Tactical Satellite 3 CDL COMMUNICATIONS,
A COMMUNICATIONS LINK FOR MISSION UTILITY

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Abstract

Tactical Satellites (TacSats) are part of the Operational Responsive Space (ORS) demonstration program to develop rapid response, low cost, small satellites, whose payloads support real-time data delivery to the combatant commander. As each TacSat is developed, further knowledge is gained towards the end operational systems.

Common Data Link (CDL) is the Office of Secretary of Defense's (OSD) mandated standard wideband communications waveform for Intelligence Surveillance & Reconnaissance (ISR) in airborne platforms. In supporting this standard, the military has numerous air, sea and ground CDL systems for theater connectivity.

While CDL is the standard for airborne ISR, it was not implemented in space until TacSat-2 launched on December 16, 2006. TacSat-2's CDL payload supports a 274 Mbps downlink and a 200 Kbps uplink. A CDL system in space brings tactical ISR data directly into existing theater ground stations, allowing for responsive tasking and collection.

Spring 2008, another CDL communications payload will be launched on TacSat-3. TacSat-3 takes the CDL communications payload a step further with networking capability and multiple data rates to continue demonstrating direct theater tasking, collection and dissemination. The satellite will support a 274 Mbps downlink data rate in addition to lower data rates for potential Remote Operated Video Enhanced Receiver (ROVER) connectivity. Rover III is a portable receive-only terminal that displays sensor data from multiple airborne platforms across Ku, C, and L-Band with over 2000 units in use.

Each CDL payload delivered was based on utilizing an existing airborne design. This paper will focus on the challenges of modifying the CDL airborne system for the TacSat-3 launch and space environment while discussing the enhanced mission operation utility CDL provides to the combatant commander.

Communication Payload Introduction

With the successful delivery and launch of the TacSat-2 CDL communications payload, L-3 Communications, CSW was placed under contract by Air Force Research Laboratory (AFRL VSE and IFGD) to deliver another airborne CDL communications system destined for space with a planned delivery date of April 2007. In addition to the Microwave Modem Assembly (MMA) implemented for TacSat-2, L-3 developed a Radio Frequency Assembly (RFA) for transmit/receive amplification and two antennas. A 12" parabolic antenna is for duplex operation with the ground station while a broad-beam horn antenna is for Rover operation at a lower data rate. A very basic CDL payload block diagram is shown in Figure 1 with the external spacecraft electrical interfaces shown in grey.

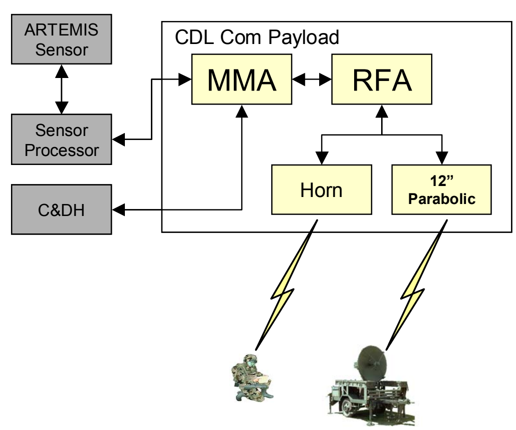

Figure 1 TacSat-3 CDL Communications Payload Block Diagram

L-3 was tasked with a serious challenge with this next version of TacSat in that AFRL wanted an airborne system that would last up to a year in the Low Earth Orbit environment. This type of reliability is not easily achieved since the Microwave Modem Assembly (MMA) was designed for an F-16 fighter pod.

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While the F-16 fighter pod is by no means a benign environment, it pales in comparison to the Minotaur launch environment, radiation, and thermal conditions in the vacuum of space. Not only is the space LEO environment cold, on the order of -100°C, but temperature swings up to +100°C are possible due to solar heating. (For reference space with no heating or light around is –2.7K, or –270°C) Even Mil-Standard components cannot support that type of environment without some type of assistance. Needless to say this was a significant challenge.

Airborne System for Space?

Now one may ask, why would the Government want to go through such a difficult task of having L-3, CSW force an airborne based communications system into a space environment? Not only is the space environment harsher than the airborne environment, but Size, Weight, and Power (SWAP) are far more critical when you factor in the spacecraft design impact in relationship to the launch vehicle. L-3, CSW is aware of the difficulty, having started development of a space qualified CDL system in 2003[1].

For the space application, many of the airborne modem's features are not needed and as a result significant reductions in size, weight and power can be made for a space qualified system. In airborne designs it is not critical to be able to power uplink and downlink electronics separately, while for space applications it is very important to have power saving modes of operation to ensure proper battery power replenishment through the solar arrays. Accessibility of circuit cards for repair in airborne environments is a normal design practice, but for space it is not as practical and adds additional volume to a design. Some airborne systems are cooled with fans over fin stock or heat exchangers, but in the absence of air or other fluids (i.e. liquids, gases) convection will not work. Typical space payloads are conductively cooled, again saving size and weight of the fans and fin stock.

A similar space qualified modem (modulator – demodulator) design using rad hard components would be roughly half the size, weight and power of the airborne modem system. Table 1 represents the SWAP differences between the space qualified and the airborne design.

Table 1. Size weight and power for the space qualified system represents a significant savings over the TacSat 3 airborne Modem system.

TacSat-3 Airborne CDL System	Dimensions (inches)	Weight (pounds)	Power (W)
Modem Section	15.75 x 11 x 11.18	43.14	238
TOTAL	1938 cu-in	43.14 lb	238 W
Space Qualified CDL System	**Dimensions (inches)**	**Weight (pounds)**	**Power (W)**
Downlink Stack	8.5 x 8.5 x 2.88	9.0	25.2
Uplink/COMSEC Stack	8.5 x 8.5 x 4.3	13.5	53.8
TOTAL	518.8 cu-in	22.5 lb	79.0 W

The airborne system also uses processors for various advanced CDL waveform and networking features, that in the space qualified effort are not needed. Those processors are eliminated in the space qualified modem, and FPGA state machine logic is used for basic configuration functions. This saves in power and size, while reducing system complexity.

With the benefits of SWAP, reliability, and reduced complexity that a space qualified CDL system provides, this approach could not be used. The problem as is seemingly always the case was time and funding. AFRL simply did not have the time or funding for L-3, CSW to complete the space qualified design. The TacSat programs have created a new breed of satellite. These satellites are procured quickly and with minimal cost.

Operational Responsive Space Paradigm

Tactical Satellites (TacSats) are part of the Operational Responsive Space (ORS) demonstration program to develop rapid response, low cost, small satellites, whose payloads support real-time data delivery to the combatant commander. As each TacSat is developed, further knowledge is gained towards the end operational systems. Knowledge is also gained in faster cycles as compared to traditional satellite development timelines.

Bottom line, if one waits for things to be done perfectly you may never get to where you want to go. Taking risk and meeting a lower threshold of typical requirements drives down cost and schedule to the point that you can launch a satellite from design to orbit in under 2 years. This alone is a huge paradigm shift from traditional satellite systems taking 5-10 yrs with costs in the 100's of millions if one is lucky, not to mention a 60-100 million dollar launch cost that is approximately ten times greater than a small sat launch. When one looks at designing, building and launching a small sat for less than the traditional satellites' launch costs alone, one can start to see how responsive TacSats can become.

Why CDL in Space?

With a glimpse into the paradigm of doing things faster and taking some risk, one might ask why use the Common Data Link (CDL) in space to begin with. There are two primary reasons to do so; 1) reuse of existing CDL wideband infrastructure in theater and 2) reduce lifetime costs.

To appreciate the utility of using the existing infrastructure requires a little background on CDL. CDL is the US military's standard wideband communications waveform for Intelligence Surveillance & Reconnaissance (ISR) in airborne platforms. In supporting this standard, the military has numerous air, sea and ground CDL systems deployed for theater connectivity. Specifically the existing ground stations can be time-shared between the airborne and TacSat missions. What better way to get real-time data to the combatant commander than to leverage his existing systems that his troops are already familiar with.

The second reason is related to the first. Since existing infrastructure is being used for the TacSat mission downlink, the military does not have to worry about developing, purchasing, or deploying more equipment for the theater. The combatant commander's troops have the utility of using the same ground station they use for airborne ISR missions as satellite missions. Figure 2 depicts such a scenario. Today this is being done for TacSat-2. An existing CDL ground station is being shared between the airborne and space missions. TacSat-2 and 3 are Low Earth Orbit (LEO) satellites and because of their orbit, they have ground access six times a day with each pass less than 10 minutes. That type of orbit lends itself well for mission sharing with the airborne assets. A potential mission configuration is depicted in Figure 3.

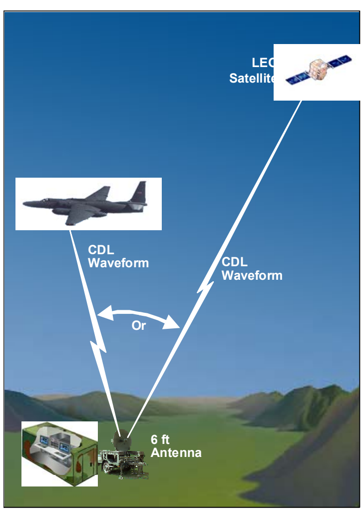

Figure 2 Existing Ground Stations Can Support Multi-Mission Operations

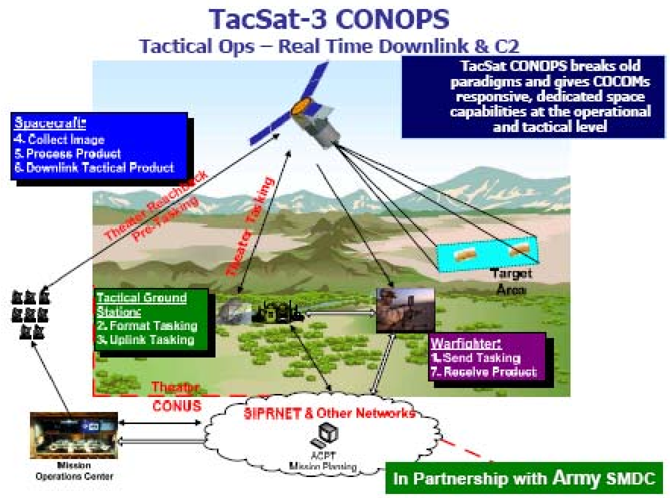

Figure 3 Notional TacSat-3 Tactical CONOPS[2]

This figure shows the sequence of events for the TacSat-3 tactical CONOPS. The sequence starts with the warfighter sending a collection task to the CDL ground station prior to a collection opportunity. A collection opportunity is defined as any time TacSat-3 can collect a Hyperspectral image within the assigned theater. The CDL ground station uplinks the formatted tasking data to the satellite. Upon receipt of the properly formatted tasking, TacSat-3 autonomously slews to the target, collects the data, processes the data, then downlinks the data directly to the warfighter using the CDL data link. The tactical data product is determined by the original tasking, and is tailorable to meet the warfighter's needs and communication capabilities. TacSat-3's objective is to demonstrate in theater, the tasking, imaging, processing, and direct down link of the HSI data in less than 10 minutes.

Once the tactical product has been disseminated in theater, the raw data is downlinked to the next available site. The raw data can be further processed for more detailed products.

The ability for the warfighter to task and receive imagery from space is unprecedented and is raising awareness in the military community as to what can now be done. This new capability is currently being demonstrated successfully with TacSat-2. Military utility assessments are planned with TacSat-2 for various upcoming exercises.

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TacSat-3 concept of operations (CONOPS) will benefit from what is learned during the exercises.

Back to the Challenge - Peeling the Onion

Having addressed the following topics

- harsh space environment
- why one would want to use an airborne system in space
- ORS concept
- and lastly why CDL in space,

we can discuss the challenge at hand: assuring AFRL that the airborne system will work in space up to a year. With the support of Aerospace Corp. and two additional consultants, L-3 started to pick the system apart piece by piece to evaluate against the environment. L-3 started generating parts lists of the existing CDL system to evaluate the following aspects:

- metals
- outgassing
- thermal
- mechanical
- radiation

Parts

The L-3 Communications system is comprised of an airborne Microwave Modem Assembly (MMA), Radio Frequency Assembly (RFA), 12" parabolic antenna, and a broadbeam horn antenna. The antenna's were new designs, which were built specifically for the space environment. The RFA, although a new design, used existing military grade components to meet schedule and cost constraints. The MMA was an existing airborne design and major modifications could not be made due to schedule and funding limitations. The MMA is a card cage chassis comprised of many slide in SEM-E modules that perform various functions:

- network processing
- system processing
- multiplexing/demultiplexing
- encryption
- forward error correction (FEC)
- modulation/demodulation
- timing
- up/down conversion
- filtering
- power conversion

With the functions the MMA performs there are >12,000 parts. Of those 12,000, there are around 1,000 active parts, with around 350 that are unique.

Metals

L-3 reviewed the entire parts list for pure tin, zinc, and cadmium since they could not be used based on whisker and sublimation concerns. Pure tin and zinc were not a big problem but many connectors in the airborne design were cadmium plated to minimize salt corrosion. L-3 had to find replacement connector parts and modify existing documentation to get these items in house for the build. The difficult part was getting these items in time for the build since they were mostly long lead items.

Outgassing

L-3 also had to minimize the systems outgassing to the greatest extent we could and used the standard Total Mass Loss (TML) < 1.0 % and Collected Volatile Condensable Materials (CVCM) < 0.1% limits. NASA's Outgassing website: **http://outgassing.nasa.gov/** was extremely useful in evaluating the various materials used in the L-3 parts system although on several occasions L-3 had to go to the vendor to determine the chemical properties. Thermal compounds, adhesives/epoxies, potting, conformal coatings, wire insulation, cable tie downs, and paints all came under scrutiny and under most circumstances required replacements and build documentation modifications.

Thermal

Thermally, the MMA and RFA are maintained by the spacecraft bus with a cold plate that is, strangely enough, more benign than the normal airborne environment. The same could not be said for the parabolic antenna since it is isolated from the bus and would see ± 100°C temperature swings. Some unique antenna designs were developed to endure the temperature range.

Mechanical

Structurally, the Microwave Modem Assembly did not require modifications based on the soft-ride data received for the launch vehicle. Although a fair amount of analysis had to be run to verify those conditions since the input vibration profile is significantly different than a typical airborne platform.

Radiation

One of the key space environmental conditions L-3 had to overcome was radiation. While TacSat-2 continues to operate in a similar environment, that cannot be used as a basis for the TacSat-3 system. This is especially true since L-3 Communications had the additional networking functionality parts to consider.

Through analysis of the orbit and inclination angle over the mission duration L-3 was able to determine that the Total Ionizing Dose (TID) would be < 70 rad (Si). This amount of dosage is insignificant to most electronics and is not considered a significant risk.

Single Event Effects (SEE) are not as easy to analyze for as TID, since test data is not available to evaluate for all the CDL parts. Aerospace Corporation reviewed most of the active parts and came up with 44 that had an unknown risk. Eventually data was found on 5 of the 44 parts that reduced some risk, but that still left 39 parts with an unquantifiable risk. L-3 then searched for radiation hardened replacements that were pin-for-pin compatible but none existed. Luck would come when an orbit change was made for the imager that lowered the inclination angle from 60° to 41° that significantly reduced the high-energy particle fluence. The orbit comparisons are depicted in Figure 4 below.

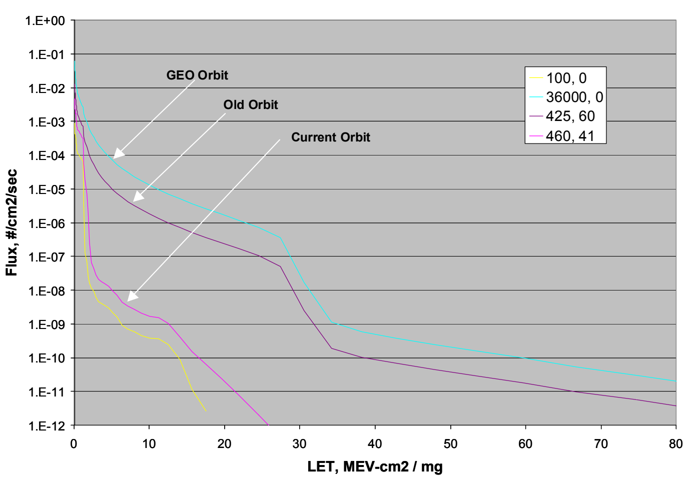

Figure 4. Flux vs LET for Various Orbits

This reduction in high energy particles along with the system only being powered on around 45 minutes/day and not being on while over the South Atlantic Anomaly (SAA) greatly increases the probability of success over the year mission duration. For reference, Single Event Effects (SEE) caused by high energy particles do not occur when equipment is powered down. Also for reference, the SAA is a region around Brazil as low as 200-300 Km that has a significantly higher energy proton flux (>10MeV at a typical flux of 3000 particles per square centimeter per second). [3]

Summary

TacSat-3 is a responsive space mission with a focus to provide a militarily relevant capability to the warfighter, while meeting the cost and schedule aspects of the Operationally Responsive Space paradigm. Utilizing CDL in space provides the benefit of using the existing in-theater CDL ground infrastructure for tactical communications. Many challenges have been overcome in the development of a modified CDL airborne system for space. While there is no way to drive risk to zero within the schedule and funding available, the mission success probability has greatly increased through analysis, testing and other efforts. Additionally, each day as the TacSat-2 CDL airborne system operates in space, the risk is lowered even more. While the efforts presented for the airborne system in space have met the current program needs, this is not preferred approach. The best way forward for future programs is to complete the CDL space qualified system. This approach provides the least impact to a program in terms of its size, weight, and power as referenced in Table 1. This approach also uses radiation hardened components and design methodologies that drive the Single Event Effects (SEE) risk to near zero. Lastly, the space qualified system is designed from the outset to meet the harsh launch and space environment.

Additional CDL Background[4]

In 1979, the Common Data Link (CDL) Program foundation originated the Interoperable Data Link (IDL) program. The United States Air Force/Assistant Secretary of Defense (USAF/ASD) and the National Security Agency (NSA) developed the IDL U-2 platform. In 1988, the Office of the ASD (OASD)/Command, Control, Communications, and Intelligence (C3I) recognized the success of the IDL program with a decision to develop a standard communication architecture that would be common across all Department of Defense (DoD) Services. OASD/C3I mandated the CDL proliferation to users involved in the collection and dissemination of wideband Intelligence, Surveillance, and Reconnaissance (ISR) data.

CDL is a full-duplex, jam resistant spread spectrum digital link supporting point-to-point and network topology communications. The uplink operates at 200kbps to 45Mbps. The downlink can operate at 2, 10.71, 45, 137, or 274 Mbps. In addition; future rates of 548Mbps and 1096Mbps can be supported.

The Common Data Link program is designed to achieve data link interoperability and provide seamless communications between multiple Intelligence, Surveillance, and Reconnaissance (ISR) collection systems operated by armed services and government agencies. CDL provides full-duplex, jam resistant, digital microwave communications between the ISR sensor, sensor platform, and surface terminals. The CDL Program establishes data link standards and specifications identifying compatibility and interoperability requirements between collection platforms and surface terminals across user organizations.

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