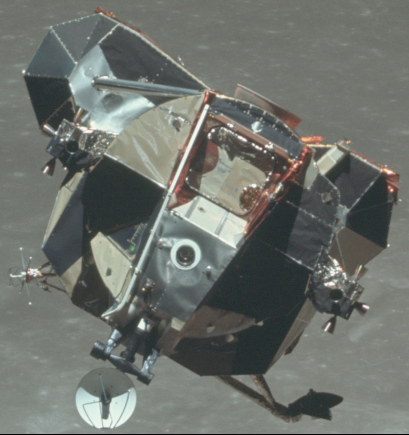
Tracking, Telemetry & Control Systems on Mercury, Gemini and Apollo



Excerpt From: Radio Communications For Next Generation NASA Crewed Spacecraft

William Boger, General Dynamics (2011)

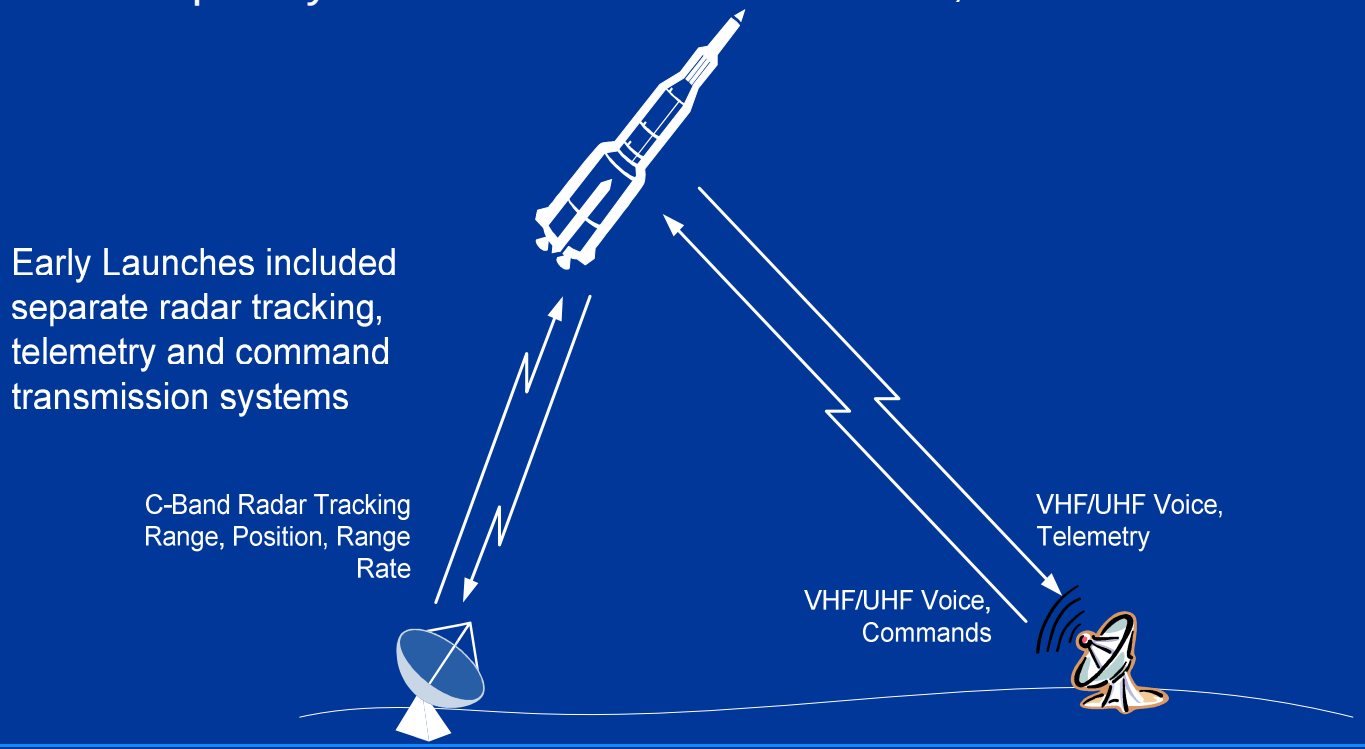
GENERAL DYNAMICS

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



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

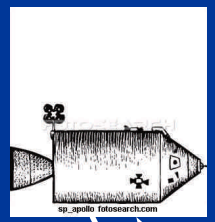
GROUND TO SPACECRAFT

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

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

Unified S-Band and
Ground Network TTC

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

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

GENERAL DYNAMICS

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

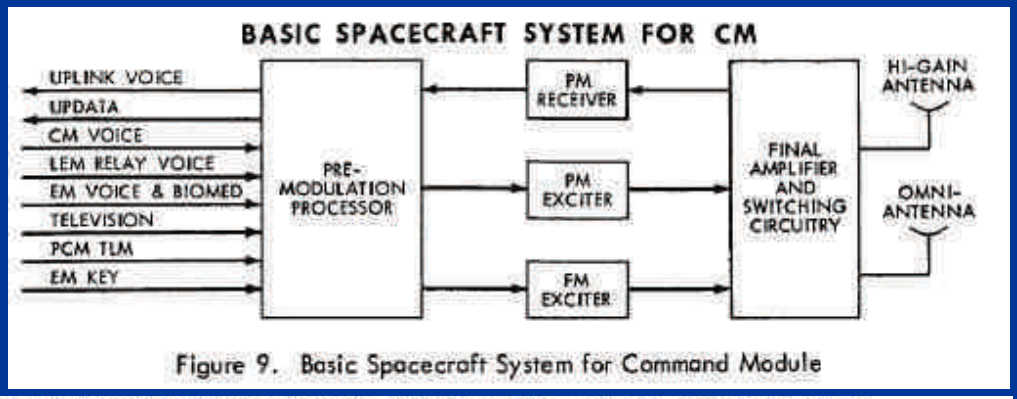


Figure 9. Basic Spacecraft System for Command Module

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

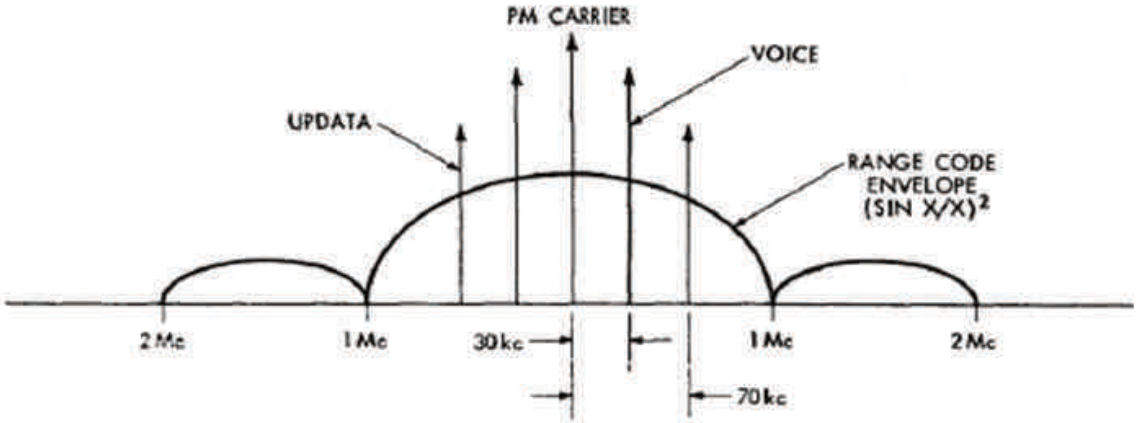


Figure 8. Uplink Spectrum

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

GENERAL DYNAMICS

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

Figure taken from Motorola Datasheet

General Dynamics Scottsdale Heritage

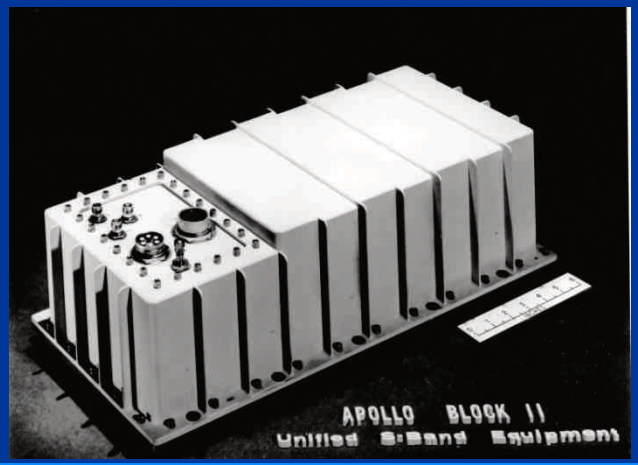
- Project Gemini and Agena Docking Vehicle Components
  - Motorola C-Band Radar Transponder for Tracking range, position and velocity
    - Gemini utilized worldwide radar ground-based tracking system

  - 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



GENERAL DYNAMICS

Images courtesy NASA and General Dynamics

General Dynamics Scottsdale Heritage

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

GENERAL DYNAMICS

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