

Test results of Wide Spectrum Neutron beam Test at UCL

Performed on Caen HV module A877 on 27 June 2000

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Abstract

An irradiation test was performed at the $p(65)+\text{Be}$ neutron beam¹⁾ at the CYCLONE machine in CRC-UCL, on a high voltage power supply prototype. The neutron beam was obtained by 65 MeV protons on Be target. The energy spectrum of neutrons was roughly flat up to 65 MeV, with ~70% of neutrons flux above 20 MeV.

The total fluence for the test amounted to 10^{12} neutrons/cm². The test put in evidence that the control, monitoring and communication circuitry was hard enough to stand a factor of irradiation $\approx 10^3$ with respect to the foreseen fluence in the balcony region of the CMS Barrel. It was also clear that the series HV regulating elements were not suited to the same environment.

Test Setup

In fig.1 is sketched the geometrical layout of the prototype A877 module where the irradiated area is highlighted. In fig. 2 it is shown the principle scheme of a regulating cell; four cells are used for Anode channels, two are used for Strip and Cathode channels.

During the test all the voltages, currents and status parameters of the 48 channels of the module were registered in a file every 10 seconds.

The irradiation area was 25X25 cm² covering the zone of the CPU controller and the first 4 HV Macrochannels 0÷3 (16 channels in total).

At the start of test Macrochannels 0÷3 were loaded, with nominal voltage settings:

- Mch 0 and 1 @ +3.8,+3.8, +1.95, -1.75 kV loads 0.5G Ω , 0.5G Ω , 0.5G Ω , 0.2G Ω
- Mch 2 and 3 @ +40, +40, +40, -40 V loads 0.5G Ω , 0.5G Ω , 0.5G Ω , 0.2G Ω

Macrochannels 4÷11 were unloaded with nominal voltage settings:

- Mch 4÷7 @ +3.8,+3.8, +1.95, -1,75 kV
- Mch 8÷1 @ +40, +40, +40, -40 V

Settings were changed along the test duration, in order to spot “bad” channels and check for control stability.

The status and parameters of the A877 CPU controller are automatically refreshed every 1s by the remote supervisor CPU residing in the A876 module. The A877 internal registers are refreshed every 250ms by the on-board CPU controller.

The aim of the test was to reach a fluence of about 10^{12} n/cm² allowing for a conservative safety factor with respect to the foreseen neutron fluence²⁾ at the balcony level, in the cavern around MB4 barrel muon chambers, where the HV power supply system will be located.

The irradiation intensity started with $0.8\mu\text{A}$, passed to $3\mu\text{A}$, and finally to the nominal intensity of $16\mu\text{A}$. The timing and integral neutron fluence along the test are reported in Table 1, as provided by the beam facility personnel.

Results

Data stored during the test were plotted on line to monitor the channels' behaviour

As an example Fig. 3 shows the plots of the whole test period and fig. 4 shows the expansion of the first ~ 2 hours for Mch 0. The pictures are rather complicated by the many variations in the settings of the channels, operated in order to understand the kind of problems along the test.

At a first analysis of the plots, checked against the status files, some facts are evident:

- 1) Since the very beginning (few seconds) of irradiation, several channels failed to regulate the output voltage even outside the directly irradiated region of the module (Mch 4÷11).
- 2) At the end of the test no HV channel was still able to regulate the output voltage in the full nominal range. A partial regulation of the channels was still possible, by applying a voltage setting near the nominal values, where the voltage drop across the VMOS elements was very low.
- 3) The communication, monitor and control functions were maintained essentially all along the test : the settings were changed at random intervals on various channels, while monitor readout of voltages and currents were consistent.
- 4) A number of transitory "events" were detected, that can be grouped in three types:
 - a) ~ 30 events of misreading (0 volt) of a voltage or current value, not time-correlated and recovered into 1 sample period of 10 s by the internal CPU refresh feature. The evidence indicates a SEU in the Σ - Δ ADC internal logic or Data-ready flip-flop, or in the channels' multiplexers address registers.
 - b) Two events of correlated misreading of voltage and currents, concerning Mch 0÷3. The channels were already all "bad" but set to, and reading out, nominal output voltages and currents. The "events" consisting in fully time-correlated reading as would be expected for 0 V settings. Most probably a SEU occurred in the reset logic common to the on/off control flip-flops of Mch 0÷3, simulating a 0 volt setting.
 - c) One event consisting in "unplugged" status response from the whole module, meaning that communication was lost. This was the only occasion where the control was lost, possibly due to a latch-up event or to a SEU in the CAN-BUS protocol chip which could be recovered only by switching off/on the power.

Events of type a) and b) were recovered into one refresh cycle. Concerning the event in c), a built-in current limitation is implemented in the module to prevent damages to the devices. An automatic recovery procedure for such a type of problem is not implemented at present and will be implemented in the slow control software of the final HV system.

The device responsible for the problems in 1) and 2) is the MTP-3N120 VMOS device used as a series regulating element in the channels (fig.2)

The intrinsic leakage current of such a device, has been measured on a bunch of ~ 200 pieces to be $50\text{nA} \leq I_{\text{leak}} \leq 100\text{nA}$ @ 800V, and $150\text{nA} \leq I_{\text{leak}} \leq 200\text{nA}$ @ 1200V.

After the irradiation all the devices were tested for leakage currents at nominal voltage of 1kV. Out of 144 devices 28 resulted to have the Gate short-circuited to the channel, while the rest showed values of I_{leak} in the range of several tens of μA .

For five devices the V/I_{leak} characteristic is shown in fig. 5. Given the $100\text{ M}\Omega$ value of the voltage divider, such an increase of the I_{leak} causes a voltage drop across the divider big enough to destroy the regulating capability of the channel.

Conclusions

From the test results it is clear that the VMOS devices are the weak component. The de-rating factor applied to their operating voltage was largely not sufficient to protect them from irradiation effects. A de-rating factor about $2 \div 3$ should probably be applied, but this would lead to a proportional increase in the number of cells and to a prohibitive increase of module volume and cost.

Hence it has been decided to substitute the VMOS components with bipolar HV transistors to be checked in a forthcoming irradiation test.

Table 1

Charge on target x 100nC	Tstart	Tstop	Δt (s)	Nominal I μA	flux x 10^9 n/cm ²	Incremental fluence x 10^{10} n /cm ²
11632	12:02:18	12:26:21	1443	~0.8	3.2	0.32
7084	13:06:53	13:15:48	535	~0.8	1.9	0.51
43556	13:17:24	14:41:38	1454	~3	11.9	1.7
907588	13:47:35	15:22:10	5710	~18	247.1	26.4
919220	15:24:11	16:57:50	5619	~16	250.2	51.4
919218	16:59:26	18:33:12	5626	~16	250.2	76.5
868072	18:47:06	20:32:00	5703	~16	236.3	100.1

References

- 1) Improvement of a p(65)+Be neutron beam for therapy at CYCLONE, Louvain la Neuve
JP Meulders, Phys. Med. Biol. 1983, Vol. 28 No. 6, 685-691
- 2) CMS NOTE 2000/068, Tab.5 R=10-11, Z=0-6
(<http://cmsdoc.cern.ch/~huu/fws.ps>)

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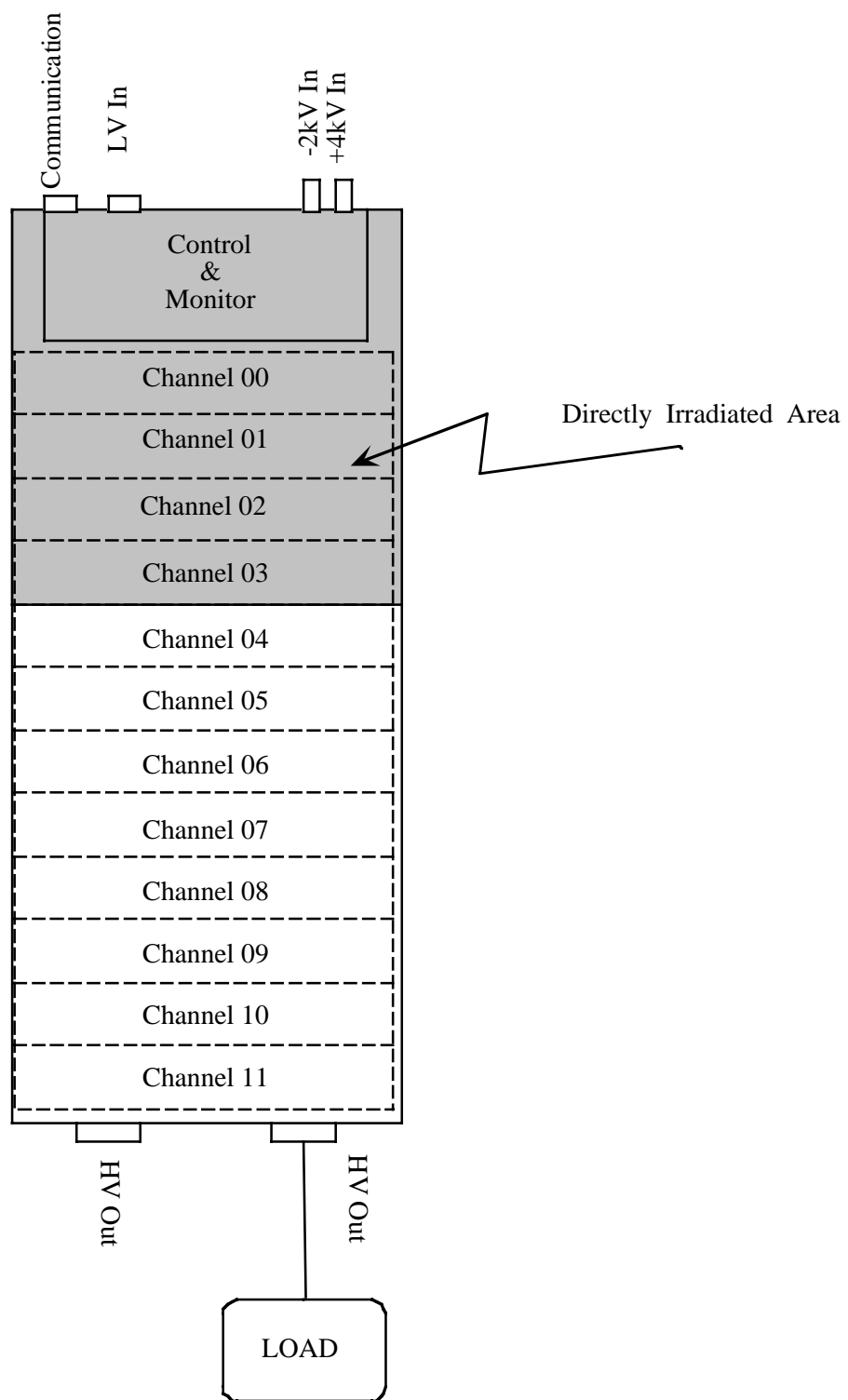


fig. 1 Layout of A877 Module

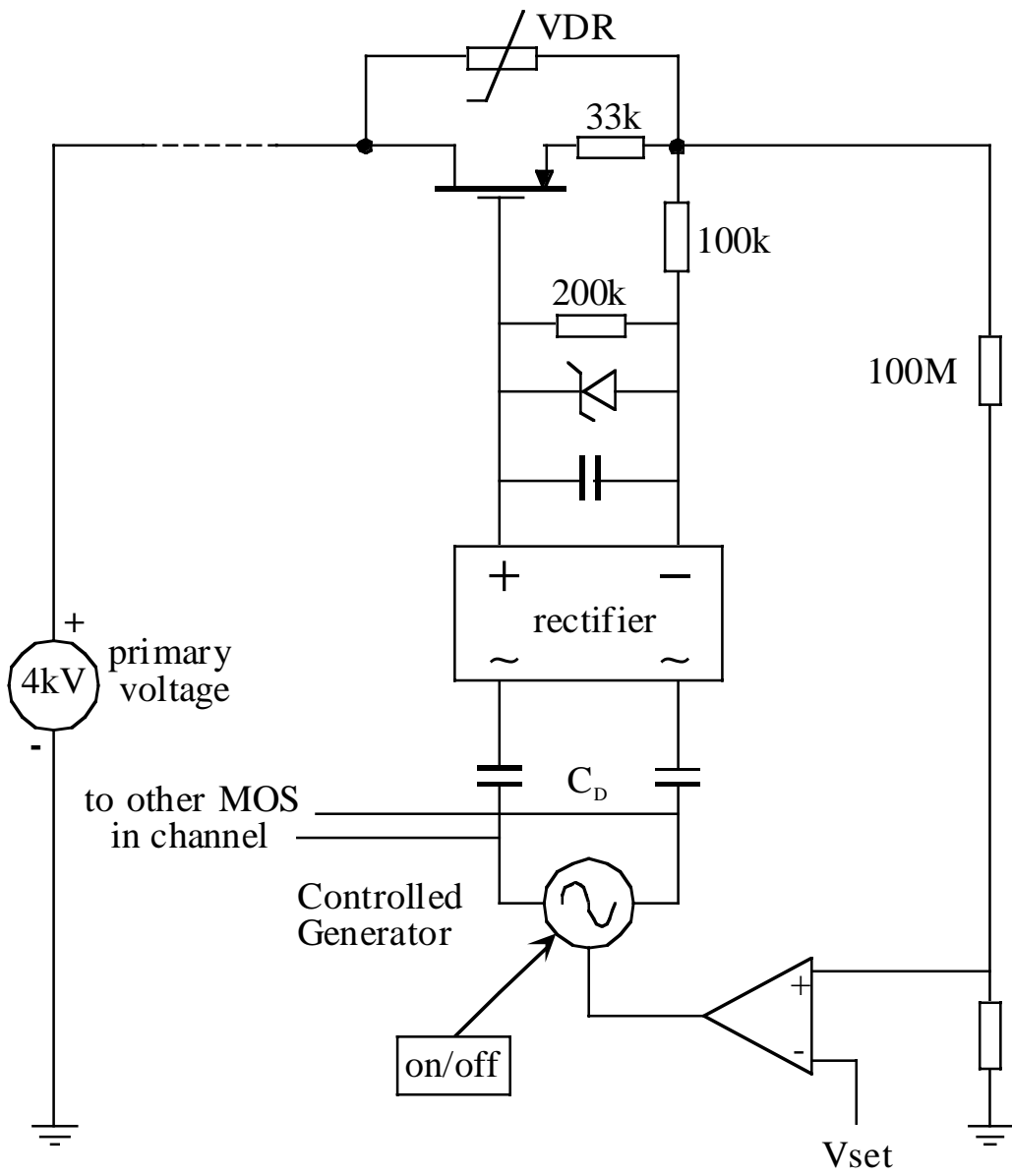


fig. 2 Anode channel MOS regulator of A877 Mod.

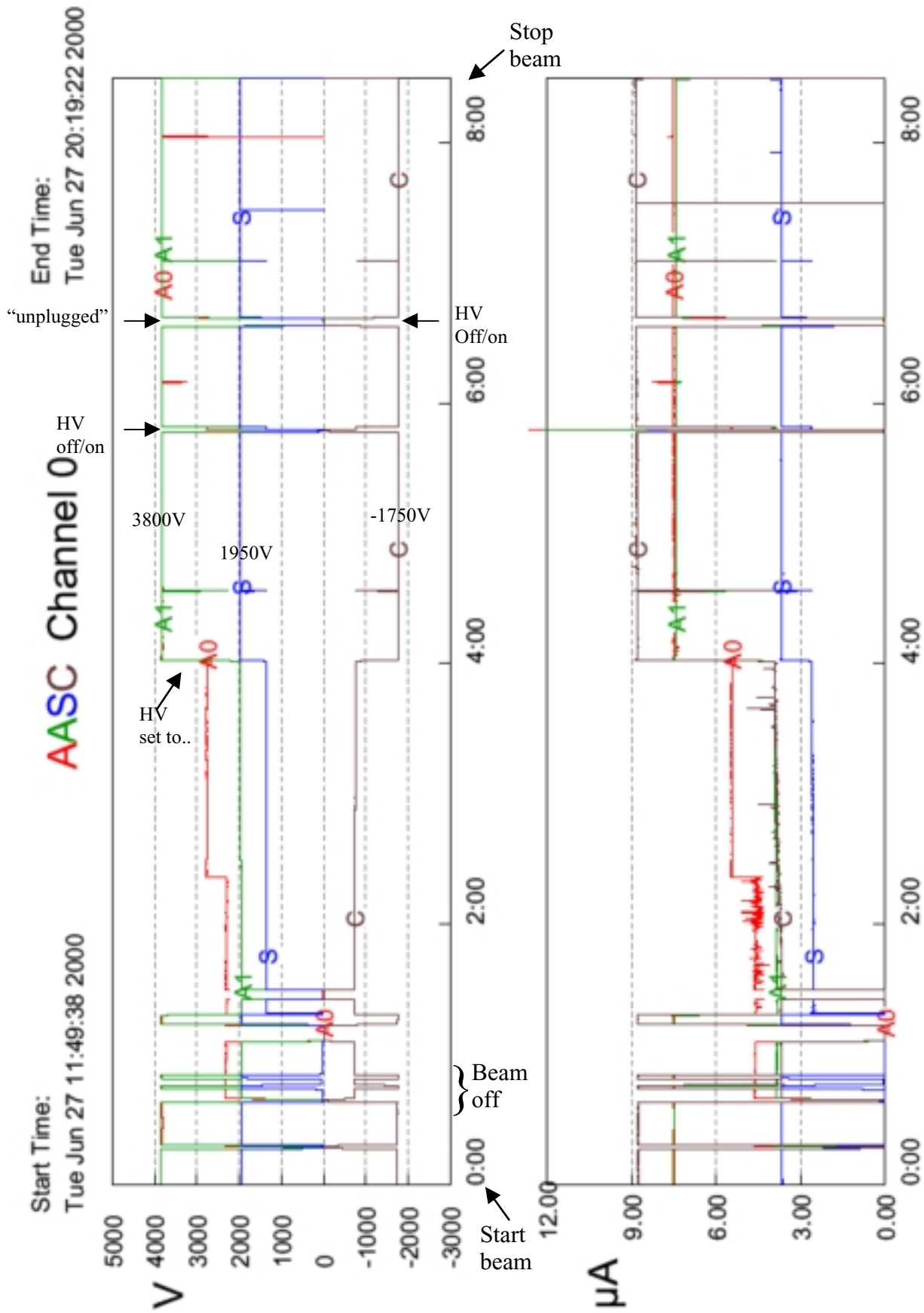


Fig. 3

Start Time:
Tue Jun 27 11:49:38 2000

AASC Channel 0

End Time:
Tue Jun 27 13:48:26 2000

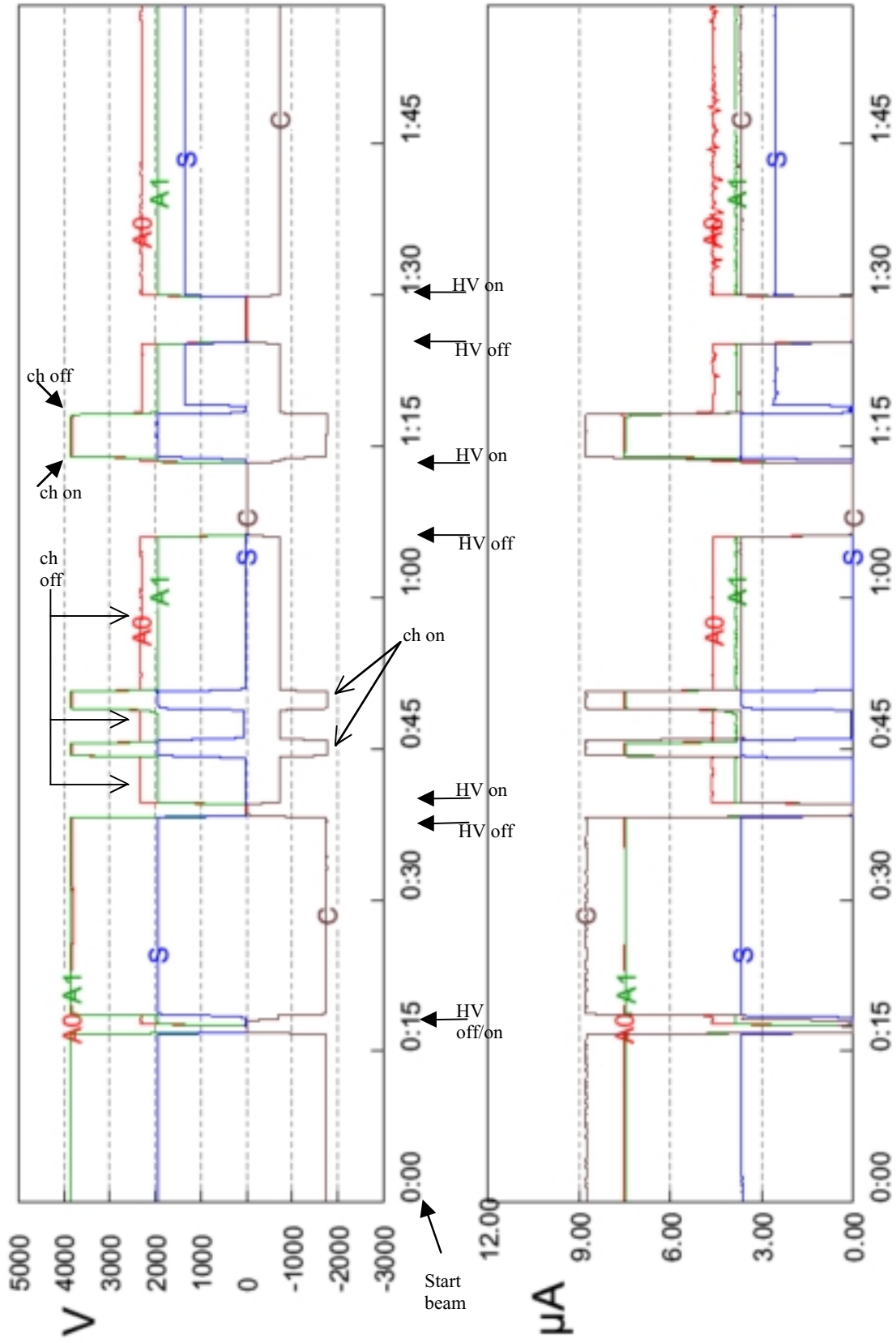


Fig. 4

Fig. 5 Leakage currents versus voltage applied for five VMOS devices

ilk_n = leakage current of MOS n ; V_{dsn} = drain-source voltage of MOS n

vin V	ilk1 μA	Vds1 V	ilk2 μA	vds2 V	ilk3 μA	vds3 V	ilk4 μA	vds4 V	ilk5 μA	vds5 V
10	0,23	9,77	0,11	9,89	0,1	9,9	0,08	9,92	0,12	9,88
20	0,41	19,59	0,21	19,79	0,22	19,78	0,17	19,83	0,23	19,77
40	0,69	39,31	0,35	39,65	0,54	39,46	0,32	39,68	0,41	39,59
100	1,80	98,2	0,85	99,15	1,74	98,26	0,68	99,32	1	99
200	4,90	195,1	1,8	198,2	4	196	1,38	198,62	2,37	197,63
400	25,00	375	4,45	395,55	10	390	3,15	396,85	7,97	392,03
500	48,00	452	6,95	493,05	15,5	484,5	4,64	495,36	16	484
600			11,4	588,6	27,23	572,77	9,01	590,99	40	560
700			19,8	680,2	46,7	653,3	18,7	681,3		
800			34,6	765,4			33,7	766,3		
900			56	844						

