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Technical characteristics of the prototype of the TILECAL photomultipliers test-bench

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Abstract: This note summarizes the technical specifications of the prototype of the photomultipliers dedicated test-bench which had been mounted in Clermont. In the introduction, we reminds briefly what are the main constraints on the design of the PMT test-bench. Then we give a general description of the set-up. Third part describe the PMT box. Fourth section concerns the light sources. Then the special Voltage dividers used in the measurements are presented. Section 6 reviews all the electronics componants of the test-bench. Section 7 explains the intercalibration of the light channels. Section 8 give some examples of automatic measurements and show their results. After conclusions, the main technical informations are given in section 10. Finally test bench photographs and detailed diagrams are given in section 11 and 12

1 INTRODUCTION.

As in the final configuration, the TILECAL will use about 10000 photomultipliers, it is clear that each of these phototubes has to be tested first to know its own characteristics, and eventually to eliminate those that do not fulfill the required specifications. It is foreseen that this task will be done by 5~7 dedicated test benches in different institutes. This document describes a first prototype of such a dedicated test bench. Following experience we get from previous laboratory tests of the R5900 phototubes, especially for Module 0, it appears clearly that the design of the PMT test bench should fulfill some constraints:

- The different test benches should be completely identical. This imply that each of this component should be also identical. This is obvious for commercial products (filter, LED, optics). For home made components (mechanics, electronic circuits), they should be done only in one place, and multiply by the correct number to equip all the test benches (including spares). The same argument is also valid for the measurement method and procedures
- The whole test procedure should be automatic.The interest of the automation of the procedure is that it makes possible to check about 20 photomultipliers per week and per test bench, and to achieve the photomultipliers characterizations in a rather limited schedule.
- The test bench should be as cheaper as possible. This imply to use standard and robust components

The tests are classified into DC light tests and pulsed light tests with an addition or not of DC light (to reproduce the effect of pile up). With the DC light source, we simply study the photomultiplier in measuring its dark current, its gain, etc. This first step doesn't correspond to the real conditions in the ATLAS calorimeter, but must help to rapidly classify the photomultipliers when considering their intrinsic characteristics. The worst will be eliminated or they will be placed in some not crucial places in the calorimeter. In the second step, we test pairs formed by a photomultiplier and its divider, as they will be assembled in the final experiment in the LHC. With the pulsed light, we also test the photomultiplier operating in conditions close to the real conditions of the experiment.

At this moment, we have verified that the different steps work correctly and are automatically executable. We describe the measurements than we plan to perform, the used configuration and methods.

2 GENERAL DESCRIPTION

2-a PLANNED MEASUREMENTS

We define two kinds of measurements and we refer to them by **STEP1** and **STEP2**. In **STEP1,** the phototubes will be operated with **DC light** and we do the following measurements :

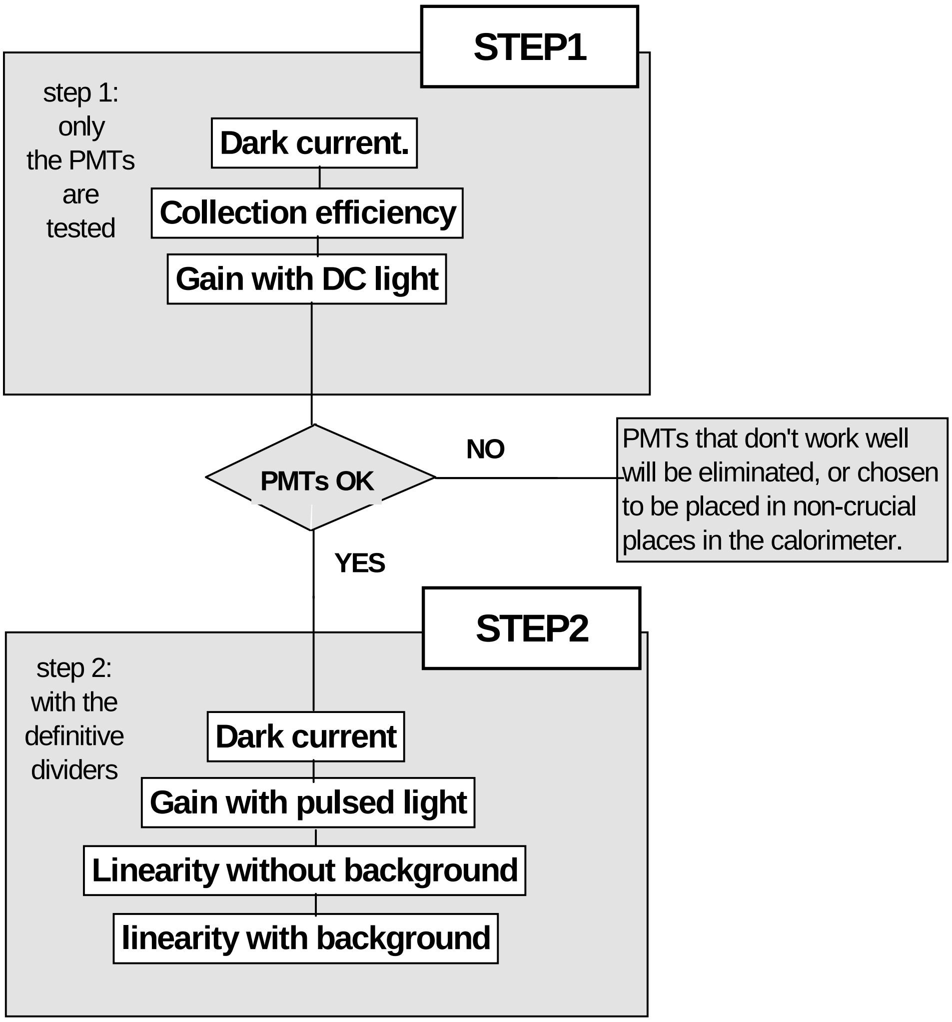
1) **collection efficiency**; i.e. measuring the photocathode current for a given light and varying the voltage between the photocathode and the first dynode .The corresponding curve allows to detect abnormal behavior in the first stage of the photomultiplier.

2) anode current in the same condition of light. Ratio of this measure with the previously measured photocathode current will give the **gain of the multiplier.**
3) **dark current** as a function of voltage after a burn-in period

For this step we use special divider .With these dividers we can switch from a photocathode mode to an anode mode.

In **STEP2** , we pair a photomultiplier already tested in STEP1 and a standard divider, and we work with **pulsed light**. We can also superimpose DC light and perform the following measurements :

1) **gain**, deduced from the mean and sigma of a spectrum of a few thousands events.
2) **linearity**, operating the phototubes with increasing and calibrated light values
3) **linearity with a DC light** superimposed
4) **dark current**



2-b A WEEK OF WORK

All these measurements can last a week of work .In this case and with six test benches, we are able to test ten thousands PMTs in about **two years**. We give below an example of what could be the schedule for a week

<table>
<tr><th></th><th>monday</th><th>tuesday</th><th>wednesday</th><th>thursday</th><th>friday</th></tr>
<tr><td>8h00-9h00</td><td rowspan="3">installation,
bench
autotest
for STEP1</td><td rowspan="4">collection
efficiency</td><td rowspan="3">dark
current</td><td rowspan="16">linearity
with
background</td><td rowspan="7">long
term</td></tr>
<tr><td>9h00-10h00</td></tr>
<tr><td>10h00-11h00</td></tr>
<tr><td>11h00-12h00</td><td>intercalibration
pedestals</td><td rowspan="4">gain
measurement</td></tr>
<tr><td>12h00-13h00</td><td rowspan="4">burning</td><td rowspan="5">gain
measurement</td></tr>
<tr><td>13h00-14h00</td></tr>
<tr><td>14h00-15h00</td></tr>
<tr><td>15h00-16h00</td><td rowspan="10">linearity
without
background</td><td rowspan="10">gain
dark current
linearity
...
...</td></tr>
<tr><td>16h00-17h00</td><td rowspan="3">dark
current</td></tr>
<tr><td>17h00-18h00</td><td rowspan="2">PM selection
next grid of PMs
for STEP2</td></tr>
<tr><td>18h00-19h00</td></tr>
<tr><td>19h00-20h00</td><td rowspan="6"></td><td rowspan="6">burning</td></tr>
<tr><td>20h00-21h00</td></tr>
<tr><td>21h00-22h00</td></tr>
<tr><td>22h00-23h00</td></tr>
<tr><td>23h00-24h00</td></tr>
<tr><td>night</td><td>long
term</td></tr>
</table>

STEP1 : Measurements with special dividers , for DC mode only
STEP2 : Measurements with final dividers , for pulse mode
and DC mode superimposed **.**

2-c GENERAL DESCRIPTION OF THE SETUP

The setup is mainly made of **three parts** :

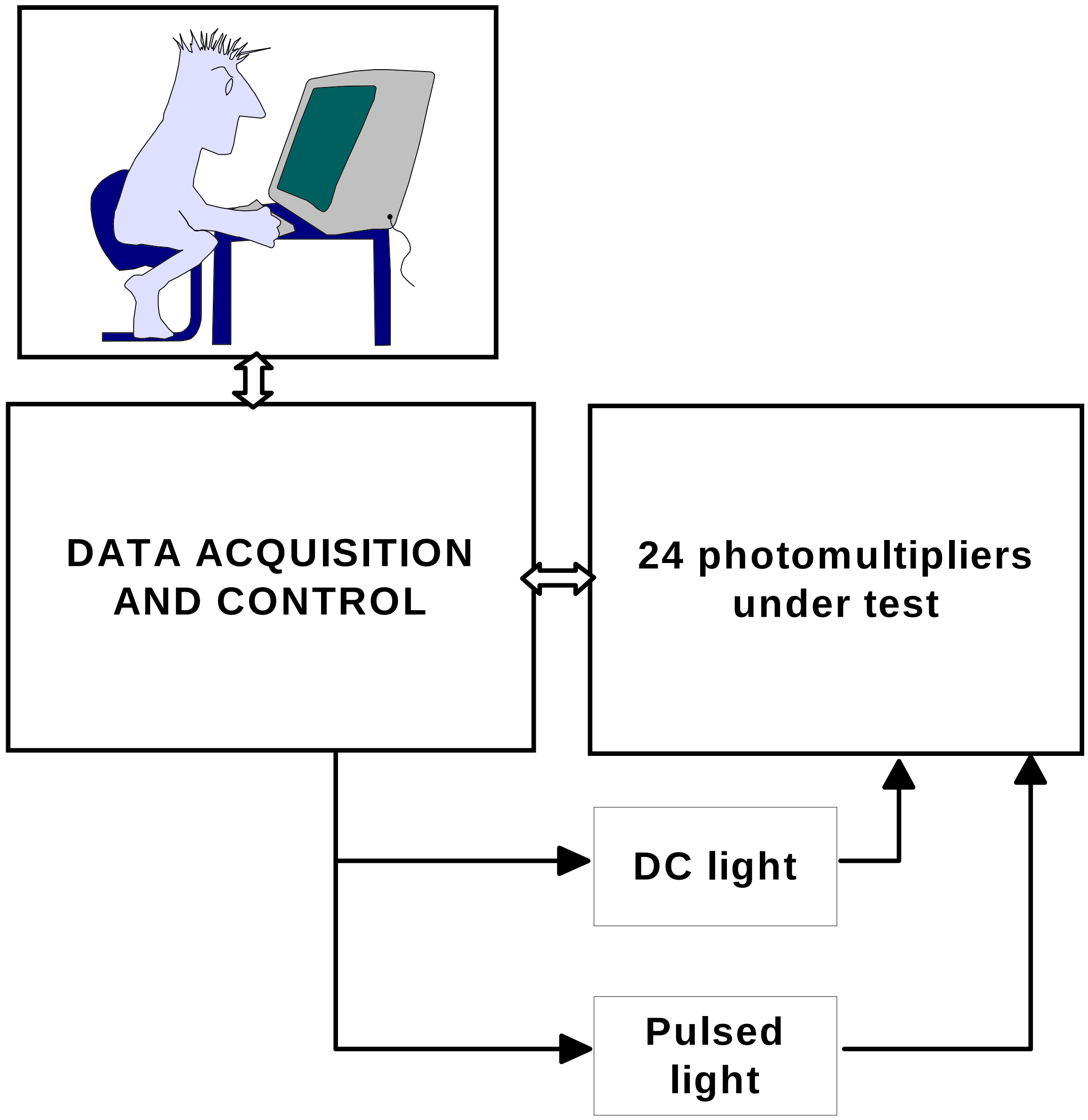
- the PMT box ,with inside the 24 positions for PMTs under test
- the light generation
- the data acquisition

Software equipment :

- 200MHz Pentium PC with 16Mb RAM
- VME/MXI interface (National Instruments).
- LabView 4.0.1.

Electronic equipment :

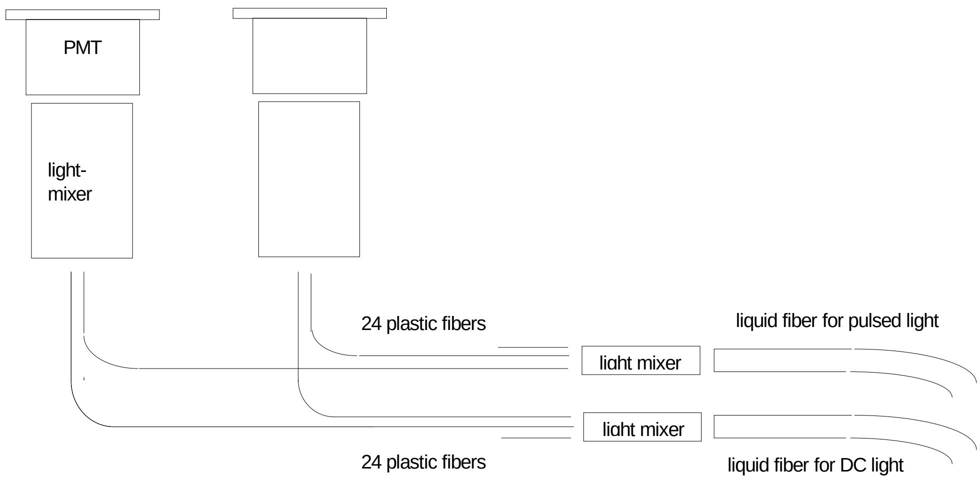
- VME crate.
- NIM crate.



3 THE PMT BOX

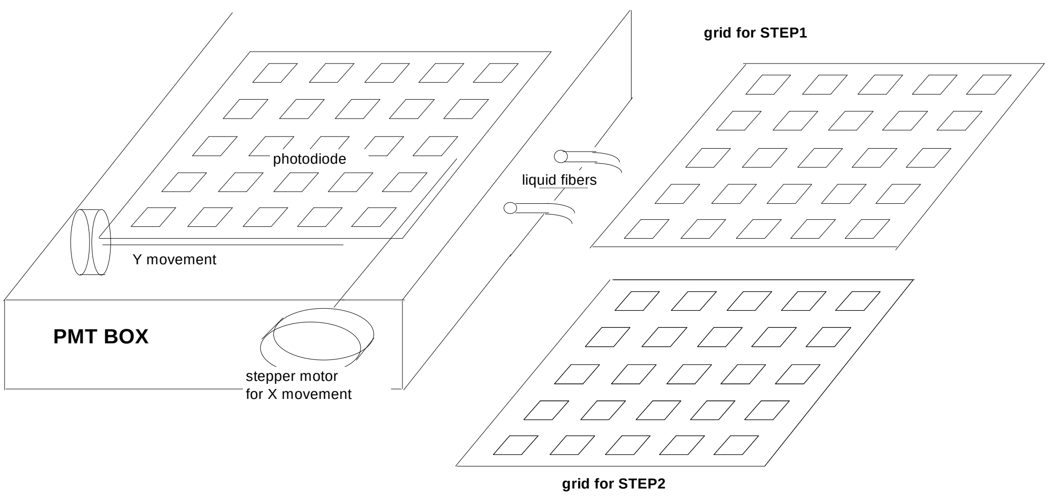
3-a PRINCIPLE

The PMT box is a light-tight and thermo-regulated box that could contain up to 24 phototubes to test. These PMTs are placed on a 5x5 matrix in front of corresponding light-mixers .On each light-mixer we bring pulsed light and DC light with two 1mm diameter plastic fibers .All these fibers are grouped in two bundles leading to optical connectors .The light comes from the two light generators via liquid fibers.



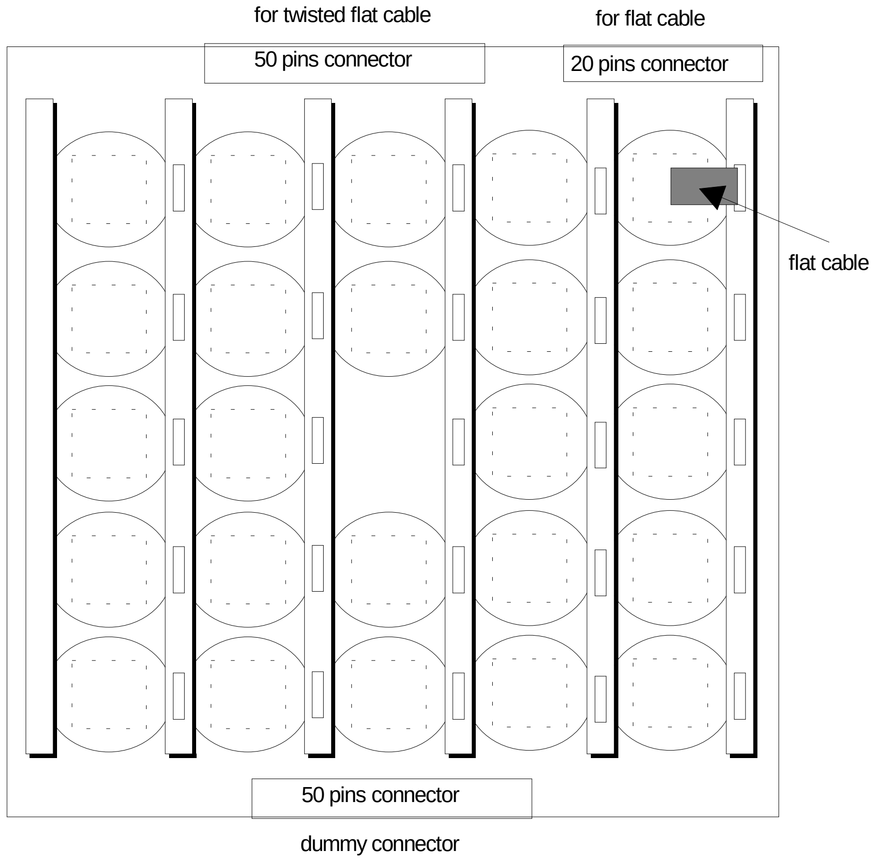
Furthermore, with a system of stepper motors we can move a photodiode placed in the center of the matrix above each light mixer .In this way we are able to intercalibrate the channels and to apply corrective coefficients to compensate the discrepancies coming from the curvature ,length and polishing of the plastic fibers.

As we have two kinds of measurements - STEP1 and STEP2 - it is convenient to have also two corresponding dedicated grids to prepare quietly the positioning and connecting of the photomultipliers outside of the PMT BOX before each of the both steps



3-b GRID FOR STEP1

As explained before ,in STEP1 we use special dividers to work in photocathode mode and in anode mode .These dividers will be described further in details (section 5).The switching between the two modes is made with the use of relays . We need to supply the dividers with a voltage varying from 0 Volt to +100 Volt and +5 Volts to control the relays .And for each photomultiplier we have to measure DC currents. A twisted flat cable with a 50 pins connector is used to extract the phototubes currents. A flat cable with 20 pins connector is used for the special dividers command. We also put a dummy connector to maintain in proper place the unused connections.

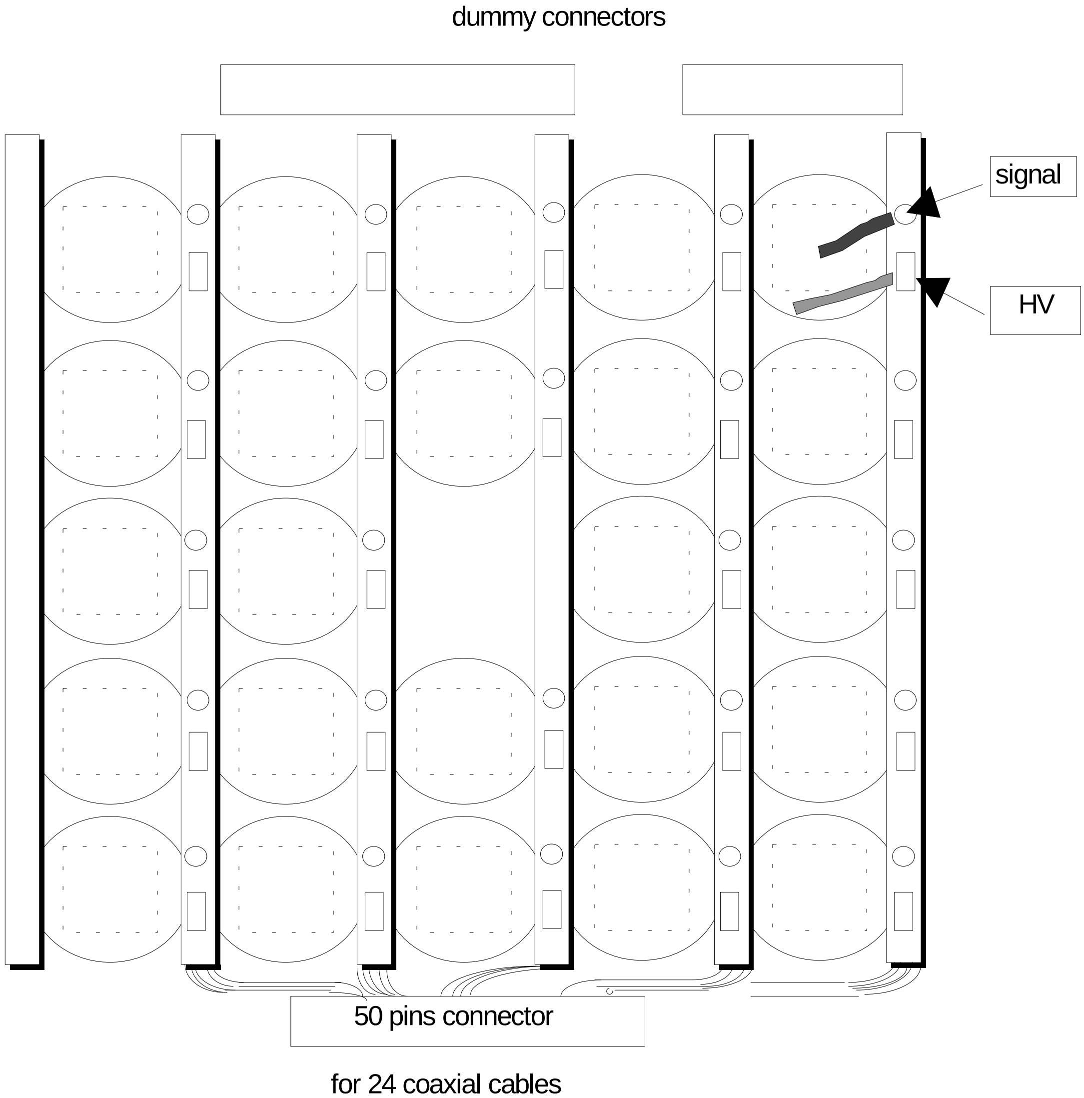


3-c GRID FOR STEP2

As mentioned before ,the grid #2 is intended mainly for pulse measurements and using standard dividers .We have only to provide the HV.

The 24 signals go out of the PMT BOX via coaxial cables (KX 21 A) using a transformed 50 pins connector for flat cable. In this way we have only one manipulation to install this grid #2 at the expense of small reflections.
The cables are then connected on Lemo connectors outside of the PMT BOX.

As for grid #1, we put a dummy connector to maintain in proper place the unused connections.



3-d PHOTODIODES INSIDE THE PMT BOX

Beside the photodiode in the center of the matrix, two photodiodes are monitoring the light coming from the light generators .For this purpose we have set apart a few fibers from each bundle.

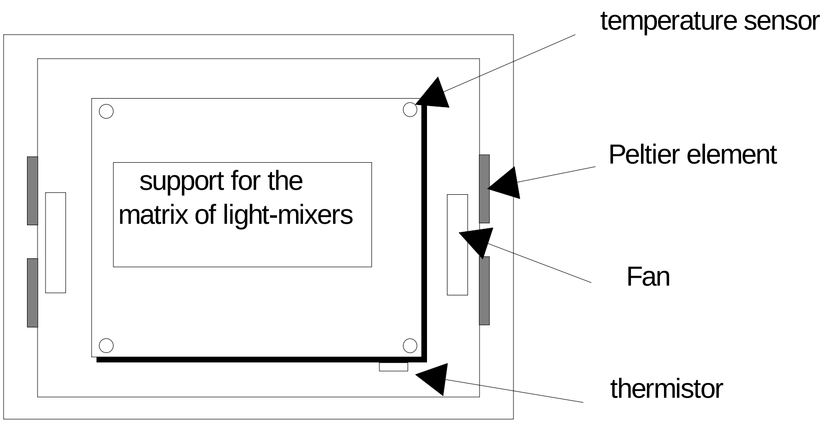
For each bundle, the square shape is the most adapted to the light-mixer in order to receive as much light as possible .We adopt a bundle of 6x6 fibers. Hence, 12 fibers are left for the photodiodes

- 2 for the central photodiode,
- 10 for the monitoring photodiode to increase the sensitivity in particular for the pulsed light

The dimensions of the corresponding light-mixer are 6.5x6.5x30 (in millimeters).

3-e TEMPERATURE REGULATION

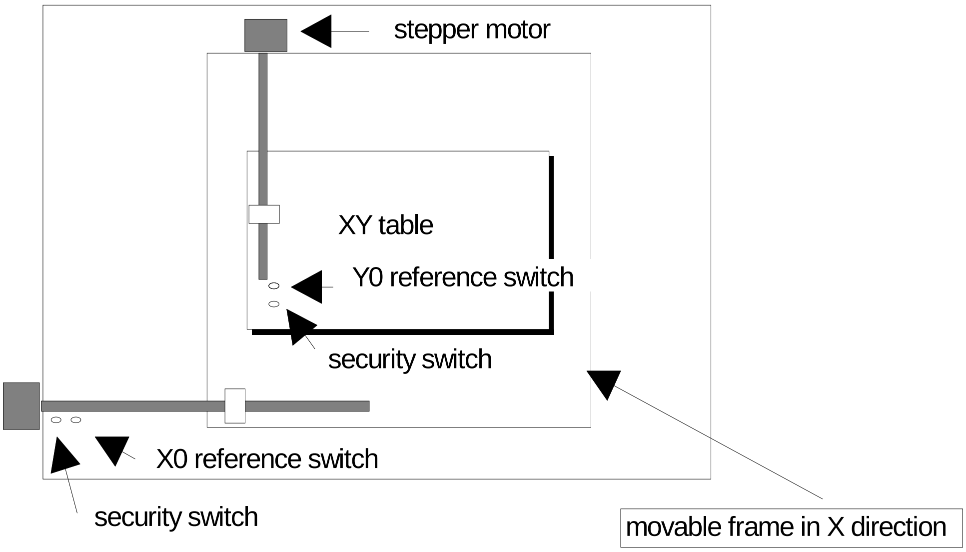
We use four Peltier elements to lower the temperature of the box around 20 degrees Celsius .A thermistor in a Wheastone bridge provides the temperature information to regulate the box .Furthermore a few temperature sensors will be placed at different places at the level of the PMTs to verify its homogeneity .Two fans can improve this homogeneity particularly after the opening of the box.



3-f XY TABLE

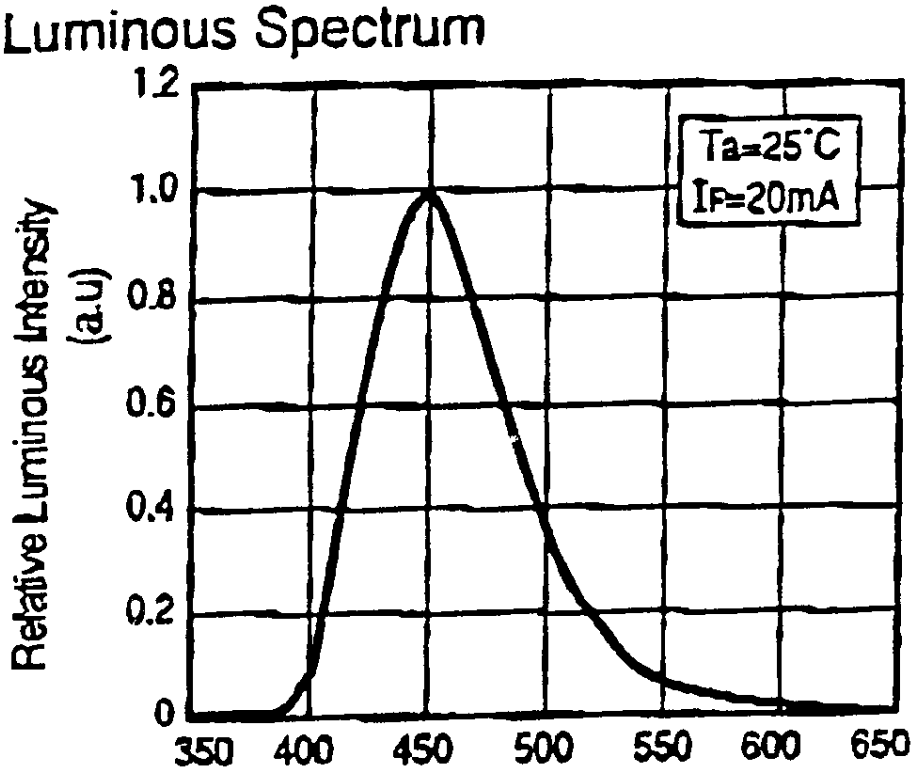
The movements of the XY table are controlled by two stepper motors .One is bound to the table and therefore is located inside the box .It is powered only when we use it (e.g. for intercalibrating the channels).

Two switches can provide status bits for reference points X0 and Y0.



4 LIGHT SOURCES

Two blue LED from Ledtronics are used for the generation of the pulsed light and the DC light .As we can see on the luminous spectrum, it yields a **mean value** near 480 nanometers.

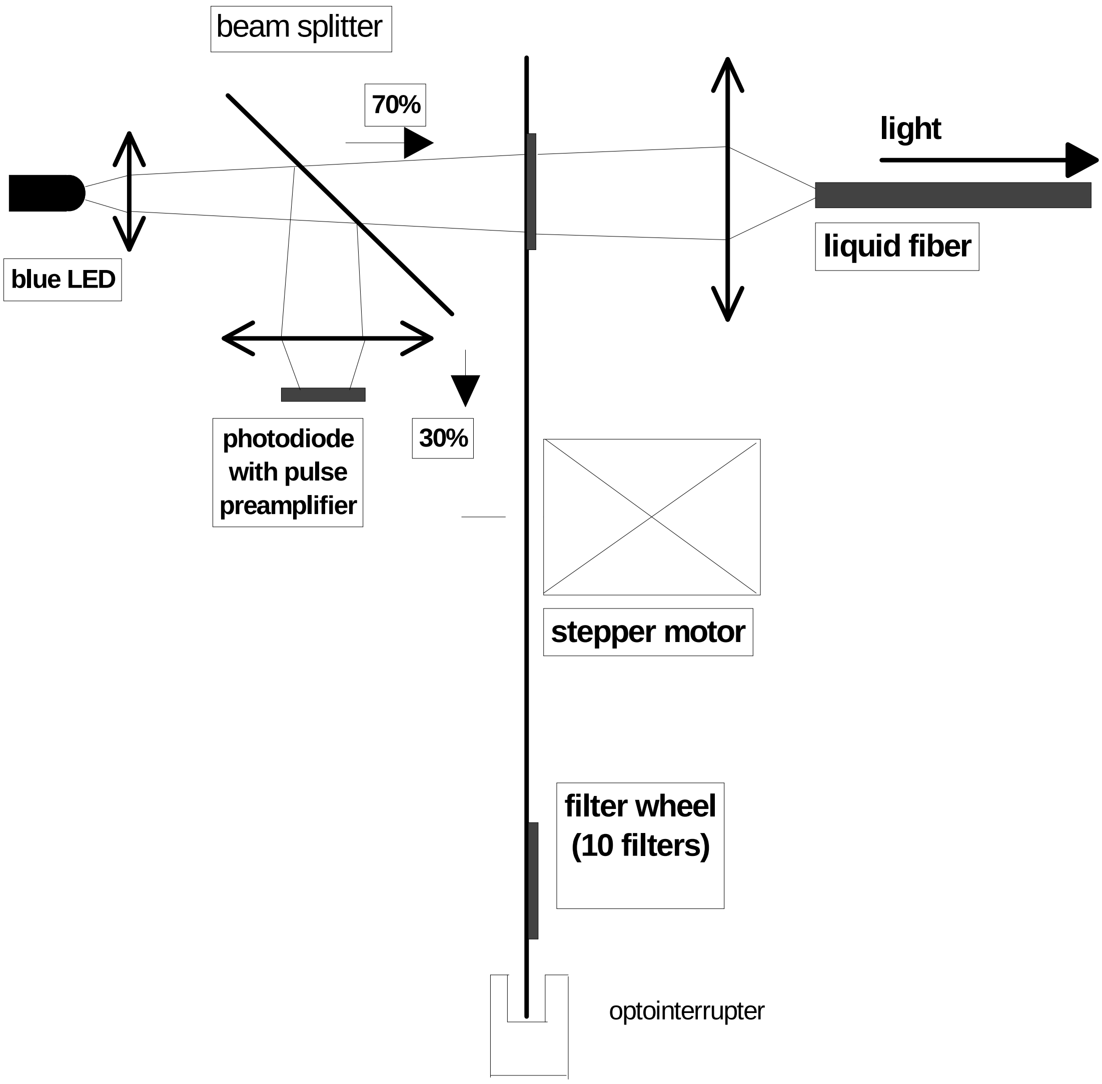


4-a PULSED LIGHT

To mimic the pulses in the calorimeter we want to obtain pulses of 15 to 20 ns with a number of photoelectrons up to more than 50000.The LED is driven by a pulse ,the amplitude of which is programmable up to 60 Volts.

The beam coming from the LED passes through a first lens and is shared in two parts by a beam splitter. A small amount of the light is monitored by a photodiode. The main part is focused on a liquid fiber by another lens. The liquid fiber has a few advantages :

- the LED is not a point-like source ,hence the image on the fiber has an extension and it is easier to focus on its 5 mm diameter.
- the numerical aperture is bigger than for a classical fiber :it corresponds to an angle of nearly 60 ° instead of 35 ° .
- the transmittance for visible light is around 98 %



10 neutral filters mounted on a motorized wheel yield given different attenuations. As the light does not strike the filters perpendicularly, each attenuation factor must be calibrated. For this purpose we can switch from the pulse mode to a DC mode on the LED and make a precise calibration with the DC photodiode in the center of the matrix inside the PMT box. In the same way we are able to intercalibrate the 24 pulsed light channels.

When speaking of 10 filters we include the position without filter and the one with a « black filter » that we use to measure pedestals. In this way we can suppress the light without turning off the LED to avoid problems of warming up.

An optointerrupter can detect an hole on wheel diameter, giving so a reference point for the stepper motor.

4-b DC LIGHT

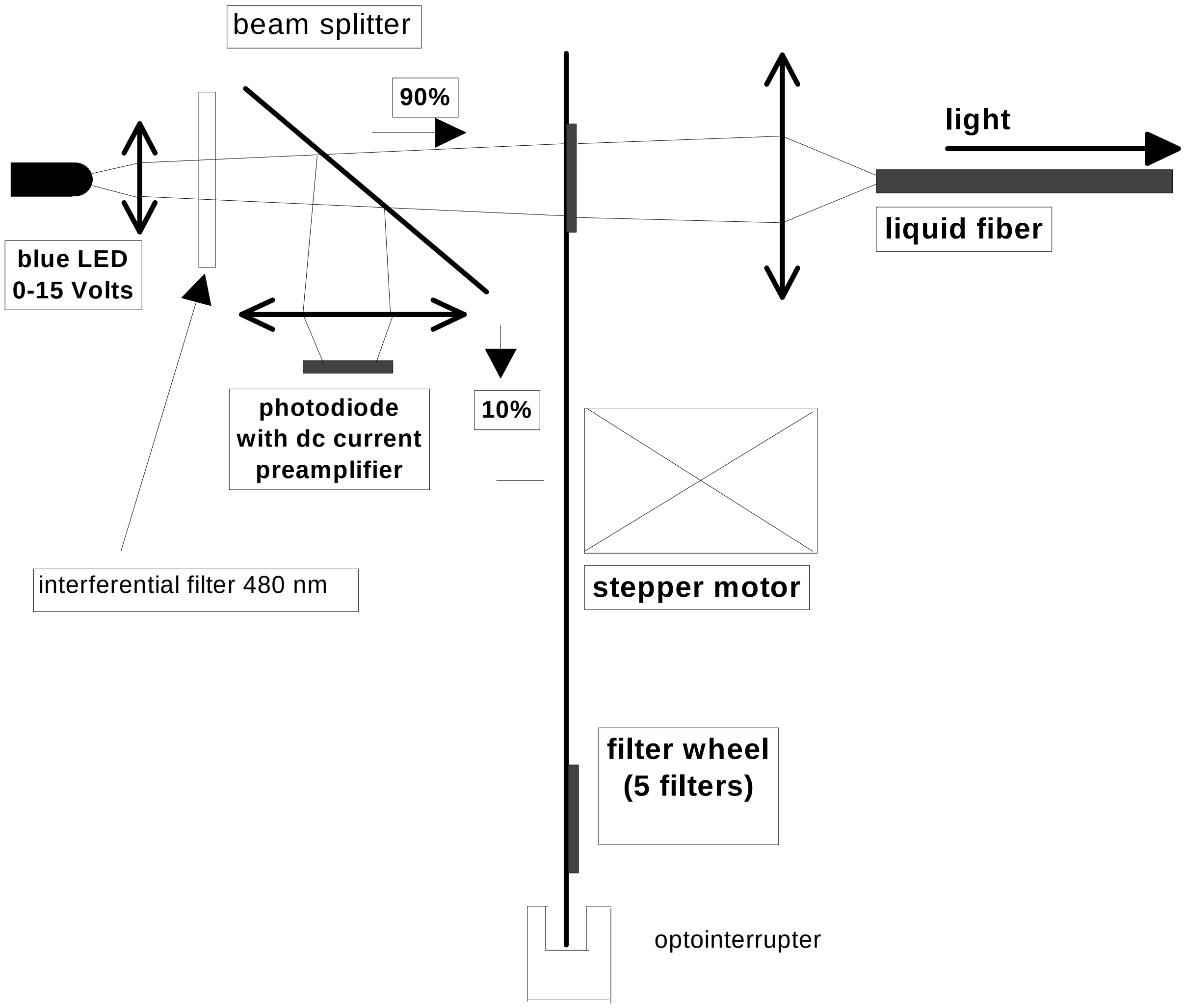
The DC light system exhibits almost the same configuration. There are two differences :

- we interpose an interferential filter to select very precisely the wavelength.
- the number of filters is only five

the five filters are:

- no filter,
- « black filter »,
- three filters to superimpose DC light in STEP2,

one filter has an attenuation of about 1000 for the gain measurement in STEP1



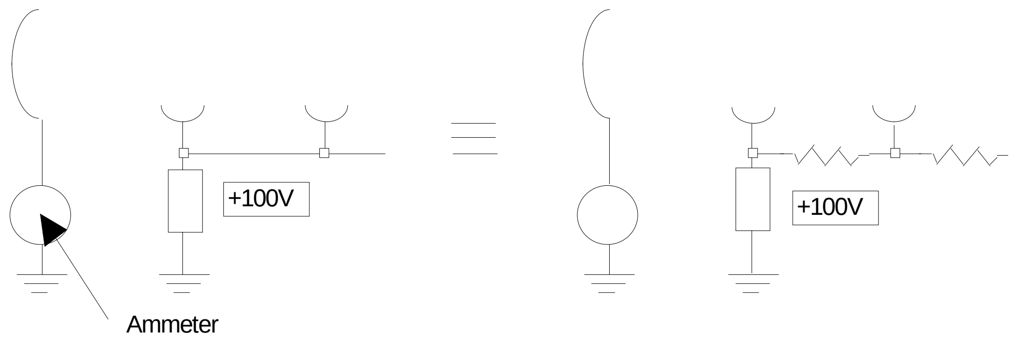
5 SPECIAL DIVIDERS FOR STEP1

In STEP1 we want to be able to switch between two configurations :

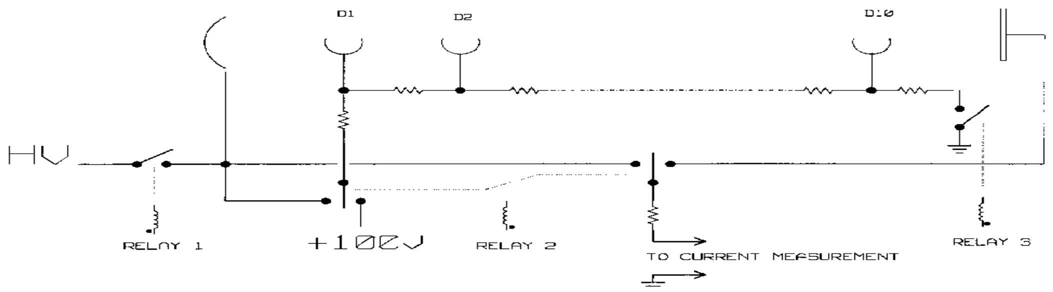
- photocathode mode
- anode mode

This can be done using relays. Using semi-conductors component would be not satisfactory, since we need a very high electrical insulation and we have to manage with potentials up to 1000 Volts. Nevertheless the lifetime of this kind of relay is around 10^6 actions and any problem arise from this point.

Usually in the photocathode mode, the dynodes are tied together.Too many relays would be necessary to realize the switching. We have measured that we obtain the same behavior keeping them at the same potential through the resistors of the divider as long as we let open the connection between the last dynode and the ground.



In this case we need now only three relays



- Relay #1 allows to remove the HV and to isolate the dividers from each other.
- Relay #2 switches the +100 Volts on the dynode #1 and in the same time the current measurement in the photocathode.
- When Relay #3 is open, all the dynodes rise at the same potential for the photocathode mode.

It is important to take notice that we cannot switch off all the relays simultaneously.It is mandatory to introduce a delay between each action.

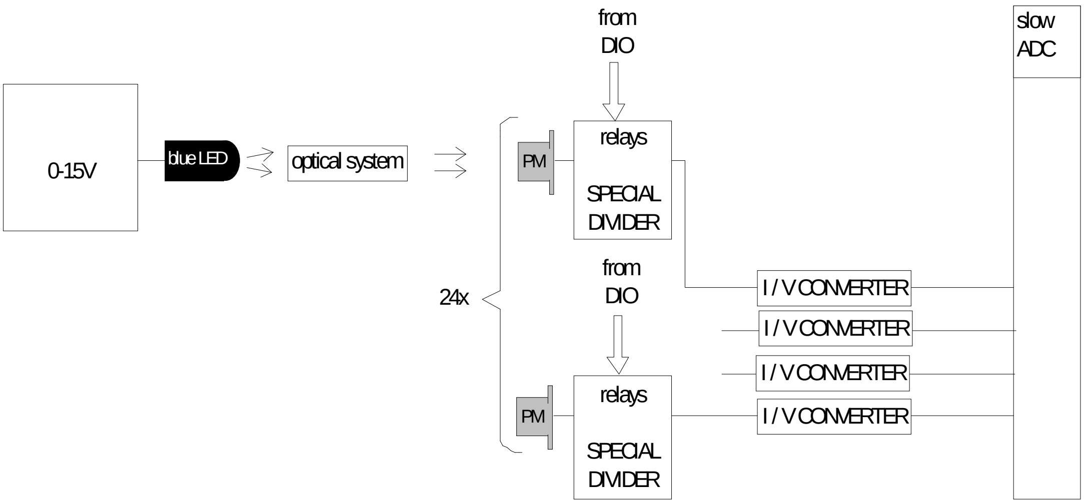
To set the anode mode :

1) close the contact of Relay #3 ,else you will apply HV between dynode #10 and anode.
2) switch Relay #2 to disconnect the +100V and to put the current measurement on the anode .
3) close the contact of Relay #1 to apply the HV

To set the photocathode mode :

1) open the contact of Relay #1.
2) switch Relay #2
3) open contact of Relay #3

The current measurement is made by converting the current into a voltage and measuring it with the ADC

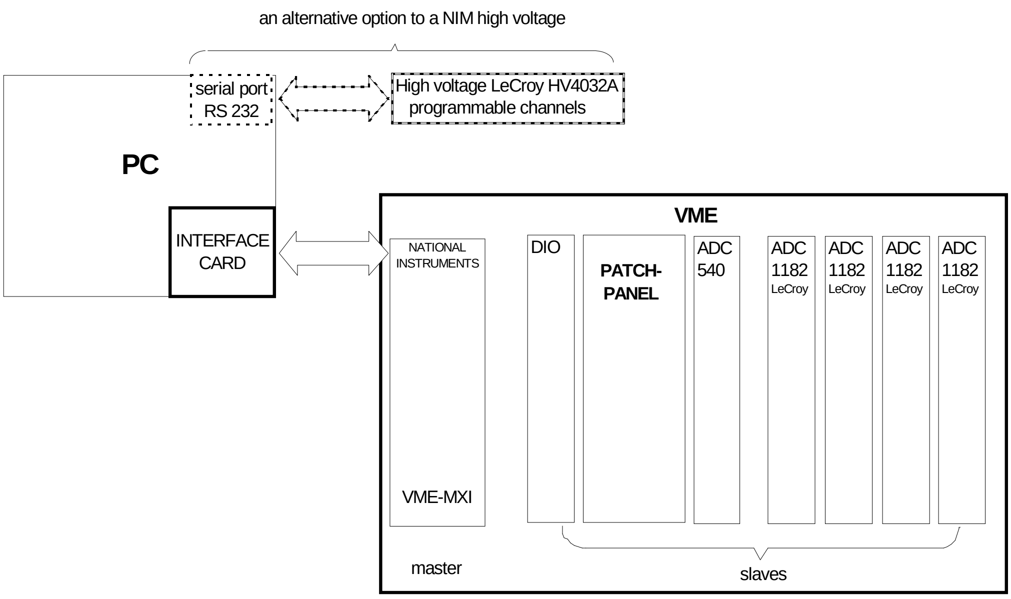


6 ELECTRONICS

6-a VME ELECTRONICS

We have 3 types of circuits :

1) a digital input/output circuit DIO
2) a 64 channels slow ADC
3) 4 charge ADCs (3 for the PMTs , 1 for the photodiodes)



6-a-1 THE DIO

The DIO:

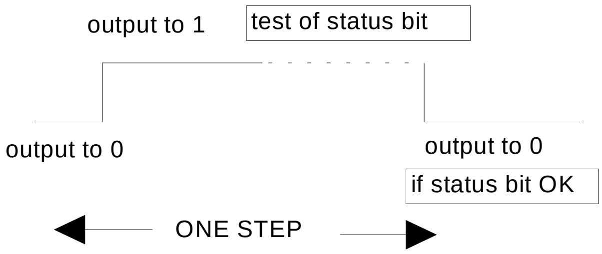
- controls the 4 stepper motors,
- programs the different voltages:
  +100V between the photocathode and dynode #1 in STEP1,
  +60V for the pulsed LED,
  +15V for the DC LED,
- It controls also the modes of working of the special dividers in STEP1 ,
- the gain of the I /V conversion circuits,
- the modes of working in STEP2 ,
- the attenuation before the charge ADCs .

<u>Control of the stepper motors for XY table</u>

We have chosen the simplest way to drive them :

- one bit of the DIO to fix the rotation (clockwise/counterclockwise)
- one bit to send the steps
- after each step a bit is used to read the status of the reference switch X0 or Y0

Hence a typical sequence that corresponds to a step looks like this :



This signal is then sent to the driver GS-D200S of the stepper motor

<u>Control of the filter wheel</u>

It is almost the same principle .The position reference from the detection of a hole on the wheel is given by the opto-interrupter which produces a status bit .The wheel turns always in the same direction ,hence we need only two bits :

- one bit for sending the steps
- one bit to read the status of the optointerrupter

We have to compensate the incertitude on wheel position due to the inertia of the wheel .The method that we use is the following : we let turn the wheel and we first detect the reference hole with the optointerrupter ,then we impose to the wheel to make at least one turn before reaching the wanted position .In this way ,we are sure to stop it always in the same conditions.

<u>Voltages control</u>

We have to control four voltages :

- HV, to apply the overall phototube high voltage (0-900 Volts)
- +100 V, to apply between the photocathode and the first dynode in STEP1
- +60 V, to supply the Light Diode Driver for the pulsed light
- +15 V, to produce the DC light.

All these voltages can vary from 0 to the nominal value under the control of a 12 bits DAC. The +100 ,+60 and +15 voltages are read back by the ADC to look at the stability and compensate eventual drifts .

Securities

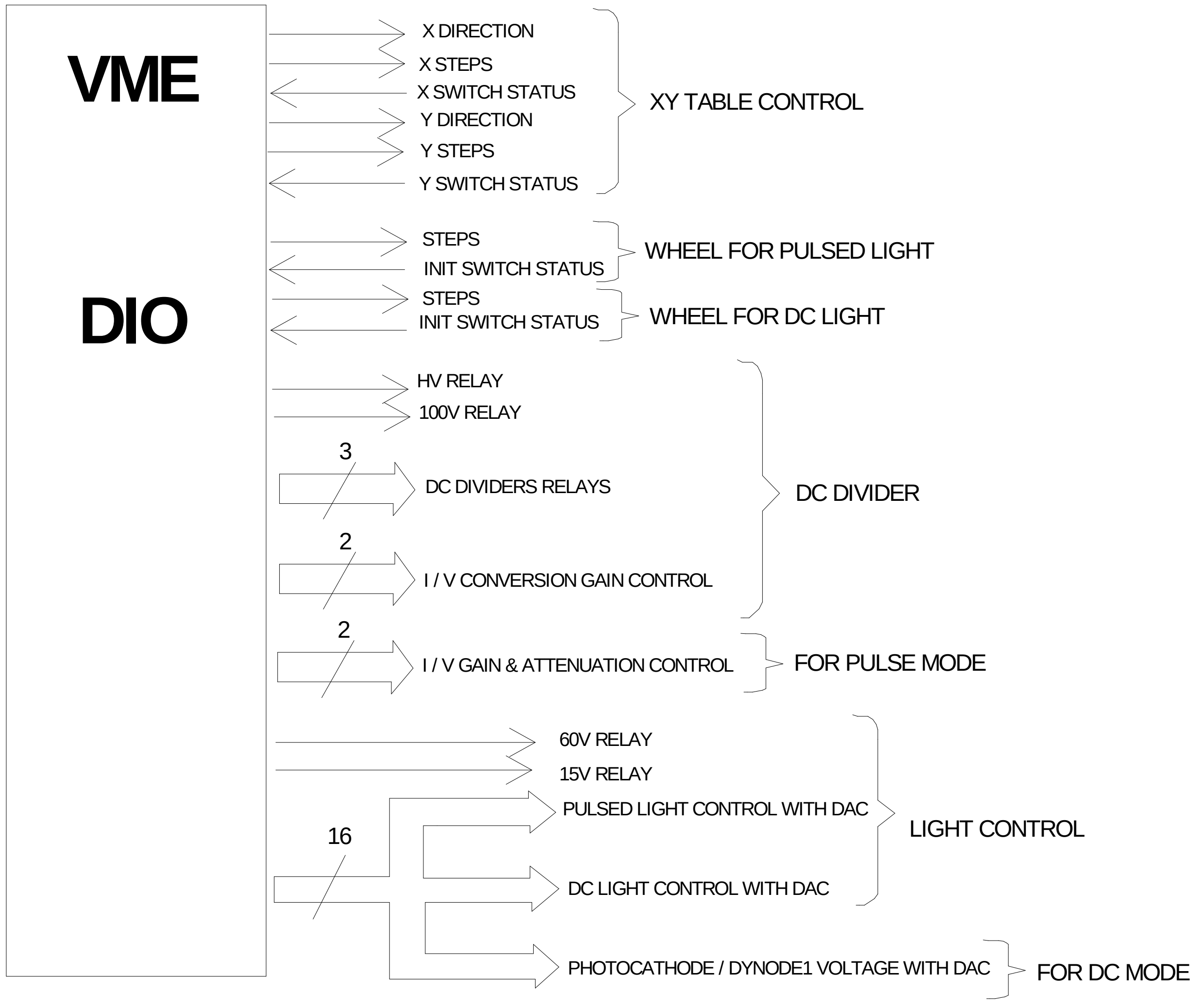
Each of these voltages can be switched off. Anyway the HV and +100V cannot not be present simultaneously on the special dividers in STEP1 .

I / V conversion circuits

To measure the photocathode current ,the anode current and the dark current , we first convert the current to voltage and we send it to the ADC .According to these different cases we have to manage with very different currents .One bit of the DIO controls the two different gains of conversion from current to voltage.

Switching between pulse mode & DC mode, control of the attenuation

In STEP2 , we want to measure the gain in pulse mode and also to measure the dark current . Furthermore it is necessary to change the attenuation before the charge ADCs to cover a sufficiently large dynamics when we measure the gain of the PMT versus HV .This part is also made by relays. And again we need two bits coming from the DIO to control these switchings (see figure in section 6-b-5)

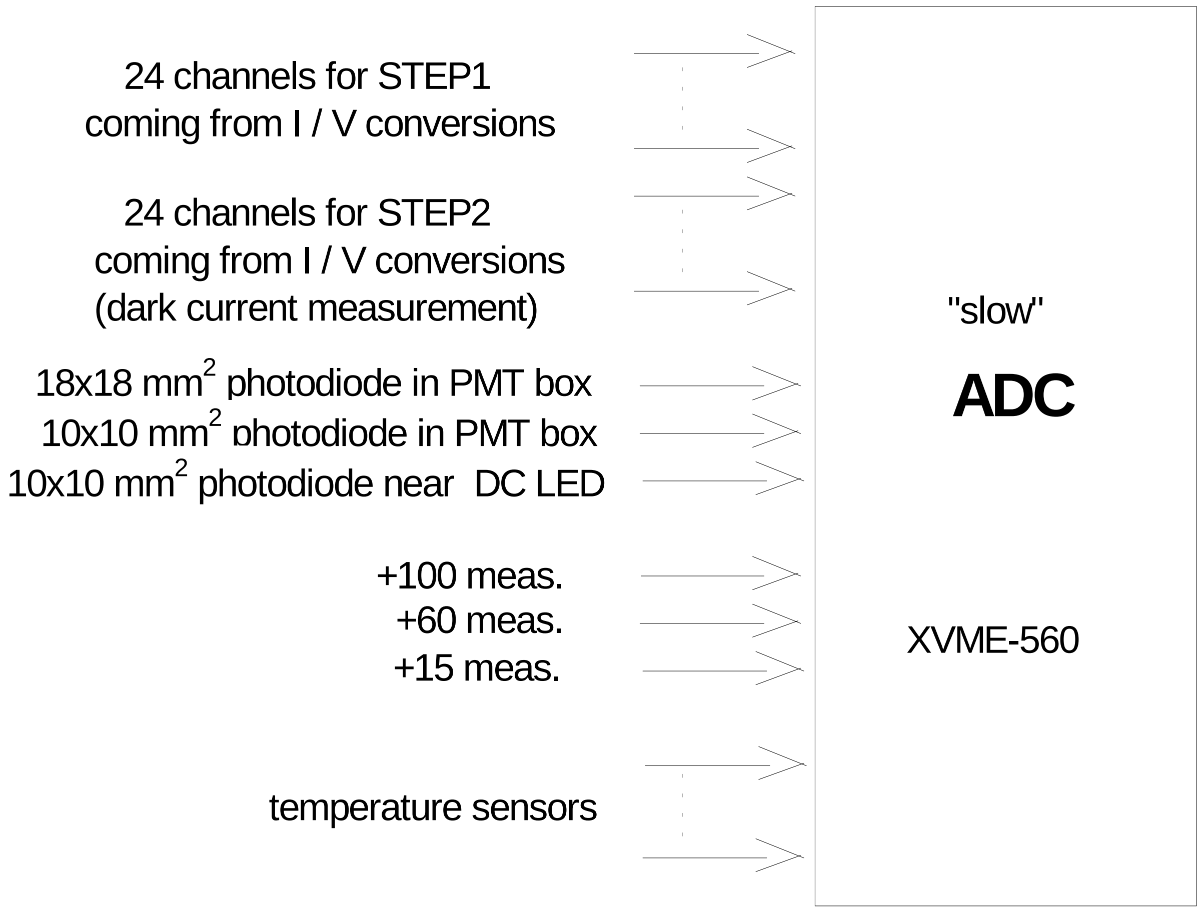


6-a-2 THE SLOW ADC

This module can perform 12-bit resolution A/D conversions on up to 64 channels in different modes :

- single channel conversion,
- repeated conversions on one channel,
- conversions on sequential channels,

The voltage input ranges are jumper selectable and its gain (1,2,4 or 8) is adjusted by the program during STEP1.This figure shows how we can use it .

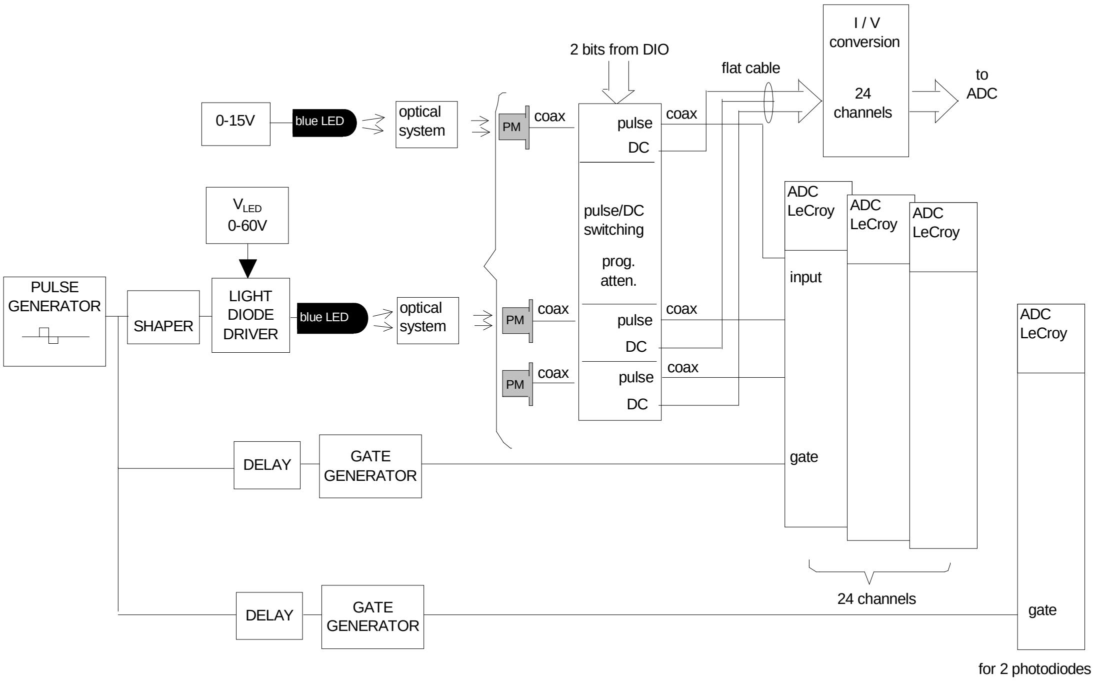


6-a-3 THE CHARGE ADCs

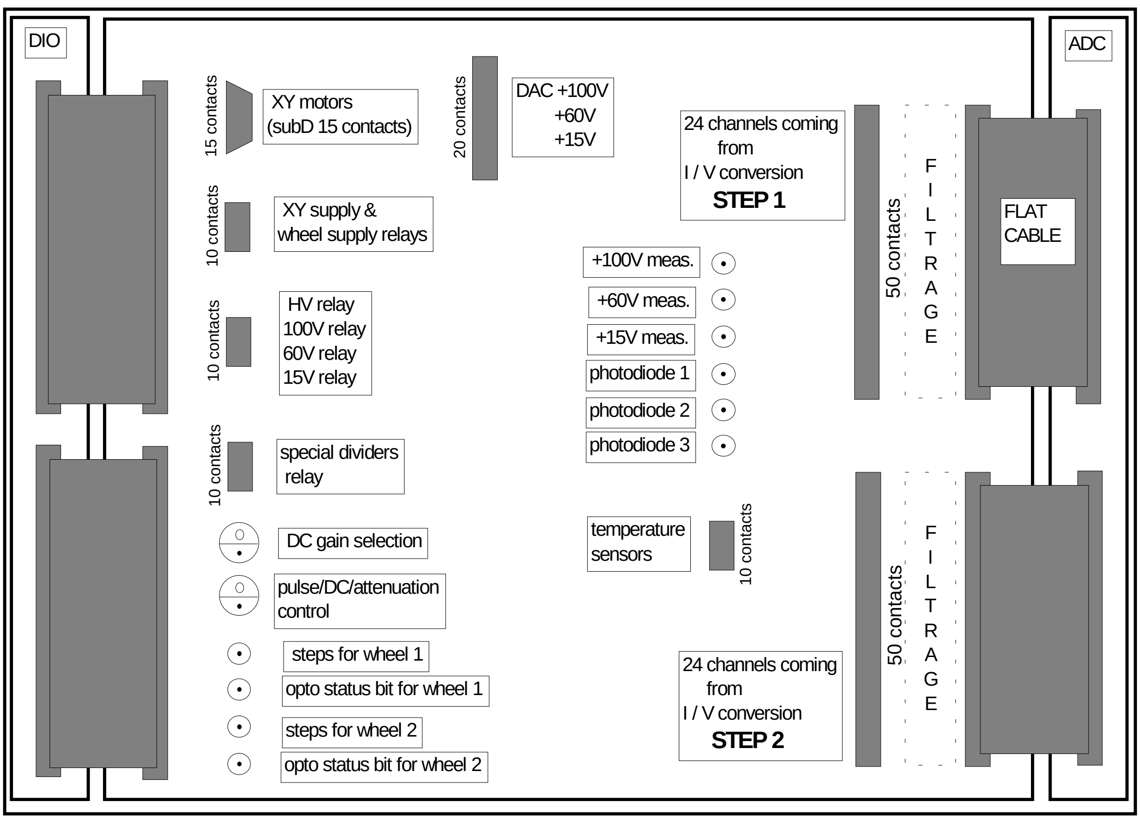
We use LeCroy 1182 charge ADC. It offers 12-bit resolution with a sensitivity of 50fC per count on 8 channels .Hence we need three of them for the 24 PMTs and one for the two pulsed photodiodes (the photodiode near the pulsed LED and the one inside the PMT box monitoring the light coming out of the liquid fiber).

As the signal of the photodiodes may be longer than for the photomultipliers ,we have to provide two different gates

The following figure gives the general principle of the electronics in STEP2. DC light source shown in this figure, is needed to simulate effect of the pile-up.



To simplify the cabling at the level of the DIO and the ADC ,we have introduced a patch panel .



6-b NIM ELECTRONICS

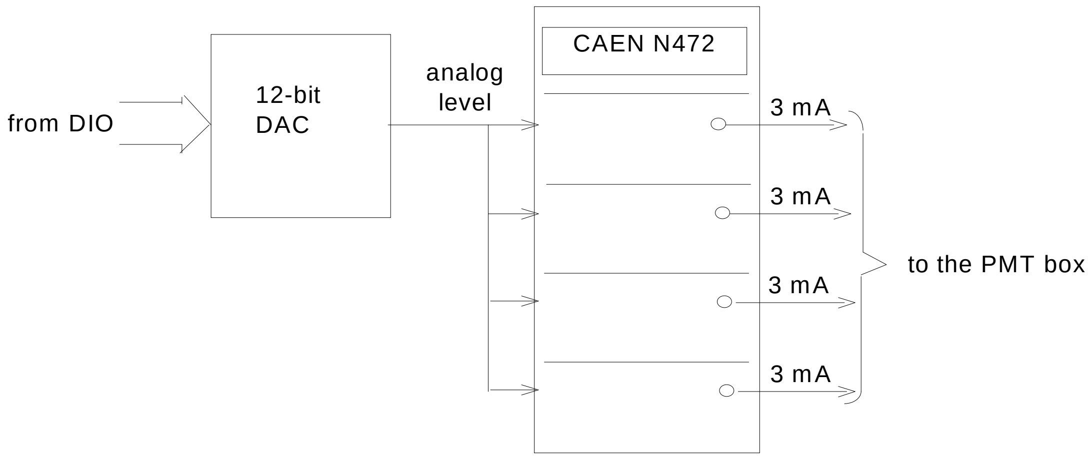
We use the following circuits for

- HV
- programmable voltages
- securities on the voltages
- I / V conversion (2 circuits)
- pulse/DC/attenuation switchings
- logic of acquisition in pulse mode
- supplies for the photodiodes

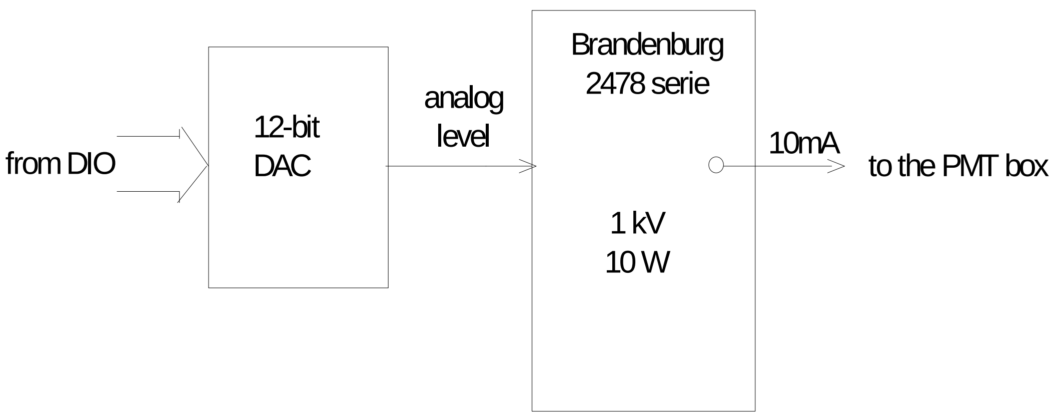
6-b-1 HV

Depending of the high voltage ,each divider can sink up to 300 microamperes , hence we need to supply a total current of at least 7 mA at 900 Volts .Furthermore this High Voltage supply must be remotely controlled .

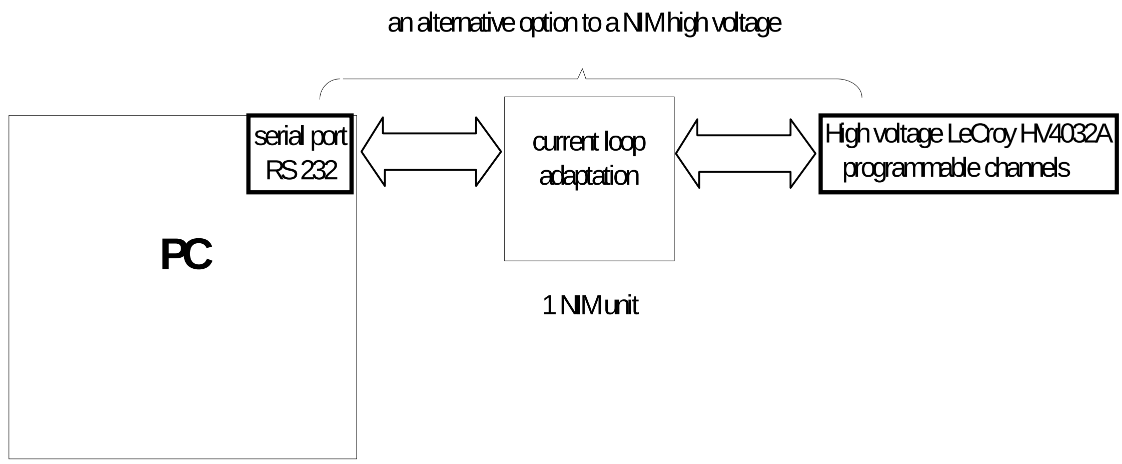
This is the case of the module CAEN model N 472 which is a double width NIM unit .It provides four channels of 3 mA and the settings of the high voltages are remotely controlled by analog levels .



An other solution is to develop his own unit around a commercial module operating from a low voltage .A few companies develop such products (for example the 2478 serie from Brandenburg ,designed to operate from a 24 dc supply and yielding 10W 1kV and programmable by voltage).It is even not necessary to foreseen a display, since we use LabView .



An other solution for people already in possession of a LeCroy HV4032 system is to use the remote mode .In our case we use a current loop in one NIM unit connected to the RS232 of the PC.

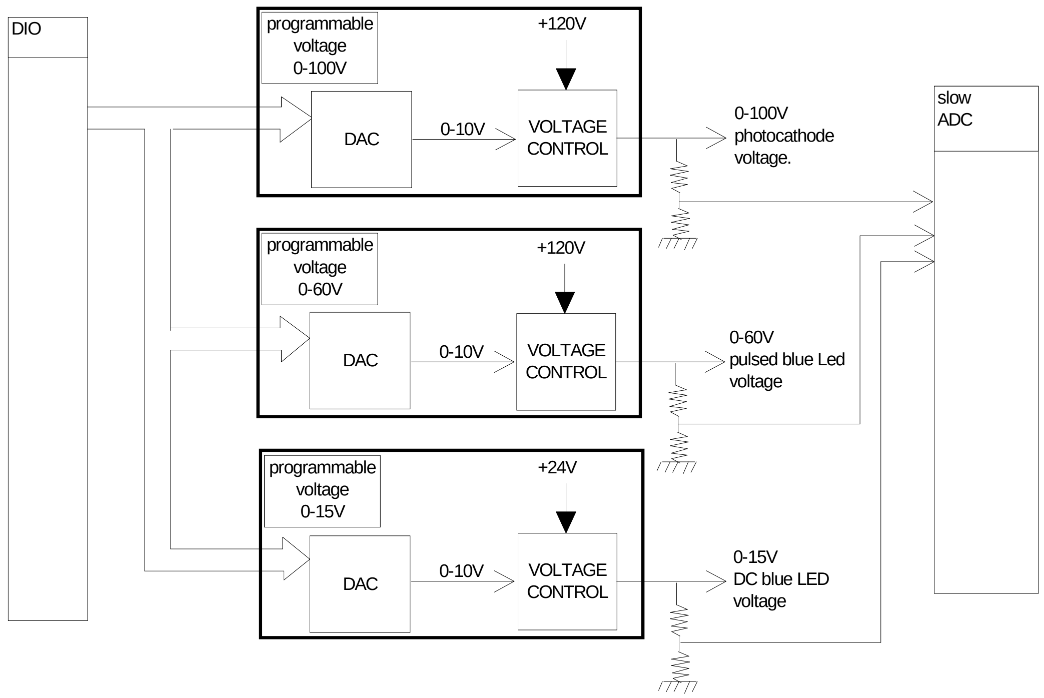


6-b-2 PROGRAMMABLE VOLTAGES

The three others voltages to program are:

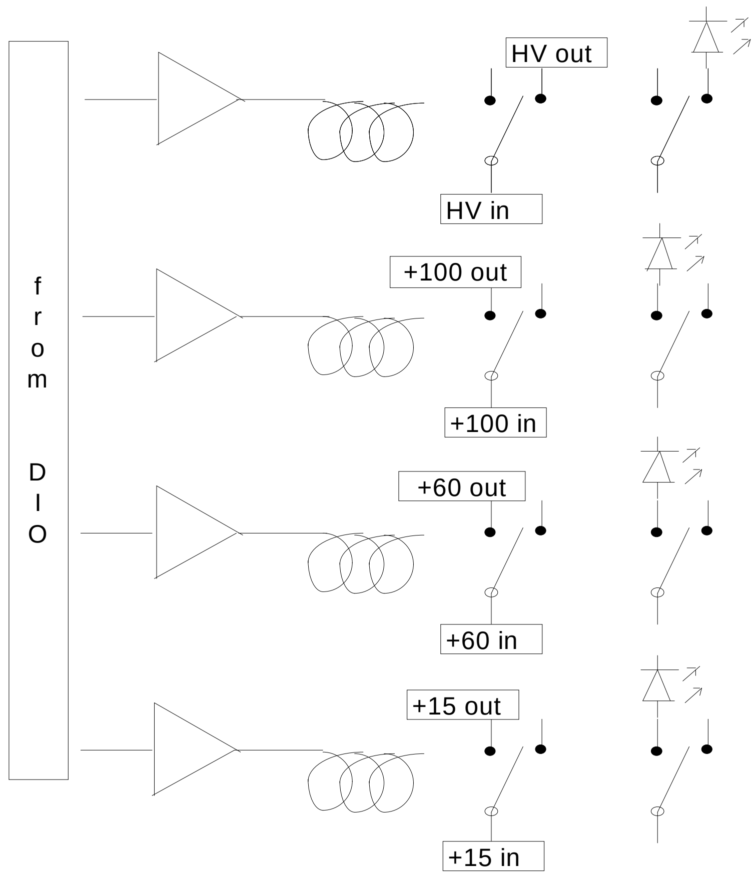
- +100V ,voltage to apply between the photocathode and the first dynode in STEP1
- +60V ,voltage for the pulsed LED
- +15V ,voltage for the DC LED

The first two voltages are made from a +120V supply and the +15V is made from the +24V of the NIM crate . The circuit takes up one NIM unit .



6-b-3 SECURITIES

All the voltages must have the possibility to be turn ON or OFF by program. Under no circumstances, the HV and +100V cannot not be present simultaneously on the special dividers in STEP1.



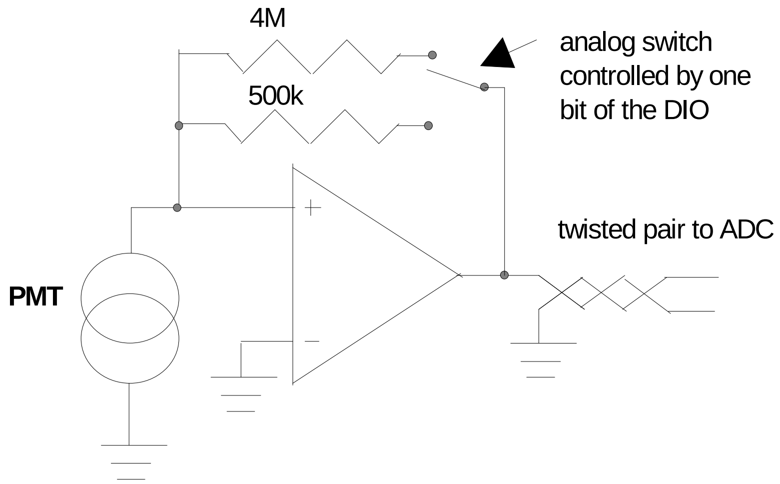
6-b-4 I / V CONVERSION

As explained before, we need to measure the DC current of the 24 photomultipliers and three photodiodes (the photodiode in the center of the matrix, the monitoring photodiode near the DC LED and the photodiode monitoring the DC light at the output of the corresponding liquid fiber) .

This current measurement is done by first converting the current to a voltage by a I / V conversion circuit according to a classical scheme with an operational amplifier. Since in our measurements, we have only to manage with DC levels ,we have chosen JFET operational amplifiers (TL083).The eventual drift of the offset will be eliminated by the acquisition of a pedestal .

Furthermore ,to measure these DC levels ,we can filter the noise by taking the average of a lot of events in a few seconds.

Since the currents to measure can be very different, we can change the conversion gain of the I / V conversion (expressed in ohms) by switching between two values of resistors.



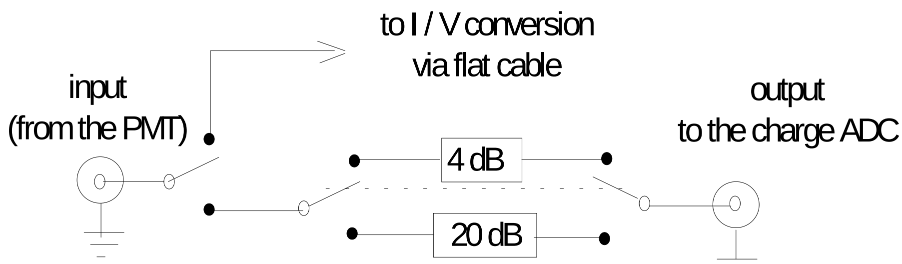
The conversion circuits are grouped by 24 channels in one NIM unit .
The currents go from the PMT box to the I / V conversion circuit via a 50 wires ,4 meters long ,flat cable (25 twisted pairs) .Then the corresponding voltages are sent to the ADC via a similar, (25 twisted pairs) 50 centimeters long ,flat cable.

The three channels for the photodiodes are similar but inside the PMT box.

In STEP2 ,we measure again the dark current and for this purpose we use an other unit of this I / V conversion circuit.

6-b-5 PULSE/DC/ATTENUATION SWITCHING FOR STEP 2

In STEP2, we perform mainly pulse measurements. Nevertheless ,since we have to measure the dark current, it is necessary to switch between a pulse mode and a DC mode .Furthermore ,in pulse mode, it is useful to be able to change the attenuation before the charge ADC in order to increase the range of the measurements.



We have tried to use analog switches but we have found that they had a few drawbacks :

- they introduce more noise than the relays
- they have a leakage current making difficult the measurement of less than 1 nA (for dark current)
- they have non linearities when using them as a « short circuit » for the pulse measurements ,for pulses of a few volts
- they presents a dispersion of a few ohms on the ON impedance.

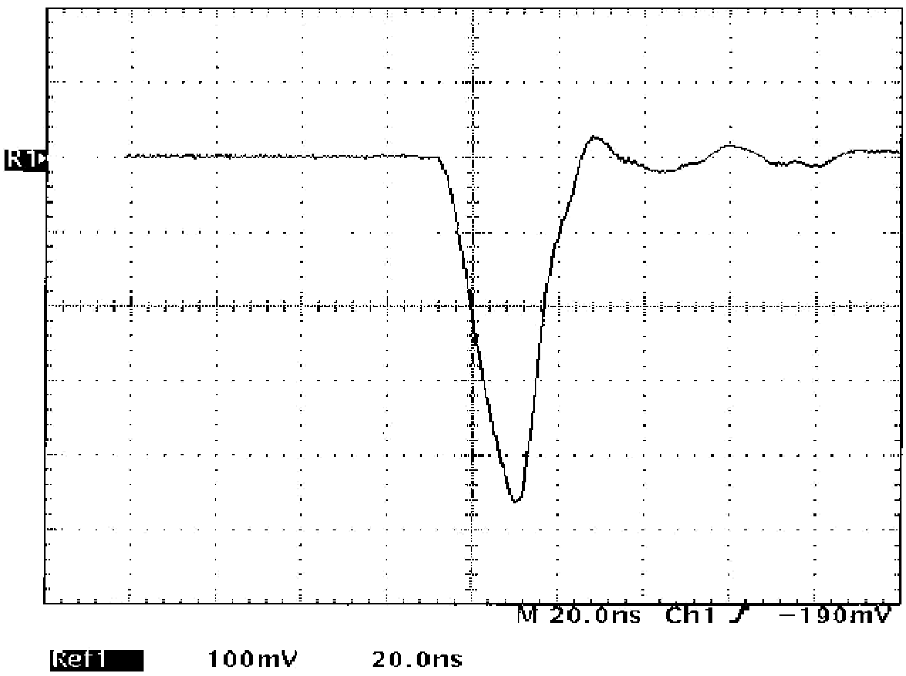
Hence we use relays .The switching is under the control of two bits of the DIO.

6-b-6 LOGIC OF ACQUISITION FOR PULSE MODE

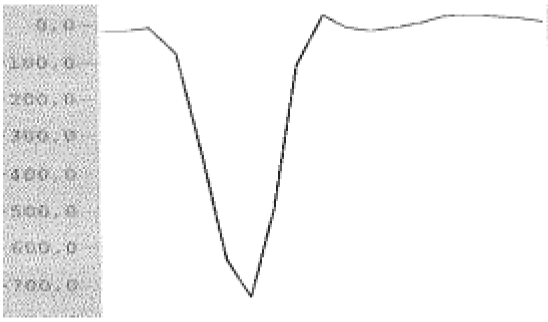
To be comparable, the measurements in pulse mode must be done always at the same frequency. Hence we use a quartz oscillator to generate the pulses and obtain a frequency of 1000 Hz. We have also to generate a pulse for the Light Diode Driver part, and two gates, one for the photomultipliers and the other for the photodiodes. See diagram of section 6-a-3

It seems also possible to reconstruct roughly the shapes of the PMT signal by displacing the gate against the signals with a step of 1 ns. The figure below gives an example for one PMT where we have acquired a few thousands of events for each nanosecond and taken the average for each point. The derivative gives then the original shape

The real pulse



The same as reconstructed with LabView



6-b-7 SUPPLIES FOR PHOTODIODES AND OTHERS

The 3 photodiodes inside the PMT box need to be supplied with + and -12V.Furthermore the special dividers need a buffer between them and the outputs of the DIO controlling the relays. These buffers should also be supplied. A NIM unit is dedicated to this purpose .

Finally the NIM crate could look like below :

HV	+100V +60V +15V	securities	photodiode supplies		I / V conversion (24 ch)	I / V conversion (24 ch)	pulse/DC/Attenuation switchings	logic for acquisition

6-b-8 SUPPLIES FOR THE PMT BOX AND FILTER WHEEL

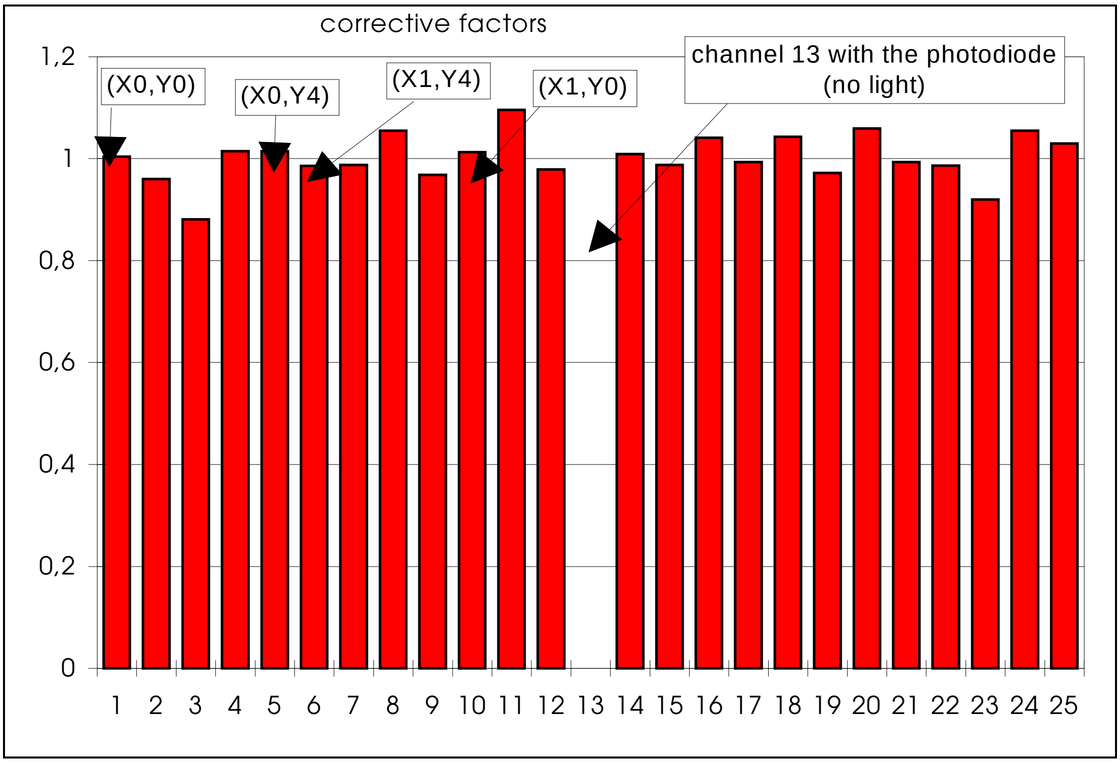
In a special crate are put together the supplies for the XY stepper motors and the Peltier elements (30V), and the supplies for the filter wheels (+12V) .Except for the Peltier elements, these supplies can be turned ON or OFF under the control of the DIO .This is made necessary because the stepper motors spent a lot of power when they are not turning.

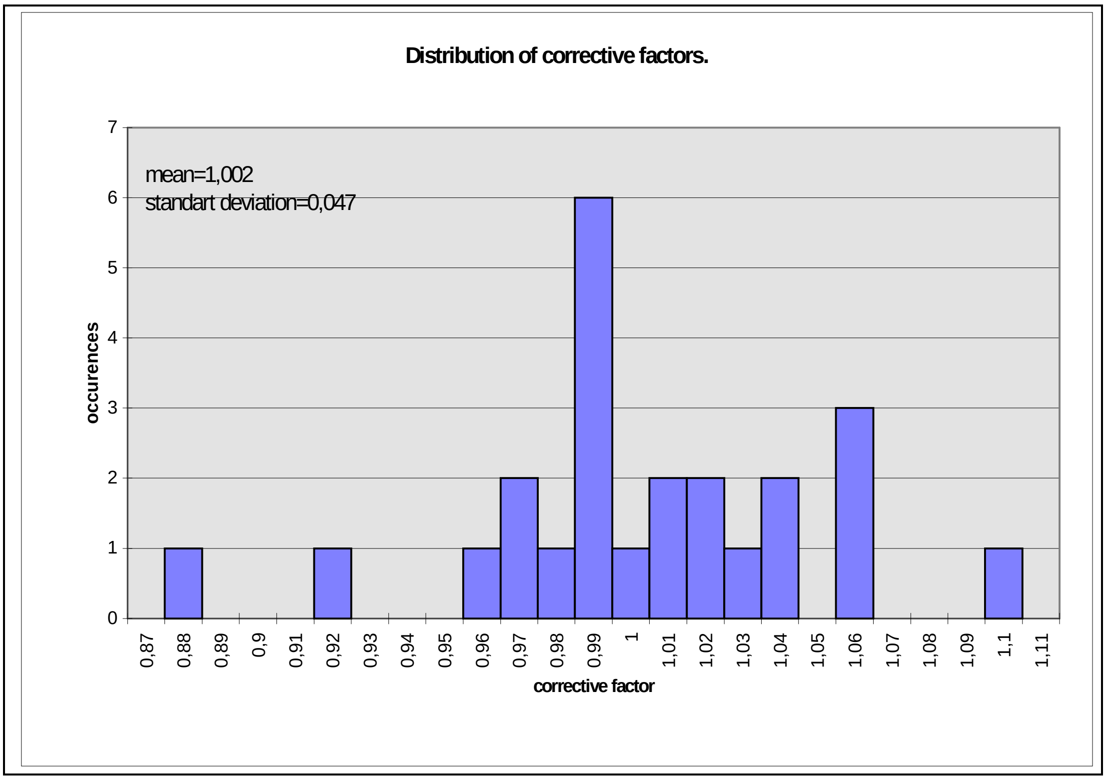
In the same crate is located the +120V supply (generating +100 and +60V)

7 CALIBRATIONS

7-a INTER-CALIBRATION OF THE CHANNELS

As explained before ,the light intensity is not equally distributed between each channel, because of the differences of length, curvature, and polishing of the fibers inside the box. So, it is very important to inter-calibrate the different channels in the test bench. We must be able to compare the results obtained with a photomultiplier to the other ones. This is done by a large area (18x18 mm) photodiode which scans all the light mixers. It gives a vector of corrective factors to apply to the different measures on each channel, to have comparable results between channels. All the programs which achieve such an automatic inter-calibration had been tested, and we have a first estimation of the light intensity on each channel.





7-b CALIBRATION OF THE FILTER WHEELS

The attenuation factors of the filters must be precisely calibrated. For this purpose we measure them with a DC light in each case. This gives more precise values ,since in pulse mode we are limited by the signal on noise ratio .Hence we have added on the pulse LED a possibility to switch it in DC mode by program (the corresponding DC voltage has no need to be programmable) .
To improve the precision ,the calibration of the filters is made several times. Below, we show the result of six successive measurements for the ten position filters wheel (pulsed light) ,which is used to perform the tests of linearity in STEP2 .

						mean	relative error(%)
84,68	84,68	84,67	84,65	84,51	84,51	84,62	0,1
30,98	31,03	31,01	30,88	31	30,93	30,97	0,2
10,03	10,06	10,05	10,06	10,07	9,99	10,04	0,3
4,88	4,86	4,88	4,88	4,86	4,86	4,87	0,2
4,14	4,13	4,14	4,14	4,14	4,14	4,14	0,1
3,08	3,08	3,07	3,07	3,08	3,08	3,08	0,2
1,94	1,94	1,94	1,94	1,94	1,94	1,94	0
1,22	1,22	1,22	1,22	1,22	1,22	1,22	0

The two others locations are :

- no filter (no attenuation)
- black filter (infinite attenuation for the pedestals)

8 MEASUREMENTS

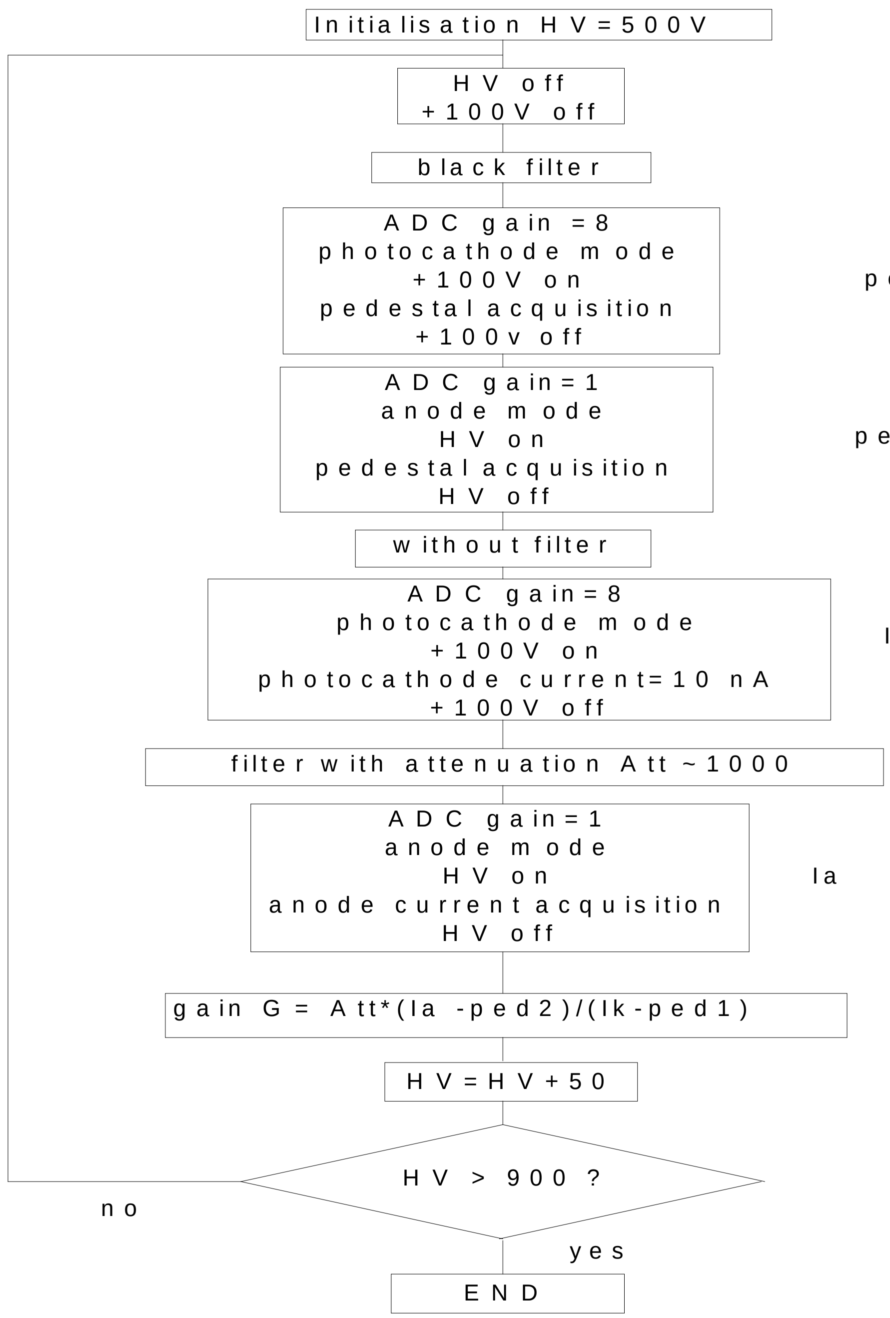
8-a STEP1

The measurements to be done are :

- the gain
- the collection efficiency
- the dark current

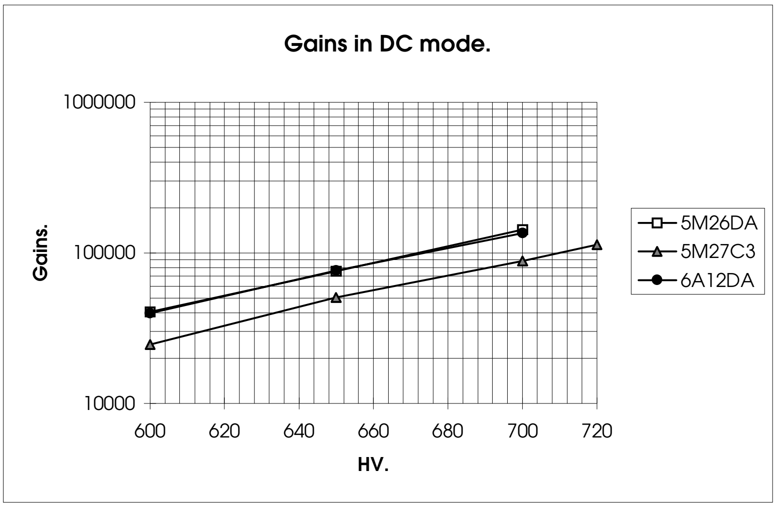
In the first two measurements ,we have to work with a fixed current of photocathode of 10 nA. This value is obtained by changing the DC light through the programmable +15V and by successive approximations. The following figure is the flow chart for the gain measurement

.



Below is an example of what can be done automatically .

	5M26DA	5M27C3	6A12DA
600	40693	24727	39648
650	75722	50446	76278
700	142335	88551	135198
720		113286	



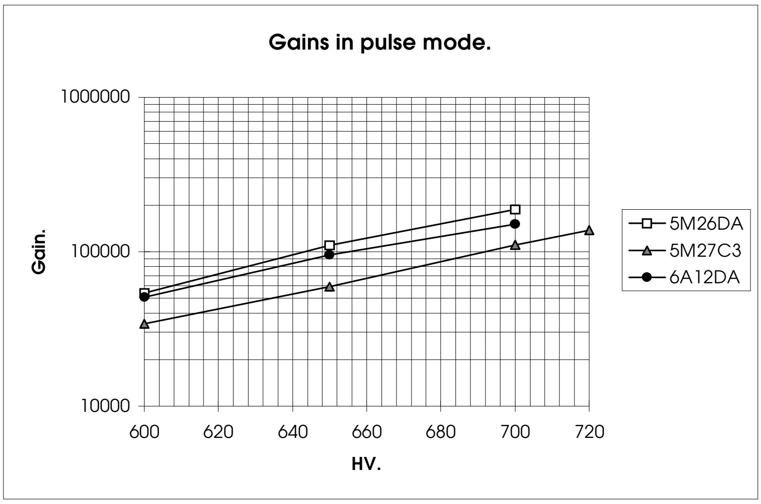
8-b STEP2

In STEP2 we pair a standard divider and a PMT and we measure in pulse mode

- the gain
- the linearity
- the dark current
- the linearity with superimposed DC light

To determine the gain ,we measure the mean <M> and the standard deviation σ. The gain is estimated by the usual method :$G = Q / (Npe * e^-)$, where Npe is the number of photoelectrons estimated by :$Npe = ((<M> - ped) / \sigma^2)$, where ped is the pedestal. The following figure gives an example of an automatic measurement.

	5M26DA	5M27C3	6A12DA
600	53864	34010	50766
650	109672	59474	95339
700	187387	110909	150491
720		138170	



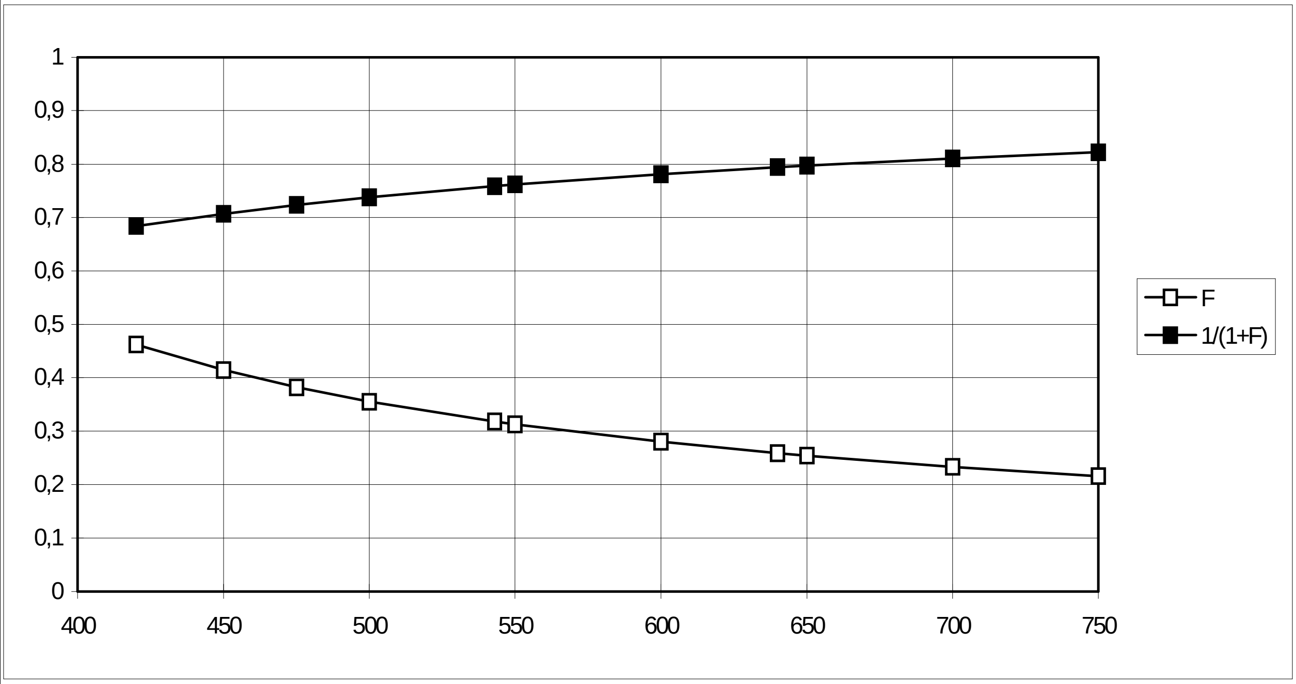
The precision can be improved by increasing the number of events and also by doing several times the same measurement to decrease the mechanical effects on the wheel.

To ameliorate these results, we can correct them with a noise factor. We have :$Npe_{corrected} = Npe_{measured} / (1 / (1 + F))$, where F is the noise factor, different for each photomultiplier. The following array is given as an example :

Noise factor for the photomultiplier 6A12DA.

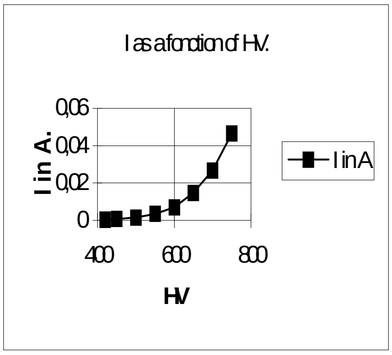
Estimation of the noise factor as a function of the high voltage, with the 2.5:2.5:1:1...1:1:2.5:2.5 voltage configuration for the PM 6A12DA.

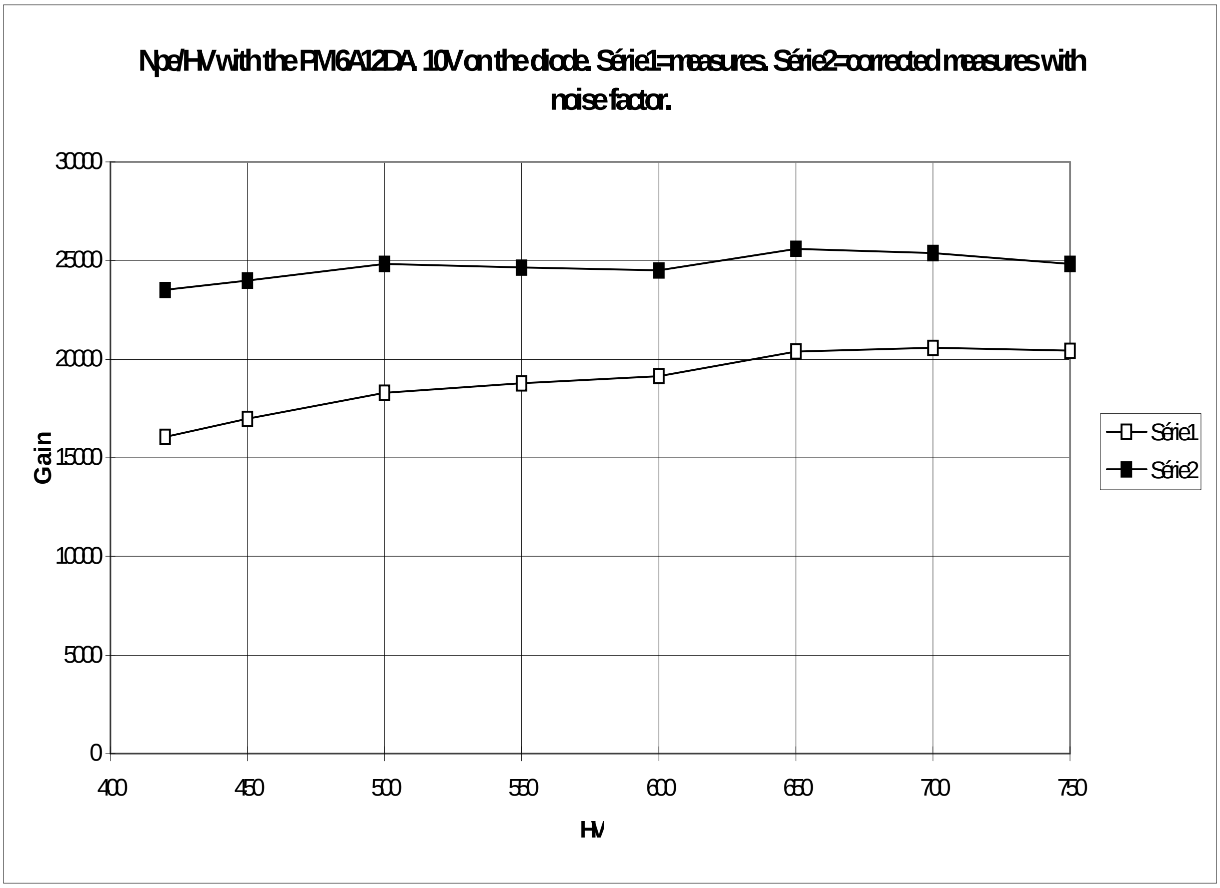
HV	v	k	v'	k'	F	1/(1+F)	G
420	24,7058824	1,689424	61,7647059	3,623623752	0,46259023	0,6837185	1868,95955
450	26,4705882	1,78933654	66,1764706	3,837924881	0,41445686	0,70698516	3319,96593
475	27,9411765	1,87174675	69,8529412	4,014685475	0,38230069	0,7234316	5208,1585
500	29,4117647	1,95343457	73,5294118	4,189896628	0,35537757	0,73780179	7983,65954
543	31,9411765	2,09236741	79,8529412	4,487891892	0,31792263	0,75876989	15870,5798
550	32,3529412	2,1148068	80,8823529	4,536021835	0,31265535	0,76181459	17657,1371
600	35,2941176	2,27374109	88,2352941	4,876917961	0,28010069	0,78118855	36443,7808
640	37,6470588	2,39929325	94,1176471	5,146213159	0,25906157	0,79424233	62380,1817
650	38,2352941	2,43047351	95,5882353	5,213091312	0,25434497	0,79722885	70977,753
700	41,1764706	2,58520089	102,941176	5,54496407	0,23338492	0,8107769	131569,823
750	44,1176471	2,73808969	110,294118	5,872893276	0,21594806	0,82240355	233716,844



The corrected estimation of the number of photoelectrons is then :

HV	Measured Npe	Corrected Npe	noise factor	G	I in A
420	16069	23502	0,6837	1868,9596	0,00035139
450	16966	23997	0,707	3319,9659	0,00063735
500	18307	24812	0,7378	7983,6595	0,00158472
550	18767	24635	0,7618	17657,1371	0,00347987
600	19146	24508	0,7812	36443,7808	0,00714531
650	20404	25594	0,7972	70977,753	0,01453284
700	20588	25392	0,8108	131569,823	0,02672657
750	20413	24821	0,8224	233716,844	0,04640869

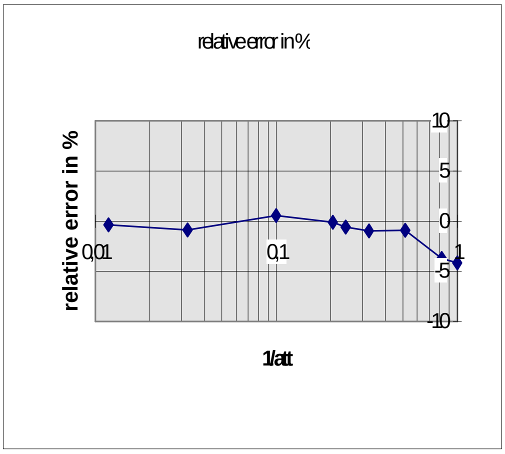


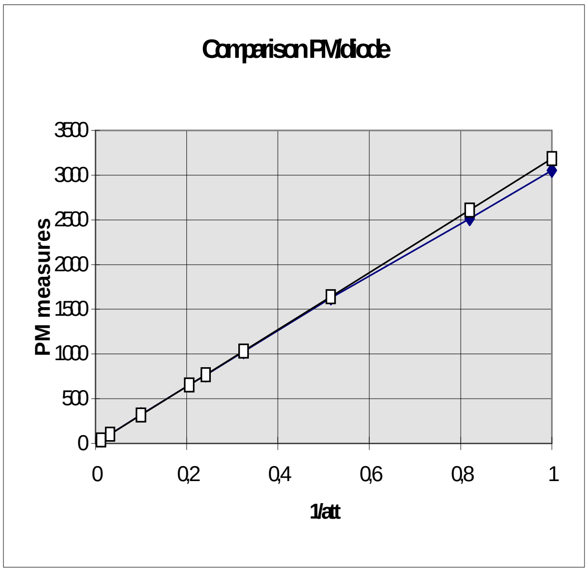


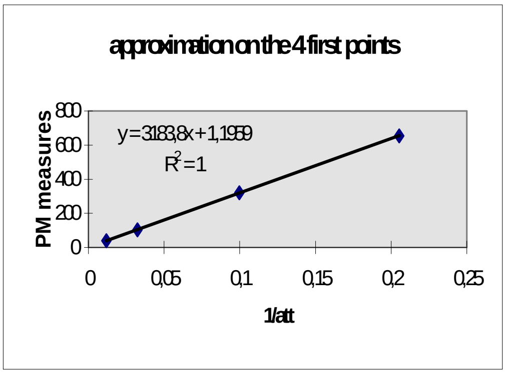
One can see clearly the amelioration .

To look at the linearity, we compare in bottom-left figure the amplitudes of the signals coming from the photomultipliers as a function of the nominal attenuation of the filters obtained with the photodiode (black symbols) with what could be expected assuming that the four first points correspond to a full linear behaviour of the photomultiplier and extrapolating this approximation (open symbols). Relative difference, i.e., the non linearity is shown as a function of 1/att in top-right figure

No filtre	1/att (with diode)	PM measures	approximation	relative error in %
2	0,011817537	38,681	38,8205743	-0,359536929
3	0,032289312	103,096	103,9986115	-0,867907304
4	0,099601594	320,046	318,307455	0,546184199
5	0,205338809	654,269	654,9536001	-0,104526503
6	0,241545894	765,653	770,2297173	-0,594201602
7	0,324675325	1024,941	1034,8972	-0,96204722
8	0,515463918	1627,239	1642,329922	-0,918872751
9	0,819672131	2514,115	2610,868031	-3,705780206
10	1	3052,371	3184,9959	-4,164052456







9 CONCLUSION

- The planned measurements can be done automatically .
- The duration of each measurement is compatible with a week of work .
- The repeatability of the measurements is good .
- LabView seems adequate for this kind of work except to manipulate large arrays such as we need with the charge ADC, where it is rather slow .This problem must be solved by developing special modules in C .

10 TECHNICAL INFORMATION

10-a Technical specifications of the VME circuits

Digital Input Output card (DIO) :
∗ reference VMIVME-2510B (VME Microsystems)
∗ input / output module, TTL, 64 bits
∗ 8 individually configurable ports
∗ transfer 8, 16, 32 bits

Analog To Digital Conversion card (ADC) :
∗ reference XVME-560 (Xycom)
∗ 64 channels
∗ resolution 12 bits
∗ voltage ranges : 0-5V, 0-10V, ±2.5V, ±5V, ±10V
∗ programmable gain 1, 2, 4, or 8
∗ conversion time 50 µs
∗ input impedance 17MΩ

Charge ADC card:
∗ reference 1182 (LeCroy)
∗ 8 channels
∗ sensitivity 50fC/channel
∗ resolution 12 bits
∗ gate 50ns to 2µs
∗ conversion time 16µs
∗ buffer 16 events
∗ input range 0 to -1.5V

10-b Parts list

Pmt Box

specification and reference	*company*	*quantity*	*price(FF)/ 1 piece*
stepper motors ref HY 200-2215-0220 AX 04	MDP	2	495
driver module for stepper motor ref GS-D200S	Thomson	2	315
Peltier element ref CP1.4-127-06L	Melcor	4	420
photodiode 18x18 ref S3204-04	Hamamatsu	1	3100
photodiode 10x10 ref 1337-11	Hamamatsu	1	800
photodiode 10x10 ref S3590-04	Hamamatsu	1	1300
fan	Etri	2	300

Optics

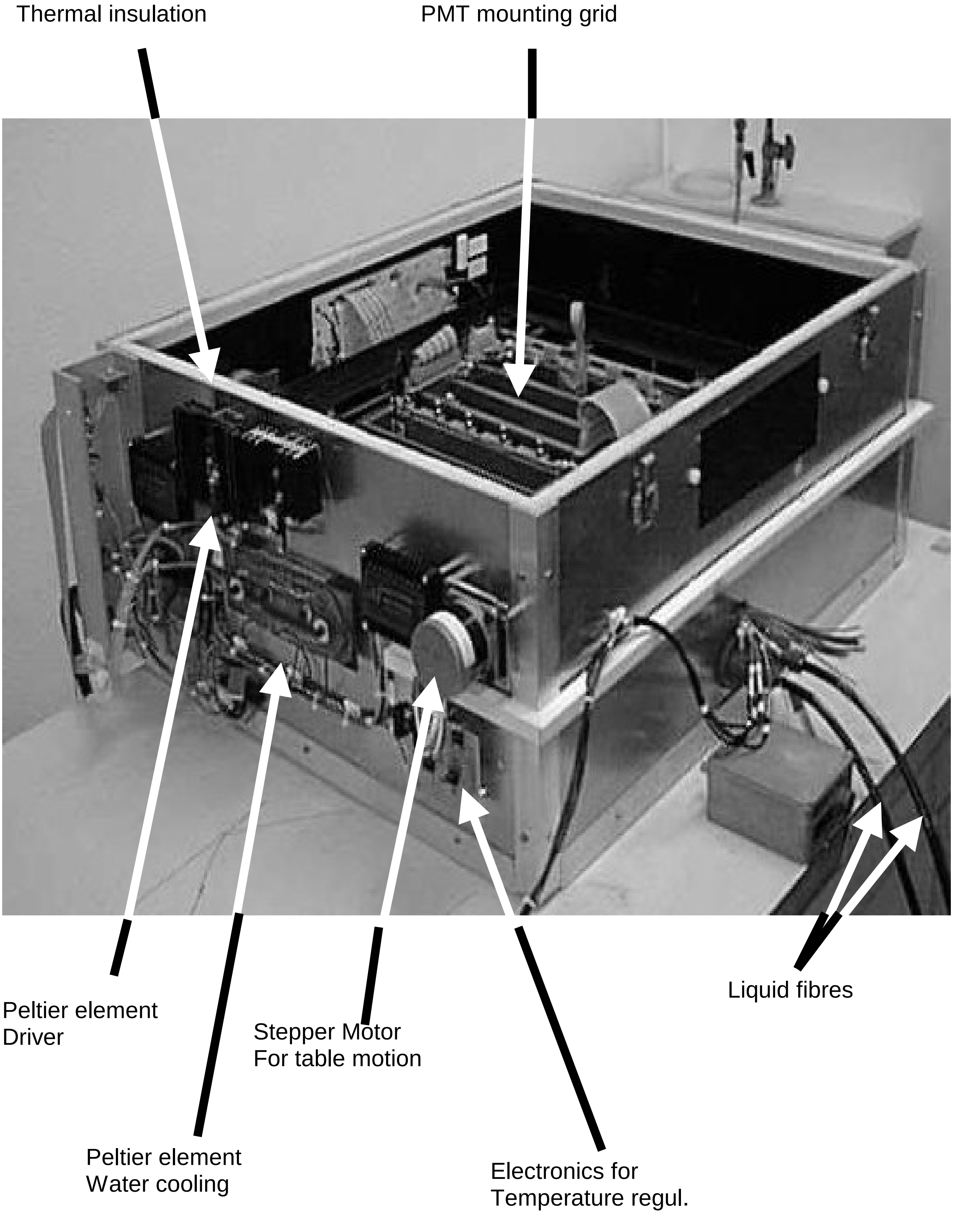
specification and reference	*company*	*quantity*	*price(FF)/ 1 piece*
liquid fiber 2m ref 77569	ORIEL	2	3000
beam splitter holder ref 78150	ORIEL	2	2600
beam splitter ref VBS-30-70-50	Andover	2	1300
interferential filter ref 480FS10-50	Andover	1	1500
Quick change filter holder ref 71260	ORIEL	1	1520
fiber bundle focusing assembly ref 77799	ORIEL	2	2020
neutral density filter	ORIEL/Mlles GRIOT	11	450
fused silica collimating beam probe ref 77644	ORIEL		960
LED ref BP280CWB1K-3.6VF-050T	Ledtronics	1	500
LED ref NLPB500	Nichia	1	150
photodiode ref S3590-04	Hamamatsu	1	1300
photodiode ref 1337-11	Hamamatsu	1	800
lens support ref 78102	ORIEL	2	0
male-female coupling ref 78122	ORIEL	2	0
lid for beam splitter holder ref 78101	ORIEL	2	0
plano-convexe lens ref ? ? ?	? ? ?	2	? ? ?
stepper motor with reduction ref 9904-112-31001	Airpax	2	500

Electronics

specification and reference	*company*	*quantity*	*Price(FF) /1 piece*
NI / VXI interface	National Inst.	1	25000
LabView software	National Inst.	1	15000
High Voltage unit ref N472	CAEN	1	? ? ?
12V supply ref SVB 12 SB	MICROEL	1	2000
30V supply ref S240-30	MICROEL	1	2000
120V supply ref ? ? ?			

11 PHOTOS OF THE PROTOTYPE

General view of the PMT box



General view of the PMT box

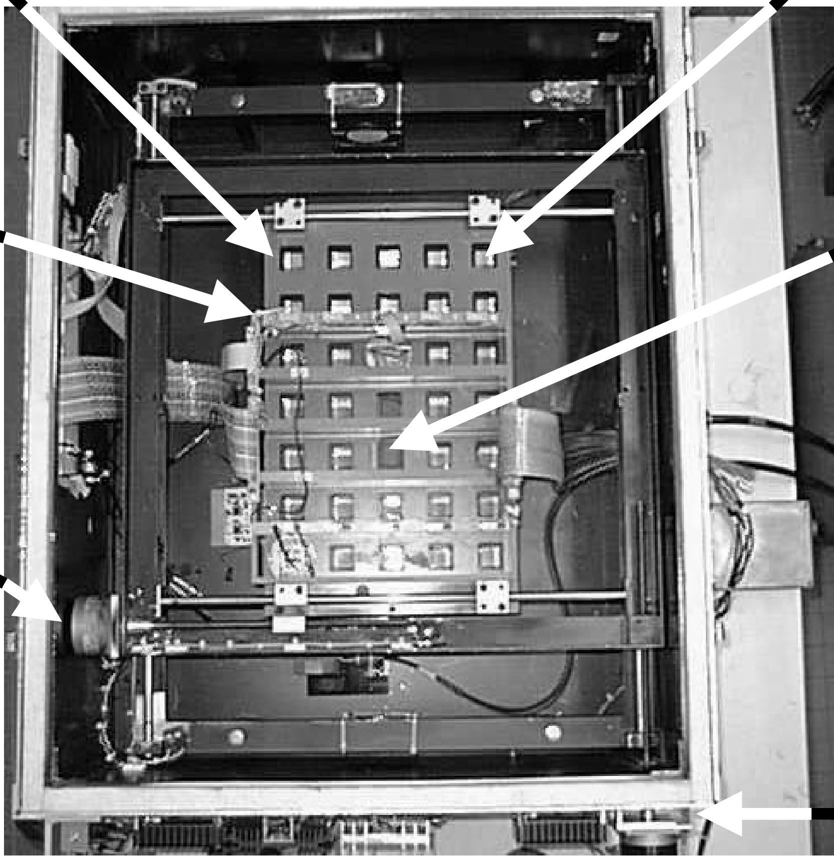
Moving table

Light mixer

PMT
mounting grid

18x18
photodiode for
Intercalib.

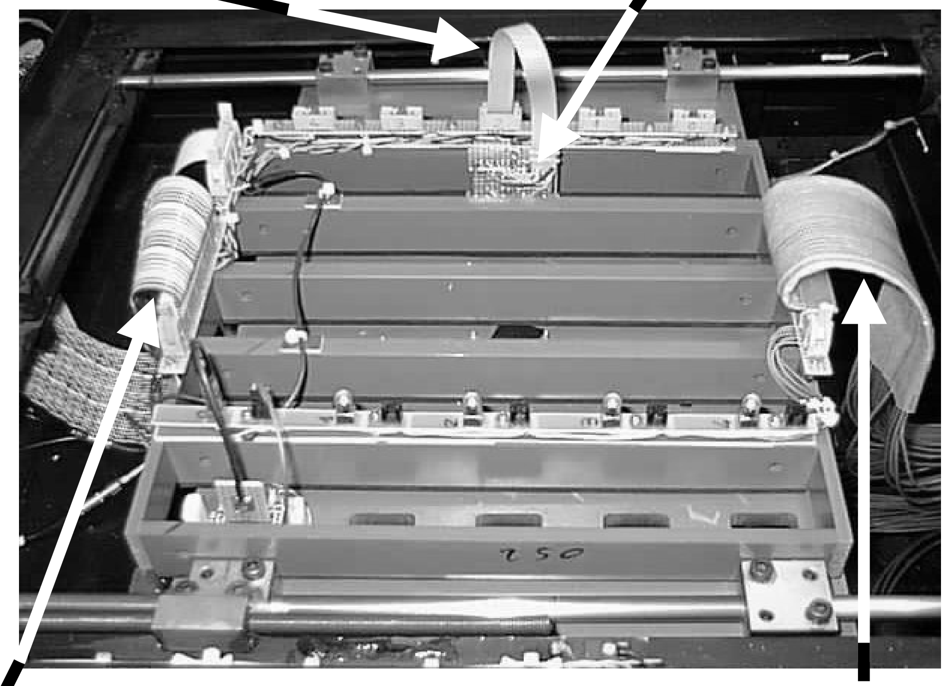
Y-stepper
motor



X-stepper
motor

Step 1 divider control cable

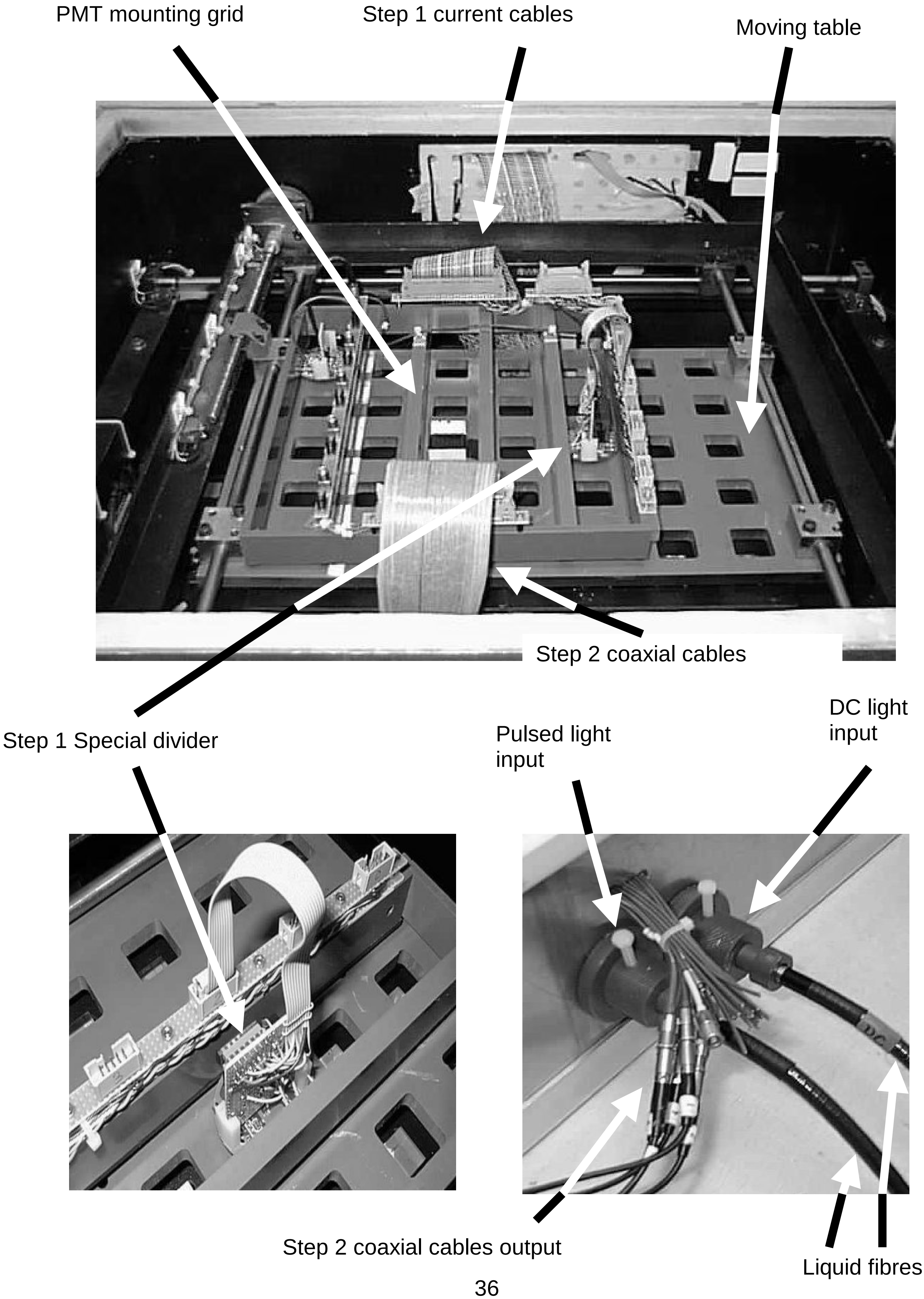
Step 1 divider



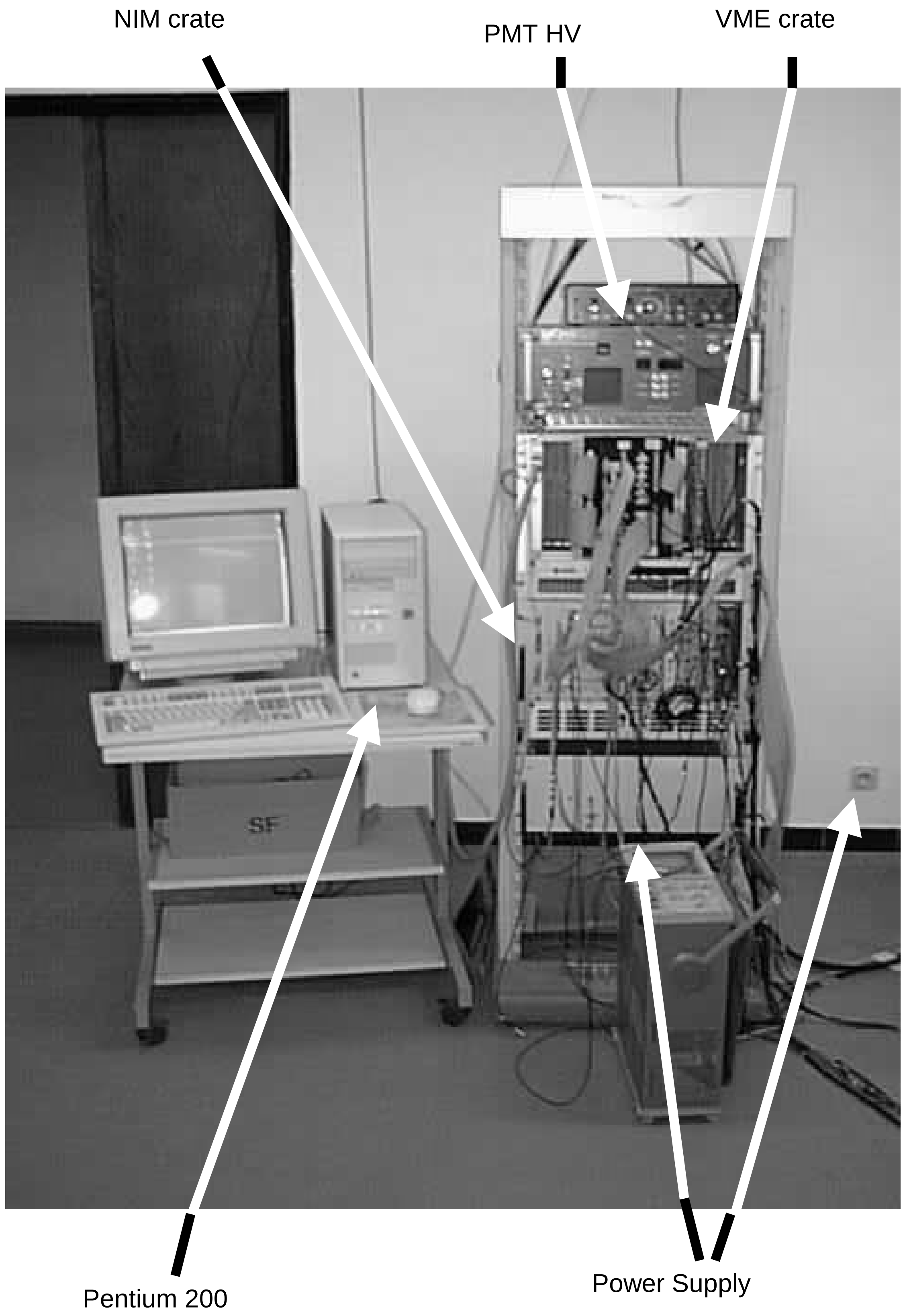
Step 1 current
Measurement twisted flat cable

Step2 coaxial cables for signal

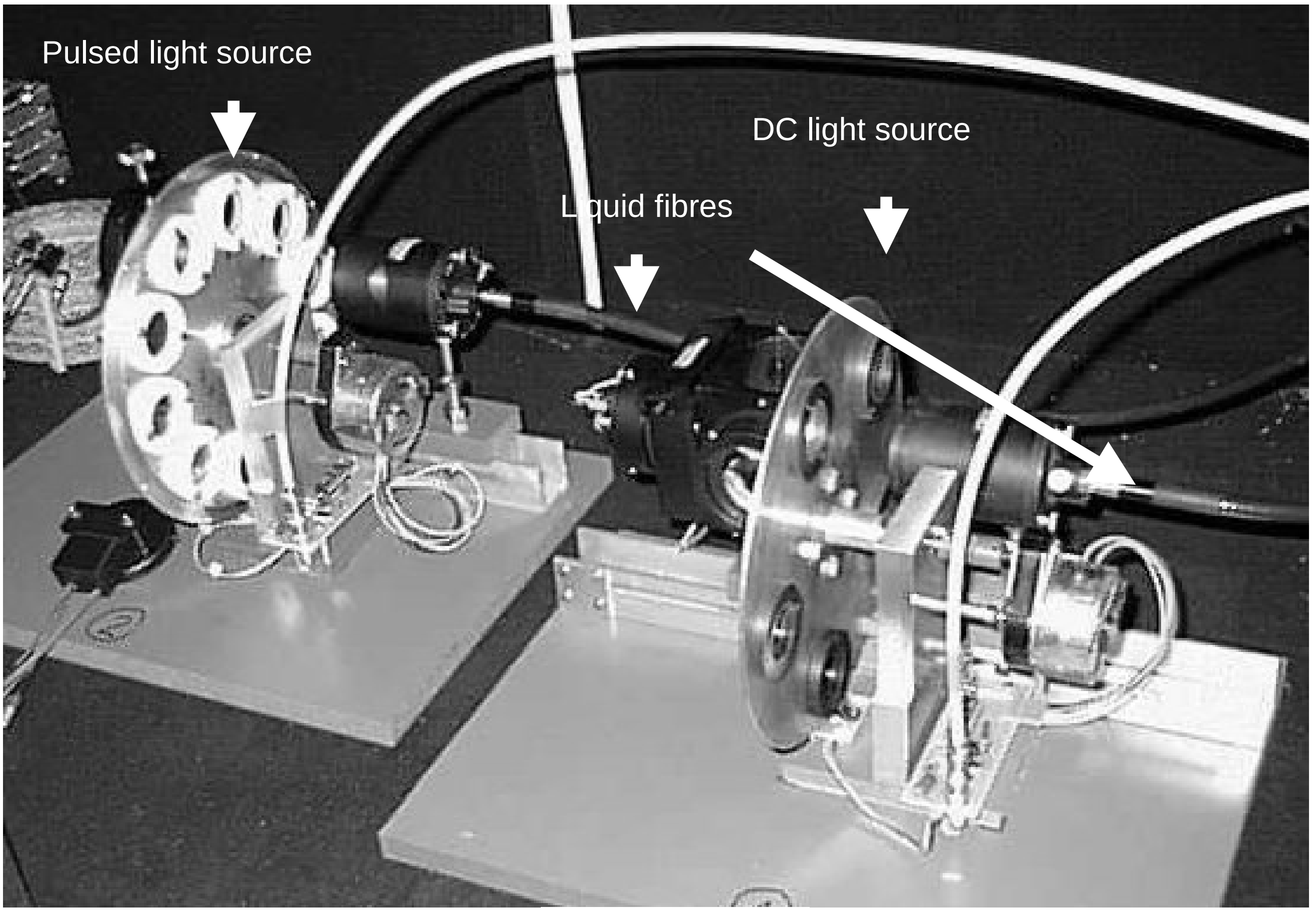
General view of PMT box



General view of the electronic of the PMT test bench

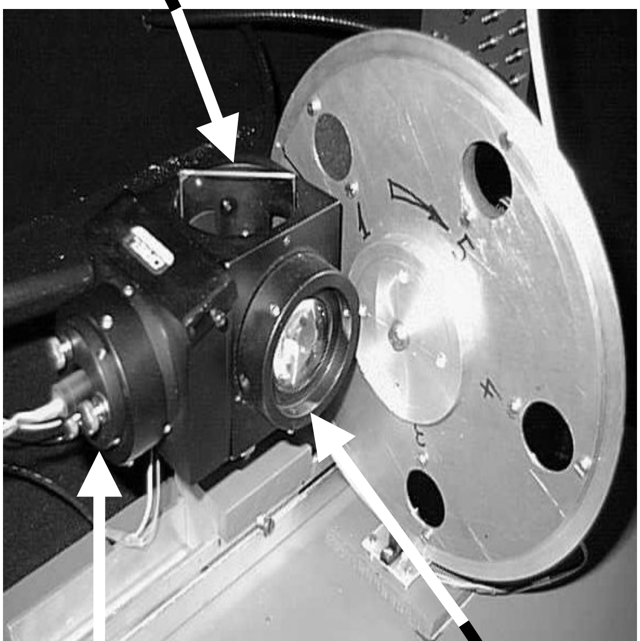


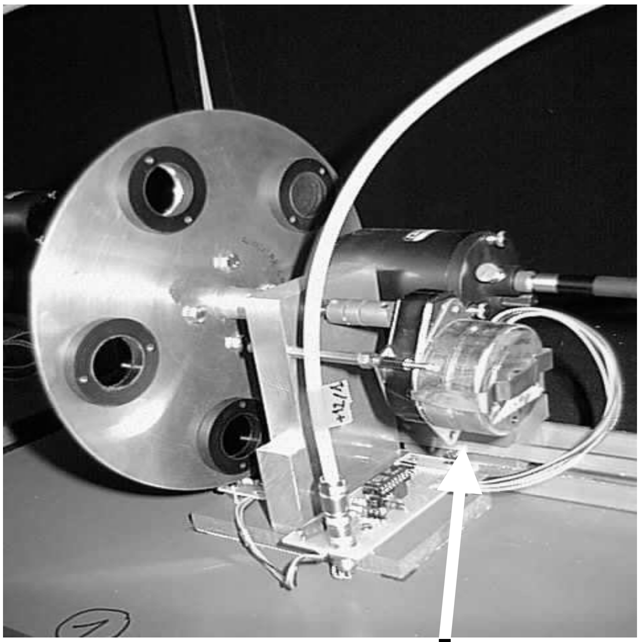
The DC and Pulsed light Sources



DC light source

Beam splitter 90-10



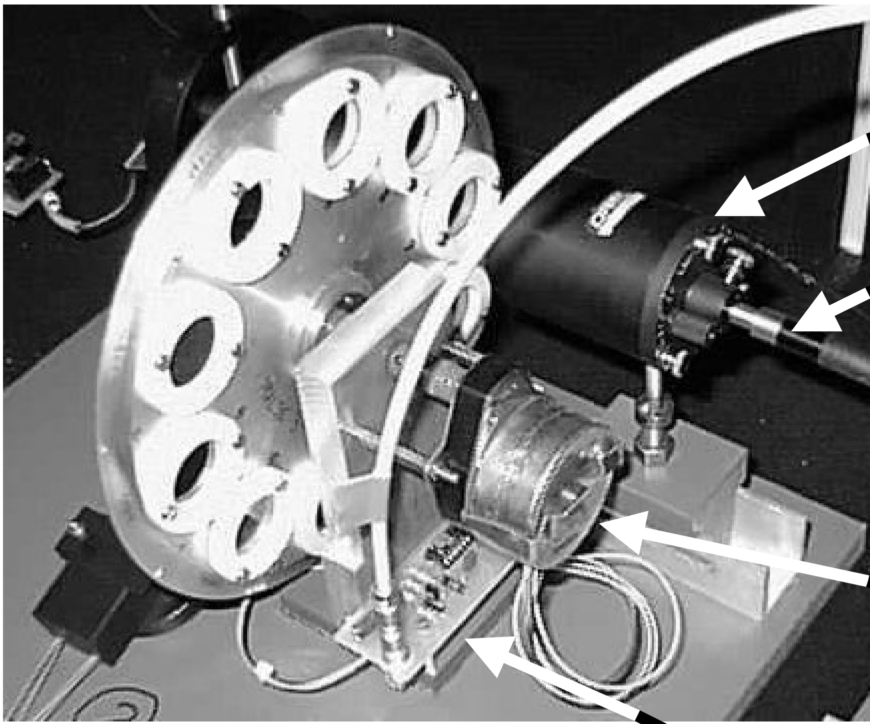


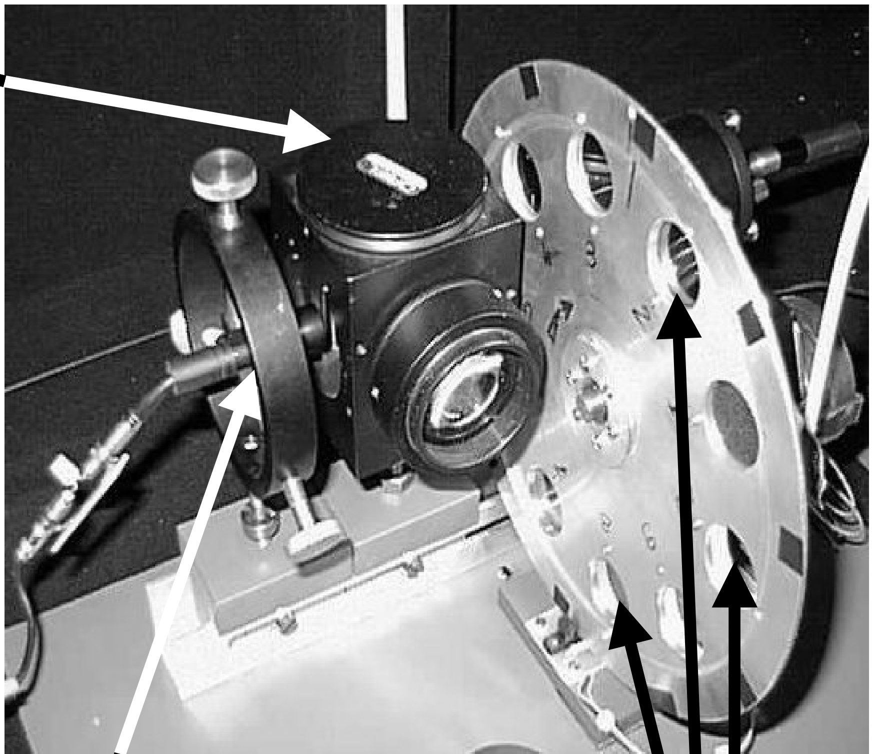
Beam splitter
holder

Filter wheel
Stepper motor

Nishia blue LED

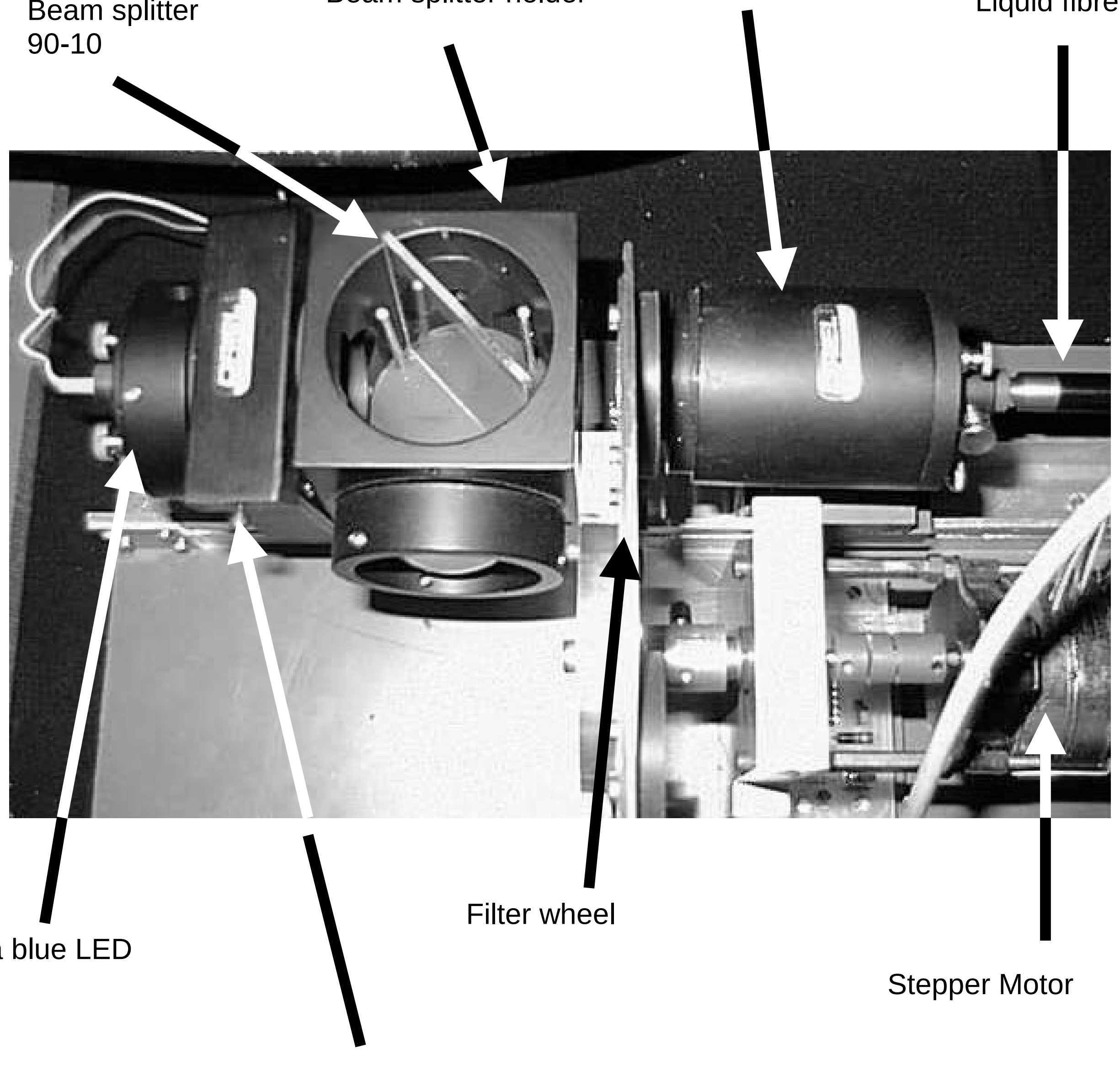
Pulsed Light Source





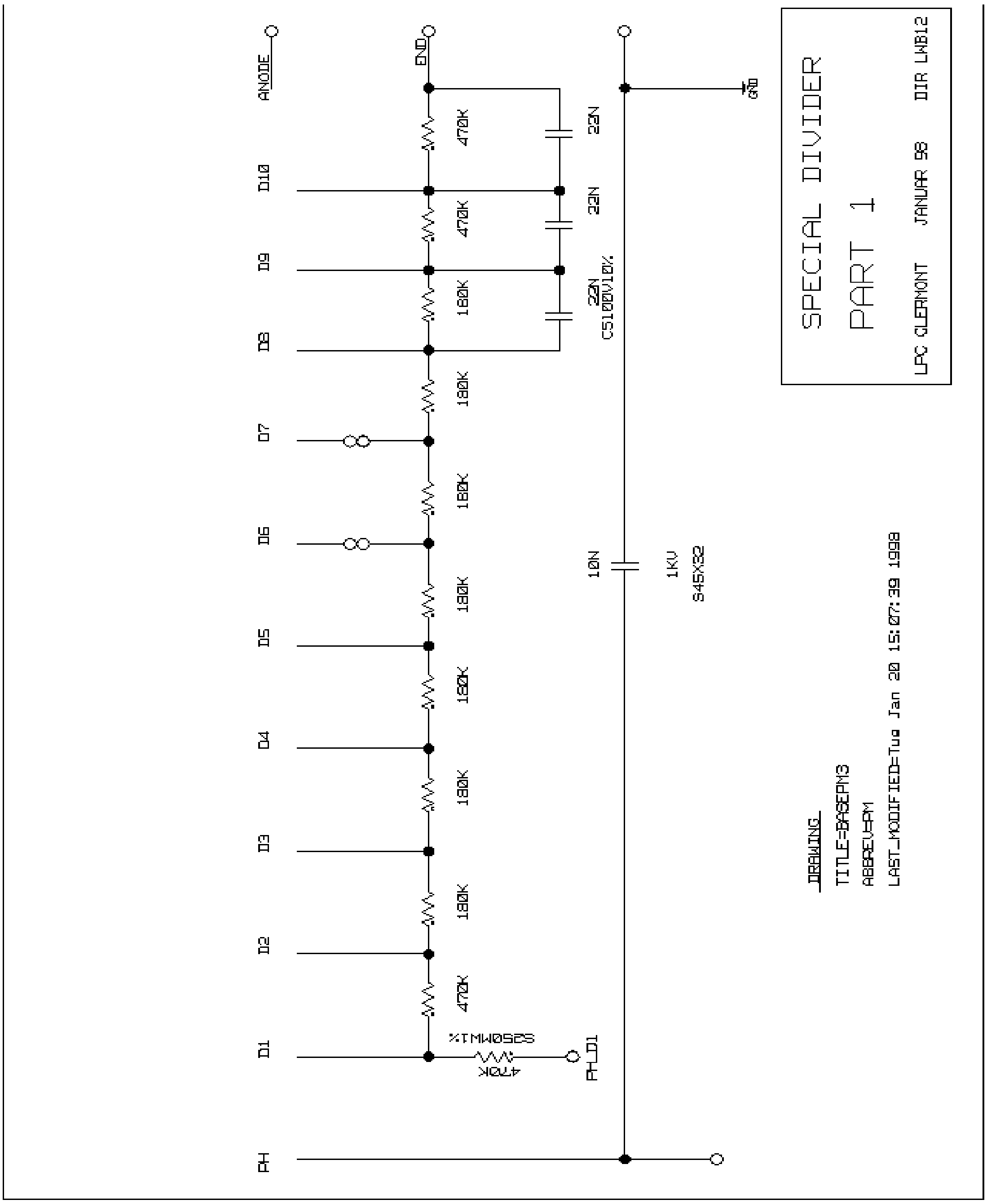
DC Light Splitter view

12 SCHEMATICS

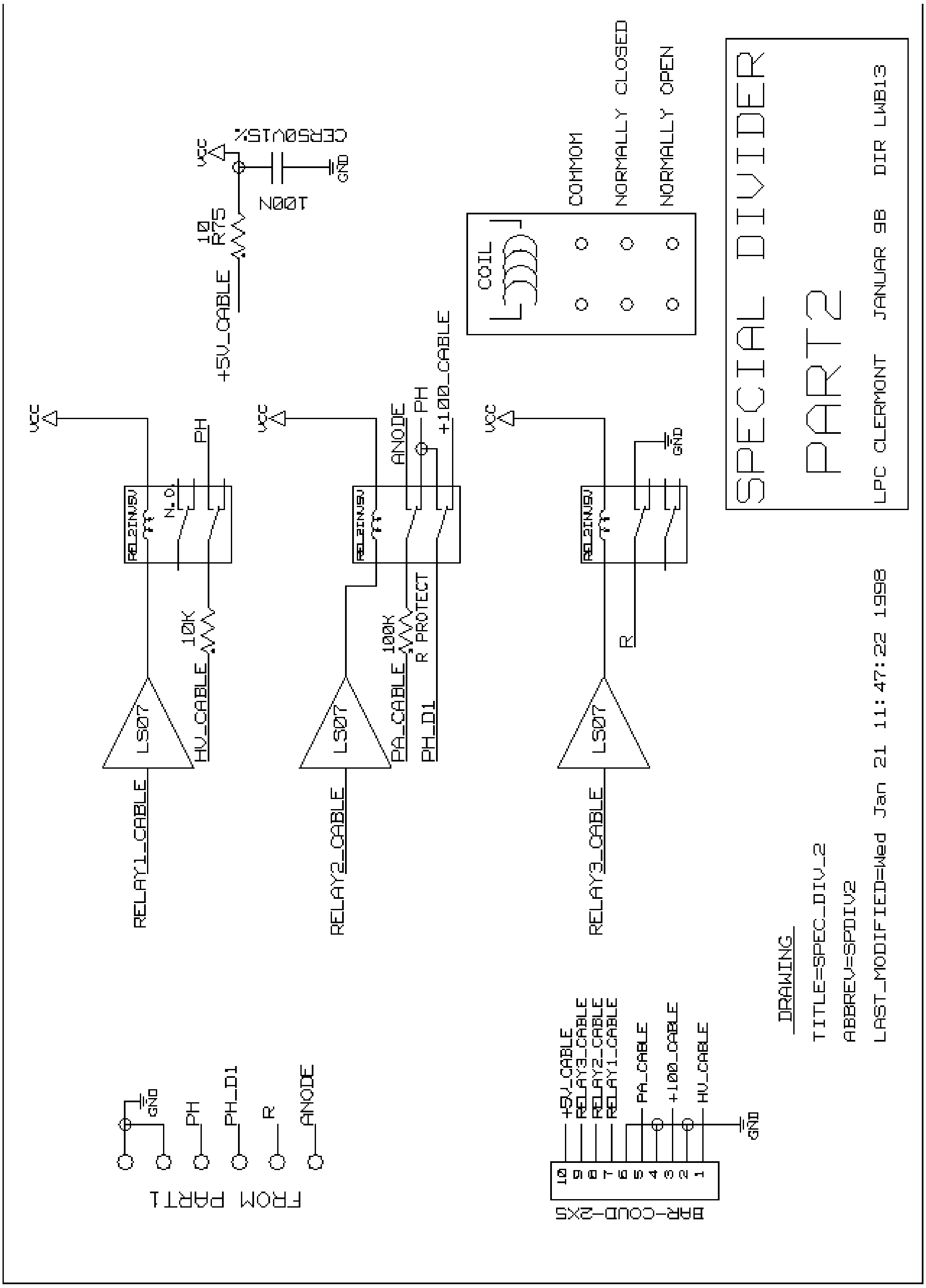


The detailed diagrams given here could be subject to **evolution**.

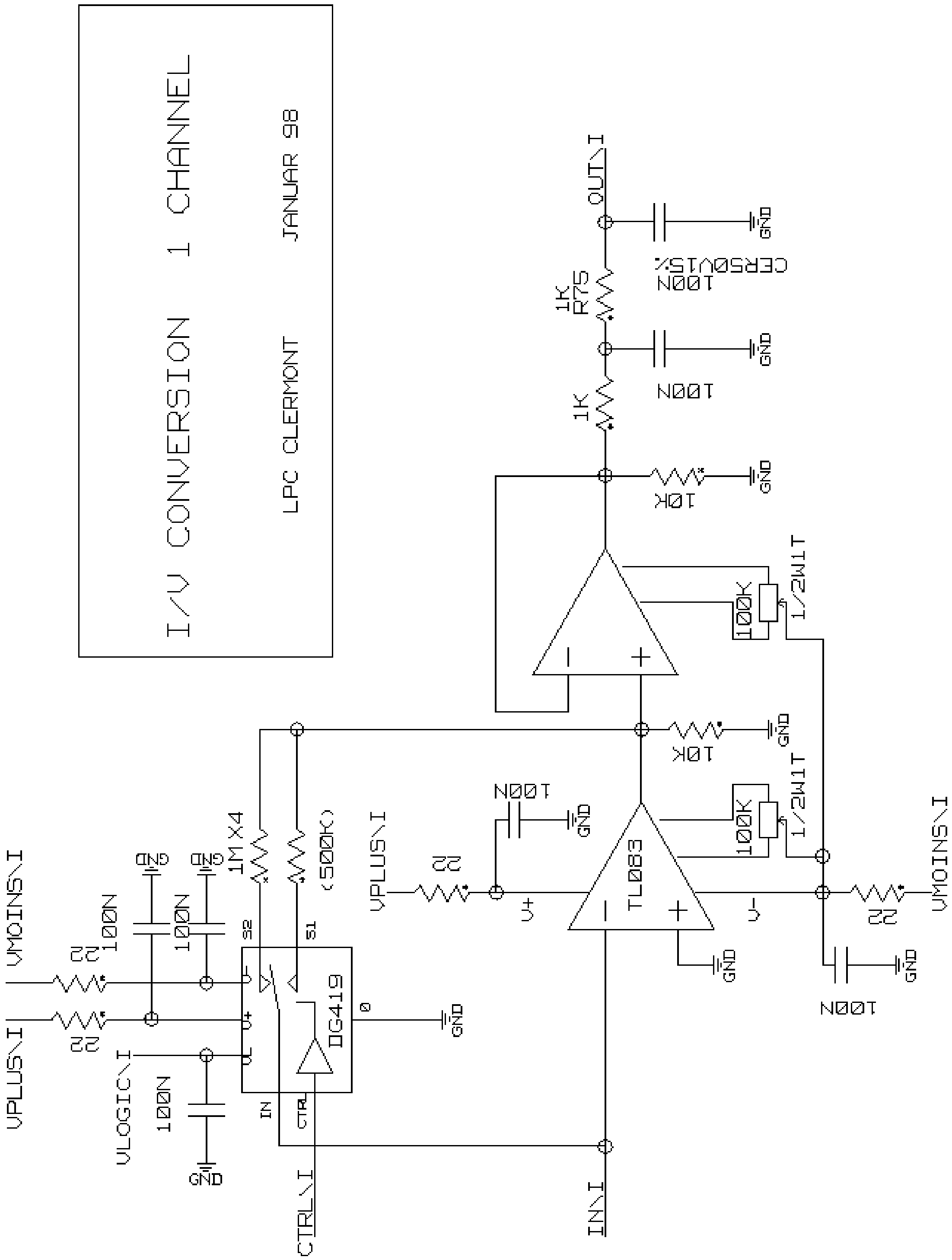
Special Voltage divider for Step 1 as described in section 5 (part 1)



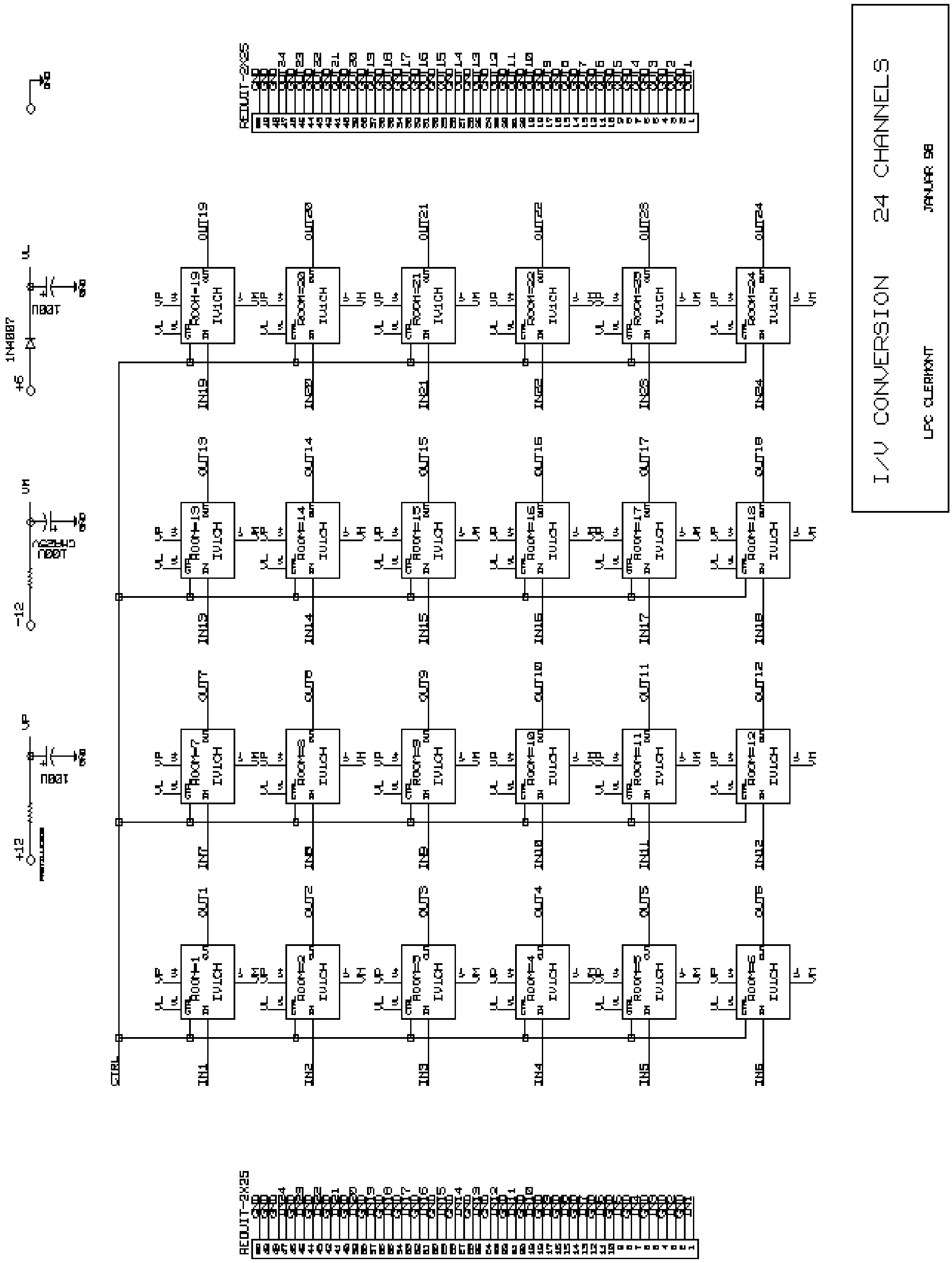
Special Voltage divider for step 1as described in section 5
(part 2)



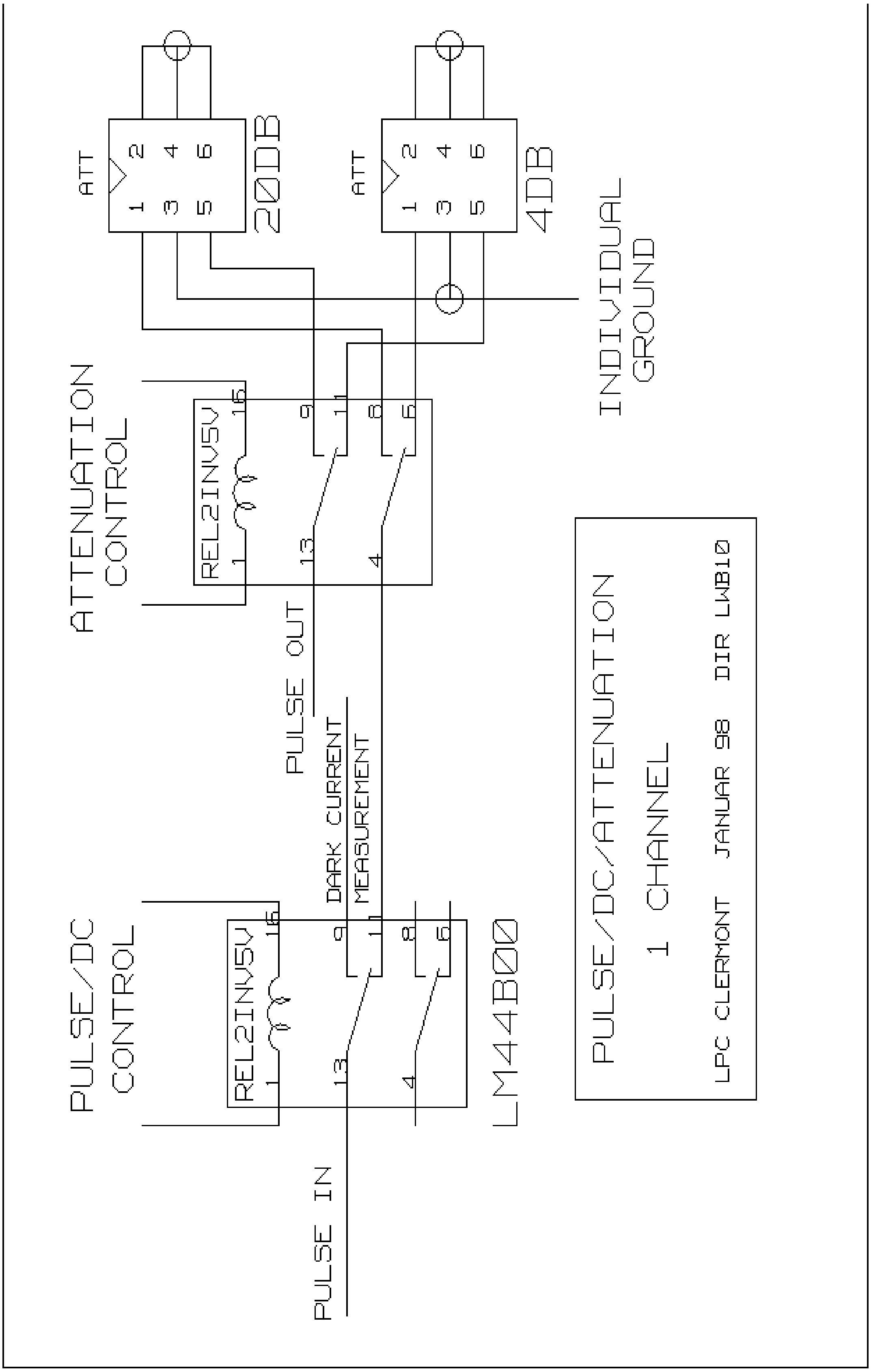
I to V converter as described in section 6-b-4
(1 channel diagram)



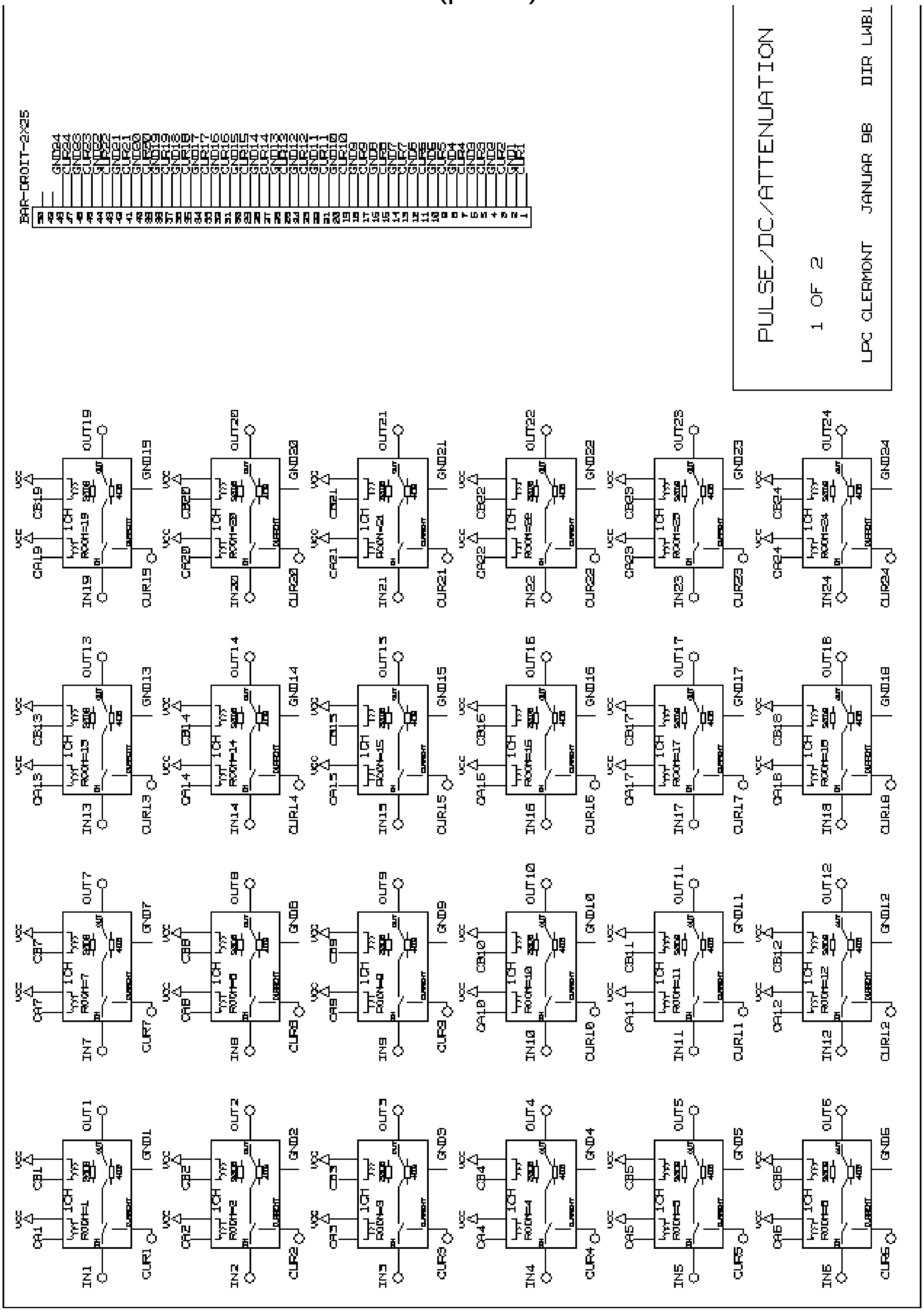
I to V converter as described in section 6-b-4
(24 channels diagram)



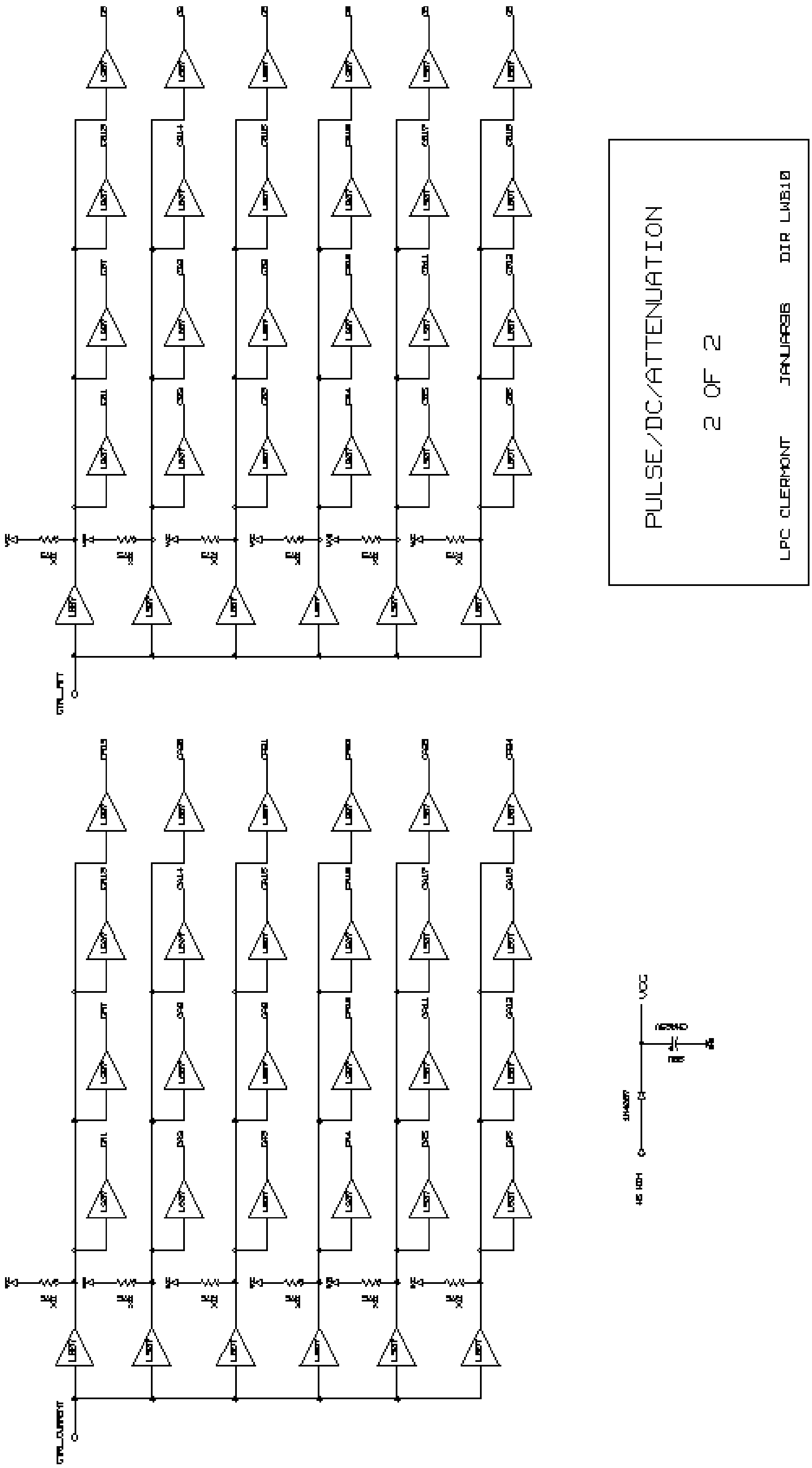
Pulse/DC/attenuation switching for step 2
as described in section 6-b-6
(1 channel)



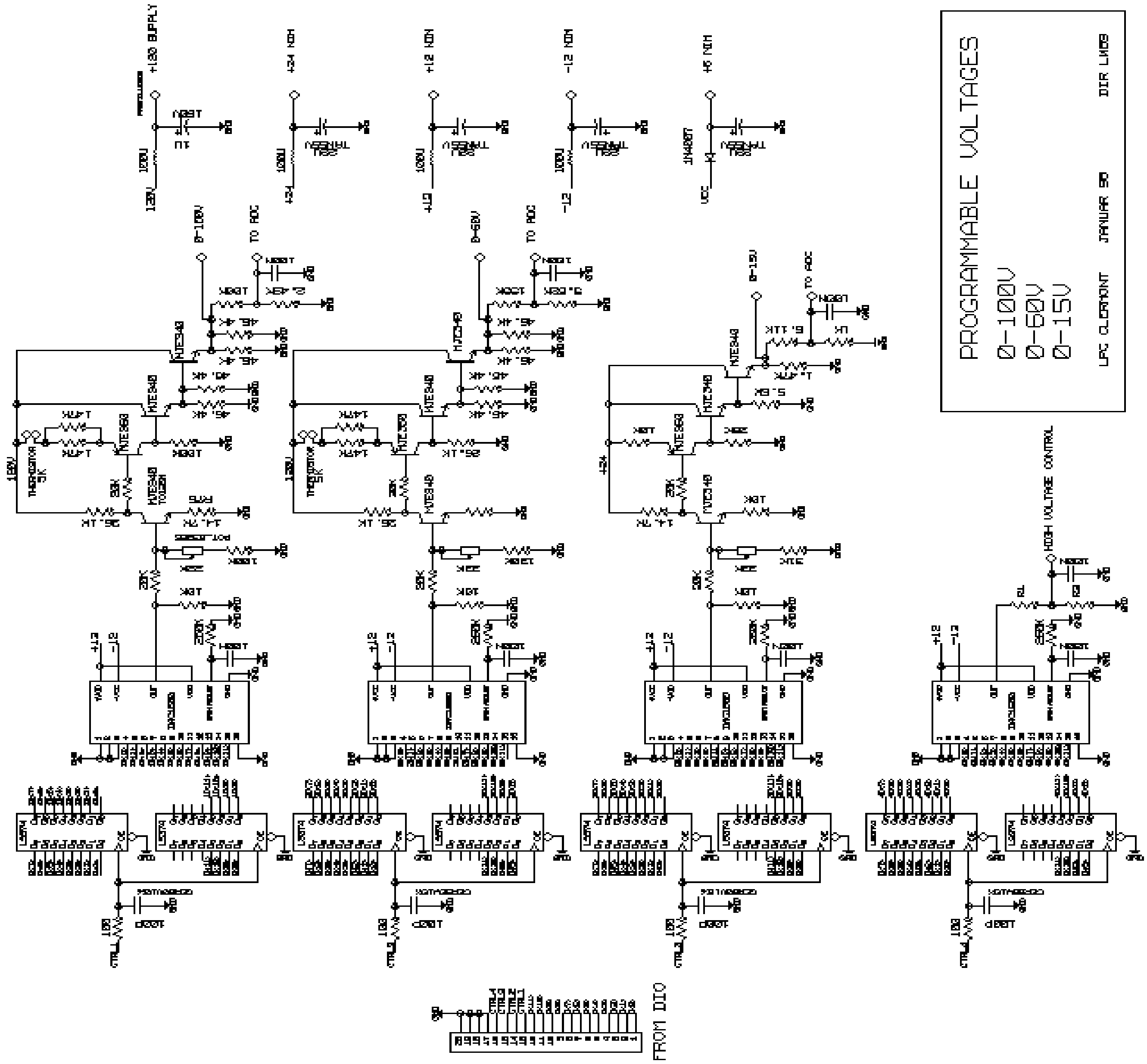
Pulse/DC/attenuation switching for step 2
as described in section 6-b-6
24 channels
(part 1)



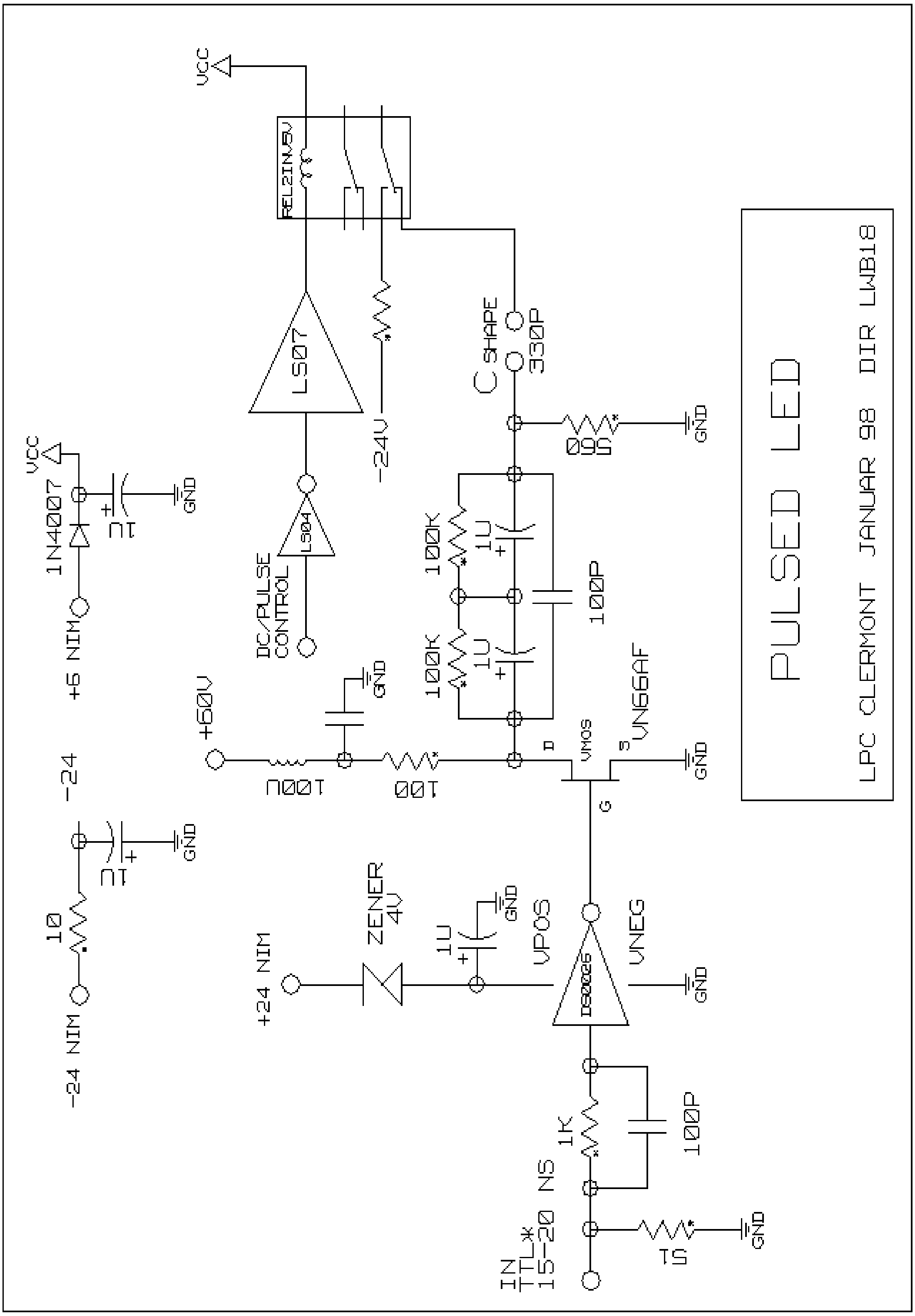
Pulse/DC/attenuation switching for step 2
as described in section 6-b-6
24 channels
(part 2)



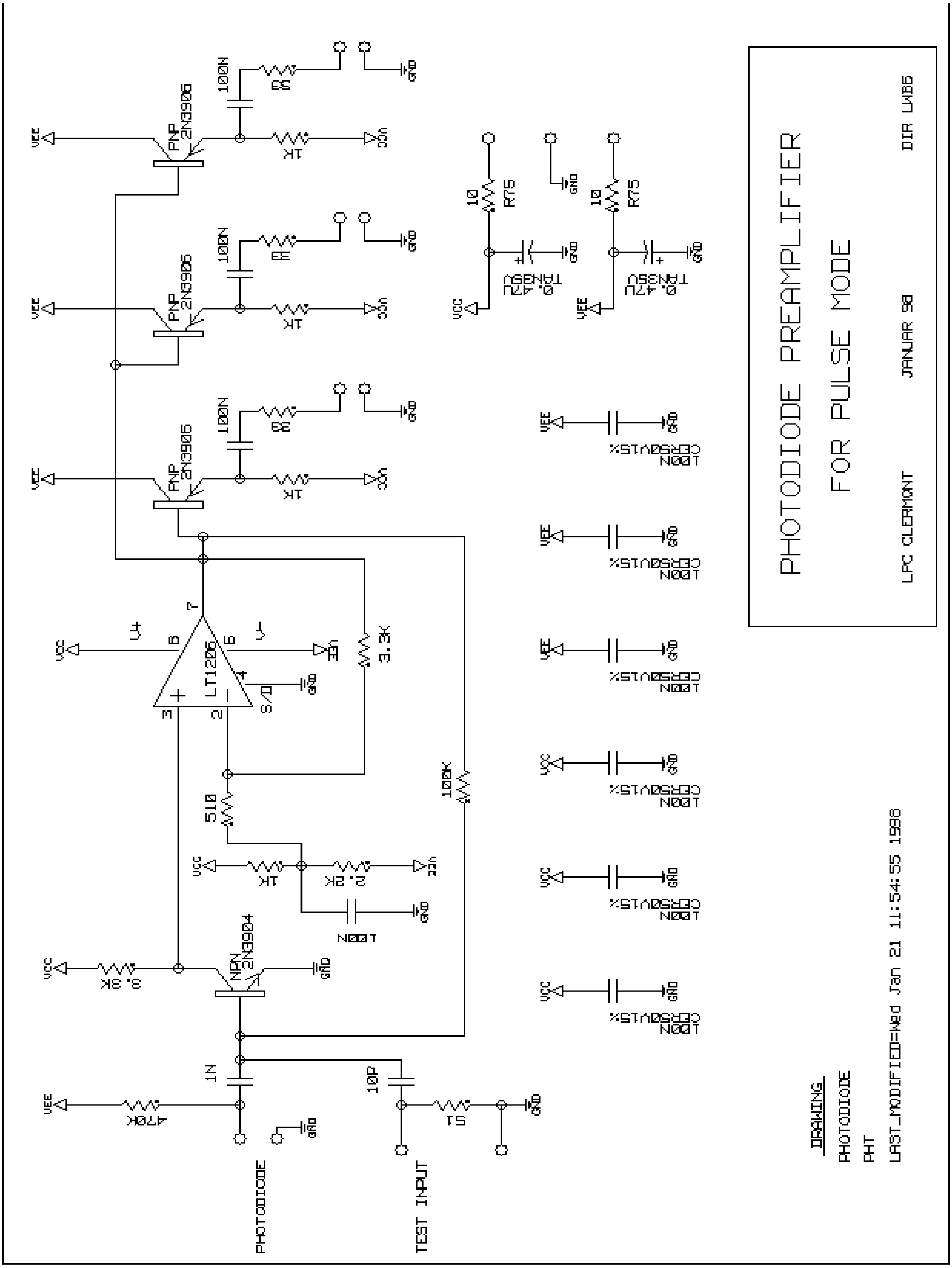
Programmable Voltages Unit
as described in section 6-b-2



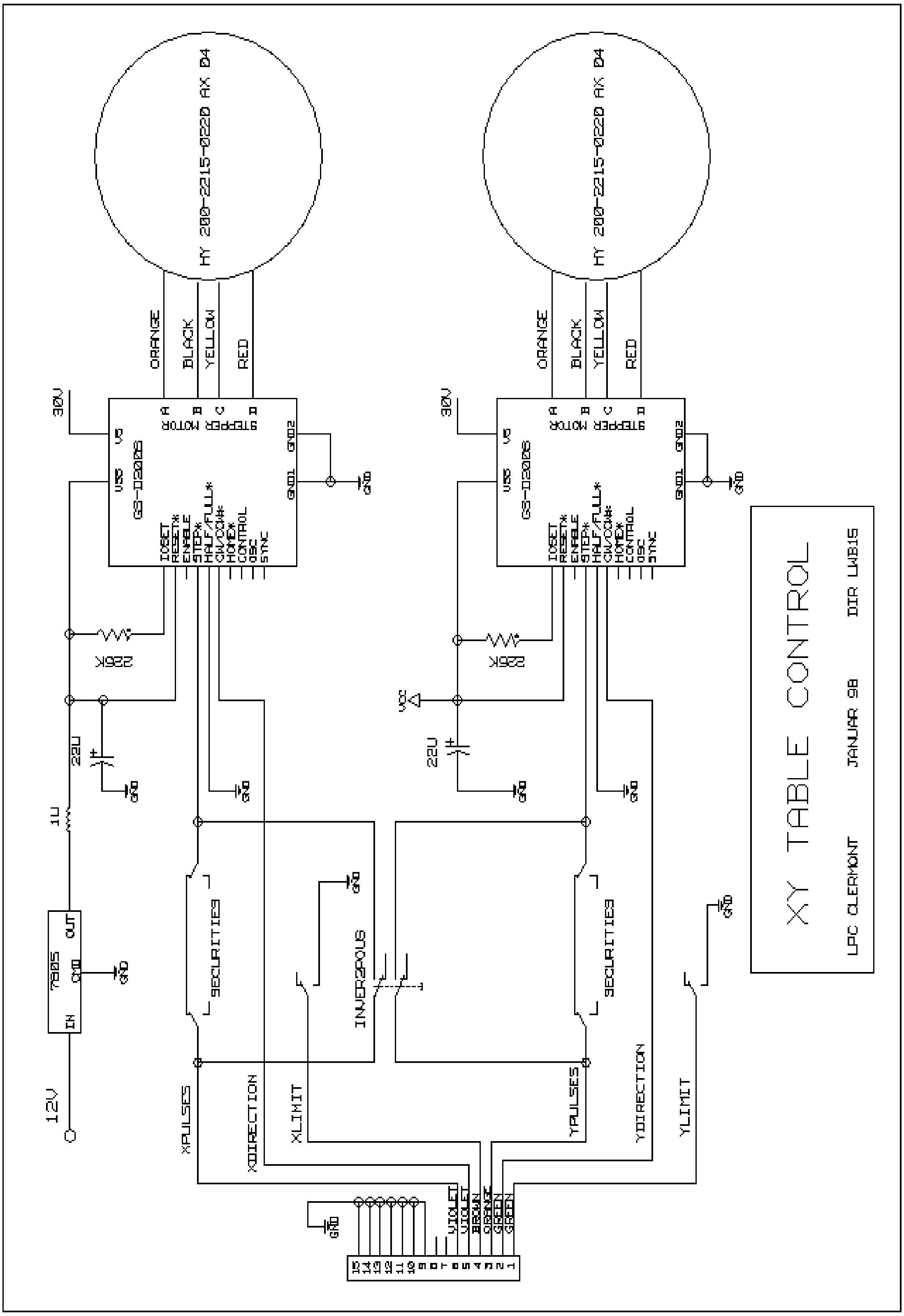
Pulsed LED command



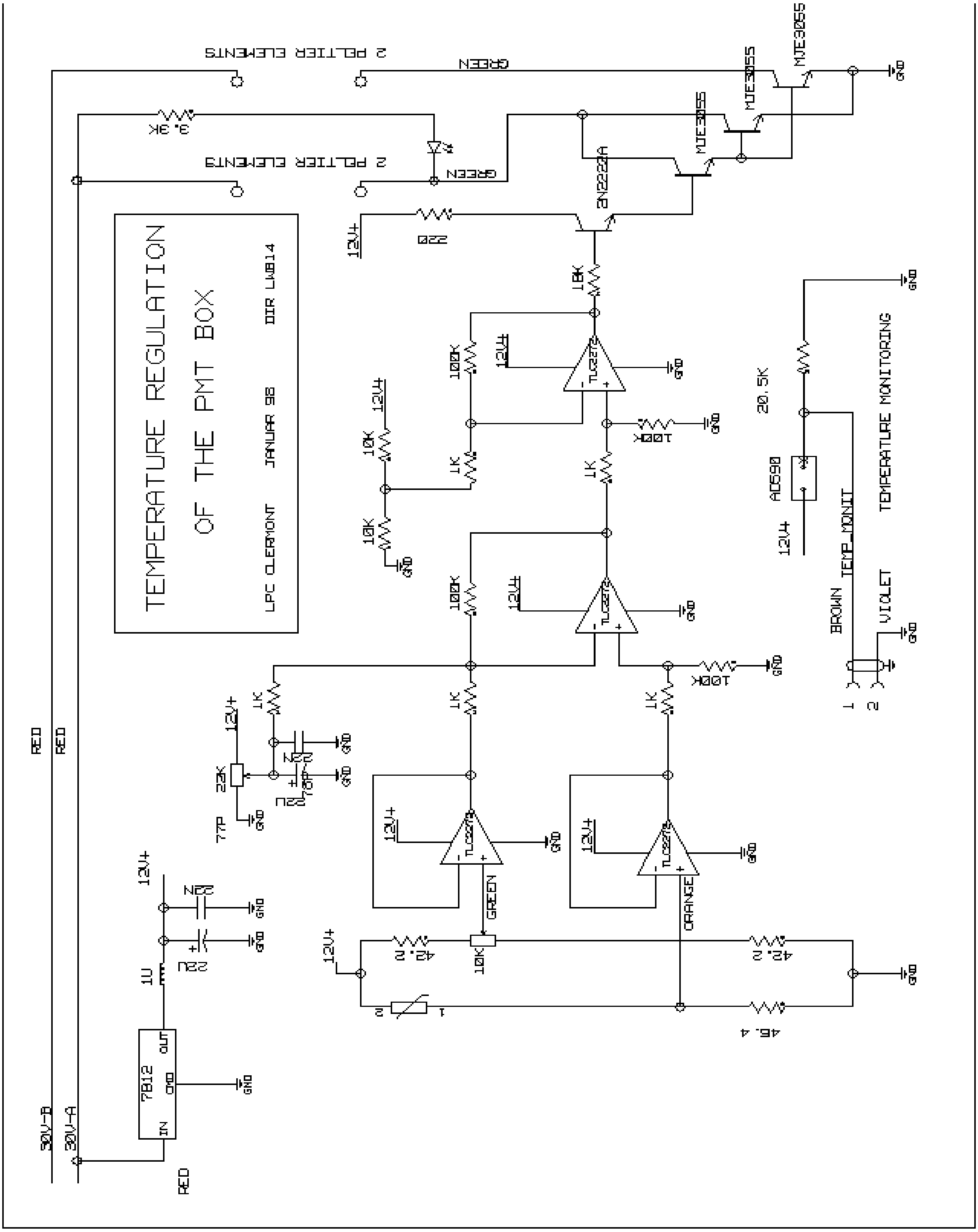
Photodiode preamplifier
(pulsed mode)



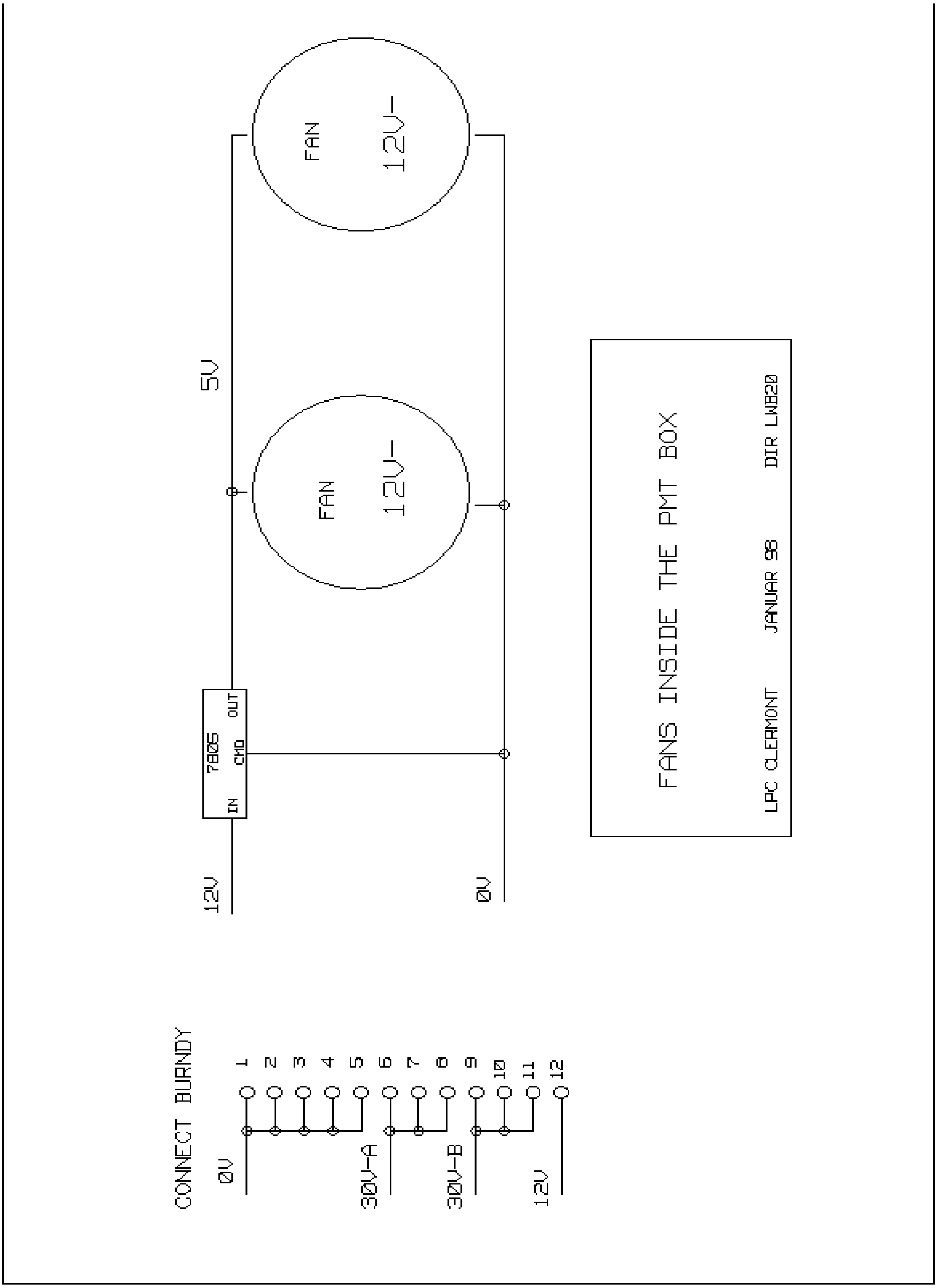
X-Y table control



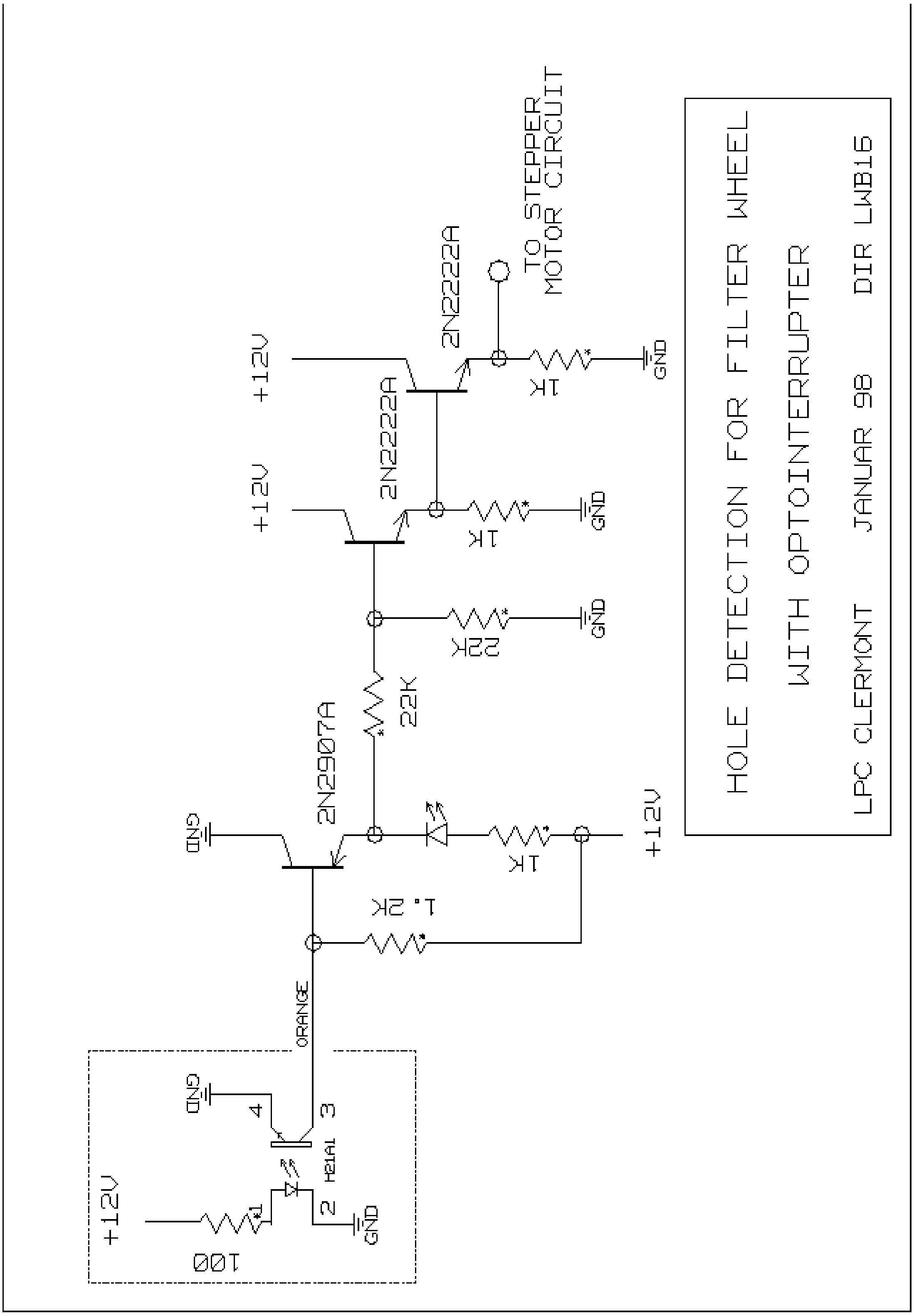
PMT box temperature regulation



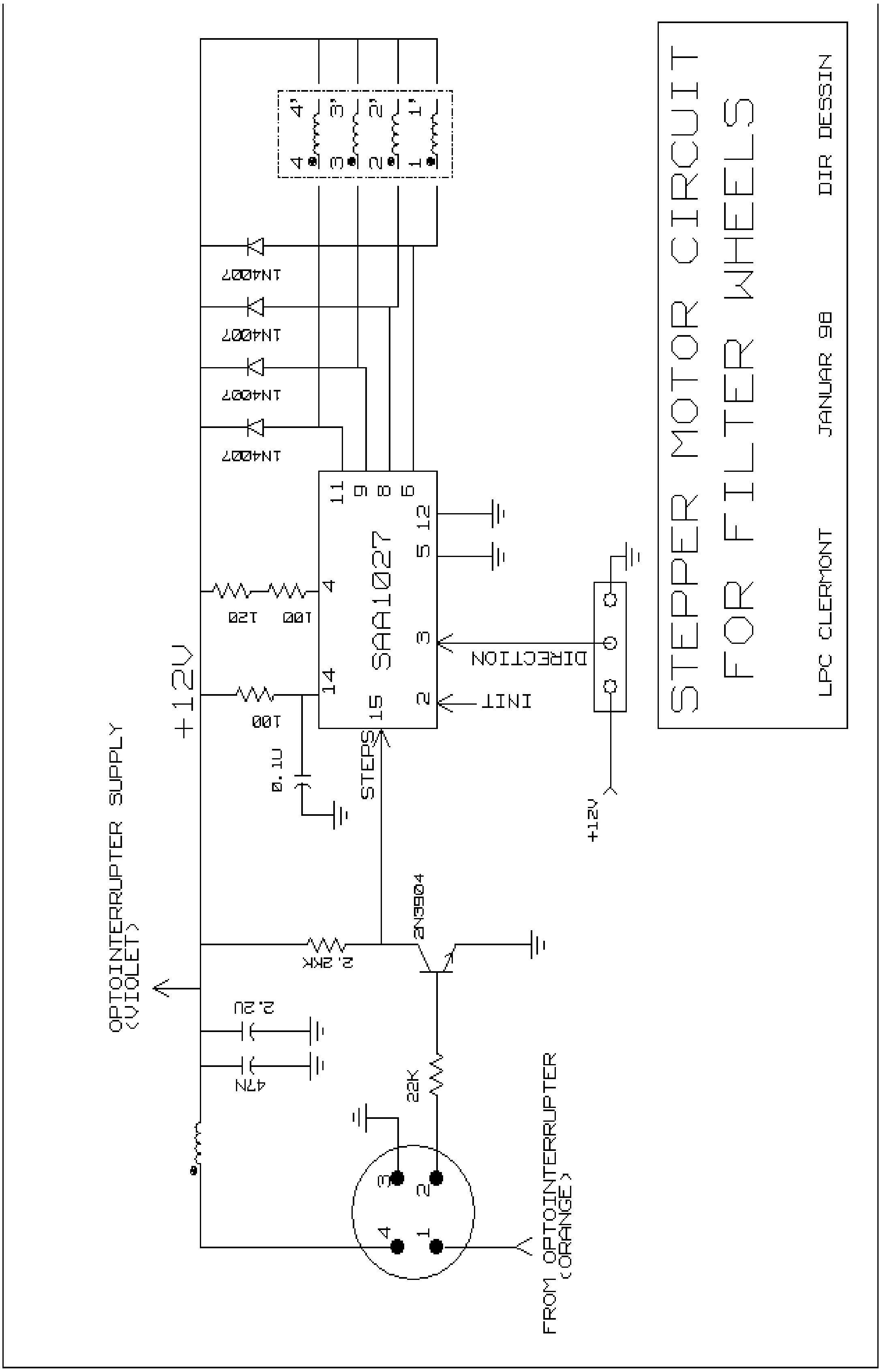
PMT box fans control



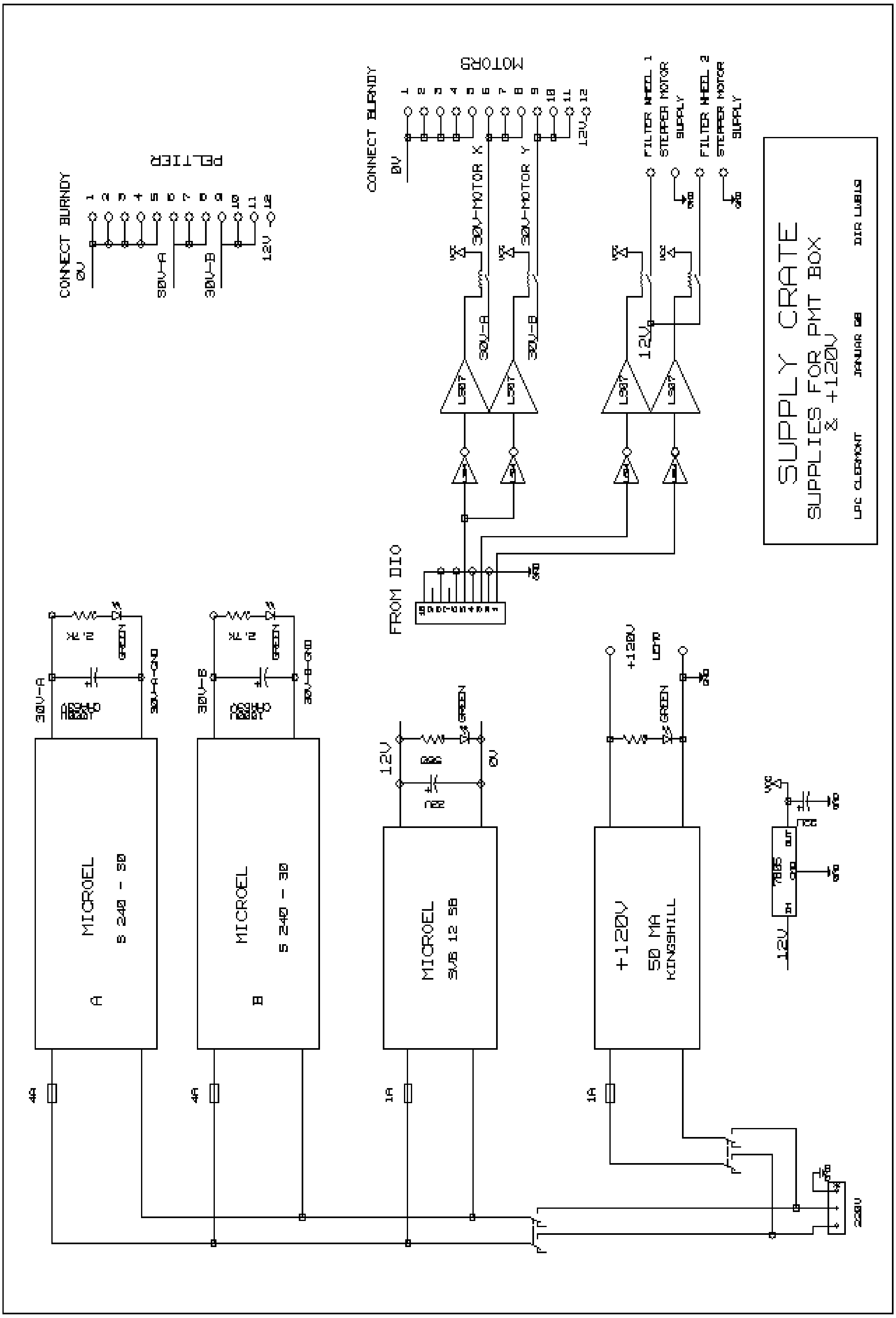
Filter wheel position control
(optointerrupter)



Filter wheel stepper motor control



Supply crate for PMT box voltages



Lecroy HV4032 unit control by current loop
as described in Section 6-b-1