National Aeronautics and Space Administration

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Pasadena, California

Engineering Challenges of Building the Mars Curiosity Landing Radar

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Presentation Topics

- Introduction to NASA – JPL
- Curiosity Rover Overview
- Mars Descent and Landing Radars
- The MSL Radar – Terminal Descent Sensor
- Engineering Challenges
- Lessons Learned
- Q&A

JPL Introduction

- JPL is one of 12 NASA centers
- Became part of NASA in 1958
- Tasked by the US government and scientific community with the robotic exploration of the solar system.
- NASA has lunched 19 missions to Mars since 1964
  - 6 Flybys, 7 orbiters, 5 landers, 4 rovers
- Latest JPL mission to Mars is the Curiosity Rover

Curiosity Rover Mission Overview

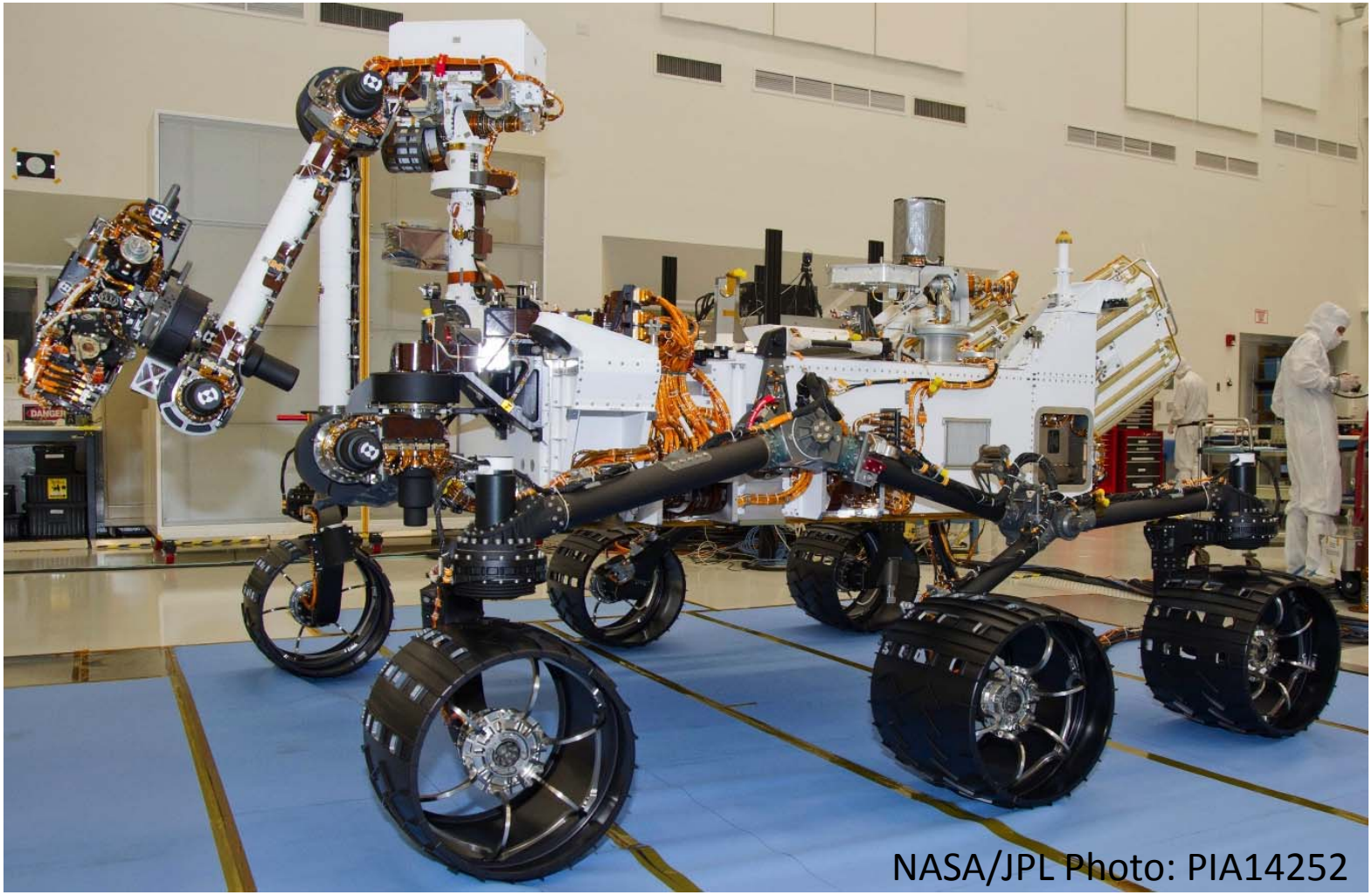
- Mission launched November 26, 2011
- Atlas V Rocket
- Landed August 6, 2012
- Target: Inside Gale Crater

Curiosity Rover Overview

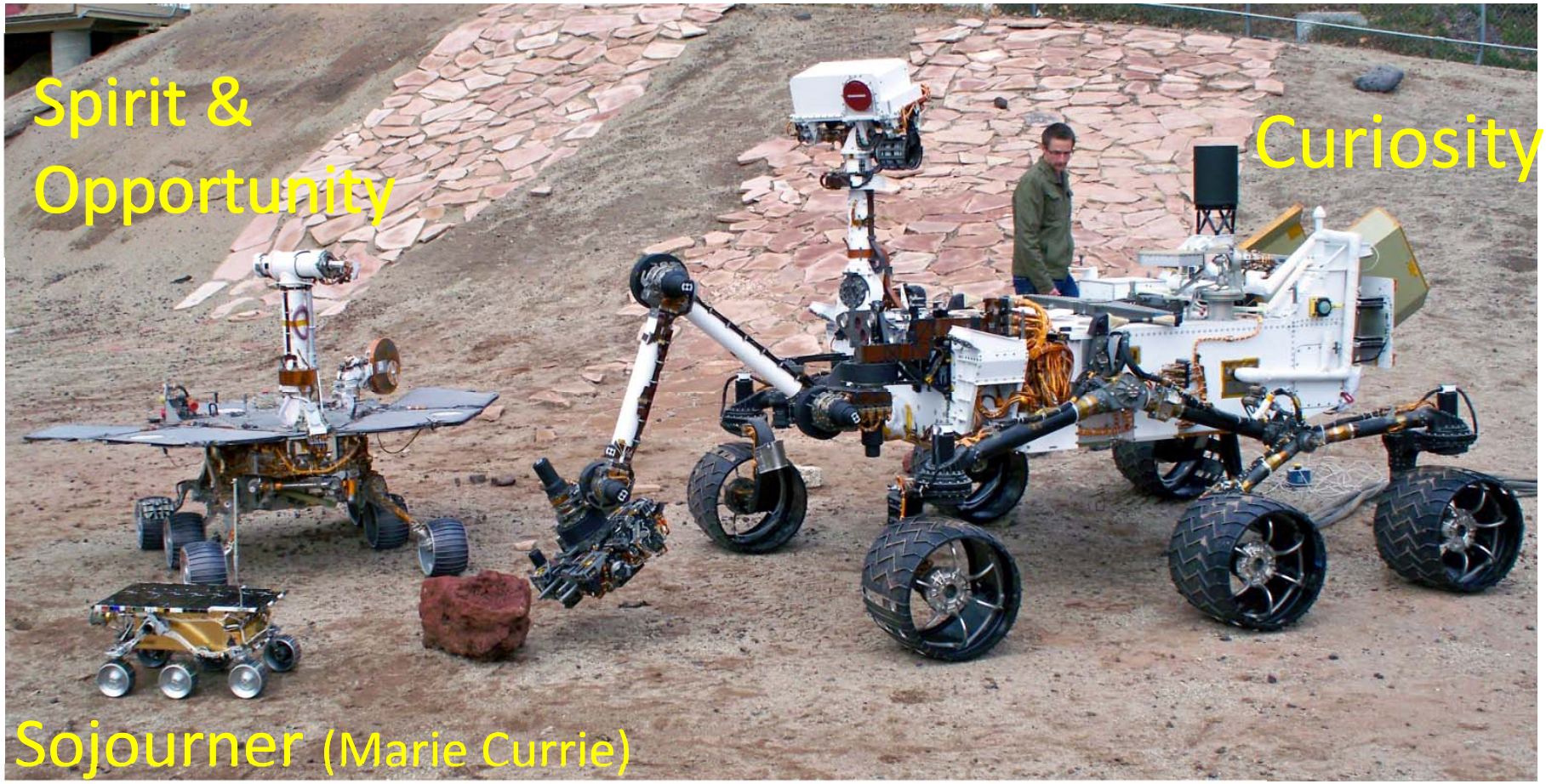
- Mass: 899 kilograms
- Size (meters): Length 3; Width 2.7; Height 2.2
- Power: Radioisotope thermoelectric generator ~2.7 kwatt hours per sol *(Yes, nuclear powered!)*
- Communication:
  - X-band transceiver 2 antennas (direct-to-Earth)
  - UHF transceiver and 1 antenna (orbiter link)
  - UHF link capacity ~ 9 Gbyte/day (via MRO orbiter relay)
- Design Life: > 98 weeks (1 Mars year)
- Science payloads: 8 experiments

Ref: http://mars.jpl.nasa.gov/msl/news/pdfs/MSLLanding.pdf

Curiosity Rover Overview



Rover Family Photo



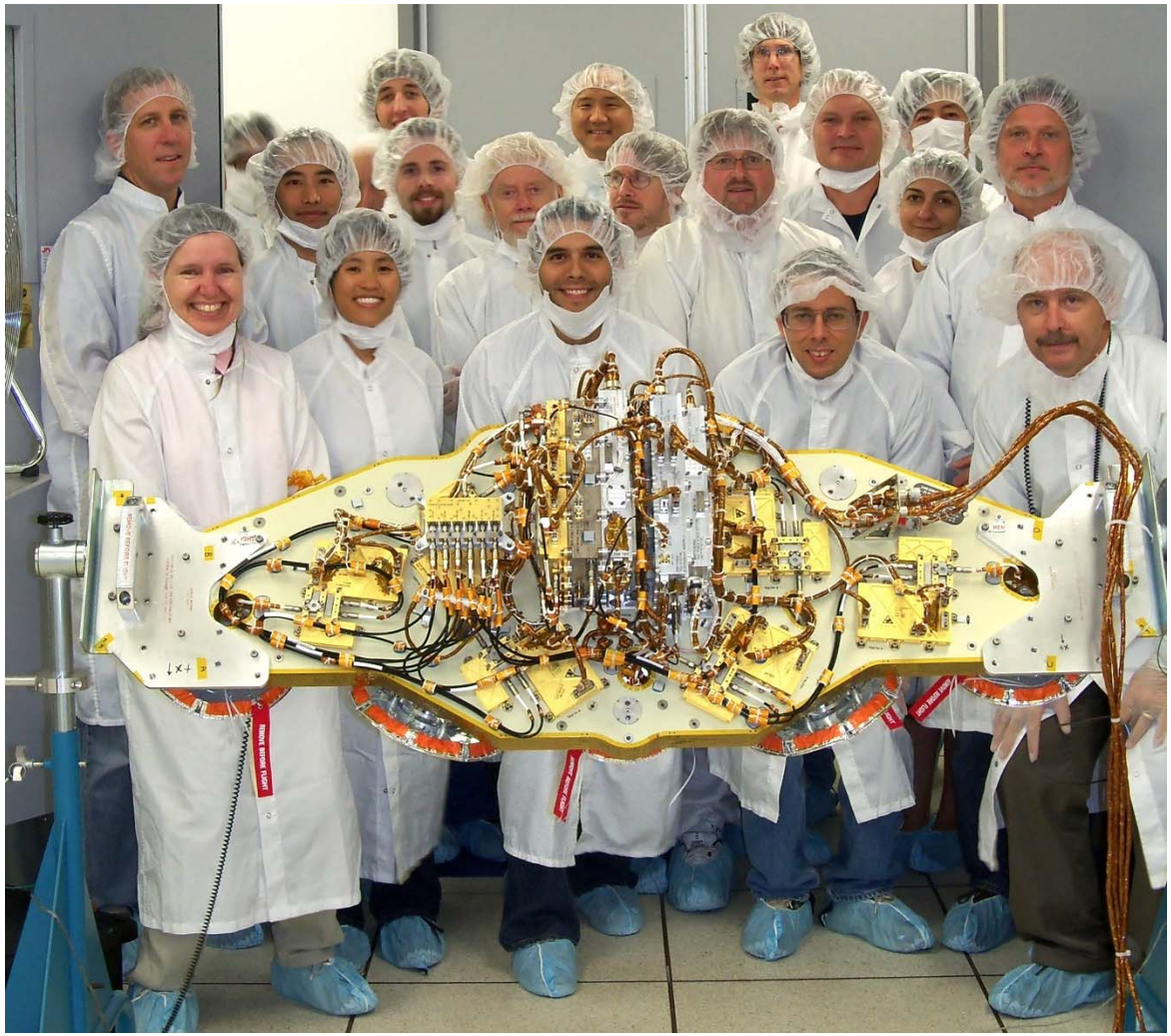
Papa rover, Mama rover and Baby rover

THE RADAR TEAMS

Programmatic Team
System Team
I&T Team
Antenna Team
Digital Electronics Team
Ground Support Equipment
Harness Team
Mechanical Team
Power Team
RF Team
Sub-Contractors

~115 People @ JPL

Radar I&T Team

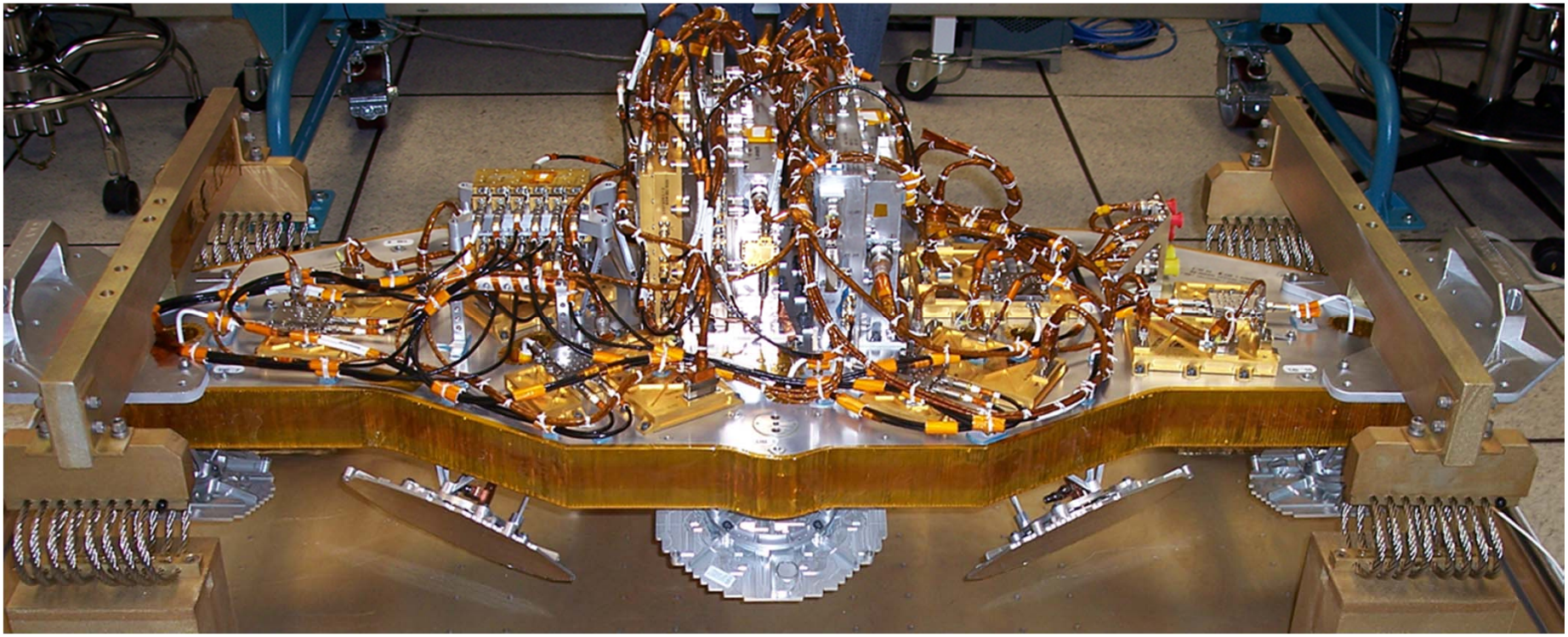


Mars Descent and Landing Radars

- Built for 8 Mars missions
- Altimeters and Velocimeters
  - Altitude (m) and speed (m/s)
- Radar specs are mission-based
  - Different entry parameters
  - Different frequencies and pulse widths
  - Antenna quantity and pointing based on vehicle structure
  - Hazard avoidance, when needed, done optically

The MSL radar – Terminal Descent Sensor

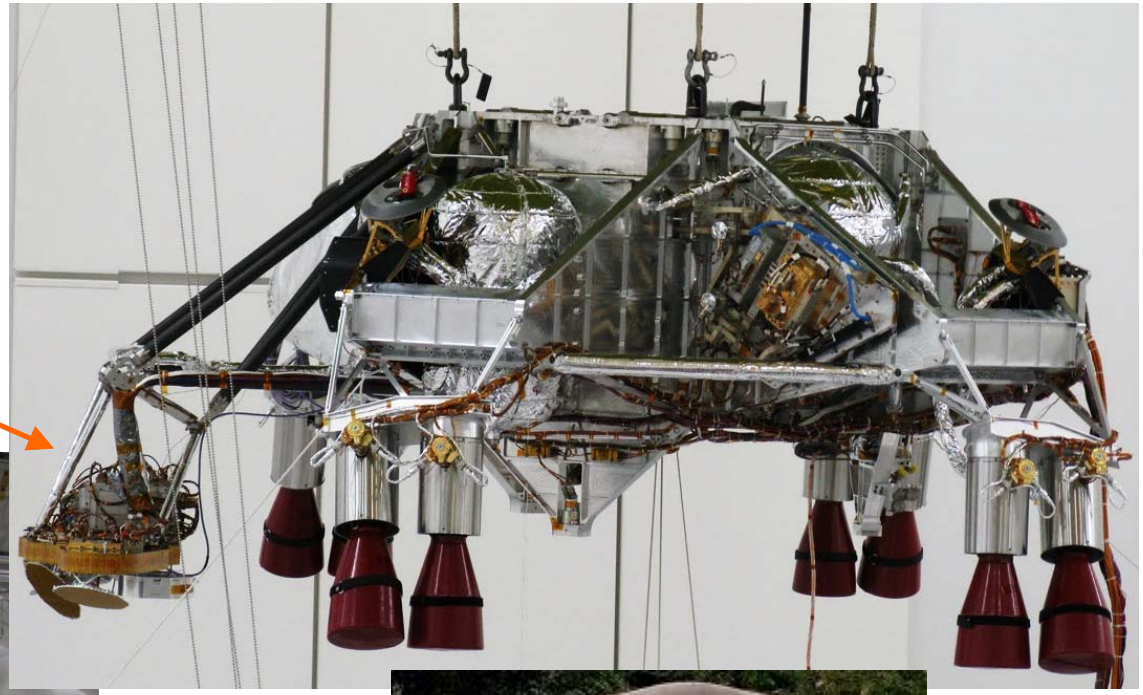
Flight unit ready for delivery

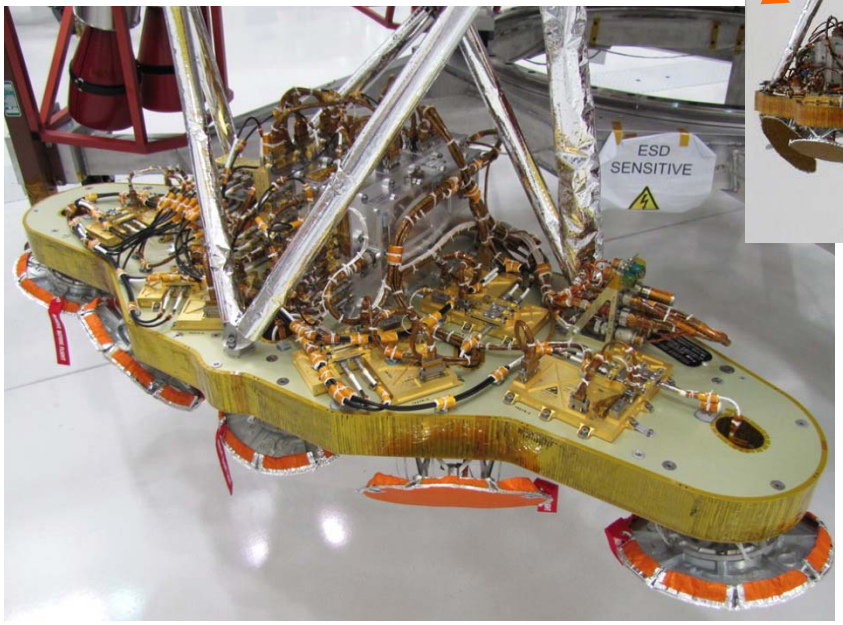


The MSL radar – Terminal Descent Sensor

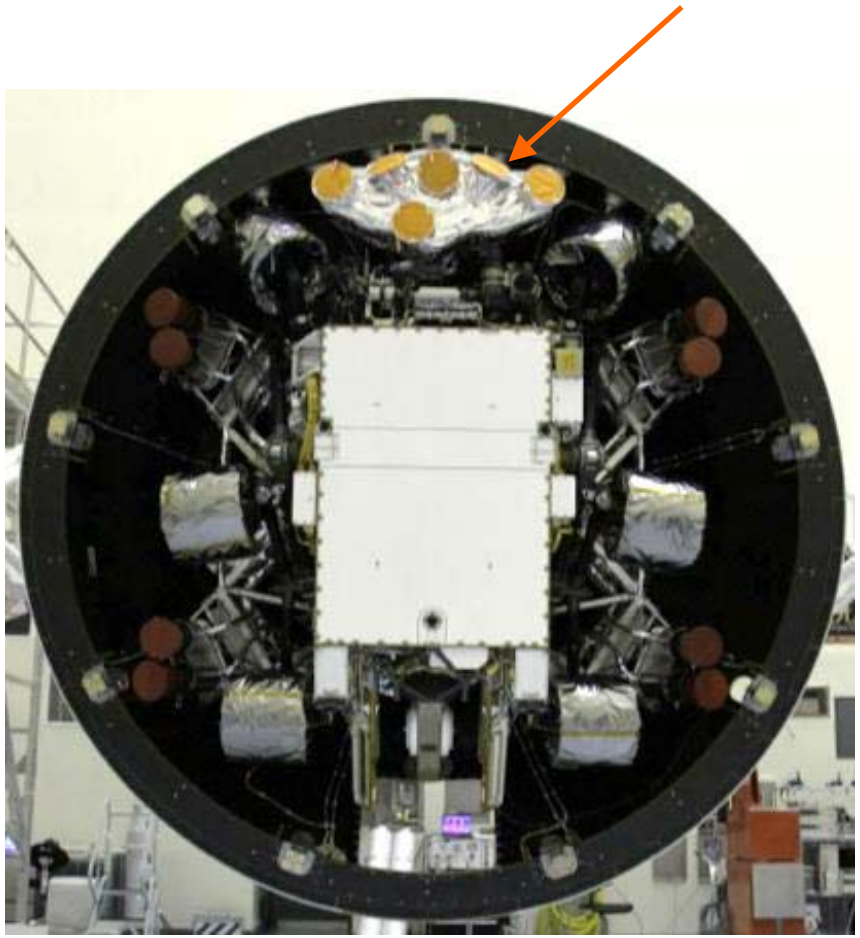
The MSL Radar – Terminal Descent Sensor

TDS mounted to Descent stage on the "Proboscis"





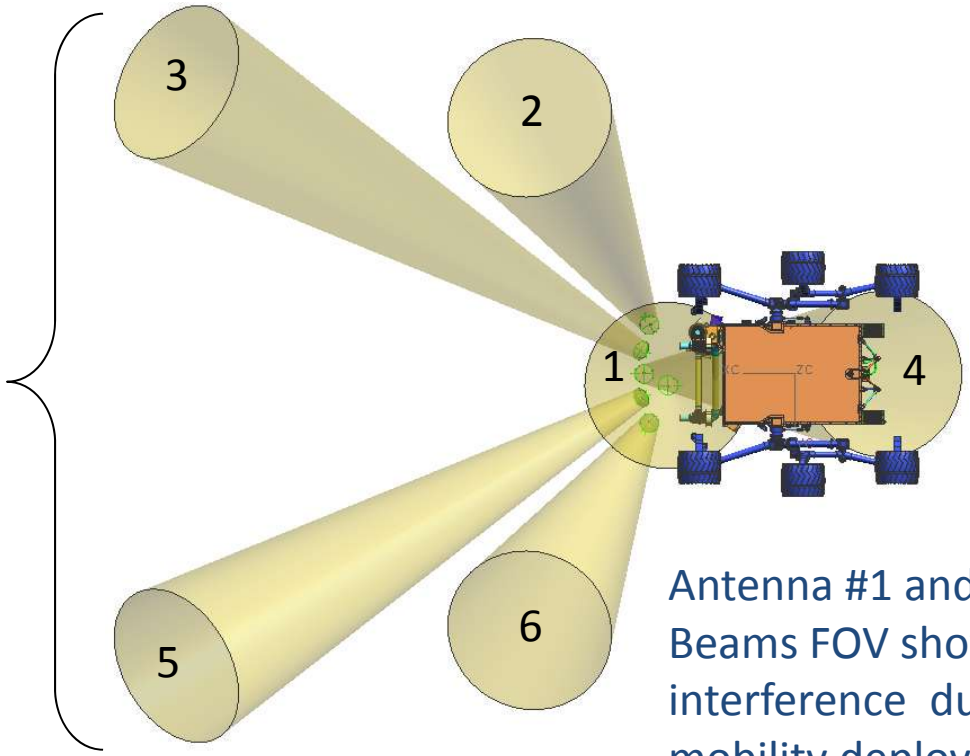
The MSL radar – Terminal Descent Sensor



- **The Radar Terminal Descent Sensor produces line of sight range and velocity measurements on 6 independent beams**
  - **Single antenna per beam, with 3 beams canted 20° off nadir, 2 beams canted 50° off nadir, and 1 nadir beam**
  - **Ka-band (35.75 GHz) center frequency**
  - **Radar used once during EDL for ~2 minutes (on for < 30 minutes)**
  - **Relatively simple pulsed Doppler radar**
  - **3500 to 5 meter range**
  - **0.75 m/s velocity**
  - **Beam update rate 50msec**
  - **"Memory-Less" data processing**
  - **35 kg mass, 110W DC Power**

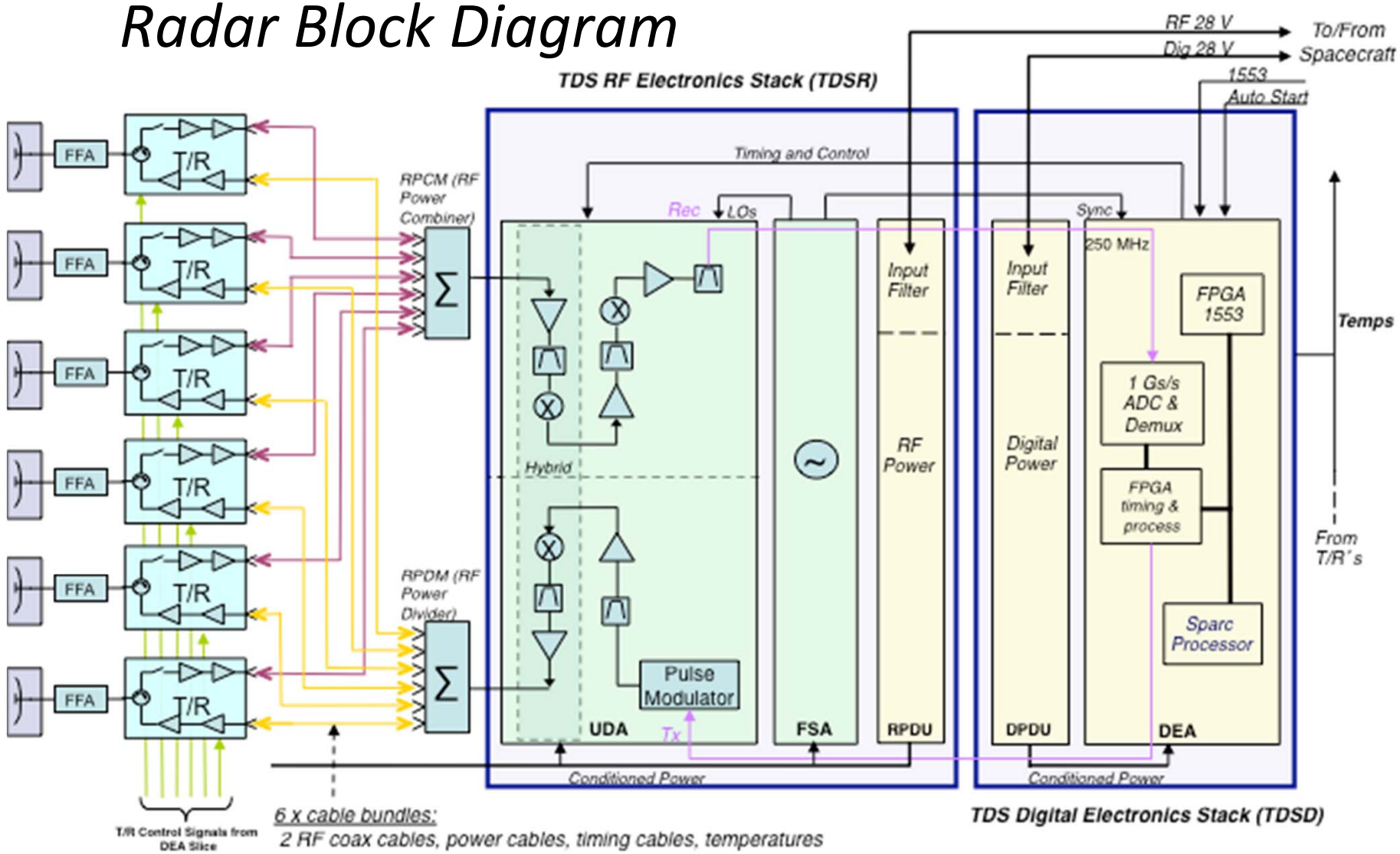
The MSL radar – Terminal Descent Sensor

- Far Field Beams of antennas #2,3,5 & 6 have a clear far field FOV during all stages of skycrane.
- However, only 2 & 5 are planned for usage due to near-field effects

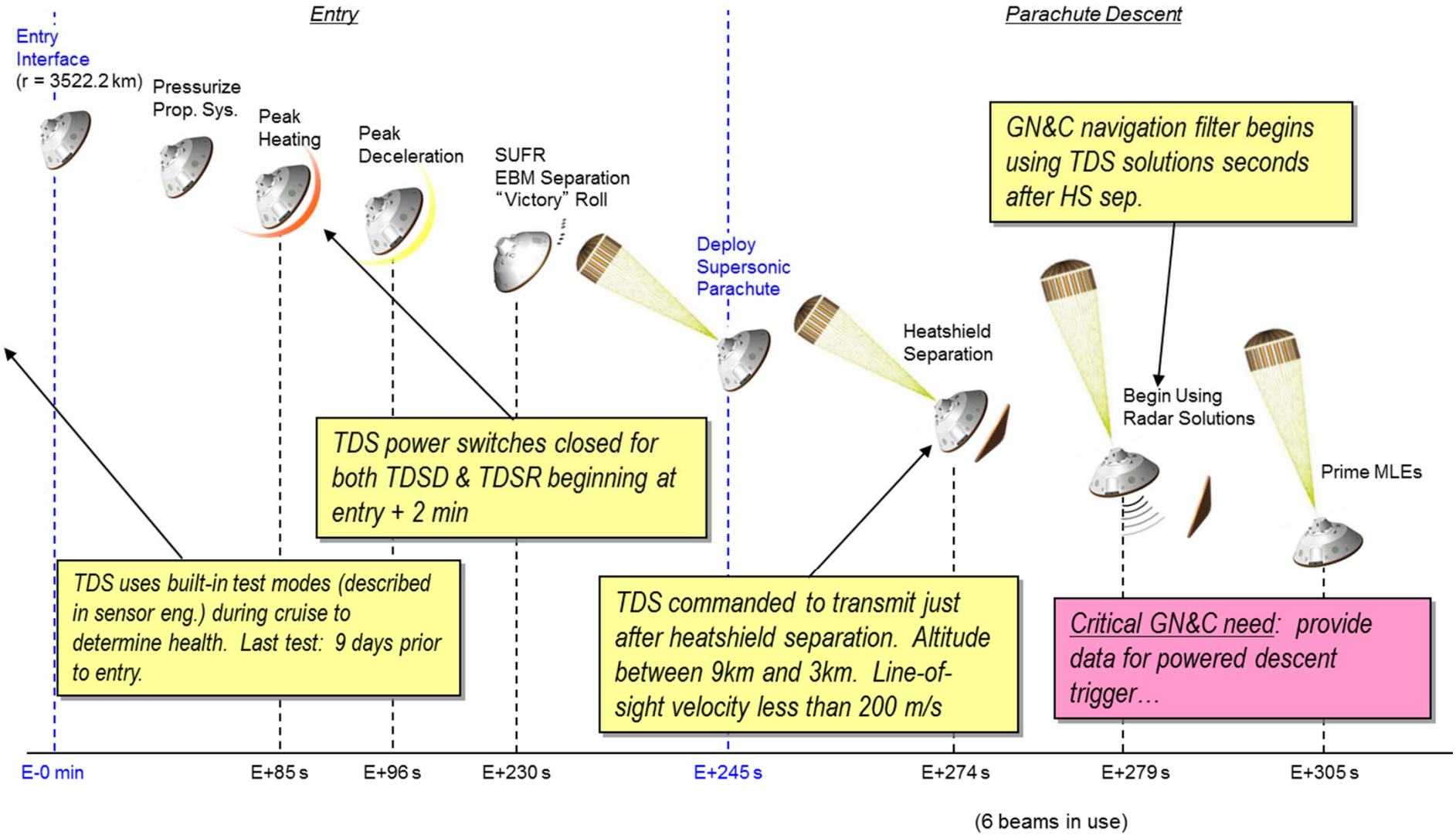


Antenna #1 and 4 far field Beams FOV show interference during mobility deployment and skycrane.

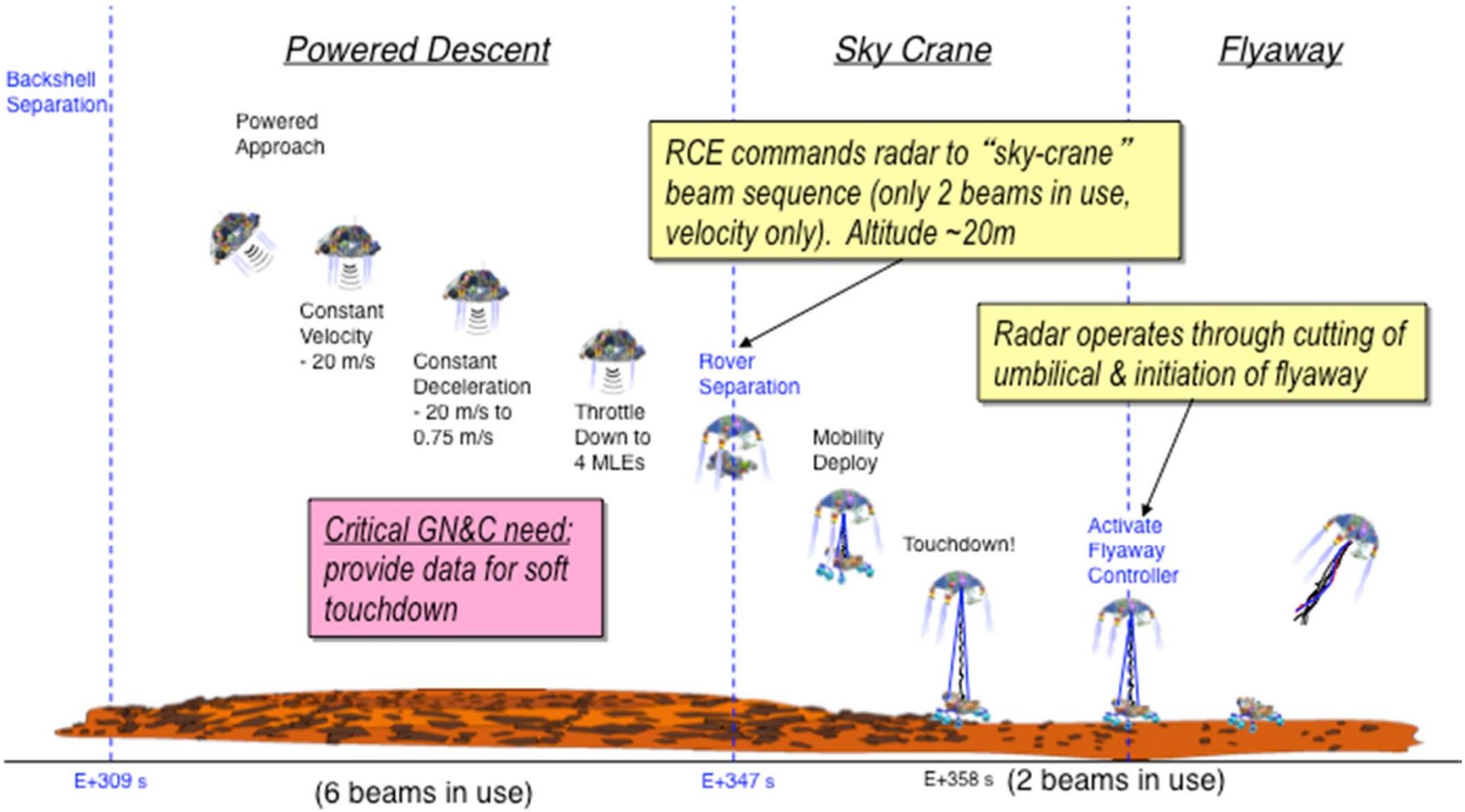
Radar Block Diagram



MSL radar – Timeline Part 1

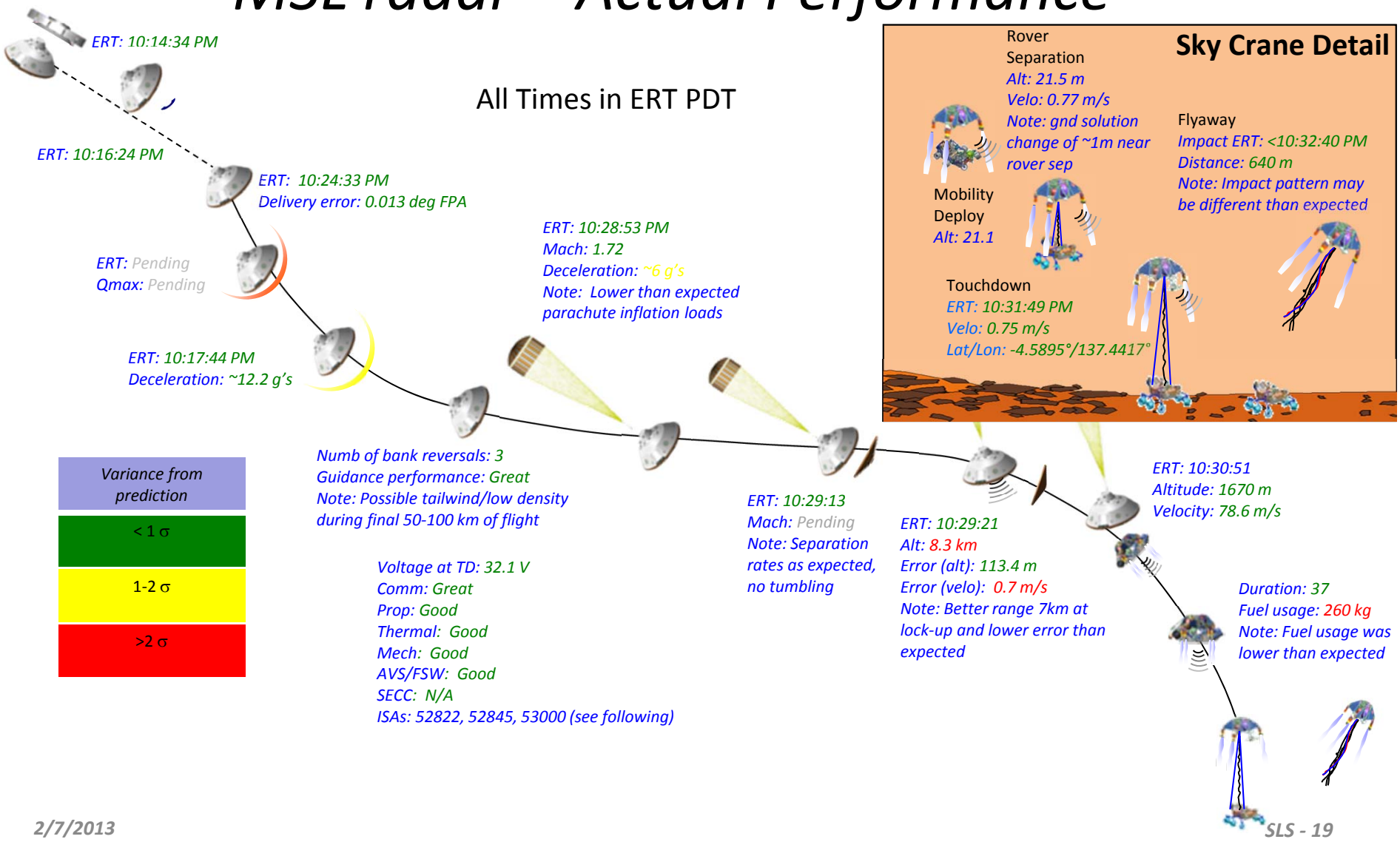


MSL radar – Timeline Part 2



MSL radar – Actual Performance

All Times in ERT PDT



Variance from prediction
< 1 σ
1-2 σ
>2 σ

Engineering Challenges

Engineering Diversity…

- Systems Design
- Computer Hardware and Software
- Structural, Thermal and Dynamics
- DC Power
- RF and Analog Electronics
- Antennas
- Support Equipment & Testing

Engineering Challenges - Design

Radar System Design

- Use legacy system designs whenever possible
  - Engineers are "Lavish Borrowers"
    - Don't like to redesign the wheel for anyone!
  - Heritage sought from Lunar Surveyor, Apollo LEM, Viking, Mars Pathfinder, MER and Phoenix
  - Several trade studies done to converge on best radar for the job
  - New innovations sought
  - Final design very similar to Viking

Engineering Challenges - Construction

Building the Hardware

- 90% of the hardware in the radar was new
- 100s of fabrication drawings required
- Reliance on 3D modeling, analysis and simulation tools
- Prototypes required to validate functionality
- Breadboards and Engineering models needed
- New processes developed for some assembly tasks.

Engineering Challenges - Testing

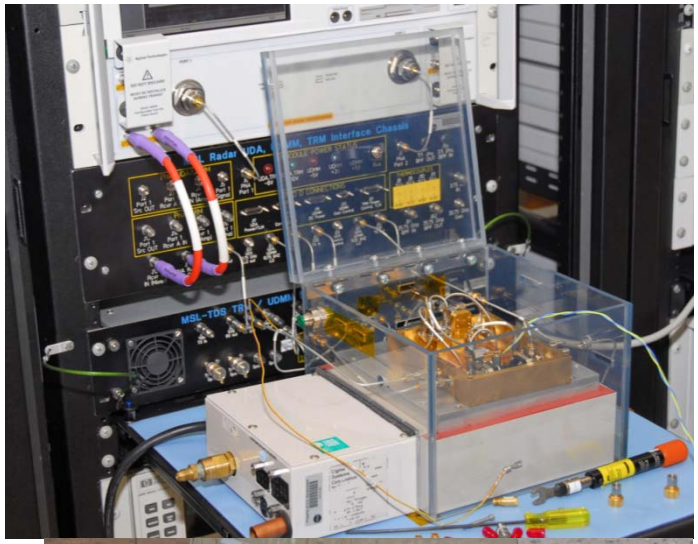
- Test-As-You-Fly mantra
- 1/3 of effort is building the flight hardware.
- 1/3 of effort is the design and building of test gear.
- 1/3 of effort is testing the hardware.
- Test gear needs to be tested and it's failure modes identified…is it safe to use? Prove it!

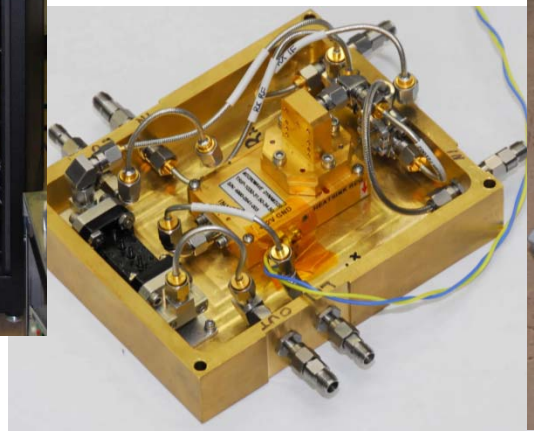
*Testing is **NOT** for dummies!*

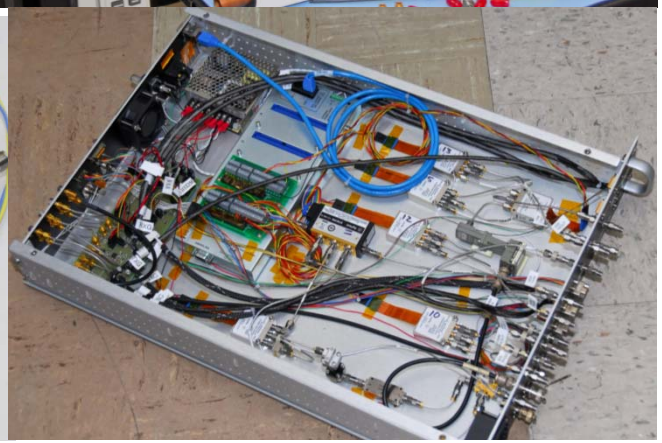
When you design a system consider how it can be built and tested!

Engineering Challenges - Testing

Test gear is a $Billion Industry!

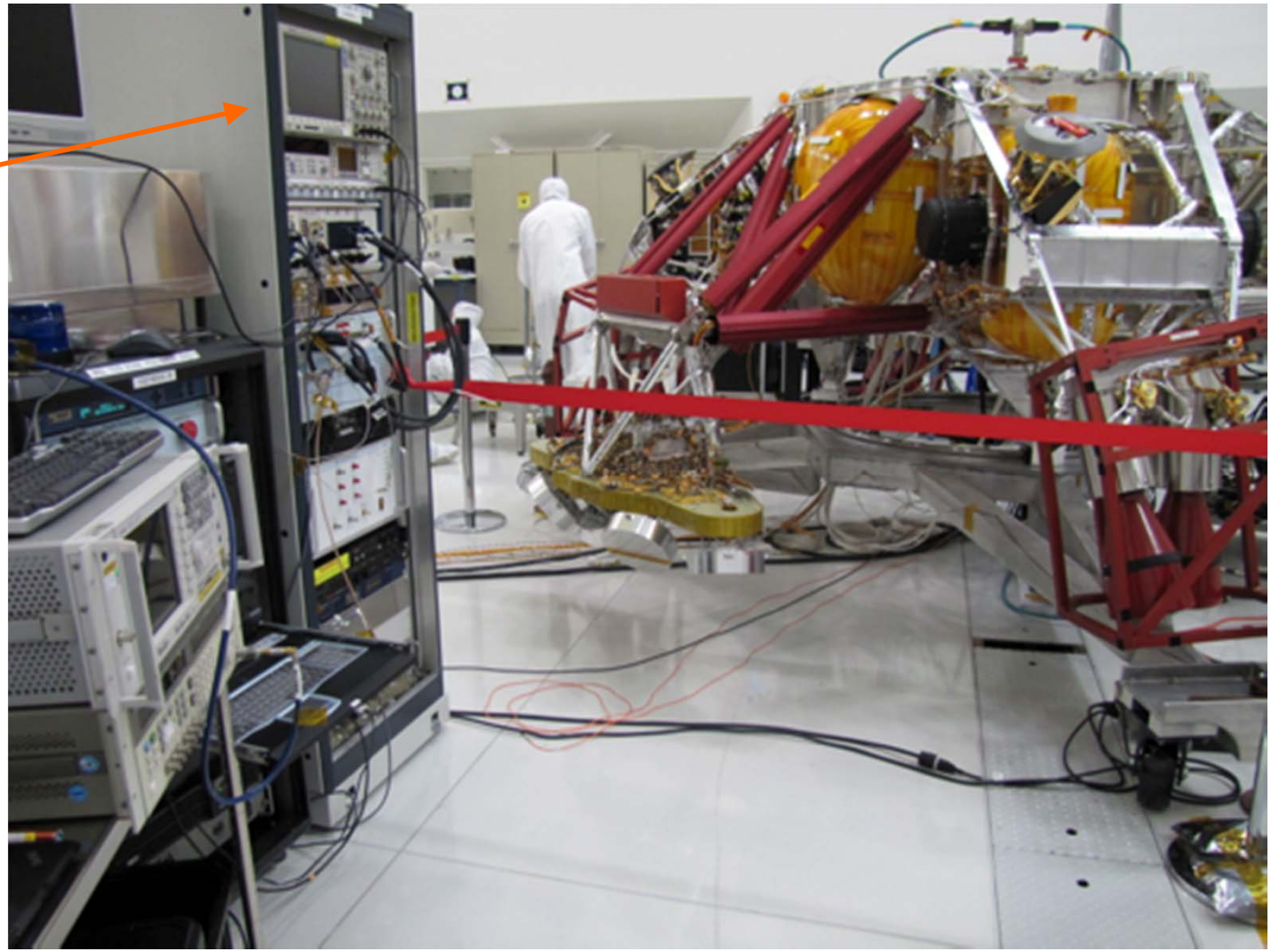






Engineering Challenges - Testing

Radar EGSE Test Racks

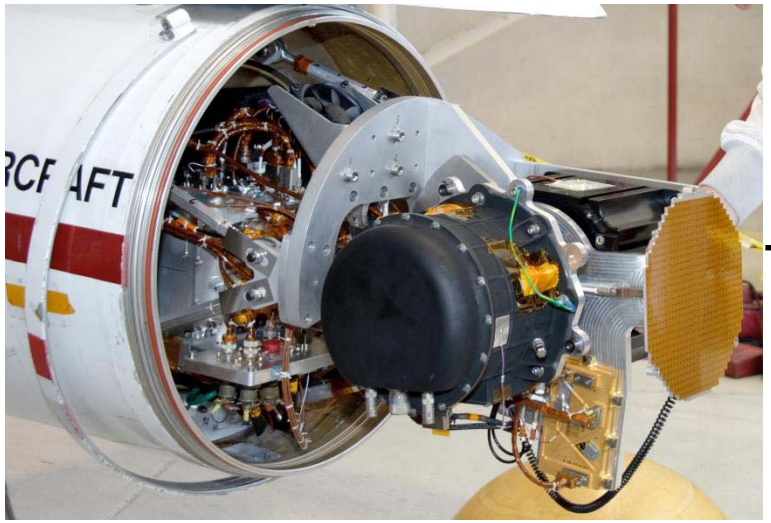


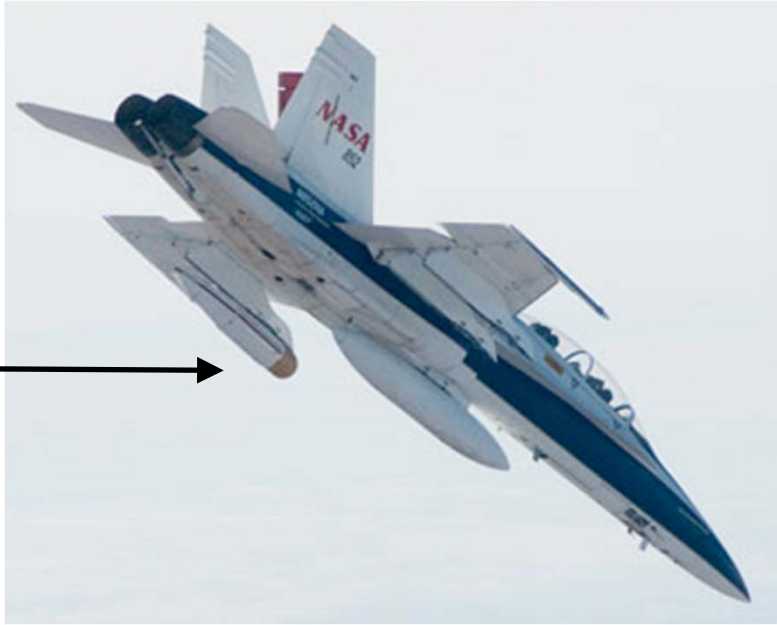
Engineering Challenges - Testing

Engineering Challenges - Testing

Radar Tests on NASA F-18 Fighter 2006 to 2011

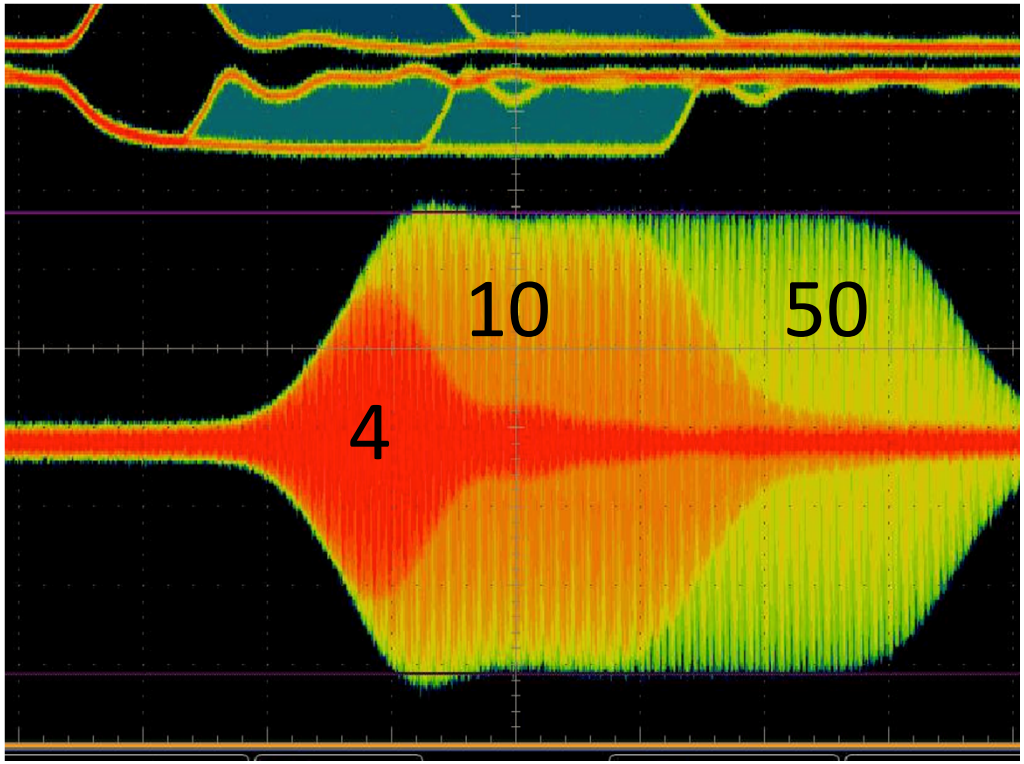
Single Antenna and TR Module Quick Test Pod

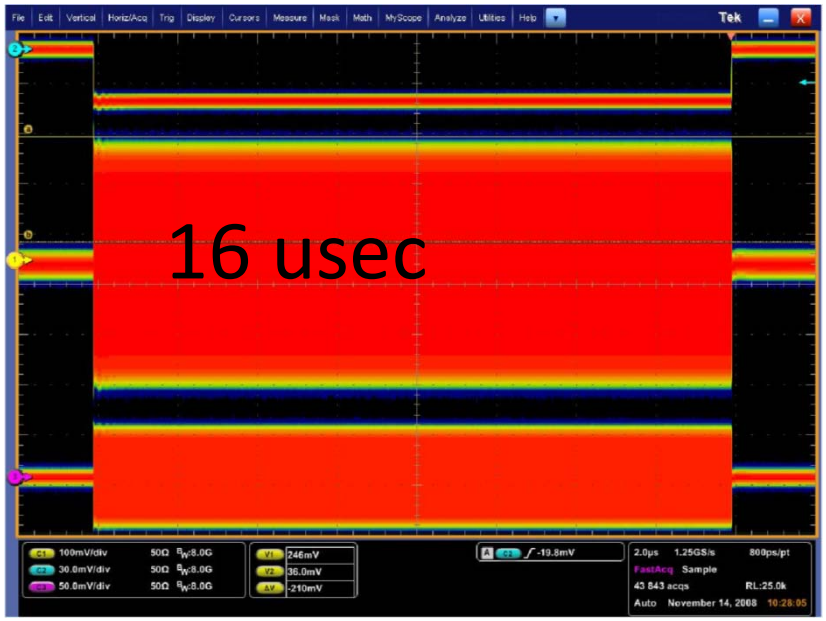




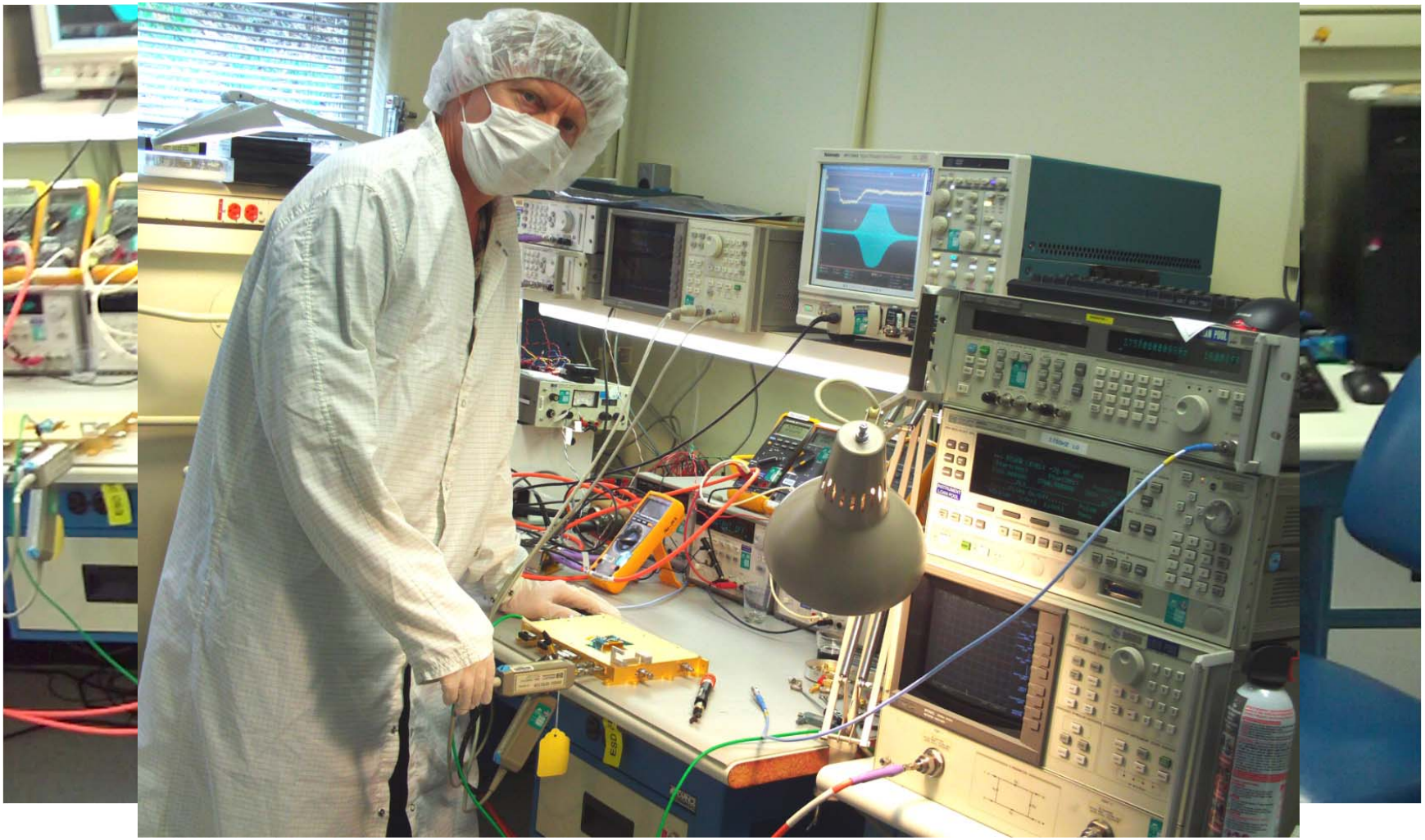
Engineering Challenges - Testing

Radar pulses range from 4 nsec to 16 usec





Engineering Challenges - Testing



Lessons Learned

- Two Major Categories
  - Management (Cost, Schedule, Resources)
  - Technical (Hardware and Performance)
- Management
  - Estimate scope-of-work early - S
  - Partition design and staff responsibilities early - R
  - Develop accurate parts costs models - C
  - Have deeper work (cost) breakdown structure - C
  - Factor in the cost of unforeseen failures - C

Lessons Learned

- Technical
  - Firm up technical requirements and specs early
  - Have good demarcation between build phases
  - Build and de-bug GSE early, not concurrently
  - Identify necessary documentation
  - Identify risky or difficult fabrication processes that can lead to latent failures.
  - Two examples:
    - Hermeticity and Parts Screening

Lessons Learned

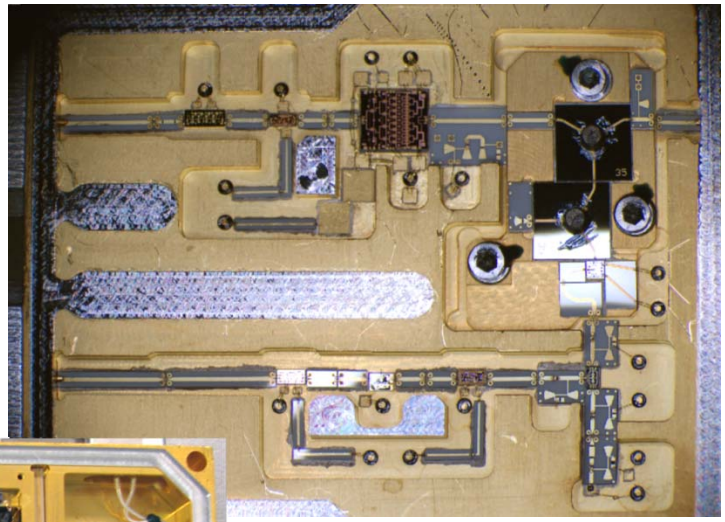
Technical Lesson #1 – Hermeticity (air tight seal)

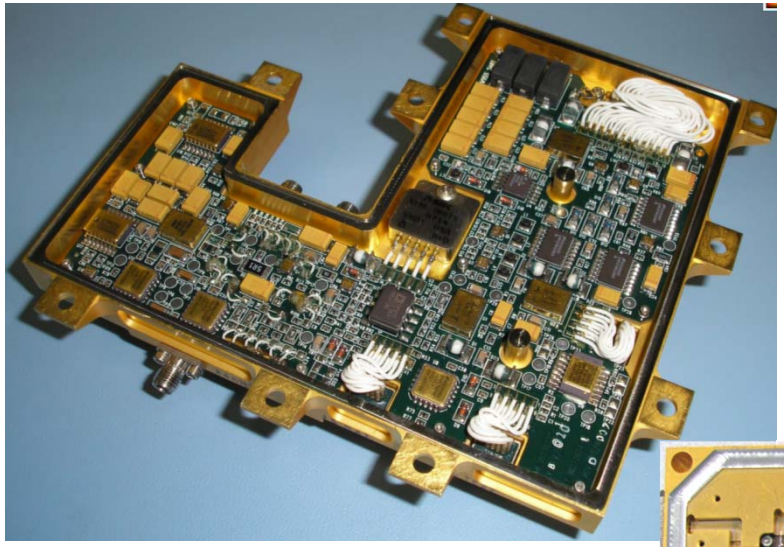
- Hermeticity was specified for T/R and UDMM modules fabrication
- Needed to prevent hydrogen poisoning, contaminating from gases (fluorine, etc.) and voltage breakdown effects
- Not really needed in this particular application
- Difficult to achieve for large enclosures
  - Laser sealing, cracks in hermetic feedthrough pins, etc.

Lessons Learned

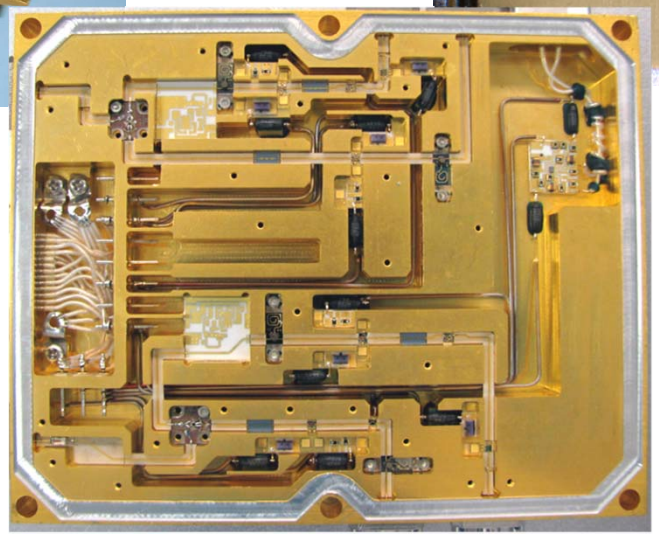
Technical Lesson #1 - Hermeticity

T/R Module RF Side





T/R Module DC Side



UDMM Module RF Side

Lessons Learned

Technical Lesson #1 – Hermeticity

Why do we need it?

- 4 Main reasons
  - #1 Hydrogen Poisoning
    - Un-passivated RF GaAs MMICs can be "poisoned" by the presence of hydrogen gas.
    - Atomic hydrogen can diffuse into the FET channel neutralizing the charge donors.
    - Degrades FET I_{DSS}, V_p and g_m and RF output power
    - Solved by thermal-vacuum bakeout, getters and hermetic seal in 1 ATM dry gas (e.g., N, He Ar, Xe).

Lessons Learned

Technical Lesson #1 – Hermeticity

#2 Contaminating Gases

- Certain gases (Halogens) and humid, salty air can etch component surfaces and lead to latent failures.
- Solved by thermal-vacuum bakeout and hermetic seal in 1 ATM dry gas (e.g., N, He, Ar, Xe).

Lessons Learned

Technical Lesson #1 – Hermeticity

#3 Voltage Breakdowns

- Voltages susceptible to ionization breakdown at certain pressures and levels (> 200V).
- Critical pressure region: 500 Torr to $5x10^{-4}$ Torr
- Region where gas density = liquid density
- Mean-Free-Path (MFP) of gas < Molecule separation
- At critical pressure secondary emissions occur because of collisions. Dielectric strength of the gas decreases and an arc occurs.
- Solved with hermetic sealing of enclosure or venting.

Lessons Learned

Technical Lesson #1 – Hermeticity

#4 "Multipaction" RF Breakdowns

- RF fields in very low pressure or vacuum can cause multiple impaction (Multipaction) of electrons from surfaces.
- Formula for MP threshold: $V_0 = (2\pi d/\lambda)^2 \times (m_e - c^2/\pi e^-)$
- RF voltages accelerate the electrons and the secondary emissions become resonant at the signal frequency.
- MFP > Molecule separation (opposite voltage breakdown case)
- Not an issue at lower RF power
- Avoided by keeping the gaps large, filling the gap with a dielectric or hermetic sealing.

Lessons Learned

Technical Lesson #1 – Hermeticity

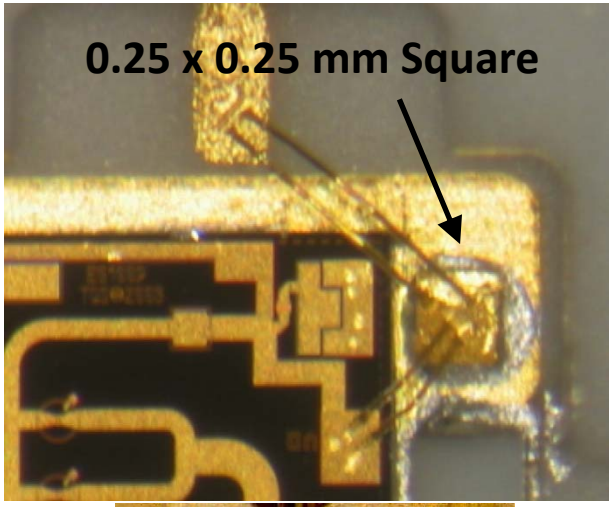
LESSON:

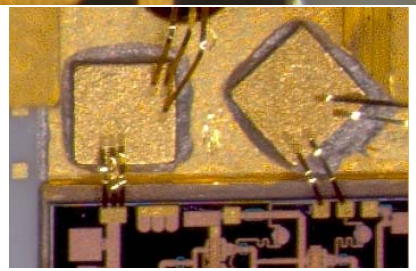
- Based on thorough analysis of the circuits involved and operating conditions, determine if hermetic sealing is ***really*** needed. If not don't use it.
- If really needed, perfect the processes needed to achieve it.

Lessons Learned

Technical Lesson #2 - Die Capacitor Screening

- Tiny die capacitors used many places (>130) in T/R and UDMM modules.
- Must be screened adequately before usage.
- Problem "popped up" during final module testing.
- Very expensive to solve after everything is built and sealed up.





Lessons Learned

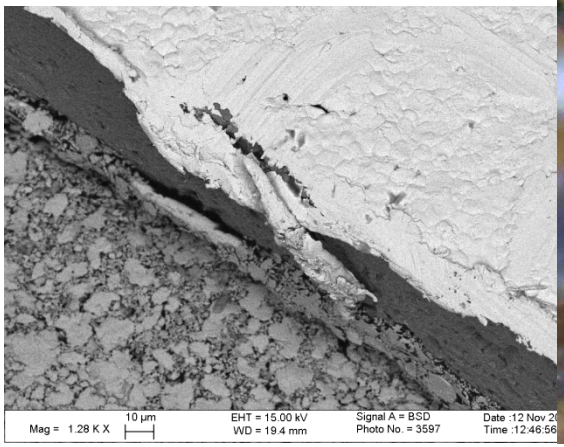
Technical Lesson #2 - Die Capacitor Screening

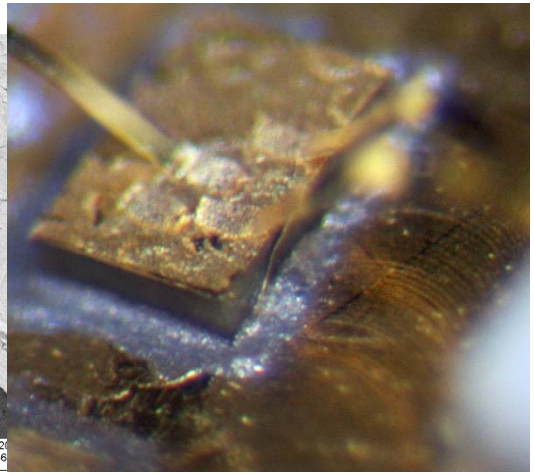
- Process used to dice capacitors smeared and broke the gold at the edges.
- Shards can move and short the capacitor
- We never experienced this before

LESSON:

Confirm parts MFGs follow their processes.

Inspect critical tolerances more carefully.





7
MINUTES OF
TERROR

Engineer Mighty Things!
Thank You
Special Thanks to Elaine Chapin, Brian Pollard,
Mike Tope, Jeff Hilland and Sean Howard @ JPL

Audience Q&A

- Please limit your questions to the scope of this presentation.
- If I don't know I will find out and get back to you
- You are welcome to contact me via email at: sstride@jpl.nasa.gov