ETR 94-11

A remote controlled high voltage supply system for photo multiplier tubes

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Abstract: Two versions of a remote controlled multi channel high voltage supply system are described. It is designed to be used for photo multiplier tubes and includes current limiting and tripping. The voltage settings and other controls are steered from a terminal or a host via a serial line. Multiple systems are controlled via one serial line. The system is in use for the SRTD and PreSampler detectors in the ZEUS experiment at Desy, Hamburg.

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The schematics and PALfiles are not included in the normal distribution. They are available upon request.

[1] Computer Aided Engineering

History

The most common way of generating the voltage steps for a photomultiplier tube is using a High Voltage supply and a chain of resistors to create the proper steps for all dynodes. An other approach is using a cascade, also known as Greinacher generator or Cockroft Walton generator. Already in 1978 L.Hubbeling at CERN described such a supply [i]. The system described was designed to feed groups of about 25 tubes, with an average current of 0.1 mA each. A later version of this design was used in the Zeus experiment at Desy[ii].

Using a cascade strongly reduces the heat dissipation, since the current in a resistive divider must be about 10 times the expected maximum current of the last dynode to ensure stability in amplification. To improve the behavior of a resistive divider, zener diodes and large capacitors are used.

The cascade, -or voltage multiplier- however, when used as a negative polarity source, has a low impedance at the stages that draw the most current. This offers the possibility to connect several PM tubes to one supply. No extra current is needed for stability. It is less suitable to be used as positive source for PMtubes, because then the impedance increases where the largest current is drawn. This mode of operation is not common in high energy physics however.

Drawback of the principle is that only fixed voltage steps are available. When a number of tubes are connected to the same supply it is impossible to adjust the individual amplification factors of the tubes by adjusting the voltage of one of the dynodes.

We build two slightly different systems according to the cascade principle for the ZEUS experiment. One for the SRTD (Small angle Rear Tracking Detector), which is operational since end 1993. And another for the PreSampler detector, installed in march 1995. For the BeamPipe calorimeter, the PreSampler version of the HV supply is used.

Principle

The voltage multiplier (or Cockroft Walton generator) generates voltage steps as big as the peak to peak value of the AC voltage at the input. To avoid too many steps the input voltage must be high enough. The impedance increases rapidly with the number of steps. When the multiplier is used as a negative voltage source, the highest taps are connected to the photocathode and first dynodes. These draw very little current and the high impedance of the voltage multiplier at these stages is no problem. The average current at the cathode is in the order of magnitude of 10^{-10} A.

Limitations here are the following: Steps bigger than 100 V increase the price and size of the components of the voltage multiplier. Smaller steps increase the number of steps and thus the number of components used for the voltage multiplier. For the SRTD 17 steps of app. 60 V are used with an auxiliary supply voltage of app. 85V.

Both types of HV units consist of a microprocessor board and multiple voltage multiplier boards.

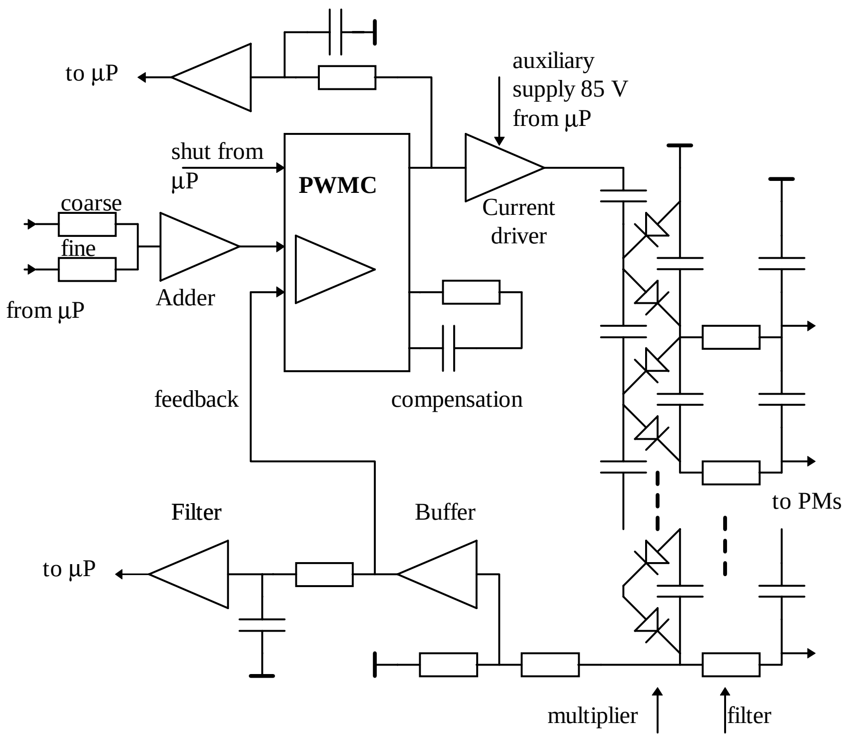

Figure 1: multiplier board

The reference for the PWMC (pulse width modulation controller) comes from the processor board. The PWMC compares this with the (divided) feedback value from the voltage multiplier. The PWMC takes care of short term stability. The divided high voltage is also returned to the processor board to be monitored by the software.

Via the shut input, the microprocessor can switch off the PWMC and thus the high voltage. This is the default state of the microprocessor board at power-up, even before program execution starts.

SRTD

The SRTD is made of app. 280 scintillation strips installed close to the beampipe. The strips are coupled to the PMtubes[1] via optical fibers. The PMtubes are mounted in groups of twenty-four in a metal housing which shields the tubes from the magnetic field. In the same enclosure the HV supply is mounted. The tubes are tested before mounting and grouped according approximately the same amplification for a certain HV. Each box contains 3 groups of 8 tubes connected to 3 HV generators. These three generators are controlled by one microprocessor. Inside each PMbox there is the micro processor, taking care of communication with the host and checking settings and status of three supplies. The auxiliary generator (see page 11) delivers app. 85 V to the HV generators. Each of the three HV generators feeds 8 PM tubes. On each tube socket there is a decoupling for the last three stages and the coaxial signal output connector.

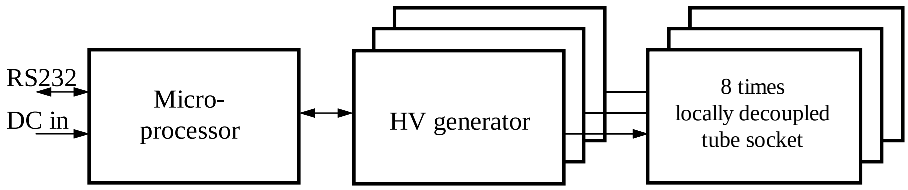

Figure 2: SRTD box

The R647 tube has been tested to determine the voltage distribution on the dynodes for best linearity. The improved linearity comes with loss of amplification compared to a linear voltage distribution. From the cathode, down to the anode the steps are: 2-1-1-1-1-1-1-2-2-2-3. The high voltage range is 800 till 1200 V.

On a small printed circuit board (base card), directly connected to the PM tube socket, the last three stages are again decoupled. There is also a 100 kΩ resistor from the anode to ground, to prevent charge building up when the signal cable is not connected.

[1] Hamamatsu R647

A specially developed communication module (ComBox) connects the 12 PM boxes. It takes care of the arbitration on the serial lines that connects the microcontrollers to the host (OS9 system). Collisions on the RS232 line are avoided by implementation of a hardware handshake (RTS/CTS) between the PMboxes and ComBoxes and between the ComBoxes. The system can be extended by adding more ComBoxes. For a description of this module see page 10.

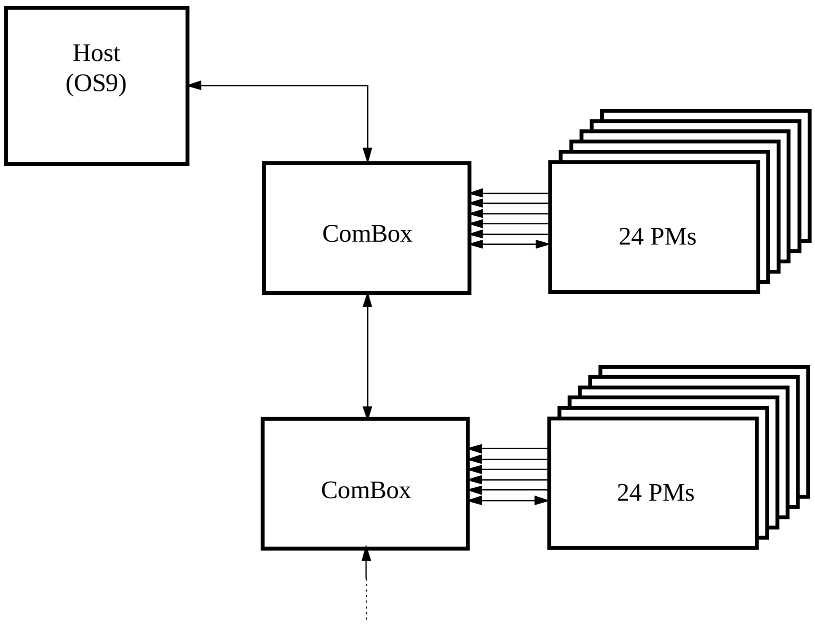

Figure 3: SRTD connection

PreSampler

For the PreSampler in Zeus 16 channel photomultipliers[1] are chosen due to space restrictions. The PreSampler detector consists out of two scintillation plate arrays; one is mounted in front of the forward calorimeter (FCAL), the other array sits in front of the rear calorimeter (RCAL). At the FCAL side there are 264 channels, at the RCAL side 314. In both cases these numbers are divided in north and south groups. The PM tubes are coupled to the scintillation plates by means of wave length shifting fibers. Each individual (16 channel) PM tube will have its own adjustable power supply. In this case one microprocessor controls 6 HV generators.

The communication structure for the PreSampler is the same as the one for the SRTD. The systems are connected near the host, in the *rucksack*[2], to be able to decouple the detectors for testing purposes, without access to the Zeus detector.

Here four HV systems, from two sides of the detector, are connected to one ComBox. There is a ComBox at the FCAL side and one at the RCAL side.

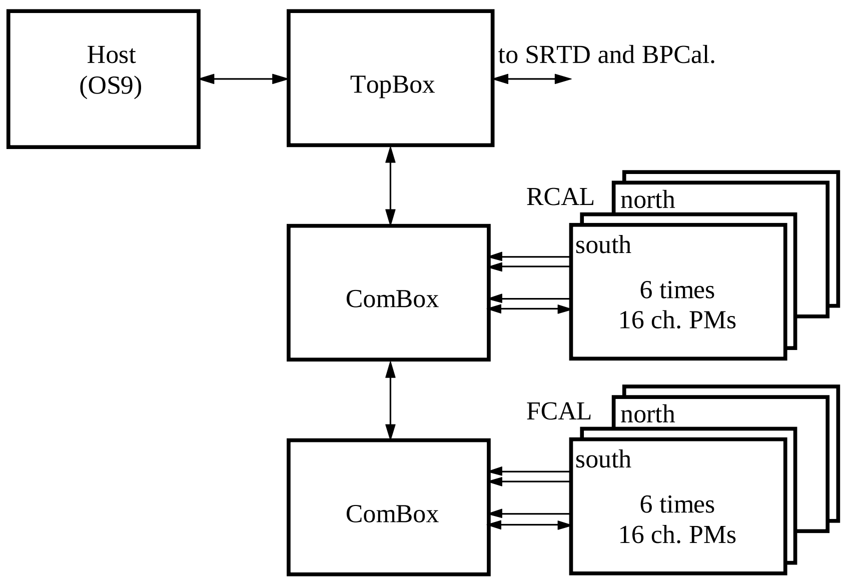

Figure 4: PreSampler connection

On the PreSampler version the steps are jumper programmable, with a maximum of 20 steps. For the R4760 PM tubes the sequence 2-1-1-1-1-1-2-2-4-3 is chosen. Tests showed this was the best configuration to obtain optimum linearity in the HV/signal range where the PM tube will actually be used. The high voltage range is 800 till 1200 V.

[1] Hamamatsu R4760

[2] Electronics hut outside the detector

BeamPipe calorimeter

The system feeds 60 PMtubes[1], individually adjustable. The high voltage units are of the same type as for the PreSampler detector.

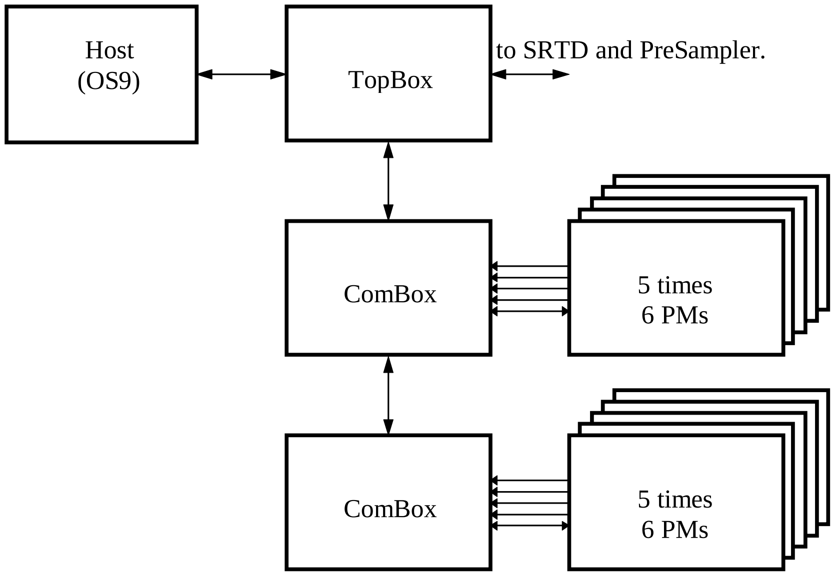

Figure 5: BeamPipe calorimeter connection

For the BPCal the stepsizes are jumper programmed to 2-2-2-2-2-2-2-2-1. The HV range is set from 600 till 1000 V.

[1] Hamamatsu R5600

The ComBox

general

The ComBox stabilizes and distributes the power coming in over a 80 m long cable from the rucksack. It buffers the RS232 lines from the host to the processors in the HV units and accumulates their responses to the host onto a single serial line. Collisions on the RS232 line are avoided by implementation of a hardware handshake (RTS/CTS) between the HV units and ComBoxes and between the mutual ComBoxes. The ComBoxes for the PreSampler are functionally the same as those for the SRTD. The difference is in the powerlines.

SRTD

For the SRTD the ComBoxes contain regulators to stabilize the ±18 V input voltage for the HV units. There is also the loop for the remote sensed +5 V. One HV unit consumes app. 80 mA from 5 V, 130 mA from +18 V and 70 mA from -18 V.

PreSampler

For the PreSampler (and BeamPipe calorimeter) the ComBox stabilizes and distributes the incoming single positive supply of 20 to 30 V to 18 V. One HV unit consumes 170 mA (150 mA @ 30 V... 180 mA @ 16 V).

TopBox

The ComBox that connects the SRTD, PreSampler detector and Beam Pipe calorimeter is called TopBox. It does not distribute the power, it only takes care of the arbitration on the RS232 lines. It contains switches to disable one of the branches. Commands from the host are not transmitted to the disabled branch and requests from the branch, to sent data to the host, are discarded.

new

The TopBox is the 3rd version of the ComBox. It is a PCB version and supports a step function for testing purposes. When a command using wildcards is sent, a number of HV systems will respond. When the step function is enabled, the response of one system at the time will be passed to host or terminal. This step function only acts locally. This means that the ports, including the auxiliary port, are stepped. A character from the host will enable the next system to sent its response. However a ComBox at a lower level may send the results of more then one HV system in the same stream.

Auxiliary supply

The auxiliary voltage is generated on the processor board and distributed to the multiplier boards. There it is used to feed the drivers that pump the voltage multiplier.

SRTD

In the SRTD version this voltage is generated on the microprocessor board from the ±18 V supply by means of a charge pump, see Figure 6. Alternatively three capacitors are charged by current sources. Then they are stacked and their charge is passed to the output. This process runs at app. 40 kHz. The output is fed back to the Pulse Width Modulator Controller that drives the process. The actual value of the auxiliary voltage can be read out via the serial line (see The microprocessor board, page 14). The maximum voltage that can be generated is app. 95 V. The setting of the auxiliary supply is controlled by the host and the load can be monitored in the same way as the multiplier drivers (see Current measurement, page 13). The maximum output current is app. 20 mA, which is enough for three high voltage generators feeding 72 PM tubes.

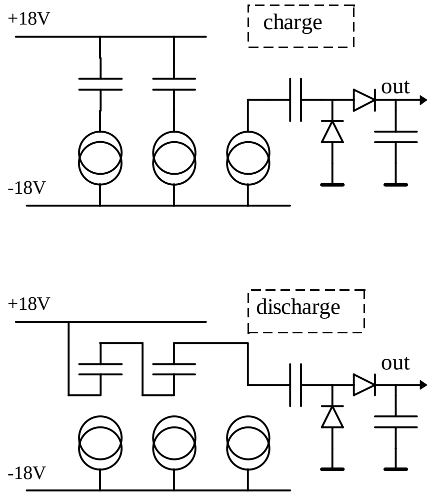

Figure 6: aux. supply SRTD

PreSampler

For the PreSampler, where six HV supplies are connected, the charge pump is replaced by a step-up converter. Besides feeding 96 photomultipliers, there is also some loss in the six HV generators. This converter uses a single coil, rather then a transformer. When a transformer is used the coils must be tightly coupled. This is no problem when a ferrite core is used. In case of the PreSampler detector the power supply is located in a magnetic field, which would saturate the core. A single aircoil does not show this problem, but has a lower efficiency due to the poor coupling between the windings and the resistance of the coil. Since a mere 20 mA is needed in normal operation, this poor efficiency is no problem. When the supply is used close to the PMtubes, it is likely it is in a magnetically shielded area. For this reason, room is left on the printed circuit board so a core can be added. This will then shield the magnetic field, generated by the coil, from the PMtubes.

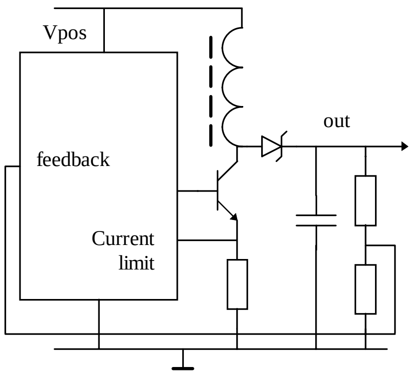

Figure 7: aux. supply PreSampler

Vcc generation

The logic on the microprocessor board operates at 5 V. In the SRTD the +5 V is stabilized at the ComBox by a remote sensed power supply in the *rucksack*, 80 m away. For the PreSampler version of the HV system, only +18 V is generated by the ComBoxes. A step-down converter on the microprocessor board generates the Vcc.

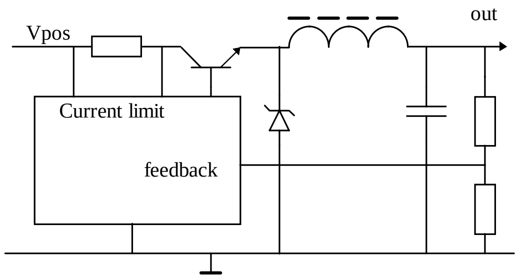

Figure 8: step-down converter

Multiplier driver

SRTD

The auxiliary supply on the microprocessor board is used on the multiplier boards by a push-pull current source to pump the voltage multiplier. A pulse width modulation controller (PWMC) is used to control the inputpower to the multiplier. A simple way to regulate this power is to connect the PWMC via a resistor to the (capacitive) multiplier. The behavior is non linear then and therefor regulation range is limited. Also stability over the whole load range is a problem.

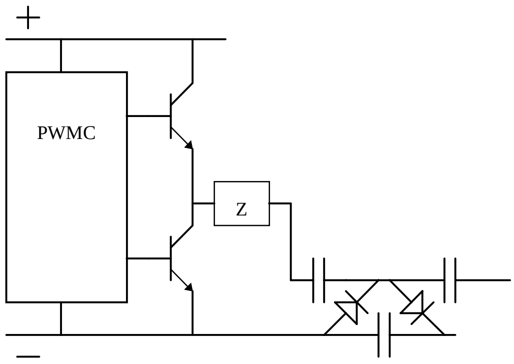

Figure 9: simple driver

Therefor current drivers are used. This improves the stability, especially in the SRTD version, where the feedback is taken from the last tap on the multiplier. This introduces a time delay in the process to be controlled, which can only be handled by an integrating behavior of the error amplifier in the control loop.

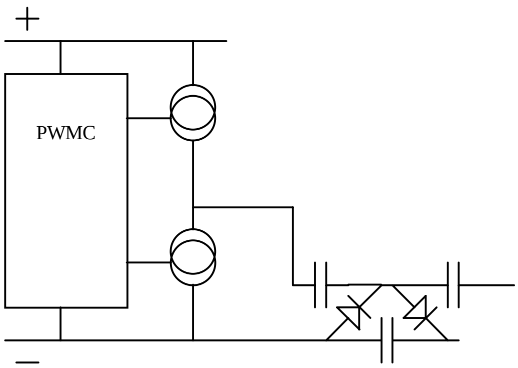

Figure 10: improved driver

The feedback for the control loop is taken from the highest tap of the voltage multiplier. This serves three purposes:

- The actual HV on the cathode is measured and stabilized.
- There is a minimum load which makes regulation easier and more stable.
- The load makes down regulation possible (the current source can only increase the voltage) and the charge of capacitors disappears after switch off for safety reasons.

PreSampler

The PreSampler version takes the feedback from the fourth tap. The impedance of the feedback resistor is lower which makes the supply less sensitive to noise, capacitive coupled in. In the normal enclosure this noise is shielded off, but during calibration and experiments it can be rather disturbing. There is a separate load resistor at the last tap of the multiplier for down regulation and safety. In this case the actual HV is not measured directly, but must be calculated from the value measured. Because the load at the higher taps is very small, the error introduced at varying loads is very small. The delay in the regulation process is shorter, thus improving stability. When the assembly is calibrated, the HV is measured at the highest tap used to represent the cathode voltage.

Current measurement

SRTD

The settings of the current sources also determine the maximum current that can be delivered to the output. This value is fixed by hardware. Monitoring the duty cycle of the PWMC gives a good impression of the load of the supply. In this way the current is monitored in the SRTD version of the supply. This measurement is not very accurate. It depends for example on the setting of the auxiliary supply voltage. It can however be used by the internal software to monitor the load of the supply and switch it off if the value exceeds a preset value. This value is determined during calibration. There is also a user programmable limit, see the software description for more details.

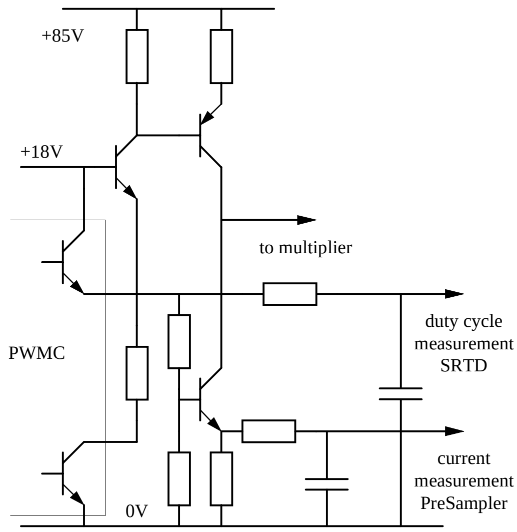

Figure 11: current measurement

PreSampler

In the PreSampler version the current steered into the multiplier is monitored. This allows a more accurate measurement compared to the SRTD version. It is calibrated to give an indication about the height of the anode current. The actual value of the anode current depends mainly on to which tap of the multiplier the last dynodes are connected. Since this is jumper programmable the user (or host software) must correct the measured value at least by dividing the returned value with the tap number of the last dynode. How to interpret the value measured is explained on page 20 (Current measurement example).There is a filter with a cut off frequency of app. 1 Hz to allow for short strong pulses. See also page 17.

The microprocessor board

General

The microprocessor board mechanically supports the multiplier boards. Three boards in case of the SRTD, a maximum of six for the PreSampler version. The microprocessor, a 80C552, communicates with the host via RS232 at 9600 bd. It will only send messages upon a request from the host. The modules can be individually addressed. Also wildcards are supported. Hardware handshaking is implemented to prevent the responding modules to talk to the host simultaneously. This handshake can be disabled by a host command for a test set-up. The HV control program is stored in an Eprom. For buffers, stacks etc. 32 kbyte Ram is installed. The size of the EEprom is 32 kbyte. Here calibration values are stored. It can also be used to download a new program. This is useful during testing new software versions. This can still be done when the HV systems are installed in the detector. The hardware also supports Ram in programspace

SRTD

The HV control program is stored in a 32 kbyte Eprom. The memory map changes completely when running from EEprom. This makes programs stored in Eprom and Ram incompatible

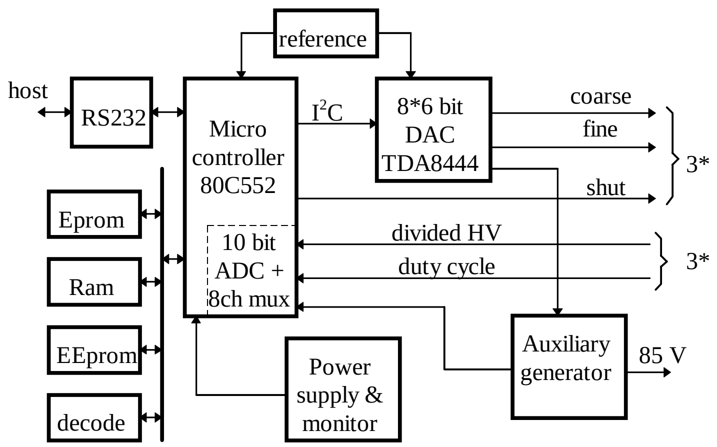

Figure 12: processor board SRTD

PreSampler

In the PreSampler 32 or 64 kbyte Eprom is supported. When running from EEprom in the PreSampler version, the memory map is more compatible with the situation when running from Eprom. Still, space is rather limited.

Here two TDA8444 chips are used to generate the reference voltages for the HV boards. The shut signals come from a third I^2C chip, a PCF8574.

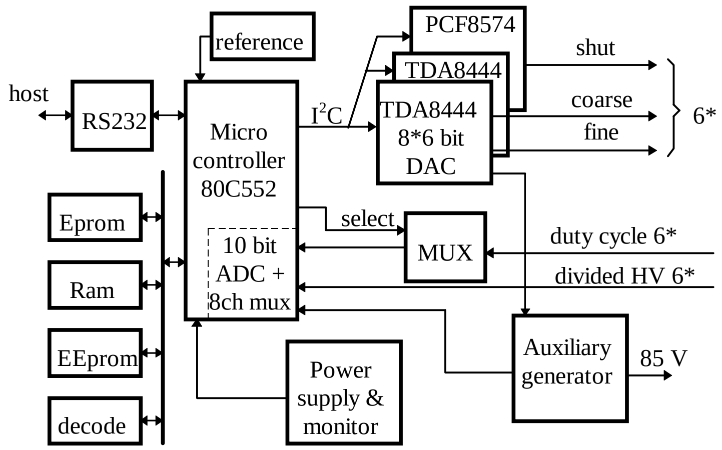

Figure 13: processor board PreSampler

Reference voltage

Via the I^{2}C protocol the processor sets the DAC, thus generating the references for the HV generators. The DACs are 6 bit each. For one reference two outputs are used: a coarse and a fine setting. The values are added on the multiplier boards. The DACs itself are not very accurate. They show an offset on each output of app. 0.5V. Simply adding two of those outputs will give us a reference with a resolution close to 12 bits, but not an accuracy of 12 bits. This is not very important however, since the system is a closed loop. The values can be adjusted until the correct value for the high voltage is measured by the ADC. However, the characteristics of the DACs are determined during calibration. This makes it possible to do an educated guess for the settings when a new high voltage setting is required.

Measuring

A high voltage from the voltage multiplier is divided and returned to the processor board (see Figure 14: control loops). After low pass filtering, the measured value is sampled by the processor. It contains a 10 bit ADC which, together with a stable reference, ensures an accurate measurement. To reject noise several samples are taken before any corrections are done towards the reference setting for the PWMC. The low pass (anti alias) filter ensures the measurements are done correctly. The time constant of the filter is app. 1 s. A typical setting performs a measurement every 100 ms. After 10 samples the result is compared with the required value. Then the DAC settings are adjusted if necessary. If the correction needed is bigger then a value, determined during calibration, an error has occurred. A possible cause is a too low setting of the auxiliary supply voltage for HV required. The supply is then switched off and a status bit is set. This can be read by the host. The resolution of the measurement is further improved by subtracting a fixed value from the HV measurement. This is possible since the output voltage will be in the range of 800 to 1200 V. Since the measurement range is divided by 3, more than one bit accuracy is gained. Multiple measurements improve stability, since noise is reduced. Accuracy is improved by $\sqrt{n}$, where n is the number of measurements.

During calibration several measurements of the ADC (at several HV settings) are compared with an external precision instrument. Calibration values are calculated from the results and stored in EEprom. During operation these values are used to determine the required averaged ADC value to generate the requested high voltage.

Long term stability is depending on a small number of components; the resistors used in the feedback, the microprocessor's ADC and the reference generator. The filter plays no role in the DC component to be measured. Short term stability is provided by the local loop.

In Figure 14 the connection between the PWMC and ADC is the current monitor. This signal is also filtered before it is digitized. This is in fact also part of the control loop, since the high voltage is switched off in case the current drawn becomes too high.

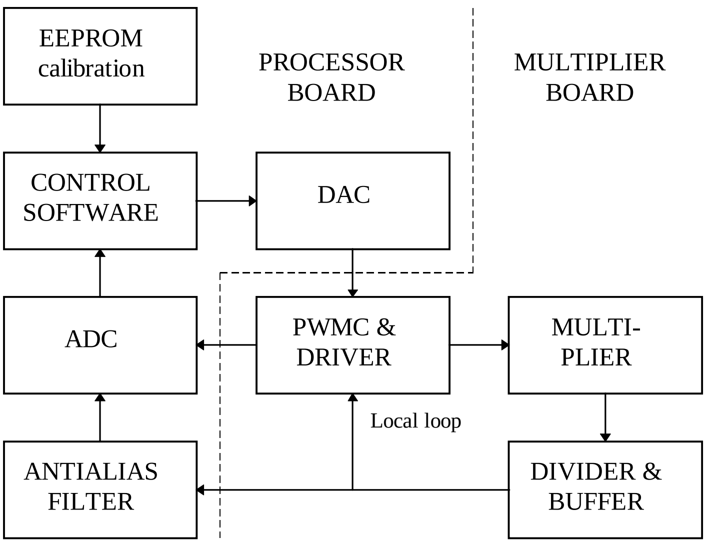

Figure 14: control loops

Current limiting

The current measurement is described on page 12. The software checks whether the value measured becomes higher than the capacity of the supply. During calibration the ADC value of the current measurement is stored when the HV supply under test is shorted. The PWMC and driver section work at their limit at that moment. When this happens at normal operation, it means that either the auxiliary supply voltage is too low compared to the high voltage requested or the load is too high. Another limit that is checked is the user programmable current limit. A 'dark current' value is determined by the user at a convenient moment. This dark current is the load of the PMtube in its normal environment, without signal. Also a tolerance on this dark current must be defined by the user. These values are stored in EEprom. The 3rd user defined parameter is the number of restarts. If the current measured breaks the limit (dark current + tolerance), the supply is switched off. If the value for restart is bigger than zero, the processor will switch on the supply again. This happens app. 1 s after it has been shut down. There is a lock out period to enable the HV generator to start. After this period the current is checked again. If -after the specified number of retries- the current is still too high, the supply remains switched off. The host can recognize this situation from a status bit. For more details see the software description[iii]. The supply is only switched on again after a command from the host.

The processor measures an average of the current. The anti alias filter has a timeconstant of app. 1 s and the processor also averages a number of measurements. This protects the photomultiplier tube against too much total accumulated charge, which determines its lifetime. To protect against peak currents the driver of the supply has a build in current limit. This absolute maximum value is determined by the component values in the current driver section. Fast and strong illumination of a tube may lead to bigger currents for a short time due to the charge accumulated in the filter on the multiplier board and the decoupling capacitors on the PM base. This cannot be avoided without serious degradation of the signal quality.

Memory maps

SRTD

The memory map of the processor can be changed under software control. In this way a program can be downloaded from the host into EEprom or Ram. This is useful when testing new programs or when new options are implemented. This can be done remote, so access to the boards is not necessary. The programs are written in C and cross compiled on an IBM compatible computer.

A new program can be down loaded in *Intel hex*-format[1] after the download command. The current running program interprets the code and stores it at the proper locations into EEprom. Then in the loader program a jump is made to the last location of the mirror image of Eprom FFFEH [2]. There is the instruction to switch to the new memory map. EEprom is mapped into programspace and the program counter advances to the first location in EEprom. Execution of the new program is started.

To switch back to Eprom a similar switch instruction in the program loaded is executed. In this case it is physically and logically located at 7FFEH. The mirror image does not exist and, when running in EEprom, the system will crash when jumping there. After the switch instruction, the program counter advances to 8000H. There is then the mirror image of the Eprom location 0000H. Execution of the Eprom program starts as after a reset.

Loading programs into Ram is similar. Because of hardware limitations in the SRTD version, the memory map changes totally however.

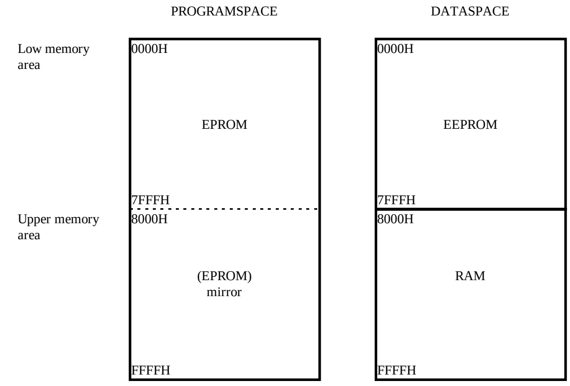

Figure 15: standard memory map (V1)

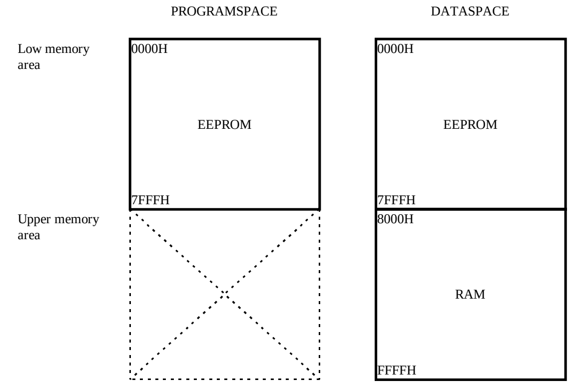

Figure 16: running from EEprom (V1)

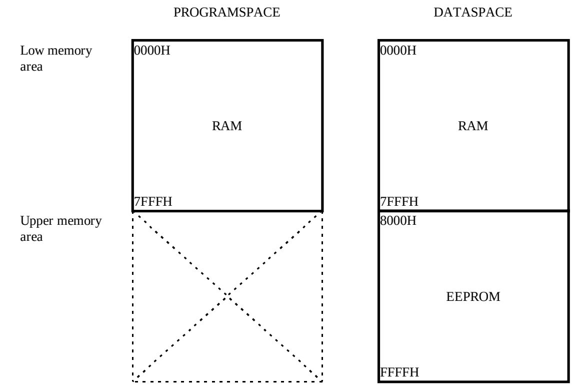

Figure 17: running from Ram (V1)

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[1] A standard format, generated by the cross compiler and interpreted by the HV controller software

[2] The actual location in Eprom, determined by the address decoder, is 7FFEH

PreSampler

In the PreSampler version of the processor board 32 or 64 kbyte of Eprom can be installed. In dataspace 32 kbyte Ram and 32 kbyte EEprom are installed. Both can be used to download programs, with the limitation that space is still occupied by their original purposes. Therefor they are smaller than the Eprom.

The address decoder in the PreSampler is different from the one used in the SRTD version. In this case, when running from EEprom or Ram, a mirror image in the upper half of programspace does exist. This makes programs compiled for Eprom compatible for usage or just testing in EEprom or Ram.

It is not possible to store data in EEprom from a program running in EEprom.

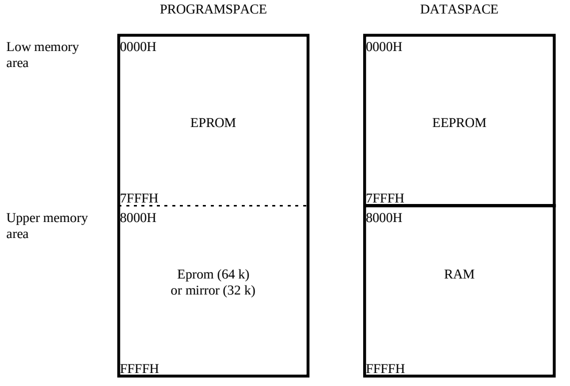

Figure 18: standard memory map (V2)

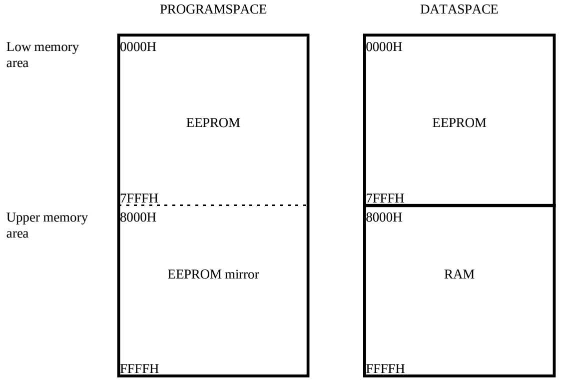

Figure 19: running from EEprom (V2)

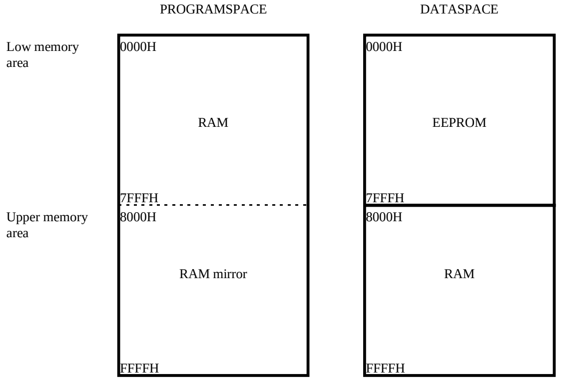

Figure 20: running from Ram (V2)

Current measurement example

SRTD

Using the RDC command, the duty cycle of the PWMC can be read. This gives an indication of the load. The value read depends on the value of the high voltage (see page 13).

PreSampler

Using the RCU command returns a value that should be multiplied by 100 nA to find the actual value. The value measured by the ADC is calibrated to represent the input current of the voltage multiplier. The correction is needed to subtract the current drawn by the feedback resistor and the bleeder resistor at various high voltages. For this purpose values are stored in EEprom during calibration. The measured load depends on the current drawn and the tap number where the load is applied. If a current of 10 µA is drawn from tap 5, the processor will measure 5*10µA=50µA. This makes it hard to define what this current measurement tells you. We will do a little exercise, assuming the amplification at each stage is 3 [1] and the current drawn from dy10 is 10µA. We will use the voltage distribution of the PreSampler [2]. The current for dy9 will then be 10µA/3=3.3µA. The processor measures the 10µA from tap 3 (=30µA), plus 33µA*5. The current from dy8 contributes 3.3µA/3*7=7.7µA. Etc.

Pin	**tap**	**current [**µA]	**measured [**µA]
dy10	3	10µA	33µA
dy9	5	3.3	16.5
dy8	7	1.1	7.7
dy7	9	0.4	3.6
dy6	10	0.12	1.2
dy5	11	0.041	0.45
dy4	12	0.014	0.17
dy3	13	0.0046	0.06
dy2	14	•0	•0
dy1	15	•0	•0
cat	17	•0	•0

total measured by the processor: 63µA

So the current measured by the processor is not the current of just one of the pins of the PM tube. It is better to recalculate to the power consumption of the tube. When the high voltage is set to 1000V, the voltage step going into the voltage multiplier is 1000V/17=58.8V. So in this case the power consumption is app. 3.7mW.

[1] This not correct with the voltage steps used, but this value will be used in this example

[2] 2-1-1-1-1-1-1-2-2-2-3

References

[i] L.Hubbeling, CERN-EP Internal Report 78-5
[ii] The Zeus Detector, Status Report 1993 / B.Lu et al Nucl. Instr. and Methods A313, 135/1992.
[iii] Description of the software for the SRTD high voltage supply, by Henk Boterenbrood.