Radiation Dose Testing on Juno High Voltage Cables

Nelson W. Green, Harold Kirkham, Wousik Kim, and Bill McAlpine

Jet Propulsion Laboratory, Pasadena, CA USA
California Institute of Technology

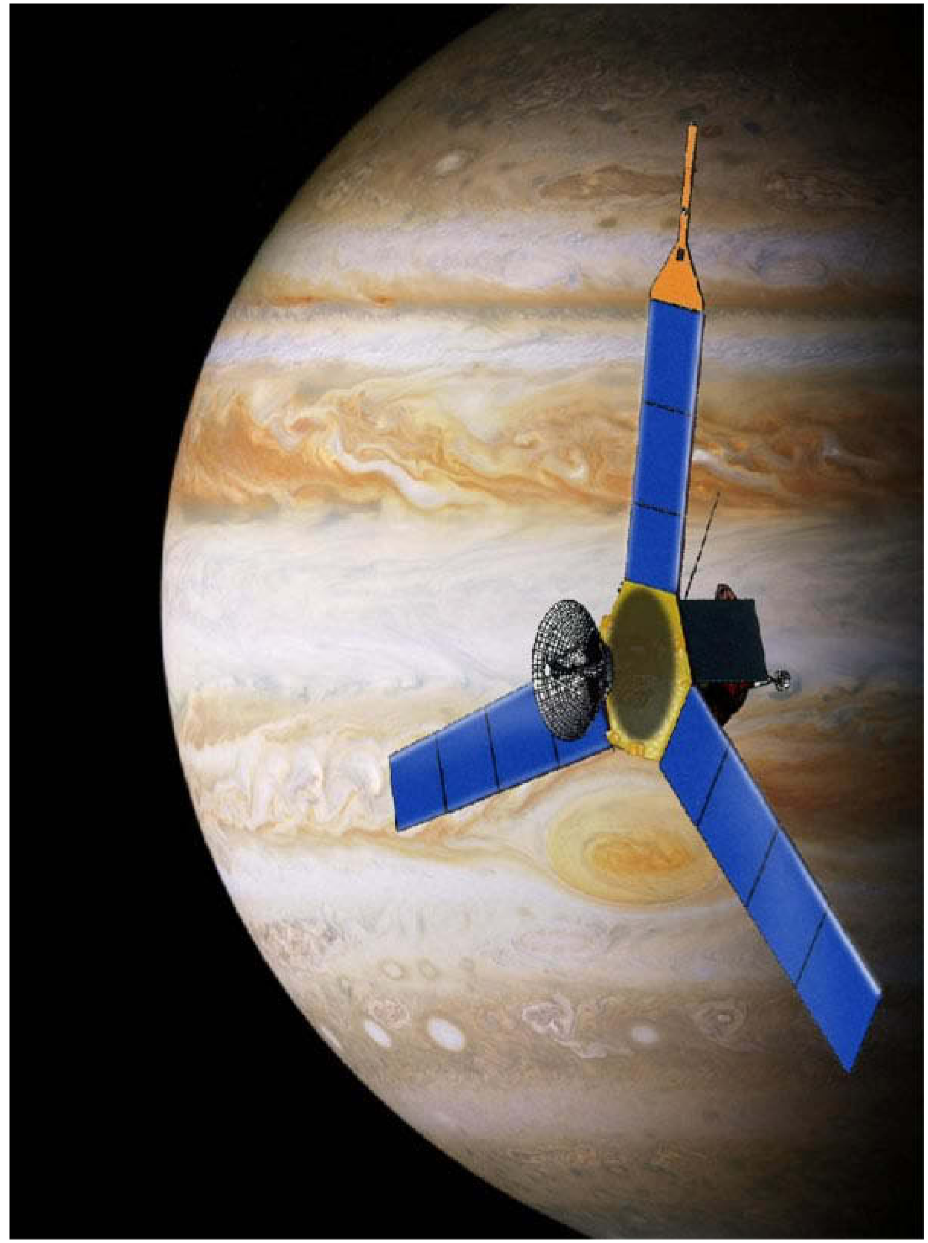
Presented at the

47th AIAA Aerospace Sciences Meeting and Exhibit
Orlando World Center, Marriott, Orlando, Florida

January 5th, 2009

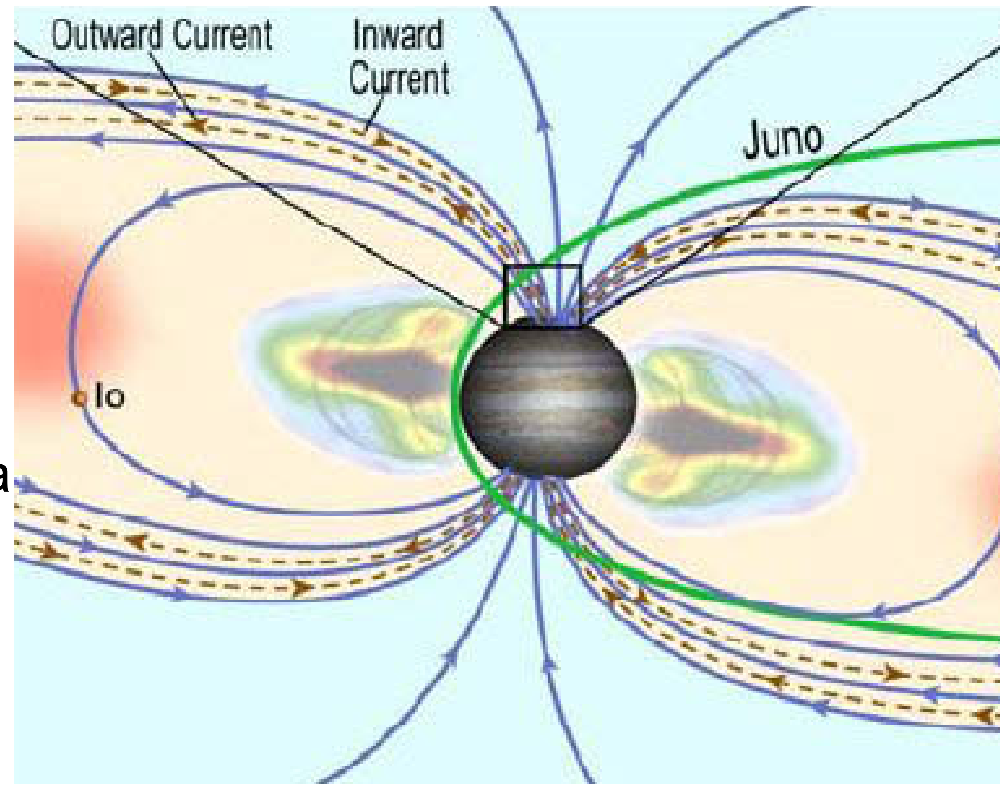
Topics

- Introduction
- Mission Environment
- Sample Selection
- Experimental Setup
- Results
  - Capacitance
  - Partial Discharge
  - IESD
- Conclusion



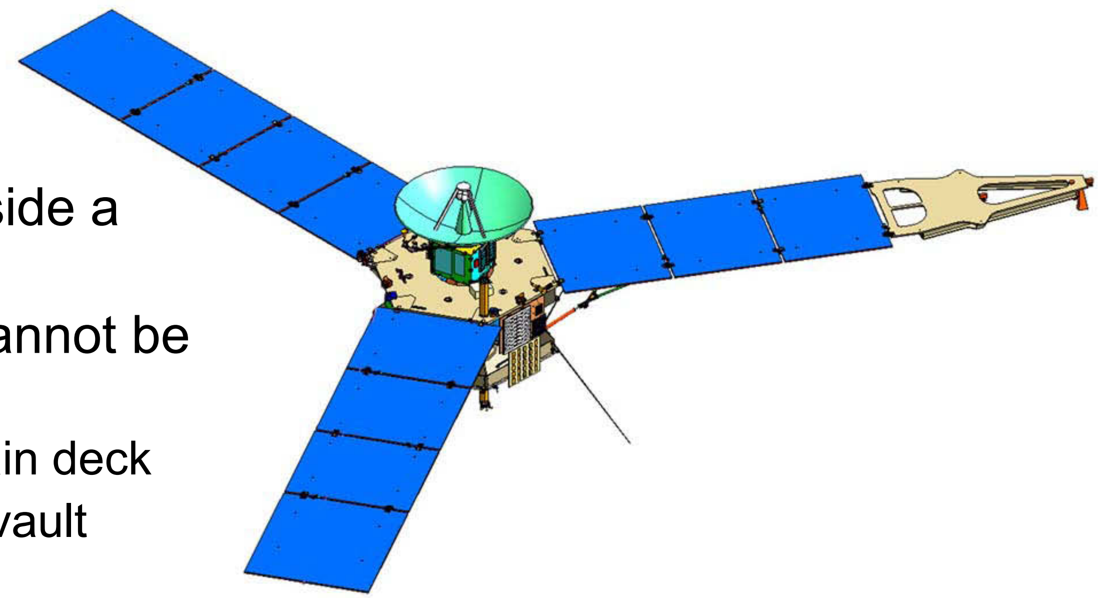
Introduction

- Juno mission to Jupiter
  - New Horizons mission
  - Launch in 2011
  - Arrive at Jupiter in 2016
- Mission objectives
  - Map interior of Jupiter
  - Measure magnetic fields and aurora
  - Observe atmosphere in detail
- Highly elliptical orbit
  - Closest approach 1.06 Rj
    - ~11 day orbit
  - Passes through auroral zone and under radiation belts
- Total mission
  - 32 science orbits
  - ~ 1 year in duration



Introduction

- Radiation environment
  - Orbit designed to avoid main radiation belts
  - Still very heavy radiation dose

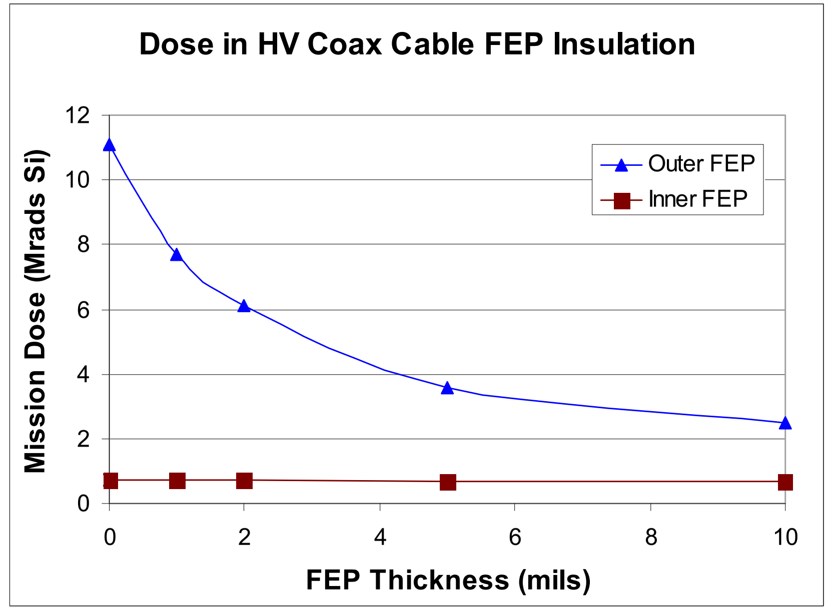


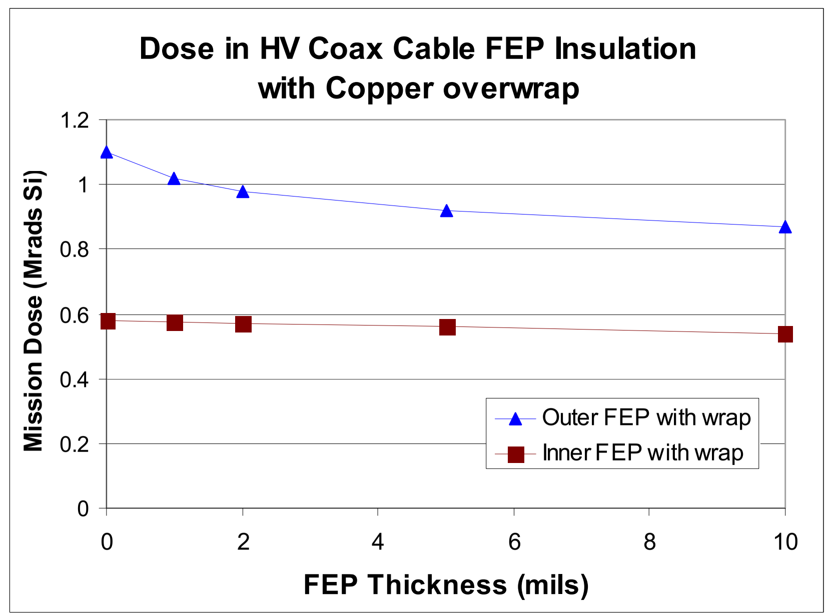
- Mitigations
  - Most spacecraft electronics inside a protective vault
  - Several science instruments cannot be inside vault
    - Measurements made from main deck
    - Power and processing inside vault
    - Connections made via cabling

- Effect of radiation on cabling is unknown
  - Particular interest in High Voltage cables
    - Teflon (FEP) insulation
    - Changes in dielectric properties due to radiation

Mission Environment

- Environmental definition
  - Dominated by energetic electrons
    - Energetic protons present but fluxes are orders of magnitude less
  - Test spectrum centered on electron flux
- Cables mounted on top deck
  - Under thermal blankets
    - Thermal blankets block low end of spectrum
    - Keep temperatures at -50°C
  - Energetic electrons will still impart dose
- Copper outer shield (100µm)
  - Used to block EMI
  - Order of magnitude less dose to outer cable jacket
  - IESD reduction



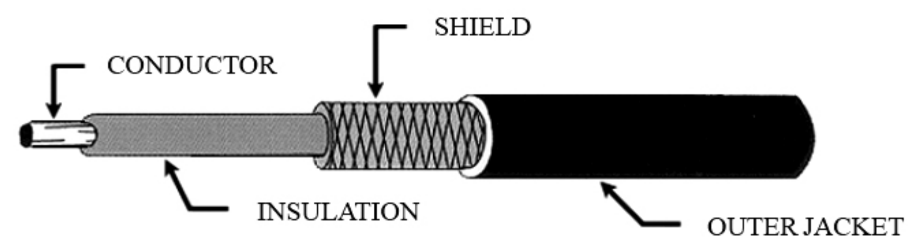


Mission Environment

- Calculated environment for testing
  - Radiation Dose Factor (RDF) of 2 was used for testing
  - Inner FEP insulation
    - Without copper shield – 1.4 Mrad
    - With copper shield – 1.2 Mrad
  - Outer FEP jacket
    - Without copper outer shield – 22 Mrad
    - With copper shield – 2.2 Mrad
  - Temperature under MLI thermal blankets: -50°C
- Radiation sources (planned)
  - Inner dielectric dose
    - 1.5 MeV and 750 keV electrons
    - Cobalt-60 (Co-60) gamma
  - Outer jacket
    - 75 keV electrons

Sample Selection

- High Voltage Cables
  - Coaxial cable
  - Two sizes to be used on spacecraft
    - Thicker cable
      - Diameter: ~3 mm
      - Rated for 22 kVdc
    - Thinner cable
      - Diameter: ~2 mm
      - Rated for 18 kVdc



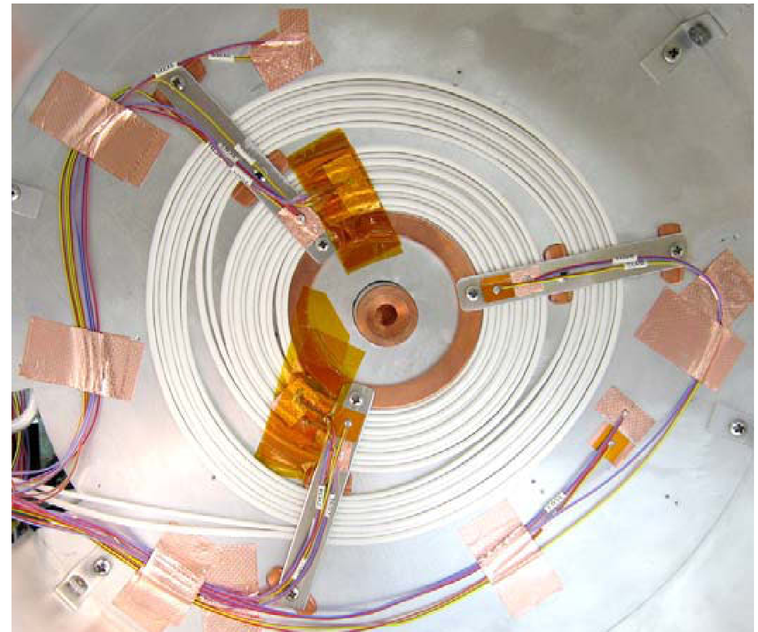
- Derated by half for flight use
  - Max voltage applied: + or – 10 kVdc
  - Voltages are DC or a very slow stepping ramp

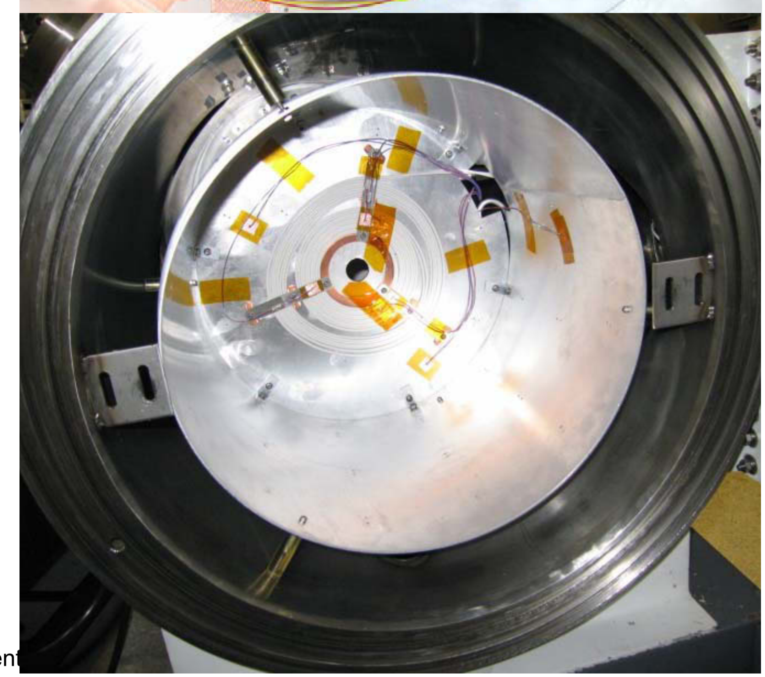
Sample Selection

- Cables will be used by several science instruments
  - High voltage sources in protected vault
  - Instruments on outside
    - Total cable length ~4 meters
- Test Samples
  - Supplied by science instrument manufacturers
    - As flight-like as possible
    - Both sizes to be tested
  - Cable characteristics
    - ~45 ohm nominal impedance
    - ~100 pF/m capacitance per unit length
    - White in color without added pigment
  - No copper outer shield to facilitate exposing outer jacket

Experimental Setup

- Both cables tested simultaneously
  - 4 ½ meters of each cable cut from length supplied
    - 4 meters of each cable to be exposed
    - ~ ½ meter left to attach to chamber feedthroughs
- Cables cooled during exposure
  - Conductive cooling
  - Cables wrapped in a spiral
  - Strapped down with thin Al strips
    - Hold cables against plate
    - Improve thermal contact
- Cold cylinder (mini shroud) used to reduce radiative heat transfer from chamber walls





Experimental Setup

- Exposure conditions
  - Samples on cold plate placed in a vacuum chamber
    - Vacuum at ~5×10^{-6} torr
    - Outgassed for overnight prior to cooling
  - Cold plate cooled with liquid nitrogen (LN_2)
    - Monitored with thermocouples
    - Temperatures controlled with an automated system
      - Cable surface temperature: -45°C
      - Cold plate temperature: -100°C
    - Cables allowed to reach thermal equilibrium prior to exposure

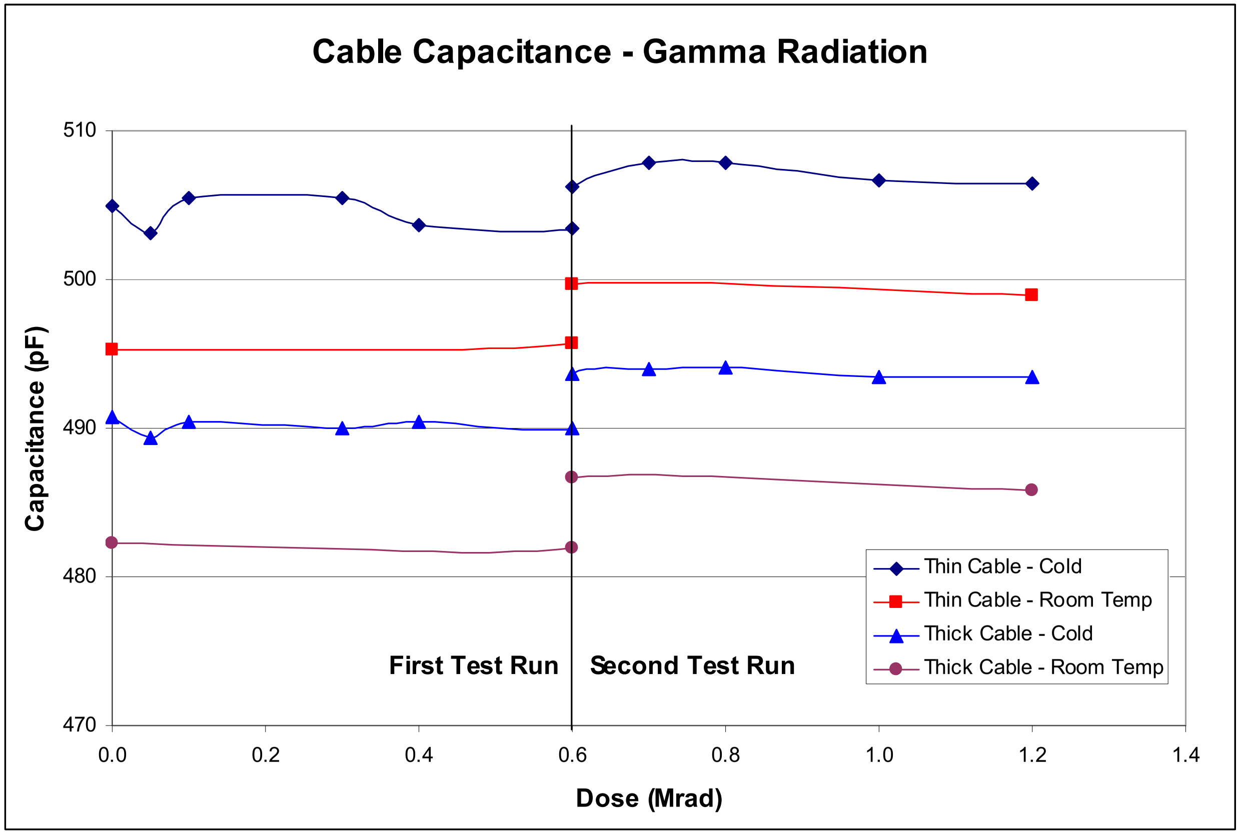
Experimental Setup

- Radiation Sources
  - Plan called for three sources
    - Inner dielectric dose
      - 750 keV and 1.5 MeV electrons
      - Co-60 gamma
    - Outer jacket dose
      - 75 keV electrons
- Source problems
  - High energy electron accelerator failed
    - Accelerator down for more than 5 months
    - Co-60 gamma used for all inner dielectric dose
      - Used to maintain schedule and cost
  - Dose given in three segments
    - Co-60 gamma (0.6 Mrad)
    - 75 keV electrons (2.2 Mrad)
    - Co-60 gamma (0.6 Mrad)

Capacitance Measurements

- Cable electrical parameters
  - Used two basic instruments
    - Capacitance meter
    - Partial Discharge tester
- Capacitance
  - Load on instrument high voltage supplies is mostly capacitive
    - Cable capacitance is a large portion of the load
    - Changes in cable capacitance may influence accuracy of the measurements
  - Capacitance measurements
    - Before test
    - After cooling, before radiation exposure
    - At intervals during radiation
    - After radiation
    - After warming to room temperature
  - Capacitance measurements were only tests done in situ

Capacitance Results



- Capacitance changed very little due to radiation
  - Absolute change (room temp) ~0.7%
  - More likely due to instrument measurement issues
- More capacitance change due to temperature
- Likely not to be an issue on spacecraft

Partial Discharge Measurements

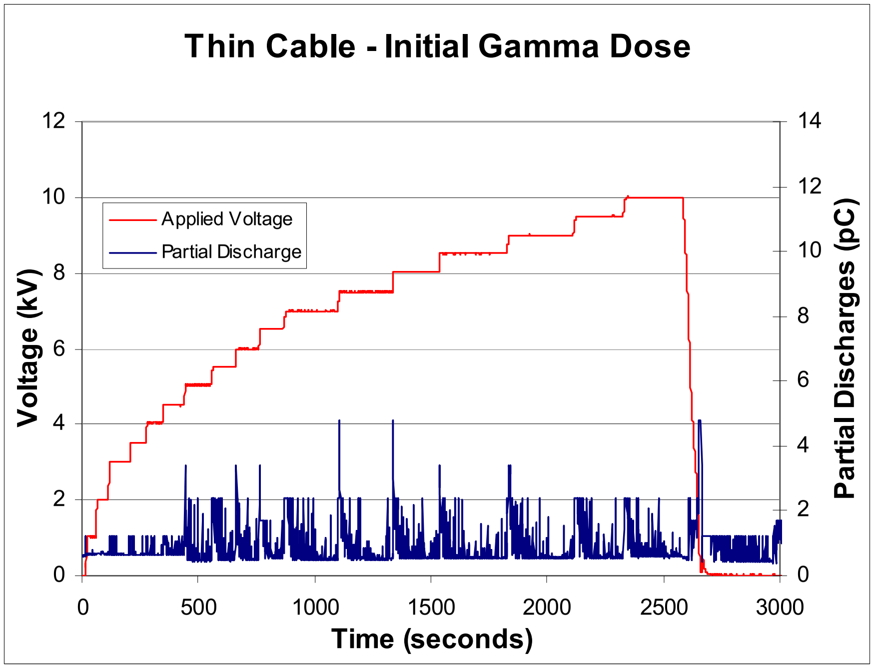
- Non-destructive
  - Used to determine insulation quality
- High fields placed across insulation
  - Field intensification at voids or inclusions
  - Small, non-breakthrough discharges occur
  - Redistribution of charge measured by detectors
    - Higher pC number = More frequent or larger partial discharges
      - Generally indicate lower quality insulation
- Extensively used in power industry
  - Well researched for 50-60 Hz (AC) use
    - 10 pC used as a pass/don't pass threshold
  - Not often used in DC applications
    - No fixed standard
    - Borrow threshold from AC testing

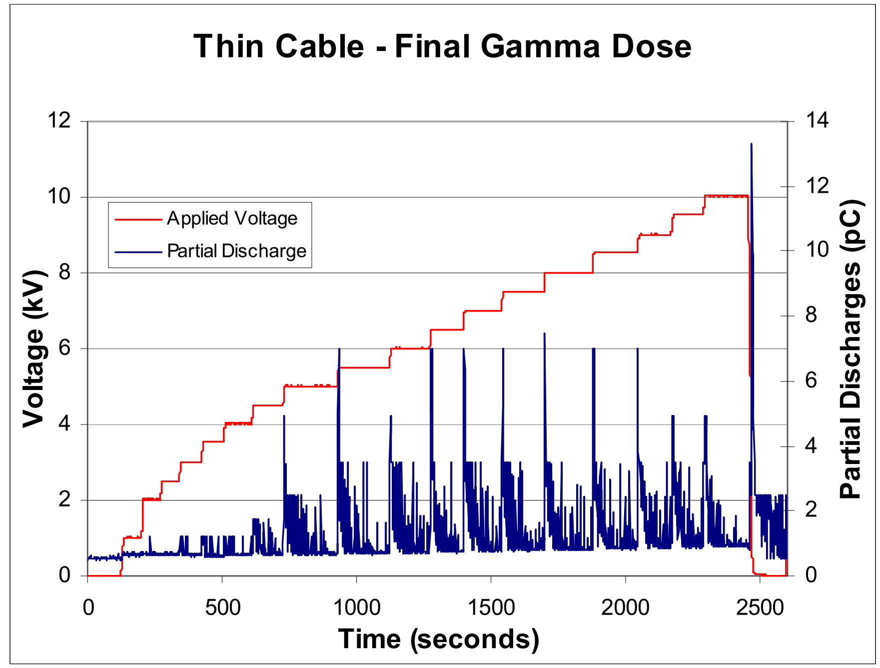
Partial Discharge Measurements

- Measurement technique
  - Based on research done at Goddard**
  - High voltages increased in steps
    - Each step looks a little bit like AC
    - Allows transition changes to be examined
      - Changes in electric fields
      - Polarization effects
  - Partial discharges at changes likely to be higher
  - Sustained partial discharge level of greater importance
- Cables tested in a Faraday cage
  - Room pressure and temperature
  - Less electrical noise to disturb measurements
  - In situ measurements found to be impractical

**Bever, R.S., "Ramp Technique for dc Partial Discharge Testing," IEEE Transactions on Electrical Insulation, Vol EI-20, No 1, February 1985 pp. 38-46

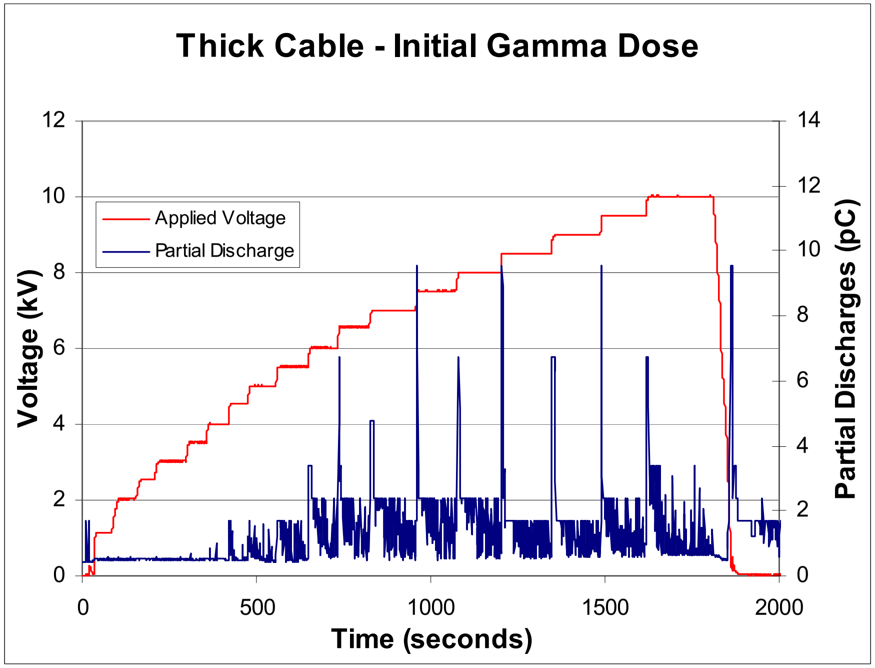
Partial Discharge Results

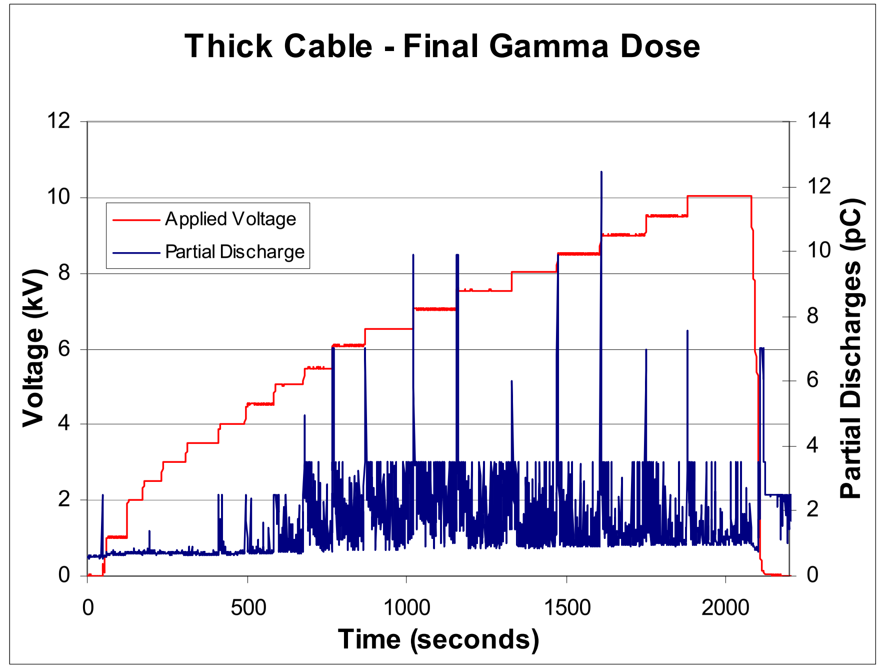




- Measurements shown are after first and last radiation exposure
  - Pre-test measurements unusable due to calibration error
- Noticeable change due to radiation dose
  - Height and frequency of peaks at voltage change
  - Sustained partial discharge levels increased
- Still well below 10 pC threshold from AC testing
  - Cable dielectric seems likely to survive without issue

Partial Discharge Results





- Similar results with thicker cable
  - Changes are not a pronounced as seen with the thinner cable
- Changes with increasing radiation dose
  - More and higher peaks with voltage change
    - Peaks beyond 10 pC level
    - Likely not significant
  - Sustained partial discharge level increased

IESD Testing

- Additional test beyond original test plan
  - Possible during outer jacket exposure
    - 75 keV electrons
    - 100 pA/cm^2 current density
- Cable outer jacket charged by electrons
  - 75 keV electrons stopped in outer FEP jacket
    - Electrons trapped in insulator
      - Charge migration to ground very slow
      - Large electric fields generated by large numbers of electrons
    - Image charges gather on nearby conductors in proportion to gathered electrons
  - Discharge Occurs
    - Field intensification at some trigger point
    - Dielectric breaks down and arcs
      - Plasma cloud may be emitted into chamber
      - Positive charges attracted to negative surface
  - Image charges redistribute in conductors
    - Image charge movement monitored with an oscilloscope

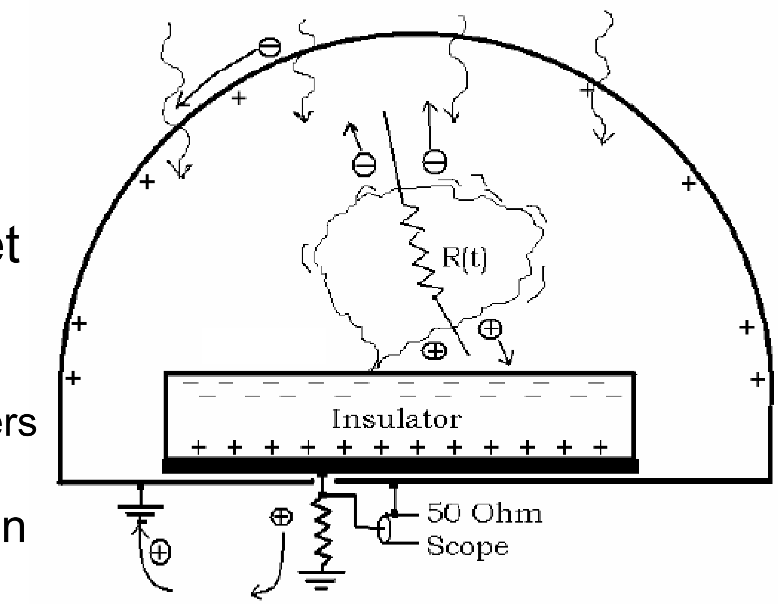
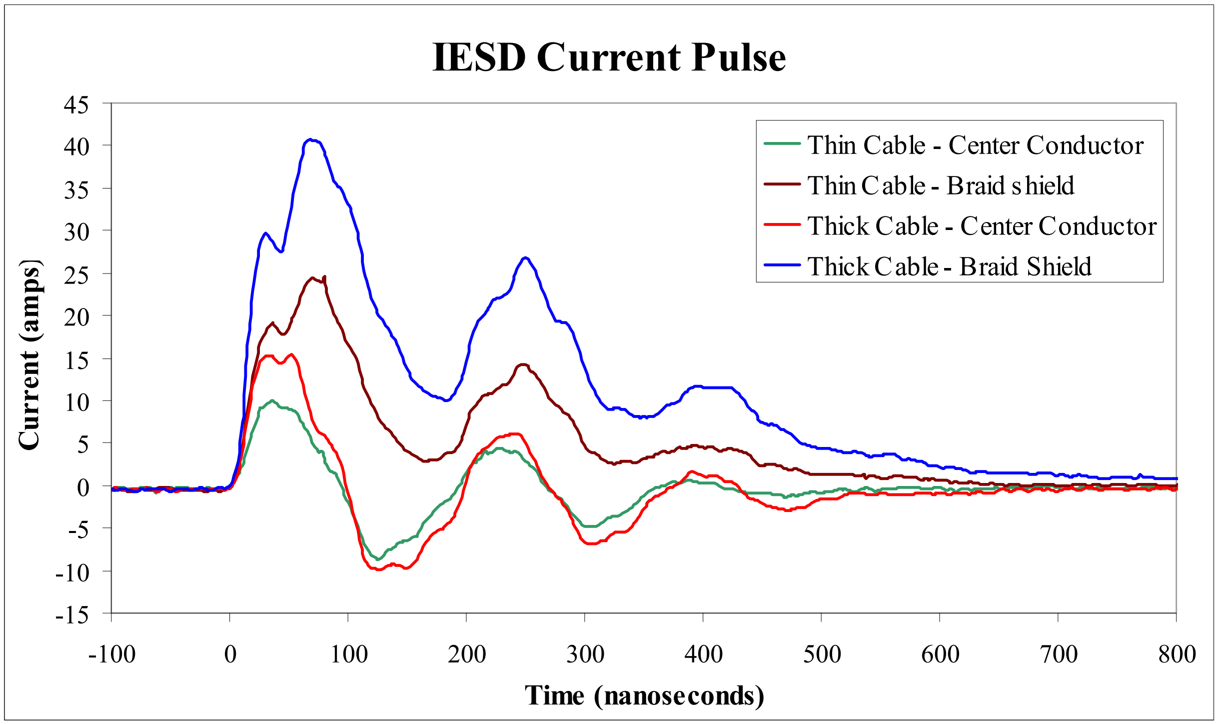


Image by Robb Frederickson

IESD Results



- Largest pulse seen during 75 keV electron exposure
  - Peak current at 40 Amps in braid shield
  - Center conductor current mostly due to capacitive coupling
- Large pulse due to large area of ungrounded/unshielded dielectric
  - Point discharge produced plasma cloud
  - Positive charge in plasma spread out and neutralized large area
- Not realistic for actual flight cables
  - Grounded conductive outer shield would reduce area discharged
  - Less image charge movement on inner conductors

Conclusion

- Juno spacecraft is heading to Jupiter
  - Examine structure of the planet
    - Orbit brings it close to planet
    - High radiation environment
  - Most of the spacecraft electronics are heavily shielded
    - Some instruments and cables must be outside shields
    - Effects of radiation on high voltage coaxial cables is unknown
- Samples of two high voltage coaxial cables were tested
  - Placed in flight-like environment
    - Vacuum: ~5×10^{-6} torr
    - Temperature: -50°C
  - Given radiation dose twice that of calculated dose
    - RDF of 2
    - Inner FEP insulation: 1.2 Mrad
      - Co-60 Gamma
    - Outer FEP jacket: 2.2 Mrad
      - 75 keV electrons

Conclusion

- Cables electrical properties measured
  - Capacitance per unit length
    - Looking for changes in dielectric constant
    - No changes observed due to radiation dose
  - Partial Discharge testing
    - Non-destructive measure of insulation quality
    - Small but measureable changes
      - Increase in peaks with voltage changes
      - Higher sustained partial discharge level
    - Still within general threshold based on power industry standards
- Internal Electrostatic Discharge (IESD) measurements added on
  - Large pulses observed
    - Due to large area of ungrounded dielectric surface
  - Supports decision to wrap flight cables in grounded copper shields
- Test results indicate that these high voltage cables will survive the end-of-mission radiation dose without a problem

Acknowledgments

The research described in this paper was carried out at the Jet Propulsion Laboratory, the California Institute of Technology under a contract with the National Aeronautics and Space Administration. The authors gratefully acknowledge the following colleagues for their contributions of data and expertise: D. Thorbourn, B. Rax, I. Jun, R. Helizon, K. Peretick, and P. Bowerman.