Conducted Emission Measurements of HPS1 TESLA 200VDC Power Supply with 17 MHz Suppression Output Filter III

B.Palan, G. Blanchot, J. Weichert, S. Nemecek, D. Roda dos Santos
bpalan@cern.ch

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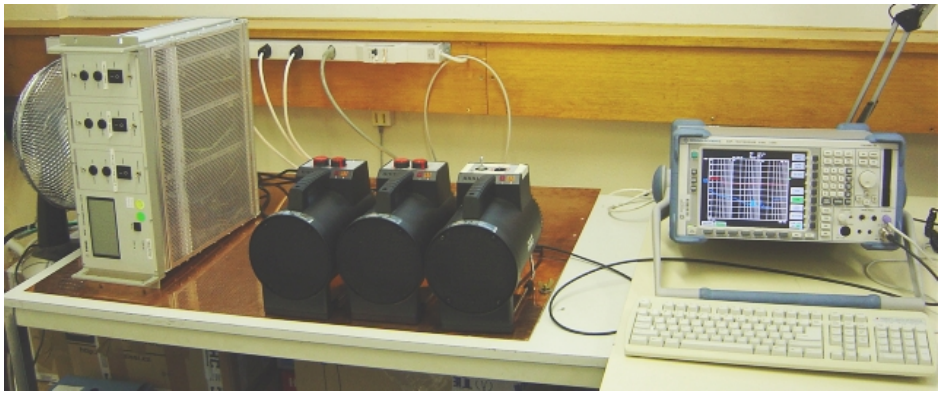
This report describes the measurements of common mode conducted current noise emission of HPS1 TESLA 200VDC power supply in the range 150 kHz -100 MHz. It follows the EMI emission test reports carried out on HPS1 power supplies for ATLAS/TileCal in the USA15 control room [1], and measurements of 17 MHz noise spectra performed in bld.512/LVPS [2].
High disturbing noise of 72dBuA @ 17MHz is reduced by two elements: common mode suppression ferrites mounted on Vout cables (reduction of max -20dBuA), and by additional designed low pass LC filter (min -25dBuA). Presented LC filter sufficiently reduces all disturbing spectra above 3MHz, including 17 and 35 MHz noise peaks.
Combination of both methods is successful and noise kept under the ATLAS noise limits only when one of three 200V channels is ON and loaded. When all three channels with LC filters are ON, common mode ferrites will significantly help to lower the noise above 15 MHz. However, the noise spectra below 3MHz still demonstrate several harmonic peaks exceeding the ATLAS noise limits.

Devices Used

• Rohde & Schwarz ESPI Test Receiver 9 kHz – 3GHz
- Maximum peak detection method used
- Measured frequency range 150kHz – 100MHz
- Step frequencies, resolution bandwidths, and meas. time used, see following Table 1.

	RANGE 1	RANGE 2	RANGE 3
Start	9 kHz	150 kHz	30 MHz
Stop	150 kHz	30 MHz	100 MHz
Step Size(A)	80 Hz	4 kHz	40 kHz
Res BW	200 Hz	9 kHz	120 kHz
Meas Time	50 ms	10 ms	10 ms
Auto Ranging	OFF	OFF	OFF
RF Attn	20 dB	20 dB	20 dB
Preamp	OFF	OFF	OFF
Auto Preamp	OFF	OFF	OFF

• Calibrated Current Probe ETS-Lindgren, model 91550-1L, EMC Test Systems Inc, USA.
• TESLA HPS1 3channel 200VDC/8.5A power supply, ID 20LLFZUPB00017 [3].
• Three resistive loads of 750W/1.44kW with cooling ventilators built from Honeywell heaters.



Measurement Setup

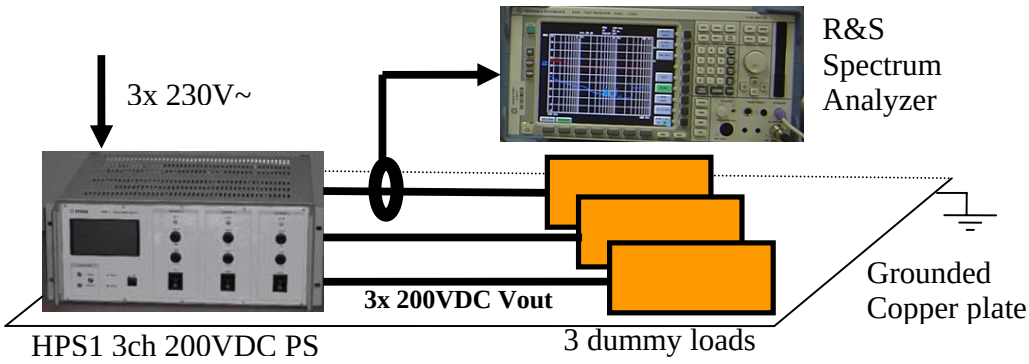


Figure 1. Conducted noise emission measurement setup.

Three HPS1 200VDC power supply outputs are connected to three resistive dummy loads by using 1m (not shielded) three wire cables (positive, return, and yellow/green dummy load chassis connection), see Fig 1. Each dummy load simulates the equivalent load ~750W of four finger LVBOXes connected to the HPS1. Each 200V channel of the TESLA power supply can have three states: switched OFF, switched ON (STBY mode), and output enabled (200V ON).

The maximum admissible common mode currents from the tested interconnecting cables (shielding included) for the ATLAS experiment [1] are listed in Table 2. They were obtained from maximum emission voltage limits of the CISPR11 IEC standard assuming 50 ohms connected load.

Table 2. The ATLAS EMI conducted emission limits.

Range	9 kHz to 500 kHz	500 kHz to 100 MHz
Limit	45 dBµA	39 dBµA

HPS1 17 MHz spectrum suppression output filter

Twenty four HPS1 [3] power supplies and sixty four output cables are installed in USA15 control room for the TileCal detector, see Fig.2 (a). Conducted EMI noise measurements of 200V power supply [1, 2] demonstrated very high disturbing noise of 72dBuA @ 17.7MHz and 55dBuA @ 34MHz (compare it with conducted emission limits in Table 2). In consequence of discovered 17MHz conducted common mode noise, two ferrites [4] were mounted on each 200V output cable (see Fig.2.b) to suppress 17MHz noise peak down to 52dBuA. Unfortunately, the installed ferrites could not suppress significantly all disturbing common noise spectrum under the ATLAS allowed limits.

An additional low pass common mode LC filter has been designed in cooperation between Prague physics institute and TESLA Company to suppress disturbing 17 MHz noise spectrum of HPS1, see scheme in Fig.3. This filter can be fixed inside the PS and connected on 200V channel output. A prototype realization for all three Vout channels is shown in Fig.4. Successful noise reduction with the installed output filter will be presented in the next section.

(a) (b)

Figure 2. Twenty four HPS1 3ch 200VDC power supplies will be installed in USA15 control room for TileCal (a), mounted common mode ferrites (2 ferrites on 1 turn) on 64x 200V output cables under floor (b).

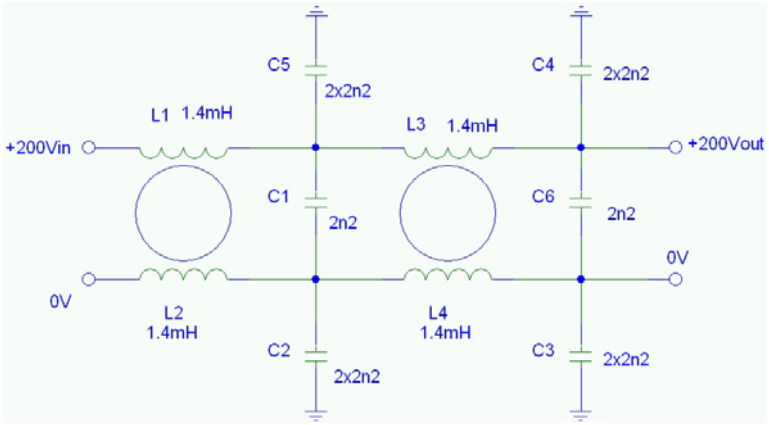
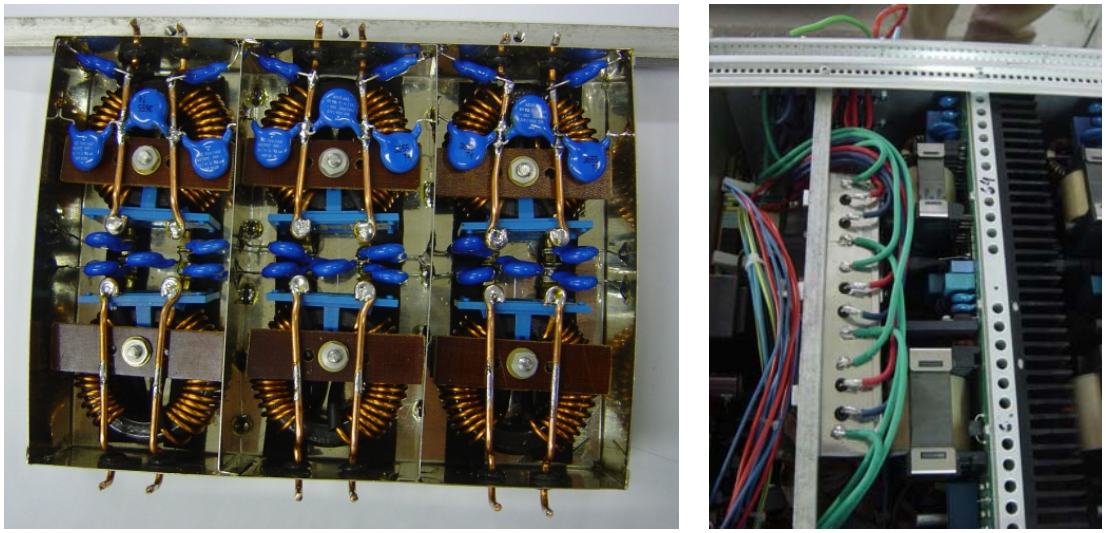


Figure 3. Designed TESLA/FZU LC filter for one 200V Vout channel.



(a) (b)

Figure 4. Prototype of realized 3channel LC filter (a), installed filter inside HPS1 is fixed close to CH1 board (b).

Measurement Results

Several configurations and measurements of the EMI conducted emissions are measured (150 kHz -100 MHz range):

- HPS1 channels without output filter, noise measurements from previous tests.
- CH1 200V ON with LC filter, without and with ferrites
- CH2 200V ON with LC filter, without and with ferrites
- CH3 200V ON with filter, with ferrites
- CH1, CH2, CH3 ON, with filter, with ferrites

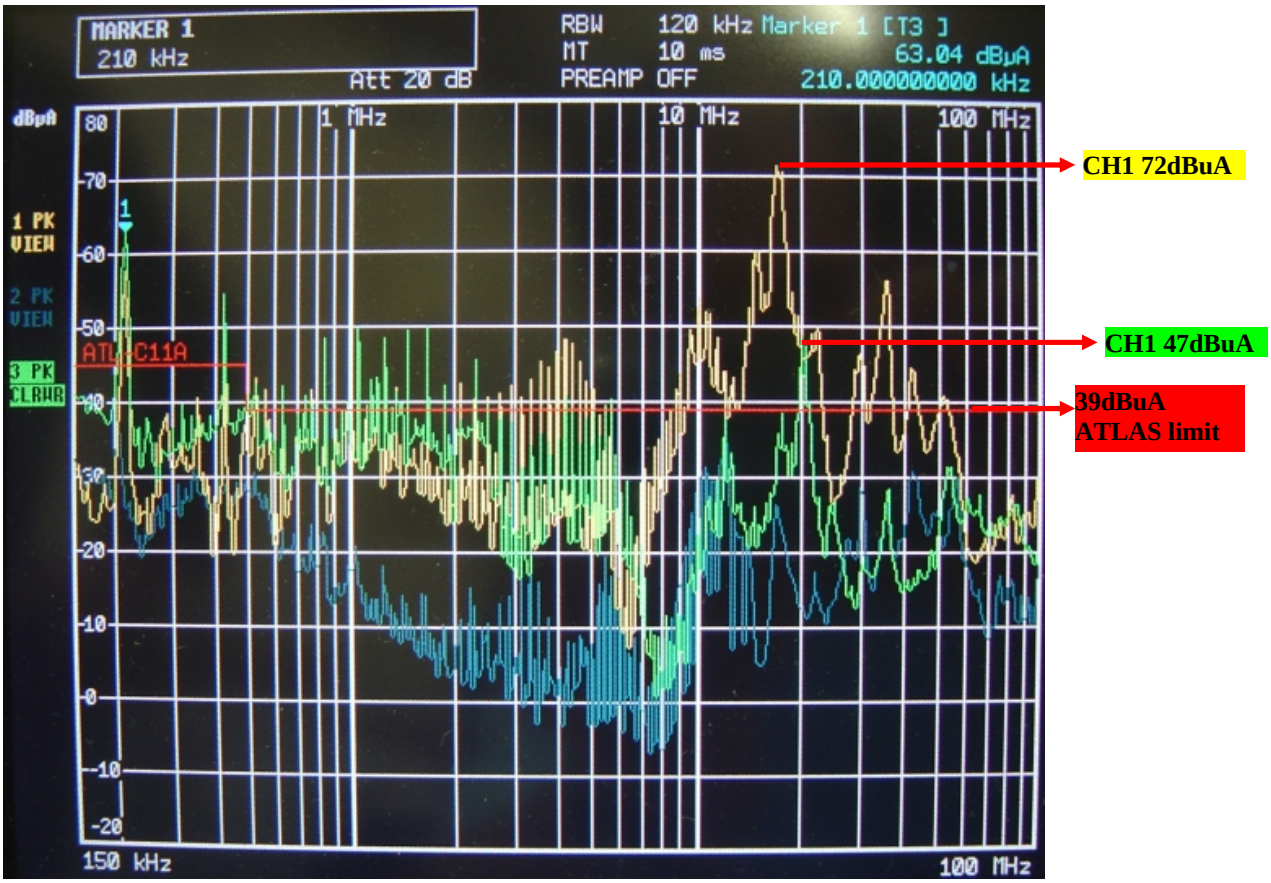


Figure 5. Conducted noise measurements on HPS1: CH1, CH2.

Yellow curve: Old initial measurements, CH1 noise; CH1 is ON and loaded by equivalent resistive load ~740W, without installed output filter, no ferrites. Other channels are in STBY mode. We can see dominant noise peak of 72dBuA at 17.7MHz.

Blue curve: Old initial measurements, CH2 noise in STBY mode, no output filter, no ferrites. Noise is under the ATLAS required limit – red line.

Green curve: New measurement, CH1 noise; it is ON and loaded by ~740W, with described output filter, no ferrites. Other channels are in STBY mode. The conducted noise reduced from 72dBuA down to 47dBuA, the peak frequency moved from 17.7MHz to 20MHz.

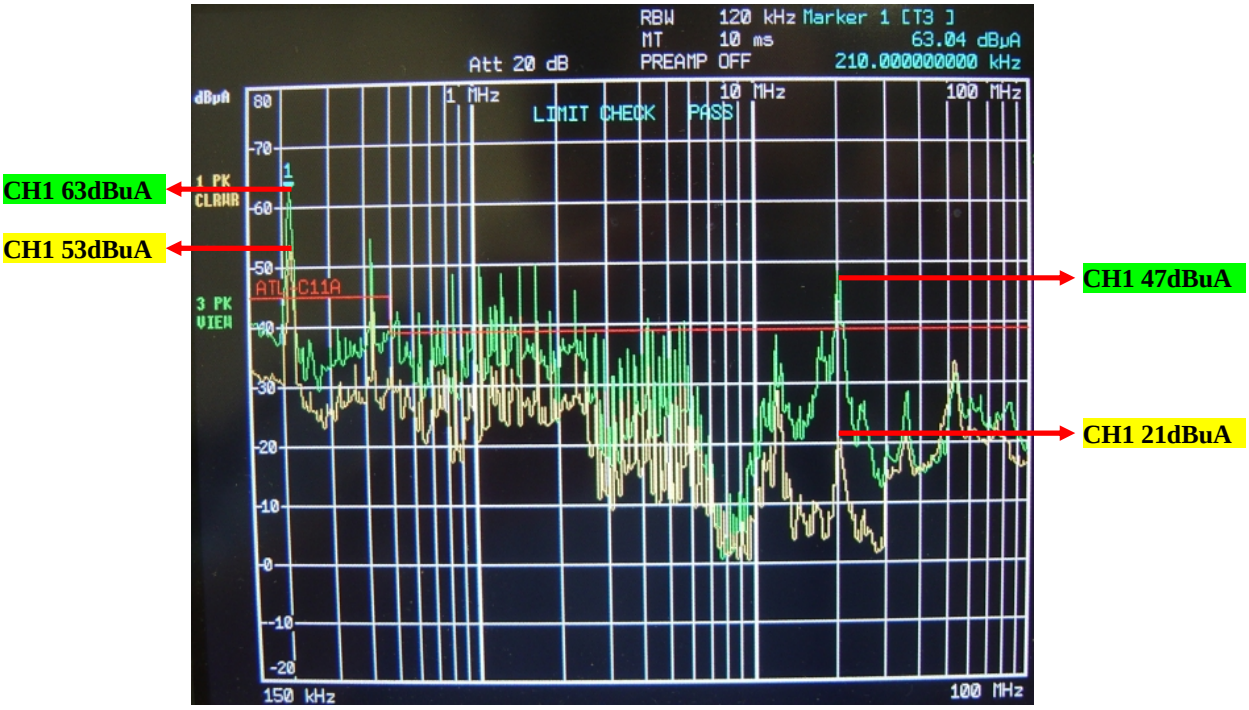


Figure 6. Conducted noise measurements: CH1 is ON, loaded by ~740W, other channels are in STBY.
Green curve: CH1 noise again as from Fig 5; with output filter, no ferrites. The conducted noise dominant peak at low frequency is 63dBuA @ 210 kHz; at high freq. it is 47dBuA @ 20MHz, respectively.
Yellow curve: CH1 noise; with output filter, with two ferrites on Vout cable. The conducted noise peak was reduced to 54dBuA @ 210 kHz, at 20MHz frequency down to 21dBuA.

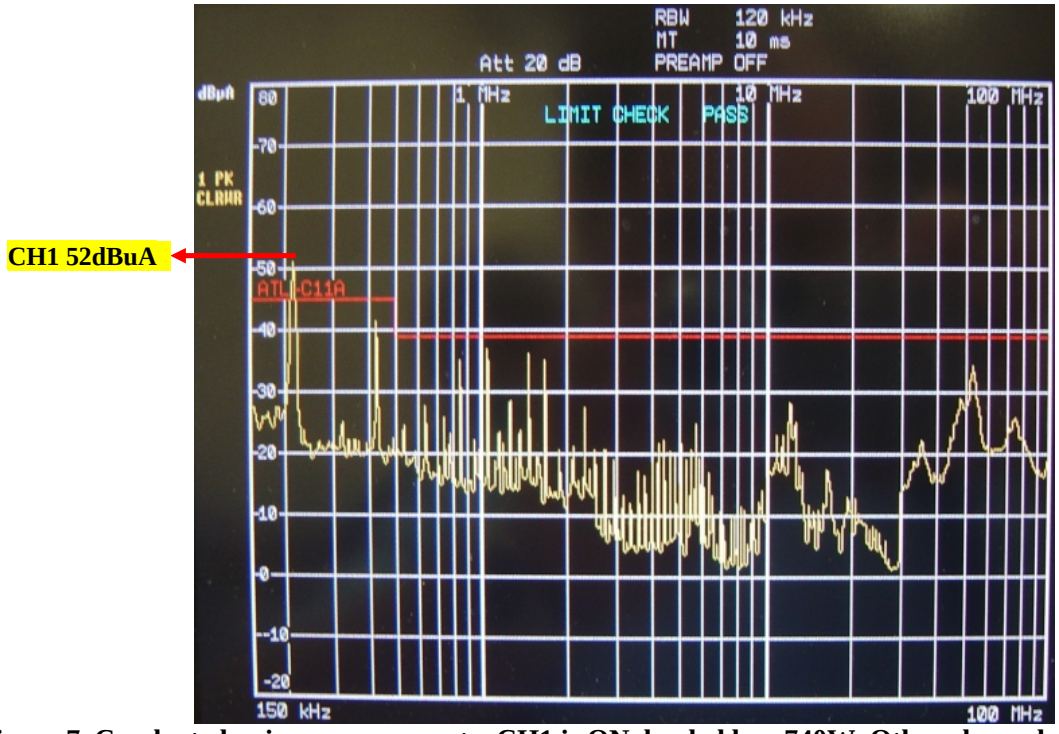


Figure 7. Conducted noise measurements: CH1 is ON, loaded by ~740W. Other channels are in STBY.
Yellow curve: Repeated CH1 noise again, as from Fig.6. ; With output filter, with two ferrites on Vout cable. The only noise peak exceeding the ATLAS limit is 52dBuA @ 210 kHz.

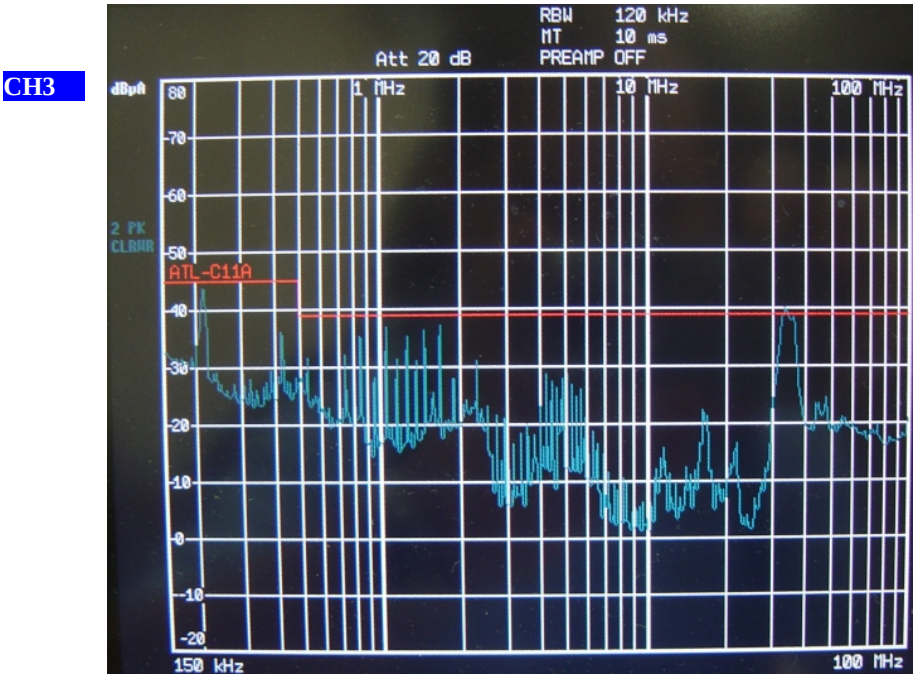


Figure 8. Conducted noise measurements: CH3 is ON and loaded ~730W, other channels are in STBY.
Blue curve: CH3 noise; with output filter, with two ferrites. The noise does not overpass the ATLAS limits in the whole measured frequency range.

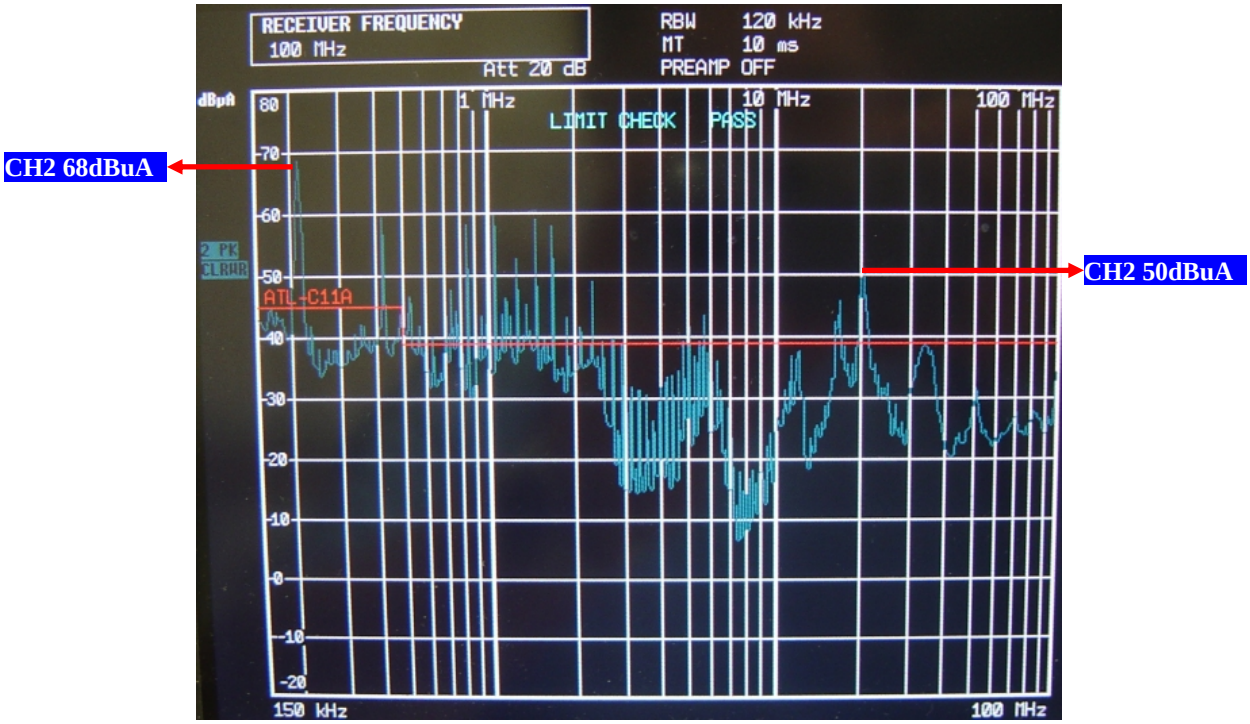


Figure 9. Conducted noise measurements: CH2 is ON, loaded by ~740W, other channels are ON and loaded.
Blue curve: CH2 noise; with output LC filter, without ferrites. The maximum noise peaks are: below 3MHz - 68dBuA @ 210 kHz, and above 3MHz - 50dBuA @ 20MHz.

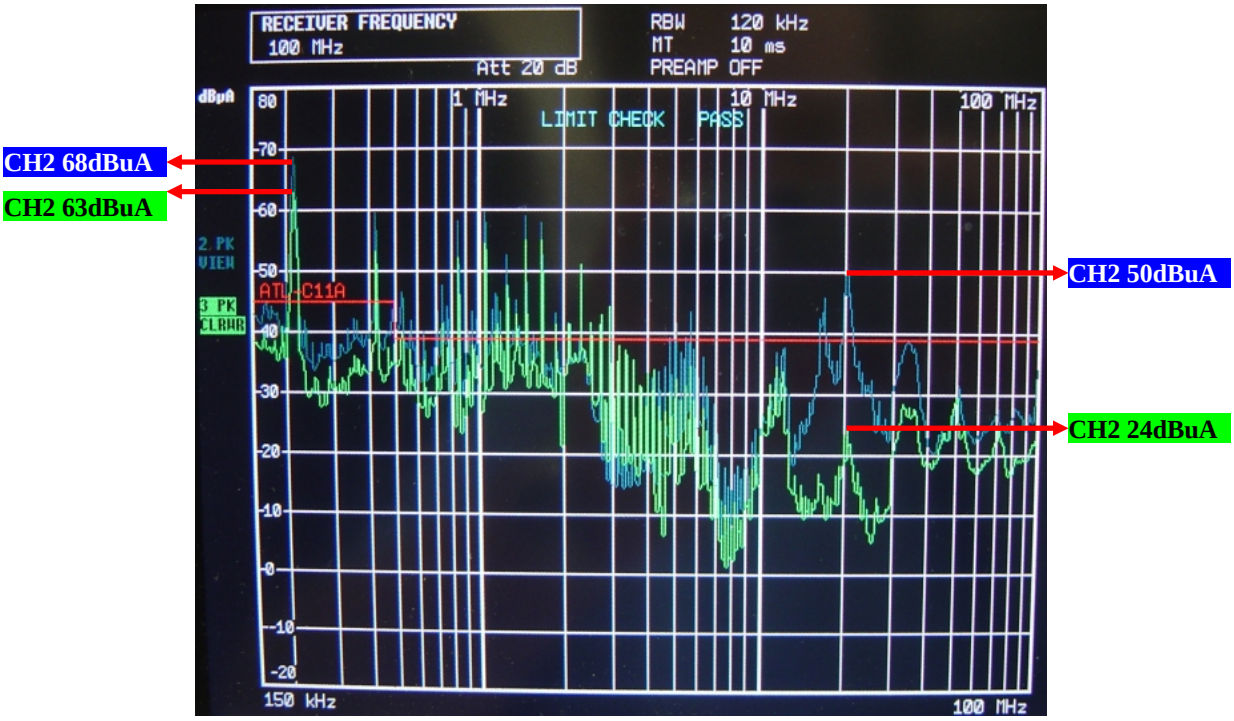


Figure 10. Conducted noise measurements: CH2 ON, loaded by ~740W. Other channels are ON and loaded. Blue curve: CH2 noise as from Fig. 9; with output filter, without ferrites.
Green curve: CH2 noise; with output filter, with two ferrites.

The maximum conducted noise peak at low frequency was reduced to 63dBuA @ 210 kHz, at high freq. reduced to 24dBuA @ 20MHz. The CH2 noise spectra (when other channels are ON too) below 3MHz present many harmonic peaks above the ATLAS limit at 210 kHz, 420 kHz, 840 kHz, 1.1 MHz, etc. The noise spectrum above 3MHz is sufficiently suppressed by using ferrites.

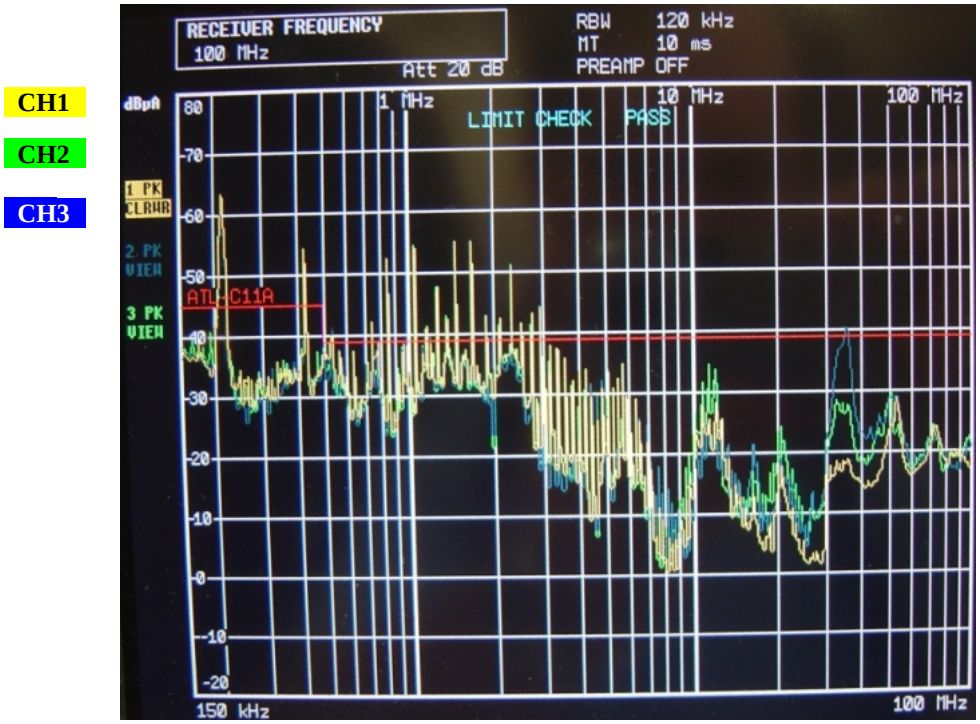


Figure 11. Final conducted noise measurements: CH1, CH2, CH3 ON, loaded by ~740W, all channels with output filter and two ferrites. Yellow curve: CH1 noise, Green curve: CH2 noise, Blue curve: CH3 noise.

CH1

CH2

CH3

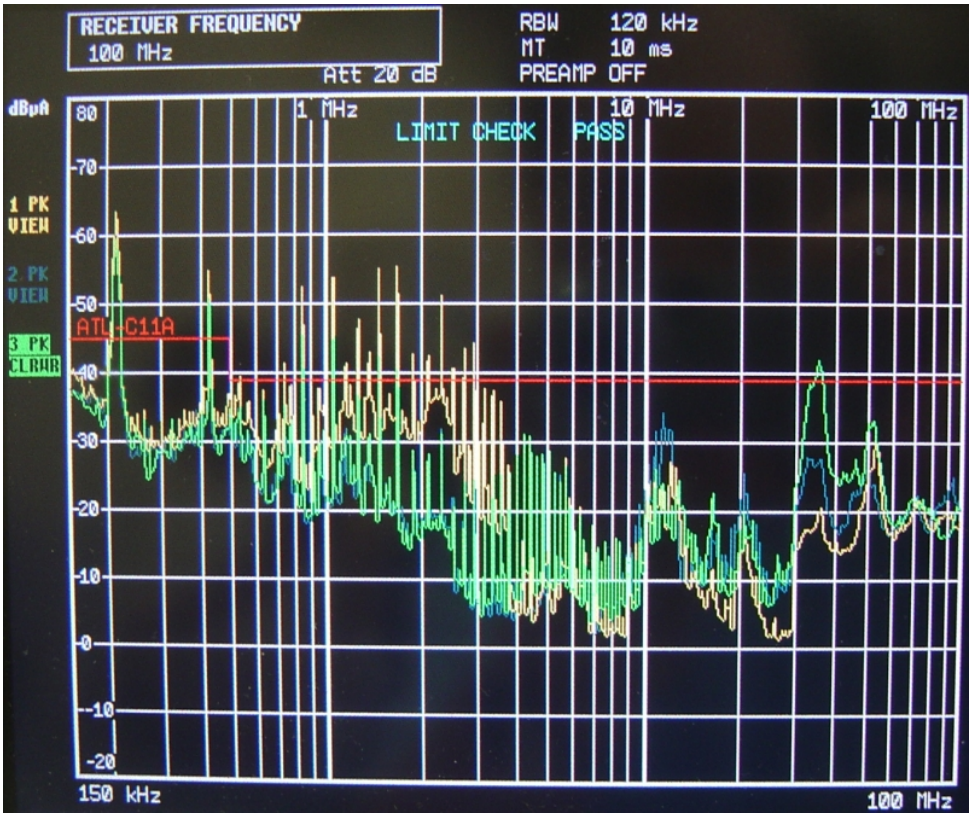


Figure 12. Repeated final conducted noise measurements from Fig. 11 after 30 minutes of power supply operation: CH1, CH2, CH3 ON, loaded by ~740W, all channels with output filter and two ferrites. Yellow curve: CH1 noise, Blue curve: CH2 noise, Green curve: CH3 noise.

The noise spectra of 200V Vout loaded channels are sufficiently reduced above 3 MHz (compare this spectrum with the yellow CH1 curve in Fig. 5); including 17MHz and 35MHz noise peaks. Visible differences between CH1 - CH2 - CH3 noise spectra in the frequency range 20 – 50 MHz from Figures 11 and 12 are most probably caused by the physical distance of the three LC filters from each channel board output. CH1 noise is the most reduced, and also its LC filter is connected by the shortest way to the channel output. Vice versa, CH3 noise is minimally reduced in this frequency range, as well as it has the longest connection between channel board and the LC filter. Thus, the nearest LC filter installation to the channel output (and thus as closer as possible to the noise source) can become important. One can envisage trying to incorporate common mode suppression ferrites directly inside of the HPS1 power supplies.

All three channel noise spectra below 3 MHz display many harmonic peaks exceeding the ATLAS noise limit at 210 kHz, 420 kHz, 840 kHz, 1.1 MHz, etc, se again Fig 11, 12. It is dominated by CH1 noise, probably due to first saved measurements and still cold CH1 running board components. CH2 and CH3 were already loaded and continuously running for about 30minutes before the performed measurements, their background noise visibly lowered of -10dBuA in the freq. range 400 kHz – 4 MHz.

The noise behavior of HPS1 has to be measured in the USA15 control room and verified with the LAr project. It has to be proved that the high exceeding noise peaks still presented below 3MHz frequency do not influence the quality of their sensitive analog front-end electronics.

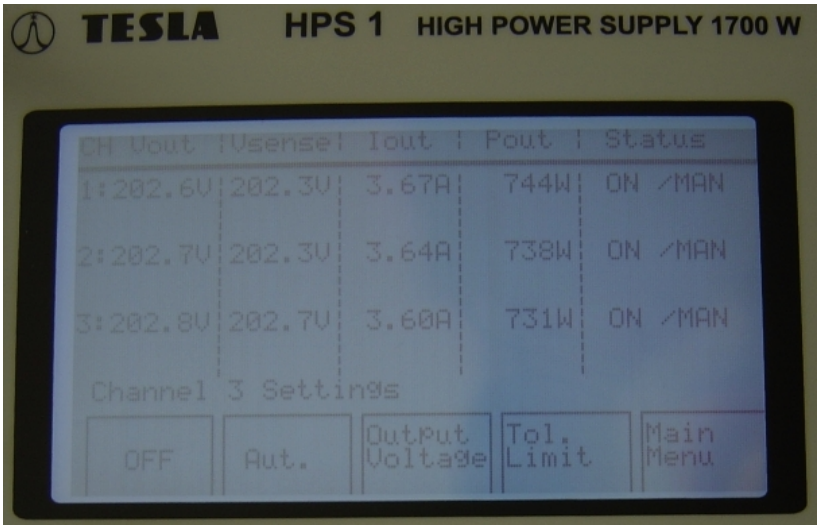


Figure 13. HPS1 front side touch screen; three channel behavioral parameters displayed during noise measurements from Fig. 11 and 12.

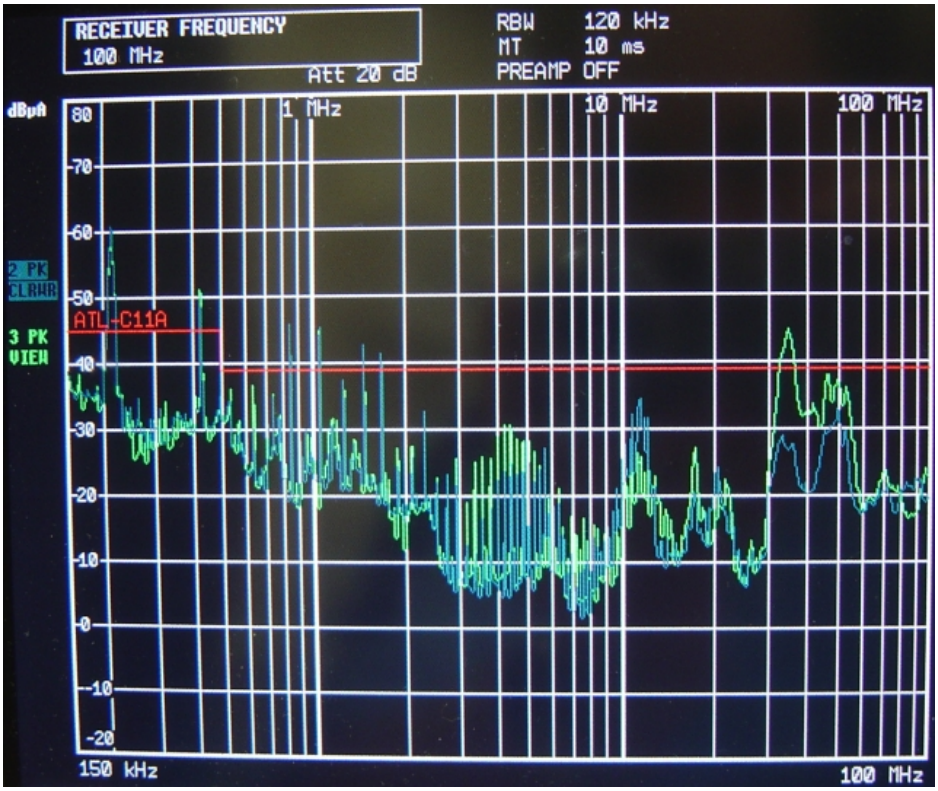


Figure 14. Complementary noise measurements: CH1 ON and loaded by ~740W, CH2 and CH3 loaded by maximum load 7.21A (1440W), all channels with output filter and two ferrites. Blue curve: CH2 noise, Green curve: CH3 noise.

The HPS1 will never work at the maximum load but it is interesting to see increased noise and differences between channels above 30MHz (compare with Fig. 12). Again CH3 noise dominates probably due to the longest connection between channel board output and its LC filter.

Conclusions

Measurements of common mode conducted current noise emission in the range 150 kHz -100 MHz of HPS1 TESLA 200VDC power supply was presented in this report. Confirmed 17MHz noise peak from previous measurements was reduced by two methods:

1) Using common mode suppression ferrites, mounted on Vout cables. This method brought maximum -20dBuA noise reduction at 17MHz but did not significantly suppress the noise spectra in the whole measured frequency range.
2) Applying additional LC low pass common mode filter at Vout output. Presented and proposed filter sufficiently reduced all disturbing spectra above 3MHz, including 17 and 35 MHz, as shown in Fig. 11, 12. The noise spectra below 3MHz demonstrated many harmonic peaks still exceeding the ATLAS noise limit at 210 kHz, 420 kHz, 840 kHz, 1.1 MHz, etc.

Combination of both methods to reduce conducted noise emission of HPS1 is very efficient when only one 200V channel of three is ON and loaded, see Figures 7, 8. When all three channels with LC filters are ON, ferrites will efficiently help to suppress noise above 15 MHz; at lower frequencies below 3MHz only some 3-5dBuA can be gained, see Fig. 11, 12.

The closest LC filter installation and common mode ferrites on the 200V channel output (and thus closer to the noise source) can become more important in the frequency range 20 – 50MHz. We can also propose to add common mode suppression ferrites directly inside of the HPS1 power supplies.

When HPS1 power supply is continuously running, we can also distinguish a further noise reduction of -10dBuA in the freq. range 400 kHz – 4 MHz, see observation in Fig 12.

Noise reduction of HPS1 with installed LC filters and common mode suppression ferrites on 200V cables has to be measured in USA15 control room too, and verified with the LAr project. It has to be confirmed that higher noise peaks below 3MHz do not deteriorate their sensitive analog front-end electronics.

This report presented and measured only conducted noise issues and its improvements. However, an impact on the HPS1 Vout output behavior at transients, and power supply stability with new LC filter was not discussed. Proposed four order LC filter is installed inside the PS output and thus will become a part of the DC-DC converter voltage feedback when remote sense lines are used.

References

[1] G.Blanchot “TileCal Bulk LVPS 200VDC Conducted Emissions Test Report”, CERN/ATLAS-TileCal internal report, CERN, 16 July 2007.
[2] B.Palan, G.Blanchot, “Conducted Emission Measurements of HPS1 TESLA 200VDC Power Supply II, CERN/ATLAS/TileCal/LVPS technical report, CERN, 12-14 September 2007.
[3]"High power supply HPS1 Operational Manual", TESLA Hloubetin, Prague, CZ, technical manual, 2005.
[4] Datasheet of common mode suppression ferrites, SIBALCO AG, type 7427137, www.sibalco.ch.