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Technology
Facilities Council
ISIS Neutron and
Muon Source
Welcome

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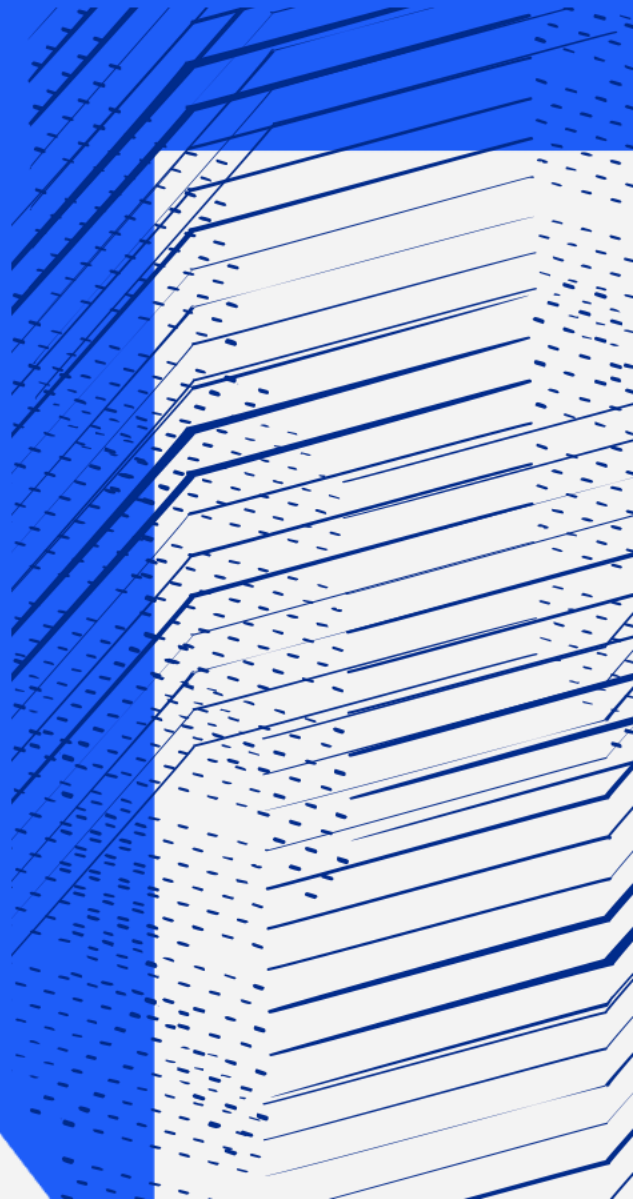
Development work on pulsed 35kV electrostatic chopper with 10ns rise times

Maliq Martin

PulPoKS 2023

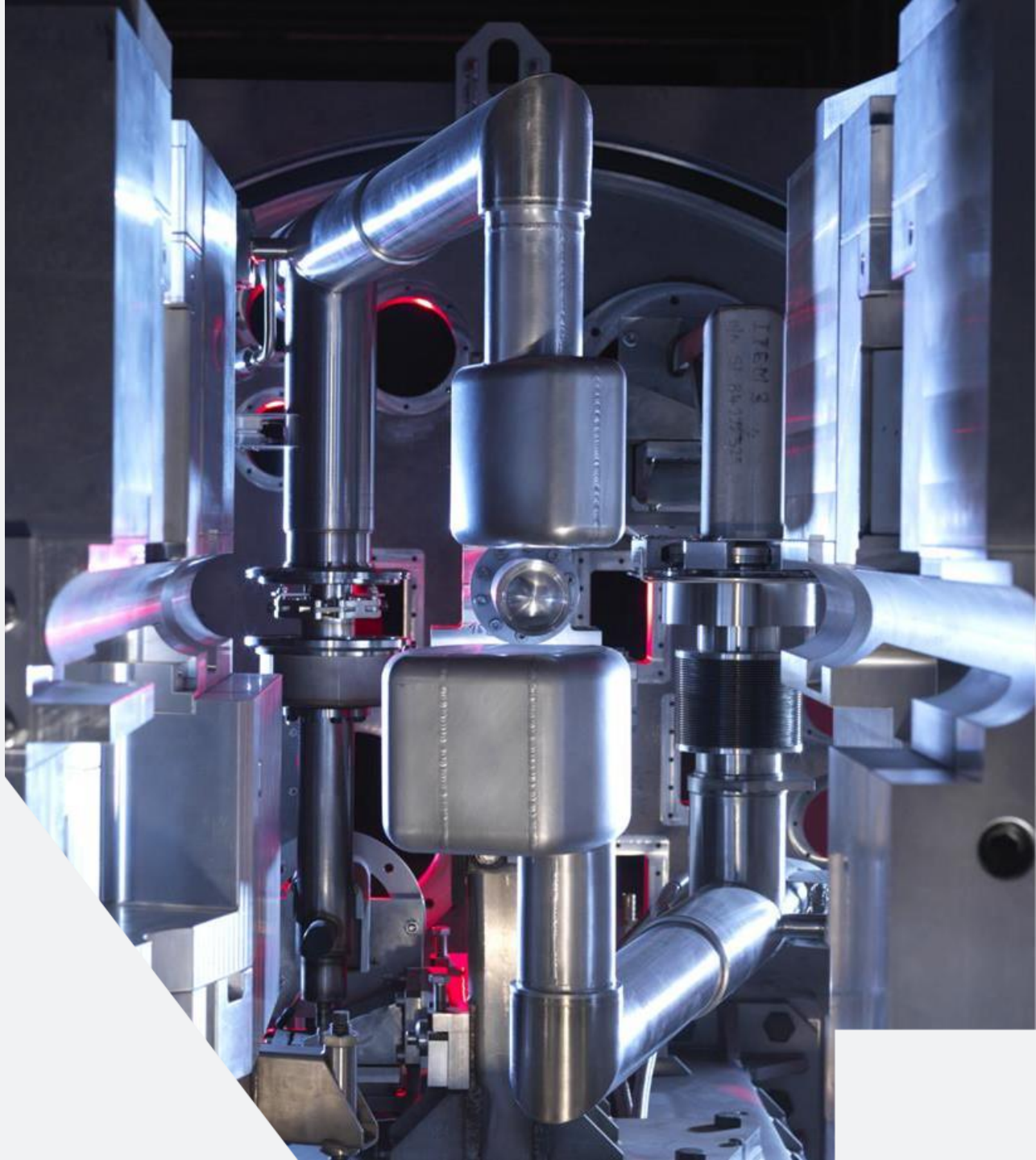


Agenda

1 Super MuSR Overview

2 Chopper Feedthrough Design

3 Pulse Power Supply Testing



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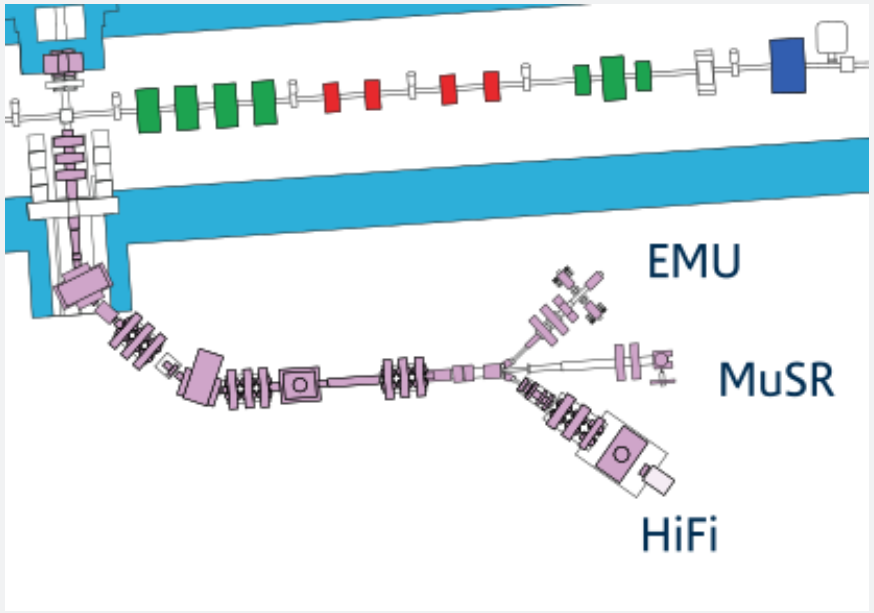
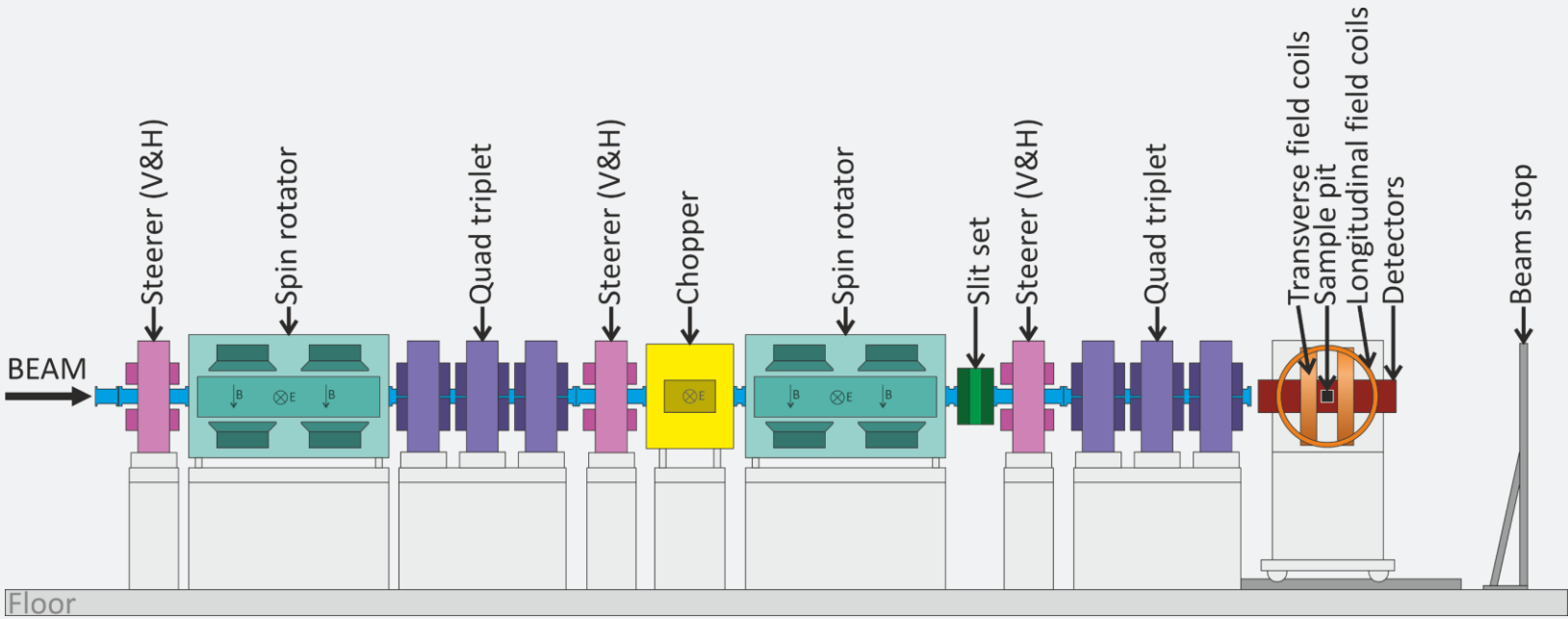
Super MuSR Introduction

Super MuSR is an upgrade to the existing MuSR muon beamline at ISIS. The new beamline will improve data rates, enables transverse field measurements and allow a sliced pulse mode that will improve the time resolution.





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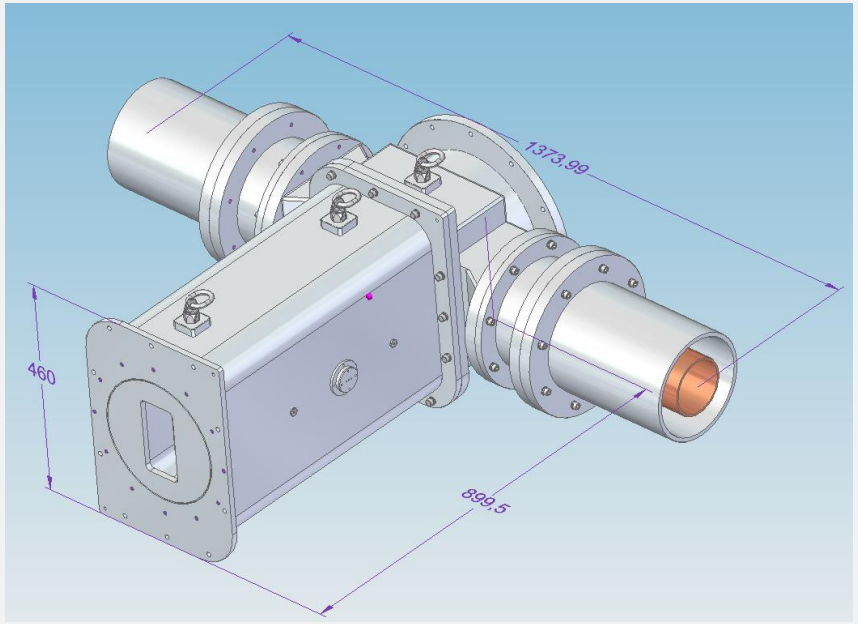
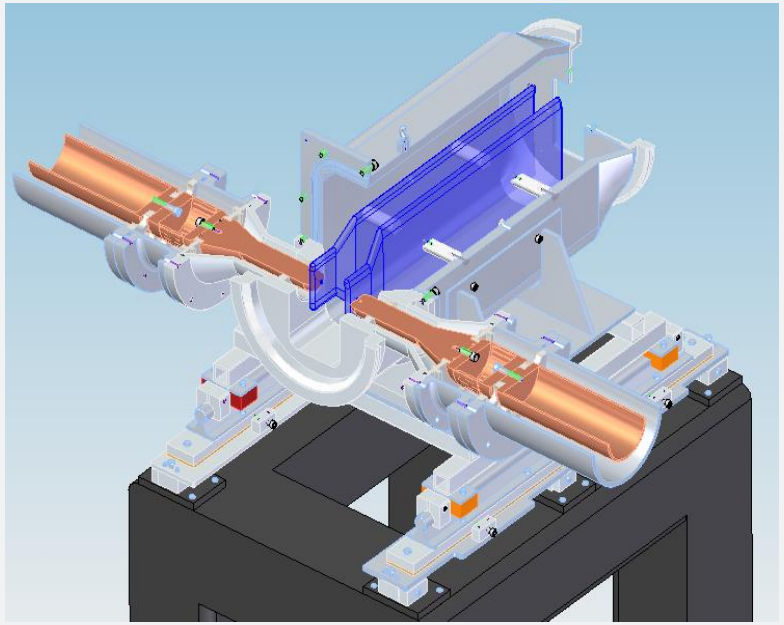
Electrostatic Chopper

The chopper will steer the full muon beam from one side to the other, allowing only a short spray of muons to pass towards the sample.

Muon pulse:
- Positive muons
- 3.81 MeV initial energy
- 131 ns bunch length

Chopper:
- 500mm length, 60mm separation
- ±35 kV
- 10 ns transition
- 32 Ω impedance
- 50 Hz repetition rate





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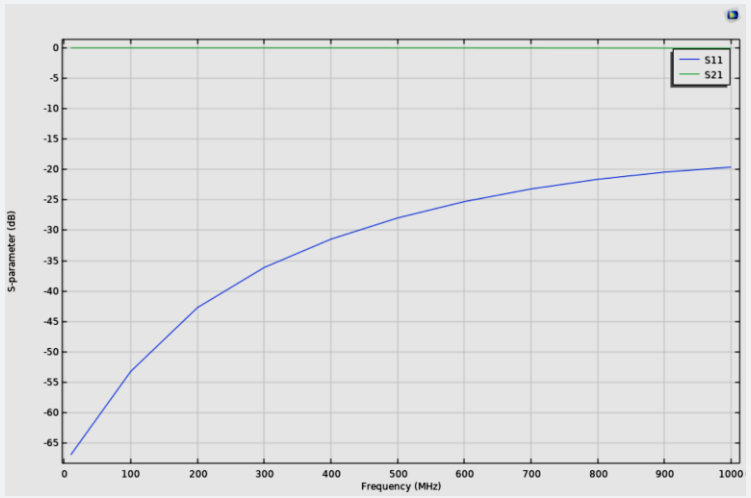
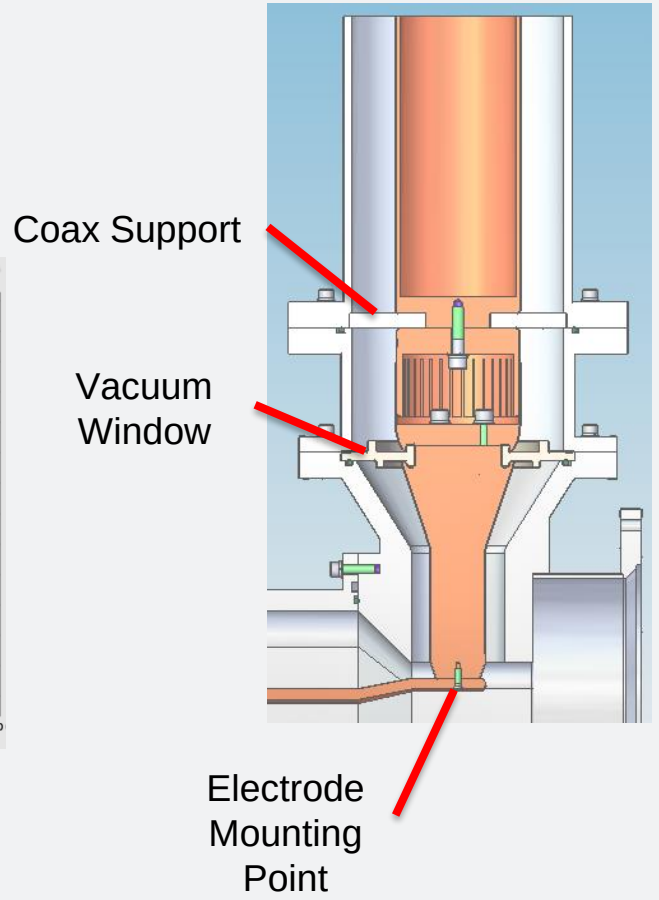
Feedthrough Design Work

- The vacuum feedthrough, which connects the 32Ω coax line to the electrodes, proved to be a difficulty assembly to design both mechanical and electrical.
- The vacuum window must support the pressure difference, without excessive deflection, while being thin enough to cause minimal distortion to the travelling EM wave
- Modifications to the inner conductor must be kept to a minimum to prevent excessive electric stress
- An OEM is looking into the design of the necessary spacers in the coax line and bullet connector





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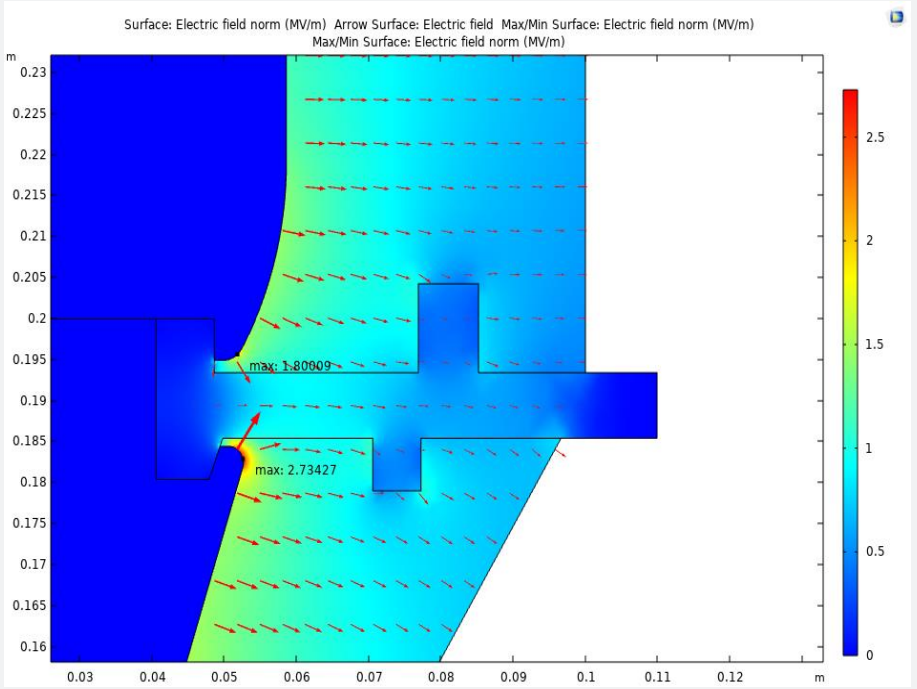
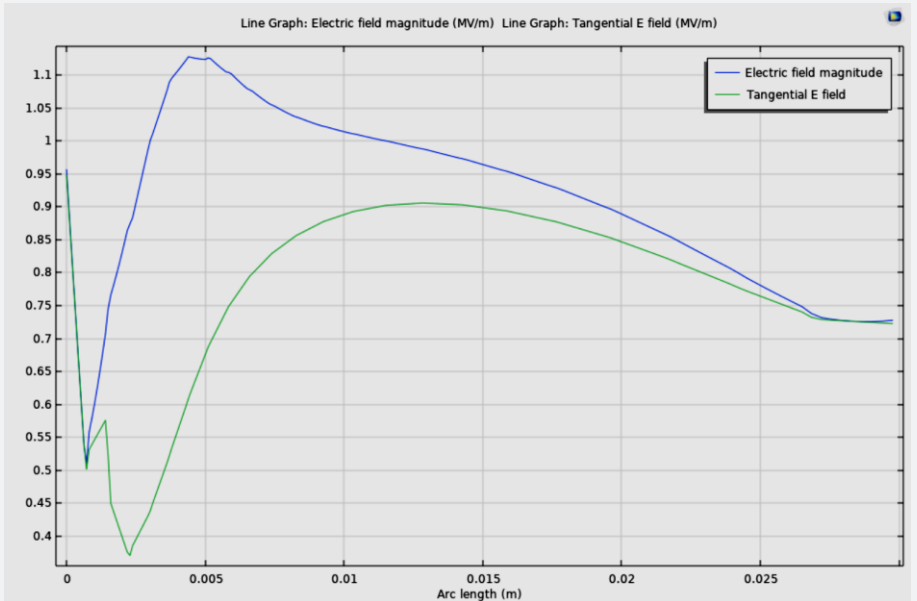
Feedthrough Design Work

- FEA electrostatic simulations were performed to ensure electric breakdown did not occur.
- The region of greatest concern is on the air side close to the vacuum window, where tracking can occur across the dielectric.
- After consultation with industry it was suggest a safety factor of 4 should be used for breakdown in air giving a limit of 0.75MV/m
- Using this safety factor a new dielectric will be required for the coax line, ideally a vacuum. If this proves to be the case the coax line can be redesigned simplify the feedthrough design.





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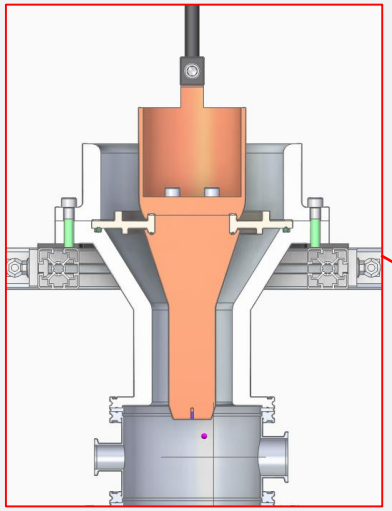
Next Steps

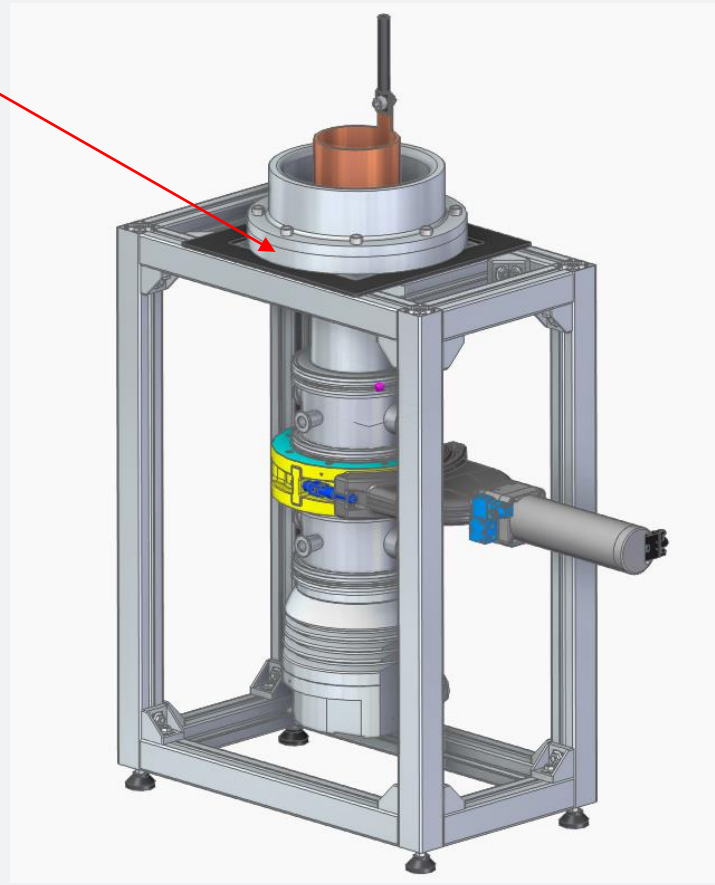
High voltage testing of the vacuum feedthrough at 35kV:

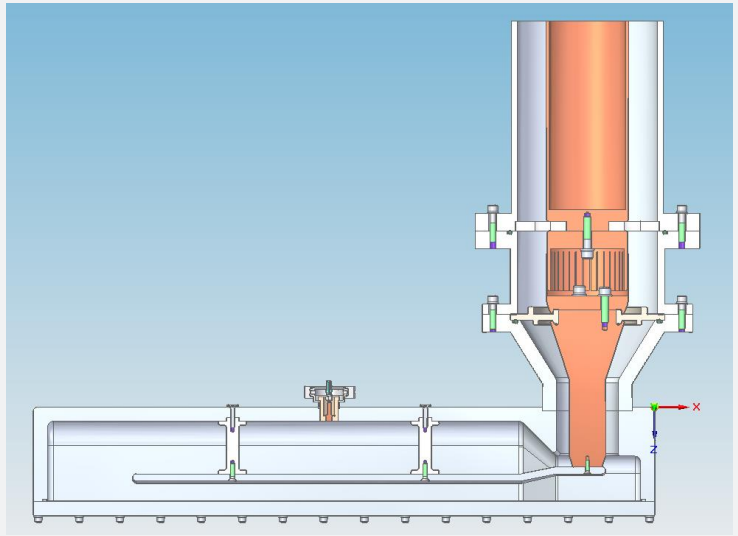
- The mock-up is currently being manufactured on site and will be tested shortly
- Based on the air-filled coax line
- Test to see if the x4 safety factor is required
- Generate Weibull distribution for electrical breakdown of feedthrough

RF Testing using a low voltage 10ns transition pulse and a vector network analyzer:

- The design for this mockup is currently being finalised
- Includes a Ddot sensor the measure the electric field inside the vacuum chamber







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Prototype Power Supply

Two companies were selected to produce a report and prototype power supply(Company A and Company B) to increase confidence in delivering the full specification.

The prototype power supply was to include:

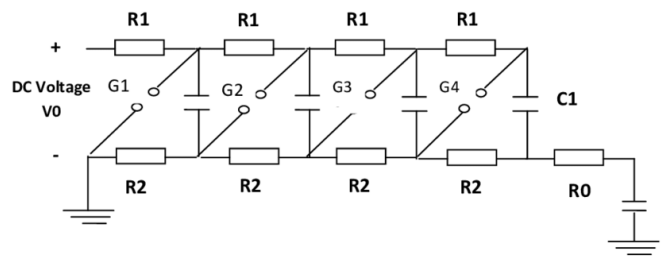
- Demonstration of technology and scalability
- ±15 kV into 36 Ω (51pF) or full current into a scaled load
- <10 ns transition
- 30 ns plateau pre- and post-transition

- Emphasis was place on the effects of scaling prototype to full rating and minimising reflections via impedance matching.
- It was noted that a lumped capacitance will be unlikely to replicate the reflections when the EM wave reaches the unterminated end of the plate

Prototype Topology

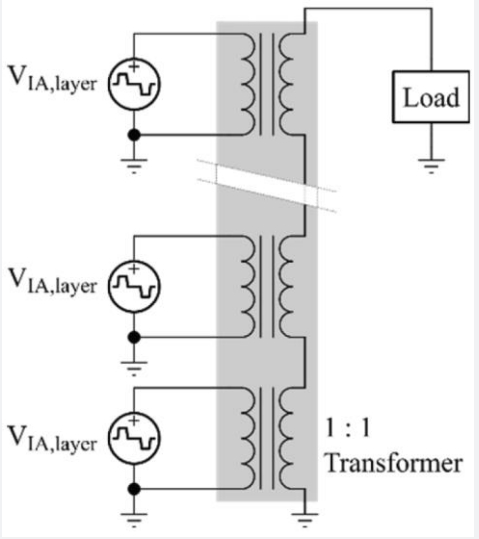
Company A – Marx Generator

- ±15 kV
- 10 ns transition
- 400 ns pre/post
- 5 Hz repetition
- Capacitive load (50pF)



Company B – Inductive Adder

- ±3.5 kV
- Peak current >1kA
- 10 ns transition
- 1 µs pre/post
- 50 Hz repetition
- PFL load of equivalent value (4.5Ω)



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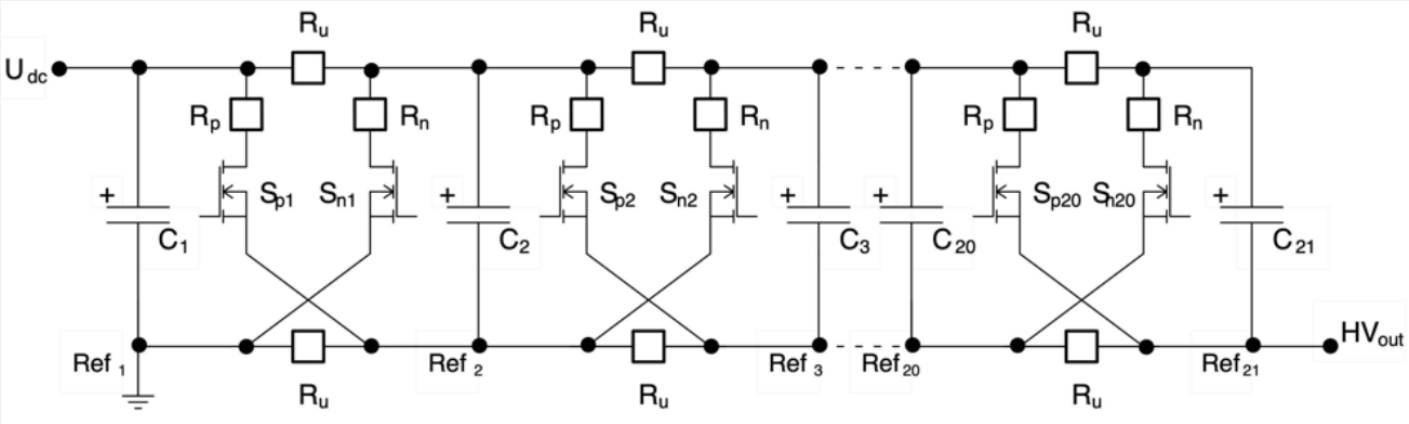
Company A – Marx Generator

20 Stage bipolar Marx generator

- Each stage is charged to 800V from single HVDC supply
- SiC MOSFET used for stage switching
- Each stage is connected in series and then reversed in polarity to supply the transition required
- The positive pulse switches, S_{pi}, are 6 devices in parallel, will the negative pulse switches, S_{ni}, are a single device



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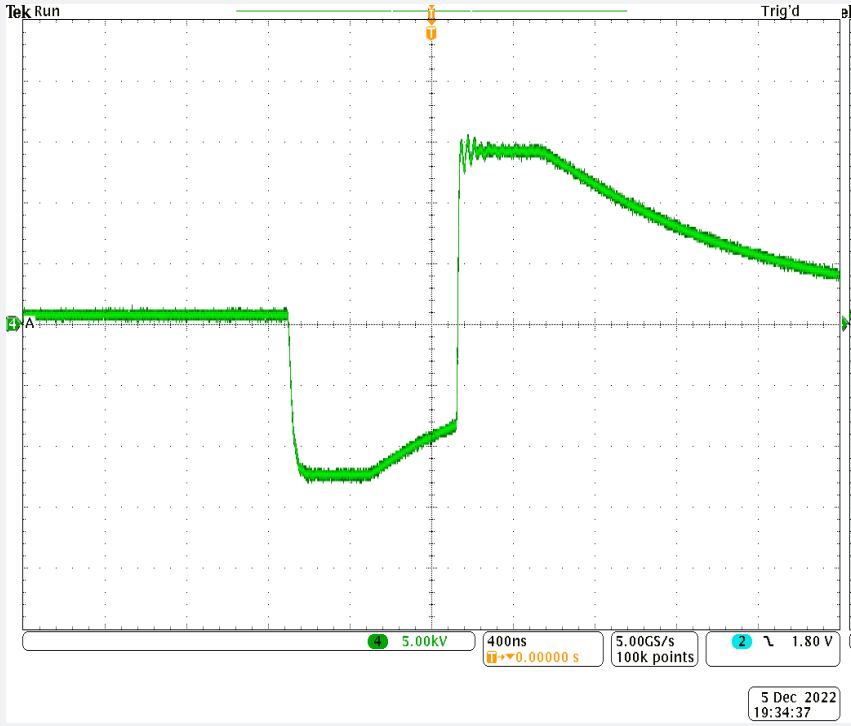
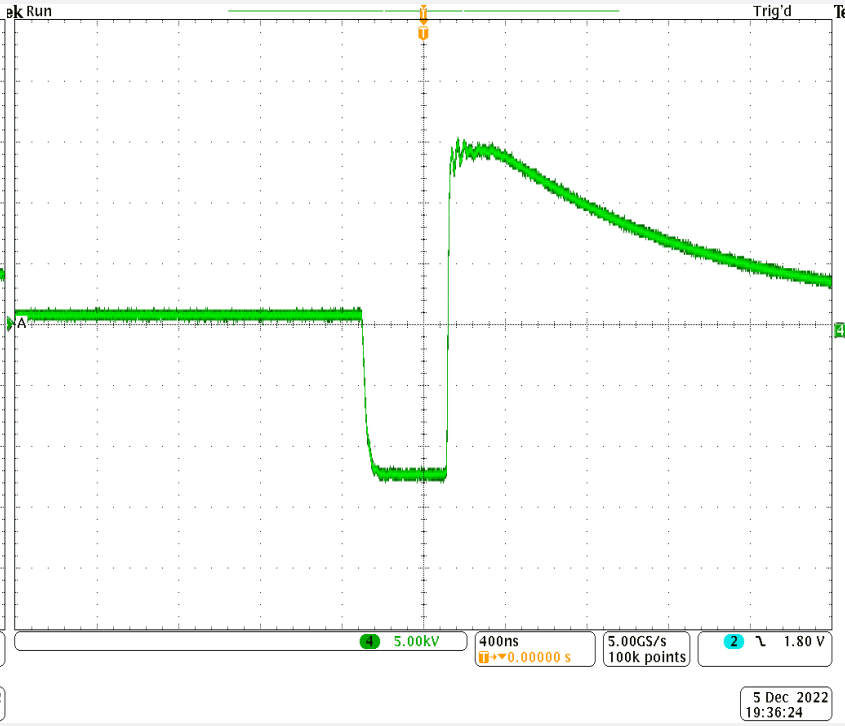
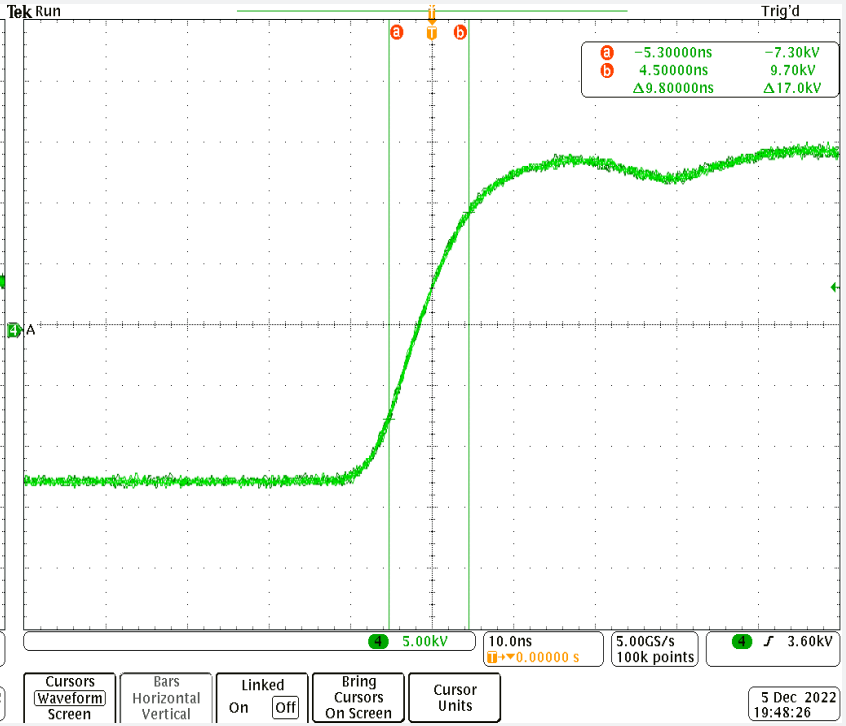
Company A – Direct Connection Capacitive Load Test



400ns Dead Time



Minimum Dead Time



Close up of Rising Edge

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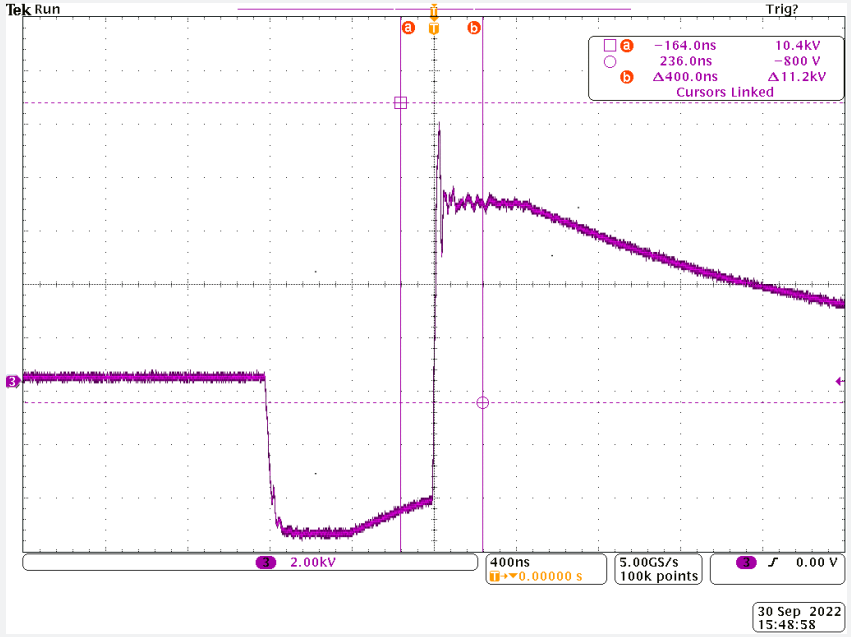
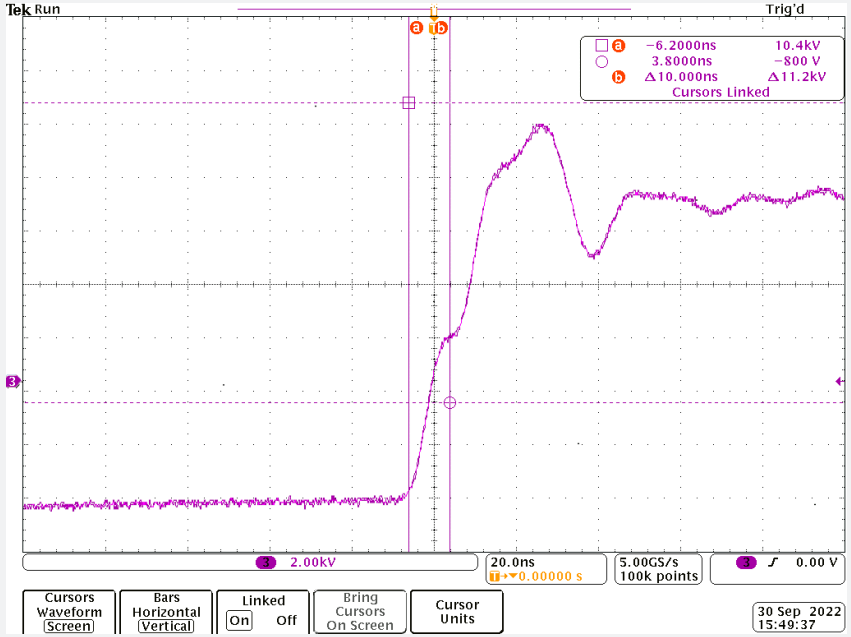
Company A – 50Ω Coax Test

20 Stage bipolar Marx generator

- Each stage is charged to 600V (limited by test setup)
- 50Ω coax line (0.5m of C9220 adding 50pF)
- The lack of an appropriate impedance matched connection between the power supply and cable leads to large signal distortions





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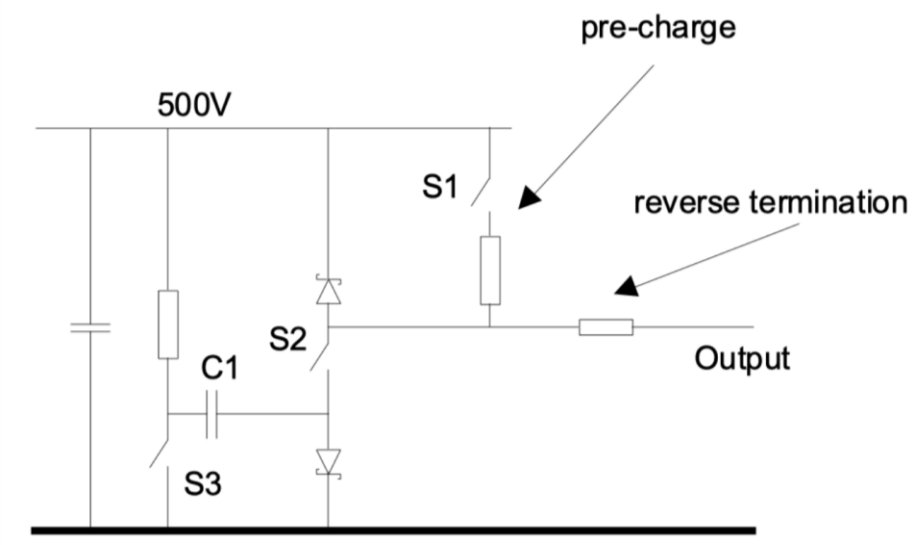
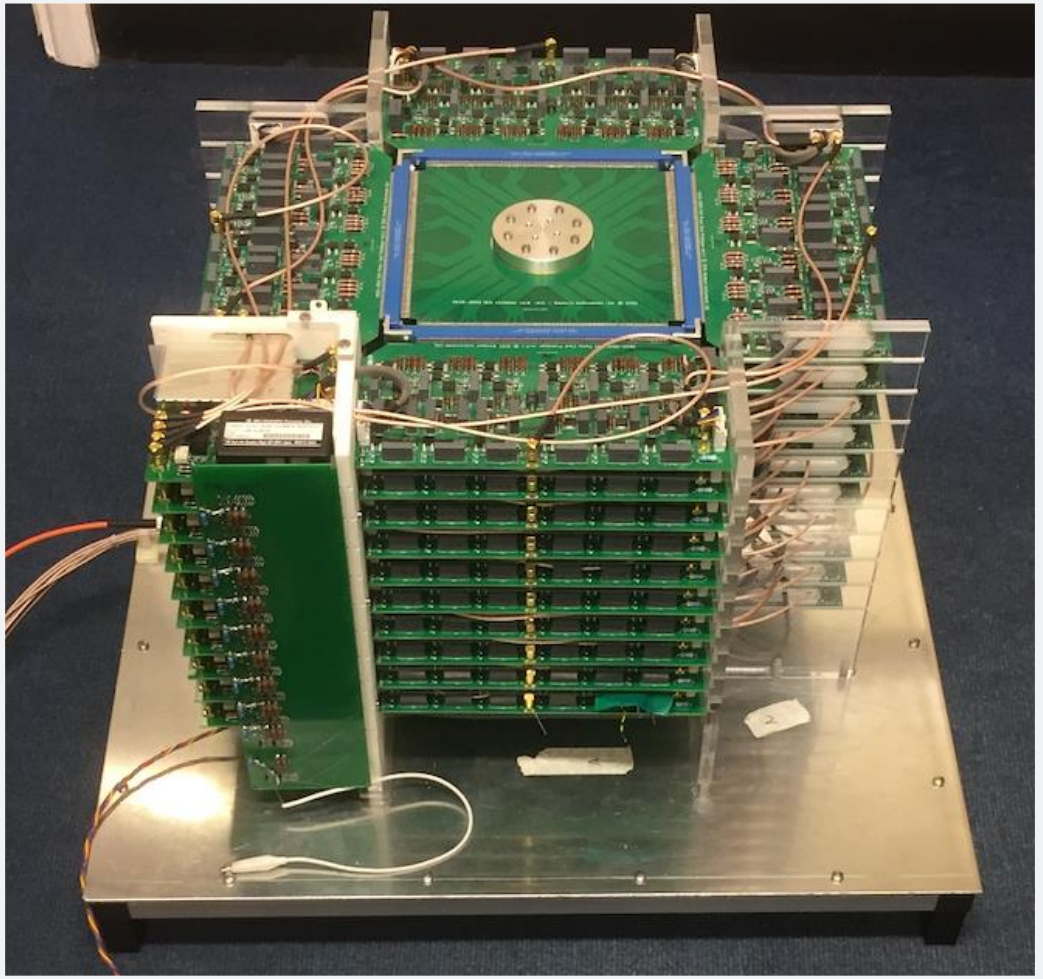
Company B – Inductive Adder

10 stage power supply using and inductive adder

- Designed to provide rated current to the Super MuSR Chopper
- Each stage charge to 500V
- Load is an open circuit 4.5Ω coax line
- Reverse termination is used to match the output impedance with the load





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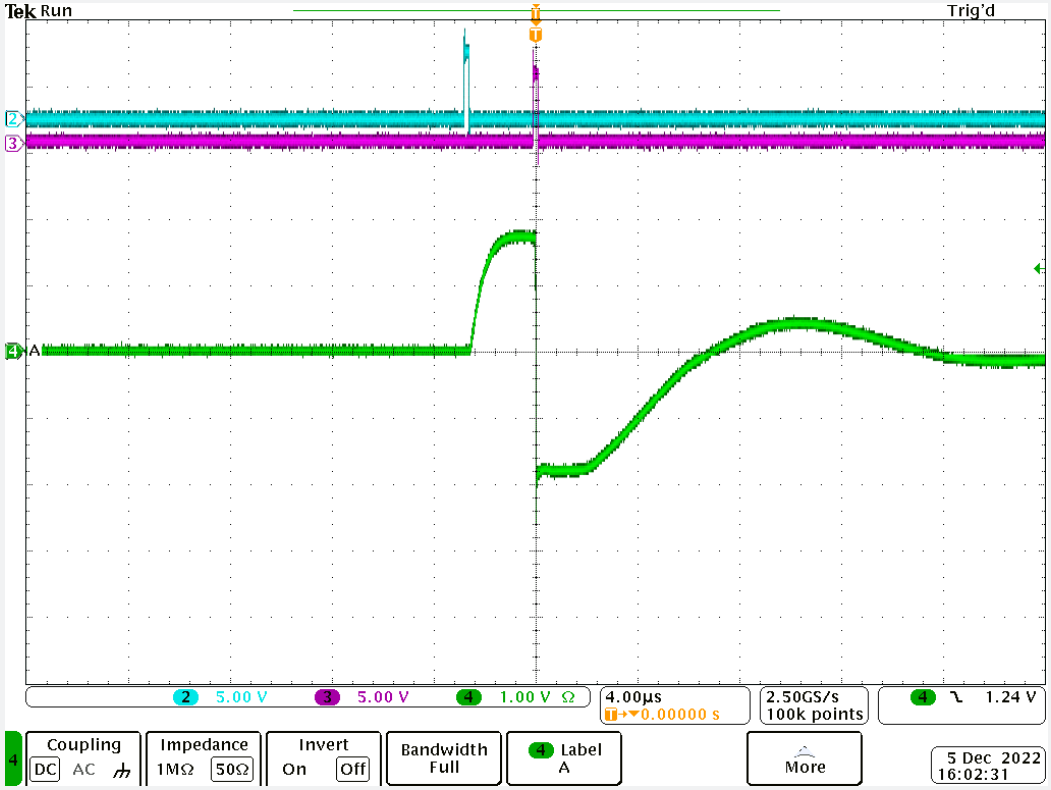
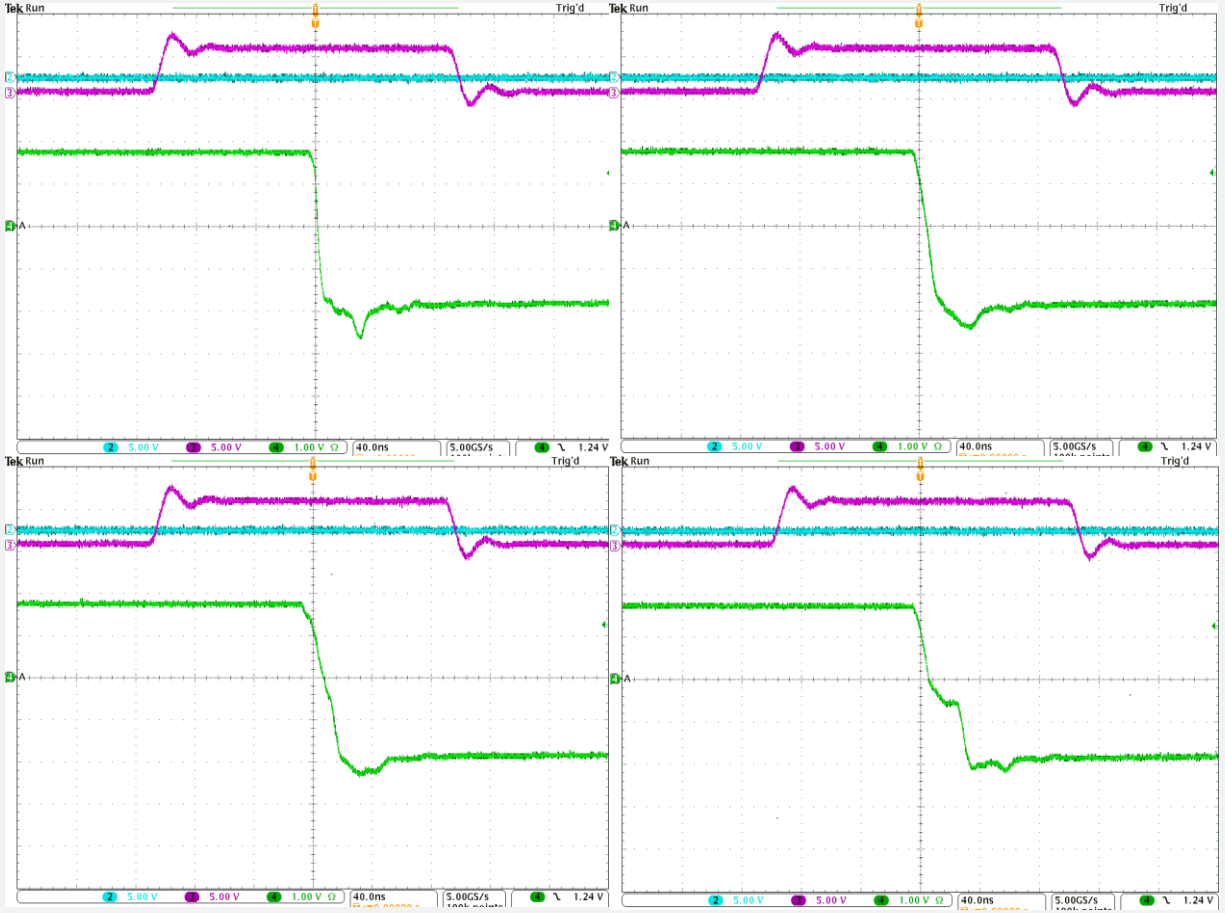
Company B – Test Results





1:2130 Voltage Scale

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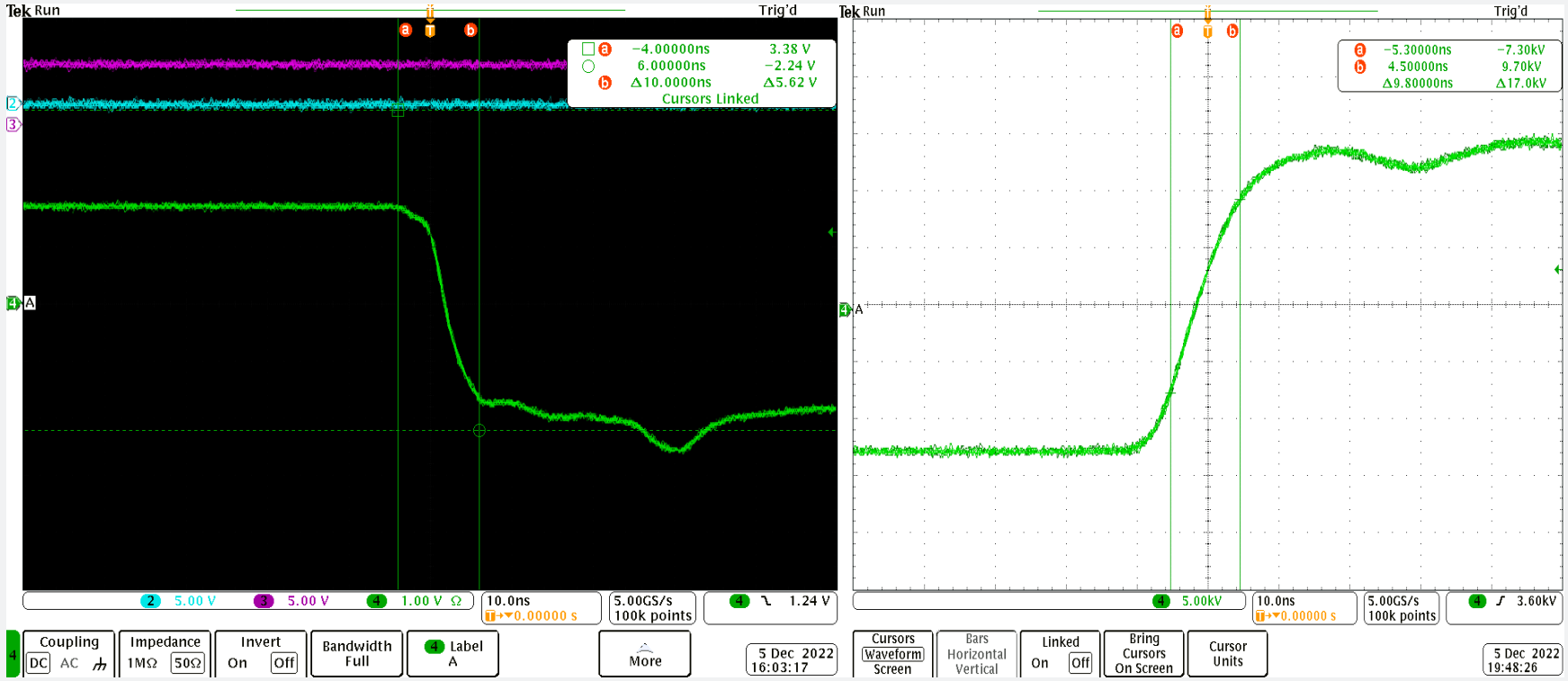
10ns Transition

Company B performance is better

- Switches at rated current through scaled load within 8ns (10% - 90%)
- Company A best case (lumped capacitance directly connected) switches ±15kV within 18ns



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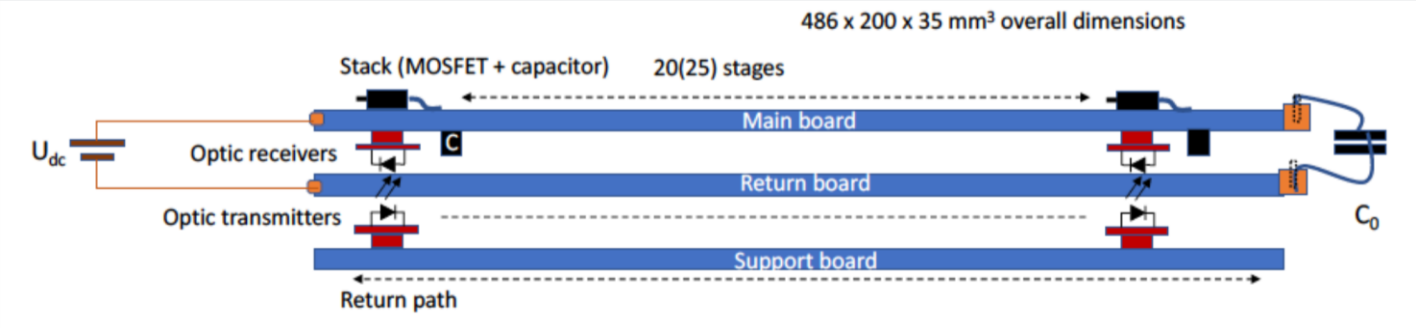
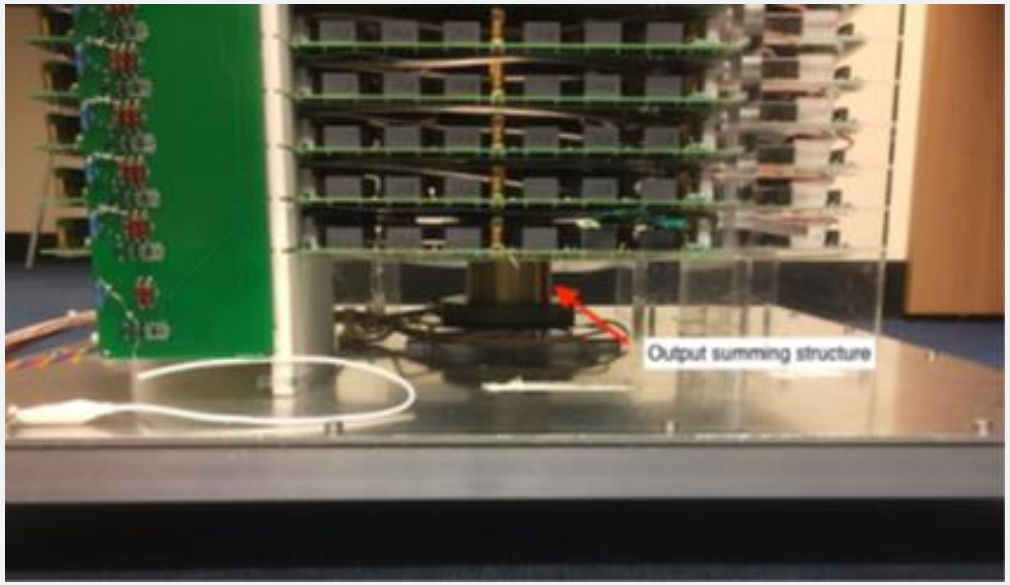
Topology Comparison

Inductive adder used by Company B is a better design choice

- Falling edge performance will not decrease as much when compared to an ever-increasing PCB
- Allows for a simpler design connecting our coax line to the power supply while preventing impedance mismatch





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Next Steps

Company A are suggesting a new circuit topology for the final system due to lessons learnt during development:

- Charging Marx capacitors in parallel
- Connecting capacitors in series to charge coax line and load
- Shorting coax line to ground, with the negative pulse providing the 10ns transition

Company B is looking into making further improvements to their inductive adder design:

- Using SiC devices to reduce stages and devices per stage
- Testing circuit protection at higher voltages to ensure fault tolerance
- Using quick fit optical components for easy swapping out of stages

Acknowledgements

- Dr Iker Rodriguez – Electrical design
- Akanay Avaroglu – Mechanical design
- Jonner Ranner – Project Lead

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Questions?

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Thank you

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