Charge management for LISA Pathfinder and beyond

Peter Wass
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Overview

- Introduction
- Measuring and modelling discharging
- Increasing robustness of discharge process
- LISA Pathfinder charge management hardware
- The future: Technology development for eLISA/NGO
• Sensor
  – 6-degree of freedom position sensing and actuation of free-floating test mass

• Discharging
  – Neutralise test mass by preferential illumination and photoemission from test mass or electrode housing

• Light injection
  – UV fibre optic feed at vertex of sensor

• Applied voltages
  – DC
  – Sensing bias constant at 100kHz
  – Actuation voltages, variable
    AC at 60-270 Hz
Test mass negative charge
Testing discharging

- Test mass positive charge
Testing discharging

- Surfaces are reflective
- Emissivity of surfaces needs to be balanced
Testing discharging

- Voltages can help discharging
Testing discharging

- Voltages can help discharging
- ...not always
Testing discharging

- Discharging tests using a torsion pendulum at University of Trento with different TM/EH combinations
  - In some cases unassisted bipolar discharge was possible
  - In others UV illumination always results in a positive test mass
  - However, discharging is possible by applying selective voltages.
    (Nominal operation for LISA Pathfinder)
  - Worst case requires a reduction in capacitive sensitivity only while discharging: still compatible with Science operations
  - Qualitatively understood by imbalance in photoemissivity
  - Variability of surfaces underestimated
  - Robustness: ratio of yields that will allow discharging
Modelling system

• Two models have been developed to explain/predict discharging results quantitatively
  – EADS Astrium: LPF flight model, ICL: UTN results
  – Ray-tracing of UV light propagation in sensor
  – Assumption of photoelectric yields (from measurements + ray-tracing)
  – Calculation of electric fields at discrete time steps
  – Propagation of electrons between housing and test mass
  – See posters: Hollington and Ziegler

• Models developed independently conclude that pendulum yields are 10:1 (TM:EH)
Increasing robustness

- Extensive period of investigation by EADS Astrium and others
- Many options to increase robustness of discharging studied
  - Understanding surface physics and controlling yield
  - Many measurements on sample surfaces
  - Selective enhancement ‘Hot-spots’
  - Selective suppression
  - Light redirection
Outcomes

- **Robustness for baseline**
  - No bias: +ve: 3.0  –ve: 2.7
  - With voltage assistance: +ve: 3.6  –ve: 9.7
  - Reduced injection: +ve: 3.7  –ve: 15

- **Robustness for redirected light**
  - No bias: +ve: 3.5  –ve: 17
  - With voltage assistance: +ve: 4.2  –ve: 36

- **Surface preparation and handling reduces variation in yield**
  - Plasma cleaning + bakeout in vacuum

- **Final test go/no-go on integrated flight hardware**
Light redirection

- Adapt ISUK tip with mirror
- Beam spread: 12-degrees
- Desired deflection angle: 40-degrees
- Simple mirror results in a lot of light missing mirror, big spot
- Narrow aperture to increase fraction of light on mirror
Light redirection

- Adapt ISUK tip with mirror
- Beam spread: 12-degrees
- Desired deflection angle: 40-degrees
- Narrow aperture to increase fraction of light on mirror
- Prototypes manufactured and tested
- Design being refined for flight model
Angular output

- Output power 11% of undeflected
LISA Pathfinder CMD

• ULU
  – Testing and calibration complete
  – Integrated on spacecraft for OSTT
  – At ICL during hibernation to resolve final qualification issues

• FOH
  – Completed manufacture and test
  – Ready for integration after hibernation
  – NEW: Attenuator prepared to adjust UV light power
LISA Pathfinder CMD
LISA Pathfinder CMD

- UV output level and stability measured in thermal vacuum
- Calibrated for light injected into sensor
- UV attenuation
  - Typical output \(~0.05-1\mu W\)
    - \(3.10^9-7.10^{12}\) photons/s)
  - Target discharge rate \(10^2-10^4\)
  - Large uncertainty in absolute level of photoelectron yield
  - Attenuate light up to 100x by altering FOH junction
eLISA/NGO

- Investigating performance and suitability of new light sources for eLISA/NGO charge management device
- Motivation for changing technology:
  - Mission lifetime longer: years rather than months
  - Can a different technology provide a more robust discharging solution
- New solid-state technologies have become available that can rival lamps in UV emission
  - Blue laser diodes doubled to deep UV wavelengths (~200nm)
  - UV LED 240-255nm
- Currently UV LEDs are most promising
• **UV LED devices have many advantages vs mercury lamps**
  - more compact
  - no high voltage power supply
  - low power consumption
  - faster modulation
  - Long-life

• **Synchronisation with sensor voltages improves robustness**

• **Lower wavelength may also increase robustness**

• **High dynamic-range by high-frequency sigma-delta switching**
Testing UV LEDs

- Previous tests...
- 255nm LED
- DC operation
- Lifetime 1000s mA-hrs

- Relatively broad spectrum
- Not all light may contribute to discharging
- Lower wavelengths may be advantageous
• Three commercially UV LED devices have been selected for detailed testing.

• Component testing underway
  – Spectral output
  – Power consumption
  – Temperature dependencies
  – Thermal vacuum
  – Vibration
  – Radiation
  – Lifetime
Testing UV LEDs

Diagram showing the setup:

- Pulse Generator
- Drive Electronics
- LED Heat Sink
- Temperature Controller
- Optical Fibre
- PMT
- Oscilloscope
- Desktop Computer

Signals:
- PMT signal
- Averaged PMT signal
- Trigger signal
- LED drive voltage

Notes:
- LED drive voltage: 300ns
- PMT signal: ~nW
• Breadboard electronics unit will be used with a sensor mockup to test discharging strategies
  – Synchronisation with AC voltages
  – Investigate surface cleaning/contamination effects
  – Test software model of discharging

• Finally delivered to Trento for discharging test using a representative TM and sensor
Summary

• Understanding of the discharge process has improved
• Strategies have been defined to increase robustness
• Implementation is underway
• LISA pathfinder hardware ready for flight
• New technology for eLISA/NGO looks promising