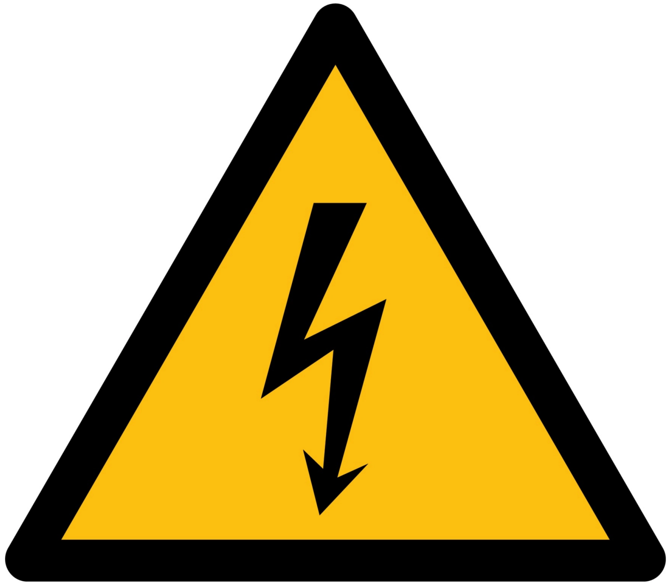
HGTD High Voltage Status

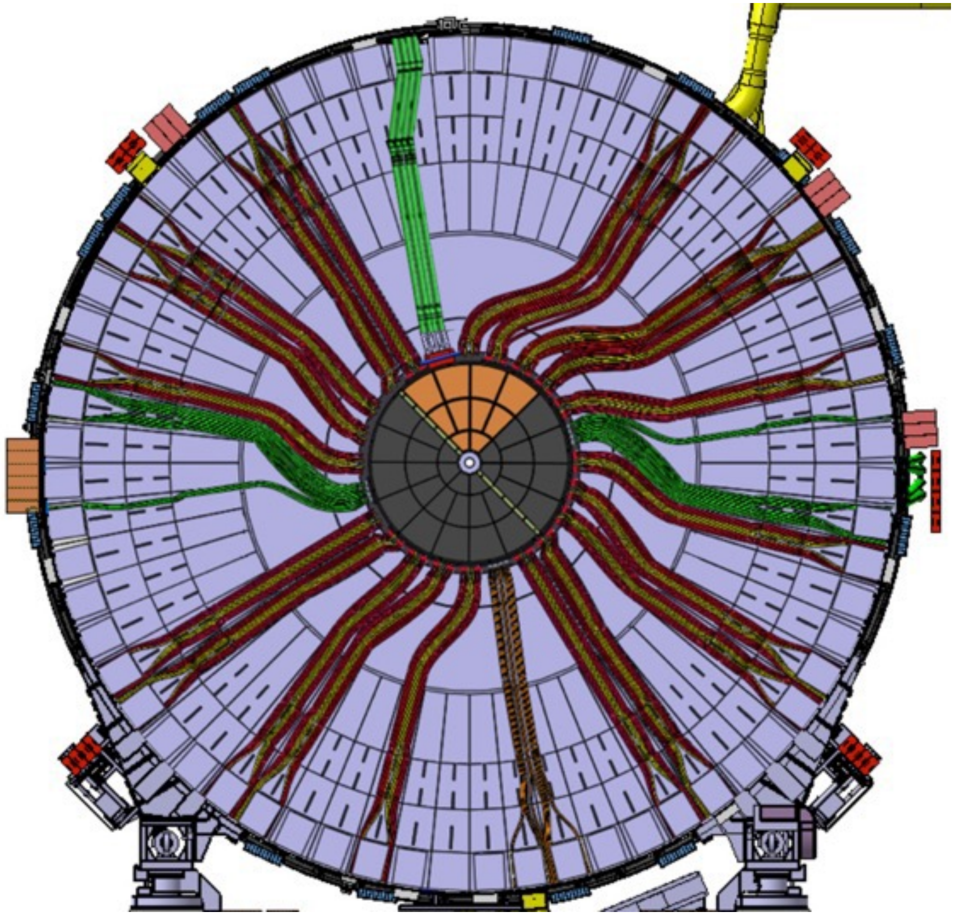


Ricardo Gonçalo (LIP/Univ. Coimbra) for the HV PS and PP teams

HGTD Week in Ljublijana, September 2023

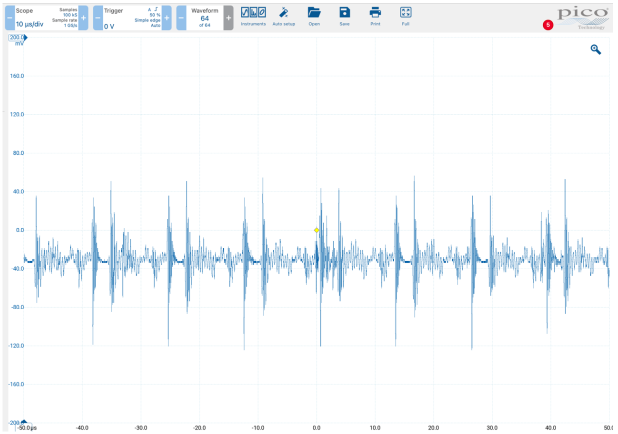
Outlook

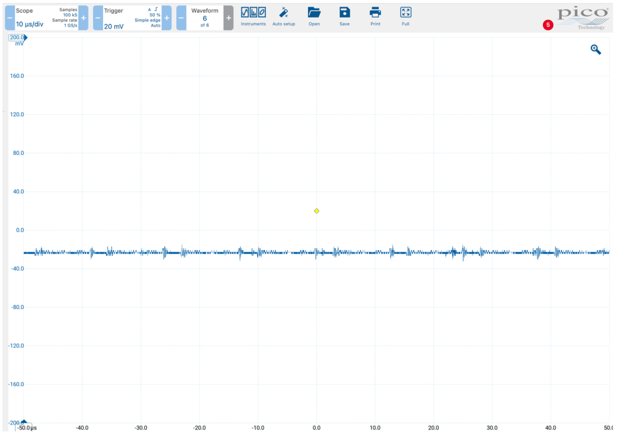
- High Voltage Power Supplies
- Patch Panels
- Grounding & Shielding
- Cables & Connectors

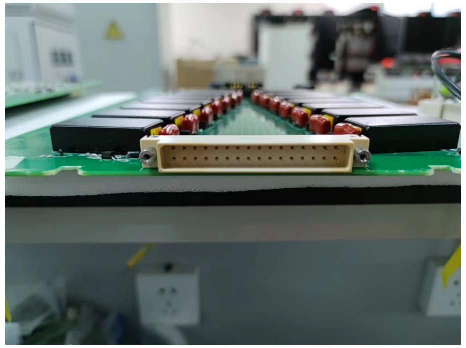


High Voltage Power Supplies

- Sent to CERN in May after factory tests
- Tested together with patch panels in June and August
- Performance good:
    - $\lesssim$ 200 mV ripple at $\approx$ 100 – 150 KHz
    - Attenuated further to $\lesssim$ 20 mV by patch panels (see A.Caramelo's talk tomorrow)

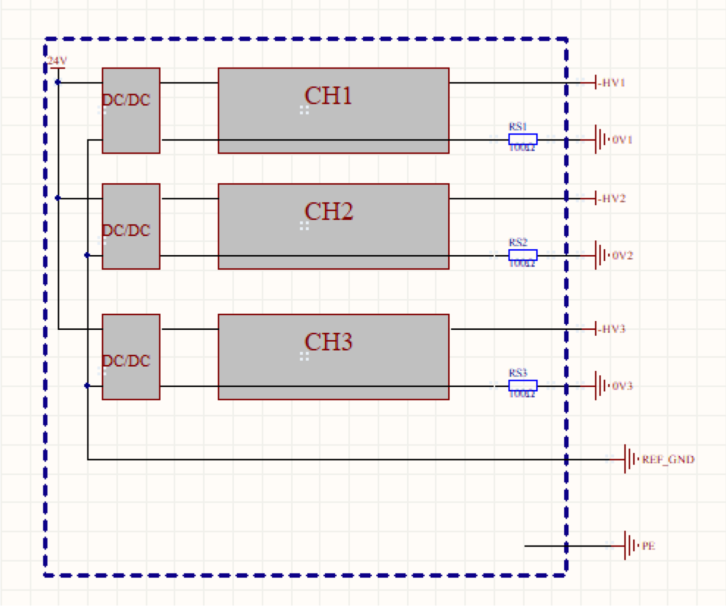




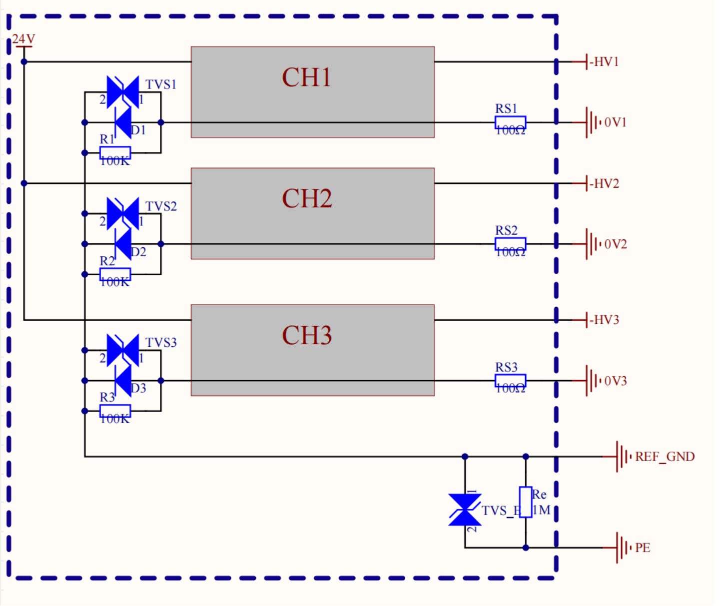


Floating Channels

- Initial prototype modules have 14 independent channels but common ground
  - Results in possibility of small (< 1 V) voltage being applied in turned-off channels
- Company investigating a fully-isolated solution and two possible workarounds
  - Inter-channel resista
  - New prototype to be produced in around one month

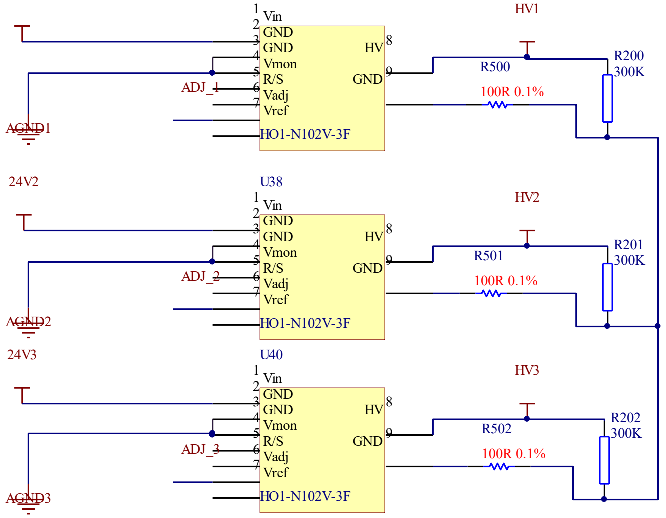


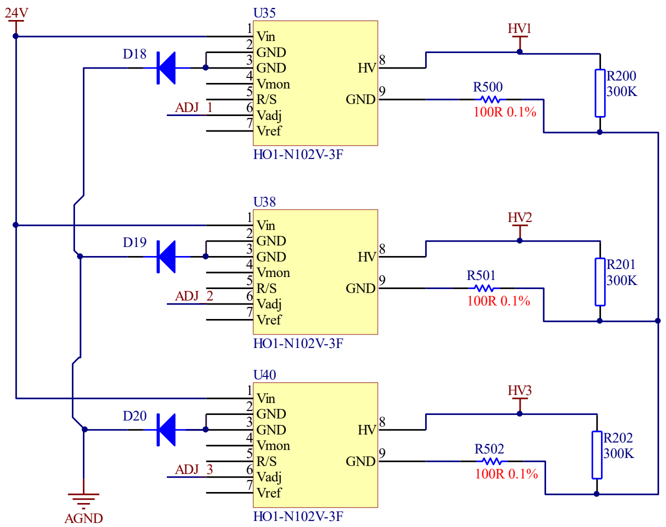
Solution 1 isolated

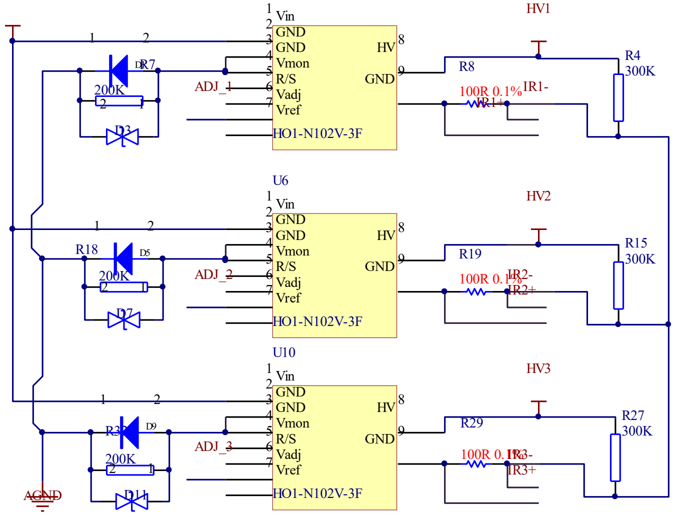


Solution 2 non-isolated

Floating Channels





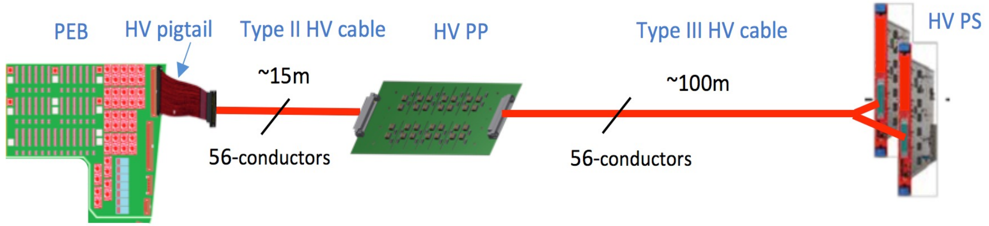


Fully insulated but ×2 in cost

Not insulated: voltage difference between grounds limited to drop in diodes

	Solution 1 Isolated	Solution 2 Non-Isolated with diodes,resistors, and voltage-regulator tubes	Solution 3 Non-Isolated with diodes
Performance	Best	Acceptable	Acceptable
Stability	Nomal	Acceptable	Best
Size	Maximum	Nomal	Minimum
Cost	Double	Minor increase	Unchanged

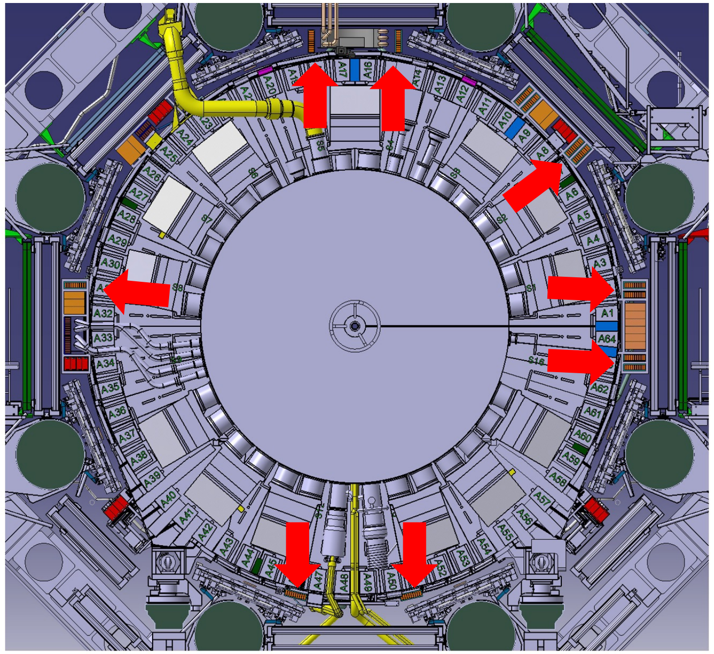
Patch Panels



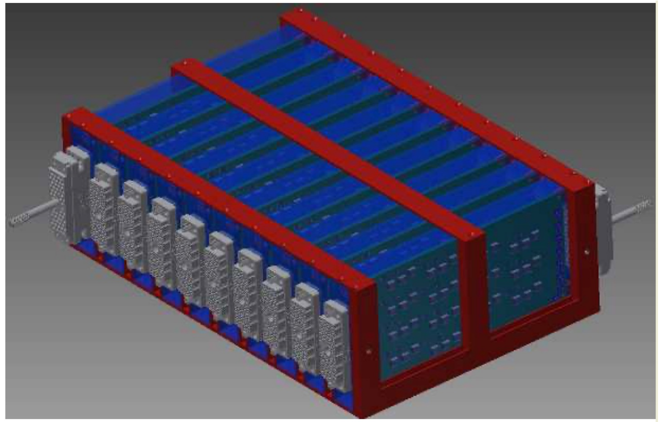
- HV filtered and routed between input long cables from USA15 and short cables to detector
  - 2nd order RC-RC low-pass filter to suppress AC noise
  - 8032 HV channels: at least 574 boards of 14 filters each

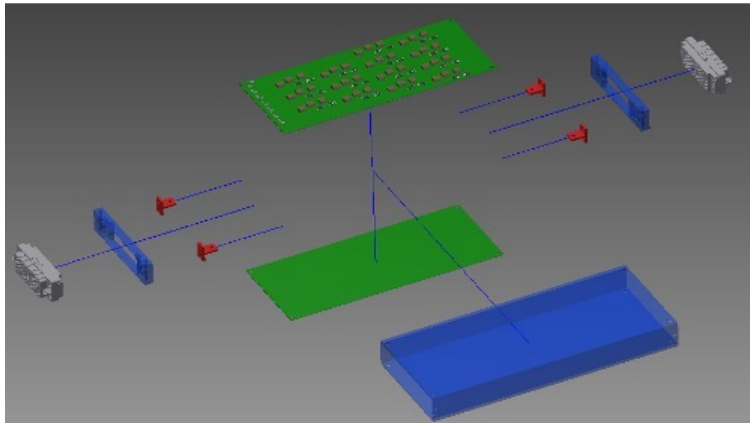
HGTD LVPS
HGTD PP 10
HGTD PP 8
HGTD DCS Box
LAr FEC LVPS 3 crate
LAr HEC LVPS

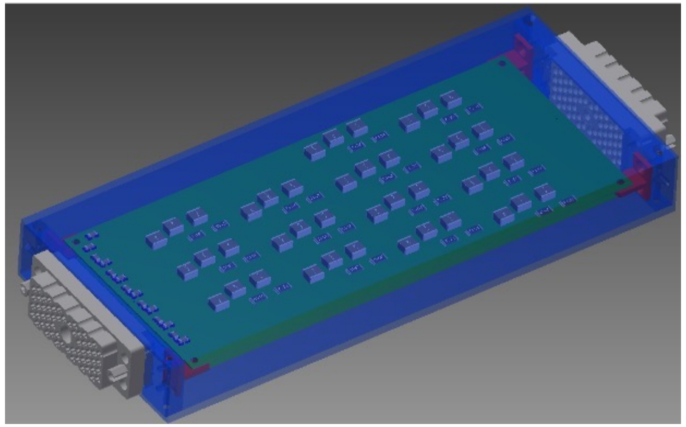
Not in scale in the legend



From Sergei and Tech.Coord.





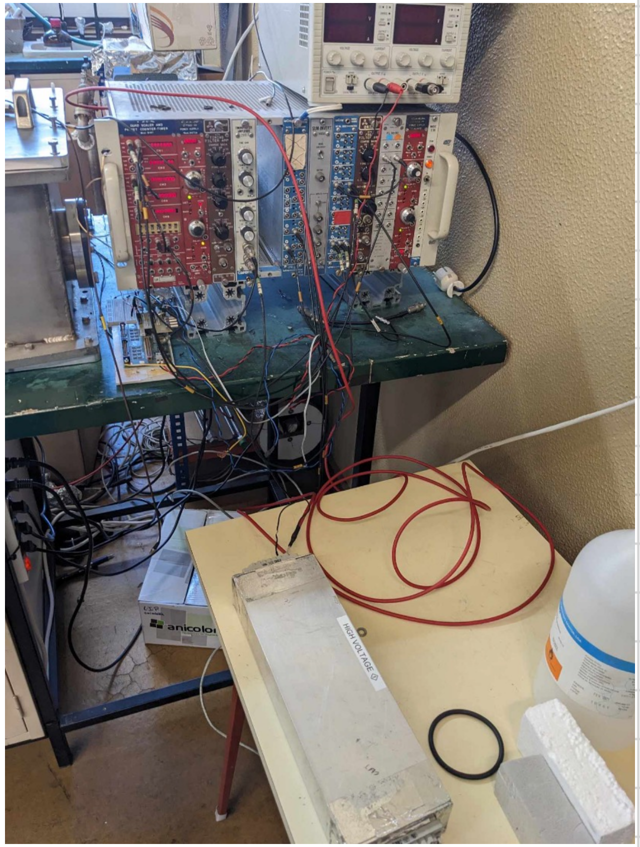


Patch Panel Prototype Testing

Leakage current:

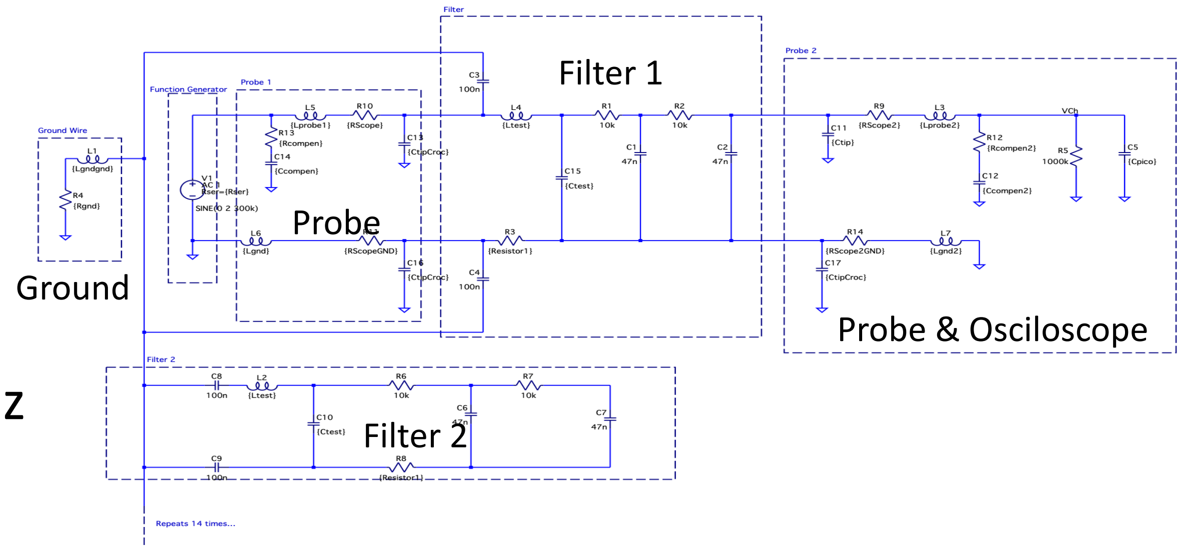
- Leakage current previously measured to be of order 500 nA
    - Turned out to come from dirt and impurities on the PCB

- After cleaning decreased to ≈ 30 nA
    - Applied insulating coating on all channels except 12 and 14
    - No significant increase in current
    - Protects surface in the long run

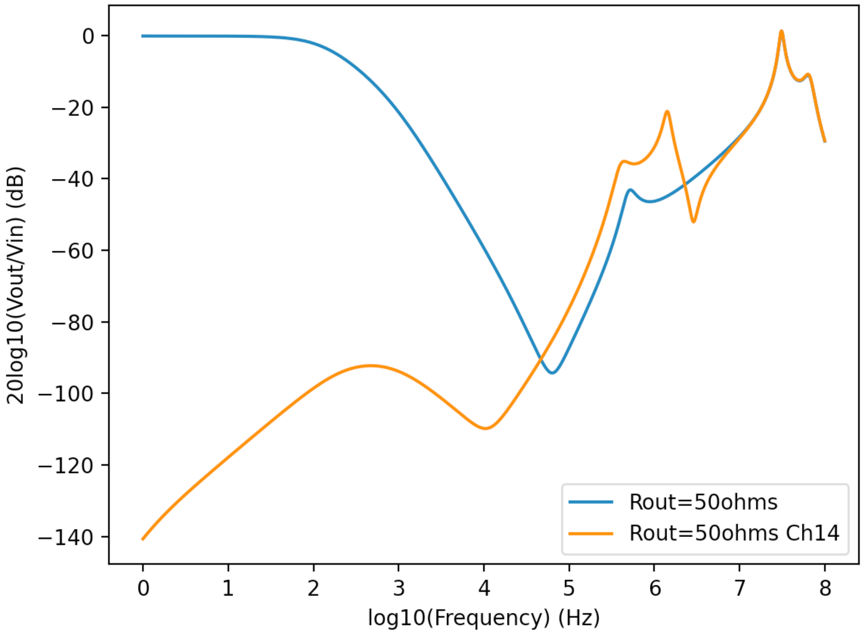


	I(nA)	
Ch	900V	500V
1	33	4
3	42	5
5	35	5
7	35	4
9	34	4
11	36	5
13	31	5
2	33	4
4	35	4
6	36	4
8	34	5
10	32	4
12	23	4
14	24	3
	+-1nA	

Frequency Response

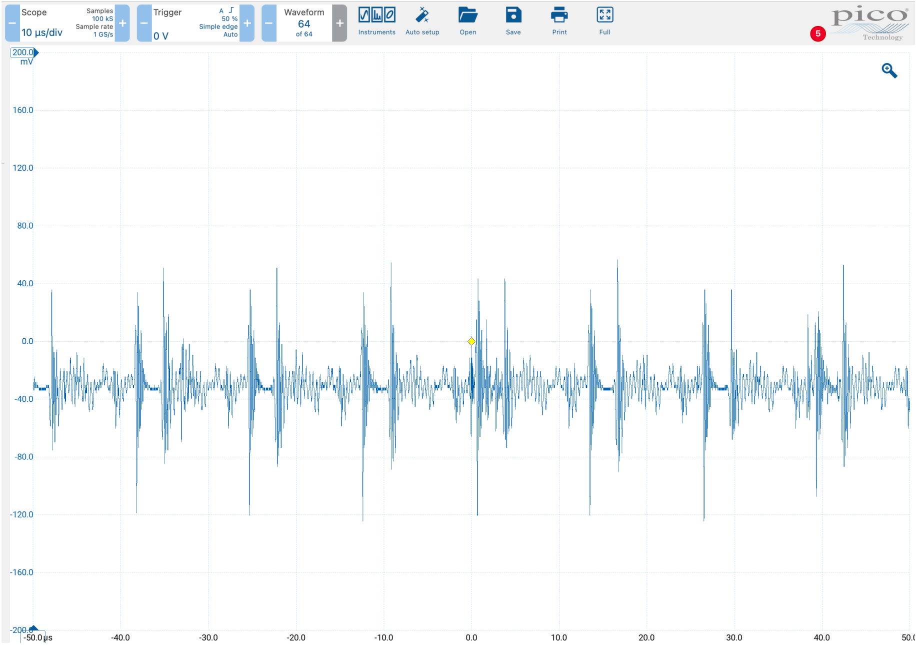


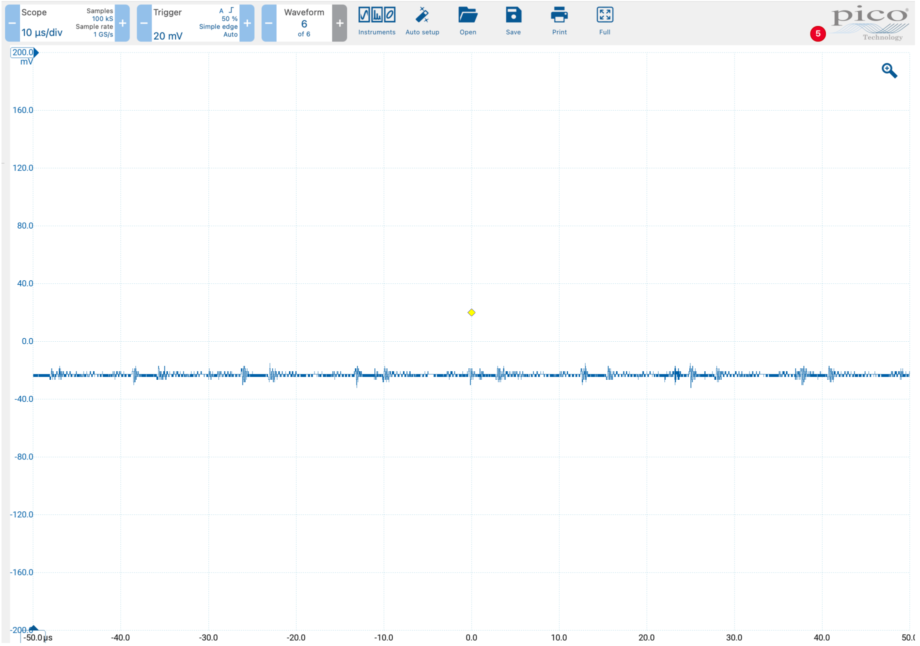
- Several effects better understood now:
  - Common mode noise transfer: above ≈ 1 MHz
  - Some cross talk: above ≈ 100 kHz
  - Changes under bias traced to changing capacitance of filter capacitors
- Complex model constructed
  - Predicts response at least qualitatively
  - Including effects from common mode, cross talk, cables &measuring probes
- HV PS ripple expected at 1 – 1.5×10^5 Hz



Combined HVPS+Patch Panel

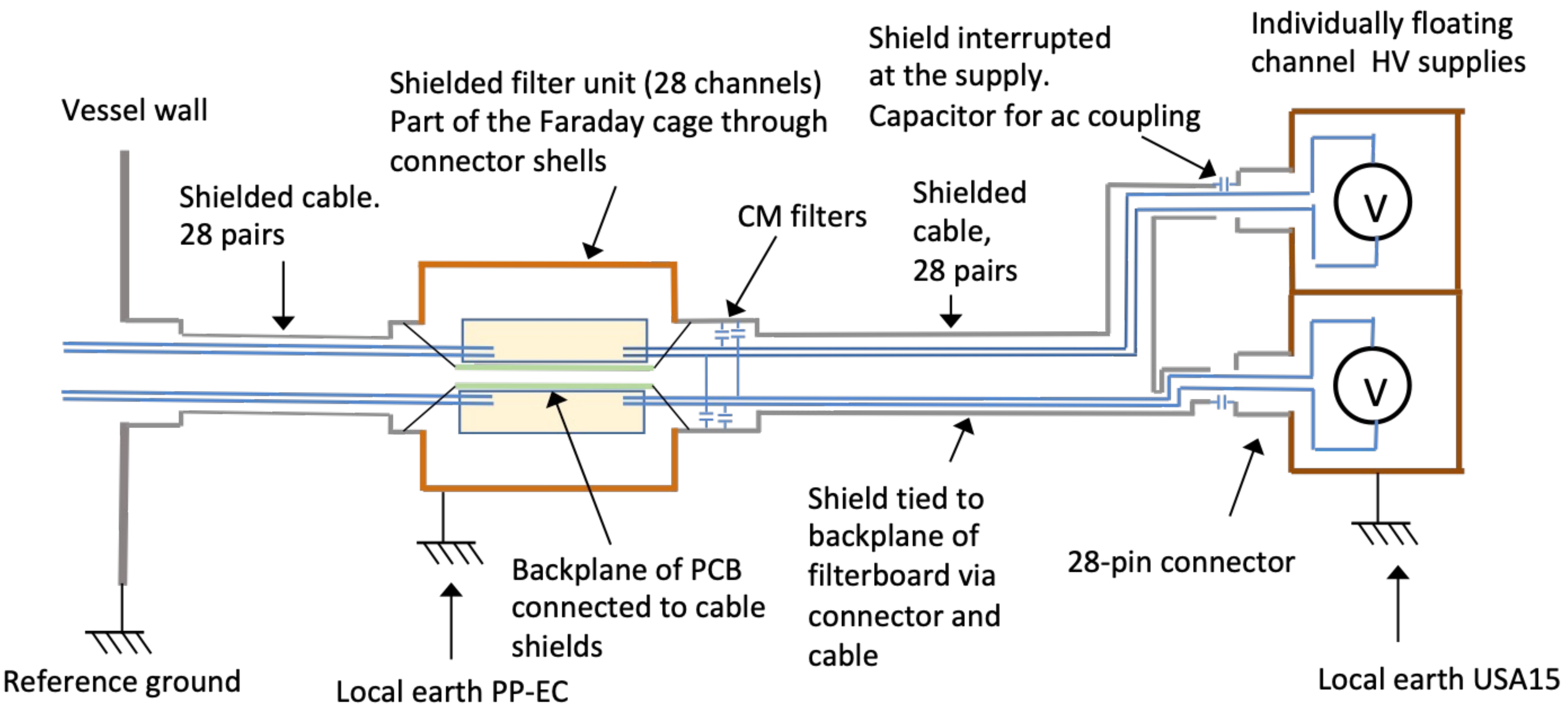
- HV PS ripple expected at 100 – 150 kHz ($1 - 1.5\times10^5$ Hz)
- Ripple attenuated by 10× (-20 dB) to ≈ 20 mV
  - Lower than initially expected (≈ -120 dB) but seems to be explained by probe L and R
- Consistent results across all channels





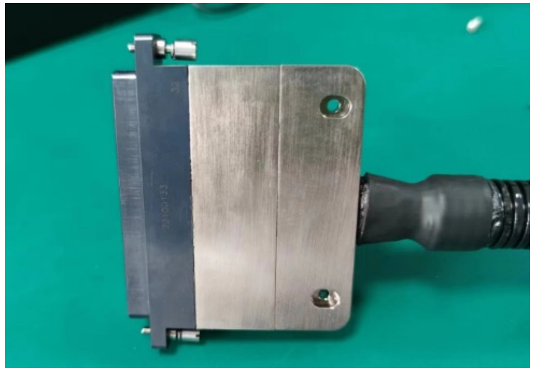
Grounding and Shielding

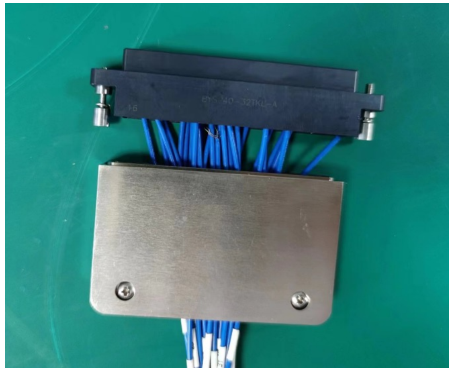
- Use filter module boxes as continuation of vessel Faraday cage
  - Also DC connecttion of filter boards backplane to cage
- DC connection of Faraday cage to local TileCal earth
  - DC current not as bad as HF AC noise
- Move common-mode filter capacitors to filter input instead of output
  - Filter common mode current at input



Cable Connectors

- Connectors under discussion: see presentation by Sergei
- Different constraints at each connection:
- Power-supply end (14 channels):
  - Not often moved and good accessibility: medium mechanical requirements
  - Company proposing own connectors (plugs for free)
  - Also testing Sub-D from Harting
- HV PS to Patch Panel connection (28 Channels):
  - Poor accessibility and frequent reconnections: need strong and easy to handle connectors
  - Using field-tested EDAC 516 connectors
- Patch Panel to short cable (28 Channels):
  - Fixed in place at installation: no special mechanical requirements
- Short cable to outer ring (28 Channels):
  - No disconnect, but very little available space (small pins) and demanding criteria for thermal and electrical behaviour
  - Planning to use Nikomatic connectors

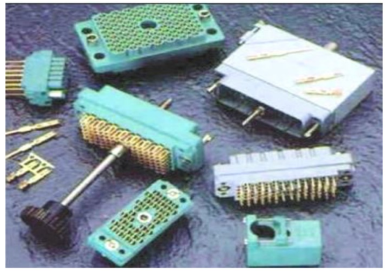




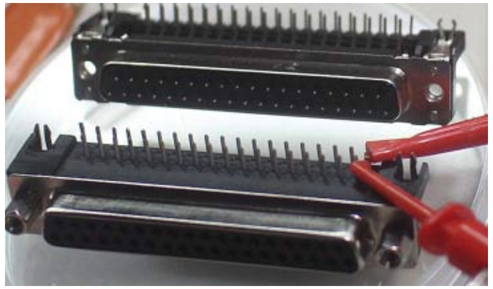
EDAC

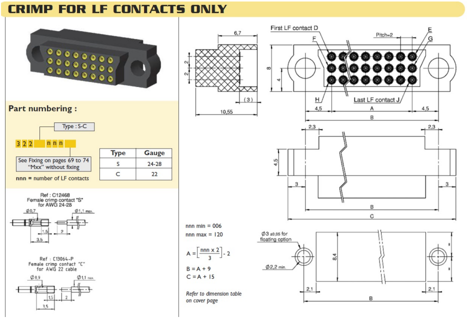
516 SERIES

RACK AND PANEL CONNECTOR (PLUG AND RECEPTACLE)

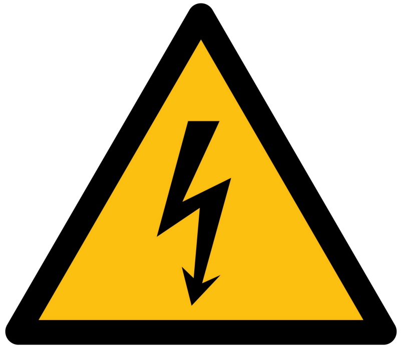


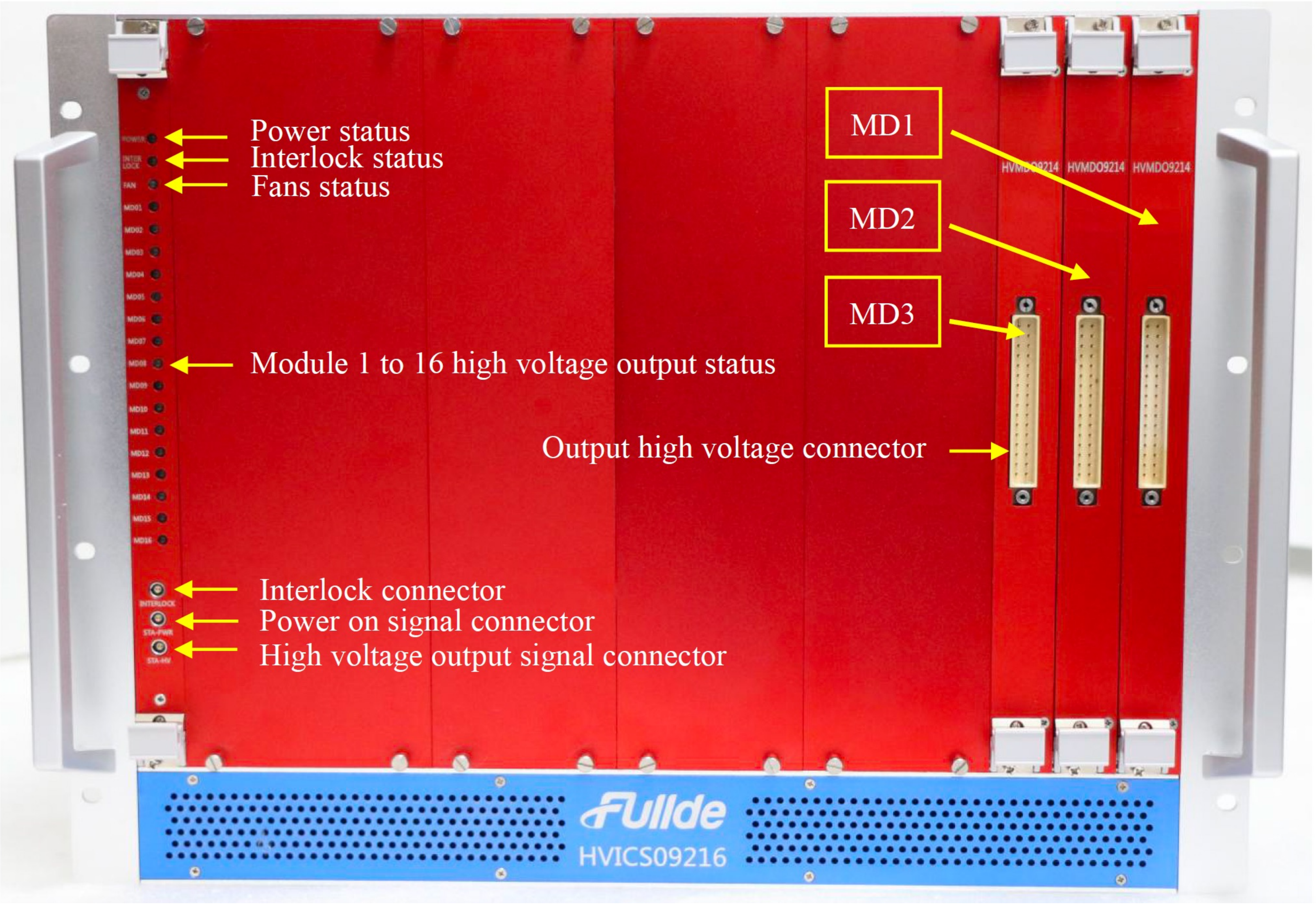
- **FEATURES:**
- .150" (3.81mm) Contact Spacing x .130" (3.30mm) or .150" (3.81mm) Row Spacing with staggered Grid
- Plug and Receptacle in 20, 38, 56, 90 and 120 Contact Sizes
- Edacon Hermaphroditic Contact Mating Design
- Contact Termination Options include Crimp, P.C. Tail, Wire Hole and Wire Wrap
- Mating and Unmating Simplified with use of Actuating Screws
- Optional Covers with Side or Top Entry Cable Clamp in Plastic or Metal material Available for all Connector Sizes
- Versatile Metal Cover Design permits Assembly or Disassembly After Cabling is Complete plus Cable Entry Style Flexibility
- Actuating Screws, Locknuts, Polarizing Hardware, Covers and Contacts Suitable for either Plug or Receptacle
- Polarizing Hardware Adjustable for 288 Mating Combinations
- Tools Available for Contact Installation, Removal and Crimping and Polarizing Changes
- RoHS Compliant & UL Certified





Bonus slides

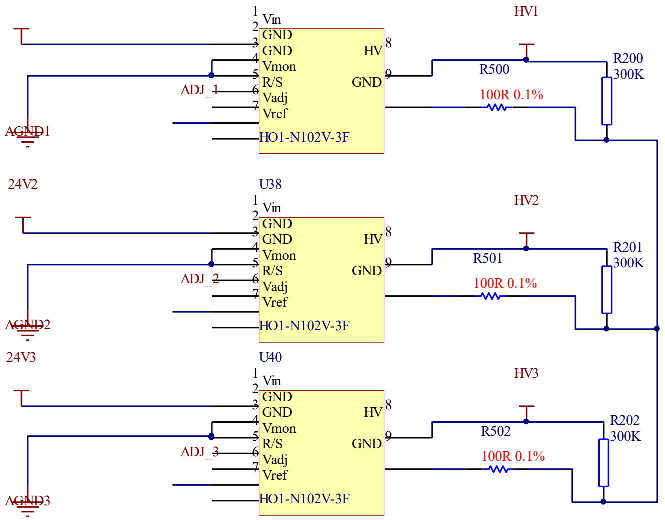




Power status
Interlock status
Fans status
Module 1 to 16 high voltage output status
Interlock connector
Power on signal connector
High voltage output signal connector
MD1
MD2
MD3
Output high voltage connector
HVMDO9214
HVMDO9214
HVMDO9214
HVICS09216

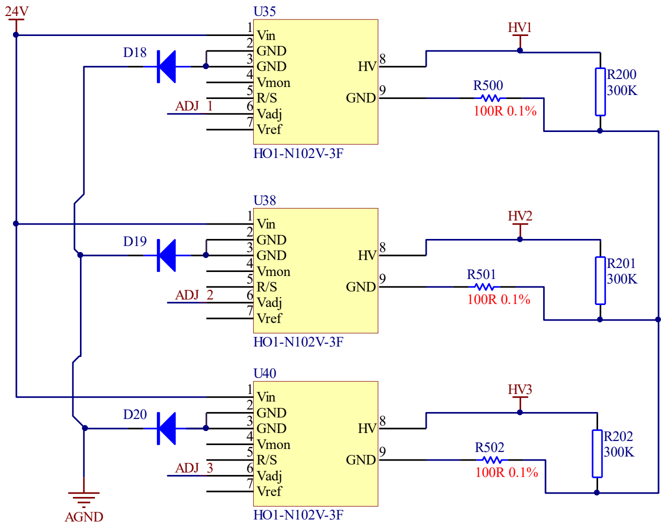
Fully insulated but ×2 in cost

- Best performance
- Increase in size; stability normal

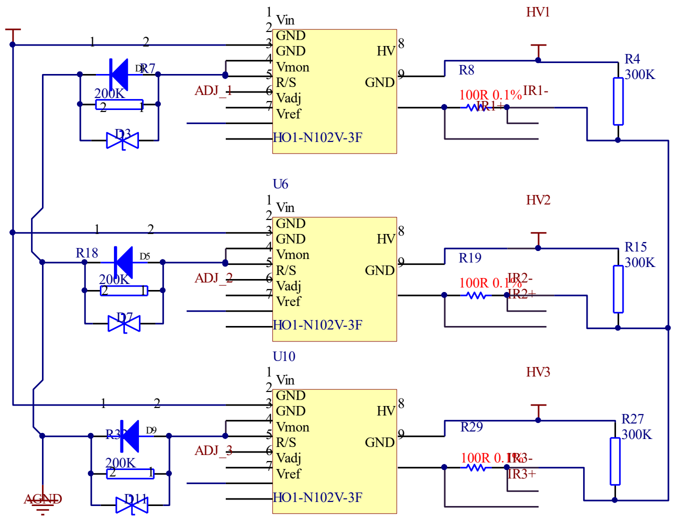


Not insulated: voltage difference between grounds limited to drop in diodes

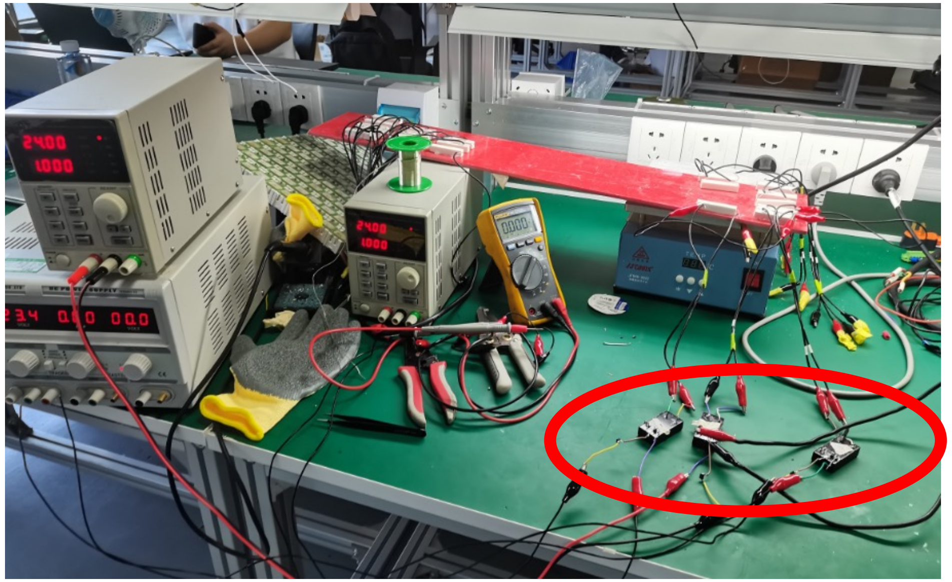
- Best stability; performance ok
- Cost unchanged



- Stability and performance ok
- Minor cost increase

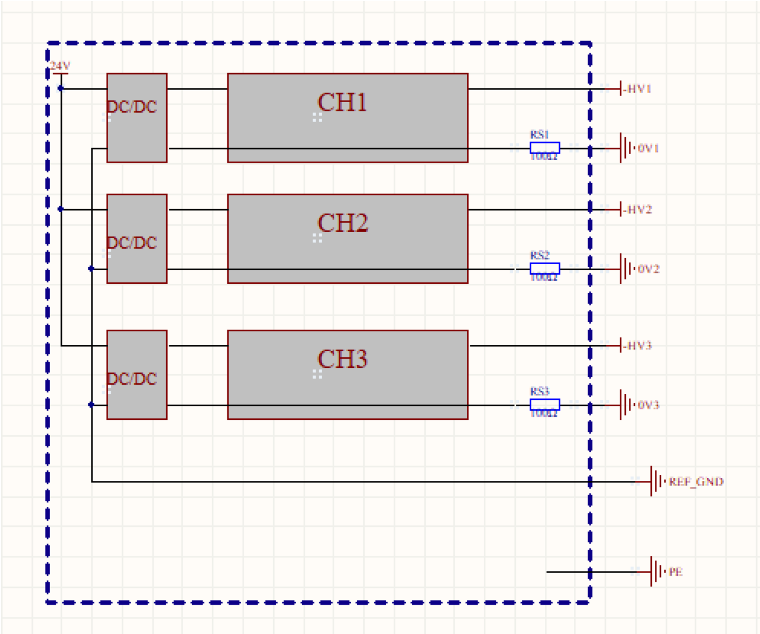


Topic 1 Test

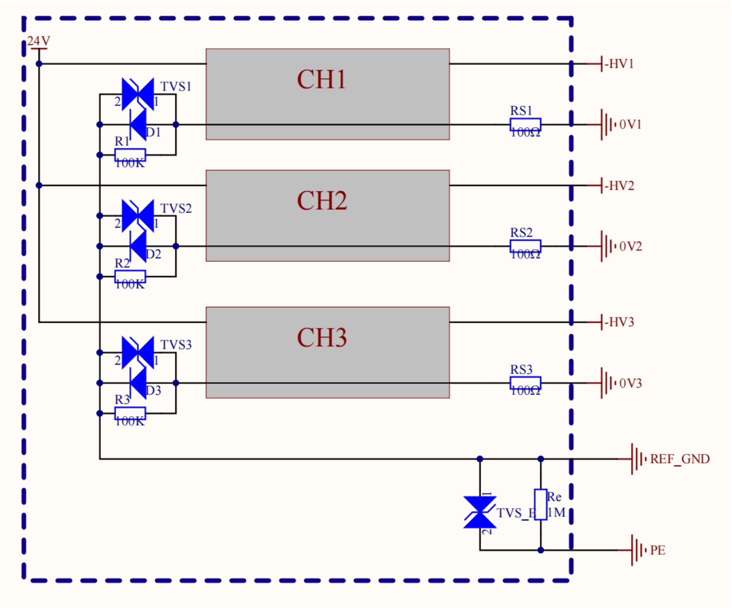


After last discussion, we built a temporary environment to test solution 1 and 2.

The test results can serve as a reference, but the formal PCB version cannot be welded until the end of the month.

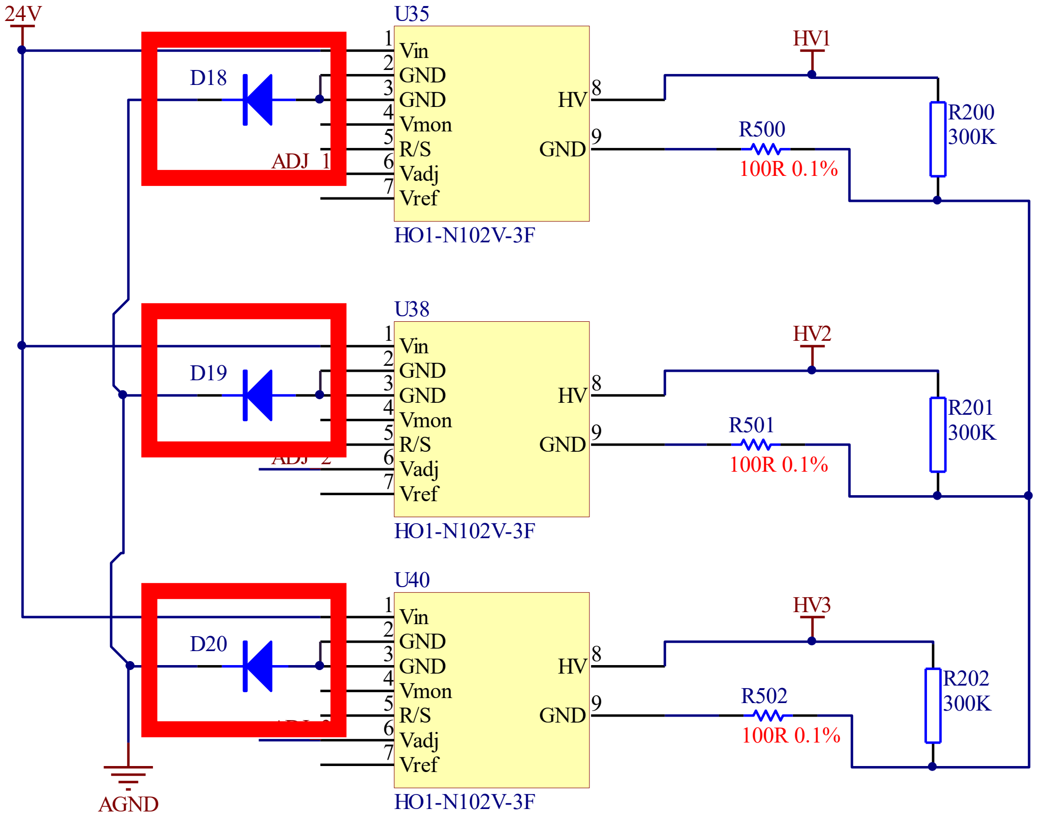


Solution 1 isolated



Solution 2 non-isolated

Test 1.1(Non-isolated with diode)



Condition

3 channels sharing the same ground through a diode.
3 loads(300k resistor) sharing ground.

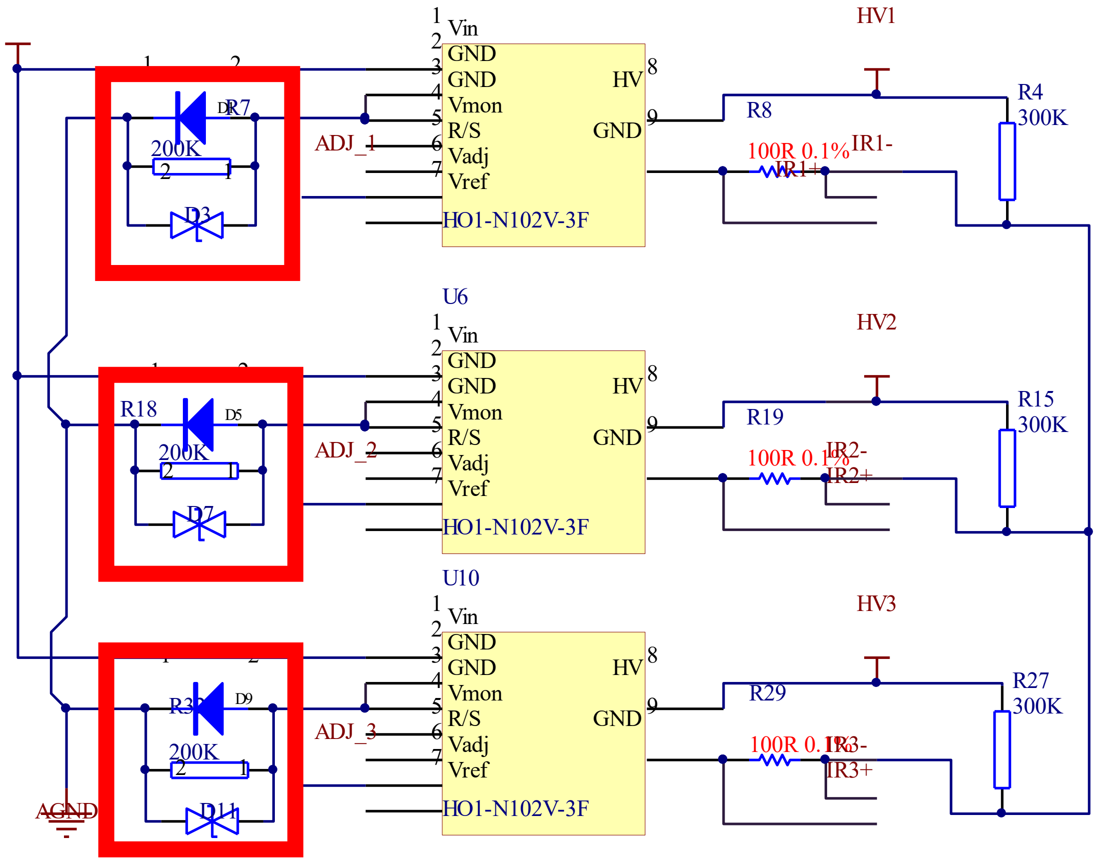
Result

	CH1 ON	CH1&3 ON	All ON
Voltage of current sampling resistor CH1	86.8mV	86.6mV	83.0mV
Voltage of current sampling resistor CH2	7.6mV	6.7mV	79.7mV
Voltage of current sampling resistor CH3	4.0mV	82.0mV	77.4mV
Voltage of load CH1	240.01V	240.08V	240.0V
Voltage of load CH2	0.008V	0.007V	240.6V
Voltage of load CH3	0.251V	241.4V	241.2V

Conclusion

The sampled current is almost equivalent to the actual load current, but there is still diode leakage current between channels.

Test 1.2(Non-isolated with resistor， diode and voltage-regulator tube)



Condition (solution 2)

3 channels is grounded through a 200k resistor ,diode and a voltage-regulator tube.

3 loads(300k resistor) sharing ground.

Result

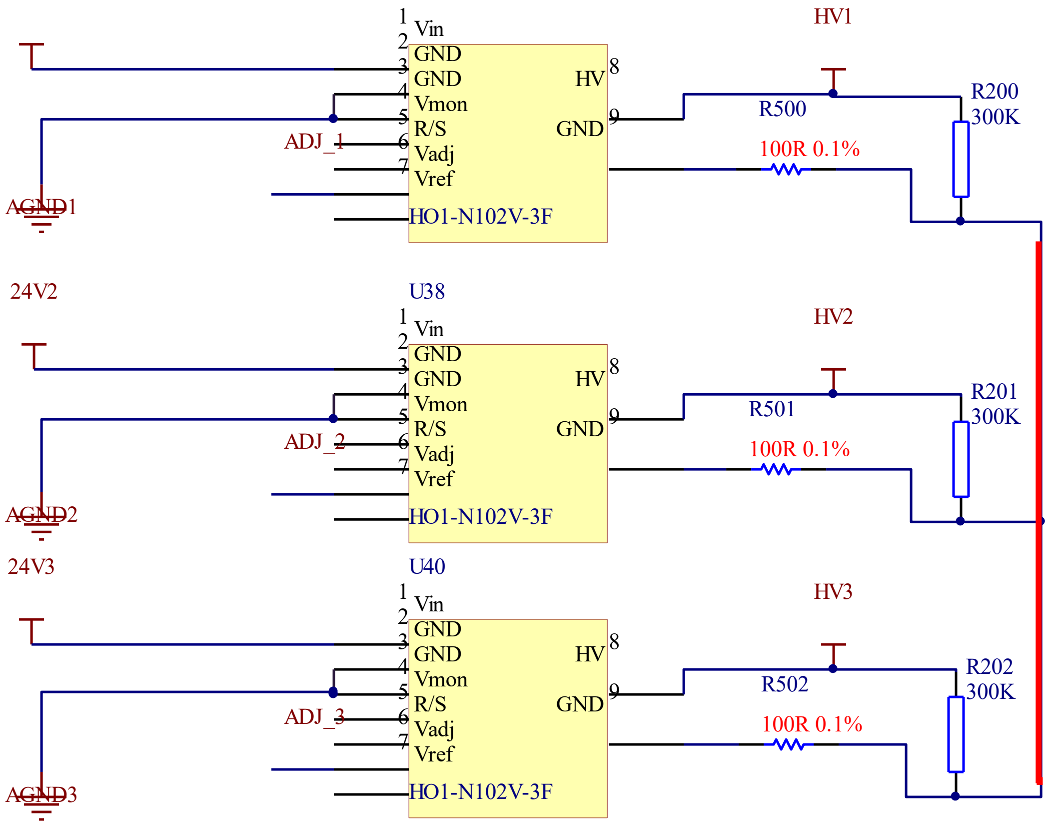
	CH1 ON	CH1&3 ON	All ON
Voltage of current sampling resistor CH1	87.2mV	87.2mV	81.9mV
Voltage of current sampling resistor CH2	7.3mV	9.3mV	80.1mV
Voltage of current sampling resistor CH3	3.1mV	83.2mV	77.0mV
Voltage of load CH1	241.0V	240.0V	239.5V
Voltage of load CH2	0.007V	0.01V	239.2V
Voltage of load CH3	0.261V	240.4V	240.4V

Conclusion

The test results are similar to the previous situation.

Without isolation, the voltage difference between different gnds will be limited to the voltage drop of the diode, so we need to discuss whether it is necessary to add the resistors and voltage regulators.

Test 2.1(Isolated)



Condition(Solution 1)

3 channels NOT sharing the same ground or 24V.
3 loads(300k resistor) sharing ground.

Result

	CH1 ON	CH1&3 ON	All ON
Voltage of current sampling resistor CH1	111.0mV	111.1mV	110.4mV
Voltage of current sampling resistor CH2	2.3mV	2.3mV	110.3mV
Voltage of current sampling resistor CH3	2.3mV	111.1mV	110.1mV
Voltage of load CH1	332V	332.0V	332.0V
Voltage of load CH2	0.001V	0V	331.7V
Voltage of load CH3	0.268V	331.7V	331.2V

Conclusion

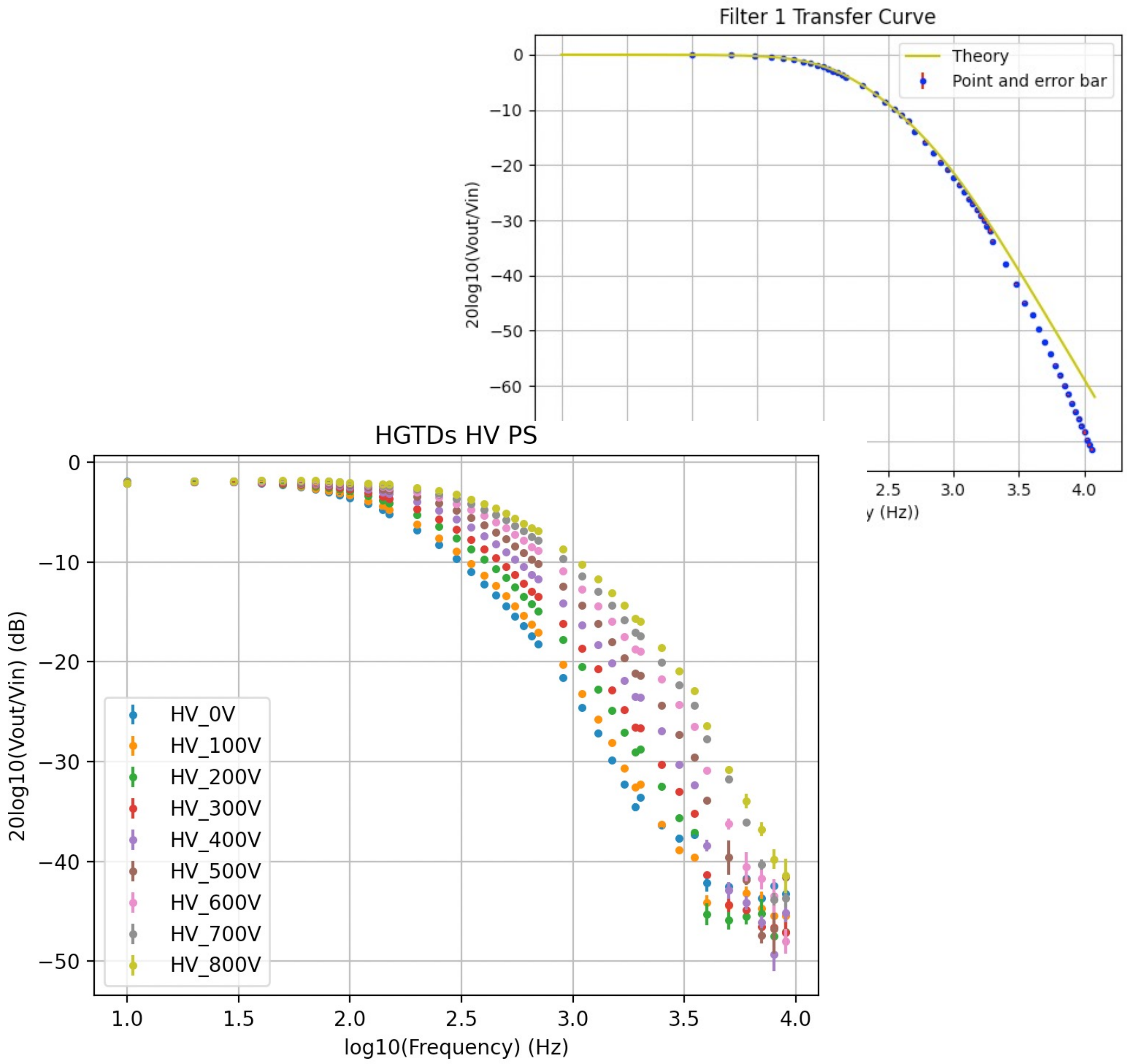
When the loads are connected to the same ground, the power supply works well.However, in order to avoid significant voltage differences between different ground wires caused by spatial magnetic fields, it is necessary to add resistors and voltage stabilizing tubes to connect the isolated ground wires together.

Discussion

	Solution 1 Isolated	Solution 2 Non-Isolated with diodes,resistors, and voltage-regulator tubes	Solution 3Non-Isolated with diodes
Performance	Best	Acceptable	Acceptable
Stability	Nomal	Acceptable	Best
Size	Maximum	Nomal	Minimum
Cost	Double	Minor increase	Unchanged

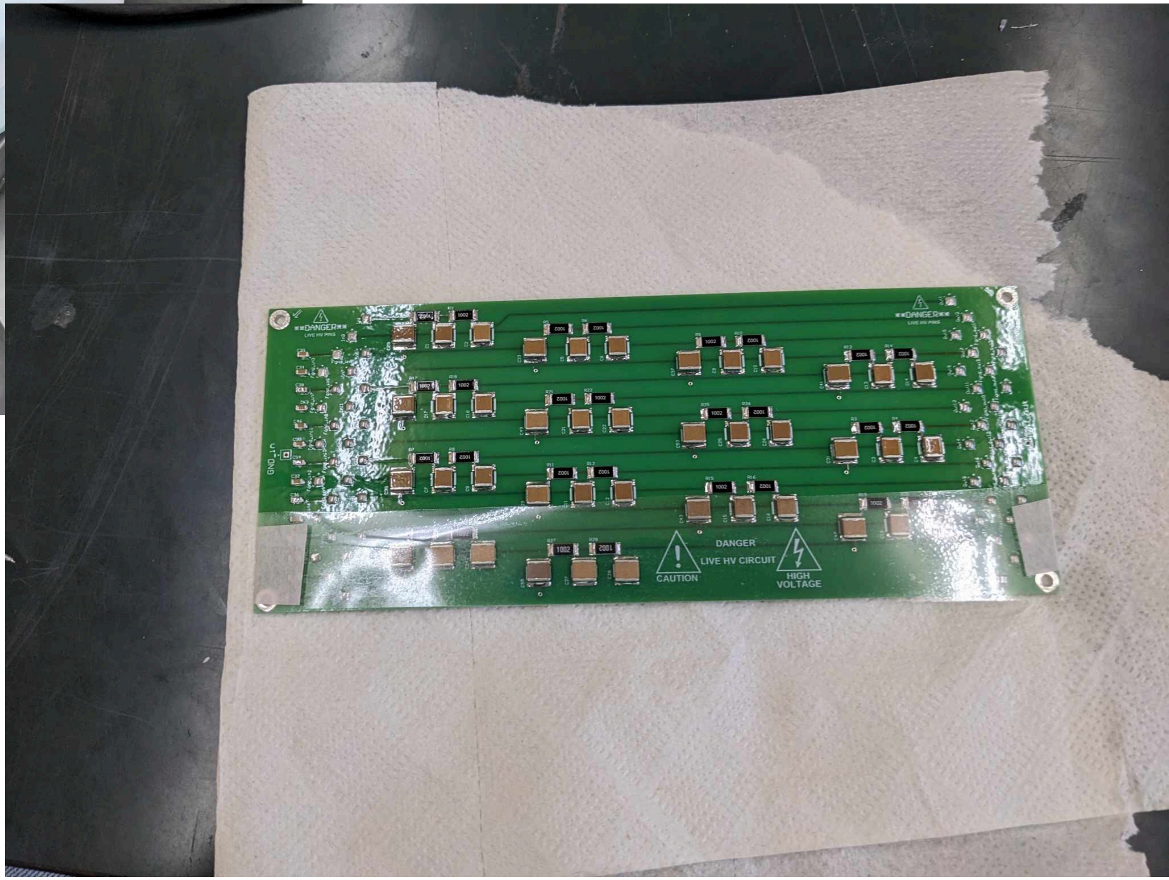
Previously

- Explained deviation from theory in LV Transfer Curve
- Cross talk was on hold
- Leakage current arround 0,5uA per channel
- Ripple attenuation
- HV transfer curve



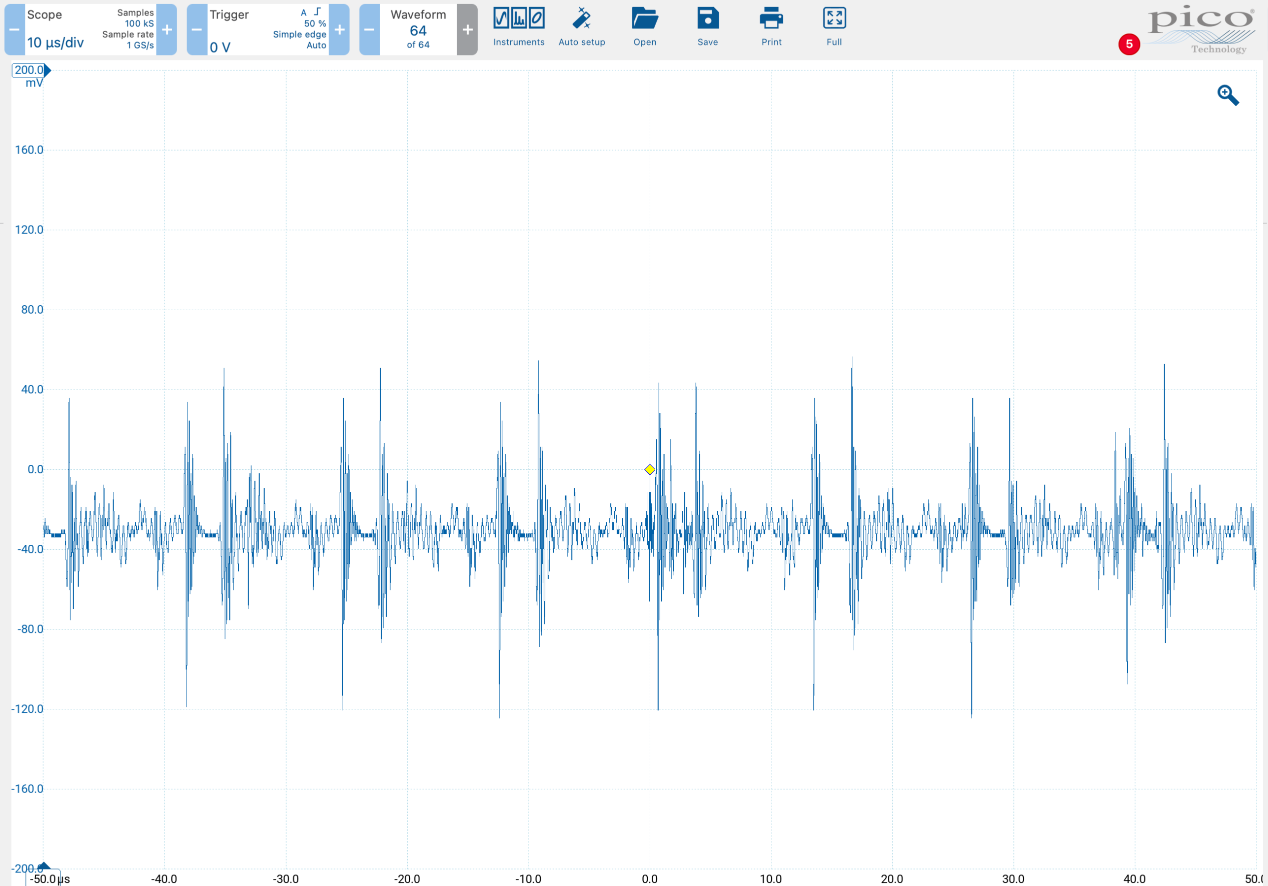
Leakage Current

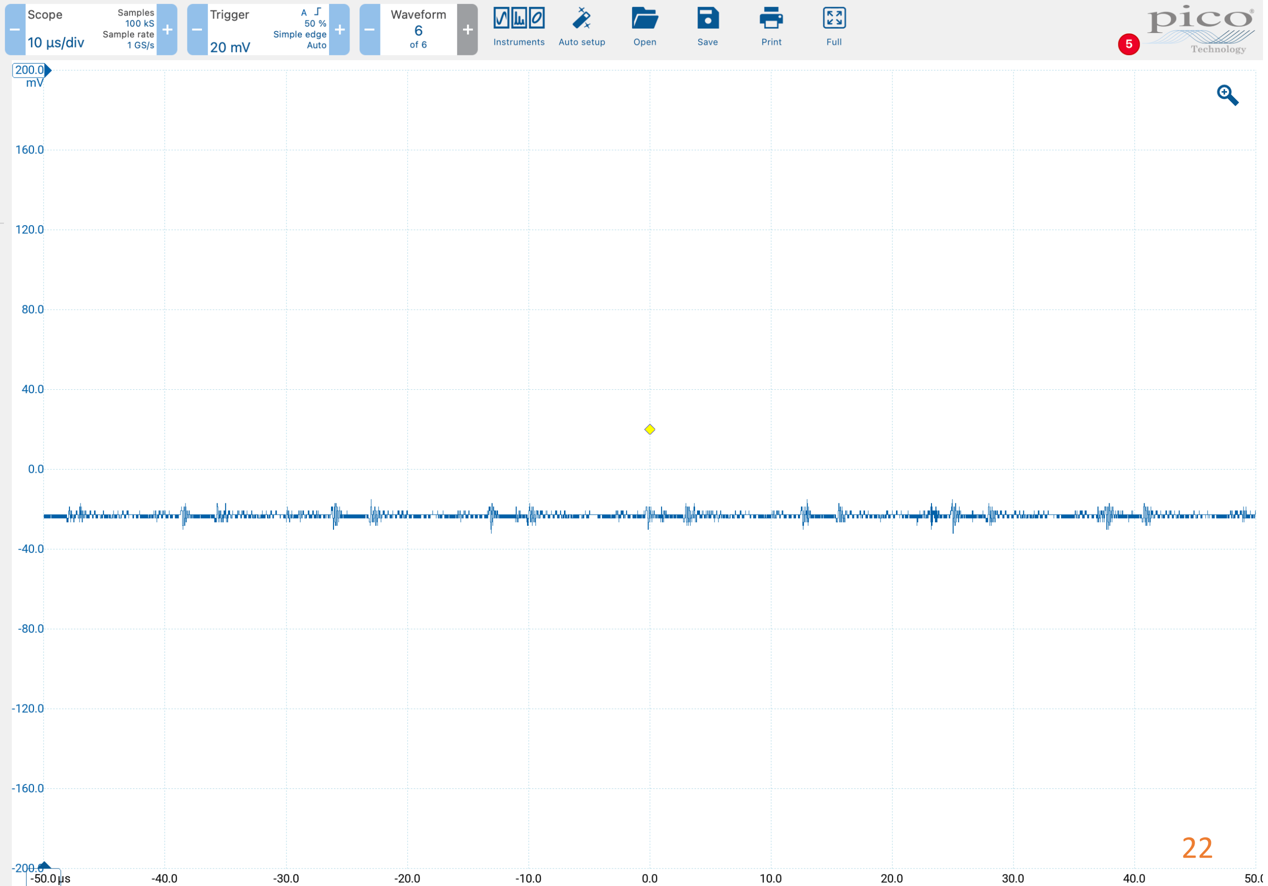
- Leakage current was deemed too high
- Board cleaned with ultrasound in methanol
- Highly resistant, protective and insulating conformal coating aplied to some channels (Urethane) (used plastic strip to protect others)
- Soldered everything together with gloves



Ripple Attenuation

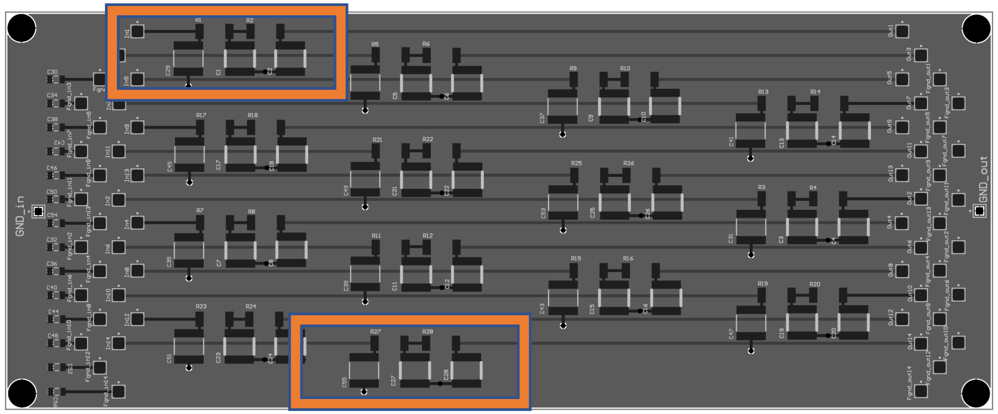
- All available HV PS channels tested together with filter board, consistent results across all channels
- Ripple big peaks go from ~200mV to ~20mV (~-20dB)
- Significant attenuation, but lower from expect theoritcal attenuation at ~300kHz (~-120dB)



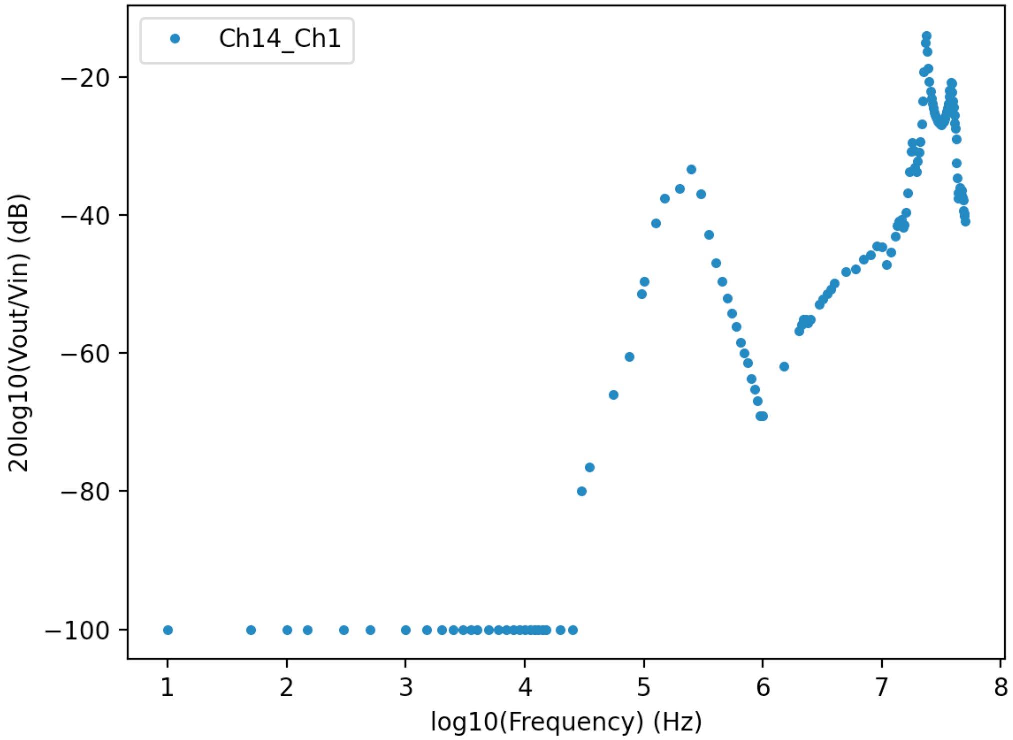


Cross talk

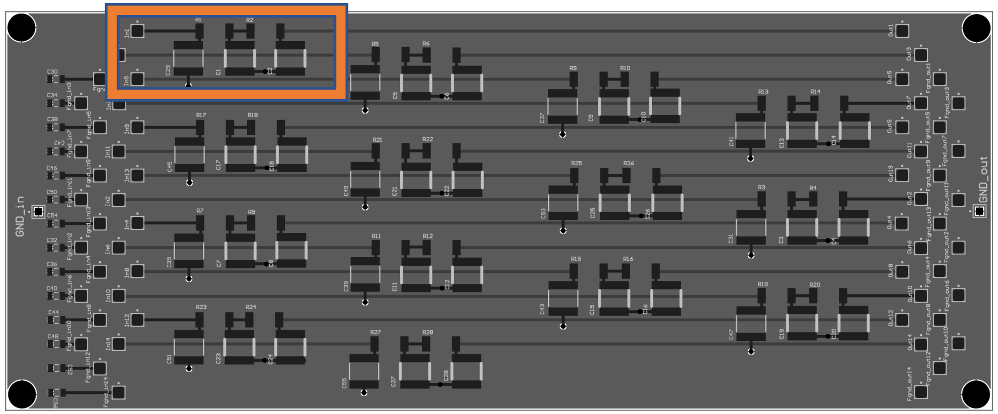
- Input into Channel 1, measured Channel 14 (furthest channel)
- Detected Cross Talk at ~300kHz and ~25MHz
- Plotted transfer curve of what channel 14 picks up from channel 1, seen in plot (done by hand using osciloscope and function generator)
- Signal actually propagates through back plane
- This prompted transfer curve study to higher frequencies



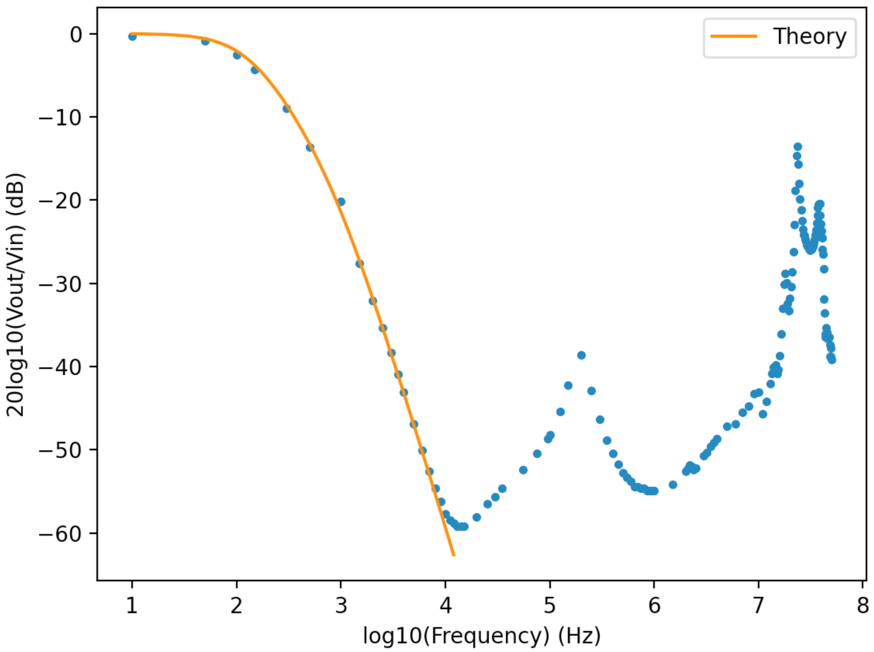
Expected no signal pick up



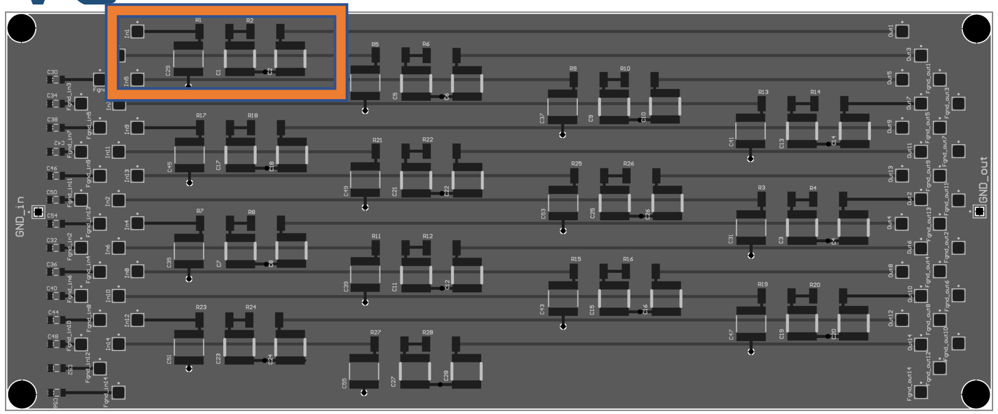
High Frequency Transfer Curve



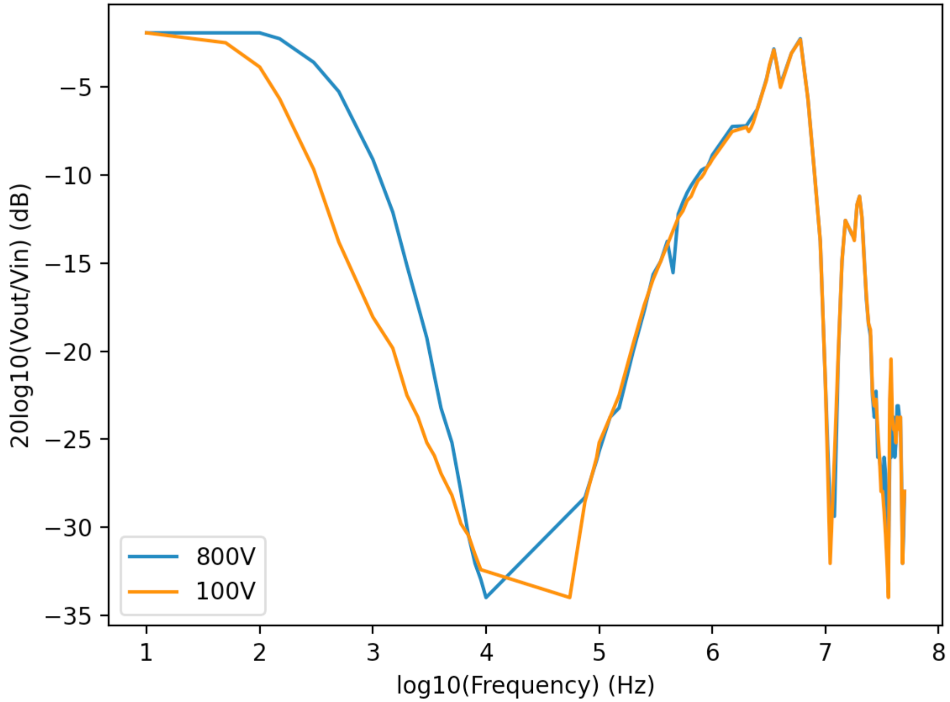
- Plotted channel's 1 transfer curve for higher frequency using osciloscope and function generator (20V 50MHz)
- High frequency measurements were not conducted before as PicoScope was limited to 2V 1MHz, and output signal being -60dB attenuated is impractical to measure.
- Curve does follow theory beyond ~10kHz



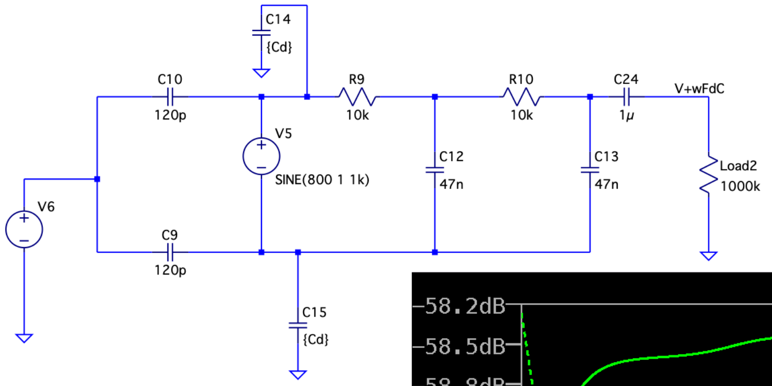
High Frequency HV Transfer Curve

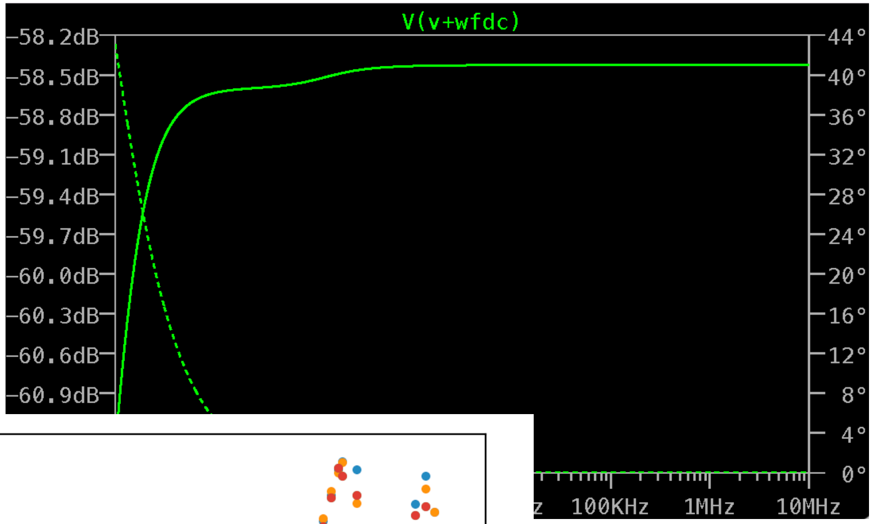


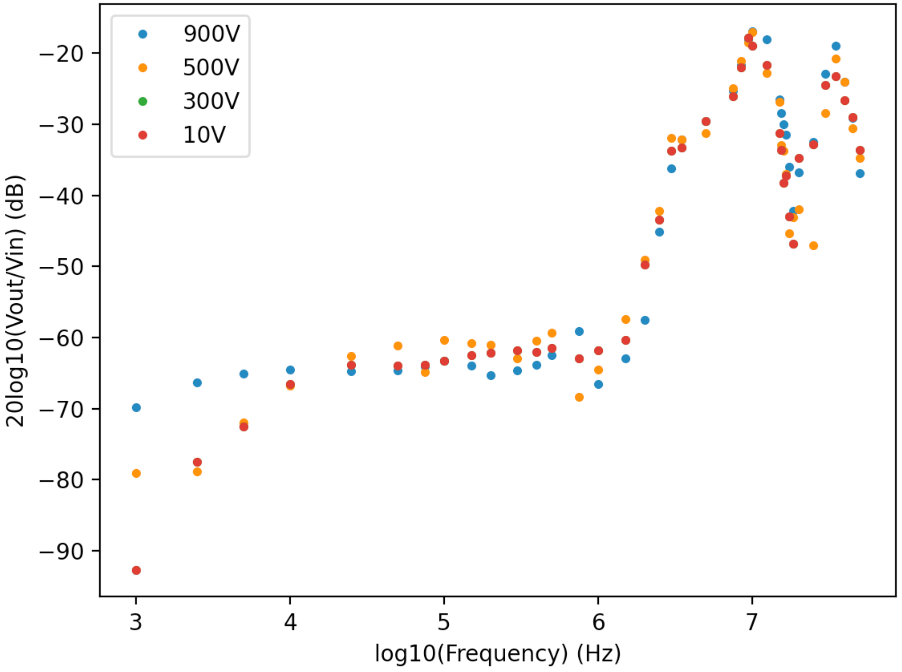
- Plotted channel’s 1 transfer curve for higher frequency using osciloscope and function generator (20V 50MHz)
- Repeated HV transfer measurement for higher frequencies
- Again peaks detected at higher frequencies, same phenomenon as before detected



Common Mode noise



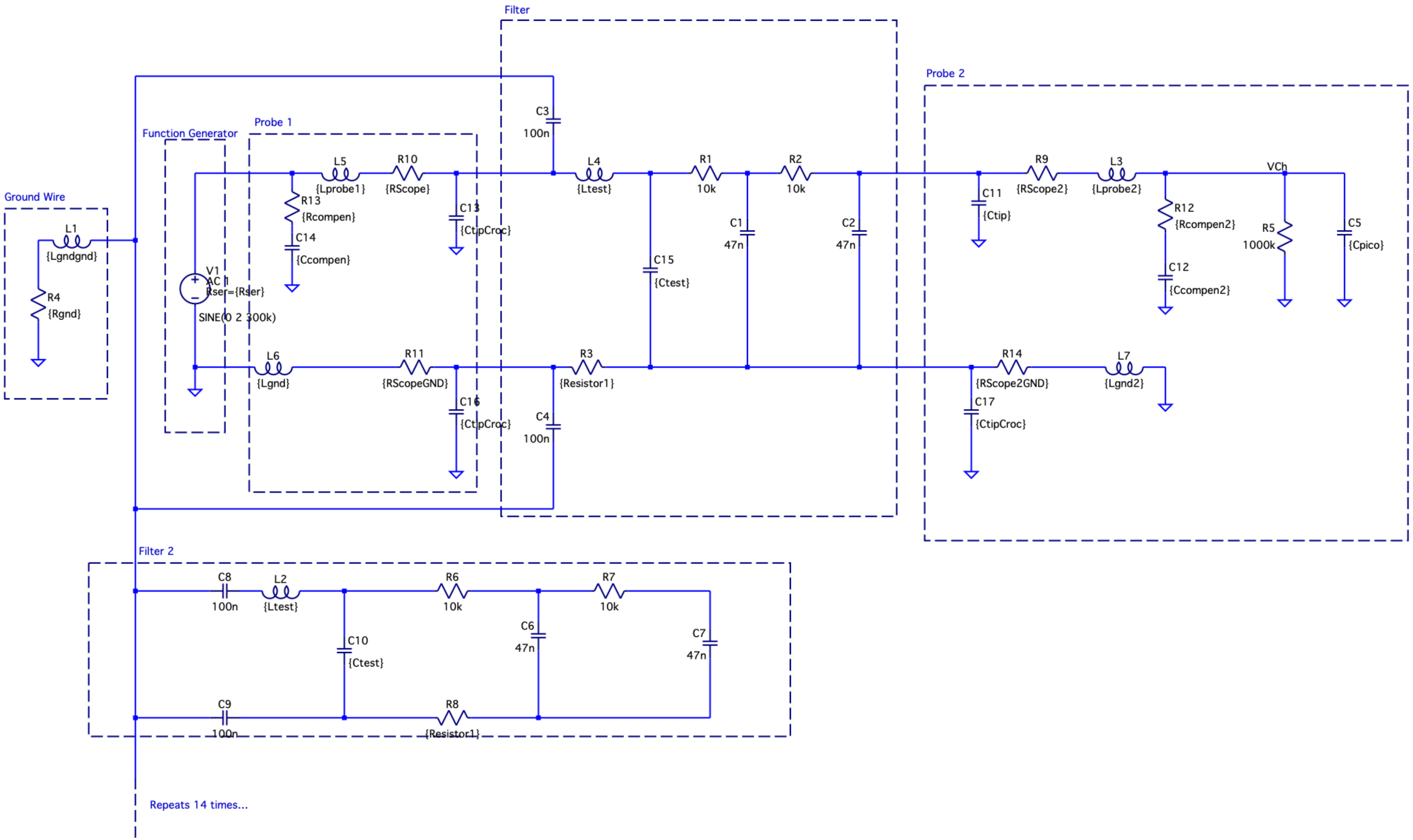




- Plotted channel's 1 transfer curve for higher frequency using osciloscope and function generator (20V 50MHz) this time for common mode noise
- Expected flat curve at ~-60dB
- Again an unexpected peak at higher frequencies, DC voltage does not seem to affect cm noise filtering

Parasitics

- Unanticipated high-frequency outcomes in ripple attenuation, cross-talk transfer function, and common mode noise attenuation prompted pursue of explanatory model.
- Explored various parasitic factors, constructing a comprehensive model with practical parameter values to account for these phenomena.
- Iteratively tested different component combinations until identifying a model approximating observed behavior.
- Ongoing refinement and simplification of the model

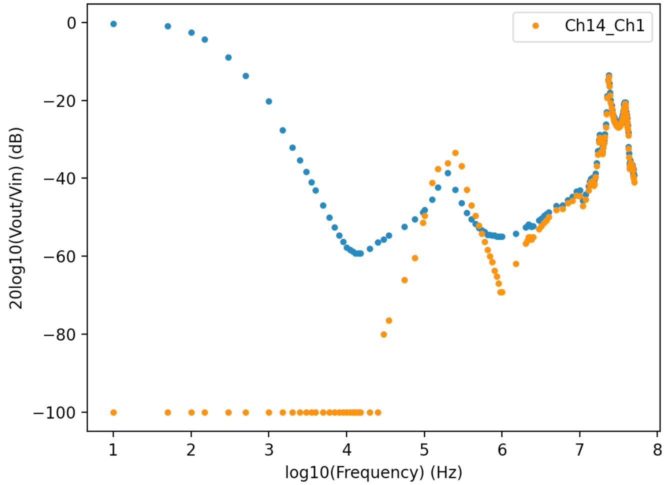


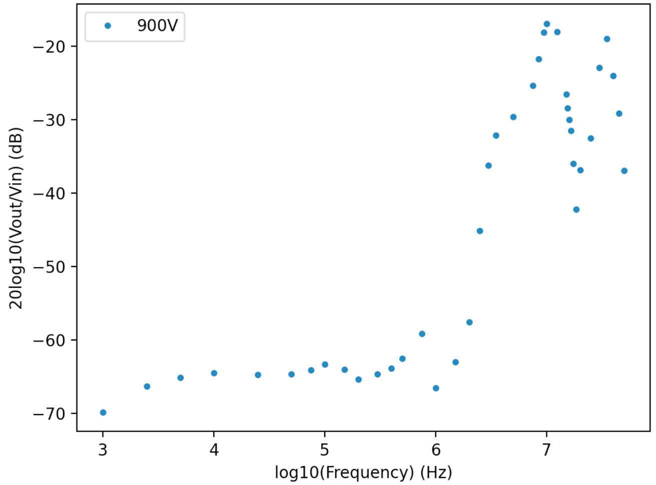
Model Predictions

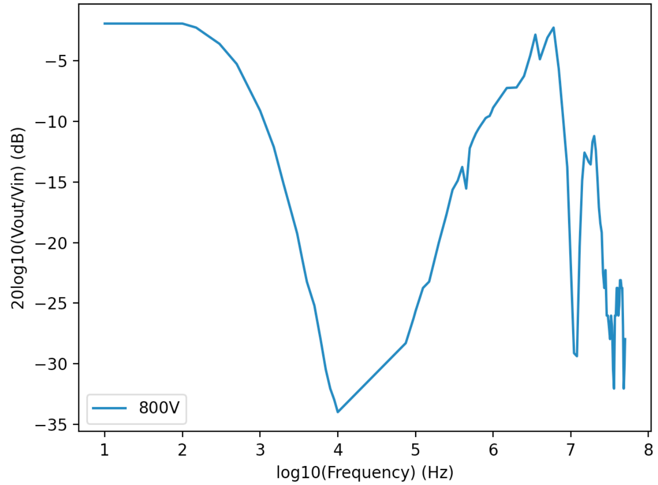
Model not perfect but seems to roughly explain measured results

LV Transfer Curve | CM noise | HV Transfer Curve

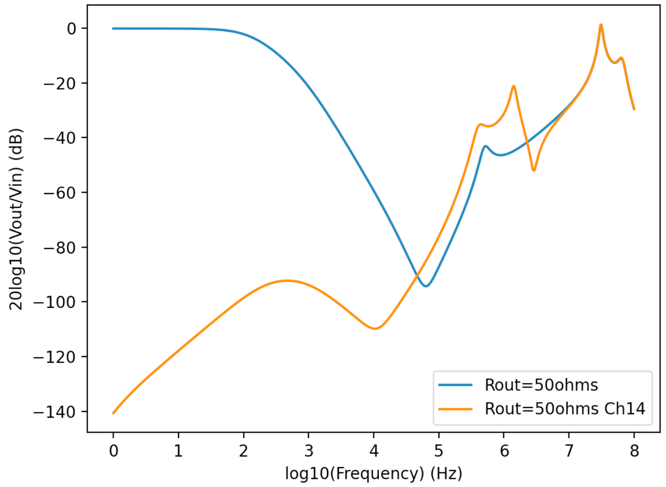
MEASURED

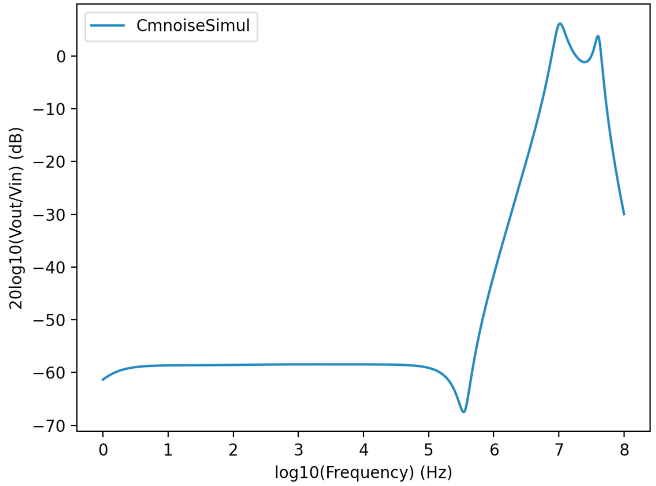


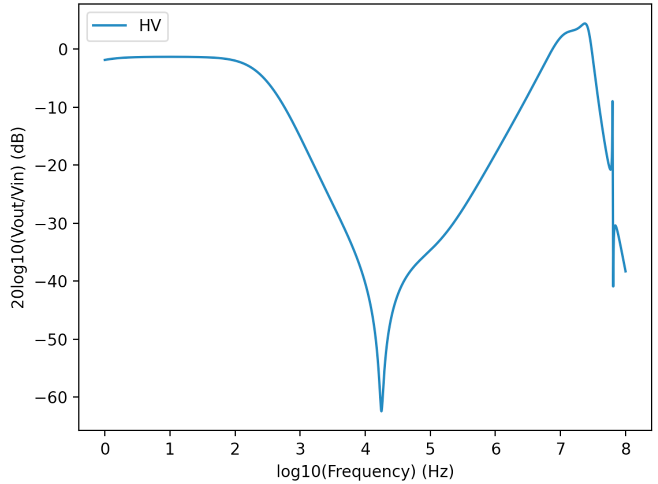




MODEL



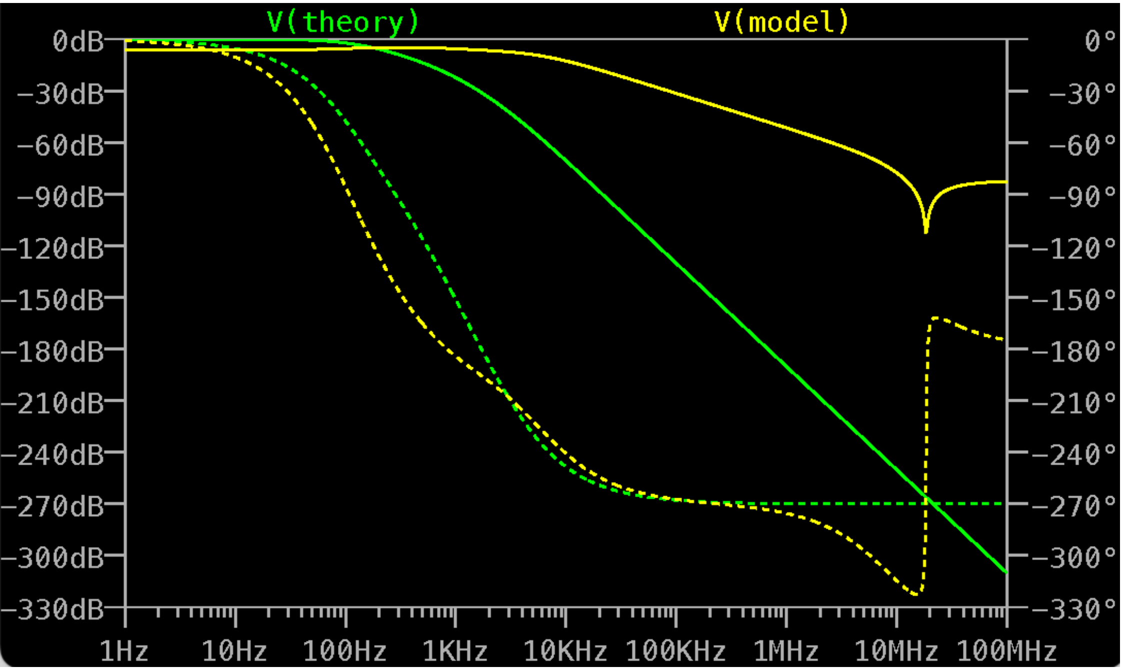


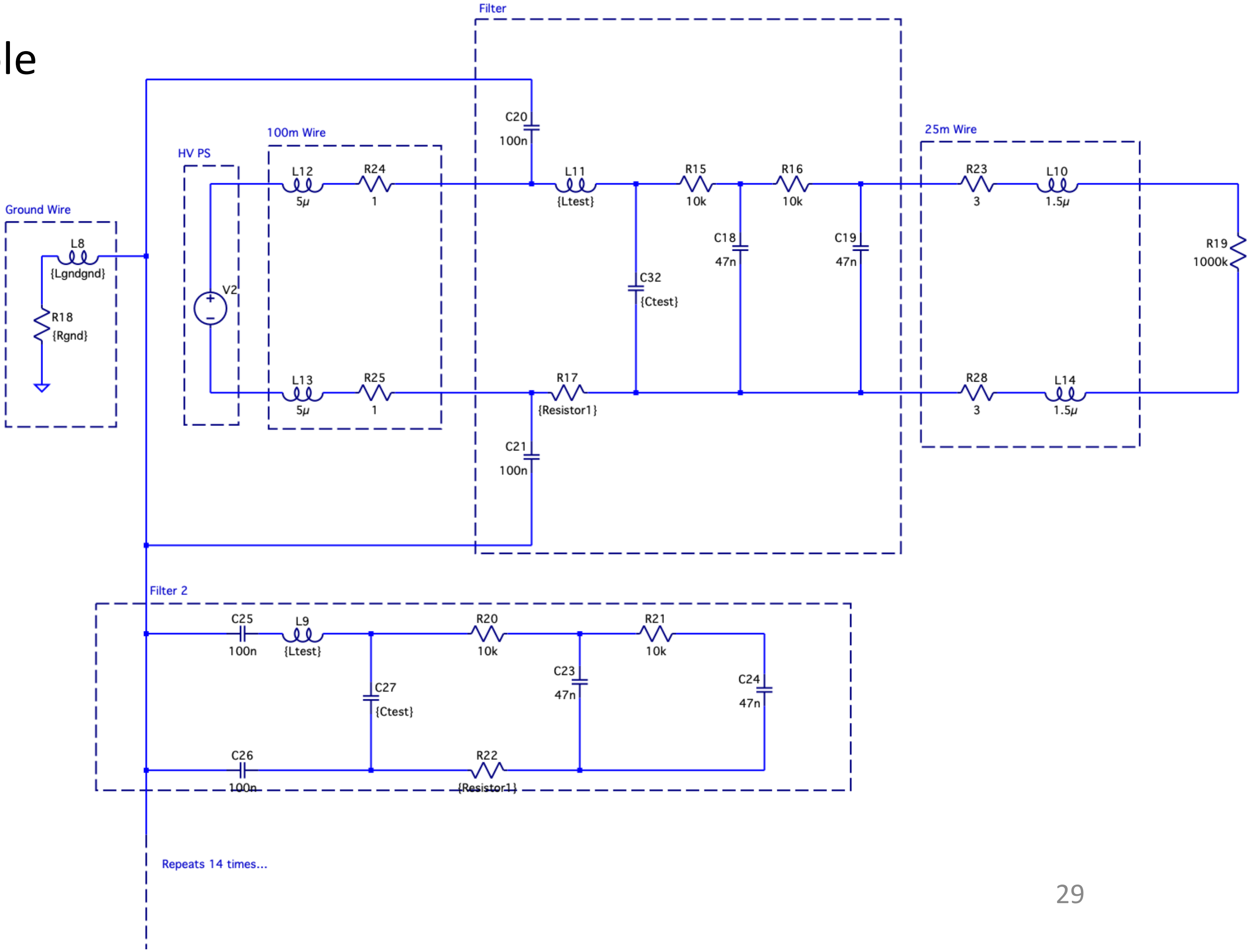


Model Final environment

- If model is correct peaks seen at higher frequencies originate not from filter board parasitics but mainly from ground wire and the probes used for measurements
- Model can be used to try to roughly predict filter behaviour in final environment, very rough aproximations for wire resistance and inductance
- Floating supply helps
- Not as good as theory but could still be acceptable
- Signal propagation through backboard

in this case is very minimal (~270dB)





Patch Panel Grounding & Shielding

- Use filter module boxes as continuation of vessel Faraday cage
  - Also DC connecttion of filter boards backplane to cage
- DC connection of Faraday cage to local TileCal earth
  - DC current not as bad as HF AC noise
- Move common-mode filter capacitors to filter input instead of output
  - Filter common mode current at input