ESPA Satellite Dispenser for ORBCOMM Generation 2

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ABSTRACT

ORBCOMM’s machine-to-machine (M2M) solutions offer global asset monitoring and messaging services through a powerful Low Earth Orbit (LEO) satellite constellation. The original constellation deployment consisted of thirty-five satellites launched in the late 1990s. ORBCOMM is launching the new ORBCOMM Generation 2 (OG2) satellites to upgrade and expand the constellation network. The OG2 satellites being manufactured by Sierra Nevada Corporation will have more data capacity with the potential for new, more robust messaging services. The OG2 satellites are planned for two launches aboard the SpaceX Falcon 9 v1.1 using a modular Satellite Dispenser built on multiple ESPA rings. Preparation for launch involves environmental assessments including acoustics, shock, and quasi-static loads. SpaceX has worked with the OG2 team to ensure that the appropriate flight environments are analyzed to demonstrate the Dispenser launch capability.

The ORBCOMM satellite network will be the first constellation to leverage the modularity of the ESPA multi-payload adapter. Since the maiden ESPA flight in 2007, numerous mission planners have developed configurations ranging from traditional rideshares to deployment vehicles to free-flying spacecraft built around the ring. Launch of constellations is an obvious use of the ring, and other programs including COSMIC 2 are considering similar ESPA configurations for their constellation launches.

INTRODUCTION

The ESPA ring originated in the late 1990s as a multi-payload adapter to provide capability to the Air Force for launching small experimental payloads.\(^1\) CSA Engineering designed the ring under a Small Business Innovation Research contract from the Air Force Research Laboratory/Space Vehicles Directorate with funding and technical requirements from the DoD Space Test Program. The prototype was designed for Atlas V and Delta IV: the EELV Medium Launch Vehicles in development at that time by Lockheed Martin and Boeing respectively. Since the first EELV flights in 2002, the United Launch Alliance (ULA) vehicles have completed over 70 successful missions. The first flight of the ESPA ring occurred in March 2007 on the Air Force’s STP-1 mission.

The ESPA structure was designed and is flight qualified to mount a 15,000-lb (6,804-kg) primary satellite and six 400-lb (181-kg) secondary satellites on an EELV Medium. Secondary satellite volume is nominally 24 inches x 28 inches x 38 inches. ESPA is installed at the EELV Standard Interface Plane, which is a 62-inch-diameter bolt circle at the top of launch vehicle upper stage. The ESPA duplicates this bolt circle for the primary payload (PPL), and the ring is designed to be stiff in all directions to provide minimal impact to the PPL. Six ports with 15-inch bolt circles provide mount locations for the secondary payloads (SPLs). The standard ring is 24 inches high, so only a small amount of volume in the fairing is taken away from the PPL allowable volume. An ESPA Ring flight unit is shown in Figure 1, and the launch stack for the STP-1 Mission is shown in Figure 2.

![Figure 1: Typical ESPA Hardware](image)

Multi-ring stacks have been considered for missions as early as 2005. A study was performed in late 2012 to determine the feasibility of an ESPA-based dispenser for launch on a Falcon 9 v1.1. Stacking flight proven
ESPA rings as a multi-satellite dispenser obviates the need for a custom adapter for the satellite deployment and minimizes the design development effort resulting in a shorter delivery schedule. To accommodate the OG2 satellite size, the taller, larger-port ESPA Grande ring was selected. The resulting ESPA Dispenser is a modular stackable design allowing flexibility in the number of satellites that can be launched on a single mission; the same design can be used for multiple launches.

Figure 2: STP-1 Integrated Payload Stack

The OG2 Dispenser will also feature SoftRide isolation of the launch stack. SoftRide provides whole-spacecraft vibration isolation for satellites to mitigate structure-borne vibration and shock, which can damage spacecraft. SoftRide systems have flown on 28 missions to date, including the Falcon 9 Commercial Resupply Services 1 (CRS-1) Mission in October 2012 with the prototype OG2 spacecraft. Figure 3 shows the CRS-1 flight isolation system that protected the spacecraft during random vibration testing.

Spacecraft telemetry collected after the CRS-1 launch confirmed hardware functionality, paving the way for the SoftRide isolation system design for the OG2 constellation launches. As part of the 2012 dispenser feasibility study, analysis demonstrated that vibration isolation of the integrated dispenser was preferable rather than isolating each spacecraft at its separation system. A coupled loads analysis has been performed as part of the flight validation effort for the OG2 Dispenser system and to predict responses at key locations on each of the eight spacecraft.

ORBCOMM GENERATION 2 SATELLITES

The OG2 satellites are being manufactured by an industry team led by Sierra Nevada Corporation (SNC). The satellite features a fully reprogrammable software defined radio being provided by Boeing’s ArgonST subsidiary that will provide enhanced messaging capabilities, increased capacity, and Automatic Identification Systems (AIS) service. The 170kg OG2 satellites utilize a four point separation system, which allows for a simple modular interface to the ESPA Dispenser.

OG2 ESPA DISPENSER

For Mission 1, ORBCOMM plans to launch eight OG2 satellites aboard a SpaceX Falcon 9 v1.1 launch vehicle. The Dispenser configuration for OG2 Mission 1 is shown in Figure 4. The OG2 Dispenser capitalizes on the modularity of ESPA, and several modifications to the ring have been implemented including the use of 5/16-inch fasteners on the port bolt circles to provide added margin for the fasteners. Other components of the Dispenser (besides two ESPAs and the SoftRide system mentioned above) are custom Flat Plate Adapters and flight Electrical Harnesses to carry power, data, and separation signals.

Figure 3: OG2 Spacecraft and SoftRide Isolators for the CRS-1 Mission

Figure 4: Mission 1 Dispenser Configuration
**ESPA Grande**

ESPA Grande was developed as an ESPA variant to provide capacity for larger and heavier secondary payloads compared to the standard ESPA. The original sizing for this ring version was the result of a NASA engineering study in 2004 for a proposed New Millennium mission: a 42-inch-tall Ring with four ports and an interior cone for mounting of a co-manifested spacecraft. That mission was not funded, but CSA completed the design under an SBIR contract to NASA Ames Research Center in 2007. The four-port, 42-inch-tall ESPA Grande that is the hub of the OG2 Satellite Dispenser is also referred to as ESPA 4-24-42 and is shown in Figure 5.

![Figure 5: ESPA 4-24-42 for OG2 Dispenser](image)

All of the standard ESPA dimensions, with the exception of height and SPL port diameter, carried through to the ESPA Grande design. The SPL bolt circle was set at 24 inches to accommodate SPLs up to 700 lbs (318 kg); this bolt circle diameter was also selected to be consistent with other adapters. ESPA Grande SPL capacity with the 24-inch port is shown in Figure 6, compared to the capacity of the standard “ESPA-class” 15-inch-diameter bolt circle.

![Figure 6: ESPA Grande Payload Capacity](image)

**Flat Plate Adapters**

A 7000-series aluminum flat plate is used to adapt the OG2 4-point-mount interface to the 24-inch-diameter ESPA port. These Flat Plate Adapters are designed to adapt from the circular ESPA bolt pattern to the spacecraft separation system and kick-off springs as shown in Figure 7. The adapters are 1.5 inches thick, machined with a 0.75-inch-deep orthogrid pattern, and finished with MIL-DTL-5541 (chem film) alodine. Figure 8 shows a Flat Plate Adapter in fabrication.

![Figure 7: OG2 Satellite and Flat Plate Adapter at ESPA Port](image)

The ESPA port has 36 fasteners on a 24-inch bolt circle. The standard fastener size is 1/4-28, but for the OG2 Satellite Dispenser this fastener size has been increased to 5/16-24. The OG2 satellites have been qualified to a 15-g static load factor, so the ESPA fastener size has been increased for additional structural margin.

![Figure 8: OG2 Dispenser Flat Plate Adapter](image)
To minimize integration time at the launch site, the Flat Plate Adapters will be integrated to the spacecraft prior to shipment to the SpaceX payload processing facility. Thru holes along the perimeter of the Flat Plate Adapters allow for attachment of the OG2 Spacecraft/Adapter assembly to the OG2 Satellite shipping container.

**SoftRide Vibration Isolation**

Whole-spacecraft vibration isolation is typically implemented to reduce the effects of one or more known launch load events or loading environments, such as resonant burn from a solid-rocket motor, or a maximum predicted vibration environment. Falcon 9 v1.1 is a new vehicle and design environments are still being developed, therefore SoftRide is included as part of the Dispenser for risk reduction due to the uncertainty of the structure-borne loads.

**Electrical Harness**

The Dispenser electrical harness distributes power, data, and separation signals from the launch vehicle to the various OG2 satellites. Connector interfaces, cable capacity, and mechanical routing were coordinated with SpaceX and Sierra Nevada Corporation. Brackets are used for connector bulkheads, and to route the harness across the ESPA rings and across the SoftRide system at the base of the Dispenser as shown in Figure 9. The Harness is being manufactured with assembly performed per NASA-STD-8739.4.

![Figure 9: Dispenser Harness with Power (red), Data (yellow), and Separation (blue) Cables](image)

**SOFTRIDE HERITAGE**

The OG2 Dispenser SoftRide system has design heritage from the SoftRide family of whole-spacecraft vibration isolation systems. Whole-spacecraft isolation has been developed to attenuate dynamic loads for launch vehicles ranging from Minotaur 1 to Delta IV Heavy, and it has been successfully flown on 28 missions.

Vibration isolation systems work by adding compliance between a base structure such as a launch vehicle and the payload, as shown in Figure 10. The isolator has low relative stiffness compared to the base structure and payload, and a precise amount of structural damping. SoftRide isolator stiffness is designed to result in a payload isolation frequency that attenuates dynamic loads from the launch vehicle interface. Isolator damping reduces payload response at the isolation frequency.

![Figure 10: SoftRide Installation at Spacecraft Interface](image)

The isolator must allow relative motion between the vibrating base structure and the payload at the isolation frequency, which is referred to as the isolator stroke. The isolation system effectively works as a low-pass filter and attenuates vibration energy above the isolation frequency. The reduction in the time domain can be substantial, as shown in the flight data reproduced in Figure 11.

![Figure 11: SoftRide Flight Acceleration Data](image)
Because the spacecraft is a major structural component of the launch vehicle/spacecraft dynamic system, variations in the isolation frequencies greatly affect the system dynamics. Any unpredicted changes in the dynamics could have an adverse effect on the launch vehicle guidance control system and cause instability and thereby loss of the mission. Therefore, the stiffness properties of the isolation system must be predictable for the duration of the flight. This requires a linear isolation system under all load cases, including tensile preloads from 2 g to compression loads of 6 g or more due to acceleration of the launch vehicle. This requirement eliminates the use of an elastomeric material such as rubber for the stiffness component of the isolation system. The SoftRide system is based on all-metallic flexures, and it is fail-safe with predictable deflections under the dynamic and quasi-static acceleration load specifications.

**FALCON 9 LAUNCH ENVIRONMENT**

Flight environments from the Falcon 9 Payload User’s Guide were reviewed with SpaceX in preparation for the Dispenser Critical Design Review. Analyses were performed to demonstrate that all Dispenser elements except the SoftRide isolators have positive margins due to all flight events with no-test safety factors. The SoftRide flexures have been subjected to a qualification program, and all SoftRide flight parts are acceptance tested.

Critical loading environments that were considered for the OG2 Satellite Dispenser consisted of

- quasi-static loads,
- acoustics, and
- shock.

As described in the Falcon 9 Guide: “During flight, the payload will experience a range of axial and lateral accelerations. Axial acceleration is determined by the vehicle thrust history and drag, while maximum lateral acceleration is primarily determined by wind gusts, engine gimbal maneuvers, first stage engine shutdowns, and other short-duration events. Falcon 9 Design Load Factors are shown using the envelope plotted” in Figure 12. The OG2 spacecraft were tested to 15 g in each direction independently, so the ESPA Dispenser interface was also designed to this level. Actual spacecraft loads, accelerations, and deflections have been computed via coupled loads analysis (CLA).

Strength analysis for the Dispenser was performed in NASTRAN using the Integrated Payload Stack (IPS) model shown in Figure 13 coupled to the Falcon 9 Payload Attach Fitting (PAF). The SoftRide system at the base of the Dispenser was modeled with NASTRAN Direct Matrix Input at a Grid (DMIG), and the satellites with interface adapters were included as Craig-Bampton reductions at the eight ESPA ports. The weight of the harness was included as non-structural mass. This model was provided to SpaceX for the coupled loads analysis.

![Figure 12: Falcon 9 Design Load Factors](image)

![Figure 13: OG2 Satellite Dispenser Analysis Model](image)
Vibro-acoustic analysis was performed with VA-One software. The IPS was subjected to the Falcon 9 v1.1 payload fairing maximum predicted acoustic environment shown in Figure 14. This environment creates random vibration of the OG2 spacecraft, adapter plates, ESPA rings and Falcon 9 PAF. The OG2 spacecraft have a random vibration limit specification; the vibro-acoustic model was used to predict IPS vibration at the interface plate for comparison with interface requirements. Similarly, the OG2 deck predictions were compared to acceptance requirements for the payload deck and equipment deck.

The Falcon 9 User’s Guide shock environment at the Dispenser interface to the PAF is shown in Figure 15. The OG2 spacecraft also have a Dispenser interface shock requirement. Shock attenuation through the Dispenser was estimated using industry accepted distance attenuation factors and experience-based joint attenuation factors, combined with test-based SoftRide shock attenuation. The predicted shock level due to launch vehicle induced events is compliant to the Dispenser/Spacecraft interface requirement.

INTEGRATION

OG2 mission integration activities at the launch site will occur on a very tight schedule in the weeks prior to launch. Integration of the IPS will be facilitated by the modular features of ESPA and eight identical satellites.

Integration activities to be performed prior to shipment to the launch site include mating of the satellites to the Flat Plate Adapters, and integration of the harnesses to the ESPA rings. SNC modified the satellite shipping containers to accommodate the flat plate adapters, so the satellite/adapter integration will occur at the SNC facility in Colorado. Initial harness integration will occur at Moog CSA in Mountain View, California, prior to shipment of the ESPA rings to the launch site.

Ground support equipment is in place for the assembly of the Integrated Payload Stack as shown in Figure 16. ICDs have been written for the integration of the satellites to the Dispenser and for the integration of the IPS to the Falcon 9 PAF.

MISSION 2

A second Falcon 9 launch for the remaining spacecraft of the ORBCOMM Generation 2 constellation is planned for 2014. The Satellite Dispenser for this mission will be based on the Mission 1 Dispenser with capability added for at least one more spacecraft.
Acknowledgments
The authors would like to acknowledge support for the content of this paper from Jim Christensen of Sierra Nevada Corporation and Dustin Doud of SpaceX.

References