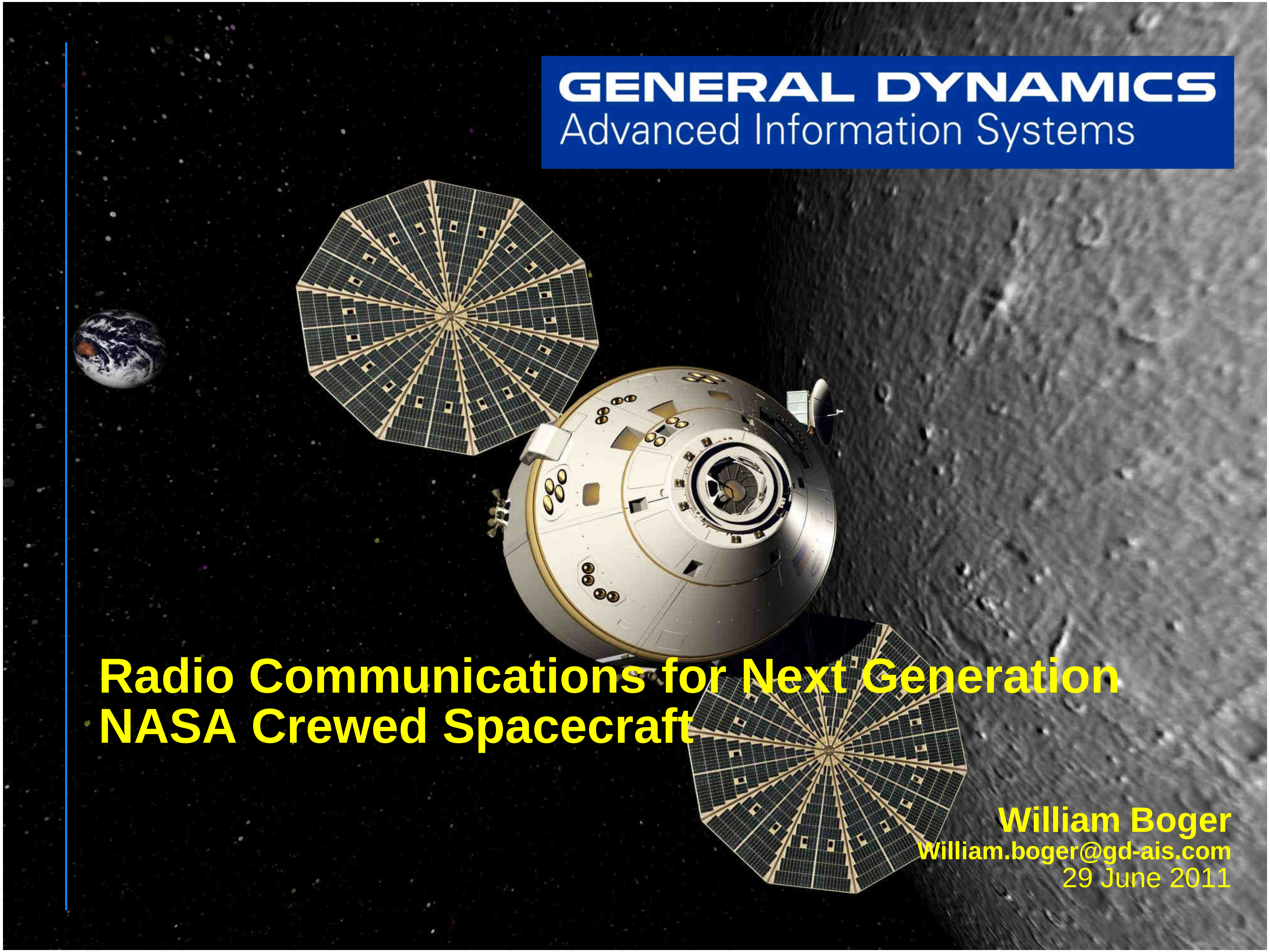

GENERAL DYNAMICS
Advanced Information Systems

Radio Communications for Next Generation NASA Crewed Spacecraft

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29 June 2011

Agenda

- Introduction
- (Brief) History of NASA's Human Space Flight Program
- Spacecraft Tracking, Telemetry, and Control (TT&C)
- (Brief) History of Human Space Flight TT&C Communications
  - General Dynamics Heritage
- Next Generation of NASA Human Space Flight
- Next Generation Communications System
  - Next Generation Requirements for Human Space Flight
  - MPCV Transponder Architecture
  - Flexibility and the Software Defined Radio
- Conclusion – Q&A

U.S. Civil Space Program Timeline

1961 Mercury Freedom 7
First US man in space

1964 First Gemini Mission

1969 Apollo 11
First US human on Moon

1979 STS-1
First Space Shuttle Launch

1958 US Human space program initiated

Space Programs (USA)

- NRL V2, SPUTNIK, EXPLORER, PIONEER, MERCURY
- RANGER, GEMINI
- APOLLO, LUNAR ORBITER, MARINER, SURVEYOR
- SKY LAB, PIONEER 10, MARINER 10, HELIOS
- VIKING, VOYAGER I, II, PIONEER VENUS, INTERNATIONAL SUN-EARTH, SOLAR MAXIMUM

1956-1962	1963-1965	1966-1967	1968-1969	1970-1975	1976-1980

GD (Motorola) contributions

- TDRSS I, SPACE SHUTTLE
- VOYAGER, NASA STDN
- S-BAND SPECIAL TEST EQUIPMENT, MARINER MARS
- APOLLO TRANSPONDERS, LUNAR ORBITER
- RANGER AND MARINER TRANSPONDERS, APOLLO STUDY
- JPL X-BAND, RANGER AND MARINER TRANSPONDERS

Timeline not to scale

U.S. Civil Space Program Timeline

1998 Russian Zarya Module First Piece of International Space Station Launched

2010 NASA Authorization Act: Congress calls for NASA to continue spacecraft development for a Multi-Purpose Crew Vehicle and Space Launch System to enable crewed missions beyond low Earth orbit by 2016m

Space Programs (USA)

- 1986-1990: MAGELLAN, GALILEO, HUBBLE SPACE TELESCOPE, ULYSSES
- 1991-1995: MARS OBSERVER, CLEMENTINE, SOHO
- 1996-2000: SPACE STATION, NEAR, MARS GLOBAL SURVEYOR, MARS PATHFINDER, CASSINI/HUYGENS LUNAR PROSPECTOR, DEEP SPACE I, STARDUST, MARS POLAR LANDER
- 2001-2005: IMAGE, MARS ODYSSEY, GENESIS, CONTOUR, MARS EXPRESS
- 2006-2011: MRO, JUNO, LRO, STEREO, DAWN (NEW HORIZONS), MARS LANDER

1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2011

GD (Motorola) contributions

- 2006-2011: MRO, JUNO, LRO, STEREO, DAWN (NEW HORIZONS), MARS LANDER
- 2001-2005: SDST, CASSINI, MARS ODYSSEY, STARDUST, SPITZER SPACE TELESCOPE, MARS ROVERS, DEEP IMPACT, MERCURY MESSINGER, MARS EXPRESS
- 1996-2000: DST, TDRSS IV, SPACE STATION, NEAR, MARS GLOBAL SURVEYOR, MARS PATHFINDER, CASSINI/HUYGENS, DEEP SPACE I, STARDUST, MARS POLAR LANDER, MARS ODYSSEY
- 1991-1995: IRIDIUM, MARS OBSERVER, SOHO
- 1986-1990: JPL DSN 3, MAGELLAN, GALILEO, HUBBLE SPACE TELESCOPE
- 1981-1985: JPL DSN, TDRSS II, III

2004 Pres Bush Announces Mission to Moon Kicks off Constellation Program

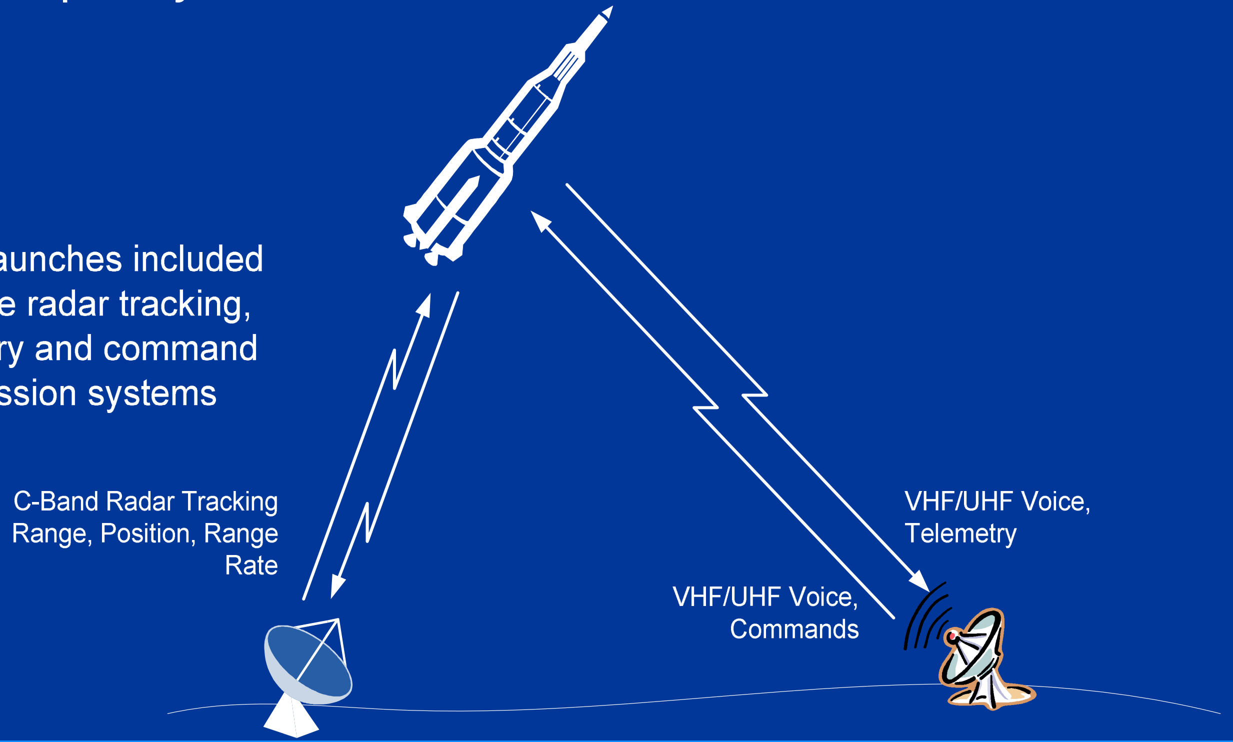
Spacecraft TT&C

- Missiles and Spacecraft Require Fundamental Communication Capabilities
- Needs can be categorized as Telemetry, Tracking, and Control (TT&C)
  - Telemetry- Downlink spacecraft status, mission data, voice & video transmission
  - Tracking- Radiometric measurements of range (distance) and range-rate by Doppler measurement
  - Control- Uplink spacecraft configuration, navigation commands, ground voice and video

Basic TT&C Systems- Early launches used 3 separate systems

- Early uncrewed and crewed launches including Mercury and Gemini used separate systems and radio spectrum for each function
  - Radar systems used for tracking
  - Low frequency VHF or UHF used for control, voice and telemetry

Early Launches included separate radar tracking, telemetry and command transmission systems



Basic TT&C Systems- "Unified" S-Band

- Apollo Mission to the Moon Created Unique TT&C Needs
  - Lunar insertion, trans-lunar flight, LEM separation, landing and docking require accurate tracking at extreme distances
  - Multiple space vehicles operating simultaneously
  - More critical re-entry phase requires accurate tracking
  - Additional command and telemetry data capacity needed, including television/video
- Unified S-Band System Developed for Apollo
  - Combines Tracking, Telemetry, and Control into one system
    - Added capability for voice and television, emergency comm.
  - One spectrum and one spacecraft radio handles all 3 functions along with voice and television
  - Capable of long distance tracking using radio PN code, range rate using carrier Doppler shift measurement

Basic TT&C Systems –
Unified S-Band Developed for Apollo

APOLLO UNIFIED S-BAND SYSTEM CAPABILITIES

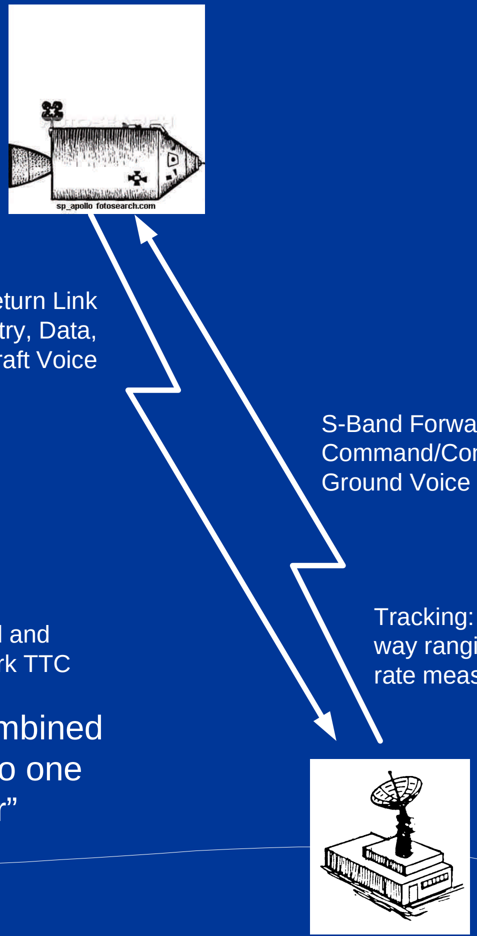
GROUND TO SPACECRAFT

1. VOICE
2. DIGITAL COMMANDS
3. RANGING SIGNALS

SPACECRAFT TO GROUND

1. VOICE
2. TELEMETRY
3. TELEVISION
4. BIOMEDICAL DATA
5. RANGING
6. EMERGENCY VOICE
7. EMERGENCY KEY

Figure 1. Apollo Unified S-Band System Capabilities



S-Band Return Link
Telemetry, Data,
Spacecraft Voice

S-Band Forward Link
Command/Control
Ground Voice

Unified S-Band and
Ground Network TTC

Tracking: 1 way and 2 way ranging and range rate measurement

Unified S-Band combined TT&C functions into one radio "Transponder"

Figures taken from NASA Document TM X-55492, April 1966

Basic TT&C Systems-
Unified S-Band Transponder and Spectrum

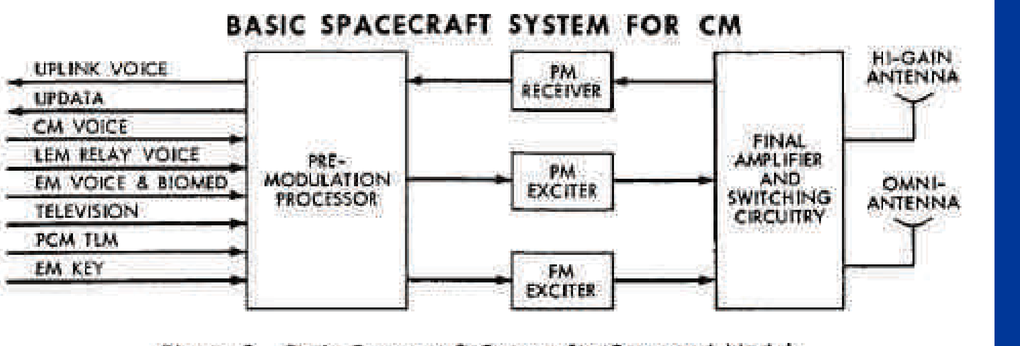


Figure 9. Basic Spacecraft System for Command Module

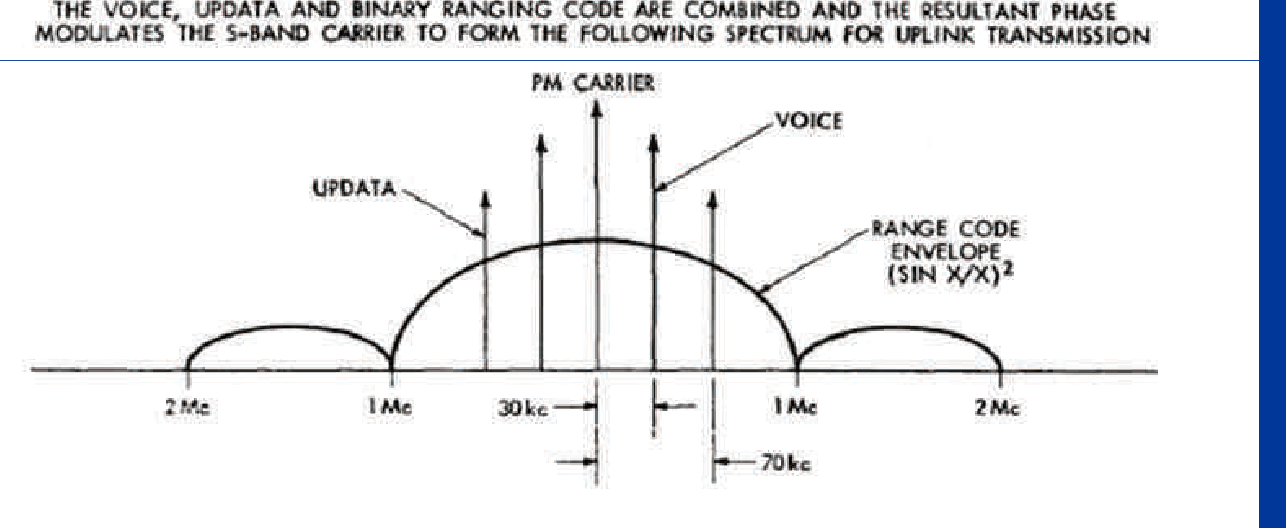


Figure 8. Uplink Spectrum

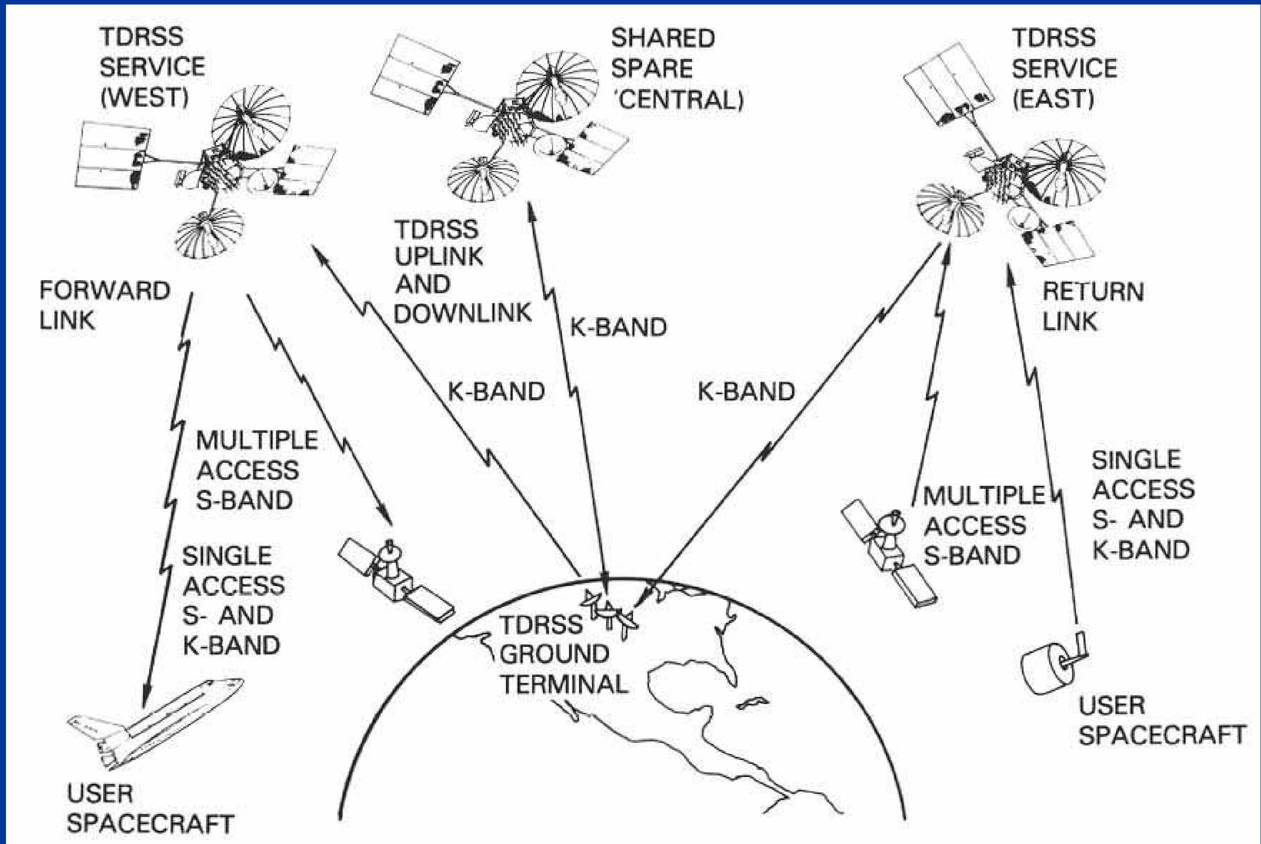
Figures taken from NASA Document TM X-55492, April 1966

Basic TT&C--
Tracking & Data Relay Satellite System

- Limitations of Unified S-Band and Shuttle Development Drove Need for Better TT&C capability
  - USB system required 11 ground stations for near-earth TT&C
  - Full orbital coverage not available
  - Limited user and data-rate capacity
- The Tracking and Data Relay Satellite System (TDRSS) system began development in the mid 1970's
  - TDRSS design was based on ground station USB TTC system previously used
- TDRSS is a system of geosynchronous satellites implementing the TT&C functions
  - User satellites communicate with a TDRSS satellite using S-Band or Ku-Band crosslinks with full orbital coverage
  - TDRSS satellite translates user signals to/from Ku-Band and link to TDRSS ground stations.
  - Ranging and Range-rate tracking is accomplished relative to the TDRSS satellite position.

TDRSS System Operation

- Services to White Sands Ground Terminal Shown
  - Guam Ground Terminal Operation is Similar



Basic TT&C
TDRSS Communications

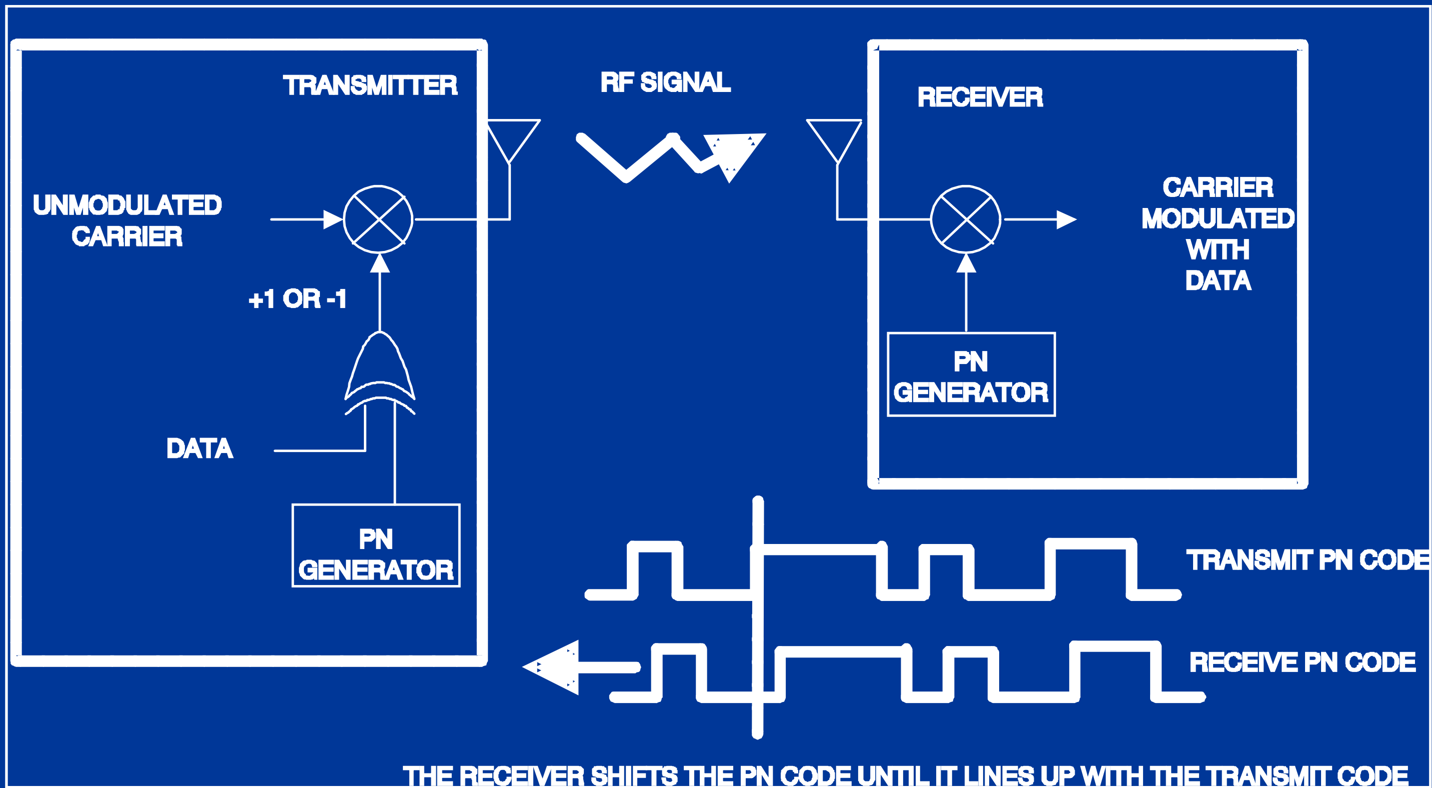
- The TDRSS system uses direct sequence spread spectrum
  - Leverages the need for PN-code ranging capability to include advantages of spread spectrum systems
  - One of the first space applications of spread spectrum
  - ~3 Megachip direct sequence spreading

- Advantages of Spread Spectrum
  - Many users share the same frequency by assigning each a unique PN code. This is known as “code division multiple access” (CDMA). Now utilized in cell phones and wireless systems
  - Transmitted power is spread over a wider portion of the frequency spectrum reducing interference to other users
  - Interfering signals, including multi-path, are rejected as they are scrambled by the receiver’s PN code
  - The PN code time delay is also used to measure the distance from the ground station to the satellite for tracking purposes.
- Multiple Access and numerous Frequency bands Provide high user communications capacity

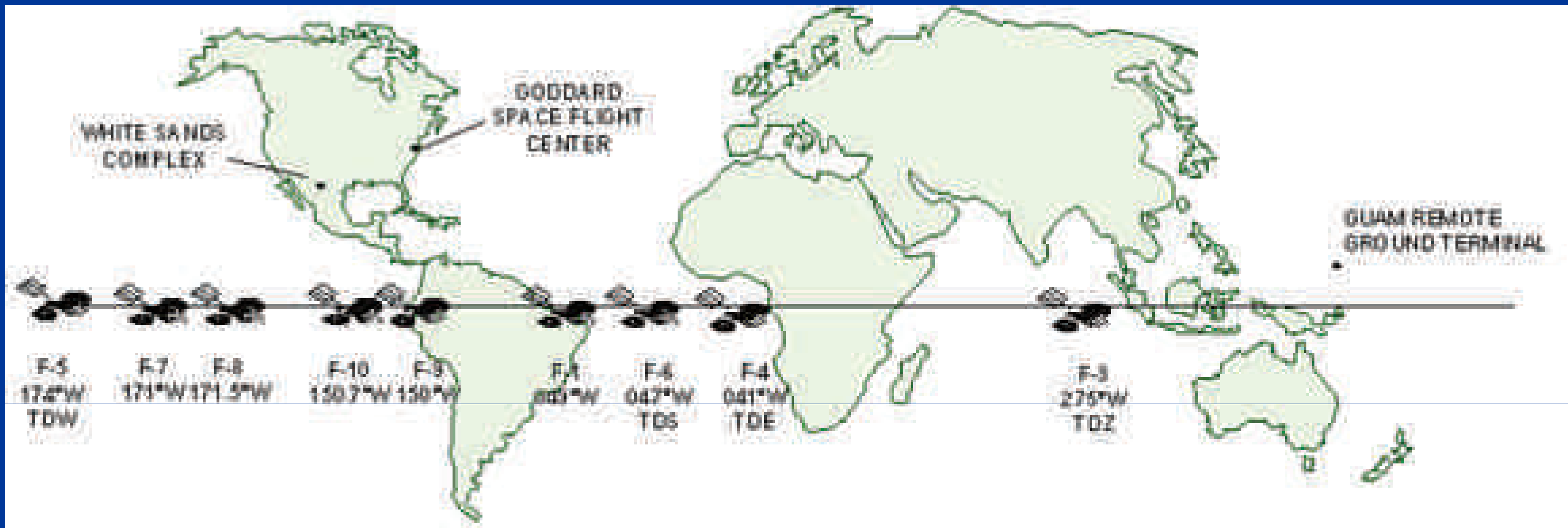
Image courtesy NASA

Basic TT&C
Ranging and DS Spread Spectrum

- Direct Sequence Spread Spectrum comes virtually for free with PN Ranging capability



TDRSS System



Tracking and Data Relay Satellite System (TDRSS)

- 10 satellites in service, including parked spares
- Ground Stations in White Sands, NM, and Guam
- 2 Generations currently flying, 3rd generation in production
- Newer generations add wide-band Ka-Band capability on crosslinks

Figure courtesy NASA

U.S. Crewed Missions TTC & Comm.

- Project Mercury, Project Gemini
  - UHF/VHF main voice communications
  - UHF Command Receiver for commands and voice backup
  - C-Band Radar Transponder for tracking
- Apollo
  - Unified S-Band 2-way Radio Transponders for comm. and tracking
    - Command Module (2) & Lunar Module
  - Lunar Rover FM Voice/Command receiver
  - Command/Destruct receivers on booster stages 1,2,3
- Space Shuttle
  - Unified S-Band and TDRSS Transponder Capability (Not GD/Motorola)
- Space Station
  - Motorola/General Dynamics S-Band TDRSS/STDN Transponder

General Dynamics Scottsdale Heritage

- Originally Motorola's Military/Government Electronics Group
  - Established in late 1940's in Phoenix area
  - Expanded into Scottsdale facility in mid 1950s
- Space communications grew out of missile electronics developed in mid-1950s
  - Need emerges for vehicle Tracking, Telemetry, and Control by ground stations
  - Motorola was a leading supplier of missile command/destruct receivers
- Project Mercury begins in 1958
  - Motorola MCR-100 series UHF receiver used for reliable backup communications
  - Flew on all Mercury missions
  - 10 channel Uplink commands plus voice backup
    - Relay control outputs
  - Mercury utilized worldwide radar tracking system

RADIO COMMAND RECEIVER

10-CHANNEL DECODER MODEL

MCR-100 SERIES

Figure taken from Motorola Datasheet

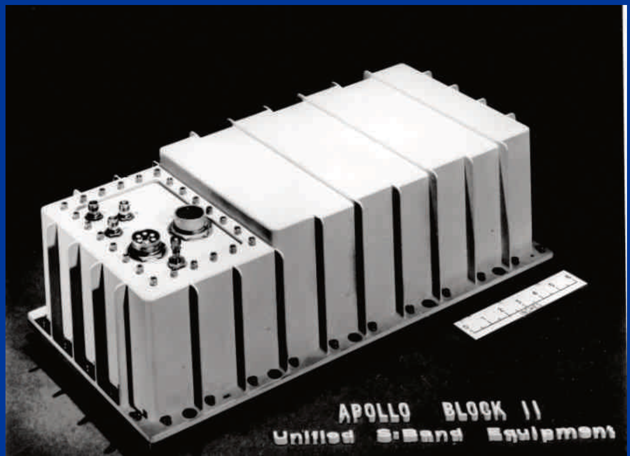
General Dynamics Scottsdale Heritage

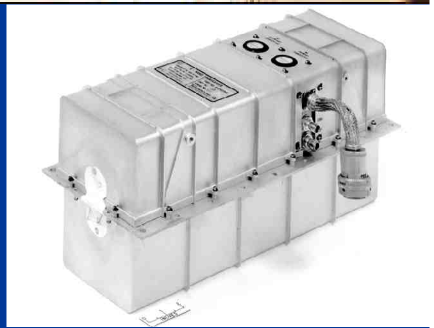
- Project Gemini and Agena Docking Vehicle Components
  - Motorola C-Band Radar Transponder for Tracking range, position and velocity
    - Gemini utilized worldwide radar ground-based tracking system

  - Motorola Digital Command System, UHF command receiver for Gemini
    - UHF FM modulation with PSK modulated sidebands and relay control outputs
  - Similar Motorola Digital Command System for Agena docking vehicle

General Dynamics Scottsdale Heritage

- Project Apollo Mission Components from Motorola/GD
  - Unified S-Band Transponder, Command Module (CM)
  - Unified S-Band Transponder, Lunar Module (LEM)
  - S-Band Communications transponder, 3rd Stage
  - Lunar Rover FM Command/Voice Receiver
  - Up-Data Link unit, (Data handling) Command Module
  - Flight Data/Command Destruct Receivers Stages 1,2,3
  - S-Band Command Receiver, ALSEP Experiment





Images courtesy NASA and General Dynamics

General Dynamics Scottsdale Heritage

- Project Apollo Mission GDAIS/Motorola Components “on the rocks”

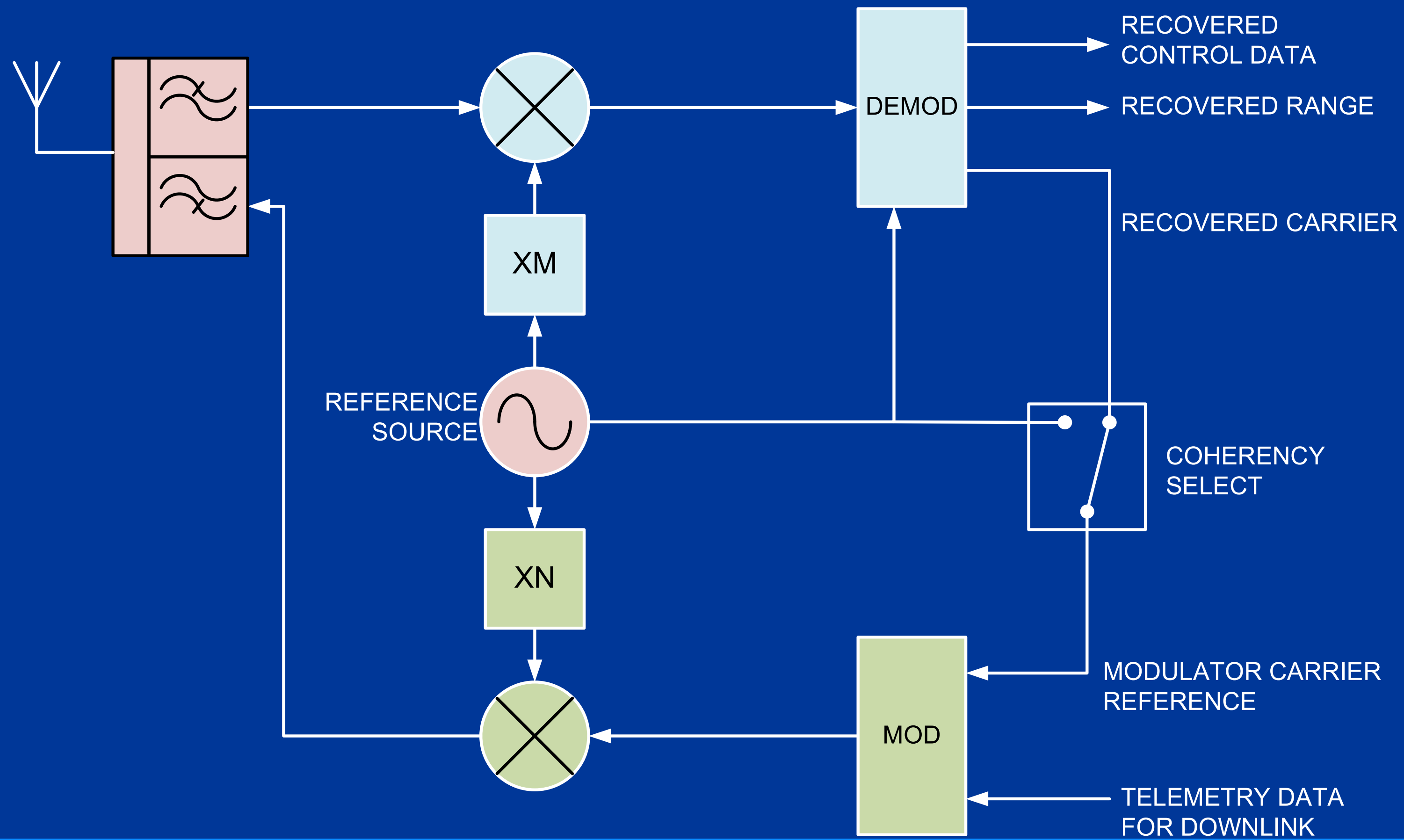
General Dynamics Scottsdale Heritage

- Space Station Freedom/ISS Mission Components
  - HRFM (High Rate Frame Mux; 2 units, part of the K-band system)
  - HRM (High Rate Modem; 2 units, part of the K-band system)
  - ACBSP (Assembly Contingent Baseband Signal Processor ; 3 units, part of the S-band system)
  - XPDR (TDRSS Transponder; 3 units, part of the S-band system)

Images courtesy NASA and General Dynamics

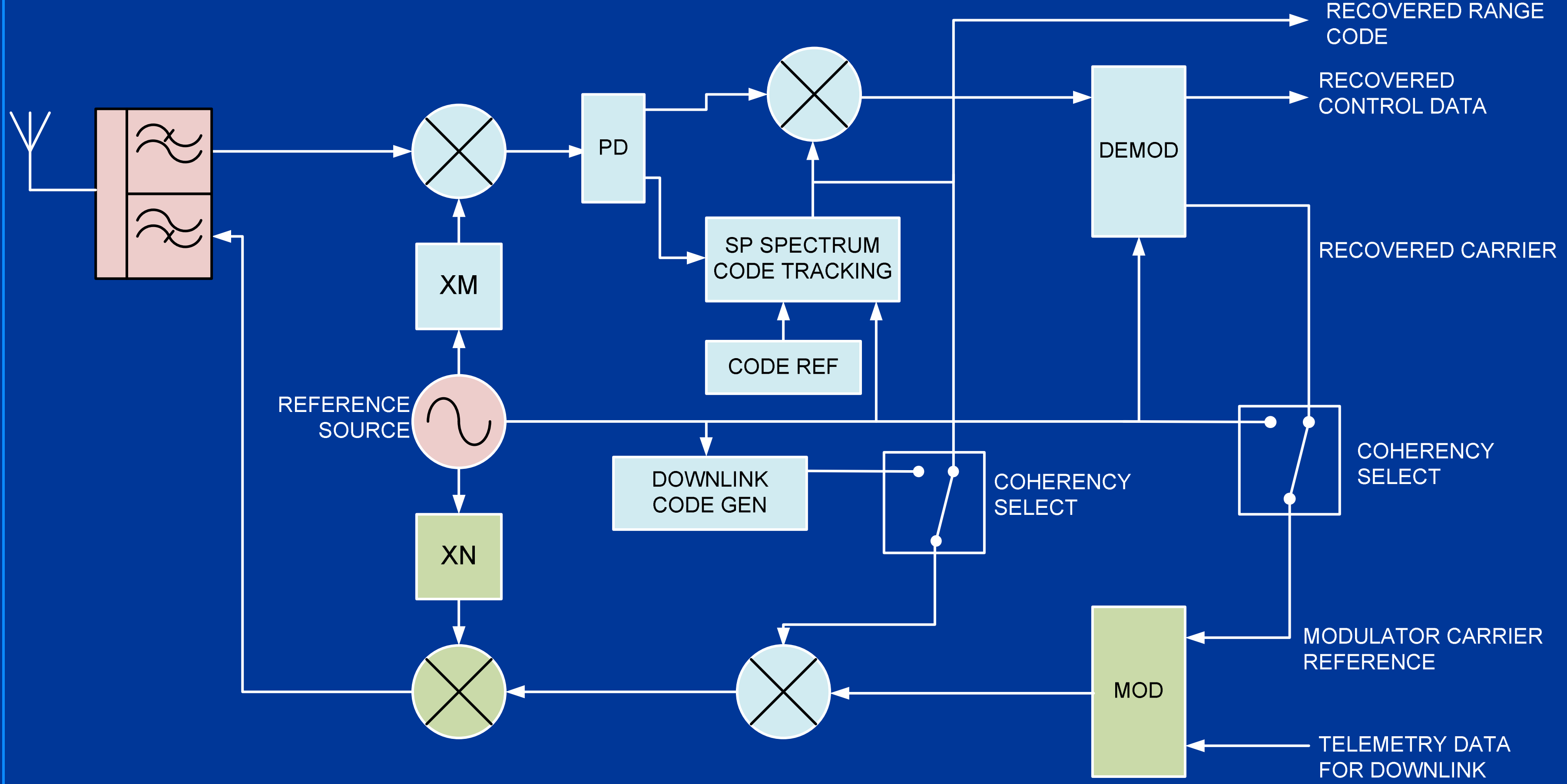
TTC Spacecraft Transponder Basics

- USB/First Generation TTC Transponder Block Diagram



TTC Spacecraft Transponder Basics

- TDRSS Spread Spectrum TTC Transponder Simplified Block Diagram



Next Generation US Human Space Flight Program

- In 2004, President Bush challenged NASA to send the U.S. back to the Moon and Mars
  - Kicked off ambitious Constellation Program to redefine the U.S. human space flight program
    - Replaces the aging Space Shuttle system including following segments:
    - Ares Heavy Lift Booster development,
    - Orion Crew Exploration Vehicle (CEV)
    - Altair Lunar Excursion vehicles

Images Courtesy NASA

Ongoing Changes to U.S. Human Space Flight Program

- Obama Administration in 2010 Directed Changes to NASA's Human Space Flight Program Objectives
  - Constellation and Orion Programs Cancelled
  - Lengthened schedule for return to the Moon, focuses on Shuttle replacement in near term
  - Increased Private Sector Involvement to develop space vehicles
- 2010 NASA Authorization Act Redirects NASA goals:
  - Continue development of Multi-Purpose Crew Vehicle (MPCV) and Space Launch System to enable crewed missions beyond low Earth orbit by 2016
    - MPCV based on Orion CEV baseline
  - Evolutionary approach and architecture supports changing objectives and timeframes

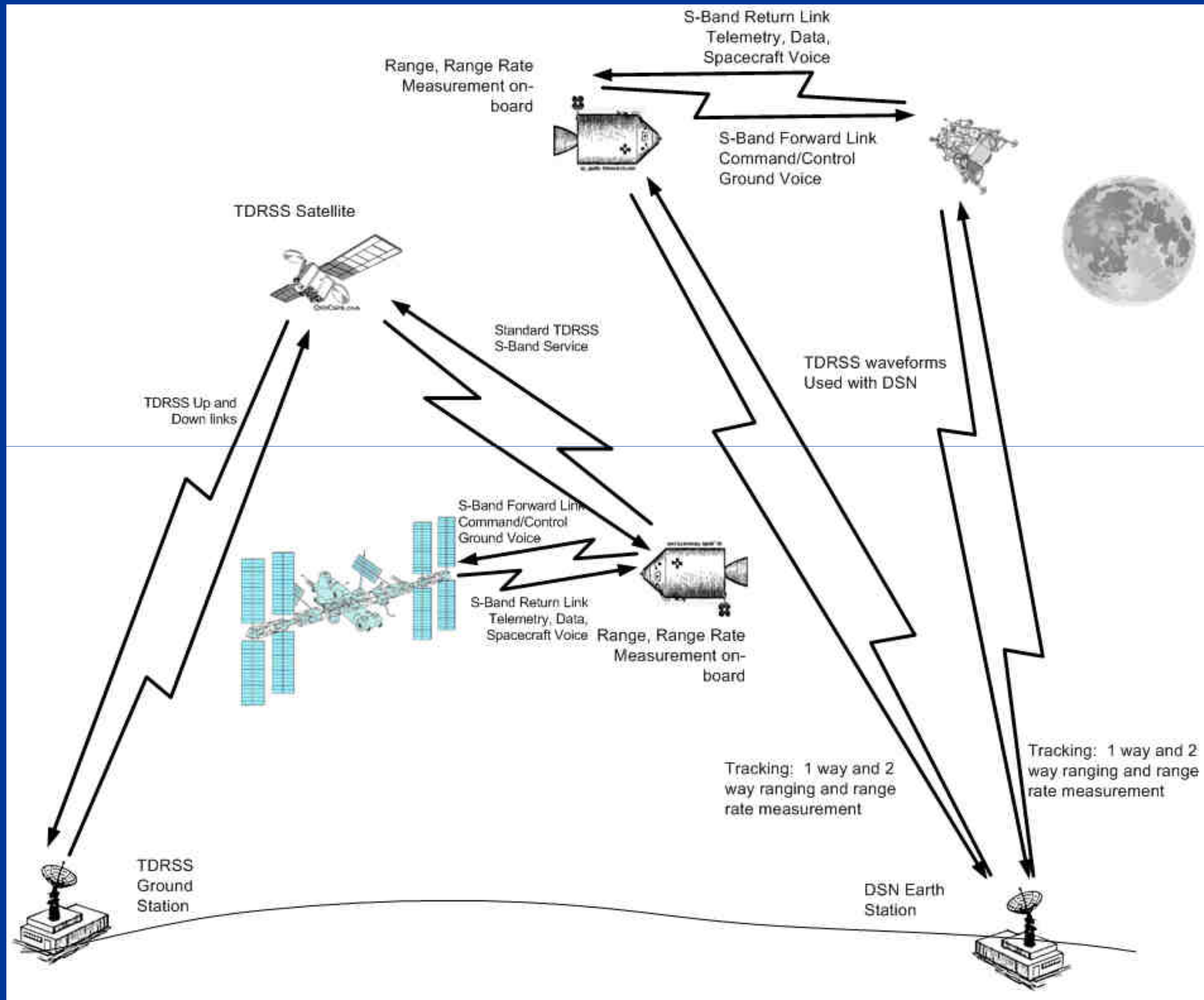
TTC and Communications for Human Space Flight Operations

- Tracking and Communications System for human space flight must support present and future missions
  - Immediate need for missions to ISS space station, including launch, rendezvous/docking, return to earth-- Shuttle Replacement
- Future missions could include Lunar orbit, asteroid missions, Mars excursions and beyond
  - Near earth operations: launch support, early Earth-orbit operations, rendezvous, in space operations, lunar transit, re-entry and landing operations
  - Lunar Operations: orbit insertion, observation, scientific surveys, and Earth transit
  - Mars Operations: Mars transit, Mars orbit insertion, surface operations, ascent, and Earth transit
- Long reaching plans dictate need for evolutionary approach to TTC infrastructure

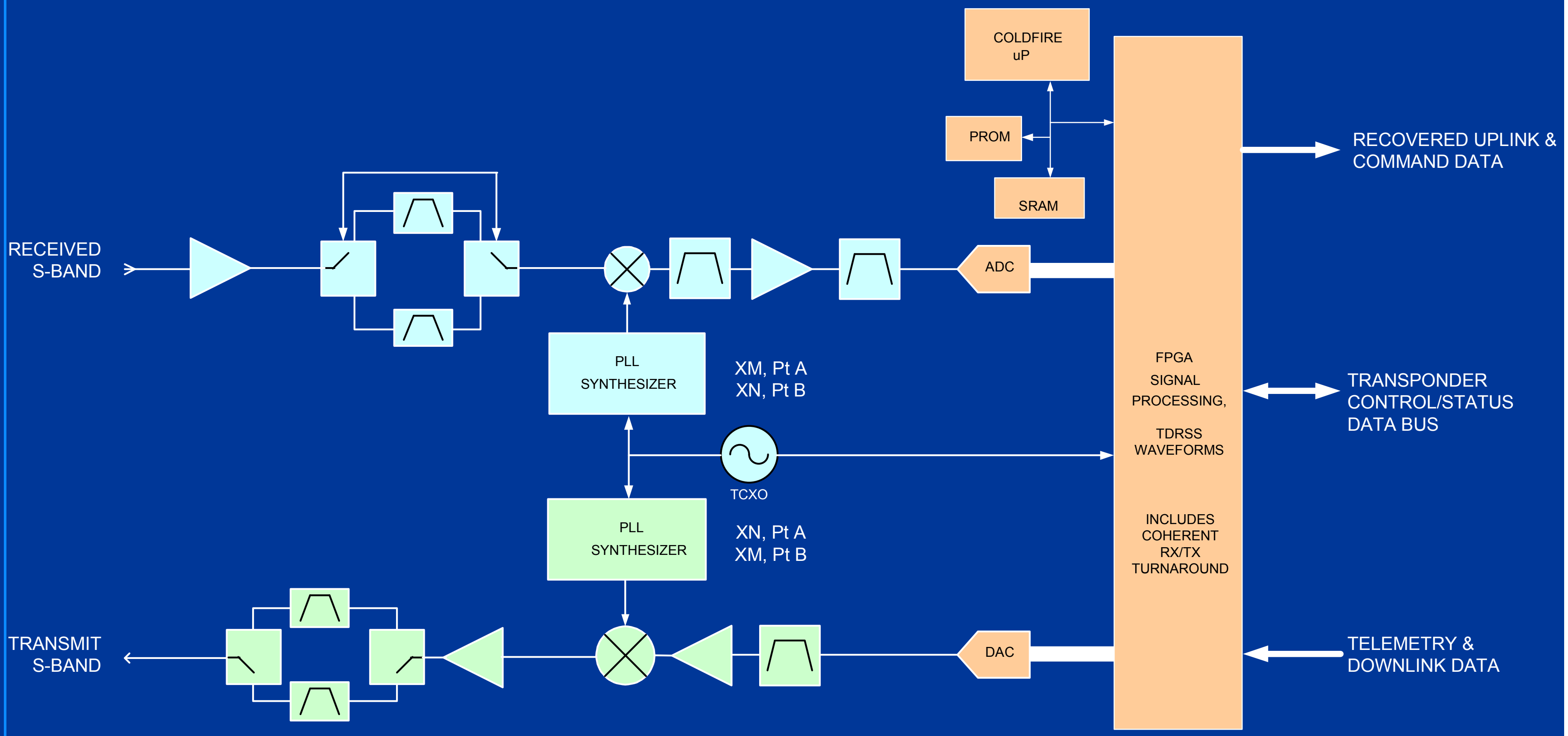
TTC and Communications for MPCV

- TTC requirements for the Multi-Purpose Crew Vehicle (MPCV) focus on immediate needs with long range mission requirements in mind
  - Near Earth needs will be satisfied by the existing Space Network Tracking and Data Relay Satellite System (TDRSS) constellation through 2025
    - Planned TDRSS upgrade deployment occurs in the 2015 time frame
  - Space-to-space TDRSS TTC allows docking and communications directly between MPCV and ISS or MPCV and Moon missions.
    - Requires dual-mode transponder capable of operation in a space-based user transponder mode or operation in Earth station mode.
      - Capabilities include space-borne ranging and range-rate measurement
  - Similar to Apollo, initial lunar sortie missions will be supported by Earth ground stations, primarily the Deep Space Network (DSN)
    - DSN upgrades planned for TDRSS compatible receivers supporting MPCV

TTC and Communications for MPCV Support
Evolution of Human Space Flight Program



MPCV POINT A/B S-BAND TRANSPONDER



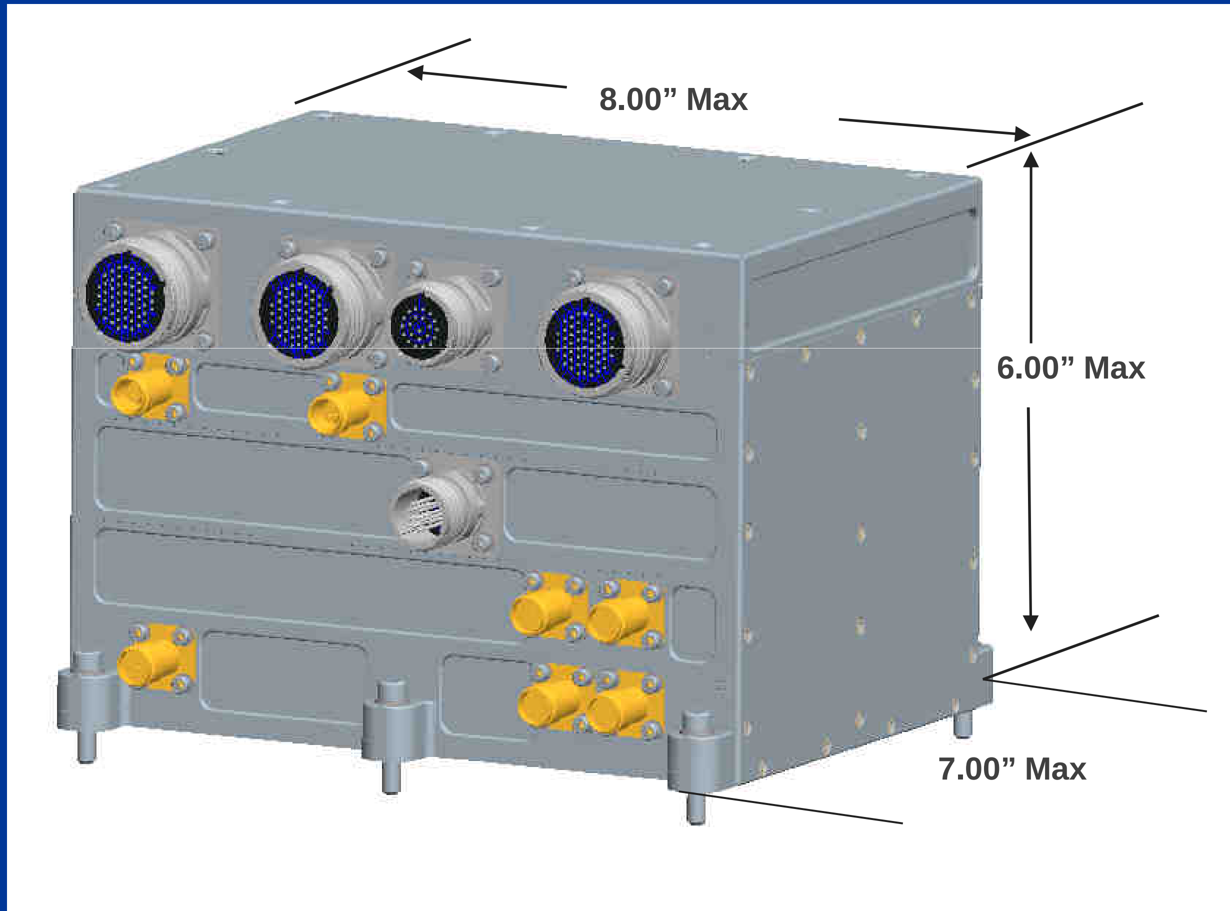
MPCV S-BAND TRANSPONDER OVERVIEW

- Functional Overview
  - TDRSS Waveform Compatible
  - Point A (User Transponder) or
    Point B (Ground Station Mode) Operation
  - Operation on 3 TDRSS frequency bands
  - Capable of majority of TDRSS waveforms on command
  - Coherent or non-coherent operation
  - Waveforms instantiated in Software and FPGA Gateware
  - Radiation hardened and ruggedized for operation during launch
  - New bandwidth efficient modulation waveforms (non-spread)
    - better spectrum utilization and higher bit rates
    - Root-Raised Cosine pulse shaping

MPCV S-BAND TRANSPONDER OVERVIEW

- Physical Characteristics
  - Mass: 10 lbs
  - DC Power:

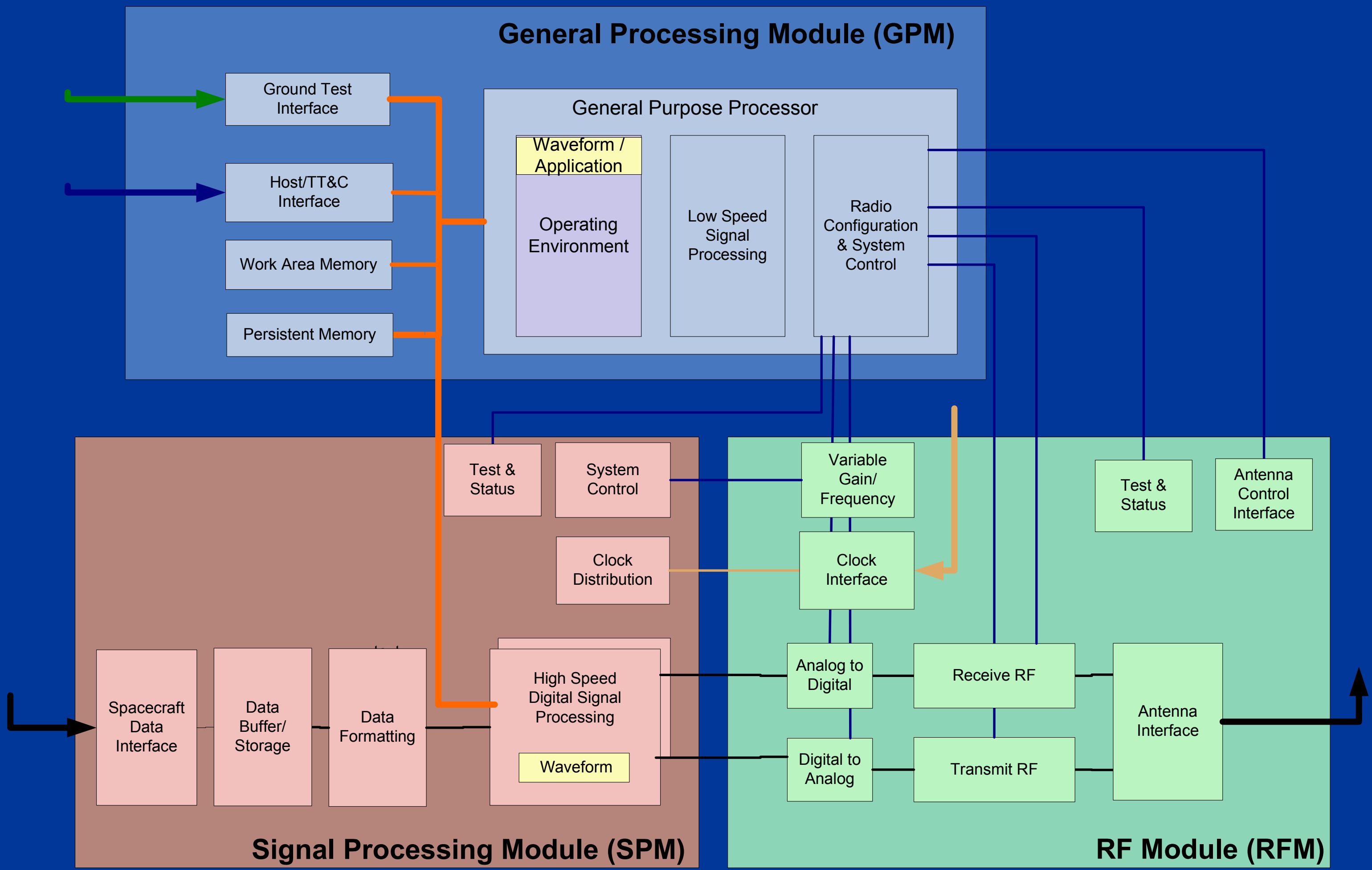
    19 W, Tx & Rx



MPCV S-Band Transponder is STRS Compatible

- Our MPCV Transponder utilizes NASA's Space Telecommunications Radio System (STRS) Software Defined Radio (SDR) architecture
  - Developed for CONNECT program
  - High level operating system provides standardized open-architecture approach
  - STRS Outer Layer provides seamless interface to detailed waveform and hardware functions
  - SDR Minimizes need for costly hardware changes
- Allows use of STRS Repository
  - Collection of hardware and software modules, definitions, documents for mission reuse
  - Allows for 3rd Party developers to easily update radio function
- Result is increased capability for evolution with changes in human space program objectives.

SDR/STRS Conceptual Diagram



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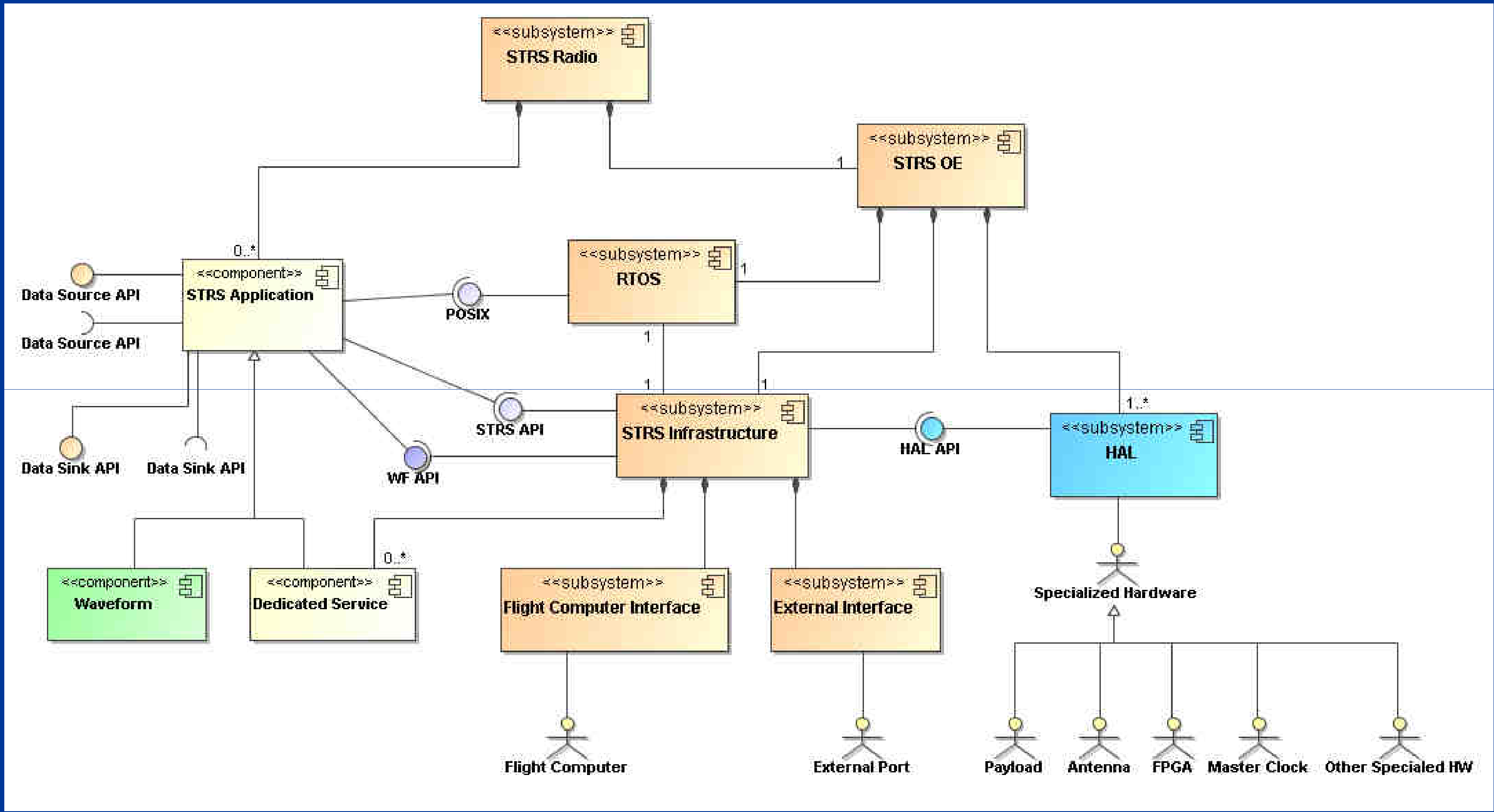
STRS Software Architecture



Summary and Conclusions

- General Dynamics AIS Scottsdale has a long heritage supporting the U.S. Human Space Flight Program
  - We are pleased to support NASA and the world in continuing human exploration of space
- Our MPCV S-Band Transponder Supports NASA's need for an Evolutionary TTC System
  - Supports near term needs but provides flexibility for the future
  - Flexibility provided by Software Programmable architecture
  - Capability of operation in TDRSS Point A or Point B Modes
- STRS SDR Provides for easy update of the MPCV transponder function to meet the needs of the future of Human Space Flight

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GENERAL DYNAMICS

Q&A

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Motorola's Government Electronics Group was acquired by General Dynamics in 2001