Advanced Space and Ground Networks Work Area
GSFC/SOMO Technology Development Program
Annual Review

TDRSS Demand Access F/L Development Task

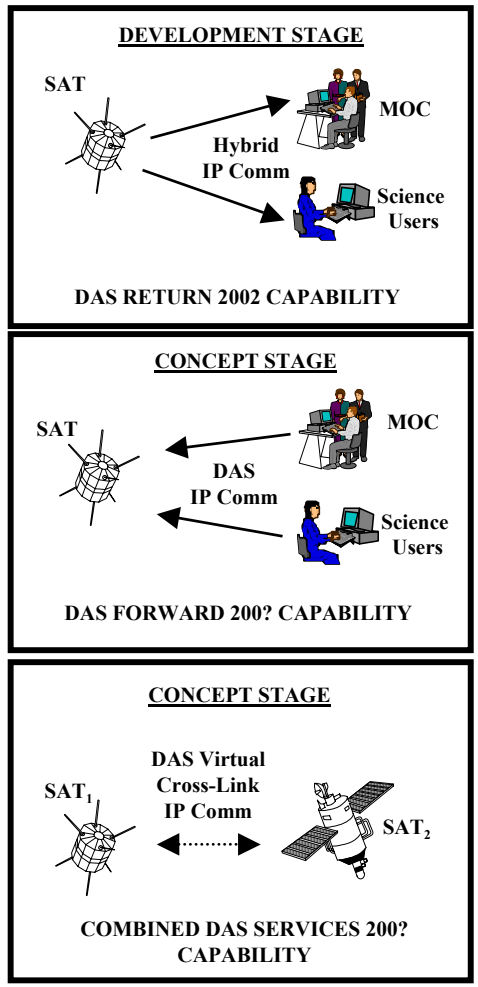
Task 5633

September 19, 2001

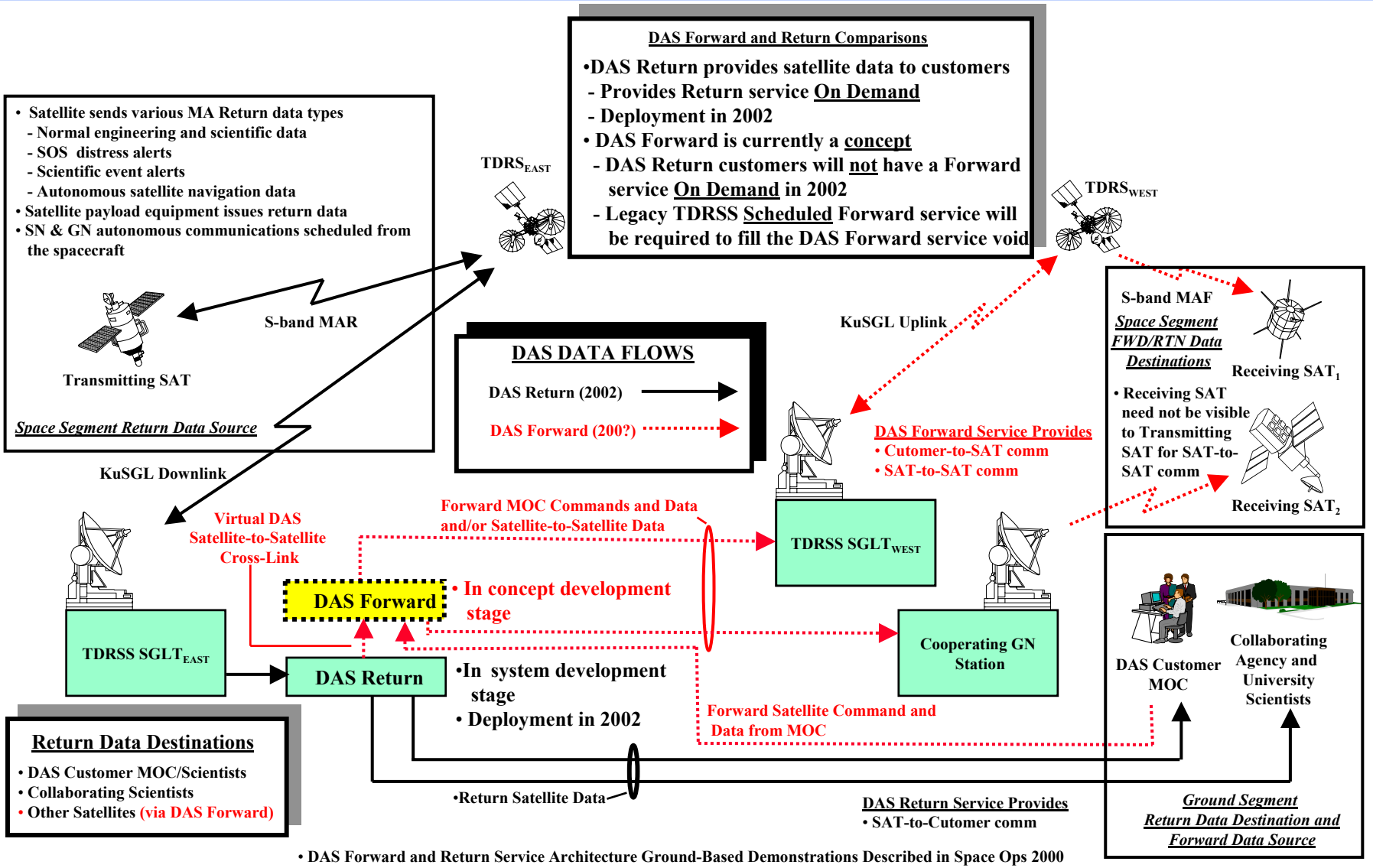
Dave Israel/Code 567

Overview of Task Objectives

- **High-Level Task Objective**
  - Build on the ongoing DAS Return Service development (GSFC Code 450) by extending it to include a DAS Forward Service capability, Internet Protocol (IP) addressing, and bi-directional support for customer-to-spacecraft or spacecraft-to-spacecraft communications
- **Detailed Task Objectives**
  - Develop detailed operations concepts for the proposed Demand Access System (DAS) Forward Service within the context TDRS/DAS Architecture issues
  - Develop detailed bi-directional IP Space Network End-to-End Communications operations concepts founded on a DAS Forward and Return TDRSS infrastructure
    - » Develop detailed DAS bi-directional end-to-end space network-to-ground network IP Routing operations concepts based on GSFC OMNI Project (Code 588) IP in Space Information Database
    - » Develop spacecraft-to-spacecraft IP network virtual cross-link operations concepts leveraged from the DAS Forward and Return synergism using either mobile routing or DAS orbit prediction capabilites
  - Develop DAS Forward and Return IP Network Demonstration Plans

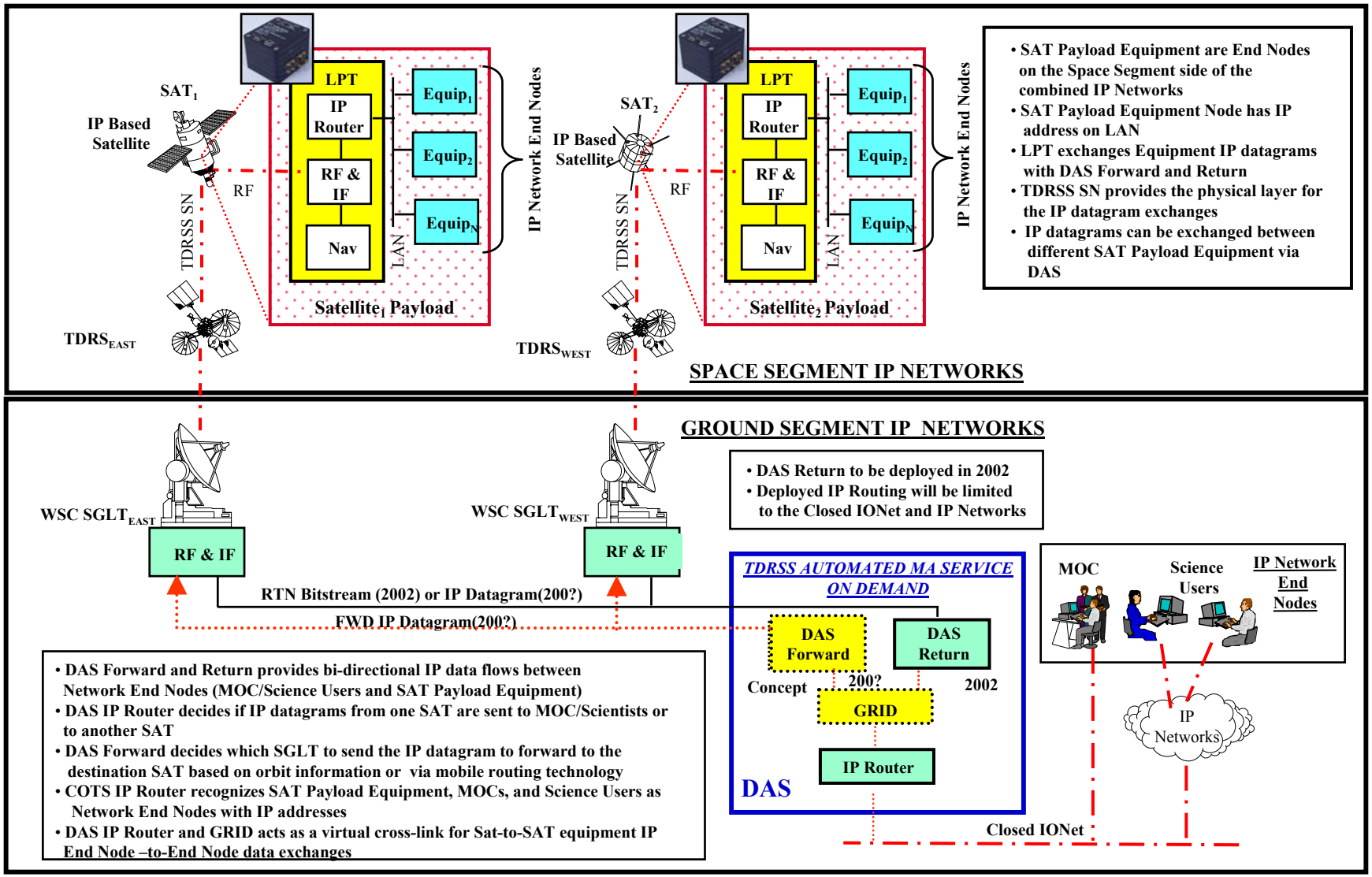


TDRSS Demand Access System (DAS) Forward and Return Service Architecture and Operations Concept Overview



• DAS Forward and Return Service Architecture Ground-Based Demonstrations Described in Space Ops 2000 Paper Entitled " Satellite Networking & Messaging in Support of Earth Science Constellation"

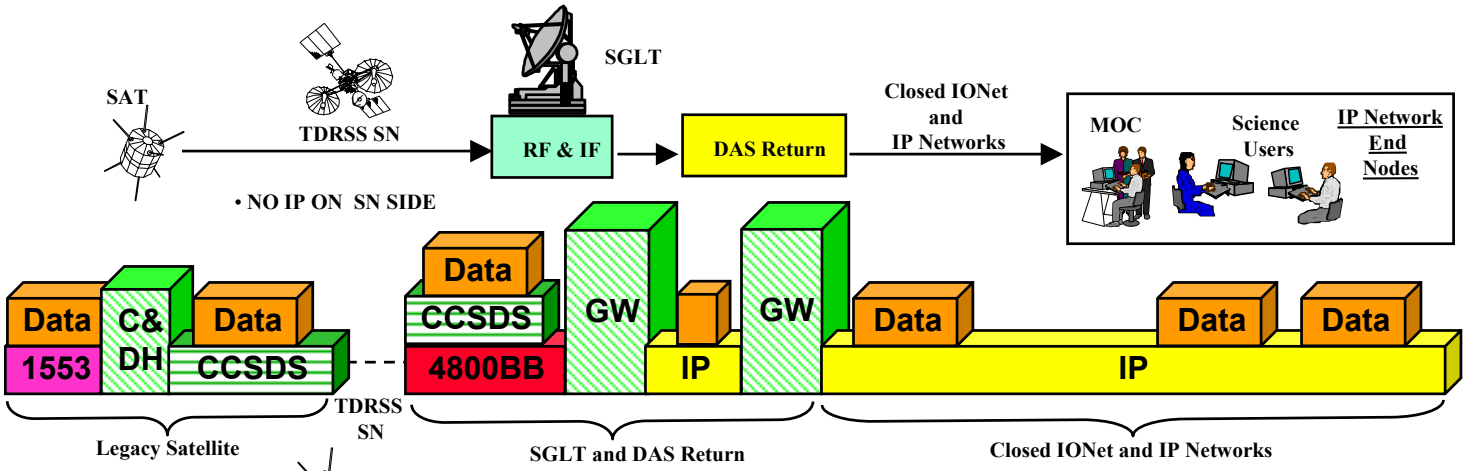
DAS IP Space Network End-to-End Communications Concept Overview



End-to-End DAS IP Network Objectives

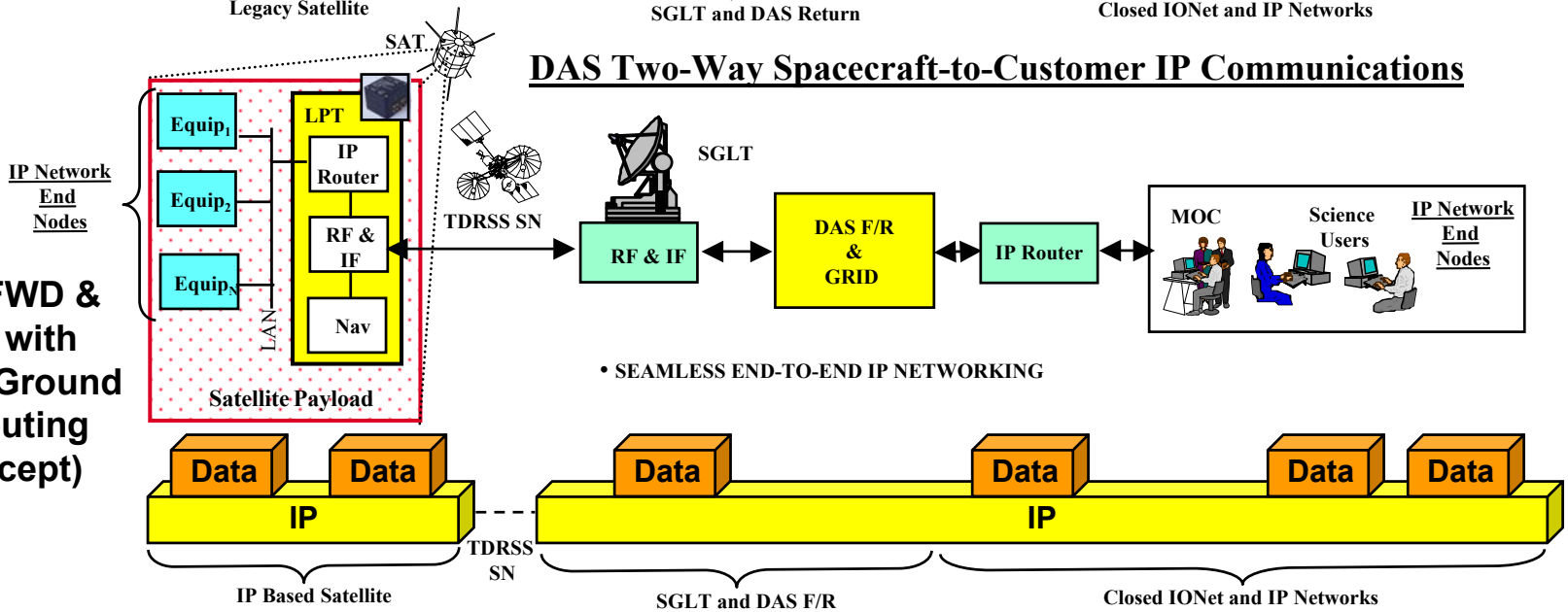
DAS One-Way Return Spacecraft-to-Customer Hybrid Bit Stream & IP Communications

DAS Return with Ground IP Routing (2002)



DAS Two-Way Spacecraft-to-Customer IP Communications

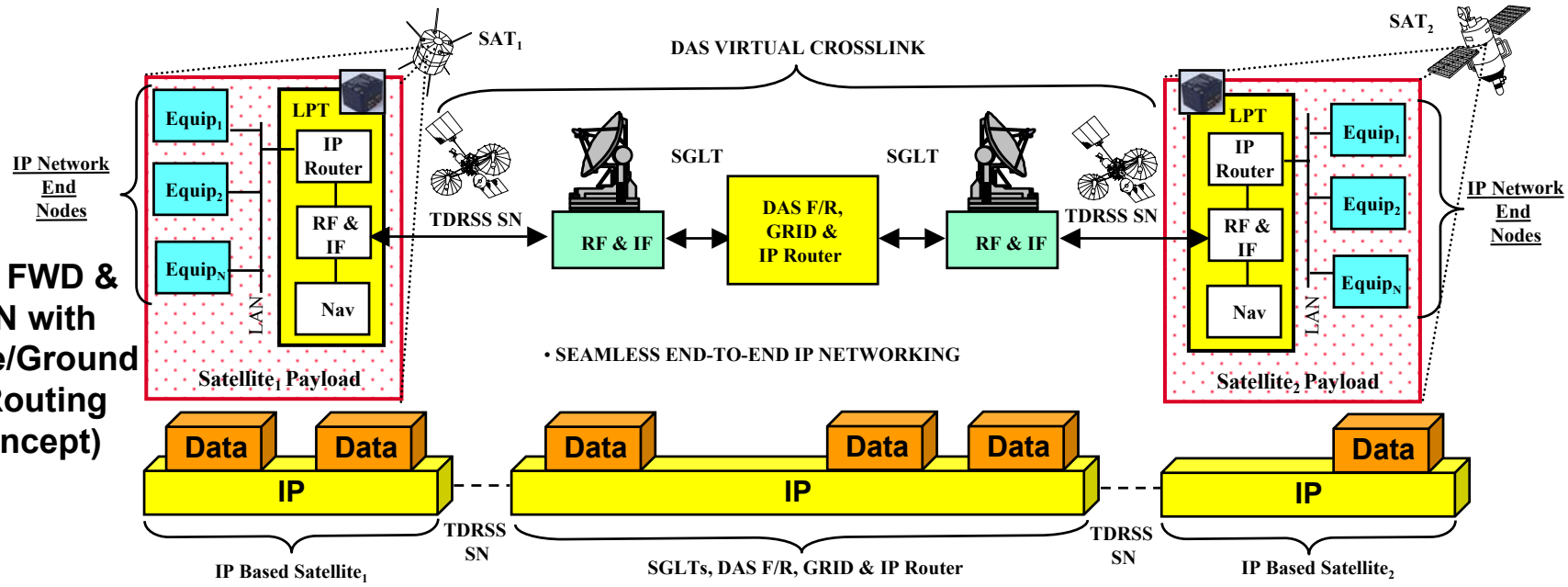
DAS FWD & RTN with Space/Ground IP Routing (Concept)



End-to-End DAS IP Network Objectives (Continued)

DAS Two-Way Spacecraft-to-Spacecraft Virtual Cross-Link IP Communications

DAS FWD & RTN with Space/Ground IP Routing (Concept)



Task Work Overview

- **Task Funding Provided in June 2001**
- **Task Work Completed since June 2001**
  - **Worked on Draft Version of DAS Forward Link (F/L) and Internet Protocol (IP) Operations Concepts Document**
- **Task Work to be Completed by September 2001**
  - **Draft Version of DAS Forward Link (F/L) and Internet Protocol (IP) Operations Concepts Document**

Low Power Transceiver Development Program

Schedule

Task	FY01				FY02				FY03			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
• DAS F/L and IP Operations Concept Document					Draft			Final				
• DAS F/L Feasibility Demonstration								Demonstration				
• DAS Requirements Analysis Document							Draft				Final	
• DAS F/L and IP Networking Development (conducted under separate tasking)									Development Initiated			

Advanced Space and Ground Networks Work Area
GSFC/SOMO Technology Development Program
Annual Review

Low Power Transceiver

September 19, 2001

David Israel/Code 567.3

Overview

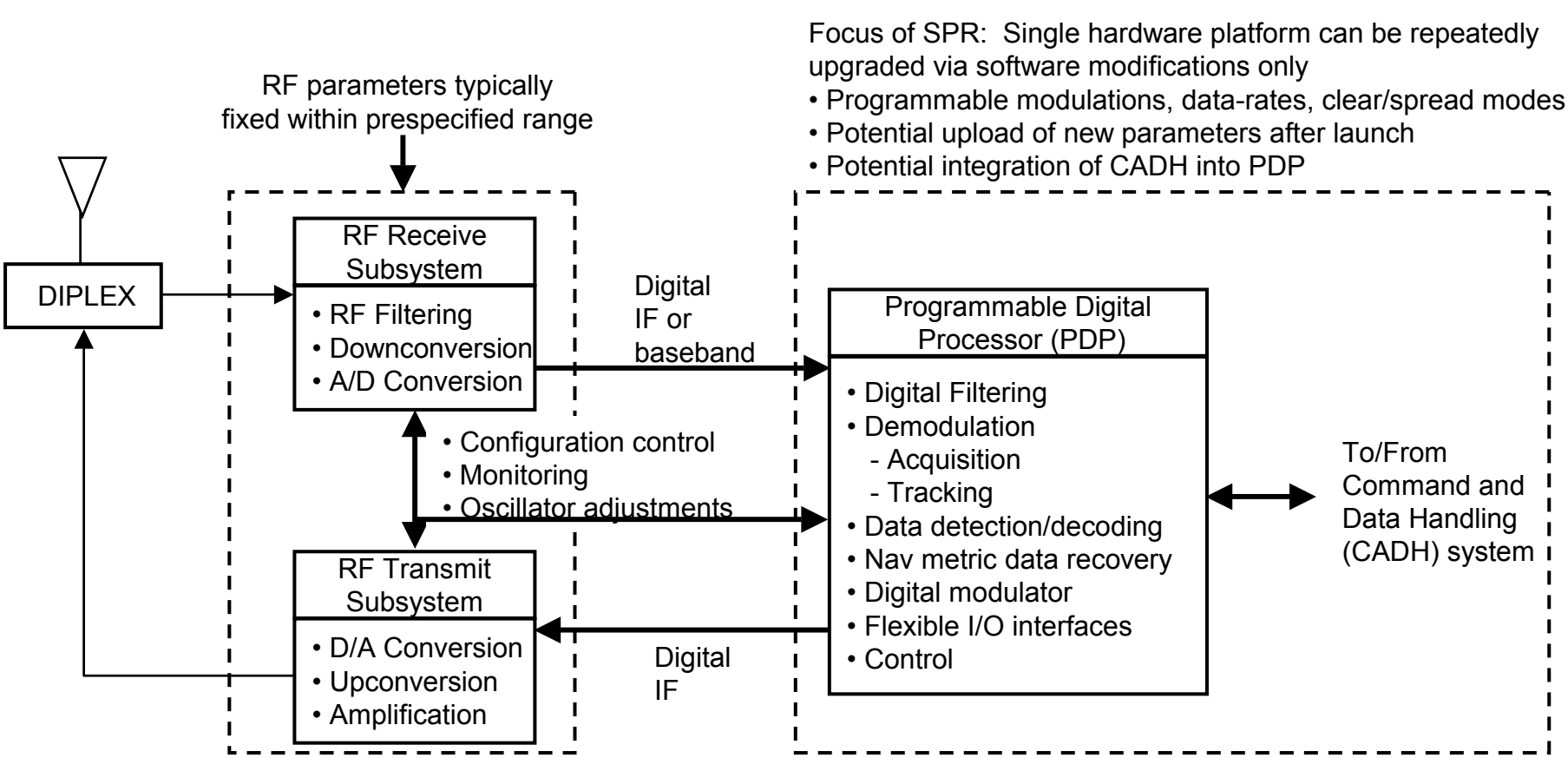
- The Low Power Transceiver (LPT), under development via the GSFC/SOMO technology program and ITT internal IR&D, represents an enabling technology for emerging, cost-effective space operations.
- The Low Power Transceiver is a collection of interchangeable hardware modules that form a software programmable platform for a variety of general purpose or specialized communication and navigation applications
  - Simultaneously process multiple RF bands in the TX or RX direction
  - Simultaneously process multiple data channels within each RF band
  - Utilize a modular architecture to provide a flexible arrangement of signal processing resources

Overview (Cont'd)

- **Goals of this program include:**
  - **Application across air, launch, and space missions**
  - **Use as an enabling technology for new/evolving mission profiles (e.g., crosslinks for formation flyers, integrated com/nav/control/ for micro satellites, etc.)**
  - **On orbit reprogrammability for mission extension/adaptation (e.g., adoption of modernized GPS waveforms when they become operational)**
  - **Use as a science data collector (e.g., Occultation)**
  - **Support of IP in space**
  - **Low power consumption, a small form factor and reduced mass as compared with legacy technology**
  - **Affordability by offering a solution that builds on open architectures, uses common modules, is scalable, has higher production volumes due to a wider range of applicability**
- **The LPT is evolving through a series of development steps to meet the needs of numerous users and missions**

Software Programmable Radio Overview

NASA/GSFC has been advancing Software Programmable Radio (SPR) technology, tailored to NASA needs, since the late 1980's



Architecture

- The LPT hardware is assembled by stacking modules to form a rigid structure
- Industry standard (PC/104) and proprietary data busses facilitate intra-module interaction
- Evolution of the LPT program is producing “generations” of the hardware platform
- The development program is geared towards expanding capability and capacity while simultaneously improving efficiency in size, weight and power
- As a result, subsequent generations may be applied to solve increasingly complicated communications and/or navigation problems
- Each new generation is an “enabler” for a new objective or operations requirement
  - 1st Gen: First to integrate the functions of communication and navigation, enabling new operations concepts including space-based range safety
  - 2nd Gen: Expanded RF and data channel capacity enables sophisticated inter- and intra-formation communication and navigation concepts for formation flying; further integrates signal processing to include advanced phased array beamforming and multi-user detection
  - 3rd Gen: Expanded programmable resources make it possible to move DSP into FPGA; enables migration to fault-tolerant hardware and software for space missions; significantly increases RF channel density.

The LPT Technology Development Program

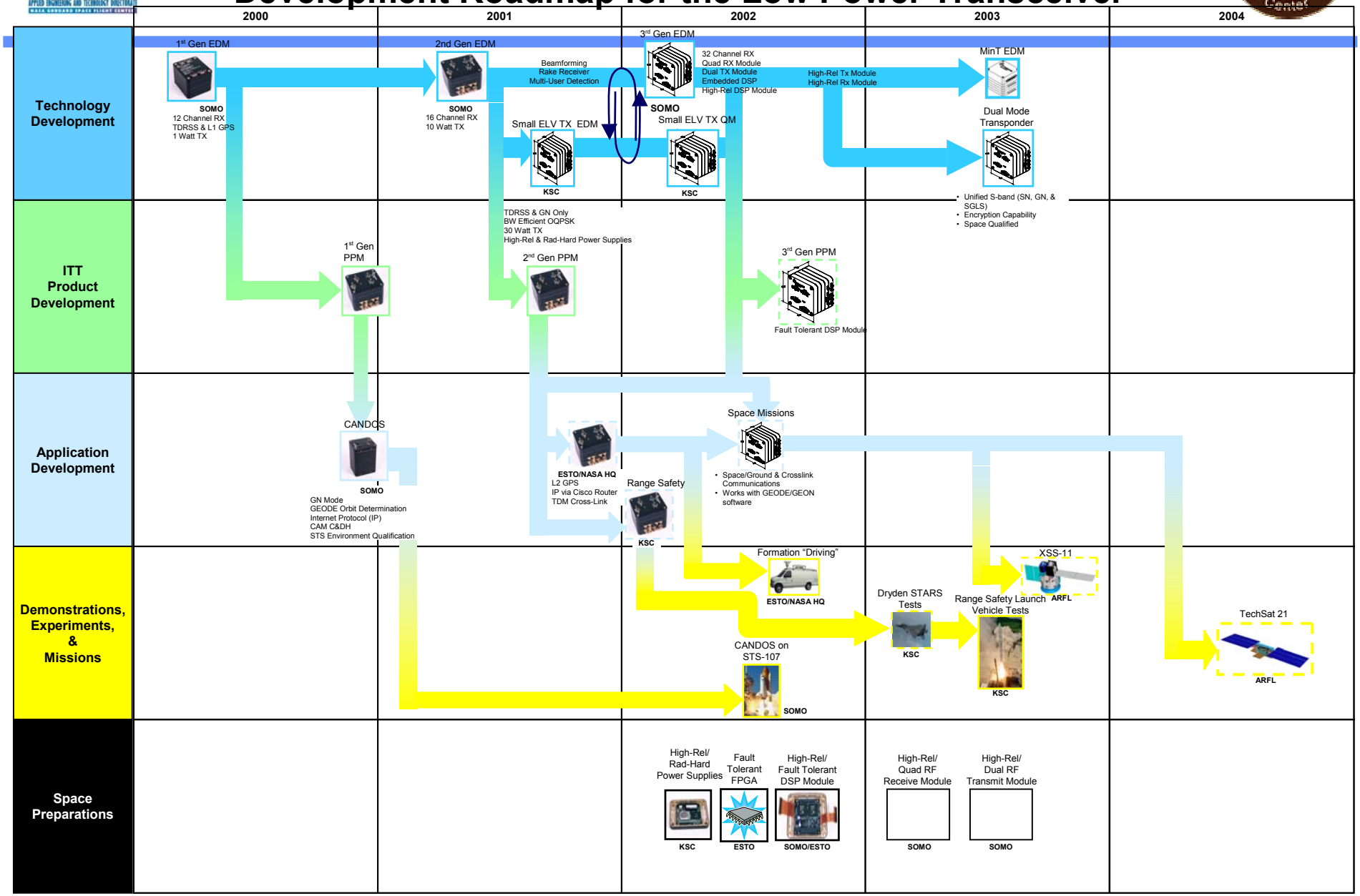
- **Low Power Transceiver Technology Development Effort**
  - Funded by SOMO (through GSFC) and ITT Industries
  - Develop the "Core" LPT modules and TDRSS/GN/GPS functionality
    - » 1st Gen EDM hardware
    - » 2nd Gen EDM hardware
    - » 3rd Gen EDM hardware (Quad RX, Integrated TX/Dual RX, and DSP modules)
    - » Beamforming, MUD, rake signal processing
  - This activity has spawned numerous LPT-based initiatives and created opportunities for experimentation, demonstration, and support of space missions
- **Low Power Transceiver Product Development**
  - Funded entirely by ITT Industries
  - Advancing EDMs to producable products
    - » 1st Gen HW has now been productized
    - » 2nd Gen HW is in process
  - ITT-owned LPTs are being used to support demonstration and experimentation activities

The LPT Technology Development Program (Cont'd)

- **Small ELV Transmitter**
  - **Funded by the ELV Projects Office at KSC through GSFC**
  - **Goal is to develop a small, highly efficient S-Band TDRSS/GN transmitter for use on smaller launch vehicles**
  - **Developing efficient transmitter hardware and firmware**
    - » **3rd Gen TX module**
    - » **High-rel power supplies and I/O modules**
    - » **30 Watt S-Band HPA module**
    - » **New constant-envelope, bandwidth efficient modulation technique that maximizes efficiency of the HPA**
      - *Little or no impact to existing ground station receiver performance*
      - *Baseband filtered OQPSK waveform*
  - **Excellent example of synergy between parallel development efforts**
    - » **LPT Technology Effort is developing the DSP module that will be used in this program**
    - » **All modules and firmware developed under this program will be rolled back into the LPT program**
  - **Development effort will provide mechanism to qualify 3rd Gen LPT modules for use in extreme environmental conditions found on launch vehicles**

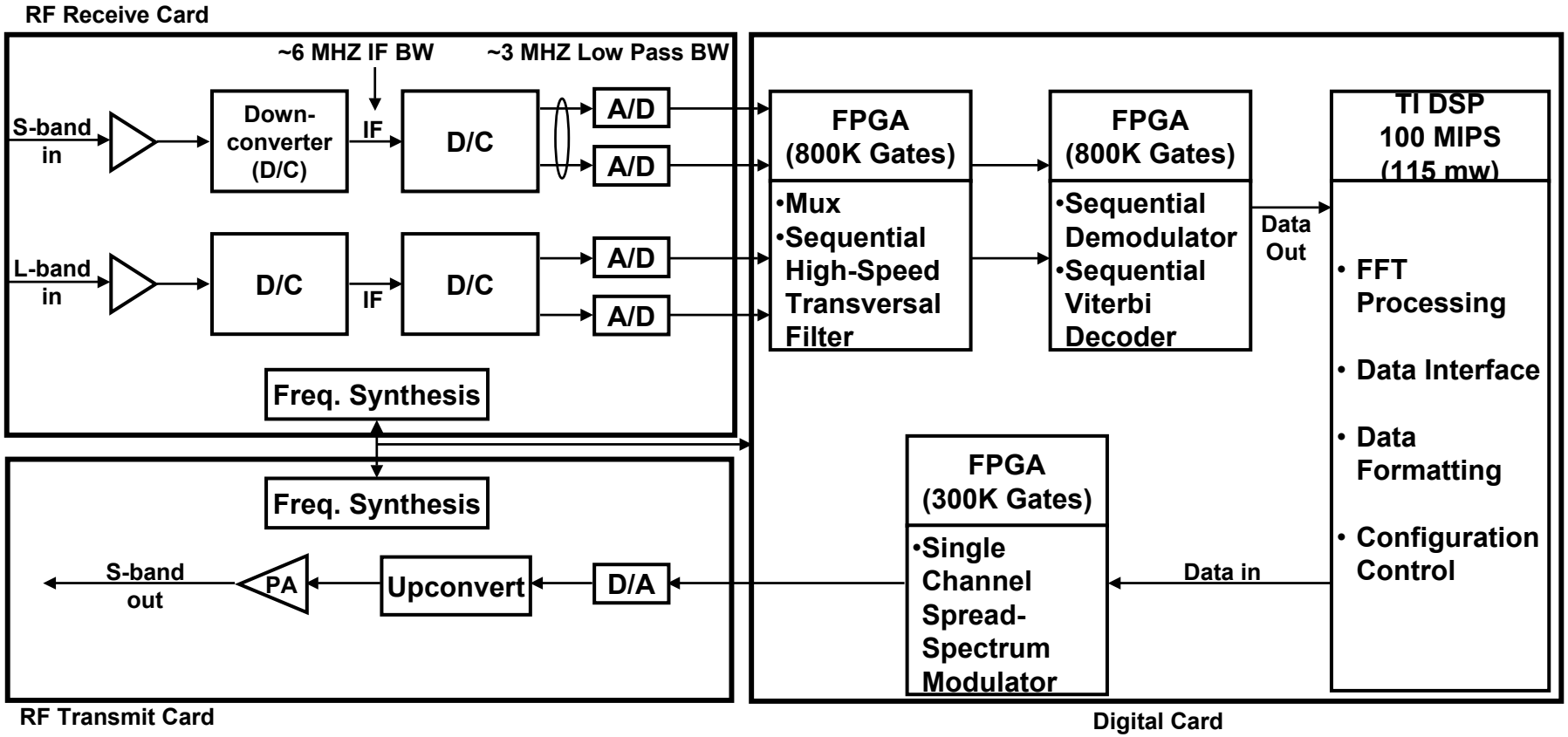
Low Power Transceiver Development Program

Development Roadmap for the Low Power Transceiver



Low Power Transceiver Development Program

1st Generation LPT Architecture



Weight: 4 kg; Power consumption (without PA): 7.5 watts; 1 watt PA: 5 watts DC

1st Generation LPT Summary

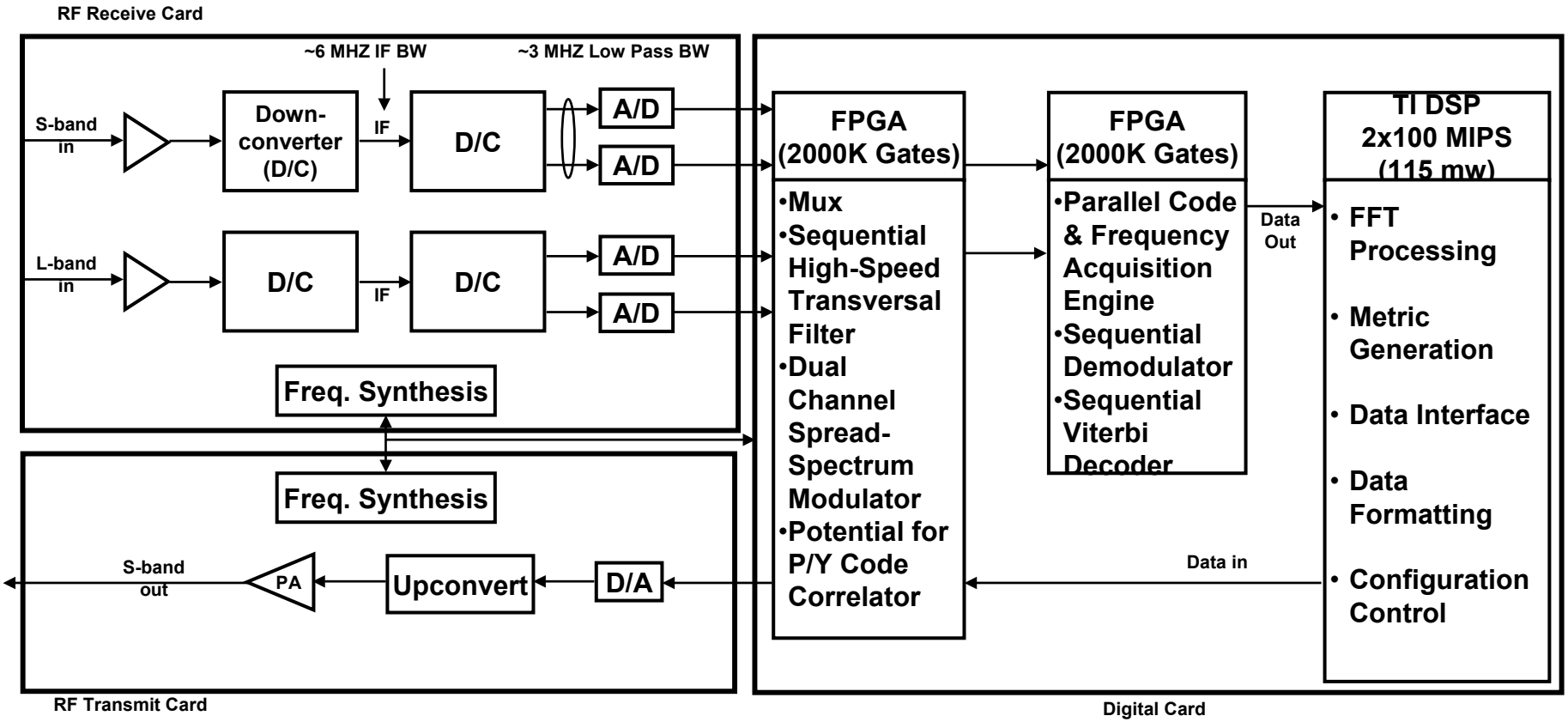
- Two 1st Generation EDM units developed, integrated and demonstrated
  - March 2000 demo operated full-duplex 64 kbps data link via TDRSS to surf the World Wide Web while simultaneously receiving 6-8 GPS signals
  - Many (>10) similar demonstrations since that date have been provided for representatives of NASA and other Government agencies
  - Power consumption is approximately 8 watts for the 12-channel receiver only, 12 watts including the 1-watt transmitter
- Two 1st Generation Pre-Production units developed and integrated
- One of the pre-production units will fly aboard STS-107 as part of the CANDOS mission

1st Generation LPT Summary (Cont'd)

- **Communication And Navigation Demonstration On Shuttle (CANDOS)**
  - **Funded jointly by SOMO through GSFC and ITT Industries**
    - » **ITT providing the "core" 1st Gen HW and SW**
    - » **SOMO funding the development of add-on modules, C&DH and integration with GEON orbit determination software (supplied by GSFC)**
    - » **SOMO funding experiment definition, integration with Hitchhiker and operations**
  - **Currently scheduled to launch in Summer 2002, will demonstrate short-duration space operations of the LPT including:**
    - » **Multiple, simultaneous communications links via the SN (TDRSS) and the GN**
    - » **Use of the Internet Protocol (IP) to control and monitor the experiment**
    - » **8 channels of GPS signal processing and GEON for autonomous orbit determination**
    - » **On-orbit reconfiguration**
    - » **Expanded operating temperature (-30C to +75C)**

Low Power Transceiver Development Program

2nd Generation LPT Architecture



Weight: 2 kg; Power consumption (without PA): 5 watts; 1 watt PA: 5 watts DC

2nd Generation LPT Summary

- The 2nd Generation LPT is the latest LPT hardware platform version
- The 2nd Generation LPT firmware application is capable of processing up to 16 receive data channels from up to four RF receive bands and two transmit data channels through up to two RF transmit bands
- S-Band communication modes include TDRSS and GN
  - Rapid acquisition CDMA (TDRSS DG1 Mode 2)
  - BPSK, QPSK, OQPSK
  - PM with optional subcarrier
  - Up to 4 Mbps/channel TX, 1 Mbps/channel RX
  - Rate ½ convolutional encoding and decoding (all TX channels, up to 4 RX channels)
- L1 GPS based navigation
  - Code and carrier phase measurements
  - 1 PPS output
  - <1m accuracy in static environment (excluding atmospheric affects)
  - Operates from earth to orbit
  - Time to first fix is approximately 3 minutes from cold start, whether stationary or in LEO orbit
- First demonstration of the Engineering Model was held in May 2001

2nd Generation LPT Summary (Cont'd)

- Communications modes being expanded to include a formation flying crosslink capability
  - ISM Band (2448 MHz)
  - TDD/CDMA modulation and multiple-access scheme
- Protocol support being integrated into LPT by adding a COTS Cisco router
  - Enables operation of IP over TDRSS, GN or crosslink communication channels
  - Router provides a 4 port hub for local area network (LAN) connectivity
  - Latest Cisco OS provides for Mobile IP as required by moving vehicles (e.g. spacecraft)
- Navigation mode being augmented to include L2 GPS capability
- Signal processing is being augmented to support multiple user environments
  - Phased array beamforming to simplify antenna design, maximize gain, and provide spatial filtering from sources of interference (nulling)
  - Multi-user detection to provide mitigation for co-channel interference
  - Rake receiver to provide mitigation/gain from self-interference in multipath environment
  - All are applicable to both communication and navigation modes

2nd Generation LPT Summary (Cont'd)

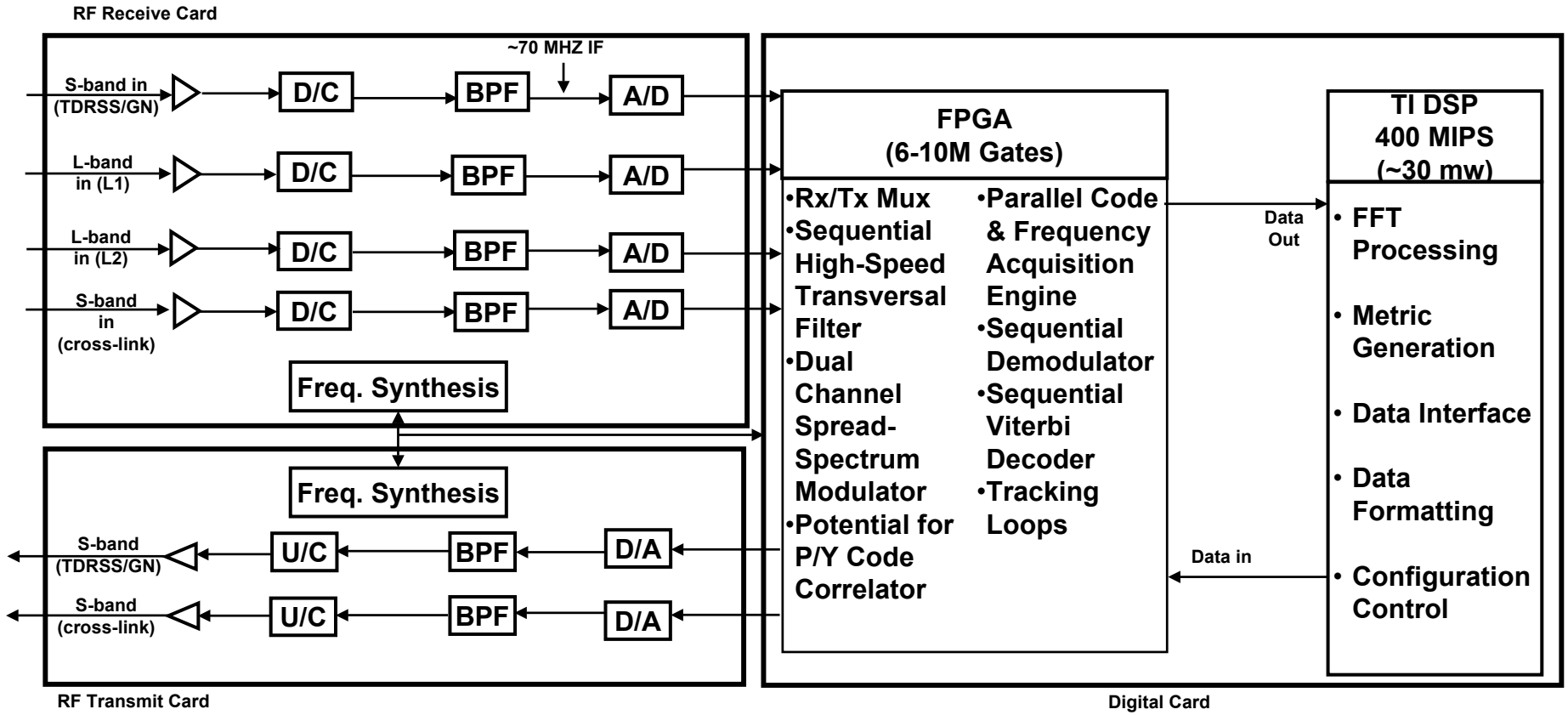
- **2nd Generation LPT Augmentation Effort**
  - **Funded jointly by the Earth Science Technology Office (ESTO) and NASA HQ**
  - **Expanding the application baseline of the LPT**
    - » **L2 civilian code capability, augmented with solution software that compensates for atmospheric effects**
    - » **CDMA/TDD S-Band formation flying crosslink capability**
    - » **Internet Protocol (IP) capability via integration of a COTS Cisco router**
  - **All existing and new capabilities will be demonstrated as part of a "formation driving" demonstration designed to simulate intra-cluster dynamics**
    - » **Demonstrate IP communications between cluster members via crosslinks and over TDRSS links**
    - » **Improved GPS solution accuracy**
  - **Two 2nd Generation LPT units will be delivered for use in additional demonstrations and/or test beds**

Demonstrations, Experiments, and Missions

- Numerous static demonstrations have been conducted that demonstrate the basic capabilities of simultaneous communications and navigation using the LPT
- CANDOS experiment on STS-107, Summer 2002
- Formation Driving Demonstration, planned for 1st quarter GFY 2002
- Range Safety Technology Demonstration
  - Procure one 2nd generation LPT
  - Install LPT on high performance subsonic and supersonic jet aircraft
  - Demonstrate simultaneous command destruct links from ground and TDRS
  - Demonstrate GPS position accuracy
  - Effort is currently in the planning stage
  - First tests may be conducted as early as 4th quarter GFY 2002
  - Intent is to gradually prove Space-Based Range Safety concept on increasingly dynamic/harsh platforms, culminating in launch vehicle testing
- LPT is currently a candidate for:
  - XSS-11 (AFRL)
  - TechSat 21 (AFRL)

Low Power Transceiver Development Program

3rd Generation LPT Architecture



Weight: 2 kg; Power consumption (without PA): 4 watts; each 1 watt PA: 4 watts DC

3rd Generation LPT Summary

- 3rd generation LPT development is currently focused on advancements in the hardware
- RF channel density is being condensed such that a single TX chain and two RX chains will fit into a single module
  - Also allows for a quad receiver module and a dual transmitter module
- Significant steps are being made to advance the LPT from industrial grade to high reliability grade (MIL-STD-883E)
  - Power supplies will be fully high-rel, Class B
  - EDMs for all new RF modules are moving to components with a more direct path to high-rel parts
  - Digital module will be high-rel as required by the emerging Class N (plastic parts) or better
- High reliability is a subset of the requirements needed to claim suitability for long term space operation
- Significant steps are being made to advance the LPT to a radiation tolerant device
  - Power supplies will be rad hard
  - EDMs for all new RF modules are replacing many of the sucseptible parts with parts from families that contain rad-hard equivalents
  - Digital module is being designed to be fault tolerant

3rd Generation LPT Summary (Cont'd)

- **Fault Tolerant LPT Development Effort**
  - **Funded entirely by ESTO via the AIST program**
  - **Goal is to develop fault tolerant FPGAs for use in LPT that are suitable for the emerging sensor web**
    - » **Analyze the radiation environments of future missions that require LPT's capabilities**
    - » **Develop a methodology for developing fault tolerant VHDL**
    - » **Migrate existing LPT FPGA VHDL into fault tolerant versions**
    - » **Develop a test fixture capable of hosting and evaluating the fault tolerant FPGAs**
    - » **Test the design in a radiation facility**
  - **Intent is to maximize program efficiency and leverage on-going LPT technology program for the mutual benefit of both activities**
  - **The development of the 3rd Gen fault tolerant DSP module under the LPT Technology Effort will be mated with the fault tolerant FPGAs developed under this program**

Low Power Transceiver Development Program Accomplishments / Plans

- Delivered 1st Generation LPT Preproduction Model to Hitchhiker for integration
- Demonstrated 2nd Generation LPT Engineering Model in May, 2001
- Proceeded with upgrades of signal processing algorithms and capabilities
- Proceeded with development of the 3rd Generation LPT (Radiation Tolerant; Space Qualification)
- LPT is under consideration for use on a UAV Program
- CANDOS mission (summer 2002)
- LPT is under consideration for use on two space flight missions

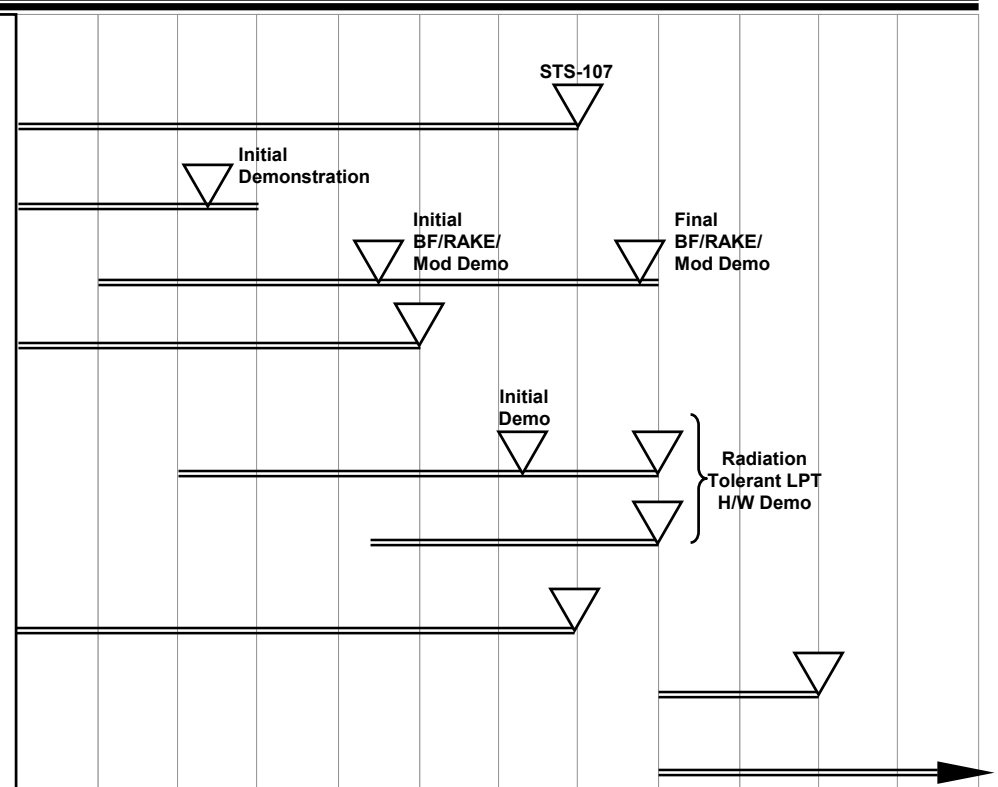
Low Power Transceiver Development Program Accomplishments / Plans

- XSS-11
  - » Experimental Spacecraft System (XSS) Micro-Satellite Demonstration Program
  - » A micro-satellite and a carrier satellite will be developed to demonstrate automated rendezvous and proximity operations
  - » LPT to serve as a secondary communication and navigation system
- TechSat 21
  - » Three formation flying satellites operating as a single "virtual satellite" with X-band transmit/receive payloads to form a large, sparse aperature system
  - » AFRL; MicroSat Systems, Inc.
  - » One year primary mission; three year operation desired (to support secondary mission)
  - » 600 Km circular orbit at 28.5° inclination
  - » LPT to serve as the space/ground and crosslink communication system and the GPS navigation system

Low Power Transceiver Development Program

Schedule

Task	FY01				FY02				FY03			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
• Candos (1st Generation)												
• 2nd Generation LPT EDM Development												
• Signal Processing Algorithm Augmentation												
• 2nd Generation LPT Proproduction Model Development												
• 3rd Generation LPT EDM Development												
• Radiation Tolerant RF Development												
• CANDOS Mission												
• Space Qualification Testing (3rd Gen)												
• Miniature Transceiver Development												
	$400K				$400K				$400K			



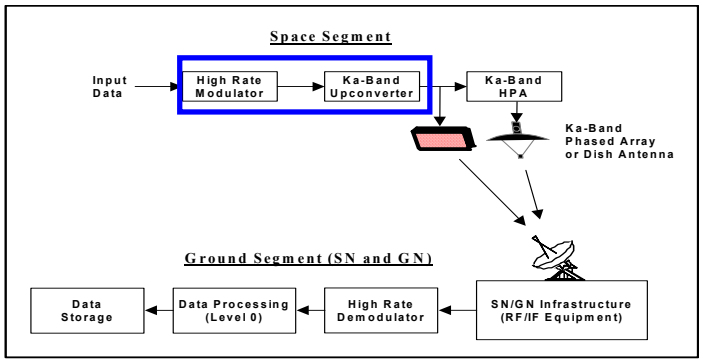
GSFC/SOMO Technology Development Program
Semi-Annual Review

Advanced Space Systems
Task 5636

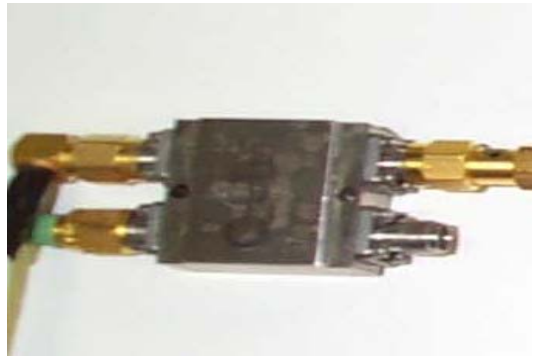
September 19, 2001

Code 567/Michael Powers, Ken Perko, and Adan Rodriguez

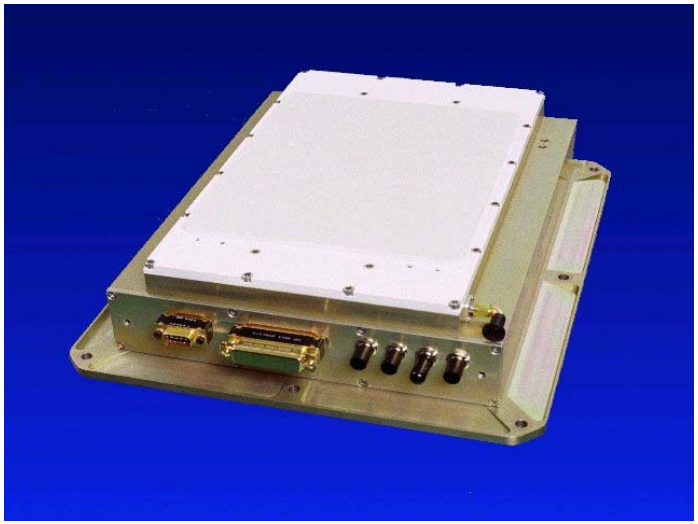
Objective: *Develop technologies useful in various spacecraft missions to improve space communications performance and reduce mission cost.*



High-rate Ka-band transmitter



Medium-rate direct Ka-band modulator



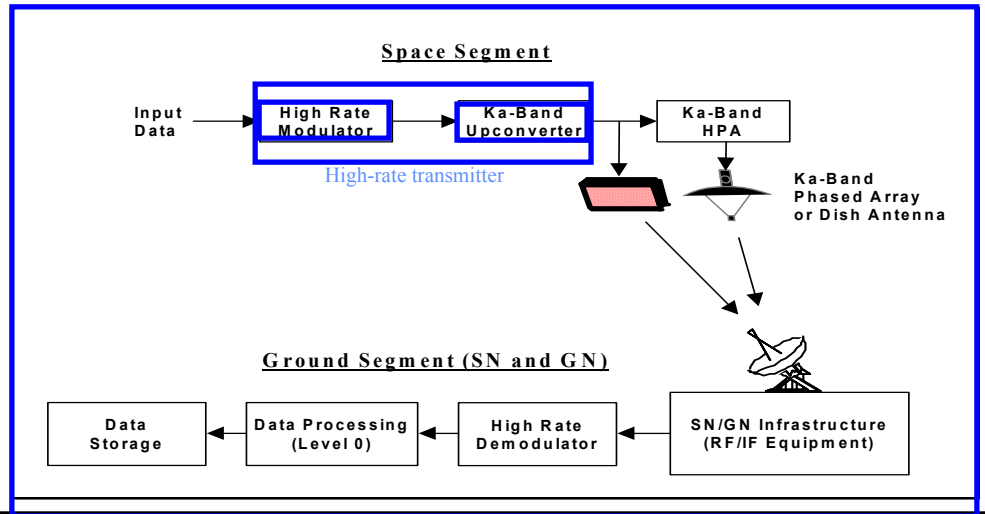
EO-1 X-Band Phased Array

X-Band Hemispherical Antenna

Low Power Transceiver Development Program

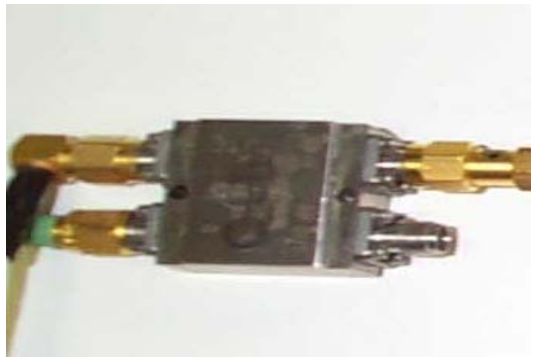
High-rate Ka-band transmitter

- **Goal:** Develop a breadboard of high-rate Ka-band transmitter (modulator and upconverter) with rates of 600 Mbps and 800 Mbps. TRL 4-5.
- **Benefit**: No high-rate, space-qualifiable Ka-band transmitter exists for future NASA missions. Development will provide prototype hardware that may be used for Ka-band TDRSS link and direct space-to-ground link. Can be used with a phased array antenna or a TWTA/dish high-gain antenna system.
- **Potential Customers:** Landsat Follow-on (EOS-1), OP-5B, and future high-rate Ka-band users.
- **Approach:** Brassboard development of a space-qualifiable Ka-band transmitter that will be compatible with TDRSS and GN network**.** Out-of-house development with spaceflight industry. Anticipate delivery early FY04.
- **Status:** Completed procurement package and initiated procurement activity. Proposals are due 9/21/01. At least 6 vendors have shown interest.
- **Plan:** Select a contractor in 1Q02.



Medium-rate Ka-band transmitter

- **Goal:** Develop a medium-rate Ka-band transmitter with direct Ka-band modulation at 300 Mbps. TRL 3-4.
- **Benefit**: Proof-of-concept development for direct Ka-band modulation at 300 Mbps (no upconverter). This will reduce the size and weight of the transmitter hardware.
- **Potential Customers:** Medium-rate SMEX-type Ka-band users.
- **Approach:** In-house development using COTS parts. New development of direct Ka-band QPSK modulator.
- **Status:** Design assembled and bench tested to 300 Mbps.
- **Plan:** Complete final characterization and begin packaging of modulator.

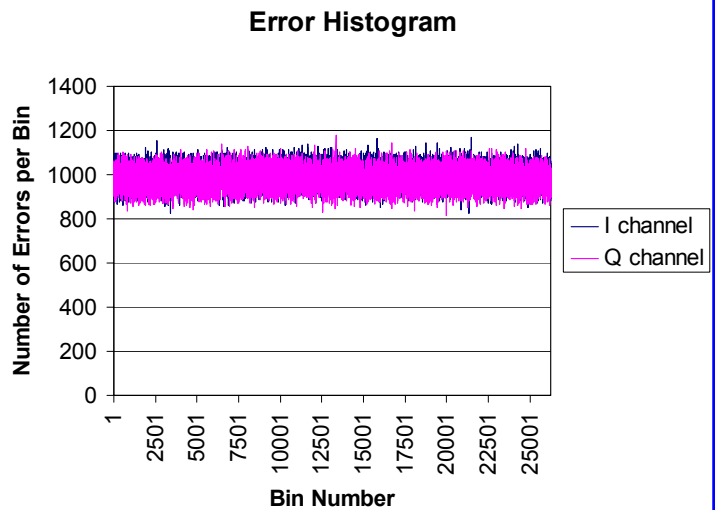


Direct Ka-band QPSK Modulator

Low Power Transceiver Development Program

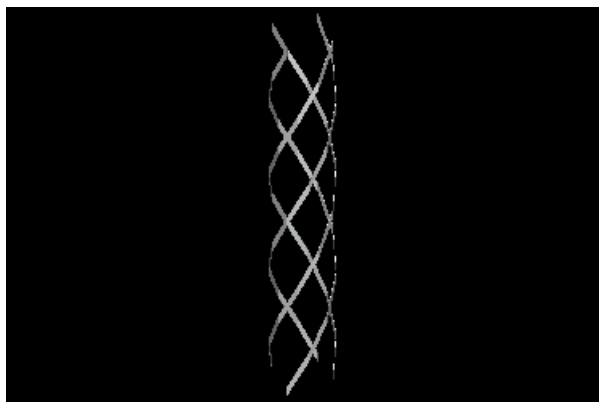
X-band Phased Array Study

- **Goal:** Evaluate phase disturbances of EO-1 X-band phased array antenna by characterizing its bit and burst error statistics while scanning. TRL 7-9.
- **Benefit**: The scanning of the EO-1 X-band phased array antenna causes phase disturbances that could impact the transmitted data quality. This task evaluates the effect of the phase disturbance on data by characterizing data bit and burst error statistics.
- **Potential Customers:** All future phased array antenna users.
- **Approach:** In-house effort. Schedule passes with EO-1 and perform data quality tests.
- **Status:** Burst and bit error statistics characterized by degrading transmission with variable noise injection. Data collected and analyzed at five bit error rates. No evidence of induced phase disturbances causing bit errors.
- **Plan:** Complete tests and summarize results by the end of October 01.



X-band Hemispherical Antenna

- **Goal:** Develop small X-band hemispherical coverage antennas for the support of future low cost missions. TRL 3.
- **Benefit:** No small aperture antennas currently exist to provide the full hemispherical coverage at X band. Development will provide low cost, small size X-band hemispherical coverage antennas to accommodate moderate rate downlinks (up to 4 Mbps) on small spacecrafts.
- **Potential Customers:** ST-5 (committed), MMS, microsats, nanosats
- **Approach:** Develop engineering model in-house including design and parts procurement to component testing and characterization. A contractor will be used for fabrication.
- **Status:** Applied Physical Laboratories in Las Cruces, NM is currently fabricating the antenna.
- **Plan:** Fabricate, assembly, and test engineering model.



Radius 0.075"; Length 0.925"