HV Tester

Introduction

IDMAR infrastructure will use a large number of photomultipliers. Each of these tubes needs an electronic control unit called a base. On these bases the following functions are implemented:

1. High Voltage Power supply, up to 1500 V on the highest dynode.
2. Analog signal buffer and conversion.
3. I2C communication unit.
4. Digital to Analog Converter to control the HV Voltage.

All these function must be tested and a test log file must be stored in a database.

Hardware

The hardware of the tester has 5 different PCB.

1. Tester main board.
   All other boards are mounted on this board or connected to it.
2. Base converted board.
   Connects the PM connections of a base from a specific manufactory to the main board.
3. HV ADC units.
   For every dynode step one is mounted. They measure the voltage between the dynodes. 15 are mounted on the main board.
4. Base control convertor.
   The base control connector is placed between the tail of the base and the main board.
5. Interface unit.
   Interface between the tester and the PC. It has an USB interface on one side and a max of 140 universal I/O pins on the other. Also a programmable logic chip (Altera) on it to control and readout the tester.

Software

The software is divided into two parts:

1. LabView program in the PC.
2. Verilog program into the Altera chip.

LabView program

All tester functions are controlled by the LabView program.
In Figure 1 the front panel of the LabView Program in the power tab is given.
Most controls are placed in a tab structure, as needed with a specific function.
Above the Tab structure 5 controls or indicators are placed. They are important at the start of the program.
When the program starts it checks the USB ports for devices with FTDI chip setting. These devices are shown in the left array. The green led next to it tells the tester is also detected.
If the tester is detected the button ‘Enable USB’ must be pushed. Until this is done the tester will send no responds to the commands send to it. In response to this command the Read USB Enable led will become green and the testers serial number is send back. This number is used to read the calibration file of this Tester.
This enable procedure is build in to avoid start-up problems with windows at the moment the USB connection is made.
The program must always be stopped with the ‘Stop’ button in the middle. Only then the USB connection will be closed properly and the program will start again if needed.

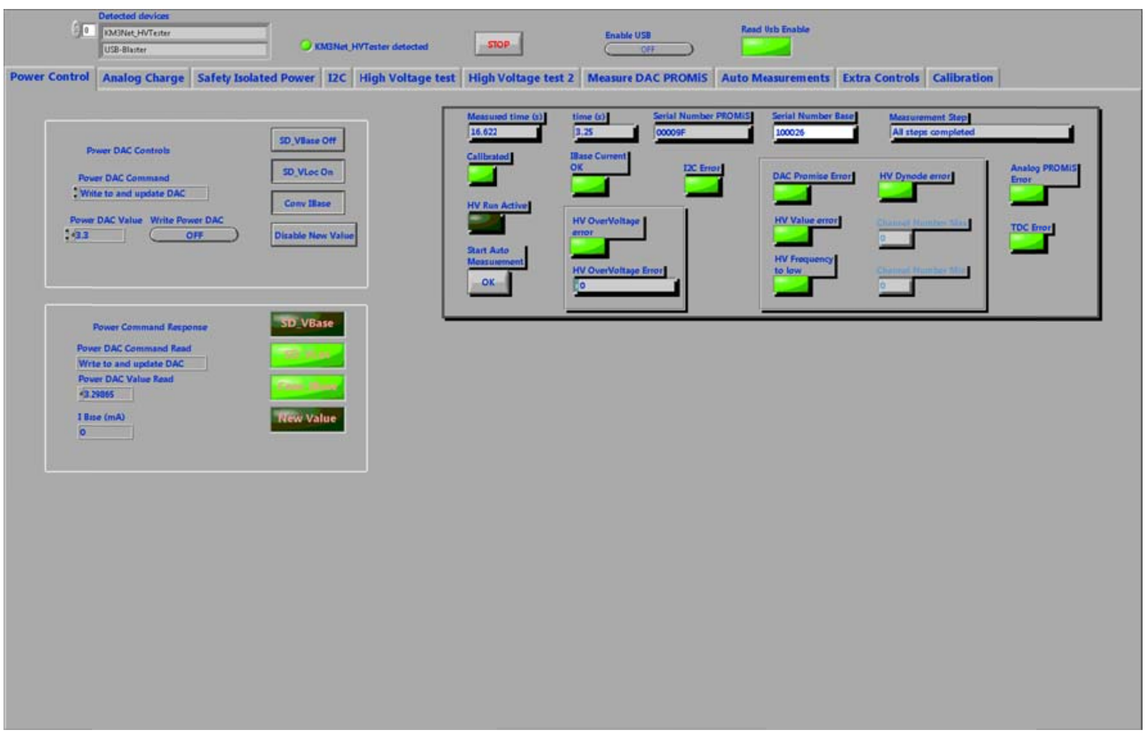

Figure 1: Front panel LabView program.

The controls and indicators on the Tab panels are divided into 2 parts,

1. Visible and controlled from all panels.
   Everything on the right hand top side, looking as if there is a shadow behind it, is always visual. They are used to start, and to show the results of, the automatic measurement.
2. Tab related controls and indicators.

Always visual control and indicators

There are 20 indicators and 1 button always visual.

1. Start Auto Measurement.
   Function, as it says pushing it will start the auto test sequence.
2. Measurement Step.
   Indicates the test that is active, also if the test stops due to a detected error, it shows in what step that happened.
3. Serial number.
   Shows the serial number read from the PROMiS. Number is used in the file name.
4. Serial Number Base
   At the start of the Automatic test sequence the program asks to scan the serial number on in bar code on the tale of the base.
5. Measured time (s).
   Shows the time needed for the last active HV measurement.
6. Time (s).
   Is counting the time during a HV measurement.
7. Calibrated.
   The system must be calibrated before measuring. The calibration is stored in a calibration file. After reloading this file system is calibrated and ready for action.
8. HV Run Active
   When green a HV measurement is busy.
9. IBase current OK.
   The base current is measured in two steps,
   a. After being switched on, must be between 6 and 27 mA.
   b. After switching on the analog buffer, must be between 60 and 90 mA.
10. I2CError.
    To make the test, I2C communication must be possible with the PROMiS. Checked this connection is done by checking if an acknowledge is received from the slave (PROMiS).
11. HV Over Voltage error.
    Indicator that becomes red if one of the measurement units detects Over voltage. The detection is only done during a measurement run. Normally the ADC measures a maximum of about 110 V. The maximum value it can measure is 140 V. Technically the unit can have 150 V, so switching of when 140 V is reached is not doing any damage.
12. HV Over Voltage Error.
    Binaries indicator, that if the Led ‘HV Over Voltage error’ is red tells which modules are in Over Voltage.
13. HV Value Error.
    Tests if the total high voltage is within a percentage of the settings.
    Test is used during 3 steps:
    a. Run HV Measurement.
    b. Run HV Test VBase Sweep.
    c. Discharge test.
14. HV Frequency to low
    The Coco can generate pulses with a maximum rate of 45 to 50 KHz. To check this value the dynodes are shorted, so the Coco will go to its maximum frequency.
15. HV Dynode error.
    The voltages on the dynodes are compared with each other. Normally they are more or

less equal. When the voltage multiplier chain has a small defect, it can result in larger differences between the dynodes. These defects can be:
   a. Diode defects.
   b. Capacitor defects.
   c. leakage currents.
16. Channel number Max.
    During a HV Dynode error the channel with the highest value indicates part of the possible defects.
17. Channel Number Min.
    During a HV Dynode error the channel with the Lowest value indicates the other part of the possible defects. Due to these numbers only a few components have to be check.
18. Analog PROMiS Error.
    The analog amplifier is also tested by generating pulses on its input and measuring the output signal. The outputs value's are checked if they are within the limits.
19. TDC Error.
    The second output of the analog amplifier is a time over threshold pulse. The time value's are checked if they are within the limits
20. DAC PROMiS error.
    After switching on the HV the DAC output goes to 1.9 V. When the DAC output stays low, the Coco won't start.

Power Control.

On this tab all power controls are placed. These supplies are:
1. VBase.
   The base power supply
2. VLoc.
   The supply of all ground referred electronics.

In the top frame all controls are given. These controls are:
1. Power DAC Command.
   Write and update DAC is the normally used command, and therefore set as default. With this command a new value is loaded into the DAC and converted to the output.
2. Power DAC Value.
   The new value of the DAC power. Can be set from 2.7 (normally 3.0) to 3.6 V.
3. SD_VBase.
   On Off switch for the Base power.
4. SD_VLoc.
   On Off switch for the local power.
5. Conv IBase.
   When switched on the Base power current is measured. When the base power is switched off the measurement is not needed.
6. New value.
   If disabled no data is send to the DAC.
7. Write Power DAC.
   Pushing this button will send the settings in the other controls to the tester.

The indicators below are giving the response of the tester to the command. Normally it should become a copy of the controls.

Analog Charge.

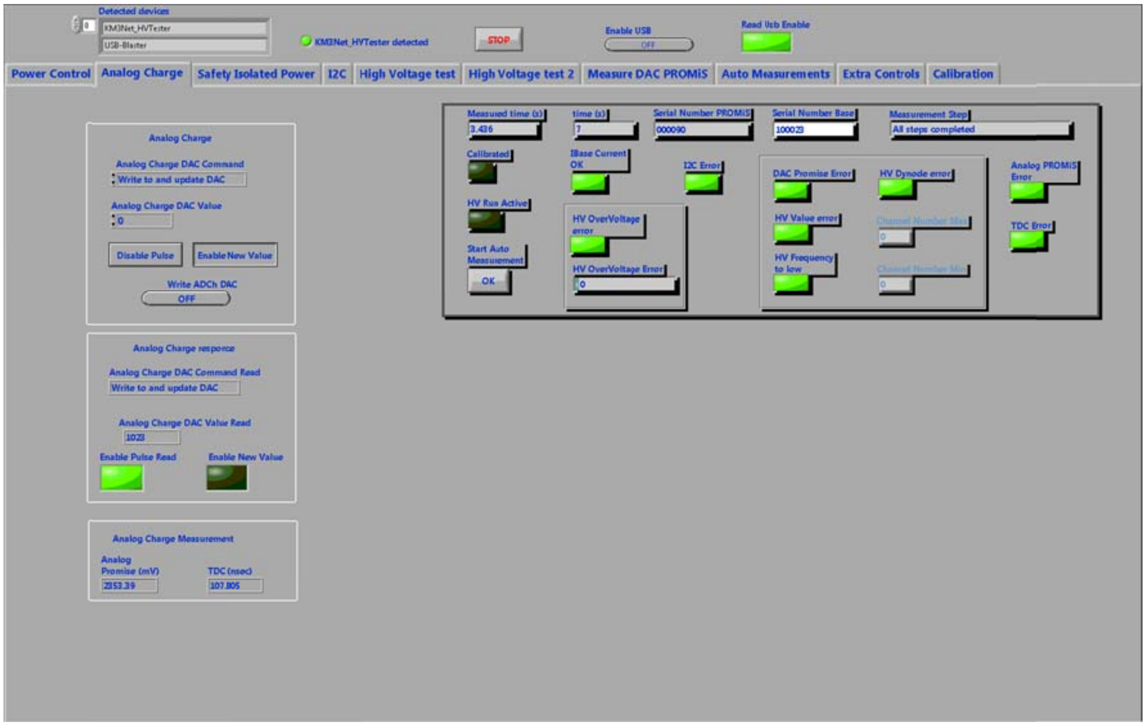

Figure 2: Front panel Analog Charge.

To test the analog amplifier in the PROMiS an analog input pulse is generated by the tester. The size of the pulse is set with a DAC. In the Top frame the controls are given:

1. Analog Charge DAC Command.
   The DAC is equal to the power DAC, so Write and update is the default setting.
2. Analog Charge DAC value.
   The new setting for the DAC
3. Pulse enable.
   If switched on the logic will generate a pulse on the analog input.
4. New Value.
   When enabled a new value is loaded into the DAC.
5. Write ADCh DAC.
   Pushing it will send the command to the tester.

In the middle frame the response of the tester is given.
At the bottom the measured value's of the analog pulse and the time over threshold pulse are given.

Safety Isolated Power.

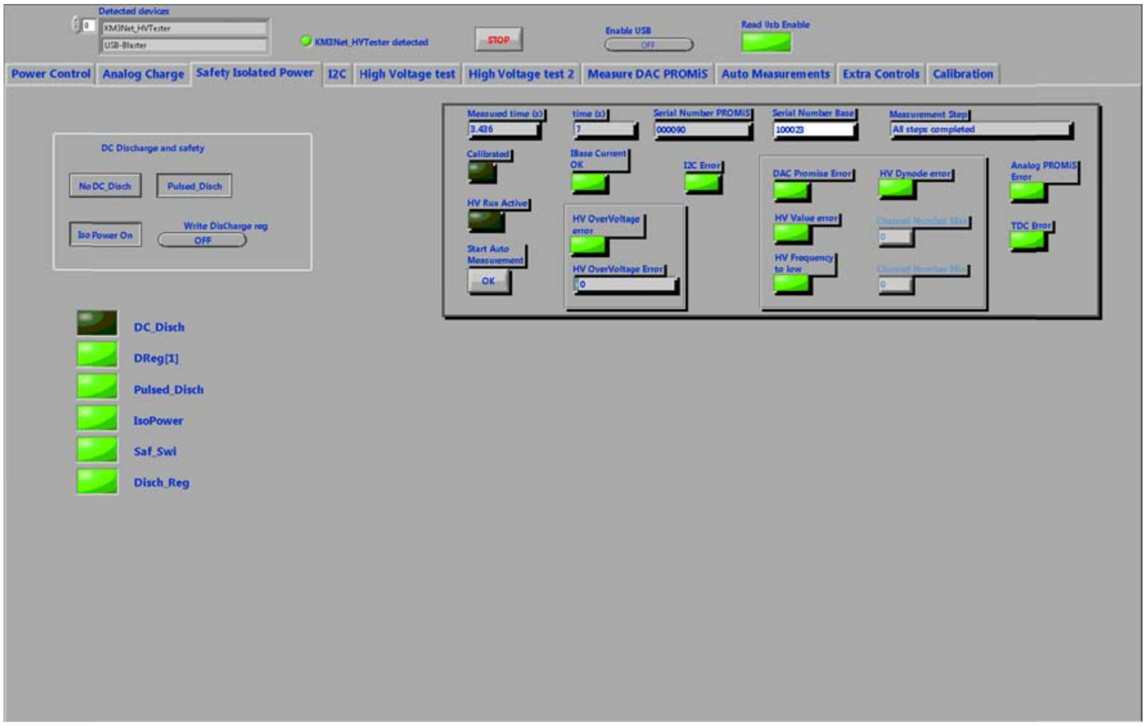

Figure 3: Front panel Safety Isolated Power.

During the test the voltage on the tester can reach values up to 1500 V. To make working with these voltages safe several safety measures are made:

1. Discharge system
2. Safety switches.

The tester has 15 measurement units, who are stacked up to each other electrically. This means, the ground of the first unit is connected to the ground, but the second one to the HV input of the first unit. The 'ground' level for this unit can go up to 150 V. The other units are stacked again. The power for these units are brought to these levels thro a transformer. All digital in and outputs are connected thru capacitors.
To make the HV measurement possible the IsoPower must be switched on.
Two discharge options are made.

1. DC Disch.
   This discharge option put a high level on the discharge input of the modules. Disadvantage is that used as first discharge the capacitive coupling can block this level. DC discharge is needed for the High frequency test.
2. Pulsed discharge.
   The discharge input is pulsed, what automatically resets the capacitive coupling is put into the working mode.

At the bottom the command responses are given. The command response is also send when the safety switch is active. Pulsed discharge is then automatically activated and the power to the base is switched off.

I2C

In the PROMiS chip an I2C interface is integrated to make a base controllable from the outside. To test a base an I2C master is integrated in the tester.

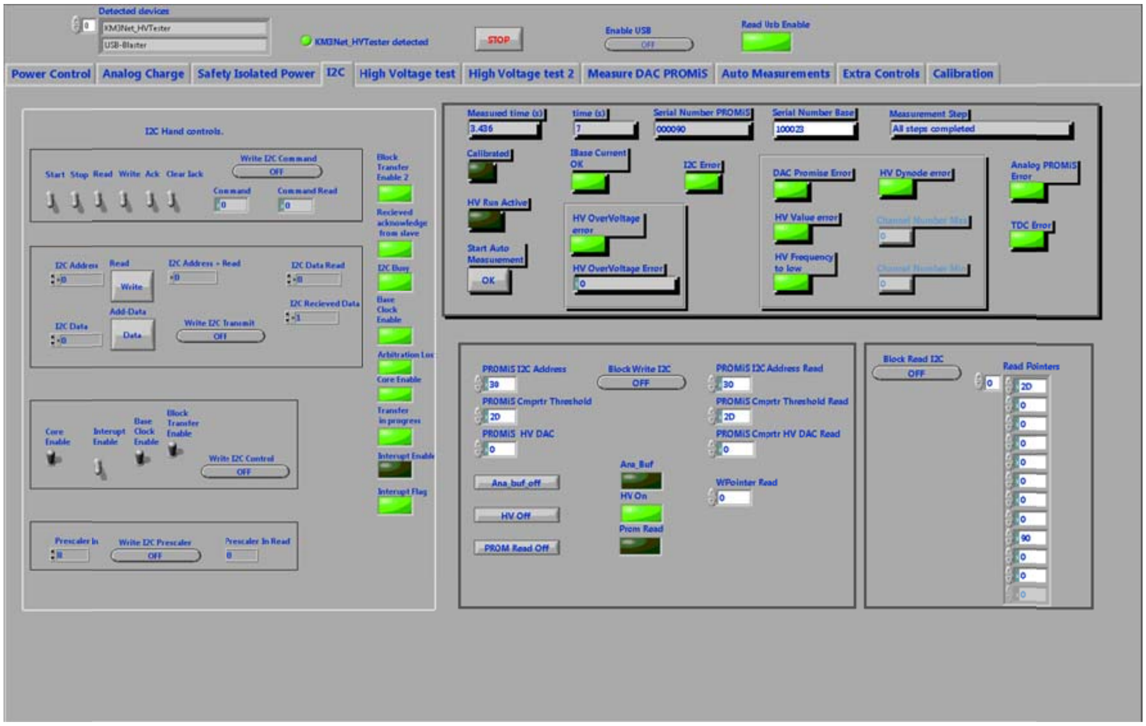

Figure 4: Front panel I2C.

In Figure 4 the front panel with the I2C controls is given. The I2C controls are divided into two sections, Hand controls and block controls.

1. Hand Controls.
   Left hand side of the panel.
   In the Test logic an I2C master core is integrated. On one side this core has the I2C interface, on the other side it has 5 registers:
   a. I2C Command register.
      The Command register tells the core what to do. The options are:
      i. Start, in combination with write generate the start sequence.
      ii. Stop, in combination with read or write generate the stop sequence.
      iii. Read, Read date from a slave. Cleared after execution.
      iv. Write, Write to a slave. Cleared after execution.
      v. If reading give acknowledge.
      vi. Clear the acknowledge.
   b. Transmit data.
      The data to be send is placed in this register before the command is given. At the start the slaves address is written with the read/write bit. When writing to a slave this data is set here.
   c. Receive data.
      Data received from a slave can be read from this register.
   d. Control Register.
      The original core has only two control bits, for this application two bits are added to this register,:

i. Core Enable.
   Core Enable switches the core on.
ii. Interrupt Enable.
   Interrupt Enable is not used, because no interrupt output connection from the core.
iii. Base Clock Enable
   Extra output from the core to enable the clock generator in the PROMiS chip. Can be switched off to save power.
iv. Block Transfer Enable.
   Allows the controls on the right to work.

2. Block transfer controls.
   Right bottom of the panel.
   Block transfer is divided in to two parts:
   a. Block Write.
      After the Block write command is pushed the new settings for the PROMiS Cmptr Threshold, PROMiS HV DAC and PROMiS cmd reg are send in one I2C string.
   b. Blok Read
      After pushing the Block read button all 11 registers of the PROMiS are read. The results are in the pointer array.

High Voltage Test.

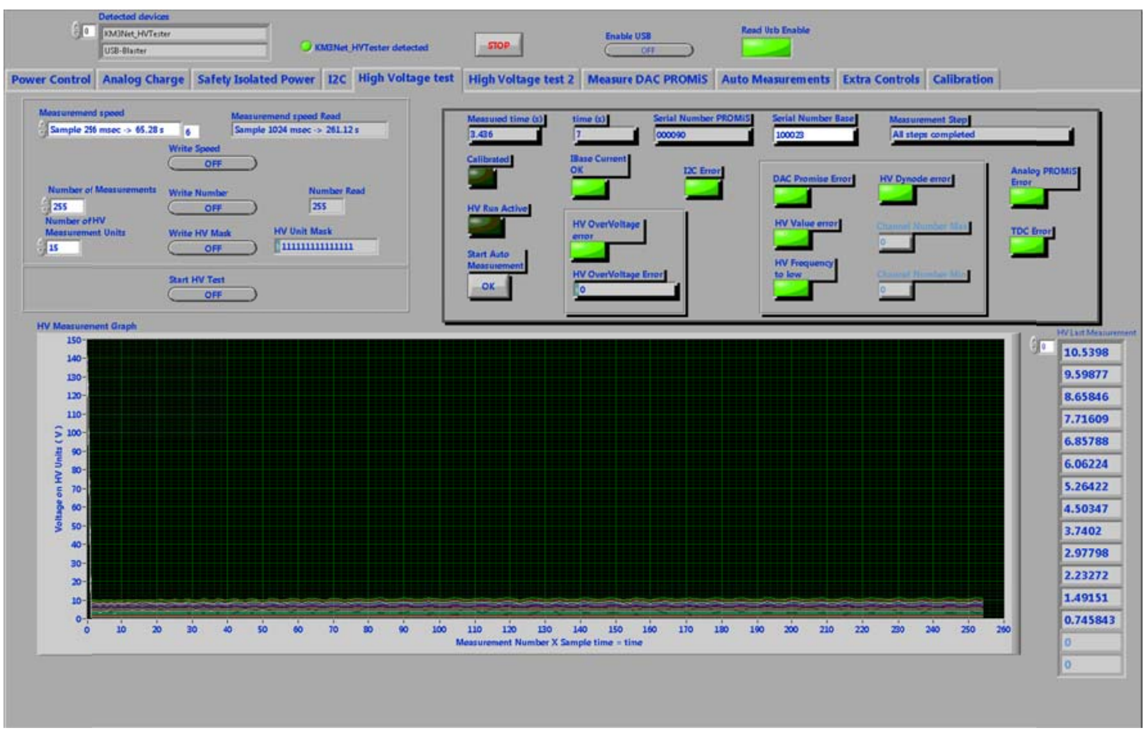

Figure 5: Front panel High Voltage test.

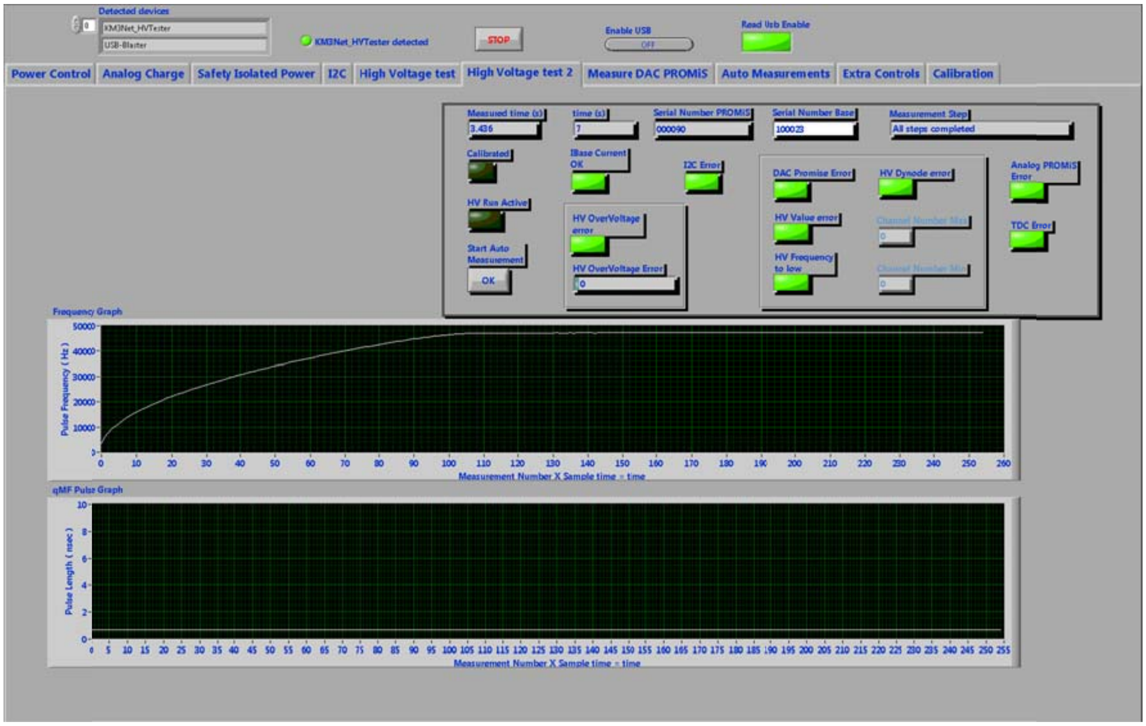

Figure 6: Front panel High Voltage test 2.

For the High Voltage test two panels are used to show all information measured.
In Figure 5 the main panel is shown. On this panel all settings are done for the HV test and the result in Volts is shown.
To init a HV measurement the following settings must be made:

1. Measurement speed
   This setting controls a divider with a range of every pulse up to ‘1 out of 32768 pulses’. Basically it is a 16 bit divider, the setting chooses a bit as output.
   In the High voltage test going faster as 1 out of 4 will cause the frequency measurement to make errors. It needs 3 pulses to work correctly.
2. Number of measurements.
   As it says the number of measurements done in one run.
3. HV Unit Mask.
   Needed for the Over Voltage detection. The logic can handle up to 16 HV Measurement units. Modules not mounted, from the top down, will give 4095 as measured value. This causes the Over Voltage protection to stop the run unnecessary, so they can be masked. As input the number of HV units is used.

In Figure 6 the second High Voltage test plane is given. On this plane only two indicators are placed:

1. The frequency graph.
   In this graph the pulse frequency of the Coco.
2. The pulse charge graph.
   Just after being switched on the pulses from the Coco cannot be at full length, because the transformer will go into saturation. During that time the pulse length and thereby the charge pumped into the transformer is limited. Shown in this graph.

DAC PROMiS.

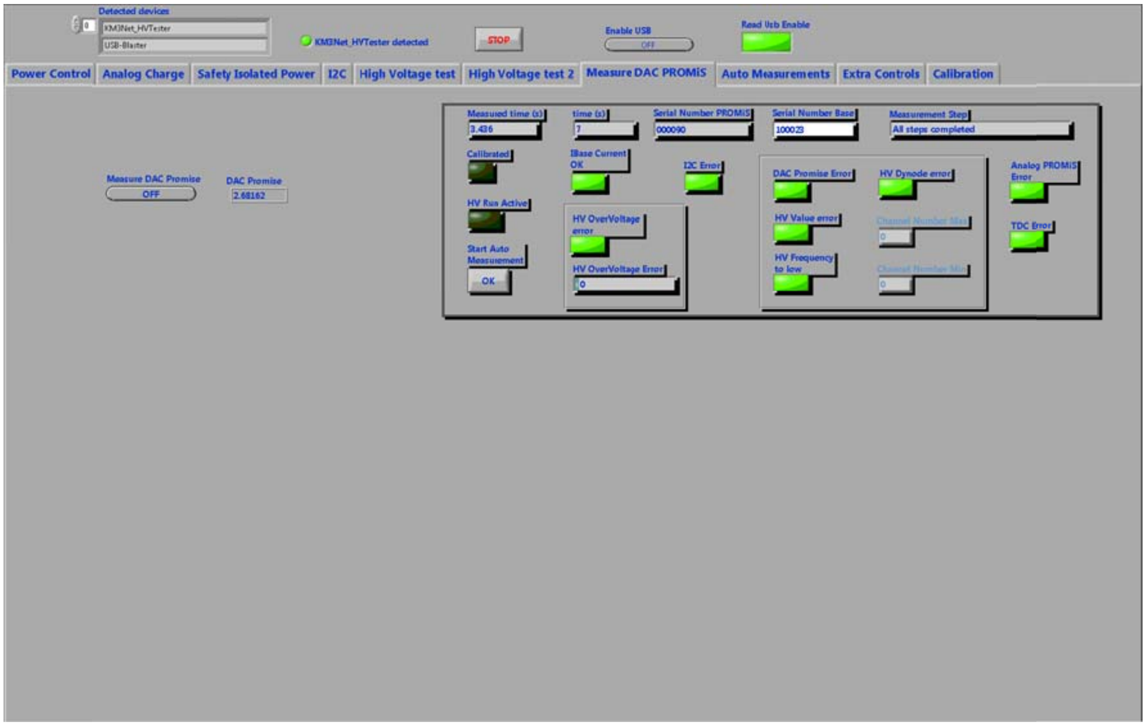

Figure 7: DAC PROMiS measurement.

In Figure 7 the front panel for the DAC PROMiS measurement is given. On this panel only the Measure DAC button and the result is given.

Still this is an important measurement, because the signal from this DAC controls the Coco chip. All control logic is in the PROMiS chip. The Coco chip is switched off by making this output 0 V. If the HV is switched on and nothing happens, this signal should be checked, because it makes clear which chip did not react. Still 0 V means problem in the PROMiS, 1.9 V or higher means problem in the Coco circuit.

Extra Controls

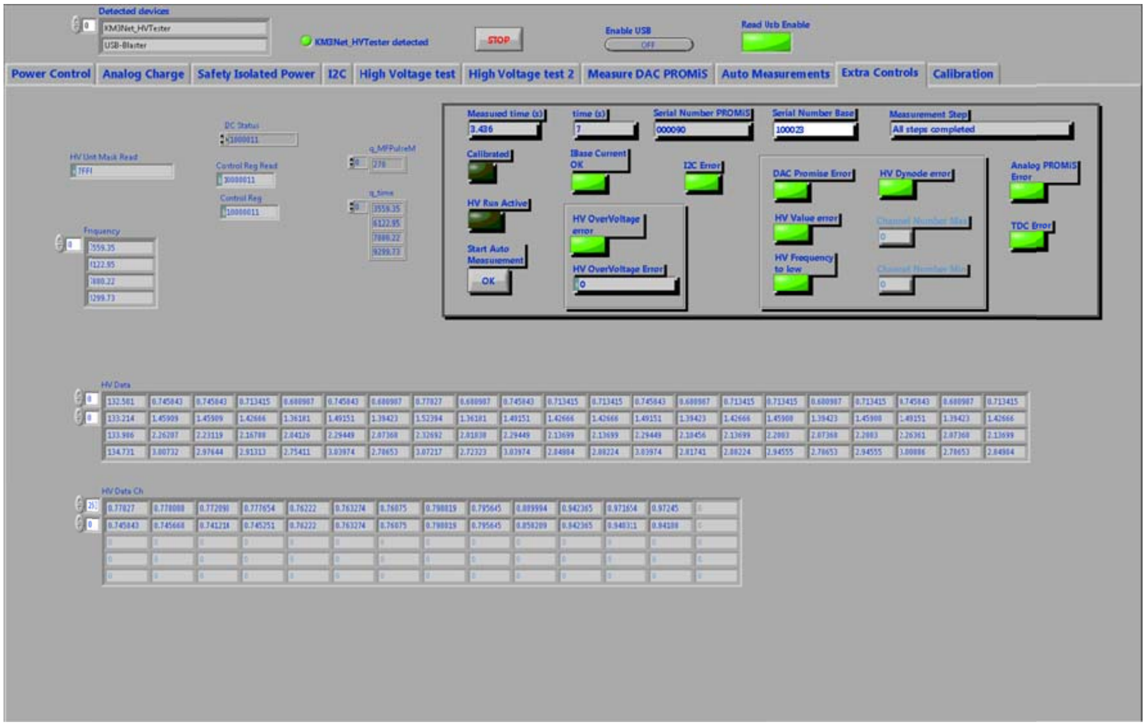

Figure 8: Extra controls front panel.

On this panel some extra indicator are placed to make debugging more easy.

Calibration.

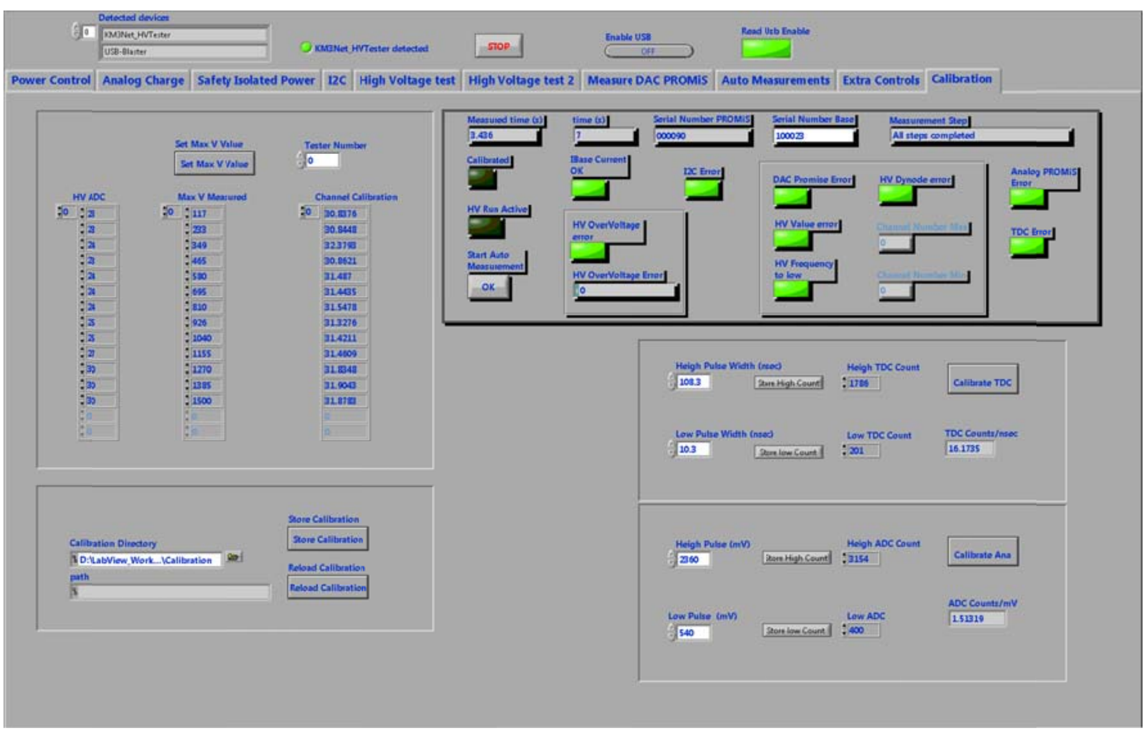

Figure 9: Front panel calibration.

In Figure 9 the front panel for the calibration of the tester is drawn. To calibrate the system 3 calibrations must be made once. After these calibrations the values must be stored in a calibration file and can be reloaded at the start of a session.
The calibrations are:

1. High Voltage calibration.
   To calibrate the high voltage measurement a working base is placed in the system. The high voltage is switched on, at its maximum value. With a high voltage meter the dynodes are measured and typed in the array Max V Measurement. Also a High Voltage measurement is done. After these two measurements the button ‘Set Max V Value’ is pushed. The HV ADC value’s are stored in the array HV ADC, and the Channel Calibration value’s are calculated.
   Only the high level needs to be measured. At the 0 V level is the measurement is not reliable due to offset in the opamp at low value’s.
2. TDC calibration.
   To calibrate the TDC two measurements must be made, one at low level and one at max level. Bothe these measurement must be done with a scoop and the tester. The buttons ‘Store High Count’ and ‘Store Low Count’ Stores the measured value’s in the controls. Pushing Calibrate TDC will calculate the TDC Counts / nsec.
3. Analog Calibration.
   The analog calibration is done at the same time as the TDC. Also with the scoop the pulse height is measured and typed into the controls. Store High and Low are used to store the ADC counts and the Calibrate Ana to calculate the number of ADC counts / mV.

With the button ‘Store Calibration’ the calibration data is stored in a file. The tester number is part of the file name.
After being stored the calibration is done until units are exchanged. At the beginning of a session the calibration can be loaded with the Reload calibration button.

Auto Measurement.

The automatic measurement checks all functions of a base after pushing the ‘Start Auto Measurement’ in 14 steps.
These steps are:

1. Switch On IsoPower.
2. Switch On 3.3 V Local
3. Switch On Base Power.
4. IBase Current Check.
5. Set I2C Control register.
6. Check I2C communication.
7. Read I2C and make file name.
8. Setup HV test.
9. Run HV test Measurement.
10. Run HV test VBase sweep.
11. Discharge test
12. HV Test Maximum frequency.
13. Switch on Analog buffer
14. Measure analog buffer.

Figure 10: Front panel Auto Measurement.

In Figure 10the auto measurement front panel is drawn. On this panel all setting are placed for the measurements. These controls will be explained below.
During the test if a problem is detected a Pop-up window is opened, with information about what’s wrong.
Explanation of the measurement steps:

1. Switch On IsoPower.
   Switches on the Isopower, who is feeding the HV measurements units.
   Integrated in this step is reading the base serial number with the scanner, or typing it ending with the ‘Enter’.
2. Switch On 3.3 V Local
   Switches on the local 3.3 V needed on the main test board.
3. Switch On Base Power.
   Switches on the Base power.
4. IBase Current Check.
   Measure the base current, and checks if it is within the limits set on the panel. In this state the IBase Low and IBase High value’s are used. When the current is to low or to high, the indicator ‘IBase Current OK’ will turn red and the test stops, and one of the following Pop-up windows will occur:

Figure 11:Pop up when IBase is too small.

Figure 12:Pop up when IBase is too high.

The IBase Low and High value's can be adjusted on the bottom left of the 'Auto Measurement Tab'.

5. Set I2C Control register.
   put the I2C master into the right mode.
6. Check I2C communication.
   Block write the setting to the PROMiS to check for receiving acknowledge. When received 'I2C Error' indicator is green. else red and test stops.

Figure 13: Pop-up when no I2C communication is possible.

7. Read I2C and make file name.
   Read all registers from the PROMiS and make the file name for the date base. File name is a combination of the tube manufacturer and the PROMiS serial number. The manufacturing name is one of the settings on the 'Automatic measurement Tab'.
   The beginning of the file is written with:
   a. Tester Number.
   b. Timestamp of the test.
   c. Base manufacturers name.
   d. Serial number PROMiS.
   e. Serial number Base.
   f. The power use of the base at start up.
8. Setup HV test.
   Preparing all settings for the HV test.
   Writing HV Header into the file.
9. Run HV test Measurement.
   The HV test does 17 measurements, with the PROMiS DAC set on h00, h0F, h1F, ….., hEF, hFF.
   The Coco needs time to regulate the HV to the set value. This waiting, or measure time is set by the 'HV Measurement Wait Times'. This array has the settings for the time base of the graph in the 'High Voltage Test Tab''s'.
   a. The first check after switching on is the value on the DAC output from the PROMiS.
      The Coco chip is controlled by this output, DAC output is 0 V, Coco chip is switched off. Switching on the HV will make the output go to 1.79 V. The Coco will generate about 700 V due to this input signal.
      After switching on the HV the first check is the DAC output. If the output is

too low the Led will be red and the Pop-up will be shown.

Figure 14: PROMiS DAC Too low pop-up.

b. The second test is the compare dynodes test. This test calculates the average value of the voltages between the dynodes. The value's should not differ more than 5 % from this average. This percentage can also be adjusted at the left of the 'Auto Measurement Tab'. A to large or to small value will make the Led go red and the following pop-up to appear.

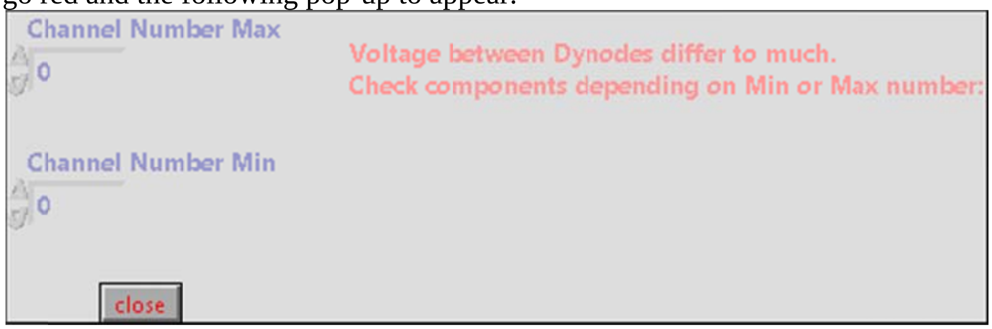

Figure 15: Dynode error Pop-up.

The Channel number Min and Max give information about where to look for the defects. This needs to be filled in.

c. The third test is the HV Value test.
On the 'Auto Measurement Tab' a control HV Value's is placed. The value's in this array are the target values for the HV in every setting. Up to now we saw this error occur when we had transformer problems. The first value was not met. Led becomes red and the following Pop-up is shown.

Figure 16: Pop-up HV Value error.

The error percentage is set again on 5 %, but can be adjusted.

10. Run HV test VBase sweep.
During this test the output voltage stays at the max value. At the beginning of the test the VBase is made 3.6 V.
From here a measurement is made for every VBase voltage down to 3.0 V in steps of 0.1 V. The 'HV Value test' is done to check the Power dependence of the system.
11. Discharge Test.
In this test the Coco is switched off. The dynodes are measured 8 sec. At the end the value's must be within 5 % of the 'Discharge Value's'.
This test makes to high leakage currents visual.
12. HV Test Maximum frequency.
During this test the Coco is switched on, but at the same time the DC discharge system is switched on. The discharge system will now keep the output voltage low, what

causes the Coco to run at his highest frequency trying to get the output higher. This frequency should be at least 45 kHz. Adjusteble with the control on the tab.

13. Switch on Analog buffer
    In this step the analog buffer is switched on. The current into the base is measured and checked against the limits set on the ‘Auto Measurements Tab’ (60 and 90 mA).
14. Measure analog buffer.
    An analog pulse is send to the input and both the analog and TDC output are measured, for 17 value’s of the DAC.
    All these measurements are checked against the Analog PROMiS and TDC value’s.

Verilog program

Main block schema.

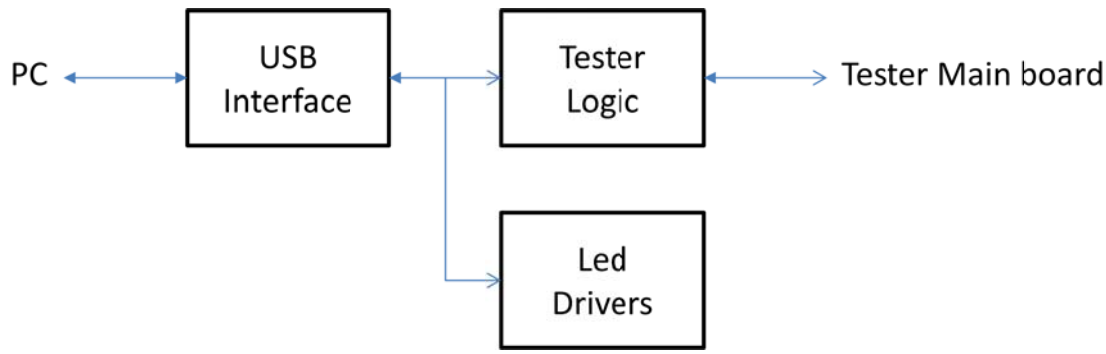

Figure 17: Block diagram if the Verilog logic.

In Figure 17 the block diagram of the logic in the Altera chip on the test interface board is drawn. The logic is divided into 3 main parts:

1. USB Interface.
   Largely common for all test set-ups.
   On the board an FTDI chip is used as USB interface chip. This chip is on one side connected with the PC. On the other side it has an 8 bit bus with two control inputs RD and WR, and two status outputs, RXF and TXE. The interface logic in the Altera communicates with these signals.
2. Led drivers.
   Largely common for all test set-ups.
   The Led drivers have a minimal output pulse of about 250 msec, when a short ‘1’ pulse is offered at the input. Stays the input ‘1’, the output also stays on.
3. Tester Logic.
   Specific for this test set-up and will be described later.

USB interface.

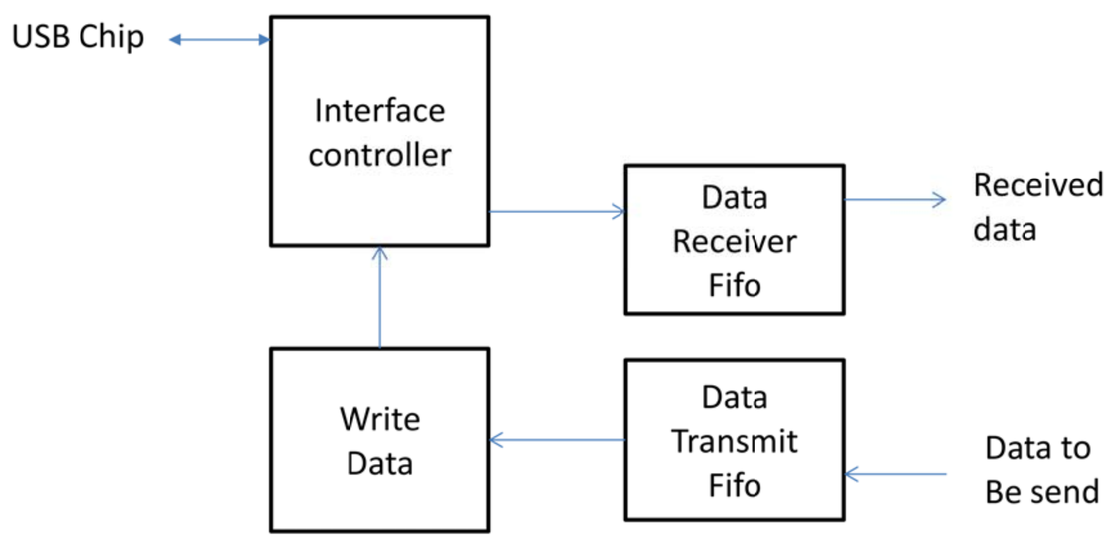

Figure 18:Block schema of the USB interface.

In Figure 18 the block schema of the USB Interface is drawn. The interface has 4 blocks:

1. Interface controller.
   This block has a state machine in it to control the data transport from and to the FTDI chip. On request from the tester data can be send to the PC or if RXF is one data is received.
   The FTDI chip has 4 control connections:
    a. RXF, Received data ready to be read.
    b. TXE, Transmit fifo is full.
    c. RD, Read data from the chip.
    d. WR, Write to the Chip.
2. Write Data.
   This block checks the output fifo for data. If this fifo is not empty the unit will request the interface controller for a new transmission.
3. Data Receive Fifo.
   Data received from the PC is stored in this fifo. The size of the fifo is 32 places Handshake with the interface is the Write Req and the almost full flag.
4. Data Transmit Fifo.
   In this fifo data is stored that must be send to the PC. Size is also 32 places. Handshake with the Write data block is the Empty flag and the Read Enable.

These 4 blocks take care of the merging the in- and out-going data on one i/o bus to the FTDI chip. The Fifo's are used to reduce the influence of speed differences.

Tester specific blocks.

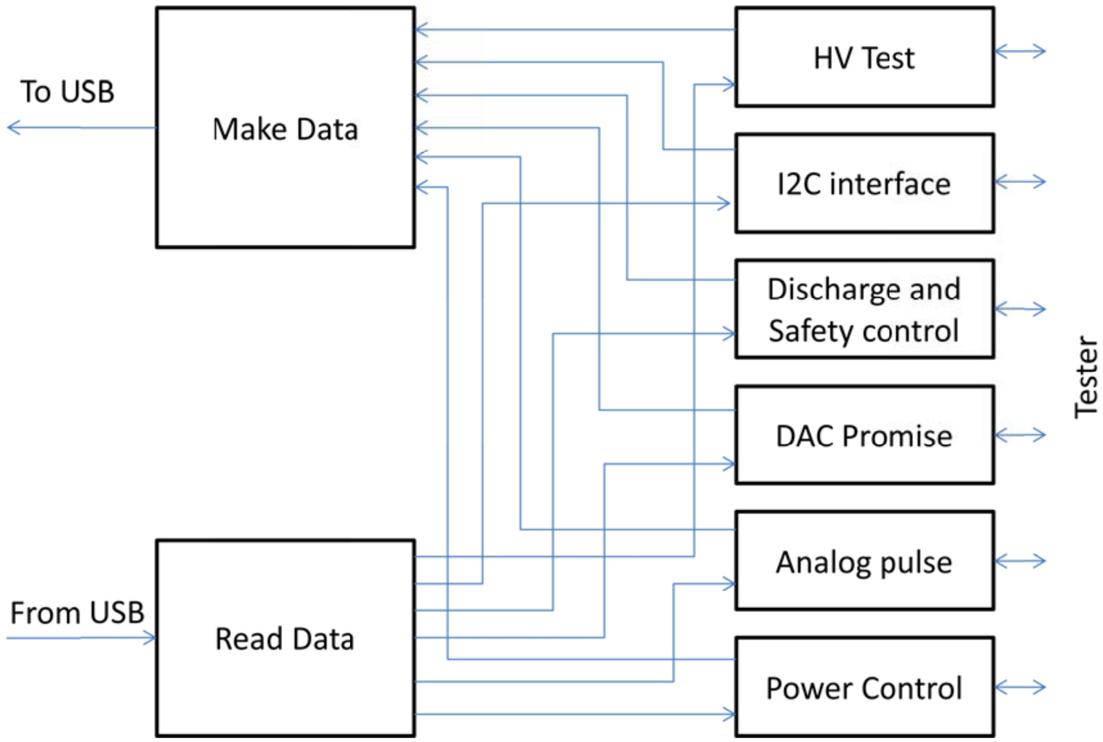

Figure 19: Tester block schema.

In Figure 19 the block schema of the tester is drawn. The logic is divided into 8 block:

1. Read Data
   The Read Data module checks the receive data fifo from the USB interface for new data. He checks the data for legal commands and sends them with the data to the right module. The data send to the tester has a specific format:
   a. Start byte of a message: 8’h66.
   b. Command Byte: 8 bits.
   c. Data Byte(‘s) as the command needs.
   d. Stop Byte of the message: 8’h99.

2. Make Data.
   The make data module prepares the data for sending it to the PC. The module writes the data into the send data fifo.
   The data send by the tester has the same format as the received data.
   This module will, after receiving a transmit request, gather the data to be send in the right format and write it into the send fifo.

3. Power Control.

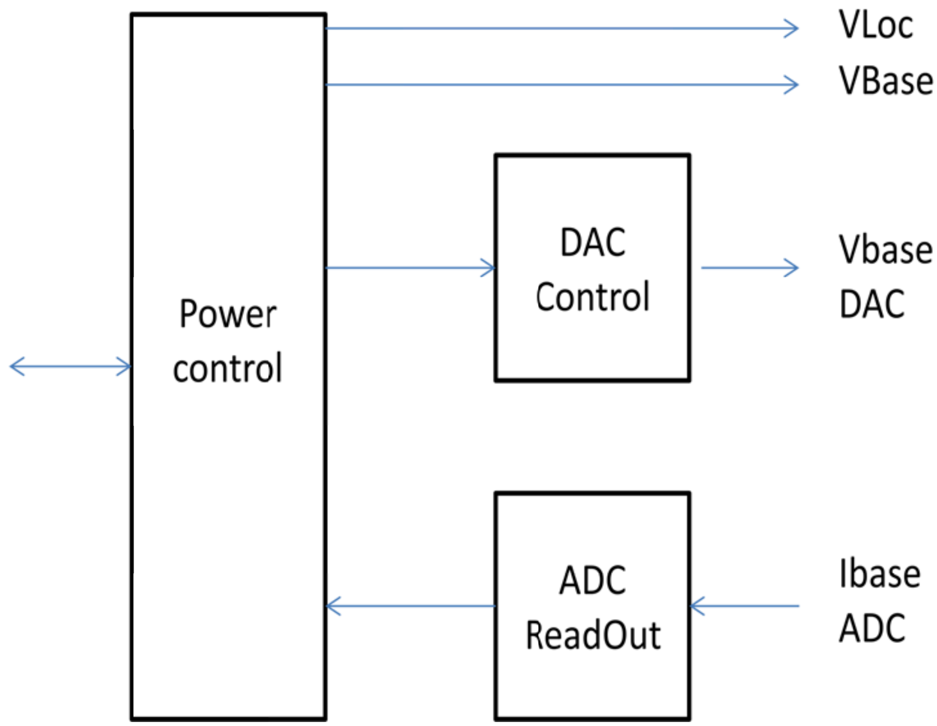

Figure 20: Block schema Power Module.

This module controls two power supplies:
a. VLoc, 3.3 V used on the tester main board for the support electronics.
b. VBase, 3.3 V used by the base. Is switched on at the beginning of a test run and switched off at the end. Can also be changed from 3.0 to 3.6 V

This module has 2 extra functions, it controls a DAC to set the VBase value and it can measure the VBase current.

4. Analog Pulse.

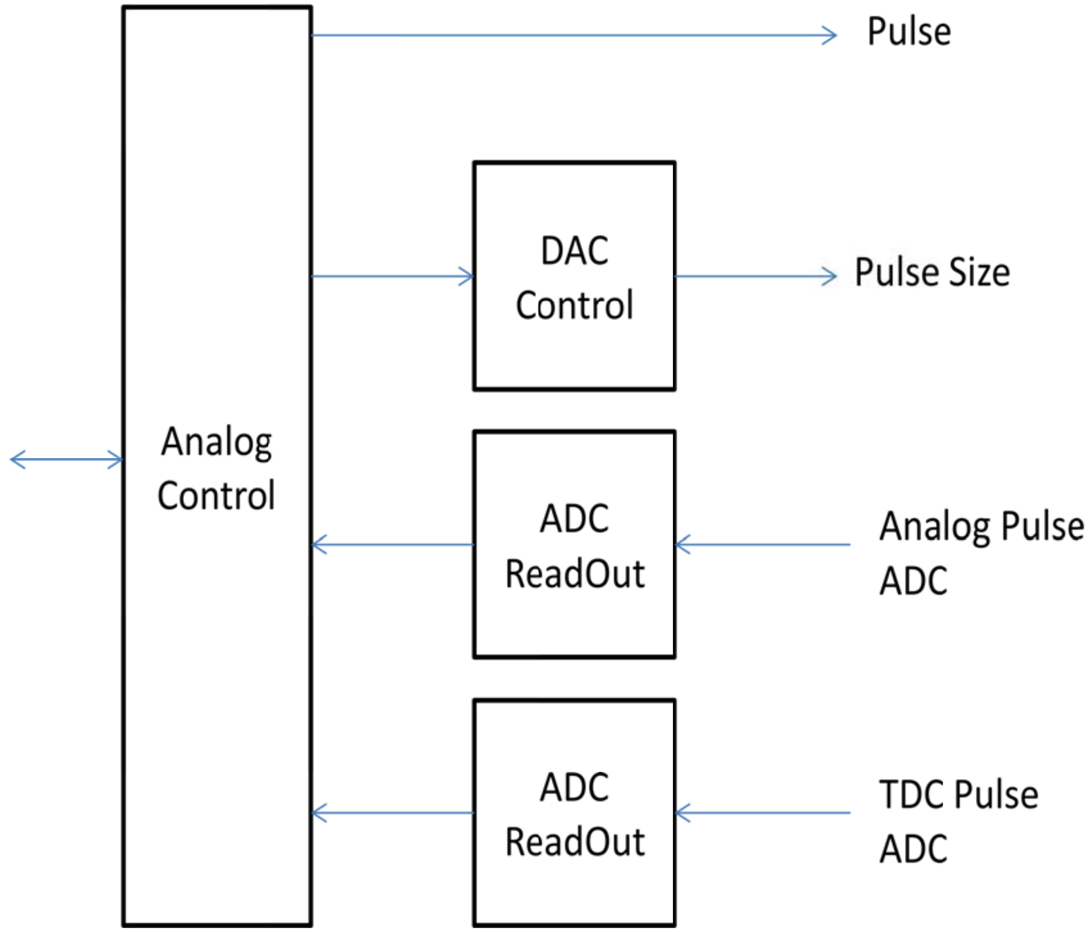

Figure 21: Block schema Analog pulse.

In Figure 21 the block schema is drawn the analog test.
In the PROMiS an analog buffer is integrated. This buffer has an analog output and a time over Threshold output. To test this an analog pulse, like from a PM tube, is injected into the input. The size of this pulse is controlled by DAC, and the result is measured with 2 ADC.

5. DAC PROMiS.

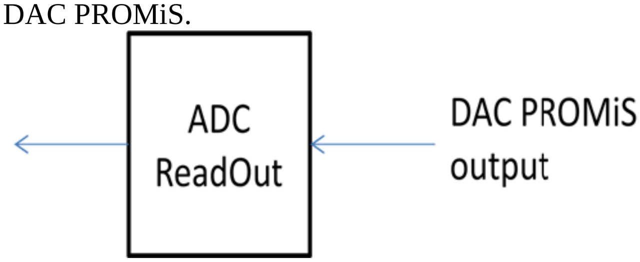

Figure 22: Block schema of the DAC PROMiS measurement.

The test of the DAC PROMiS output is only a ADC to measure its output value.

6. Discharge and Safety control.

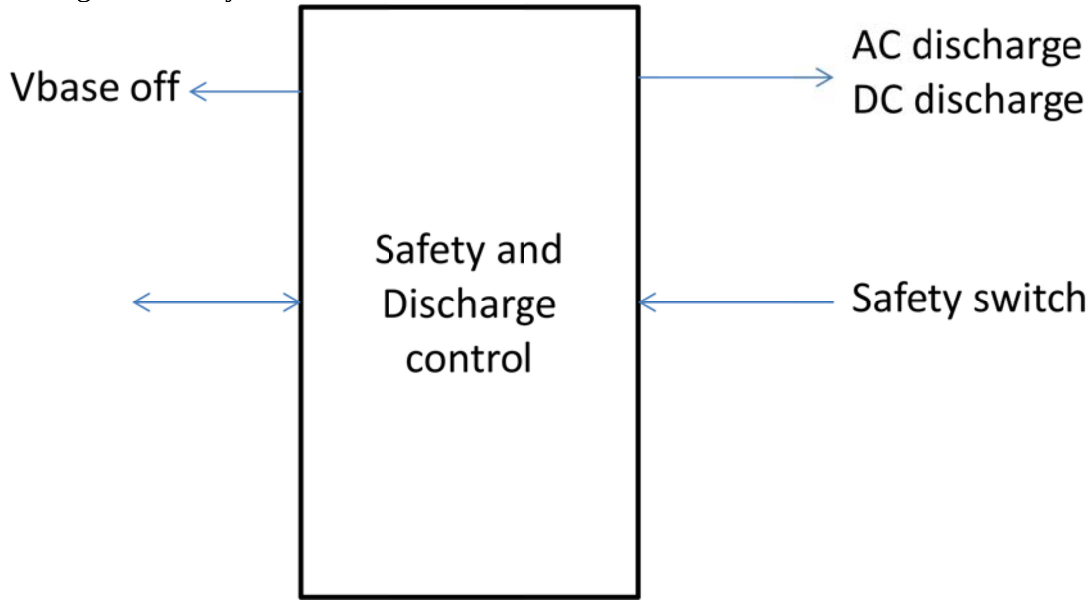

Figure 23: Block schema Safety and discharge system.

The Safety and discharge logic, see Figure 23, is an important part of the logic. During the test the total voltage on the tester can run up to 1500 V. To work safely a cover will be made over the DUT. When this cover is opened, a signal is send to the logic to switch off the Power to the base and the HV will be discharged.

7. I2C Interface.

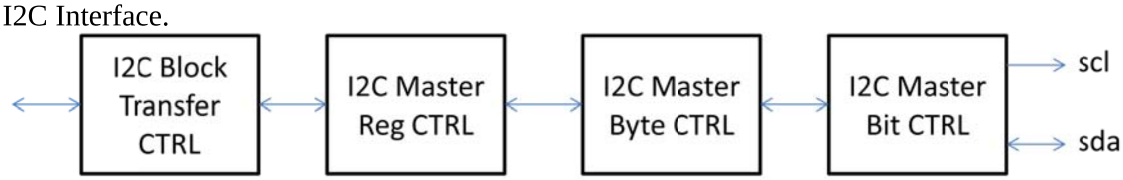

Figure 24: Block schema I2C interface.

The I2C interface is based on the open cores I2C master interface. The right two blocks are unchanged copies, while the I2C Master Reg CTRL is changed. Original the I2C interface has a wishbone interface. In this design this is changed to several register, who are written or read by the USB interface.
The I2C Block Transfer CTRL is an extra block that generates all necessary signals to write or read all registers in the PROMiS chip.

8. HV Test.

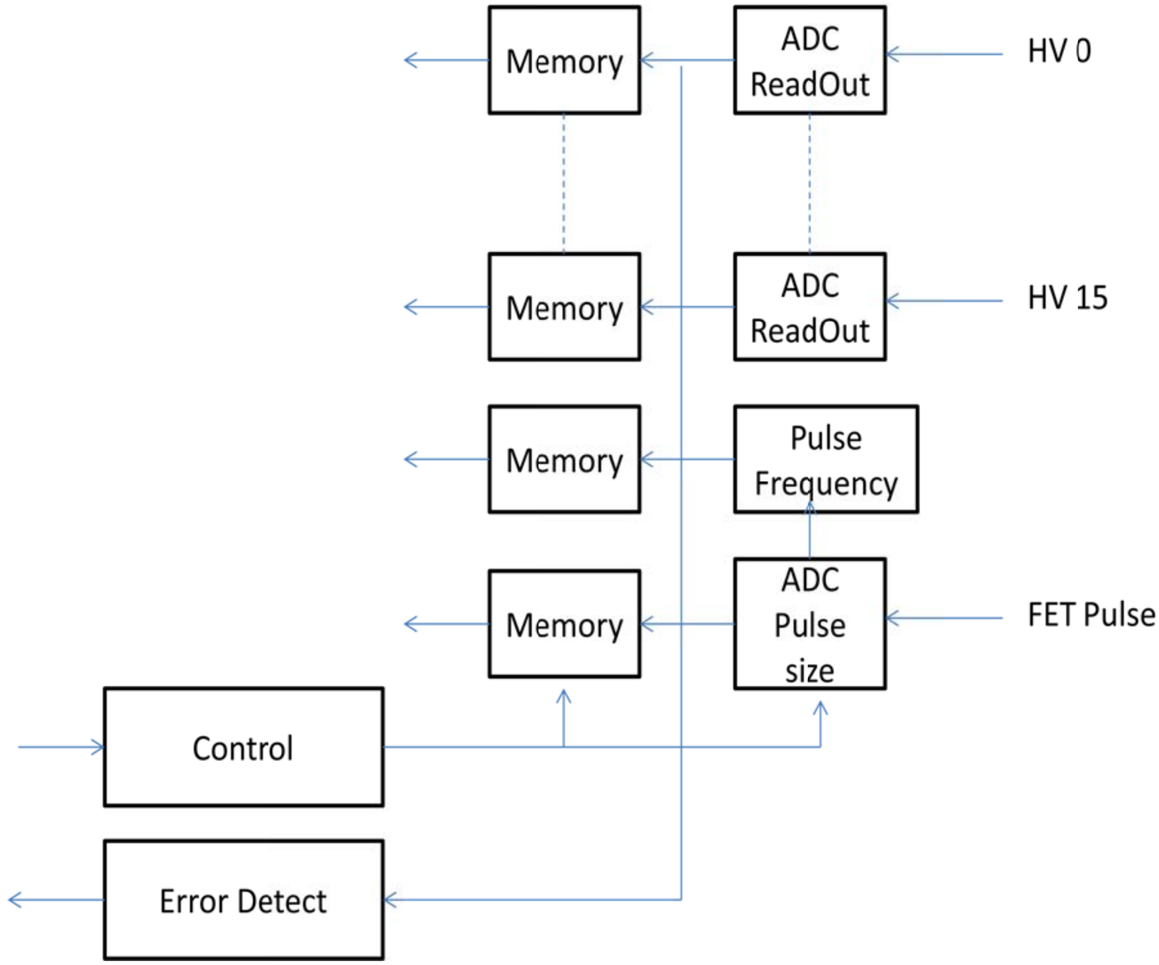

Figure 25: Block schema of the HV tester logic.

In the HV test logic all voltages on the dynodes are measured separately, by measuring the voltage between the consecutive dynodes. To do so up to 16 ADC channels can be read.
During a measurement run up to 255 measurement are stored in the memory. The measurement speed is 250 Hz. The slowest one is about 1 second. The number of measurements and the speed are set into registers in the control block.
The Error detect block detects the overvoltage error. Normally the maximum voltage between 2 dynodes is 115 V. The schema is designed for maximal 150 V. When the system detects 140 V the error is detected, and the base is switched off and discharged. The dynodes who are overvoltage are send to the PC.