Measurement and Selection of Protection Fuses and Poly-Switches for HVS1 2ch HV Control Card

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CERN/ATLAS/TileCal/LVPS
20 -22 February 2008

The maximum measured HVS1 switch-on current into each of three electronics parts of the 2ch HV control card is around 50-60mA during first 250ms, and then the steady state current decreases to 20mA. Protection fuses of these three blocks can be a fast radial 100mA pcb fuse or a poly-switch fuse to protect HVS1 crate against accidental TRACO dc/dc converter isolation breakdown during operation. This report gives a summary of measured fuse and poly-switch parameters in situ of the 2ch HV control card.

1. TRACO Problem Introduction

Commercial dc/dc converters, TRACO TMV2415S [1], are part of the 2ch HVS1 control card [2] powered from 24V bus distribution line, see Fig.1. The electronic circuits supplied from these converters are connected to -970V high voltage circuit. Although the converter's input to output isolation voltage is guaranteed to be up to 3kV, several damages (7-9 pieces during first 1000h of run) of TRACO TMV2415S have been reported. This damage has usually consequences: burning of HV fuse 100mA/1000V of the channel, short-cut of 24V power line and damage of its protection 1.5A fuse (BUSSMANN PCC-1-1/2 [6]). Moreover, the TRACO damage will most probably inactivate all HVS1 chassis with 16 high-voltage output channels.

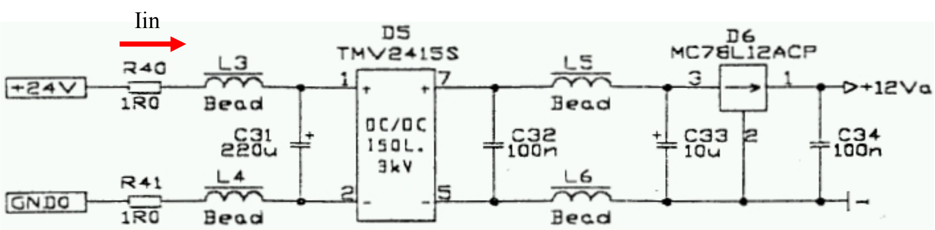

Figure 1. 2ch HV control card powering circuit with TRACO dc/dc converter.

In order to protect the HVS1 against inoperative state during TRACO damage, several actions have been undertaken:

- Discussion with TRACO ELECTRONIC AG (www.tracopower.ch) to know exact isolation limits of TMV2415S, to get spare parts, and see possible future new devices with satisfied parameters. Some alternative DCDC converters have been found from XP Power Company, USA.
- Long term IN/OUT Isolation measurements of TMV2415S to know practical and usable limits in HVS1 working conditions.
- Add additional protection fuses on 2ch HV control cards between 24V line and inputs of TRACO converters. In case of the TMV converter failure, burned local fuse will protect HVS1 crate from inoperative state and difficult removal/repair/installation in the USA15. This report is addressing this issue.

The input current measurements have been presented in [3]. The maximum input current for all three inputs to the TRACO dc/dc converters measured on 2ch HV control card is 50-60mA loading 24V power supply during 250ms. All three electronic blocks (ch1 and ch2 power supply chains, controller power supply) demonstrate similar start-up transients. The steady state current into these three blocks is about 20mA. When the HVS1 unit is switched off, the currents are going down without increase.

The protection fuses (replacing R40, R81, and R83 1R0 resistors [2]) will protect HVS1 crate against TRACO isolation damages on 2ch control card and can be dimensioned to 100mA. Two types of fuses have been investigated, see Figure 2:

- Radial pcb soldered fast fuse **SHURTER**, type MSF250, 0034.6004, 100mA/250V [4],
- Poly-Switch reset-able fuse **RAYCHEM**, RXEF010, 100mA/60V [5].

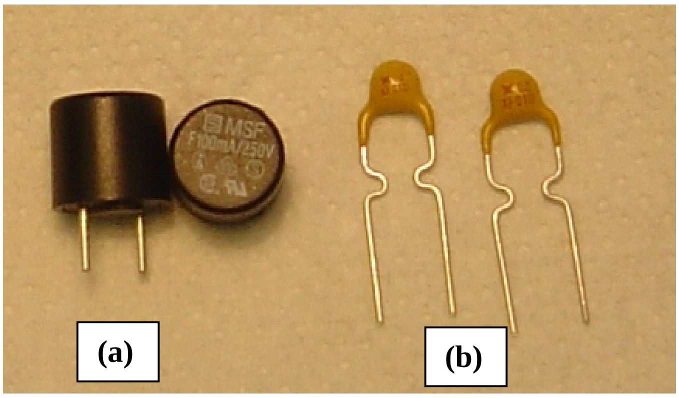

Figure 2. Tested 100mA fuses SHURTER (a), and RAYCHEM (b).

2. Measurement Setup

The measurement devices are identical to those described in report [3]. Several parameters will be measured on 2ch HV control card with fuses and poly-switches, see Figure 3:

a) Iin current measured through 1ohm resistor at ON-OFF transients, Iin = (V2-V3)/1R0,
b) Voltage drop V(Fuse) = (V1-V2) and corresponding fuse resistance Ron=V(Fuse)/Iin
   ba) V(Fuse) at ON-OFF transients,
   bb) V(Fuse) at Iin =110mA increased current (Rload=270R),
c) Fuse/poly-switch behavior (Iin) by applying Iload = 0.5A between V3 and V4 (Rload=44R),
d) Fuse/poly-switch behavior (Iin) by creating Iload = 1A between V3 and V4 (Rload=22R),
e) Fuse/poly-switch behavior (Iin) by creating shortcut between V3 and V4 (Reqv=~4R).

The input current on-off transients are measured via 1R0 resistors on 2ch HV control card (R40, R81, R83) by the differential passive probe LeCroy DXC100A, differential amplifier LeCroy DA1855A, and visualized by LeCroy oscilloscope PSLT344. Voltage drop [mV] on 1R0 resistor is directly proportional to flowing current [mA] on the scope screen. Photos of the measurement setup and details of modified cards are presented in Figure 4. In total, three 2ch HV control cards were modified and tested, 15 SHURTER fuses used and broken, and 6pcs of Poly-switches RAYCHEM.

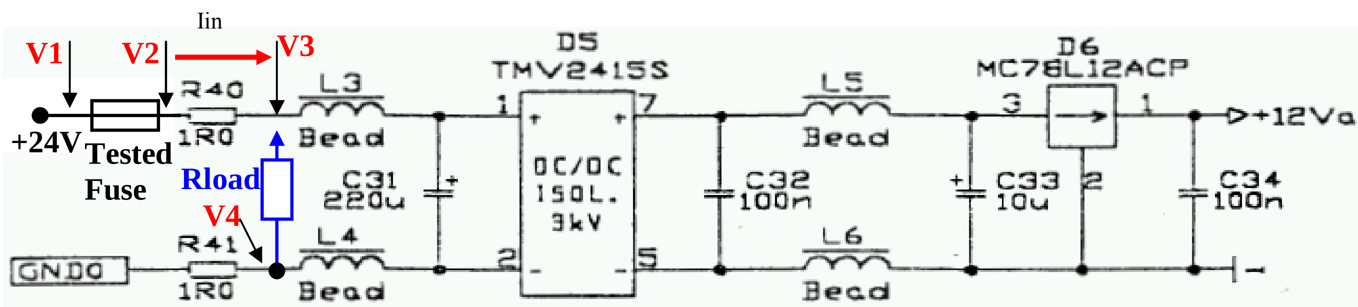

Figure 3. Measurement configuration of Iin input current (Iin=(V2-V3)/1ohm), voltage drop on fuse or poly-switch (V1-V2) during on-off transients, creation of additional Iload current between points (V3) and (V4) ~110mA (Rload=270R), 0.5A (Rload=44R), or 1A (Rload=22R) to cause fuse breakdown or poly-switch action.

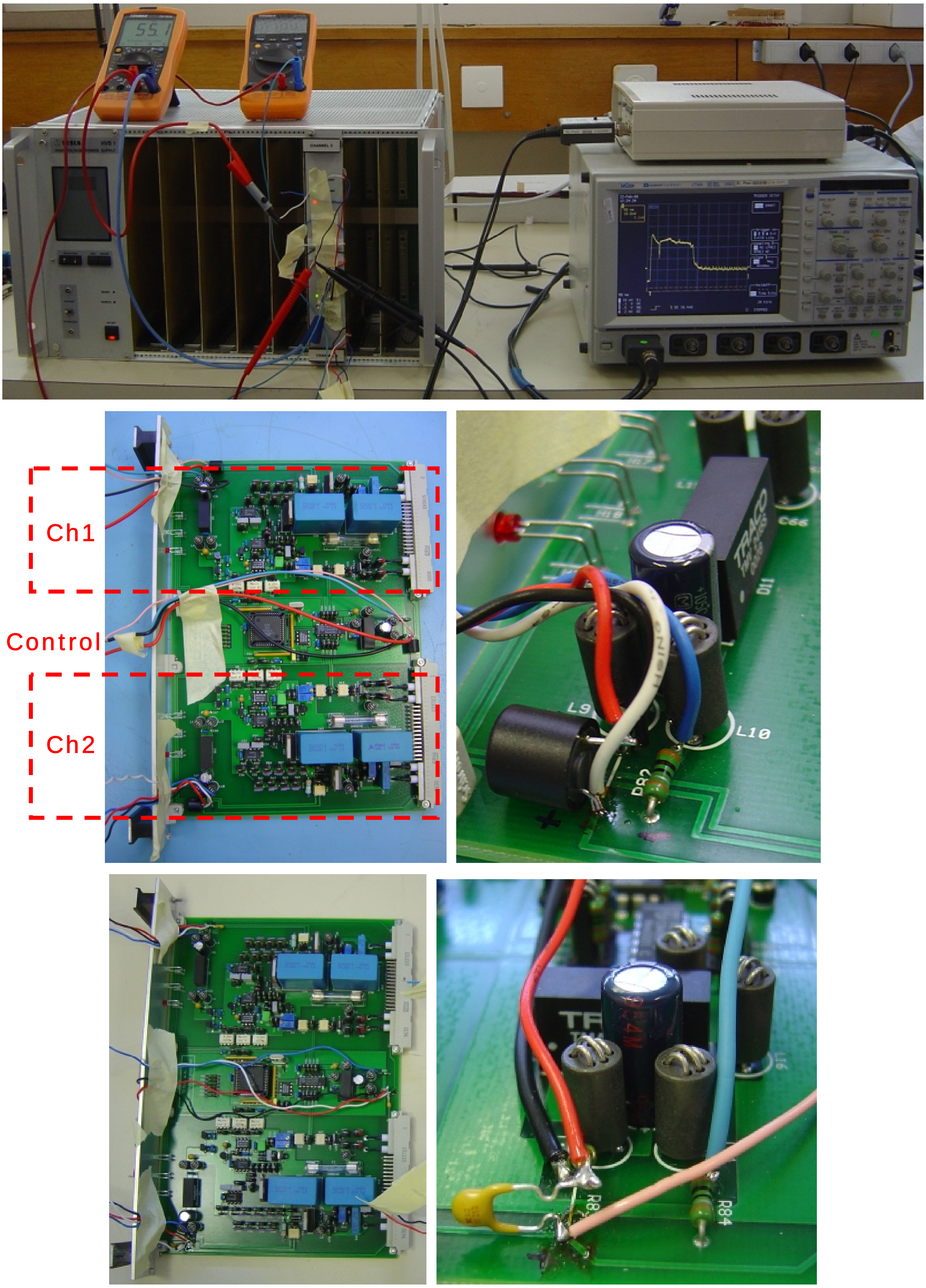

Figure 4. Measurement setup with HVS1 TESLA power supply and oscilloscope LeCroyLT344 with differential probes and amplifier. Details of modified cards with radial fuses SHURTER and Poly-Switch RAYCHEM.

3. Measurements – SHURTER Fast Fuses

This section presents all measured characteristics and transients of Ch1, Ch2, and the control part of the circuit from Figure 3.

Input current Iin = (V2-V3)/1R0, measured on 1ohm resistor at power-ON transient

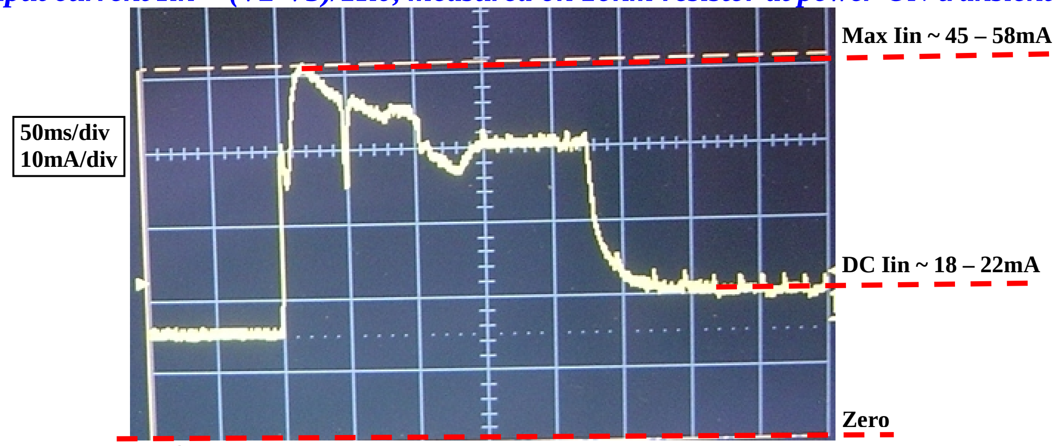

Figure 5. Typical Iin current for Ch1, Ch2, and controller part at power-ON transient, measured on 1R resistors, similar to [3]. Turn-off transient current decreases from steady state value of 18-22mA down to zero, not shown here.

Voltage drop V(Fuse) = (V1-V2) at power-ON transient

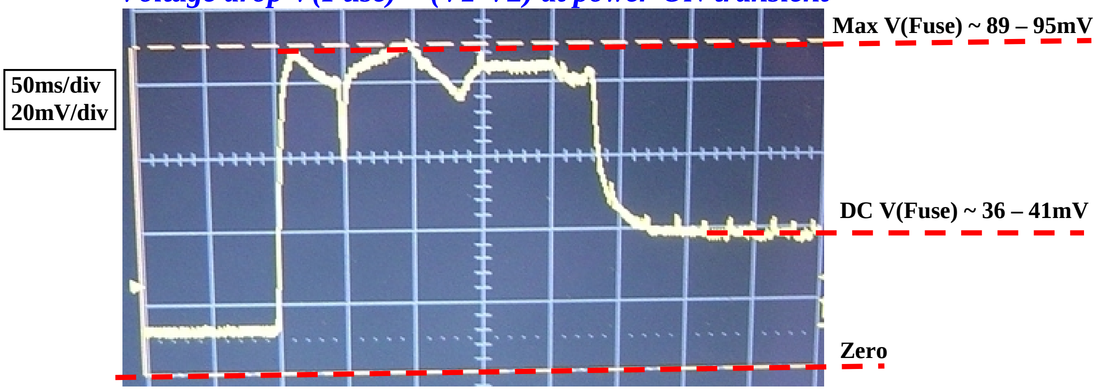

Figure 6. Typical voltage drop (V1-V2) on SHURTER 100mA fuse (CH1, CH2, and control inputs) at power-ON transient. Power-off voltage drop decreases from quiescent value of 36-41mV to zero, not shown here.

Current step 20mA => 110-115mA measured via 1R0 resistor

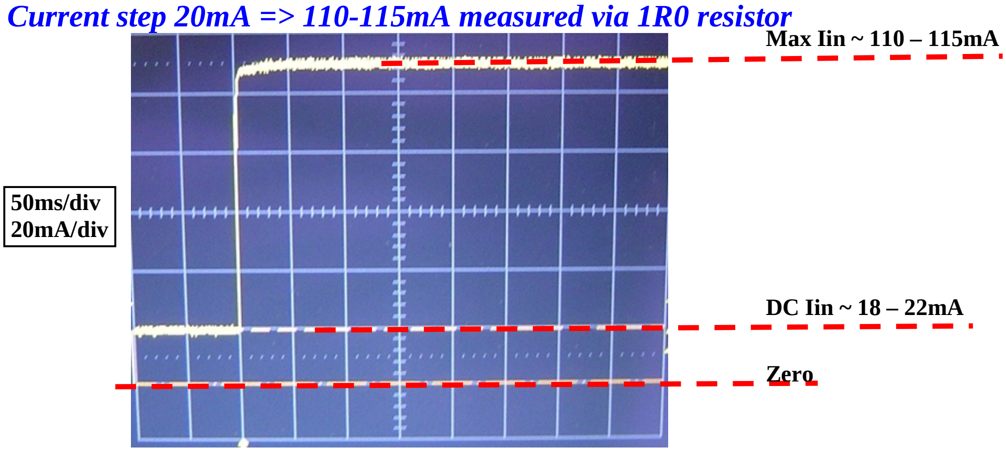

Figure 7. Typical Input current change from quiescent value of 18mA to 110 – 115 mA (depends on circuit sample) by adding Rload resistor (270R) between V3 and V4 points for maximum 3 seconds.

V(Fuse) at Iin step from 20mA => 110-115mA

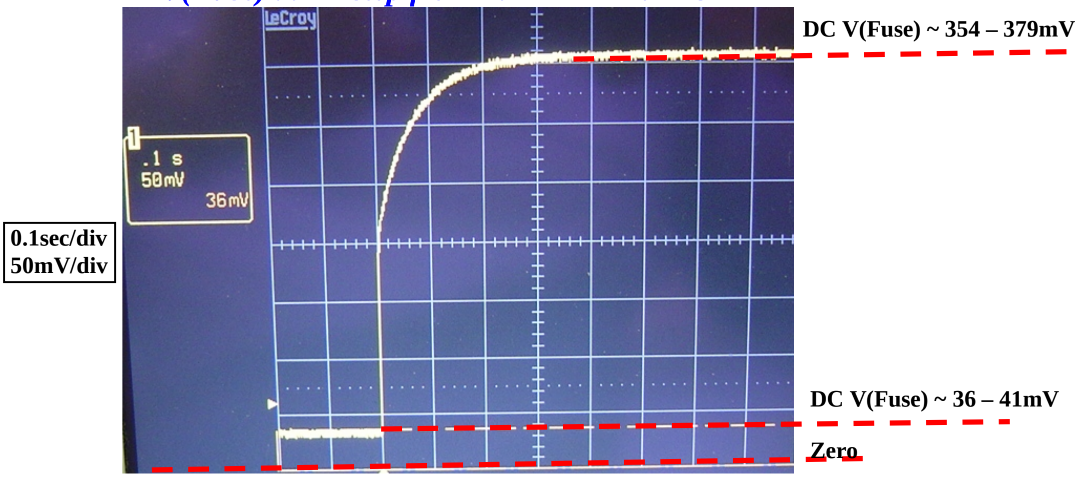

Figure 8. Typical voltage V(Fuse) change on measured SHURTER fuse of 100mA=Inom during Iin current change from 19mA -> 110-115mA (see Iin curve in Figure 7) during 3 seconds. Voltage drop on fuse is about 354 - 379mV for 110-115mA current depending on circuit measured.

Iin current transient from 20mA to 0.5A Iload (Reqv=Rload +1R+1R +Ron(Fuse) ~ 48ohm)

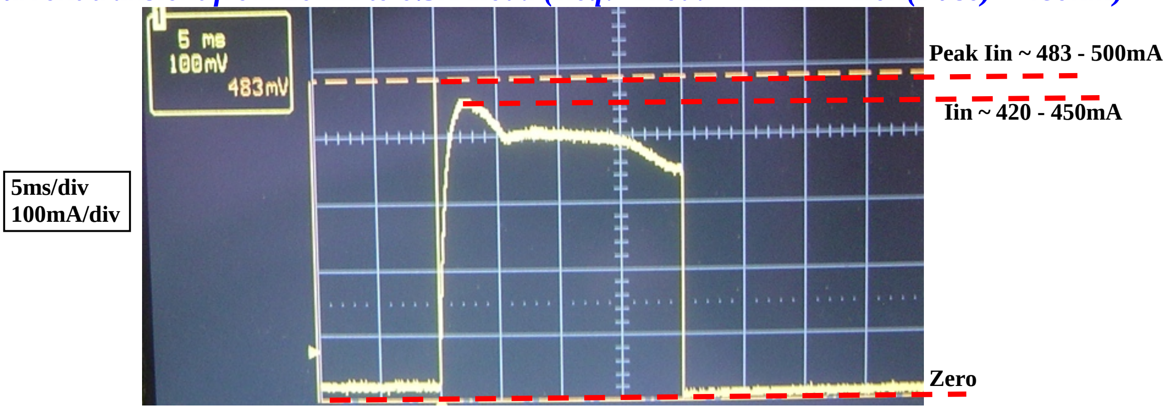

Figure 9: Typical Iin transient from 20mA quiescent current to 0.5A Iload instant application. The maximum flowing current spike is 500mA, then a current pulse of max 450mA is lasting for 18 - 20ms; then fuse broke.

Iin current transient from 20mA to 1A Iload (Reqv=Rload+1R+1R+Ron(Fuse)~26ohm)

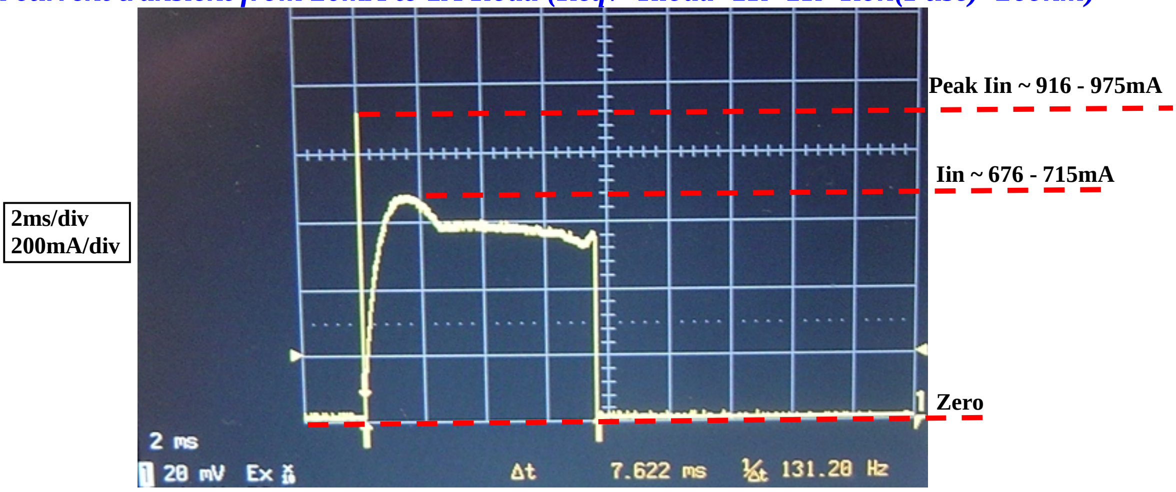

Figure 10: Typical Iin transient from 20mA quiescent current to 1A Iload instant application. The maximum flowing current peak is 975mA, then a current pulse of max 715mA is lasting for 7.2 - 8ms; then fuse broke.

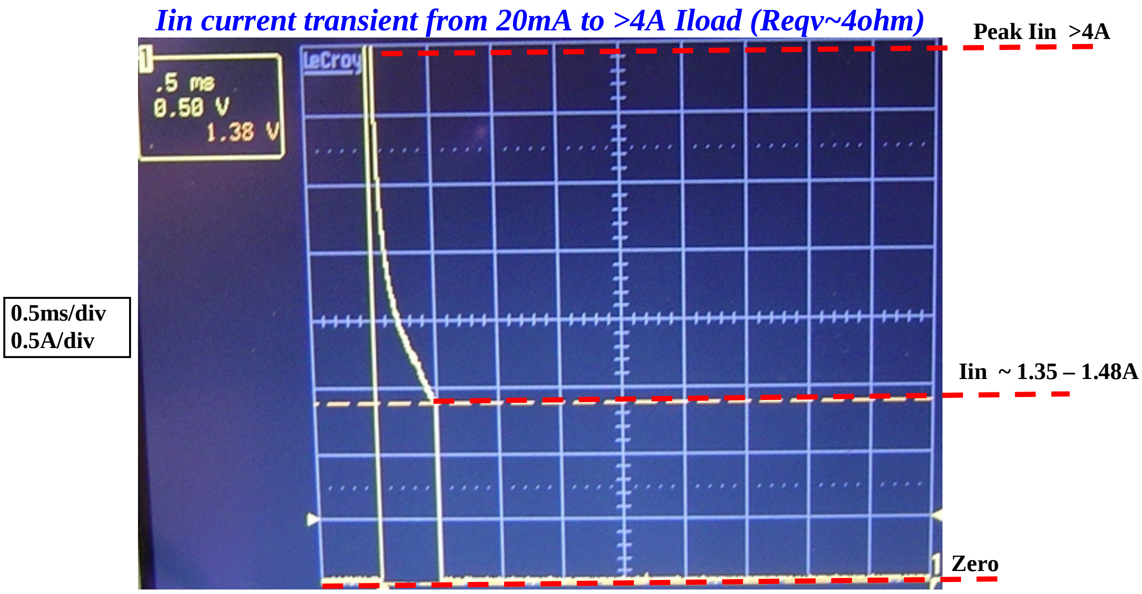

Figure 11.A: Typical Iin transient from 20mA quiescent current at the moment of >4A Iload shortcut current. The maximum flowing current peak seen is >4A, then decreases progressively down to 1.38-1.48A and fuse breaks, the fuse reaction time is approx 500us.

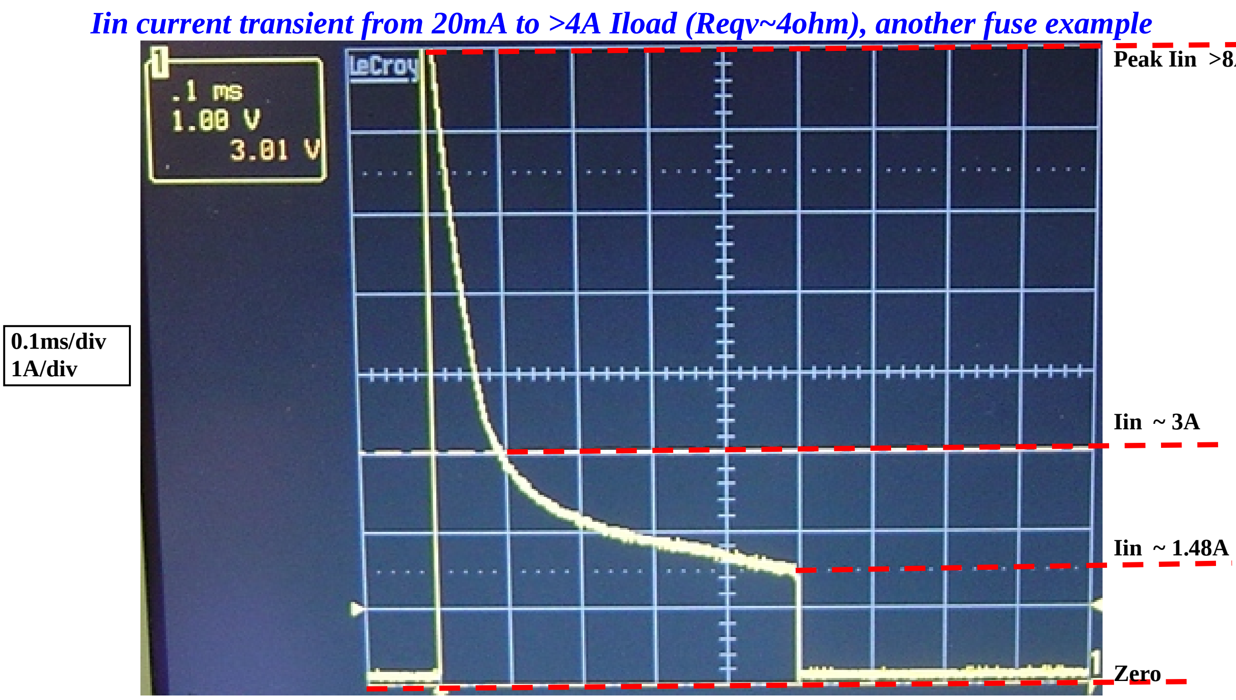

Figure 11.B: Another Iin transient detail from 20mA quiescent current at the moment of >4A Iload shortcut. The maximum flowing current peak is >8A, then decreases progressively down to 1.48A and fuse breaks, the fuse opening reaction time is 490us.

4. Measurements – RAYCHEM Poly-Switch Reset-Able Fuses

This section presents all measured characteristics and transients of Ch1, Ch2 and the control part of the circuit from Figure 3.

Input current Iin = (V2-V3)/1R0, measured on 1ohm resistor at power-ON transient

The measured currents and characteristics are the same with Poly-switches as for fuses, presented in Figure 5.

Voltage drop V(Poly-switch) = (V1-V2) at power-ON transient

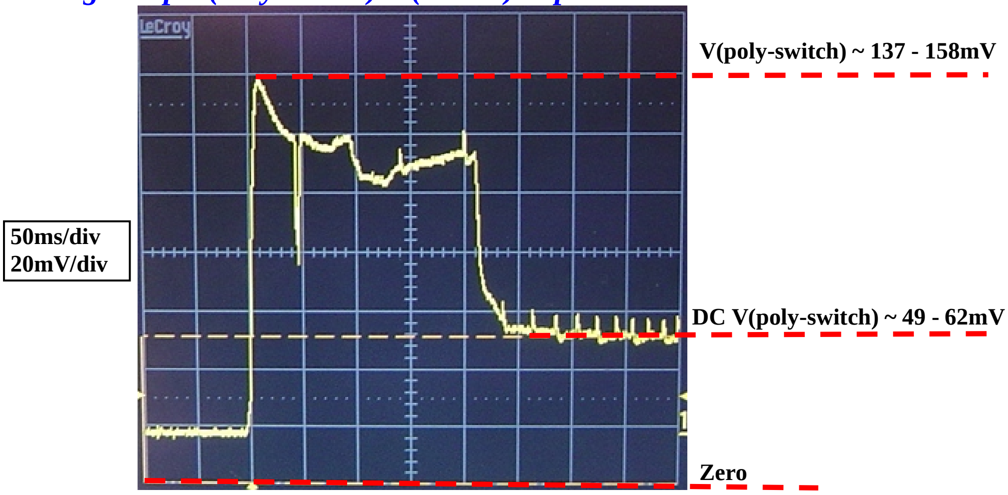

Figure 12. Typical voltage drop (V1-V2) on RXEF010 poly-switch (CH1 or CH2 inputs) at power-ON transient. Power-off voltage drop is decreasing from quiescent value of 49-62mV down to zero, not shown here.

V(Poly-switch) at Iin step from 20mA => 110-115mA

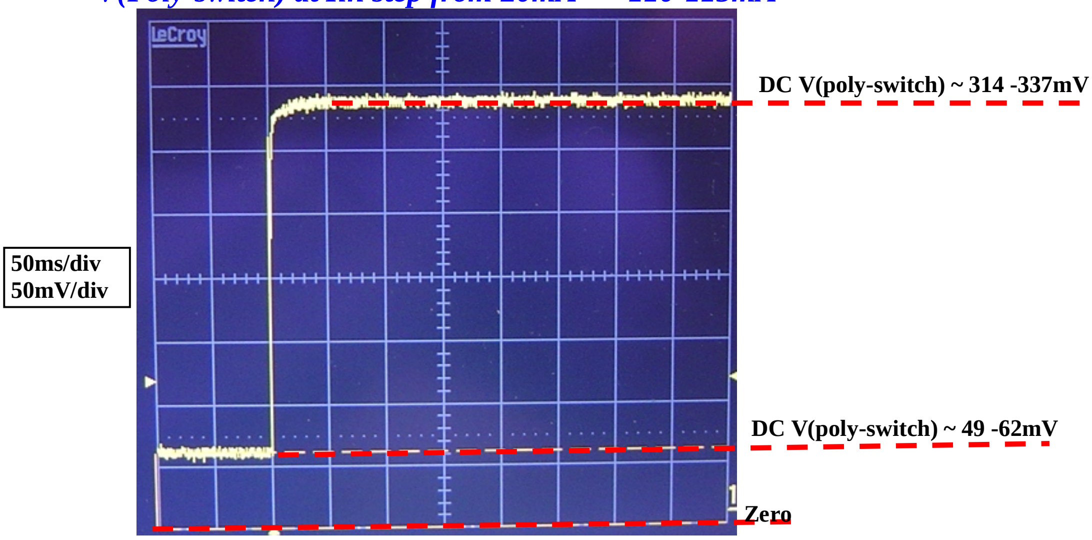

Figure 13. Typical voltage V(Poly-switch) change during Iin current increase from 19mA -> 110-115 mA (see current pulse in Figure 7) during 3 seconds. You can compare it with Figure 8. Voltage drop on poly-switch is about 314 - 337mV for 110-115mA current depending on circuit sample.

Iin current transient from 20mA to 0.5A Iload (Reqv~48ohm)

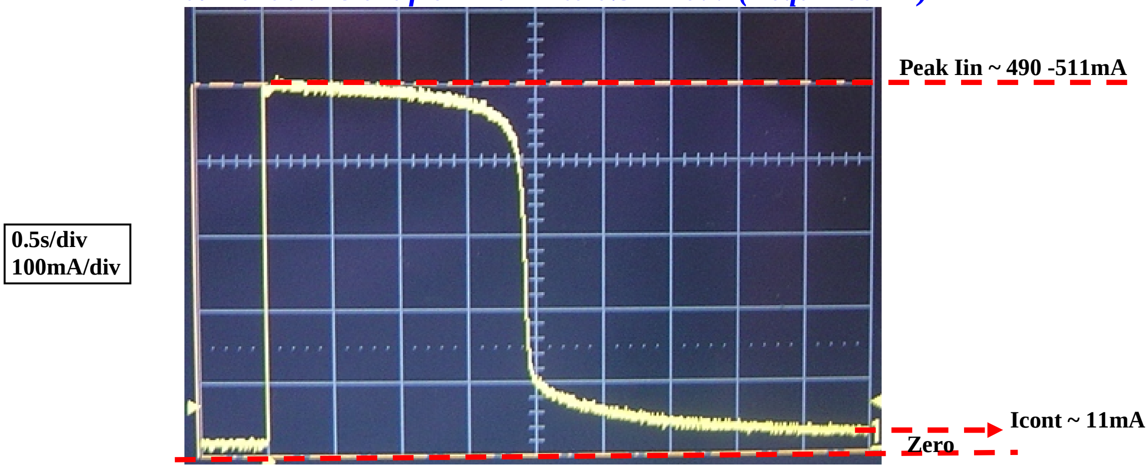

Figure 14: Typical Iin transient from 20mA quiescent current at the moment of 0.5A Iload instant application. The maximum flowing current peak is 511mA, then the current pulse is lasting for 1.7 – 3.3s; poly-switch takes full voltage Vin on itself and a quiescent current of 11mA is continuously flowing via this device.

Iin current transient from 20mA to 1A Iload (Reqv~27ohm)

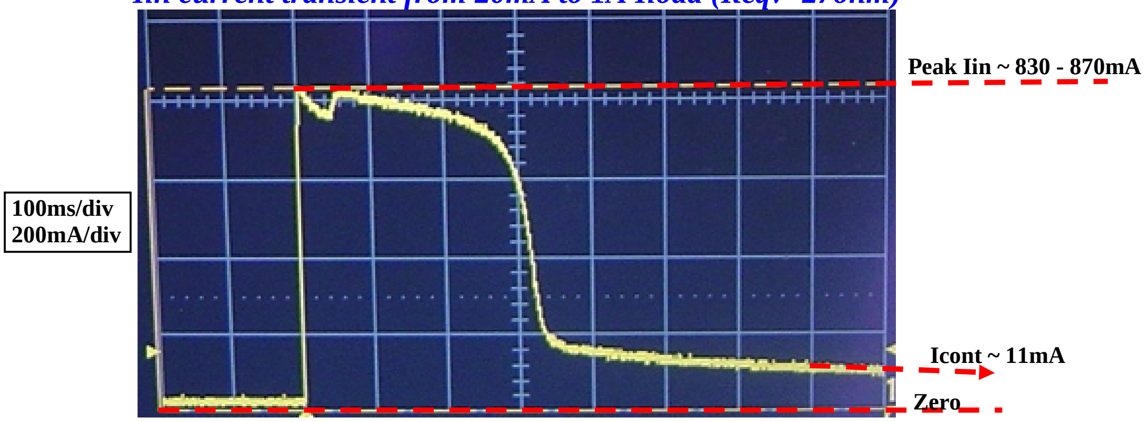

Figure 15: Typical Iin transient from 20mA quiescent current at the moment of 1A Iload instant application. The maximum flowing current peak is 870mA, the current pulse is lasting for 300 – 360 ms; the poly-switch takes full voltage Vin on itself and a quiescent current of 11mA is continuously flowing via this device.

Iin current transient from 20mA to >4A Iload (Rload~5ohm)

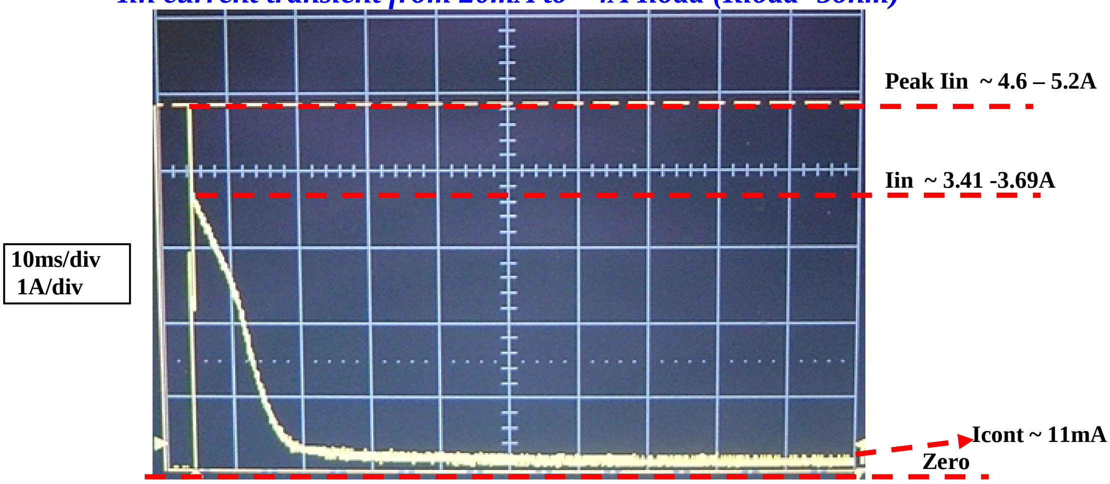

Figure 16: Typical Iin transient from 20mA quiescent current at the moment of >4A Iload shortcut current. The maximum flowing current peak is >5.2A, then the current rapidly decreases down to 0.38A and poly-switch starts to open, the opening reaction time of 6 measured RXEF010 is 8-14ms.

5. Fuse and Poly-switch Comparison Summary

This section presents summary characteristics of SHURTER fuses [4] (test with 15 samples) and RAYCHEM poly-switches [5] (test of 6 samples). All parameters were taken from measurements with 2ch HV card. Series resistances Ron measured at different currents and conditions are listed in Table 1. Measured opening reaction time (or time to trip) of fast fuses and poly-switches from all scope plots presented in sections 3 and 4 are summarized in Table 2.

Table1: Ron dc resistances of selected protection devices; measured ranges of 15 fuses and 6 poly-switches.

Fuse Type	Ron [I=20mA]	Ron [I=110mA]	Ron after1st short	Ron after 5th short
SHURTER [4]	1.8 – 2.0	3.1 – 3.3	broken	Broken
RAYCHEM [5]	2.5 – 2.8	2.8 – 2.9	3.5-3.7	4.1-4.5

Table2: Opening reaction time Tort (or time to trip) of fuses and poly-switches when Iload is changing from 20mA to 0.5A, 1A, and >4A.

Fuse Type	Tort [Iload=0.5A]	Tort [Iload=1A]	Tort [>4A]
SHURTER [4]	18-20 ms	7.2 – 8.0 ms	0.5 -1 ms
RAYCHEM [5]	1.7 – 3.3 s	300 – 360 ms	8 – 14 ms

The whole 2ch HV card with poly-switches is going to reset at the moment when 1A or higher short-circuit current is applied, it happens not only in the tested circuit (ch1, ch2, or the control circuit). In continuous short-circuit conditions (Iload of 0.5A, 1A, or >4A) the voltage drop on RAYCHEM RXEF010 becomes 24-25V, and the holding quiescent current is about 11mA. That gives Ptot=0.275W dissipation power on the poly-switch device; the datasheet typically estimates max 0.38W. The poly-switch will get warmer a bit.

A power glitch or a transient (most probably coming from the microcontroller reset) was observed when a high Iin current step (20mA -> 1A or 4A) was applied on the control part of the measured 2ch board. At first, the poly-switch reacts within 300ms and front panel LEDs also switch off. However, after approx 1second LEDs will very shortly blink again and switch off definitely. This behavior was not seen when using fast fuses.

When the short-circuit conditions are eliminated, the RXEF010 will restart to conduct normally within 3 seconds, and Iin current will go from 11mA to its working continuous level ~20mA. Here we can observe an inversed power transient situation: when the poly-switch goes from opened (high resistance) state to normal (Ron low resistance) state, the front panel LEDs will light up shortly for less than 1second, then switch off for up to 5 seconds and restart again. This behavior is most probably due to microcontroller reset time after re-powering. Again this behavior was not shown using fast fuses.

Tested channel 1 or ch2 of the HV card will be highlighted on the HVS1 front-panel display as Overcurrent state (arrow up ↑ in the current column) after the fuse has burned or poly-switch has opened. When the control part of the 2ch HV card is interrupted due to fuse/switch reaction, all front panel LEDs of the 2ch card will switch off, and also all 16channels of HVS1 will be displayed as “OFFErr ADC ↑” or “CardErr ADC ↑” error state.

During all experiments no internal output fuse of the HVS1 24V power supply crate, and none of three tested 2ch HV control cards, and no TRACO devices were damaged. During opening reaction time tests 15 fast SHURTER fuses were damaged.

6. Conclusions

This report presented a summary of measured fuse and poly-switch parameters in the application of HVS1 high voltage power supply. The 2ch HV control card has to be protected by additional fuses in case of TRACO dc/dc converter damages.

Poly-switches (reset-able protection devices) are a good circuit protection in applications where we have no access to use/replace burned standard fuses, in telecommunications; USB port in computer, random short-circuits on transmission lines, etc. It is mainly an over-current protection. It does not replace fuses and should not be used in applications with long time short-circuit. Main advantage of using poly-switch devices are their regenerative abilities from opened to normal state when a random short-circuit disappeared. Main drawback of using poly-switches is their very long reaction time, see comparative Table 2: with the current increase from 20mA to 0.5A the reaction of RXEF010 is up to 3.3s while the reaction time of selected same dimensioned fuse is only 20ms. At high current step increase the reaction time of fast fuses is still minimum 10times shorter than reaction time of poly-switches.

In our application we want to protect the HVS1 distributed 24V power against TRACO damages on 2ch cards that create short-circuits and high current demands on this power line. The transition time (when high current is flowing) should be as short as possible. This fact is leading to use the selected SHURTER fast fuses. The only drawback is the fuse replacement each time an accident occurs. But since the fuse damage on the 2ch HV card will signalize another serious problem, the card will be inspected and repaired anyway. Thus we do not see a problem of fast fuse application.

Therefore we propose to use fast fuse **SHURTER, type 0034.6004, 100mA/250V** with radial leads to the pcb and soldered (see Figure 2.a), Farnell distributor code: 1214677. This fuse will be soldered and replace resistors R40, R81, and R83 of the 2ch HV control board, see schemes in [2] and Figure 17.

Figure 17: Final proposed SHURTER 100mA pcb fuse protection.

References

[1] TRACO TMV dc/dc converter series, 1W, http://www.tracopower.com
[2]"HVS1 power supply Operational Manual and schemes", TESLA Hloubetin, Prague, CZ, technical manual, 2001.
[3] B.Palan, “HVS1 Measurements of Input Currents on 2ch HV Control Card”, CERN/ATLAS/TileCal/LVPS technical internal report, CERN, Geneva, CH, 16 Jan 2008.
[4] Non-Resettable subminiature fast-acting fuses with wire leads, Microfuse Type MSF250, model 0034.600, SHURTER Company.
[5] RAYCHEM Circuit Protection, Poly-Switch Radial Leaded Resettable Devices, RXEF010 model.
[6] BUSSMANN PC-Tron series PCC-1-1/2 subminiature non-time delay pcb fuse, 1.5A/250V.