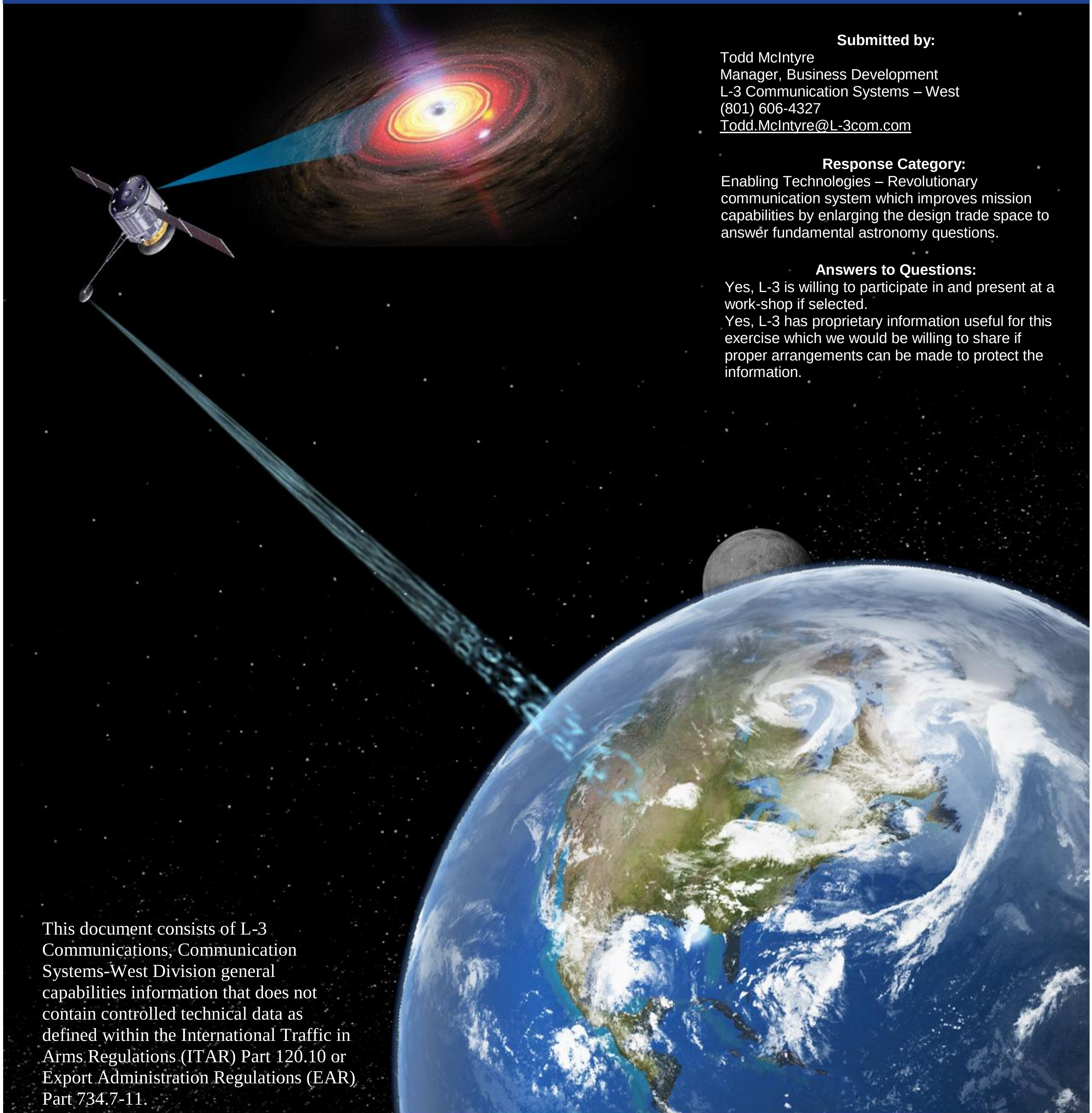
SPACE COMMUNICATION RATES AT MULTI-GBPS

RFI NNH11ZDA019L November 10, 2011



Submitted by:
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Response Category:
Enabling Technologies – Revolutionary communication system which improves mission capabilities by enlarging the design trade space to answer fundamental astronomy questions.

Answers to Questions:
Yes, L-3 is willing to participate in and present at a work-shop if selected.
Yes, L-3 has proprietary information useful for this exercise which we would be willing to share if proper arrangements can be made to protect the information.

This document consists of L-3 Communications, Communication Systems-West Division general capabilities information that does not contain controlled technical data as defined within the International Traffic in Arms Regulations (ITAR) Part 120.10 or Export Administration Regulations (EAR) Part 734.7-11.

Communication Systems-West

1.0 INTRODUCTION

L-3 advances innovative deep-space communications with multi-Gigabits/second (Gbps) data rates and an advanced digital processing architecture, resulting in a communication system that enables new and more capable science missions to inspire the American public.

NASA receives a software-programmable, multi-Gbps communication system that improves mission capabilities and enlarges the design trade space:

- **Increased data rates for**
  - Enhanced sensors
  - Multiple sensors
- **Enlarged design trade space for reduced:**
  - Size
  - Weight
  - Power
  - Cost
  - Complexity

The Hubble Space Telescope and the Mars Rovers have dazzled the world with their amazing imagery. These national treasures have literally helped re-write textbooks on astrophysics and planetary geology while captivating the public's imagination with stunning images of other worlds and solar systems. Yet these instruments are constrained by decades-old communications technology. Until now.

L-3 Communication Systems-West (CSW) is pleased to offer a new paradigm in space communications. We offer an innovative space communication system capable of unshackling the Hubbles and Mars Rovers of the future, including NASA's Physics of the Cosmos (PCOS) program, with amazing advances in data rates. Instead of still images from today's iconic exploration tools, imagine mission data streaming real-time from the world's most aggressive and advanced sensors providing high resolution insight into stellar remnants falling into a massive black hole or even finding unexpected sources of gravitational waves. Consider finally answering some of Astronomy's most fundamental questions – What happens close to a black hole? How do they grow? What happens when massive black holes merge? How do binary, Kerr black hole, e.g., OJ-287, rotations distort the quadrupole nature of gravity waves? Why is the universe accelerating? Answers to these questions, and more, are possible with SCRAM—Space Communication Rates At Multi-Gbps, a revolutionary communications system that enables enhanced sensors or multiple sensors to significantly improve mission capabilities and assist NASA in dealing with future budgetary constraints. For missions that do not require Gbps data rates, SCRAM technology provides new mission capabilities by enlarging the design trade space at the full system level by lowering the size, weight, power, cost and complexity of communication systems. Fundamentally, no NASA mission should ever be limited by communication hardware again.

Sensor technology, from hyper spectral imagers to synthetic aperture radar, continues to drive higher data rate requirements, and L-3's SCRAM technology advances communication systems to exceed those higher data rates. For example, the Synthetic Aperture Radar and Lidar instruments planned for the Deformation, Ecosystem Structure and Dynamics of Ice mission desire 2.0 Gbps through TDRSS, which SCRAM delivers, but other systems cannot. We can also provide 3.75 Gbps with a direct downlink.

For SCRAM development, CSW draws upon its extensive airborne military and space experience, as well as tens of millions of dollars in program investments from multiple DoD and classified customers, to perform component development and system integration.

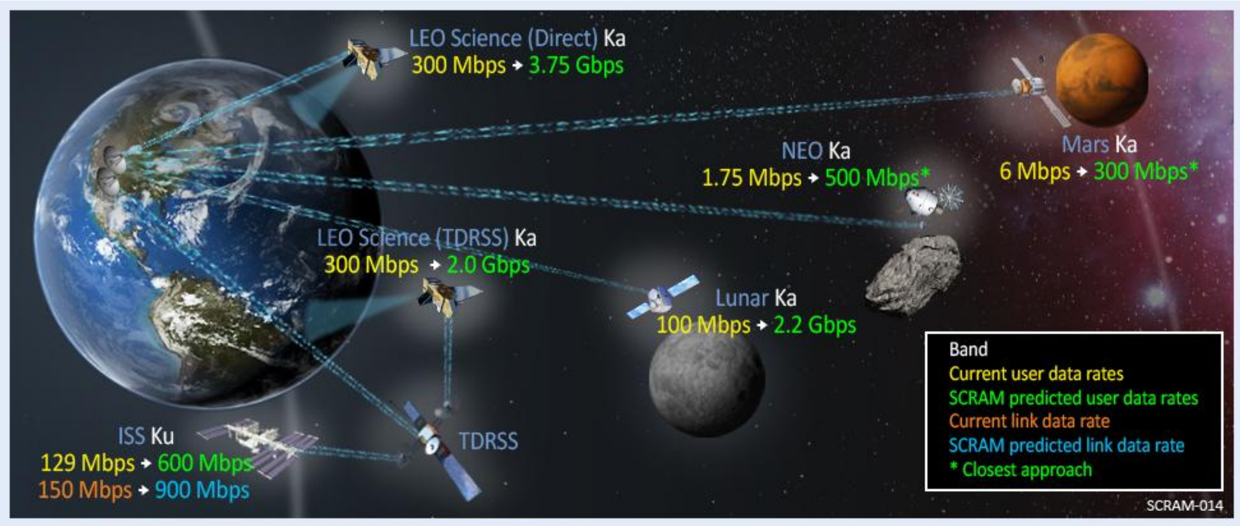


Figure 1. SCRAM Concept of Operations.

NASA receives orders of magnitude higher data rates with SCRAM.

Current state-of-the-art technology can be likened to a telephone internet connection with the existing data rates shown in Figure 1. Current technology operates in the analog domain with fixed data rates. SCRAM's technology offers the equivalent of fiber-optic capability. How are we advancing the state-of-the-art? We provide dial-a-rate capability to support multiple users and conditions allowing users to dynamically select their data rates to ensure optimal data return. We digitally pre-compensate for distortions and equalize the channel. We optimize for channel properties and hardware performance with programmable modulation. We provide forward error correction coding in accordance with channel, hardware, and data traffic. We enable multiple interface capability by handling data in the digital domain, allowing networking and abstraction of the physical layer between either optical or RF. We can also reconfigure the processor for different processing missions. All this translates to a communication system that is both scalable and compatible with legacy systems. SCRAM technology also reduces costs because higher data rates require less contact time with relay satellites or the limited number of direct downlink sites.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DESCRIPTION

SCRAM, shown in Figure 2, performs all operations in the digital domain. These techniques offer a digital communications core with benefits including constellation recovery through distortion compensation.

Another important feature is the implementation of high order modulation based on the international, commercial standard for Digital Video Broadcasting-Satellite, 2nd generation (DVB-S2). This offers NASA greater opportunity for interoperability with remote users, other government entities and system suppliers. High order modulation also offers more spectrally efficient communications for higher throughput, which is critical as frequency allocations become more constrained over time. While extending capabilities with the DVB-S2 standard, the SCRAM team is evaluating error correcting codes already developed by NASA such as the GSFC Low-Density Parity-Check (LDPC) 9/10, and Turbo Product Code (TPC) 7/8. These can be implemented via loads for the Field Programmable Gate Arrays (FPGAs) without any hardware modifications. Due to the digital architecture of the SCRAM system, SCRAM could also support both the optical science instruments and RF communications. This would provide tangible benefits in size, weight, and power trades and also allow for more intrinsic redundancy across systems.

Figure 2. SCRAM.
SCRAM exploits cutting-edge algorithms hosted on a robust hardware platform.

Fully exploiting the potential of Ka-band systems is important due to the significant demand placed on the SCaN Deep Space Network (DSN), TDRSS, and Near Earth Network (NEN). The SCRAM system provides NASA the capability to enhance service in all three SCaN networks.

Our team's approach to technology infusion for future NASA missions is inherent in the design of the SCRAM system itself. Its reprogrammable digital core provides waveform flexibility that can be expanded and upgraded to support a wide variety of communication needs (Mbps to Gbps) without having to redesign the hardware. The digital core design of SCRAM mitigates problems often encountered in analog circuits for phase lock loops, coherent down conversion, demodulation, and clock recovery. Simply put, no other software programmable system in the space industry has the flexibility that SCRAM offers for technology infusion.

The SCRAM architecture is also consistent with the objectives of the NASA Space Telecommunications Radio System (STRS) Architecture Standard in terms of modularity, commonality, and reusability. This development further matures the STRS by assessing the technology against the standard for areas of synergy and compliance.

2.2 KEY PERFORMANCE PARAMETERS

As shown in Table 1, each parameter identifies a threshold criteria used in evaluating performance throughout the program and a goal to define desired performance for the system.

Table 1. Key Performance Parameters.
Technical performance thresholds addressing NASA needs.

Key Performance Parameters		
Parameters	**Threshold Criteria**	**Goal**
1. Reprogrammable	Perform updates during testing	N/A
2. Dial-a-rate from Mbps to Gbps	Vary data rates between 250 Mbps and 2.0 Gbps	3.0 Gbps
3. Digital Pre-compensation	Demonstrate with and without pre-compensation	N/A
4. Bandwidth efficient modulation	QPSK up to 32-APSK, FEC: 7/8, 9/10	64-APSK
5. Multiple frequency capability	Intermediate frequency output = 4.8 GHz	N/A

2.3 KEY TECHNICAL PARAMETERS

As shown in Table 2, each parameter identifies a threshold criteria used in evaluating the program and a goal to define desired technical attributes for the system.

Table 2. Key Technical Parameters.
Technical thresholds addressing NASA needs.

Key Performance Parameters			
Parameters	**Threshold Criteria**		**Goal**
1. Launch/flight environments	Shock Breakpoints 100 Hz, 100 g 1.3 kHz, 2500 g 10 kHz, 2500 g	Vibration: 18.5 Grms for 60 sec	Envelope GEO launch opportunities
2. Power	< 100 W		<80W
3. Weight	6 kg		5 kg
4. Dimensions	20 cm x 20 cm x 13 cm		18 cm x 18 cm x 12 cm
5. Mission Duration	7 years		15 years
6. Reliability (using MIL-HDBK-217F N2)	R(t) > 90%		R(t) > 95%

2.4 TECHNICAL READINESS LEVEL

SCRAM leverages two existing TRL 5 systems. We derive the networking algorithms, command & control interface, space-qualified parts list, card layout, and mechanical design from the Air Force Research Laboratory (AFRL) Space Common Data Link (CDL) system. We draw the advanced digital firmware algorithms used in SCRAM directly from the AFRL SAFEGARD program. (See Figure 3).

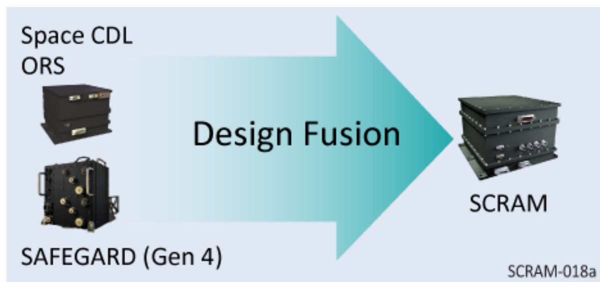


Figure 3. SCRAM Heritage.
SCRAM leverages two existing TRL 5 systems.

The Space CDL transmitter system has flown in LEO environments for TacSat 2, TacSat 3, and Operationally Responsive Space-1 (ORS-1). TacSat 2 exceeded its mission lifetime goal by a factor of 2. TacSat 3 launched in May 2009 as an experimental satellite and exceeded its mission life. It became an operational satellite in June 2010. ORS-1 was launched on June 29, 2011, and L-3's communication hardware has performed flawlessly.

The SAFEGARD system design is a modular and scalable general-purpose signal acquisition and processing engine developed for wideband military communication, Electronic Warfare (EW), and Signals Intelligence (SIGINT). SAFEGARD derives its heritage by evolving from three previous generations of communication technology, dating all the way back to the U-2 program.

The SCRAM software algorithms are matured and integrated with the hardware elements of the system. Prior to the start of the SCRAM program, the end-to-end software system has been demonstrated using hardware prototypes with existing systems and resulting test data has been analyzed to show agreement with predicted performance. Multiple demonstration events have been completed with portions of SCaN and the user community to establish confidence in the system capabilities, generate test data for link budget validation, and gather customer feedback on performance requirements.

2.5 TECHNOLOGY INFUSION APPROACH

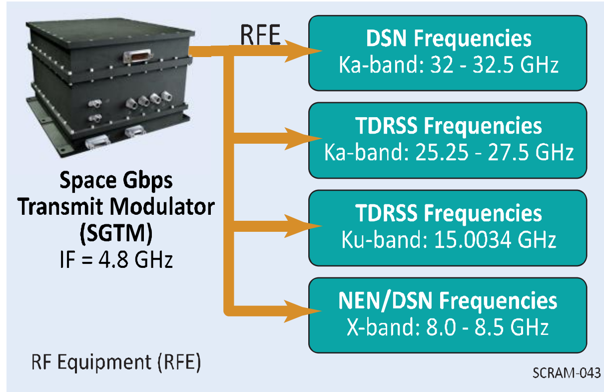


Figure 4. SCRAM Frequency Flexibility. *SCRAM supports all NASA SCaN mission networks with minor changes to the system.*

As mentioned, SCRAM's technology is based on merging the Space CDL hardware architecture and the SAFEGARD software algorithms. These architectures support a variety of DoD missions for the next decade. The SCRAM system will continue to benefit from common development platforms and software reuse with these other systems, thereby lowering costs and risk for all users. Component technology refreshes will also be deployed more quickly for airborne and tactical LEO users, further lowering risk for similar updates to the SCRAM system. As space-rated components continue to increase in capability and performance, the SCRAM system can implement data rates that already exist with the SAFEGARD program in the Gbps range. Finally, the projected markets for Space CDL, SAFEGARD/Gen 4 Hardware, and SCRAM alone approach $330M in the next few years. Therefore, as SCRAM enters commercial and government markets, it does so from a solid financial base, being able to leverage common component purchases and software development activities.

Figure 4 shows the ability of SCRAM to interface with different NASA network frequency bands with minimal modifications to only the RF equipment. This, in essence, allows NASA and other users to achieve lower cost and schedule risk for state-of-the-art communications technology with a common hardware platform that can support multiple future astronomy and science missions.

The reprogrammable nature of the SCRAM system also supports missions with long durations because improvements in modulation/Forward Error Correction (FEC) techniques or enhancements to ground infrastructure can be accommodated by new software uploads to the system. This provides cost-efficient use of critical NASA infrastructure and decreases the number of unique user configurations that must be maintained throughout the mission life.

3.0 DESCRIPTION OF HOW THE TECHNOLOGY FULFILLS THE GRAVITATIONAL-WAVE SCIENCE OBJECTIVES

As an enabling technology, SCRAM helps fulfill the gravitational-wave mission science objectives by providing the communication infrastructure for advanced sensors for NASA's astronomy missions. With Gbps data rates we enable multiple sensors to be placed on one satellite, providing lower overall NASA mission costs. For missions that do not require Gbps data rates, SCRAM technology provides new mission capabilities by enlarging the design trade space at the full system level by lowering the size, weight, power, cost and complexity of communication systems. Fundamentally, no NASA mission should ever be limited by communication hardware again.

4.0 COST

In a teleconference on Oct. 13, 2011, with Ruth Carter, Bruce Thai Pham, and Gerard Daelemans of the Physics of the Cosmos (PCOS) Program, we were advised not to submit costs for a similar RFI response (RFI NNH11ZDA018L), and have not included them here either. We are, however, willing to discuss costs in the future at the appropriate time.

5.0 SCHEDULE

The program Integrated Master Schedule (IMS) shows a rapid demonstration of SCRAM (see Figure 5). ORS-1 and TacSat 2 and 3 were successfully executed in a shorter timeframe. Major milestones, demonstration activities, and data package deliveries are consistent with NASA milestone review processes. Our critical path analysis necessitated hardware procurement to start in the Base Period. Hardware procurement starts at the onset of the program and provides a two month slack in the critical path and adequate review of hardware options to be procured. An additional two months of slack exists after the lab test prior to Option 2's final report. A detailed Microsoft Project schedule is available to NASA, but is not included due to space considerations.

This 36-month notional schedule was developed for a NASA Office of the Chief Technologist (OCT) proposal and included demonstration testing, but can be shortened to 30 months upon authority to proceed.

6.0 RELATED EXPERIENCE

NASA is assured success from a reliable team delivering proven experience developing and qualifying space communication systems with reduced cost, time, and risk.

6.1 DEMONSTRATIONS AND TESTS

We have performed three demonstrations in the last year-and-a-half which showcase our technology's performance:

GSFC/WSC Demonstration through TDRS F10 (2 Gbps) – April 2010

In April 2010, NASA GSFC and CSW demonstrated 1.6 Gbps with 8-Phase Shift Keying (PSK) and 2.0 Gbps with 16-Amplitude Phase Shift Keying (APSK) transmissions over the TDRSS Ka-band with no errors utilizing both a Modem Emulator Breadboard (MEB) and prototype receiver hardware. Performance at 2 Gbps was near theory and the test data also showed very close correlation between the MEB and physical hardware. The MEB consists of a suite of test equipment that hosts the SCRAM software algorithms and provides added flexibility in rapidly testing combinations of new modulation schemes, FEC codes and data rates. The TDRSS K-band Single Access Return Upgrade Project (TKUP) was a previous demonstration effort to enhance system performance that reliably performed only at about 1 Gbps using Offset-Quadrature PSK (O-QPSK) compared to CSW performance which was 2 dB better.

GRC TWTA in CSW Lab Capability Test – July 2010

Experiments with a Deep Space Network (DSN) frequency band Traveling Wave Tube Amplifier (TWTA) and the CSW MEB in a laboratory setting recorded data rates up through 20.0 Gbps using greater than 3.0 GHz of bandwidth and a 128 Quadrature Amplitude Modulation (QAM) as a demonstration of the future capabilities of the system. Future planned increases in component processing power will allow SCRAM to achieve these and higher rates.

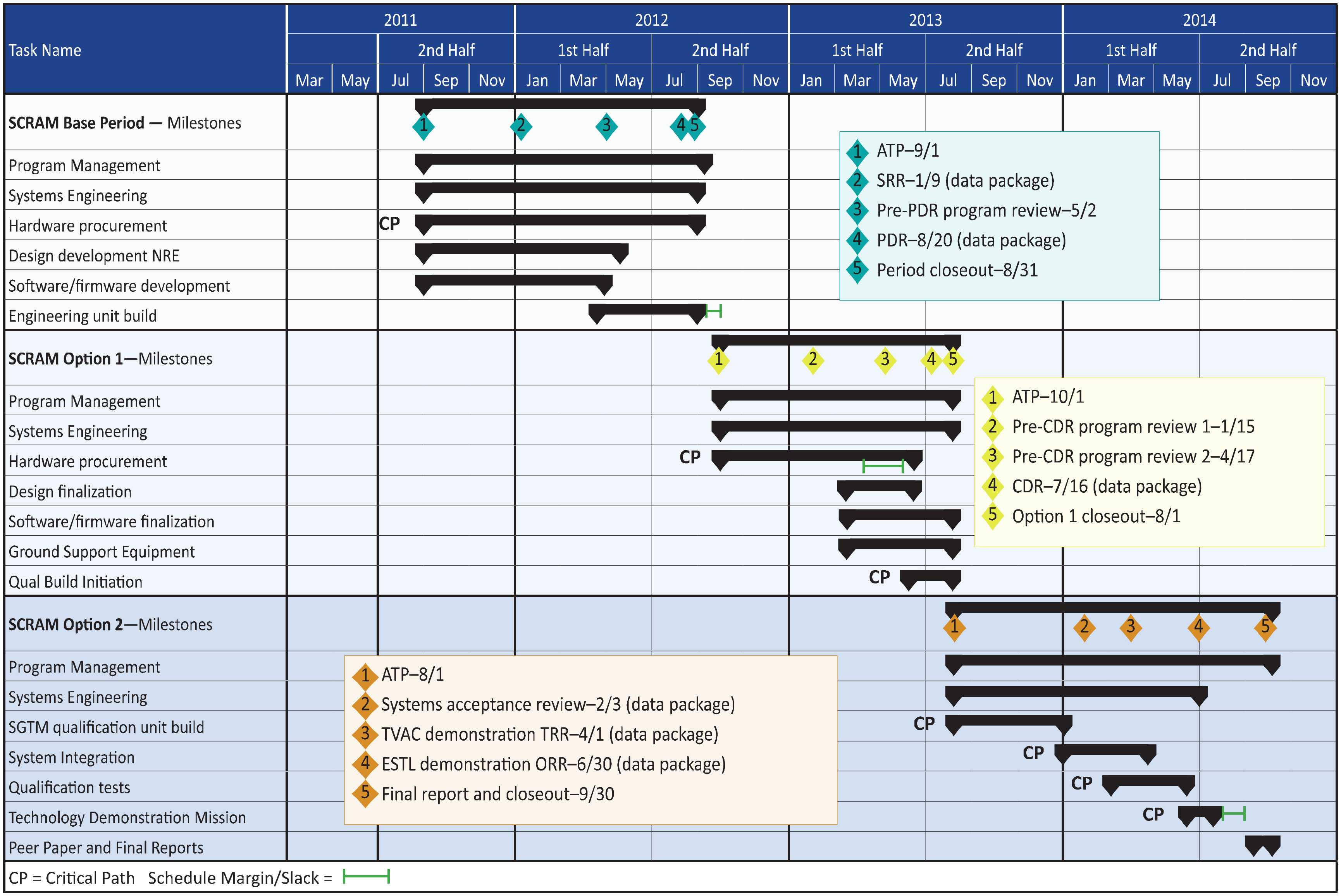


Figure 5. Integrated Master Schedule.

NASA receives hardware ready to fly within 3 years.

TDRS-K Testing in Boeing El Segundo – July/August 2011

Starting in July 2011, L-3 conducted two weeks of testing with the TDRS-K Payload Testbed using a combination of NASA standard waveforms, repeating portions of the April 2010 test cases, and new waveforms using the DVB-S2 standard mentioned earlier. The MEB was used for this test and demonstrated a peak data rate of 3.4 Gbps through the TDRSS Ka-band wideband channel.

6.2 PAST PERFORMANCE

L-3, on multiple occasions, has demonstrated reliable performance delivering program success. Recent space-related programs are listed below in Tables 3–5. For these programs we demonstrate our ability to manage under budget and either ahead of schedule or on schedule, thereby reducing customer risk.

Table 3. CSW Past Performance ORS-1.

CSW delivered ORS-1 space hardware under budget and on schedule.

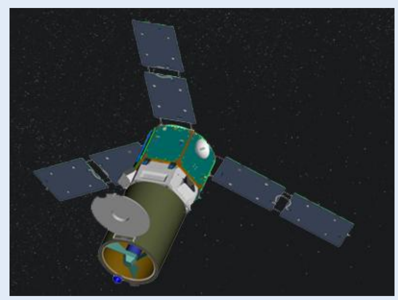
Program Information	Project Description	Relevance
Customer POC: Government Contract Officer Carla Clark 560 ACSG/GFKAA 235 Byron St Suite 19A Robins AFB, GA 31098-1670 Phone: (478) 926-8386 Carla.Clark@robins.af.mil **Cost Performance:** Delivered under budget **Schedule Performance:** Delivered on schedule	Development of a space-qualified communi-cations payload for the Operational Responsive Space-1 (ORS-1) spacecraft designed to test and demonstrate the rapid development and qualification of militarily relevant spacecraft within operationally responsive timelines.	CSW delivered a space-qualified communication system under budget and on-schedule. 

Table 4. CSW Past Performance—TacSat 2.
CSW developed TacSat 2 communication hardware for space.

Program Information	Project Description	Relevance
Customer POC: Mr. Russ Dewey Technology Service Corporation 1975 Research Parkway, Suite 310 Colorado Springs, CO 80920 Phone: (719) 884-0224 X354 Fax: (719) 884-0235 **Cost Performance:** Delivered under budget **Schedule Performance:** Delivered ahead of schedule	Development of the communications payload for the TacSat 2 spacecraft designed to test and demonstrate the rapid development and qualification of militarily relevant spacecraft within operationally responsive timelines.	CSW delivered airborne communication system hardware, upgraded for space applications, under budget and ahead of schedule. TacSat 2 communications payload exceeded mission lifetime goal by a factor of 2. 

Table 5. CSW Past Performance—TacSat 3.
CSW delivered reliable space communication hardware to TacSat 3.

Program Information	Project Description	Relevance
Customer POC: Government Contract Officer Ms. Dawn M. Ross AFRL / PKDA DARPA Division R&D Contracting Directorate Wright-Patterson AFB, OH 45433 Phone: (937) 255-5186 Fax: (937) 255-8100 **Cost Performance:** Delivered under budget **Schedule Performance:** Delivered ahead of schedule	Development of the communications payload for the TacSat 3 spacecraft designed to test and demonstrate the rapid development and qualification of militarily relevant spacecraft within operationally responsive timelines.	CSW delivered airborne communication system hardware, upgraded for space applications, under budget and ahead of schedule. TacSat 3 communications payload has doubled its mission lifetime goal by a factor of 2 and continues to operate today.