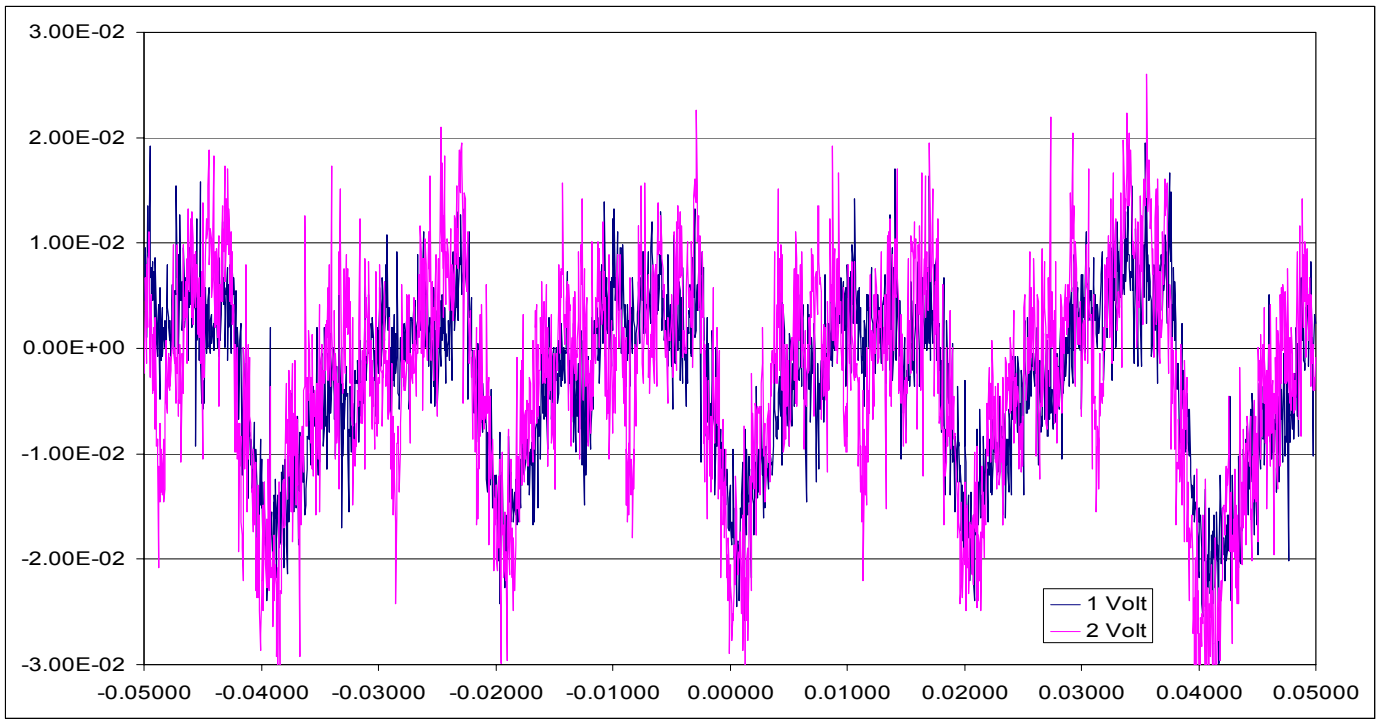
Klystron main power supply ripple compensation schemes

LHC RF meeting 26.11.2004

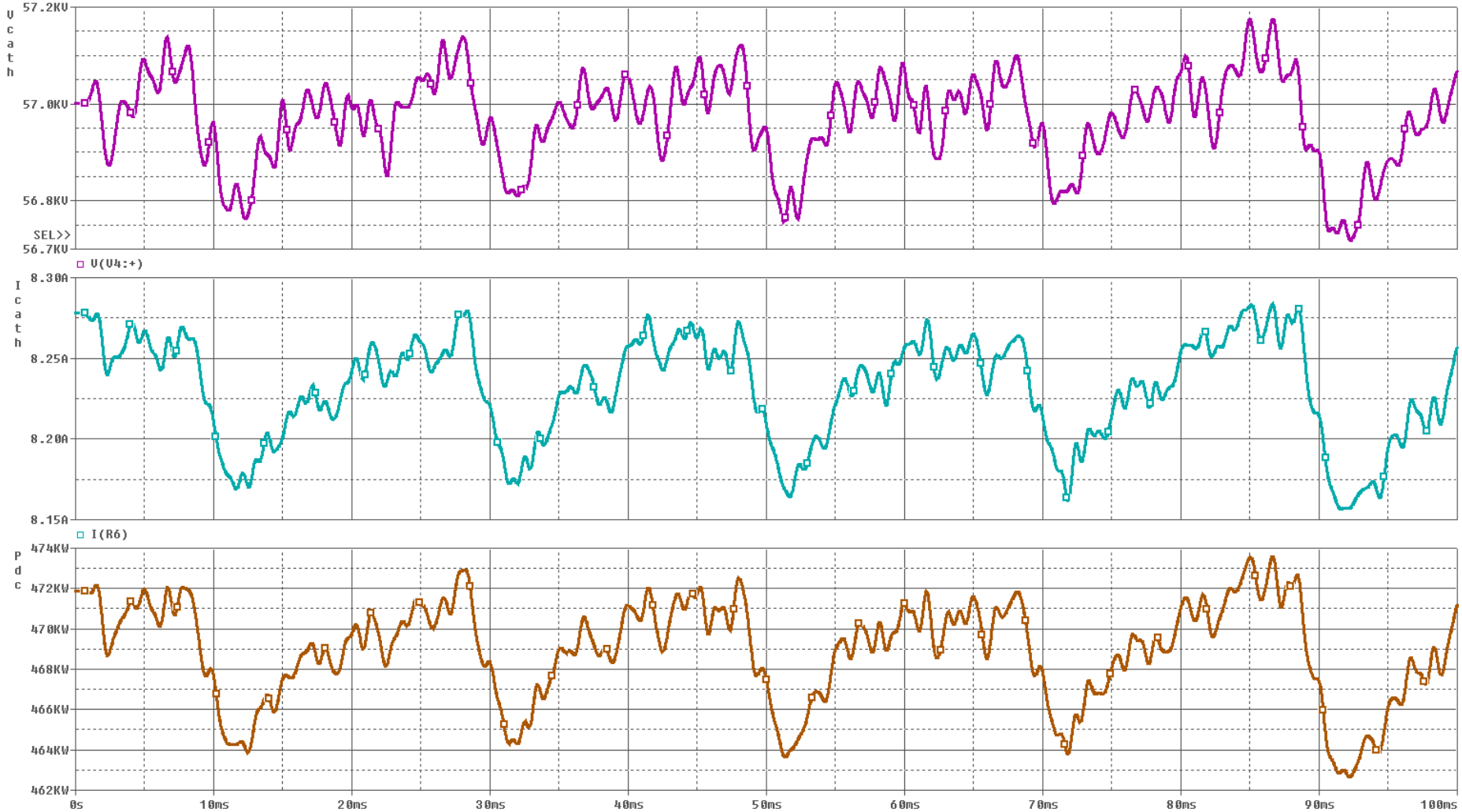
Motivation

- Voltage ripple of the main Cathode power supply leads to:
  - RF amplitude modulation
  - RF phase modulation
  - Around the saturation point also the gain modulation
- Voltage measurements were extremely noisy



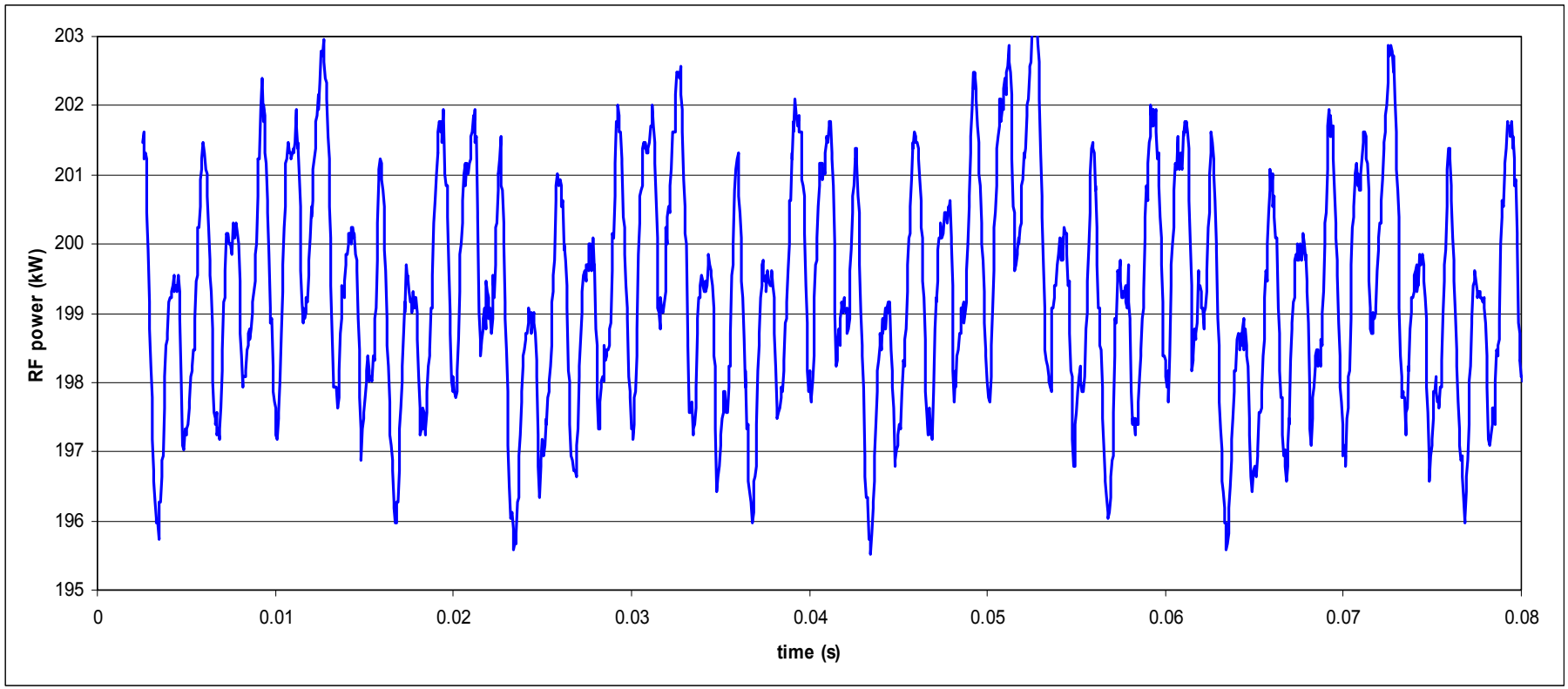
Measurements/simulations at P_{RF}=200kW

- Some post-processing filtering was necessary...



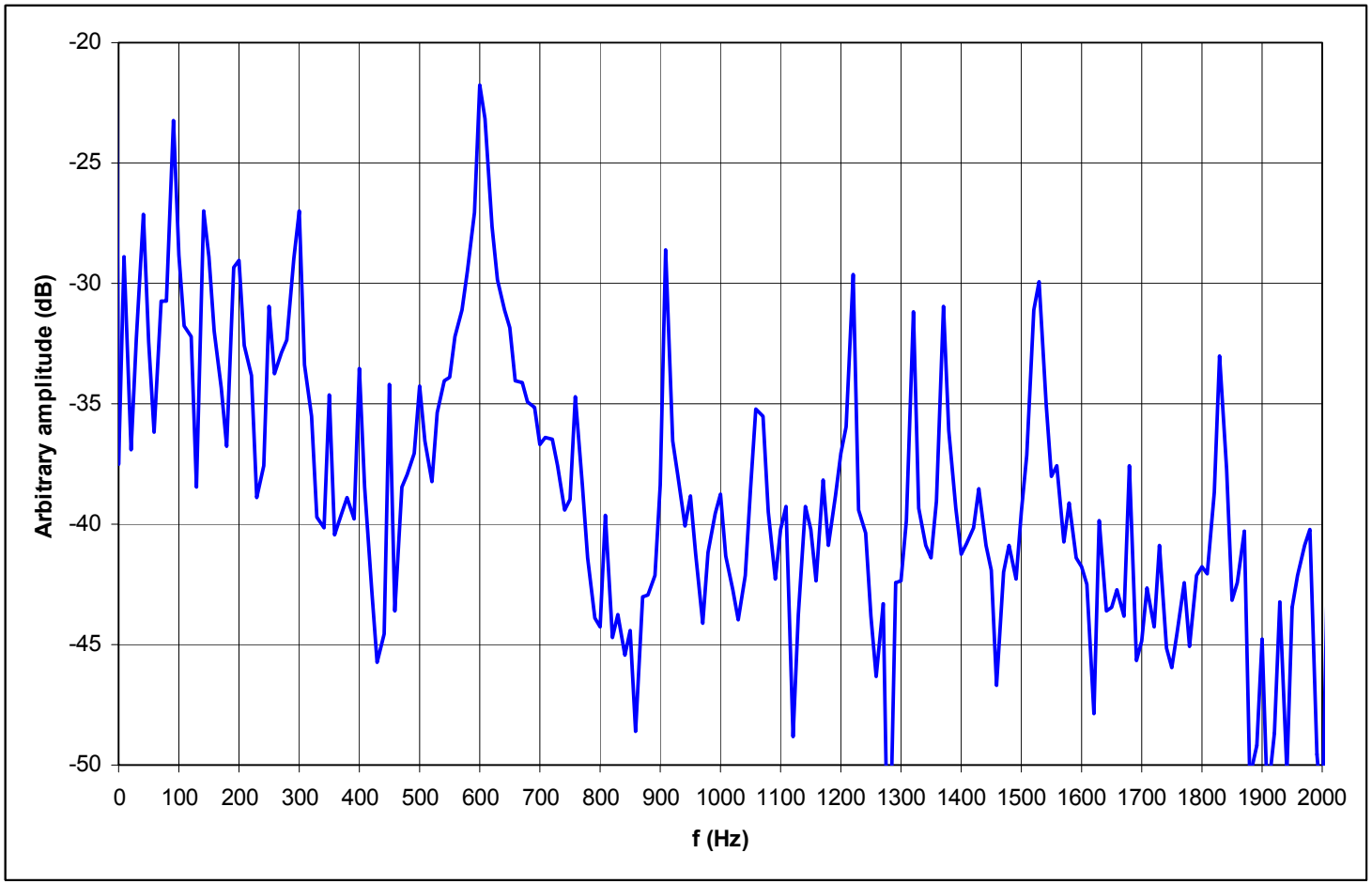
Measurements/simulations at P_{RF}=200kW

- As discovered later by an RF power ripple measurements, used filtering was too optimistic



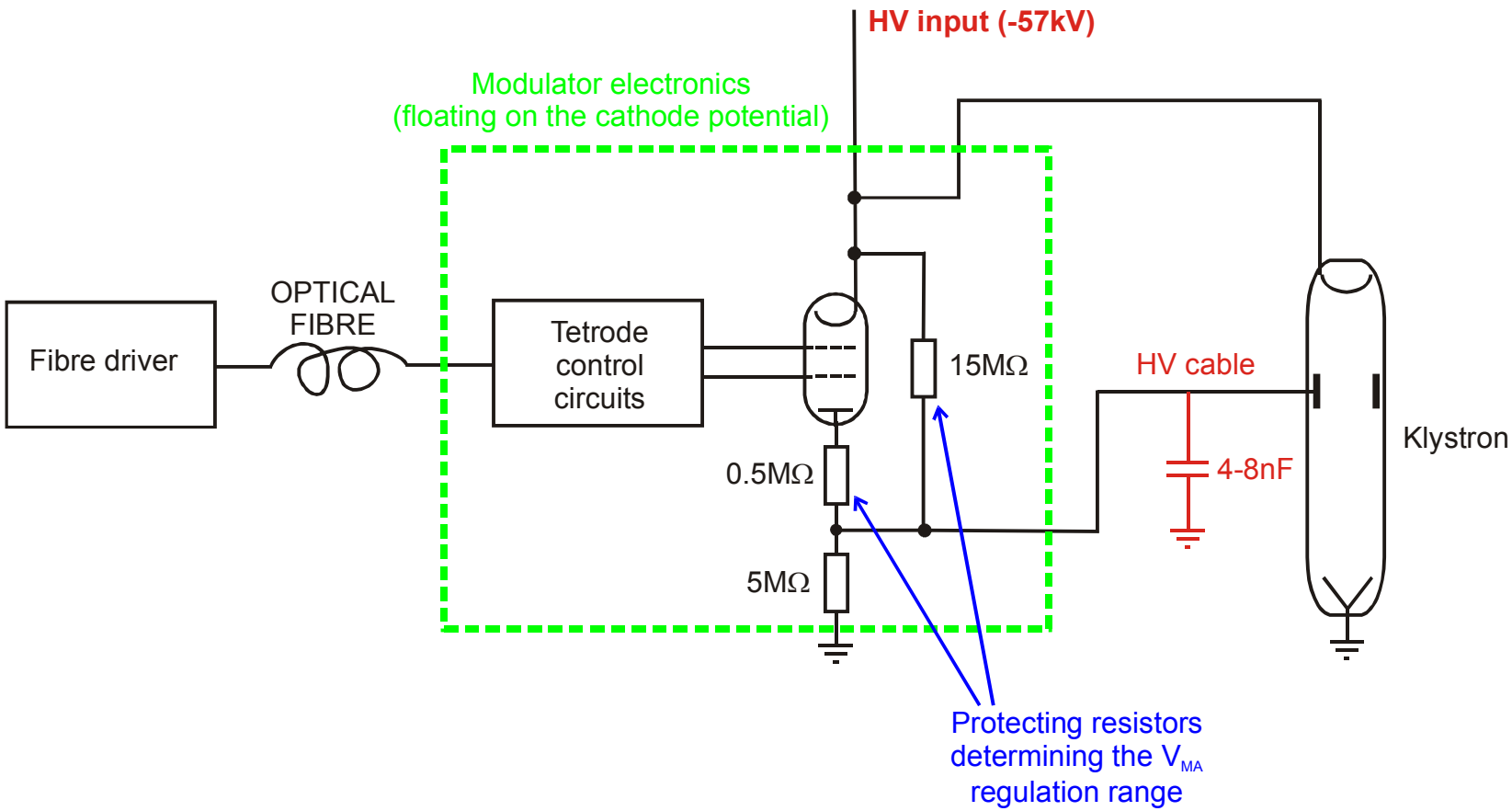
Measurements/simulations at P_{RF}=200kW

- The RF amplitude ripple has more “high-frequency” components than expected



Present status

- Open loop system with a tetrode controlling the MA voltage



Proposals...

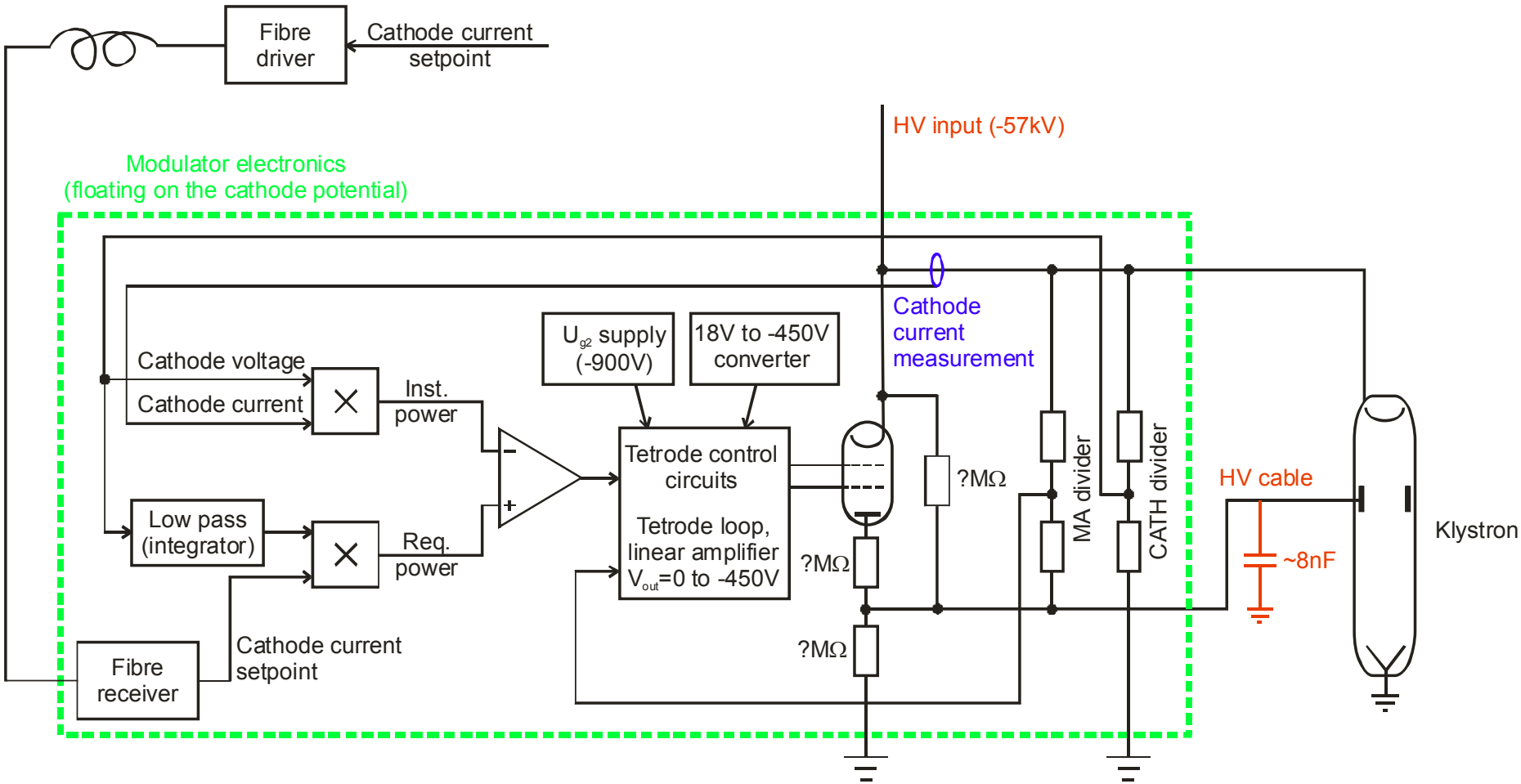
- There are two proposals to handle/compensate the ripple related effects in the LHC klystron amplifier

1. By playing with the Modulation Anode voltage
2. By inserting a linear regulator in series with the main PS

Proposal #1 – The MA controls

- The instantaneous DC power can be stabilized by compensating the voltage drop by increasing of the cathode current
- **Partially solves the amplitude ripple problem, but the phase ripple will remain untouched**
- Potential gain modulation?
- Limited bandwidth due to capacity of the HV cable

Proposal #1 – The MA controls

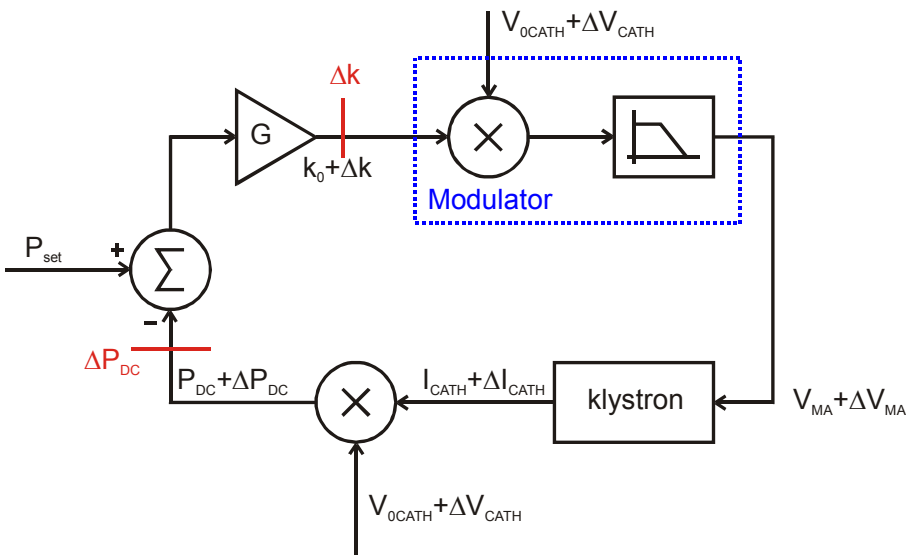


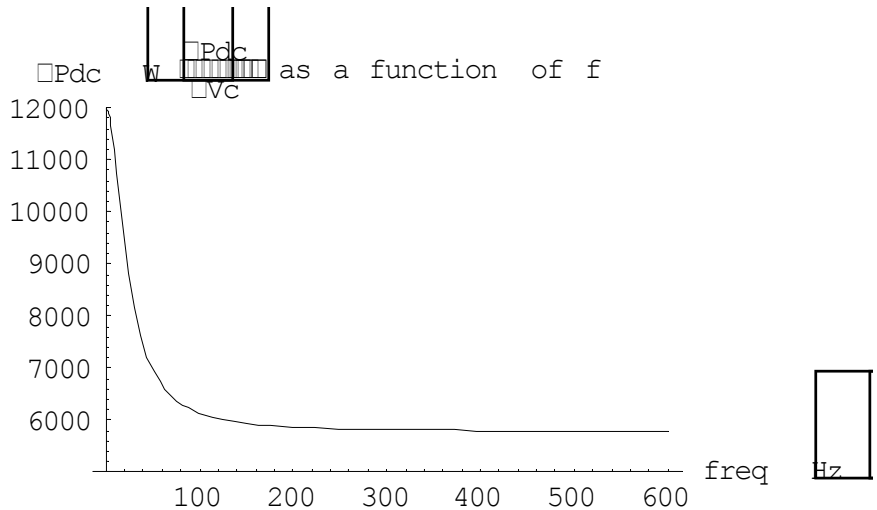
Proposal #1 – Open loop response

- DC power is product of two variable terms:

$$P_{DC} = P_{DC0} + \frac{\partial P_{DC}}{\partial V_{MA}} \Delta V_{MA} + \frac{\partial P_{DC}}{\partial V_{CATH}} \Delta V_{CATH}$$

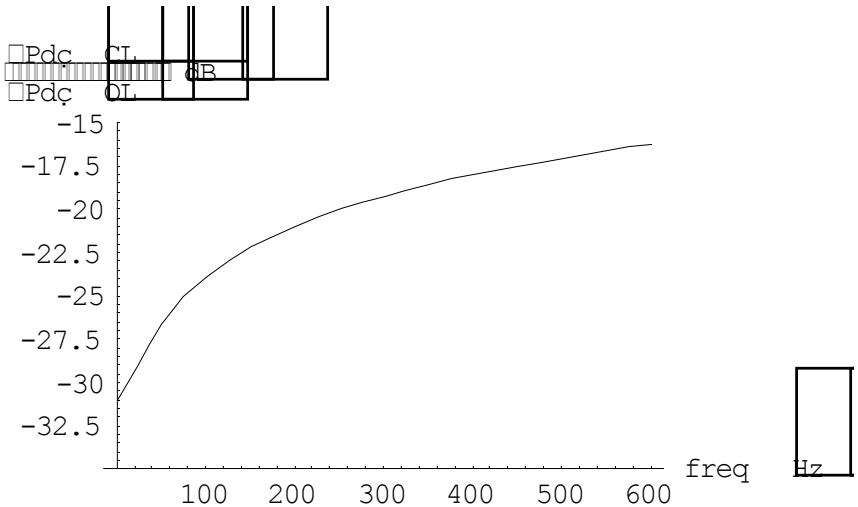
$$V_{MA} = k_0 V_{CATH0} + \frac{1}{1 + s\,T_{cable}} \left(\Delta k V_{CATH0} + k_0 \Delta V_{CATH} \right)$$

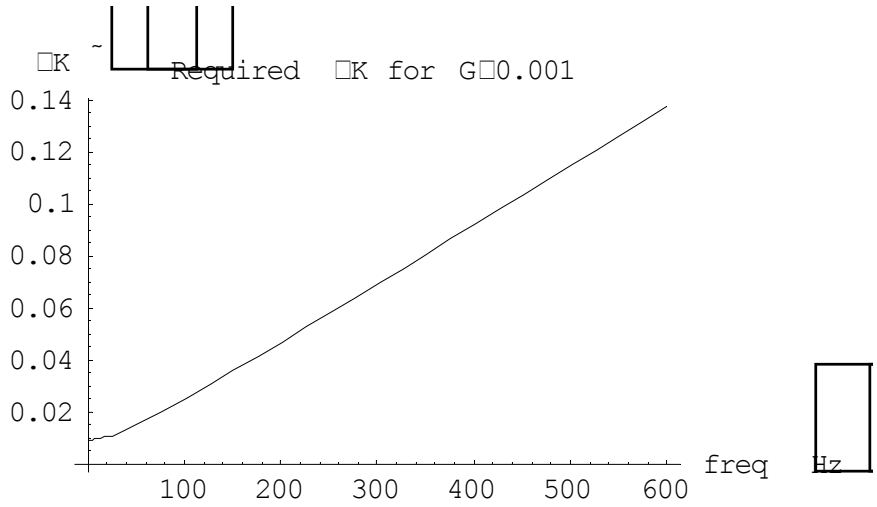




Proposal #1 – Closed loop response

- Gain of the loop is limited by maximal variation of the MA voltage
- Limited possibilities around the 300kW RF working point





Proposal #2 – Linear regulator

- By inserting a “small” linear regulator in series with the main PS, the cathode potential can be stabilized

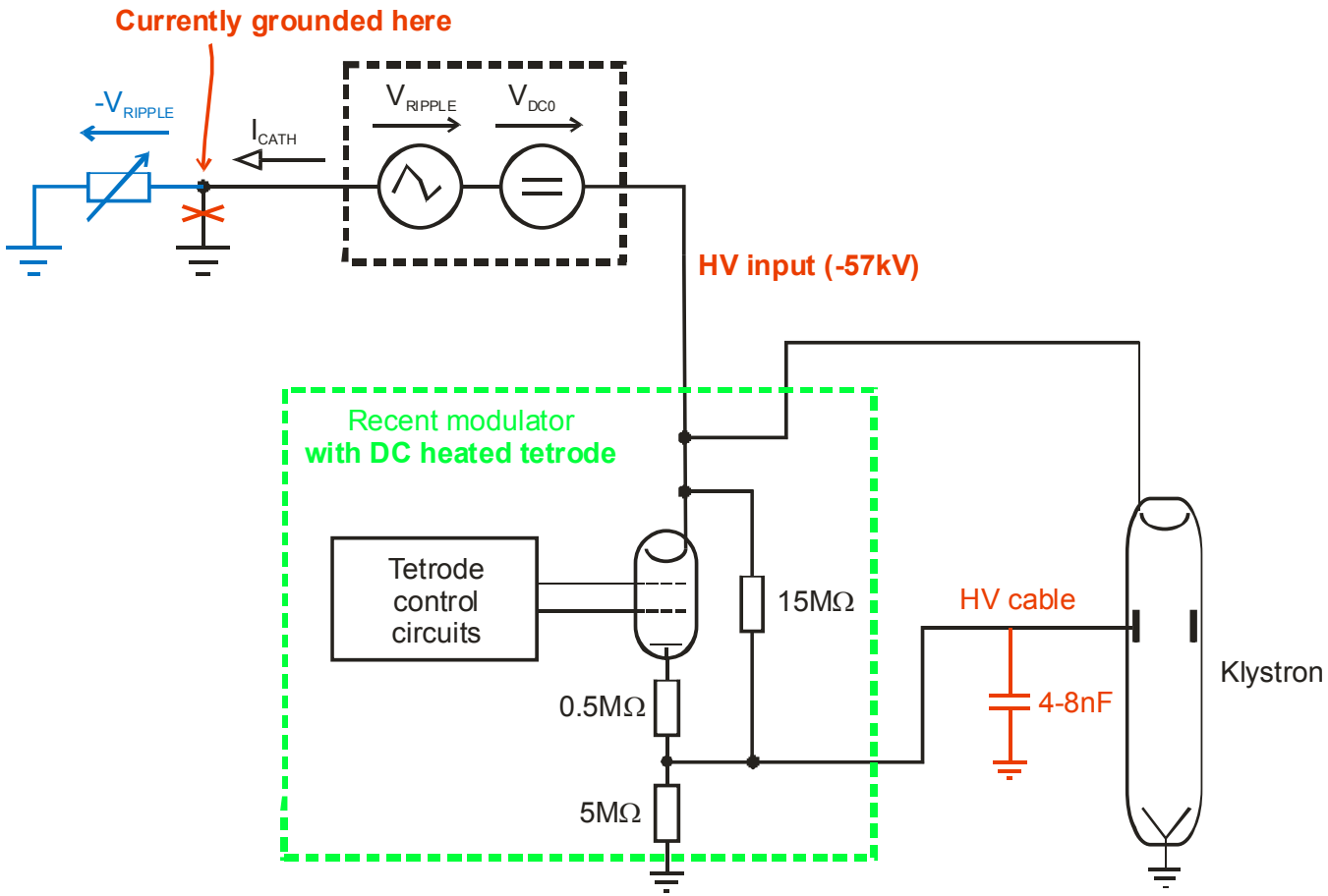
- Solves **cause** of the problem, not only the result:
  - **No amplitude ripple**
  - **No phase ripple**
  - Modulator divider can have a higher impedance (lower DC losses), does not suffer of the cable capacity anymore

- Almost **no bandwidth limitation**

- Disadvantage – the “ripple power” will be burnt (typically 10-20kW per power supply @1% HV ripple, depending on the ripple waveform)

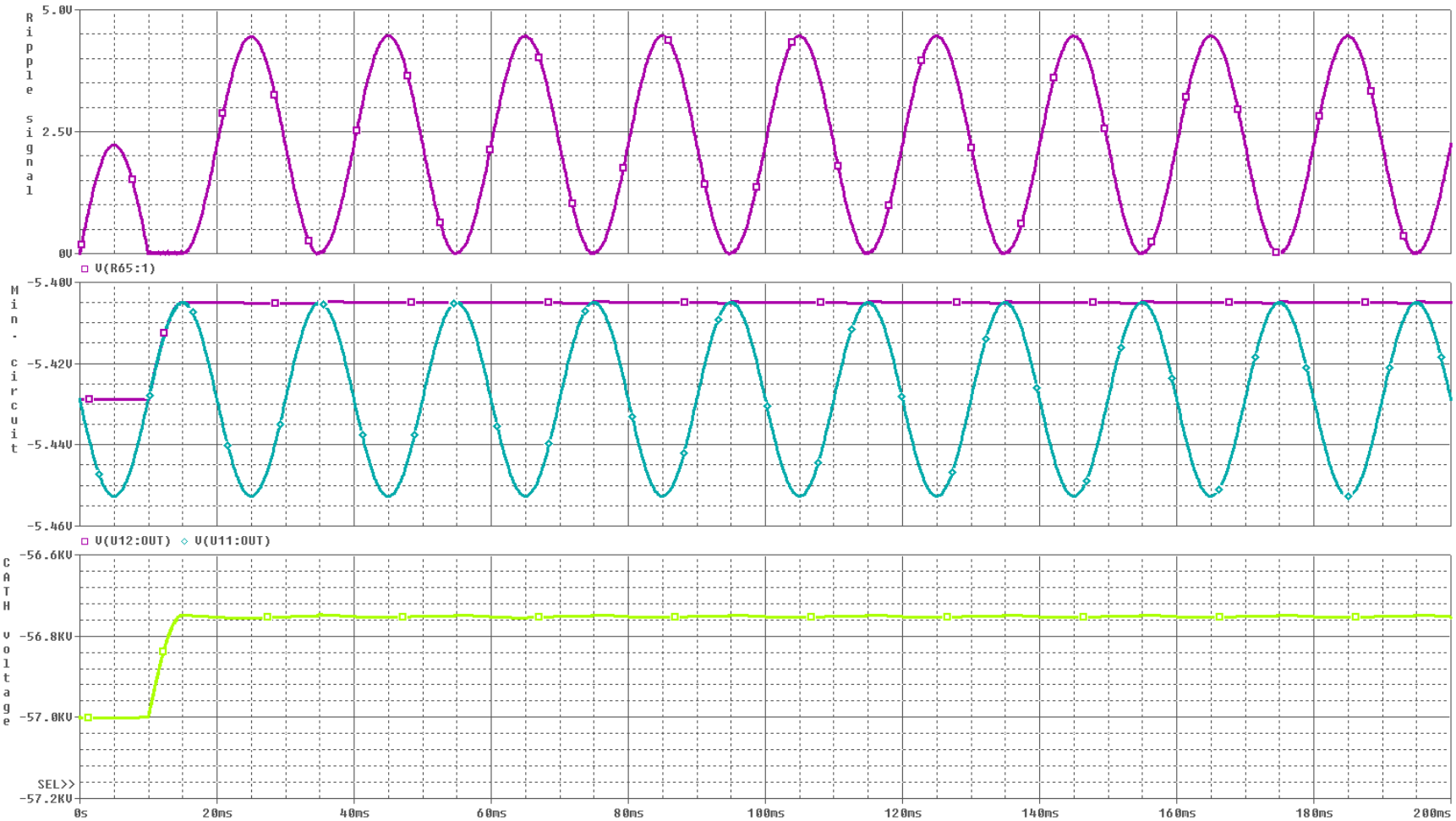
Proposal #2 – Linear regulator

- If cathode current can develop the same voltage drop at the added resistor as the ripple voltage is, the cathode potential **will be constant**



Proposal #2 – Linear regulator

- The P-SPICE simulations looks very promising...



Proposal #2 – Linear regulator

- Variable resistor can be realized by a sufficient number of a power MOSFET transistors connected in parallel, installed on the water cooled heat-sink
- Regulator is expected to be a “crowbar resistant”
- Regulator can fit easily into a 19” chassis (9U?)

Summary

- **Modulation anode controls:**
  - Compensates only the result, not cause of the problem
  - Suppresses only the amplitude ripple
  - Limited bandwidth, lot of ripple is out of the active frequency region (e.g. 600Hz)
  - Potential gain modulation
  - Control circuit works with high voltages and sits in the oil at cathode potential
  - In case of failure, the klystron is inoperable
  - With sufficient dynamic parameters the system will be probably "non-bypassable"
  - Modification of the klystron modulator is necessary (additional HV dividers, current measurement)
  - Requires more engineering work (the tetrode circuit is not very well characterized for the moment)
  - Expected cost ~500CHF/klystron

- **Linear regulator:**
  - Compensates cause of the problem
  - Suppresses all problems (amplitude and phase ripple)
  - Wide bandwidth, can compensate all components
  - Control circuit works with low voltages and sits on the ground potential
  - Requires water cooled heat-sinks
  - Broken devices will not disturb the operation, others will take over the job
  - In case of failure, the system can be easily bypassed
  - No modification of the present system needed
  - System is very simple, does not need a lot of engineering work (~2 weeks)
  - Expected cost <5000CHF per power supply

- DC heater for the tetrode must be installed for both cases
- My recommendation is for a switching mode power supply with certain redundancy (two in parallel with the fault warning?)