Tracking, Telemetry & Control Systems on Mercury, Gemini and Apollo

Excerpt From: Radio Communications For Next Generation NASA Crewed Spacecraft
William Boger, General Dynamics (2011)
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

- C-Band Radar Tracking Range, Position, Range Rate
- VHF/UHF Voice, Commands
- VHF/UHF Voice, Telemetry

GENERAL DYNAMICS
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

Figure 1. Apollo Unified S-Band System Capabilities

- **S-Band Return Link**
  - Telemetry, Data, Spacecraft Voice

- **S-Band Forward Link**
  - Command/Control
  - Ground Voice

- **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

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

Figure 9. Basic Spacecraft System for Command Module

The voice, Updata and binary ranging code are combined and the resultant phase modulates the S-band carrier to form the following spectrum for uplink transmission.

Figure 8. Uplink Spectrum
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- 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

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

Figure taken from Motorola Datasheet
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 GD/Motorola Components “on the rocks”
Motorola’s Government Electronics Group was acquired by General Dynamics in 2001