HIGH-TEMPERATURE PLASMA DIAGNOSTICS CONFERENCE 2022

OVERVIEW AND STATUS OF X-RAY STREAK CAMERA DESIGN AND IMPLEMENTATION ON THE Z-MACHINE

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Abstract — PH26

An x-ray streak camera is being built and tailored for installation on the Z-Machine [1] at SNL to record fast (sub 100ps temporal resolution) time-resolved x-ray emission from the short-lived pulsed plasma experiments. This will be the Streak Camera Observatory with Radial and Polar Implementation On Z (SCOPRIONZ).

- leveraging existing streak camera designs at NIF, e.g., SPIDER [2] and DISC [3].
- Planning for Two instruments,
  - one observing on-axis from above - "Axial" position (formerly "Polar")
  - one observing orthogonally from the side - "Radial" position
- SCOPRIONZ will record emissions from the Z-pinch with
  - X-ray Energy Range 1-15 keV using CsI & KBr PhotoCathodes (Au for UV testing)
  - X-ray Energy Range 0.2-2 keV in axial position
  - Temporal records 2-100ns w/200 resolution elements
  - 200 spatial record elements
  - temporal broadening of less than 3%
  - maximum temporal resolution of 25 ps at the fastest sweep speed
- Design Challenges of the Z-machine environment include
  - Harsh EMI environment
  - Mechanical shock
  - Gamma & neutron background

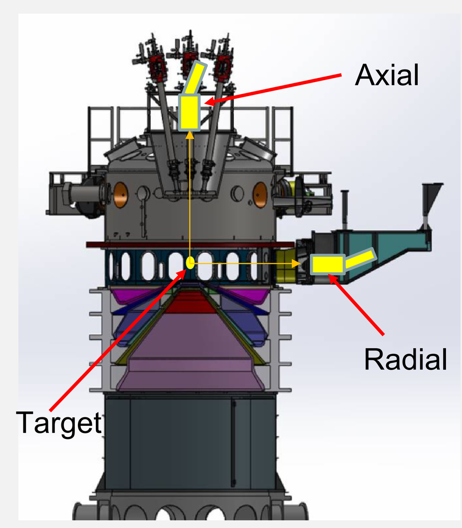
SCORPIONZ PROJECT TIME-LINE

	FY21			FY22				FY23				FY24	
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Radial		RR	CDR			FDR	Assy	Test Cal	Ready				
Axial		RR						CDR	FDR	Assy	Test Cal	Ready	

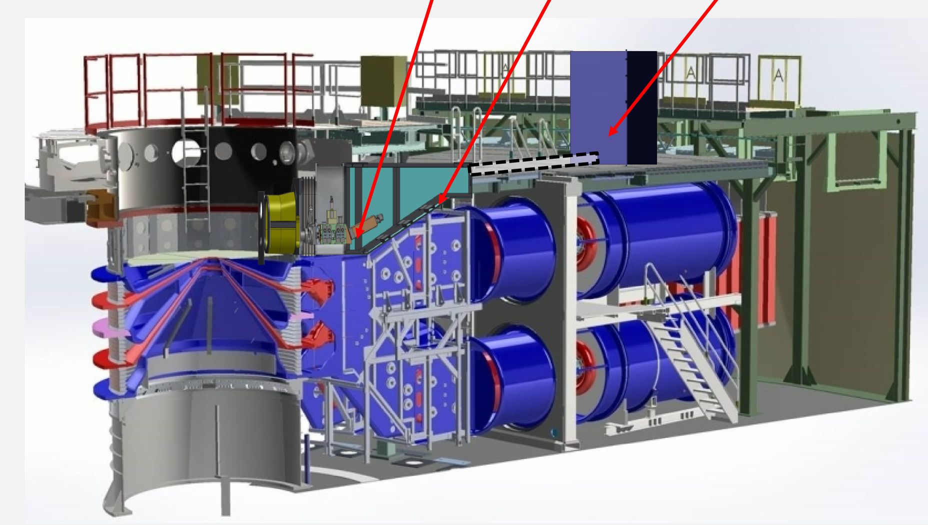
RR - Requirements Review; CDR - Conceptual Design Review; FDR - Final Design Review; Assy - Assembly; Cal - Calibration

Lines of Sight

Two lines of sight planned
- Radial – LOS90-0°
  Sits in boat below water line
- Axial – Suspended above target chamber



Target chamber and electrode stack

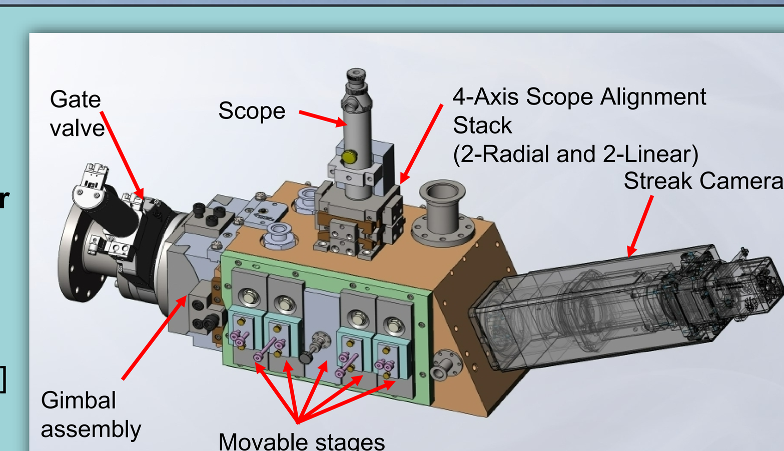


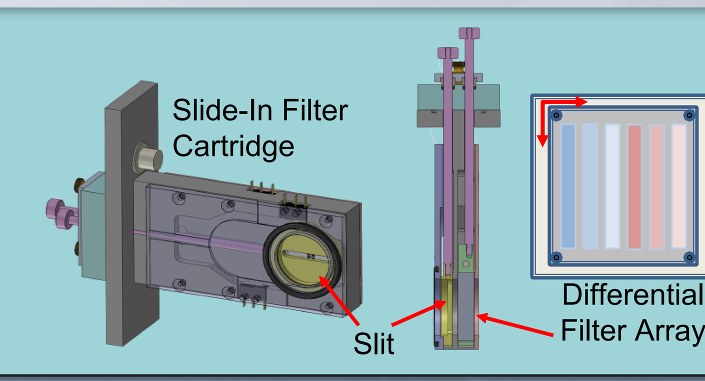
Half-Sectional view of Z-machine, single radial section shown.

Interface to the Z Target Chamber

Couples Streak Camera to Target Chamber
- Gate Valve & Optics Box
- Gimbal for Pitch & horizontal translation
- Filter cartridges
  - Differential filter elements for energy measurements, as done in SPIDER [2]
  - manual actuation
  - position monitoring & logging
- Alignment scope and beam splitter for viewing slits & chamber alignment target
- PCD – detector for timing alignment

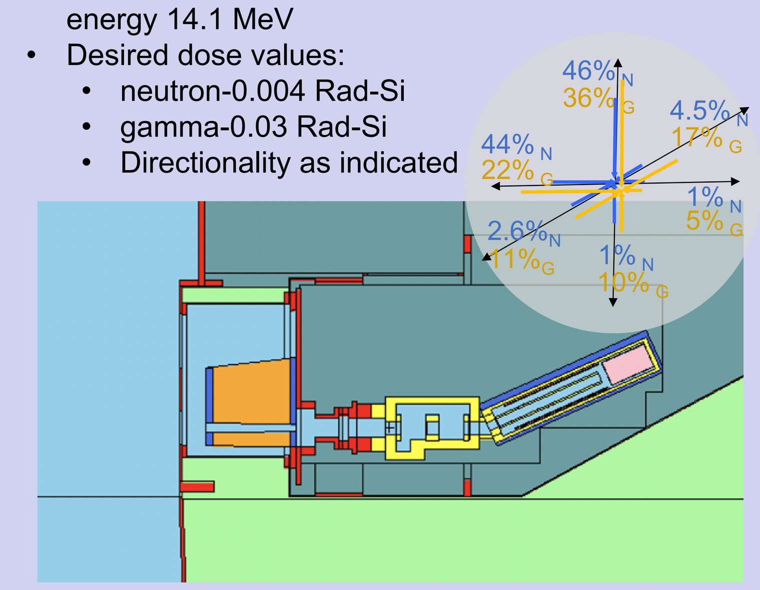
Alignment Scope & fiducials
- Removable alignment scope & camera
- Insertable Beam splitter & mirror used to align two fiducials in beam path with fiducial in target chamber.





Radiation Modeling

MCNP Simulation
- Neutron and Gamma Dose in the SCORPIONZ Streak Camera
- Modeled diagnostic in boat with surrounding materials: vacuum, metal, water, air, etc.
- Neutron yield per D-T shot = 1.0E+14 neutrons with energy 14.1 MeV
- Desired dose values:
  - neutron-0.004 Rad-Si
  - gamma-0.03 Rad-Si
  - Directionality as indicated



MCNP Model for radiation dose simulation *(courtesy of H. Khater, S. Sitaraman).* Green: water; Pink: Si; Light Blue: vacuum; Gray: air; Red=Steel/St. Steel; Yellow: Al; Dark Blue=tungsten

Table of Results – Dose rate at CCD camera

Case	Neutron (rad)	Gamma (rad)
Unshielded	0.0185	0.0280
Fully Shielded	0.0032 (-83%)*	0.0083 (-72%)*
Partially Shielded- Shroud only	0.0059 (-68%)*	0.0219 (-23%)*
SPIDER [2] Model (1E16 DT)	0.0036	0.0320
SPIDER Survival (5E16DT)	0.0090+	0.0800+
DIXI-1 [4] MCNP (1E17DT)	1.00	1.33
DIXI-1 Upset (2E16DT)	0.150++	0.200++

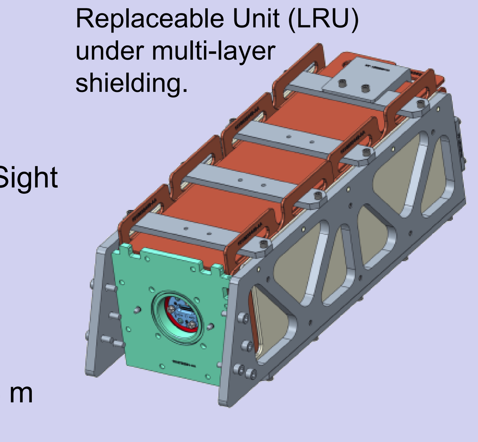
*(% reduction of dose compared to unshielded)
+Modeled radiation dose multiplied by 2.5 as conservative estimate given predicted vs. actual signal data
++Modeled radiation dose multiplied by 0.15 as conservative estimate with no predicted vs. actual signal data to base calculation on

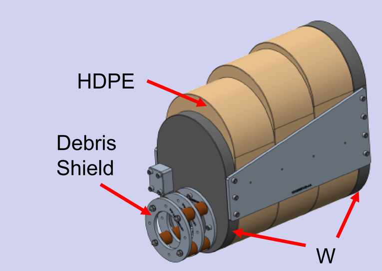
Line of Sight Shielding

LRU Shielding
- 1" Tungsten - sides
- ¾" Tungsten - top
- 1 cm Tungsten - bottom

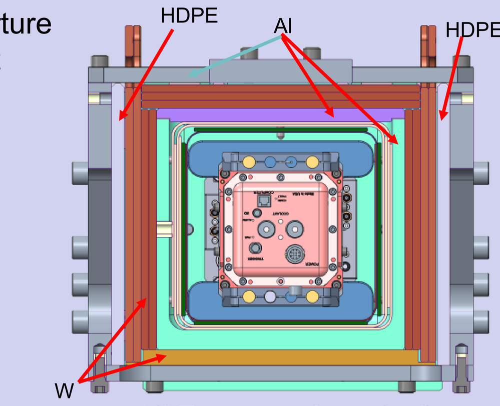
In-shroud Shield/Collimator
- CCD Camera tilted 22° out of Line of Sight
- Multi-Layer Shielding Protects CCD Camera
  - 2 x 1" Tungsten
  - 12" HDPE
- 100 mm max Field of View defined by aperture at a standoff distance of 2.88 m from the target.
- Debris shield baffles on input aperture mitigate debris ingress from target chamber.

Streak Camera in Line Replaceable Unit (LRU) under multi-layer shielding.

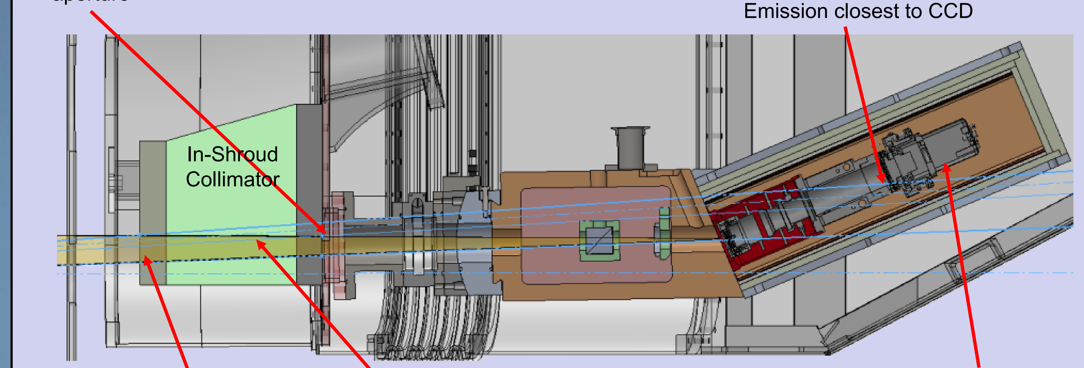




In-shroud shield/collimator: 2 x 1" Tungsten, 12" HDPE



¼" Tungsten plates (red), 10mm Tungsten (Yellow)



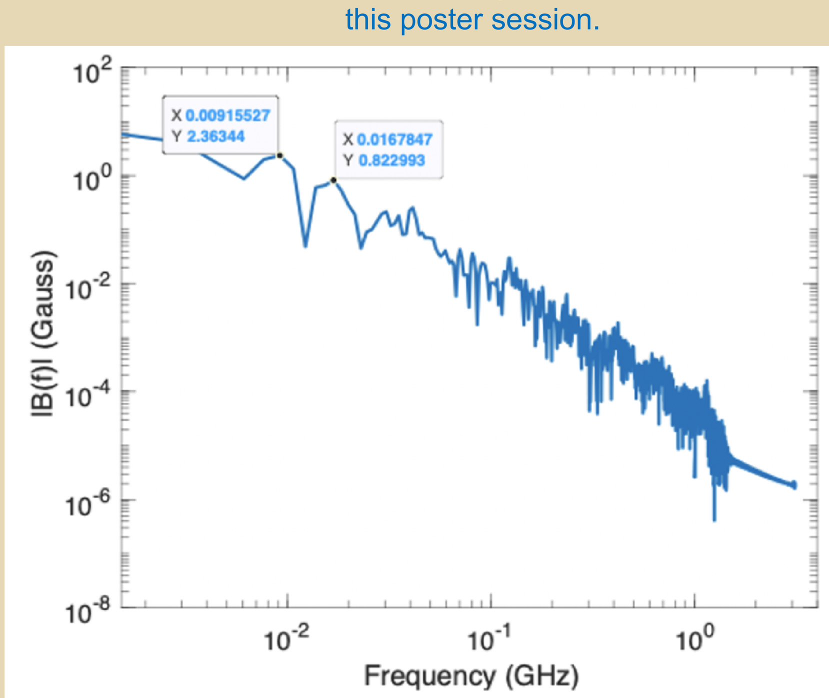
EMI Measurements & Shielding

Transient Magnetic Field Measurements [5] of intense EMP during a shot

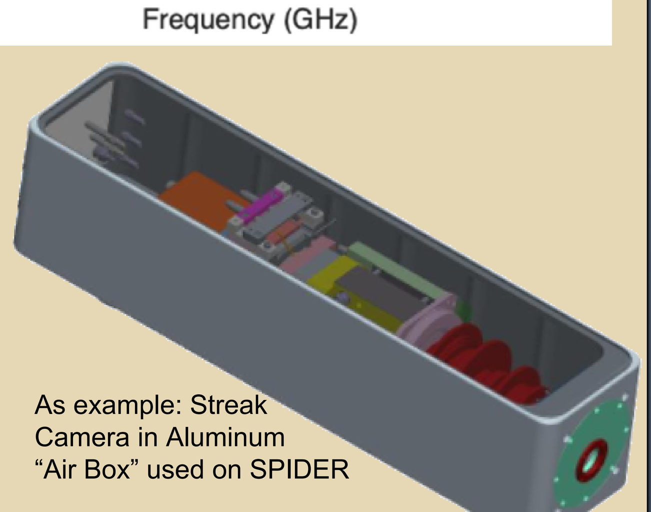
See poster PH21 by Brian Ritter in this poster session.

- B-Dot probes from PRODYN, model B-60
- Frequency spectrum measured.

PRODYN B-60 Probe with Balun

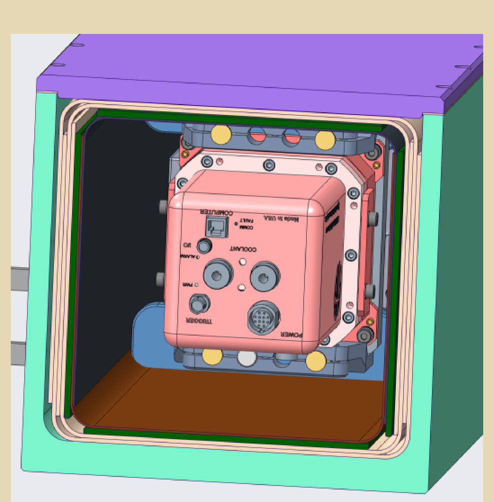


Static Magnetic Shielding of the Streak Tube
- Streak Tube electron beam is sensitive to the Earth's magnetic field, requiring a layer of Mu Metal.
- Z's EMP introduces both transient electric and magnetic fields that can effect the Streak Tube's electron beam.
- Multi-Layered shielding is implemented
  - Transient Magnetic
    - Faraday Cage provided by a Monolithic Aluminum enclosure with lid (sides 10 – 16 mm thick)
  - Static Magnetic
    - 1-mm Mu Metal inner layer
    - 2-mm Netic Intermediate layer



As example: Streak Camera in Aluminum "Air Box" used on SPIDER

Multi-Layer magnetic shielding on SCORPIONZ:
- Aluminum Faraday Cage: Green & Purple
- Mu-Metal: Red
- Netic: Tan

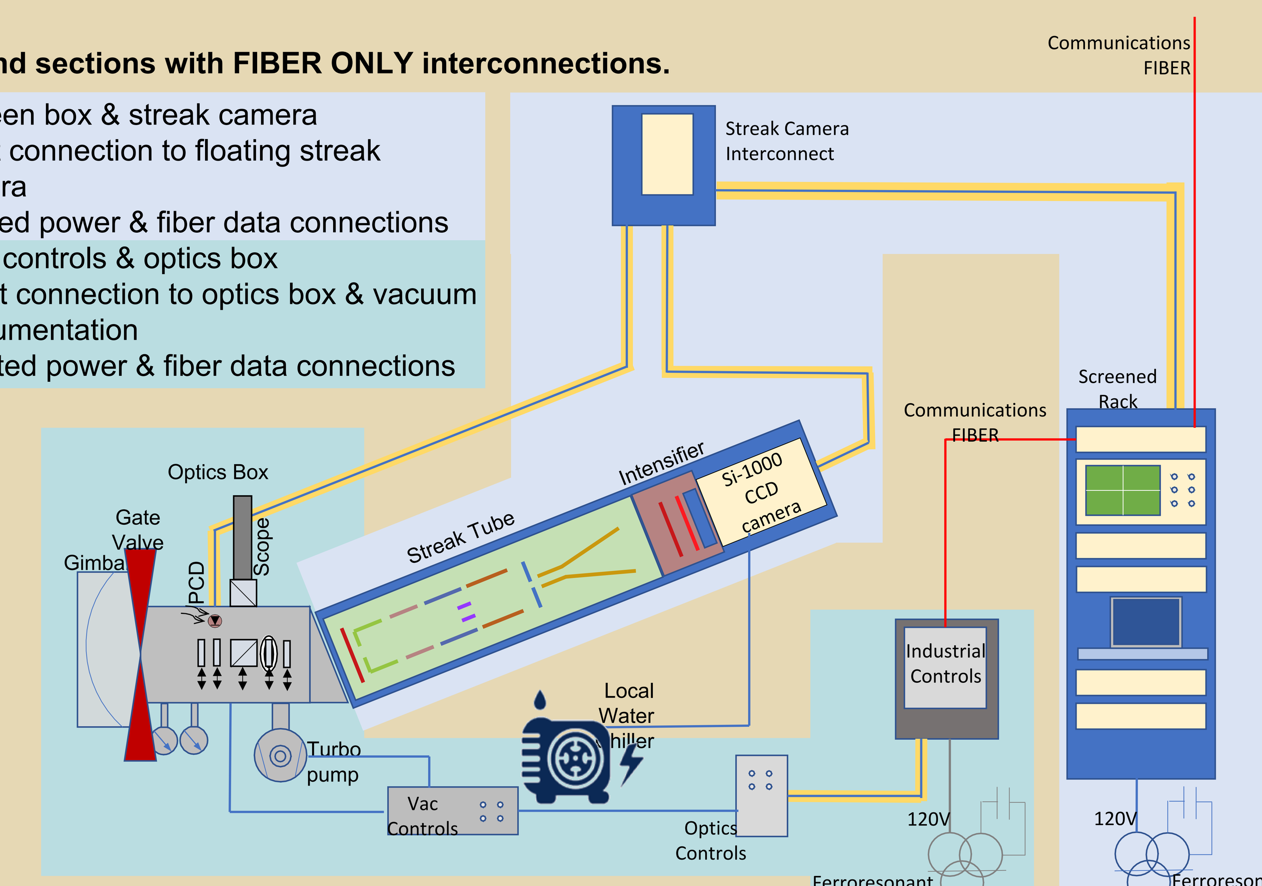


Static Magnetic Shielding Cut-away

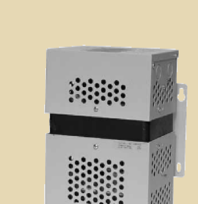
Grounding and Shielding

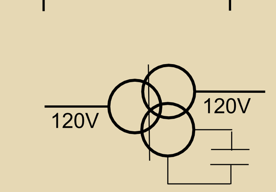
EMI shielding and electric isolation
- Sensitive components will be shielded
  - RF-Shielded enclosure with dual layers of copper & silicon steel, *by ETS Lindgren*, contain two 19-inch racks.
- Single point ground avoids ground loops
  - LRU electrically isolated from local ground
  - Cable shields connect LRU to screen box.
  - System grounded only at the screen box.
- Cables run through shielded insulated conduit
  - Electri-Flex HFEMCS – bronze core double-braid shielded, insulated
  - Connects grounds of all outer shields and enclosures

Isolated ground sections with FIBER ONLY interconnections.
- Main screen box & streak camera
  - direct connection to floating streak camera
  - isolated power & fiber data connections
- Industrial controls & optics box
  - direct connection to optics box & vacuum instrumentation
  - isolated power & fiber data connections



Electri-Flex, type **HFEMCS** bronze core flexible conduit with tinned copper shield with a Polyurethane protective jacket for low-smoke, low flame spread and zero-halogen emission.



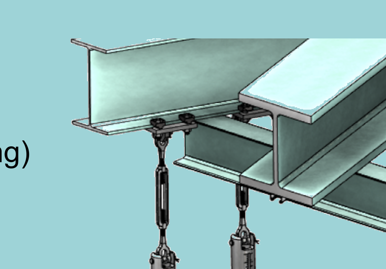


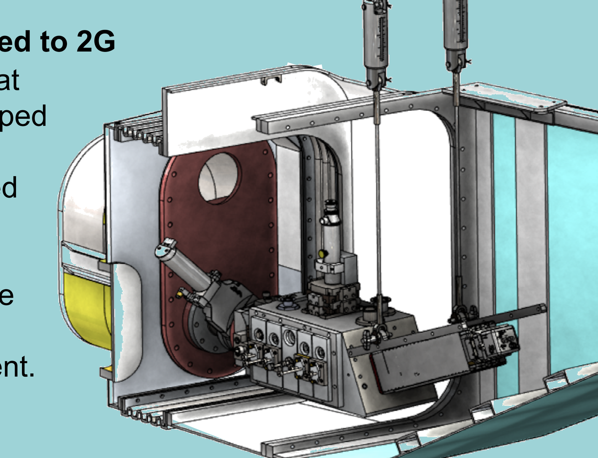
Sola CVS series Ferroresonant Isolation Transformer (+/-1%) Voltage Regulation

Support with 8G Shock Load

Diagnostic is protected from Intense shock load
- Boat lower surface has 1.5" displacement
- CCD camera sensor **optical coupling** to streak tube is the **weak link** and must be protected
- Diagnostic weight of 650 lbs (with shielding)
- Target Chamber flange cannot support cantilevered load

- **Shock load of 8G reduced to 2G**
- Diagnostic is suspended at its CoG using spring damped cables
  - Static Load eliminated on vacuum flange
- Customized Gimbal pitch radius about CoG and free floating design reduce vertical shock displacement.





References

[1] M. Keith Matzen, et al, "Pulsed-power driven high energy density physics and intertial confinement fusion research" Physics of Plasmas 12, 0555503 (2005)
[2] S. F. Khan, et al, "Measuring x-ray burn history with the Streaked Polar Instrumentation for Diagnosing Energetic Radiation(SPIDER) at the National Ignition Facility(NIF)" SPIE 2012, San Diego, CA Aug. 12, 2012, LLNL-CONF-566492
[3] J. R. Kimbrough, et al, "Standard design for National Ignition Facility x-ray streak and framing cameras" Rev Scientific Instruments 81, 10E530 (2010)
[4] [5] B. Ritter, et al, "HTPD22 Overview and status of EMI Measurement and Characterization on the Z-Machine", This Conference, HTPD 2022, May 2022, Rochester, NY, [PH21]

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