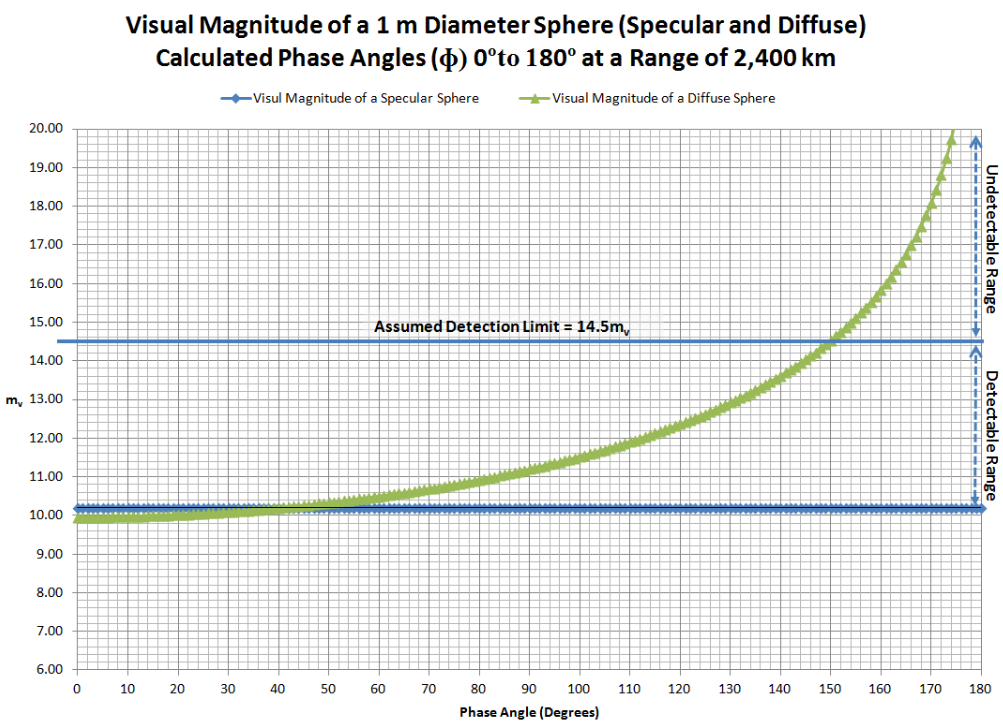


Fig. 3. Hosted SSA Sensor Performance

Given the visibility curves defined in Fig. 3, this modest SSA sensor is capable of detecting 1m diffuse spheres up to 2400 km away (approximately 3 degrees of longitude from the hosted platform). At this range, two cases are assessed to determine the resulting orbit determination performance of the posited sensor. The first case consists of the hosted sensor detecting a new and unknown object approaching the host vehicle. No additional sensors contribute to the solution and only measurements from the hosted sensor are used to recreate the trajectory of the new object. For this first case, 3 separate target trajectories are examined: stationary, inclined, and drifting. These cases bound the potential approaches for an unknown object. For these cases, it is also assumed that the target is favorably illuminated by the sun for 12 hours and then lost due to either sun exclusion violations or poor illumination.

For each of the three target trajectories, metric observations are generated and the resulting 3 sigma root sum square position uncertainty is generated as each new measurement is processed by the orbit determination process. The orbit determination process includes nominal bias values for the sensor as well as considering a 10m uncertainty in the geostationary host's position. As illustrated in Fig. 4, the stationary case is the most challenging due to the poor geometry and minimal information provided by each observation. In this case, the surrogate sensor requires nearly the entire 12-hour visibility window to develop a 1 km solution on the target. The drifting case in this example is drifting slowly towards the host vehicle at 0.5 deg/day rate. Again, as shown in Fig. 4, this small drift rate provides only negligibly more information than the stationary case and requires significant monitoring to resolve the orbit. In contrast, a representative inclined object's trajectory is rapidly resolved due to the significant relative motion between the hosted SSA sensor and the target.

Given GSSAP, SBSS, GEODSS, Space Surveillance Telescope (SST), and other contributing SSA sensors, the case where the hosted SSA sensor is the only sensor capable of observing an unknown object for a protracted length of time should be rare. More likely is the second case that constitutes another SSA sensor is used in concert with the hosted SSA sensor to generate an exquisite solution for the object's orbit. For this example, the same geostationary platform is used with the same performance parameters, but then 10 minutes of ancillary data is included with hosted SSA sensor's native data. The benefits of even this small amount of contributing sensor data are easily seen by the blue line in Fig. 4. Regardless of the source, the benefits of unique geometry from alternate vantage points results in the position knowledge of the target object to quickly draw down towards the errors in the combined system. Of particular importance, is the fact that this blue curve is effectively the same for either of the previous cases' targets specifically stationary, inclined, or drifting.

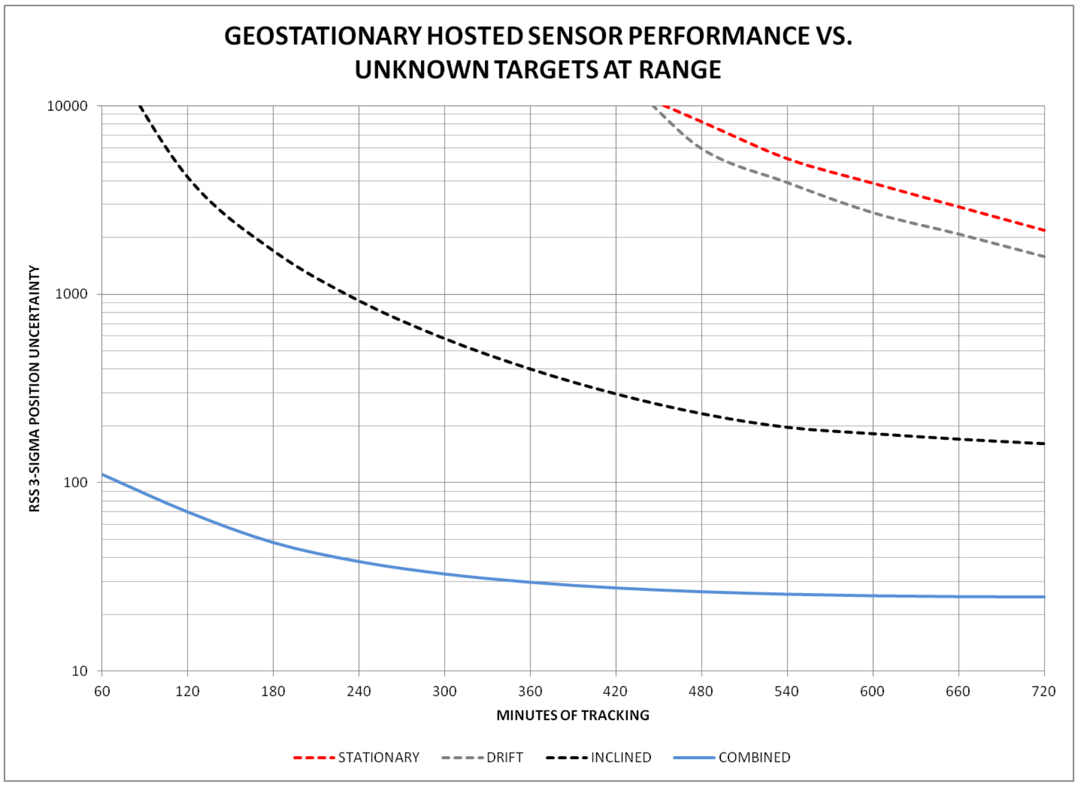


Fig. 4. Improved Orbit Determination Accuracy

4. GROUND SYSTEM AND PROCESSING CONCEPT OF OPERATIONS

Hosted payloads offer timely and cost-effective mission data delivery by leveraging the existing commercial communications networks of the host spacecraft system. Orbital proved the efficacy and cost effectiveness of this model on the CHIRP program. By using the existing commercial ground and data transport infrastructure to downlink and transport CHIRP data, we avoided the expense of deploying new and dedicated ground systems for the sensor. The same approach can be used for hosted SSA payloads.

One of the most challenging aspects of commercially hosted SSA payloads may be the integration of commercially hosted data products into the existing SSA enterprise at the JSpOC. Fig. 5 shows a conceptual approach to ground system operations and processing that is efficient and meets government security requirements. In this model, raw sensor imagery, sensor state of health telemetry, and precision time tags are downlinked to a commercial ground station through the host's transponder via the Secondary Payload Interface. The commercial ground station sends the raw sensor imager, state of health telemetry, and the host spacecraft orbit information to an Orbital operations center. The Orbital operations center strips out state of health information, monitors the instrument control and status, and performs any non-sensitive processing. Raw sensor data and the host spacecraft orbit information are sent to a government facility for processing.

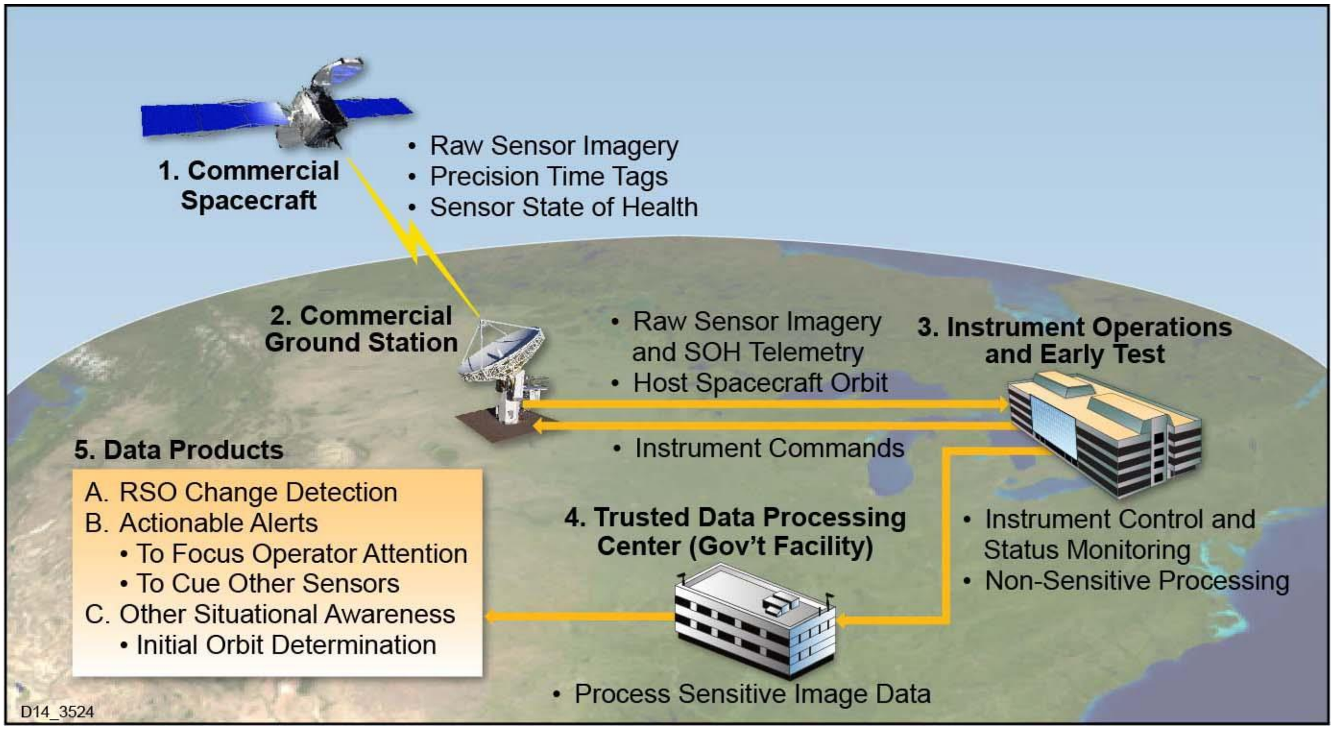


Fig. 5. Ground System Concept of Operations

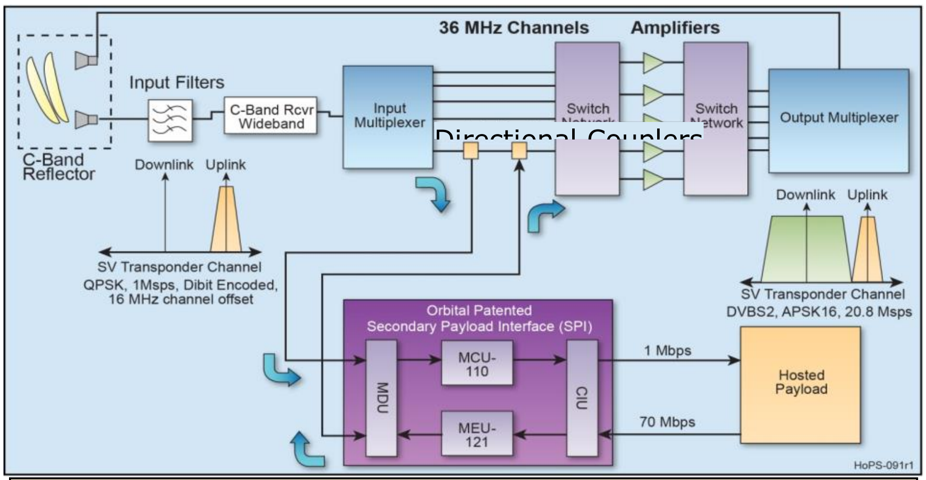
This approach meets government security requirements by protecting SSA data products from raw image creation through delivery to a government processing center. It also leverages commercial segments to minimize costs and increase efficiencies. An alternative approach to provide SSA products to potential commercial users is discussed in Section 6.

5. HOSTED PAYLOAD ENABLERS FOR AFFORDABILITY

Hosted payloads are inherently cost effective compared to dedicated free-flying spacecraft because they leverage available volume and power on the commercial host and thereby preclude the need for a dedicated launch vehicle and bus. However, the commercial operator needs to recover revenue that could be otherwise obtained with commercial use of the vehicle's transponders and for the shortened host spacecraft mission fuel life attributed to the increased mass of the hosted payload. For this reason, operator fees for hosting a payload can be somewhat significant.

Orbital Science's patented Secondary Payload Interface is a key cost saving option for hosted payloads. A unique feature of the SPI is that it enables the commercial transponder used by the hosted payload to be turned back over to the satellite operator when not in use. This provides an unprecedented level of flexibility for the hosted payload and reduces life cycle cost risk to the government. If the threat environment changes, or the HVA under surveillance should relocate or become nonoperational, and the hosted SSA sensor is no longer required, the payload can be powered down and there is no remaining cost to the government. This flexible capability could also enable a new model in which sensors are placed on commercial hosts and only activated when situations necessitate increased surveillance. This model would be analogous to a war time reserve fleet which could be activated on demand.

The SPI is a Technology Readiness Level 9 subsystem with a Crypto Interface Unit (CIU) component that was specifically designed to interface with hosted payloads and Government furnished cryptographic equipment. The Orbital CIU is easily adaptable to include the additional interface functions such as GPS receiver integration and higher data rate downlinks.



MDU = Modem Data Unit > Bandwidth Efficient DVBS2 Software Defined Radio

MCU = Miniature Crypto Unit > L3 Standard

Fig. 6. Orbital's Secondary Payload Interface

The SPI enables hosted payloads to employ a standard commercial transponder channel providing independent secure hosted payload commanding and data downlink. The SPI connects into an available commercial transponder channel or a dedicated transponder on the host spacecraft. The hosted payload operator sends commands through the SPI uplink and receives telemetry and mission data through the SPI downlink. No interaction is needed with the host spacecraft mission operations. The SPI's key technology seamlessly returns the transponder to commercial revenue-generating service by simply turning off the hosted payload at the end of the mission. The unique feature significantly reduces the cost of services as compared to a fully dedicated transponder or a dedicated transmitter and receiver.

The SPI also reduces hosted payload mission costs by utilizing existing space and ground high speed communications infrastructure already in place on commercial communications satellites and ground segments. This innovative technology eliminates the need for separate dedicated hosted payload transmitters, receivers, and space and ground antennas. The SPI minimizes risk to the host spacecraft by minimizing data handling interfaces between the host spacecraft and hosted payload. The SPI reduces hosting feed by allowing the borrowed transponder to be returned to commercial revenue-generating service once the hosted mission is complete.

6. COMMERCIAL APPLICATIONS

Commercial operators are especially interested in SSA products for safety of flight. More accurate positional knowledge of objects on projected collision courses with a commercial spacecraft can decrease the amount of fuel needed to maneuver to avoid collision. Using less fuel for unnecessary maneuvers increases the spacecraft lifetime accordingly. With the advent of Analytical Graphics Inc.'s (AGI's) Commercial Space Operations Center (ComSpOC), a new commercially-based market is emerging for SSA data products to support commercial needs.

AGI publications state that the ComSpOC will provide commercial subscribers with a range of data products including ephemeris and covariance data, and will utilize a sensor network employing multiple phenomenologies [5].

Commercially hosted SSA sensors are an ideal match to support commercial SSA needs. These sensors could be commercially procured and their data delivered directly to SSA service providers such as the ComSpOC. This model would provide commercial users valuable neighborhood watch information without having to rely on U.S. government organizations.

7. SUMMARY

Commercially hosted SSA payloads on GEO platforms may deter adversaries from attempting to degrade or disable U.S. high value assets in GEO by providing persistent and highly accurate coverage on RSOs in the vicinity of the HVA. Additionally, they increase the overall resiliency of the SSA mission area architecture. Technical developments such as Orbital's SPI are available to execute SSA hosted payload missions at low cost. This capability may also have commercial applications as source data products for systems such as ComSpOC.

Hosted SSA payloads provide significant benefits at a low cost. Previous hosted payload missions such as CHIRP demonstrated the value of leveraging commercial hosts for other mission areas. Now is the time to show what commercially hosted payloads can do for SSA.

8. REFERENCES

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