Test results on 60 MeV proton beam at CYCLONE - UCL
Performed on CAEN HV prototype module A877
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Introduction

The test performed on a A877 module on 25 Oct. 2000 1) at 60 MeV proton beam at CYCLONE - UCL put in evidence that the Control, Monitoring and Communication systems worked properly while being irradiated with an integrated fluence of $5*10^{10}$ n/cm^2. At the same time the two solutions of high voltage regulators based respectively on a DC-DC voltage multiplier and on a npn HV transistor passed positively the test. The solution based on the IGBT device failed since the start of the test, proving to be unsuitable for the CMS Barrel Muon HV system.
As the solution based on the npn HV transistor allowed for marginal changes in the module structure, a full module has been built based on this solution.

Following the recommendations in 2), a test with a 60 MeV protons beam has been set up at the CYCLONE machine in UCL.
With reference to the same document the TID at the level of the balconies (MB4), where the high voltage regulating modules will be located, is estimated to be ~40 Rads referred to 10 years (5 x 10^7 sec) of CMS operation at full luminosity. TID and displacement damages are considered negligible 3) given the dose and the particle fluence well below the critical $3*10^{11}$ level, also for the NPN transistors. SEEs are considered for particle energies above 20MeV 4), with a total particle fluence about 10^9/cm^2 at the barrel balconies' level, in the cavern.
All the electronics located on the balconies is neither required nor designed to be rad hard, on the other side a fluence of 10^{11}/cm^2 60 MeV protons carries a TID of 14 kRads 1), which is about 3 orders of magnitude higher than the dose foreseen in the CMS-BMU environment.
In order to limit TID to an affordable level, a target integrated fluence of ~$5*10^{10}$p/cm^2 (TID ≈ 7kRads) has been chosen for the test, compromising between safety factor (~50) in flux and an affordable TID.
The layout of the new prototype is essentially the same as it was in the first full prototype 1).
The npn HV transistors used as regulating elements are the BUH2M20AP by ST.

Set Up

Fig.2 shows the channels layout: the lower portion allocates the Anode circuits, while the higher portion allocates the Strips and Cathodes. As the beam diameter was about 9 cm, the irradiation of the module had to be performed in several steps, so to allow for each channel to receive the foreseen fluence.

In order not to exceed the foreseen maximum TID it was decided to use a collimator. The window was dimensioned in such a way that the sensitive regulation circuitry of two adjacent Anodes or one Strip and one Cathode of the same Macrochannel were fully covered in each irradiation step, as shown in fig. 1.

In the case of Strip and Cathode also the local Monitor circuitry was included, while for the Anodes a part of it exceeded the collimator window. Anyway all the monitor circuitry was already successfully checked in a previous test1).

With reference to fig.2, the channels were irradiated in 12 steps (I ~XII); the CPU board was also irradiated in two steps (β,γ) and, just for cross-check, the local Monitoring circuitry exceeding the collimator window of Anodes 2-3 was also irradiated in an additional step (α).

The basic scheme of one regulation cell is shown in fig 3a and 3b respectively for a positive and a negative channel.

Each step ranged to an actual fluence of $5*10^{10}$ n/cm^2.

The test was performed without any load on the channels and with output settings near the off condition:

Anodes +200 V
Strips +100 V
Cathodes - 100 V

representing the heaviest working conditions for the series regulating devices.

The settings of each solution were not changed during the relative test period.

The time period allowed for the test was 6-7 hours . The useful beam diameter was about 9 cm and the flux was set to ~ $5*10^7$/cm^2 *s.

Before the start of irradiation, the module was switched on to check various initial conditions:

- channels offsets with only LV on
- Test voltages @ +200V, +100V, -100V
- nominal output voltages @ +3800V, +1900V, -1900V

The voltage, current and status of the channels were recorded for reference. Examples of voltage and current diagrams of Macrochannel 2 are shown in fig.4, fig.5 and fig.6 for the three conditions respectively .

The irradiation of the channels took place on 27 June 2001 from 15:30 to 21:02 (I ~XII), the rest was carried on the day after (α,β,γ) from 15:45 to 16:57.

The status and parameters of the A877 CPU controller were automatically refreshed every 1s by the remote supervisor CPU residing in the A876 module, while the A877 internal registers were refreshed every 250ms by the on-board CPU controller, this feature of the modules dealing transparently with the SEU category.

Channel currents, voltages and status were automatically filed every 1 second, and plots displayed on line, to monitor the circuits for single event effects. Examples of voltage and current diagrams during the test are reported in fig.7 and fig. 8 for step II, and in fig9 and fig.10 for step XI. Fig.11, fig.12 and fig.13 show the voltage and current diagrams of Macrochannel 2 (A20,A21,S2,C2) during steps α,β,γ.

In fig.14, fig. 15 and fig. 16 are shown as examples, the voltage and current diagrams for Macrochannel 2 , 7 and 11 during the post-irradiation check at nominal votages and load..

Results

All along the test no SEE of any kind was detected. Only a transitory increase of Strip currents to ~100nA was seen during irradiation, that promptly dropped to the previous value as the beam went off.

Immediately after irradiation the module has been checked at full voltage outputs under load:

Anodes: +3800V @ 1.0 GΩ
Strips: +1900V @ 0.5 GΩ
Cathodes: -1900V @ 0.2 GΩ

Showing full consistency of readings.

The test was performed in three steps: in the first step were loaded MC0÷MC3, in the second MC4÷MC7, in the third MC8÷MC11.

A long term test was carried on the module a few weeks after irradiation, showing no deterioration in stability and performance.

MTBF evaluation

Single Event Effects of a non repairable type are the ones that can strongly affect the reliability and efficiency of a large and distributed system like the HV power supply tree of the CMS BMU drift tube detector.

The evaluation of the mean-time-before–failure parameter of such a system depends by the number of failures occurred during the test, extrapolated to the actual consistency of the final system and its foreseen lifetime.

The foreseen neutron fluence above 20 MeV in 10 calendar years of LHC full luminosity operation, in the region where the HV modules will be lodged, is 10^9/cm^2 over $5*10^7$ sec. As the integrated fluence in this test was $5*10^{10}$ p/cm^2, the full module ran the equivalent of $2.5*10^9$ sec. Being the estimated LHC duty cycle ≈ 1/6, the module ran for an equivalent of 477 calendar years, or 79.4 years of continuous LHC operation.

However, the total consistency of the HV system will be of 250 modules, while only one was subject to the test. The scale factor with respect to the whole system is then 250.

Given the nature of SEEs, a reasonable model to apply is the exponential model$^{5)}$ for which a constant parameter of Failure Rate can be defined.

Having measured 0 SEEs, the method gives a lower limit for the MTBF of the tested devices with a 90% confidence level:

$\mathrm{MTBF}_{t1/1} = \mathrm{T}_{1/1}$ / -ln(0.1) = 79.4*0.434 y = 34.45 years of continuous operation
$\mathrm{MTBF}_{t1/6} = \mathrm{T}_{1/6}$ / -ln(0.1) = 477*0.434 y = 207 calendar years

Scaling to the whole system the lower limit of MTBF becomes:

$\mathrm{MTBF}_{s1/1} = \mathrm{MTBF}_{t1/1}$ / 250 = 50.3 days of continuous operation
$\mathrm{MTBF}_{s1/6} = \mathrm{MTBF}_{t1/6}$ / 250 = 302 days of continuous operation

This figure, taking into account the limited accessibility to the balconies, will grant a sufficient reliability of the HV system with respect to non-recoverable SEEs.

Test results confirm those of the previous test$^{1)}$ indicating that the bipolar transistors show a decrease in the collector reverse currents.

This modification can in principle be induced both by TID and displacement, but the displacement is still negligible$^{3)}$ at the fluence of $5X10^{10}$ p/cm^2 so the TID (~7krad) has to be considered the main responsible of this degradation, which will not happen in the balconies' environment.

As the range of operating currents of the regulating cells is < 200 μA, while the driving circuits can feed much higher base currents, the implied reduction in the β does not affect anyway the functionality of the overall circuit.

References

1) Test results of Wide Spectrum Neutron beam Test at UCL ...

http://edmsoraweb.cern.ch:8001/cedar/doc.page?document_id=303608&version=1

2) A global radiation test plan for CMS electronics in HCAL, Muons and Experimental Hall http://cmsdoc.cern.ch/~faccio/proced.pdf

3) Radiation effects in the electronics for CMS

http://cmsdoc.cern.ch/~faccio/tutorial.pdf

4) Optimisation of the CMS forward shielding CMS NOTE 2000/068

http://cmsdoc.cern.ch/~huu/fws.ps

5) Engineering Statistics Handbook

http://www.itl.nist.gov/div898/handbook/apr/section1/apr161.htm

http://www.itl.nist.gov/div898/handbook/apr/section3/apr311.htm

http://www.itl.nist.gov/div898/handbook/apr/section4/apr451.htm

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Federico Faccio of RD49/COTS project, for his efforts in putting into efficient operation this collaboration, and for his constant help all along the test.

Positioning of collimator windows with respect to sensitive components of HV channels

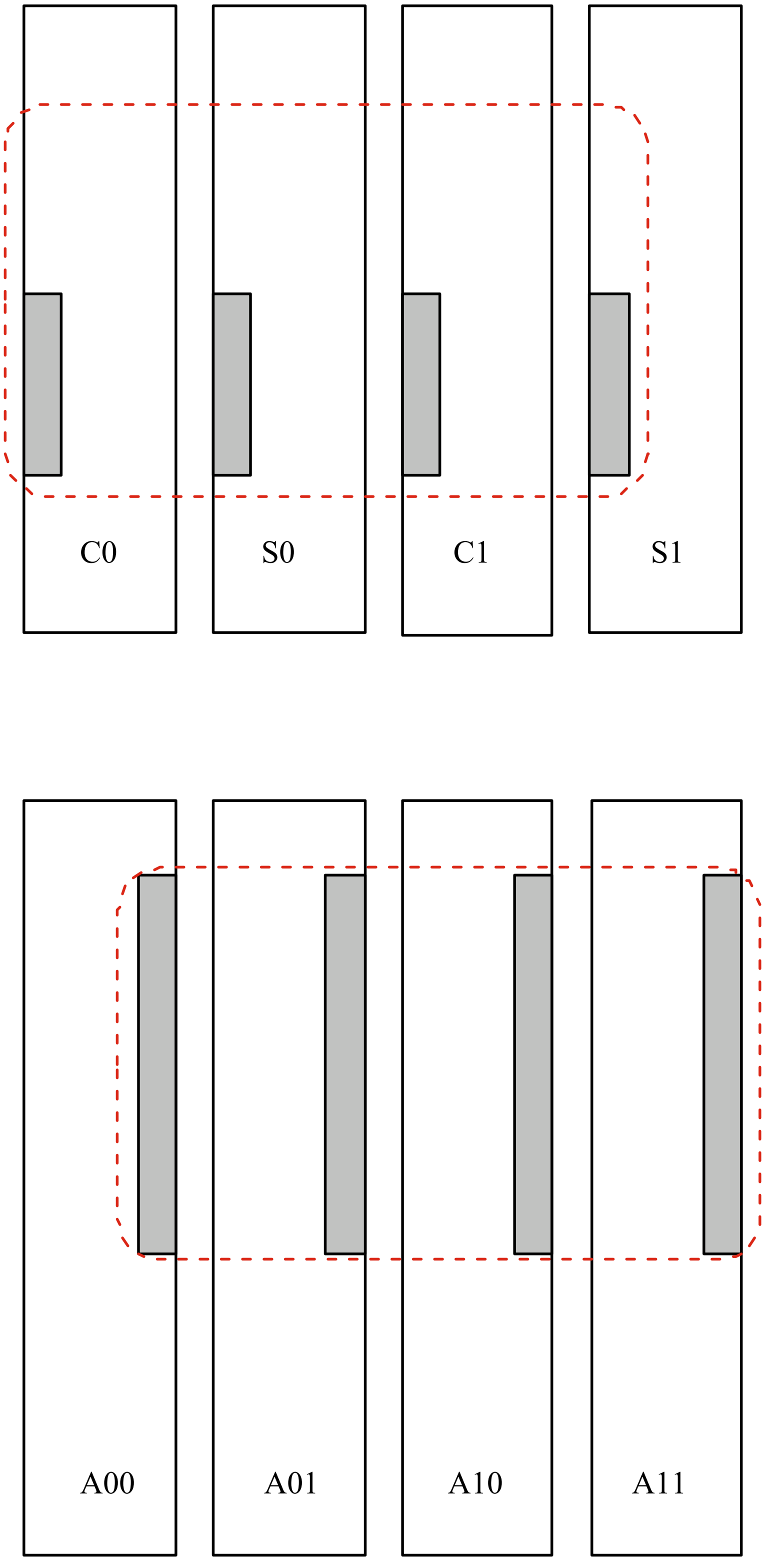


Fig.1: Macrochannels 0 and 1 location relative to collimator window positions

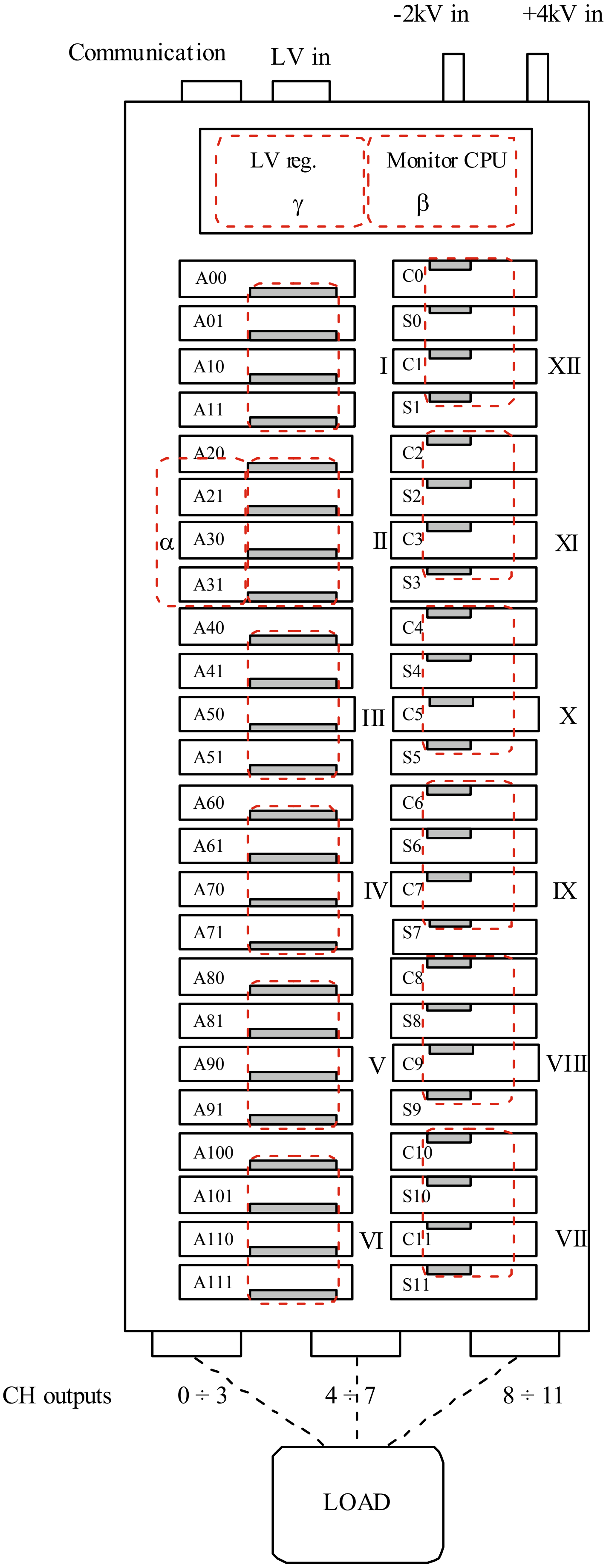


Fig.2: Module layout and steps of irradiation

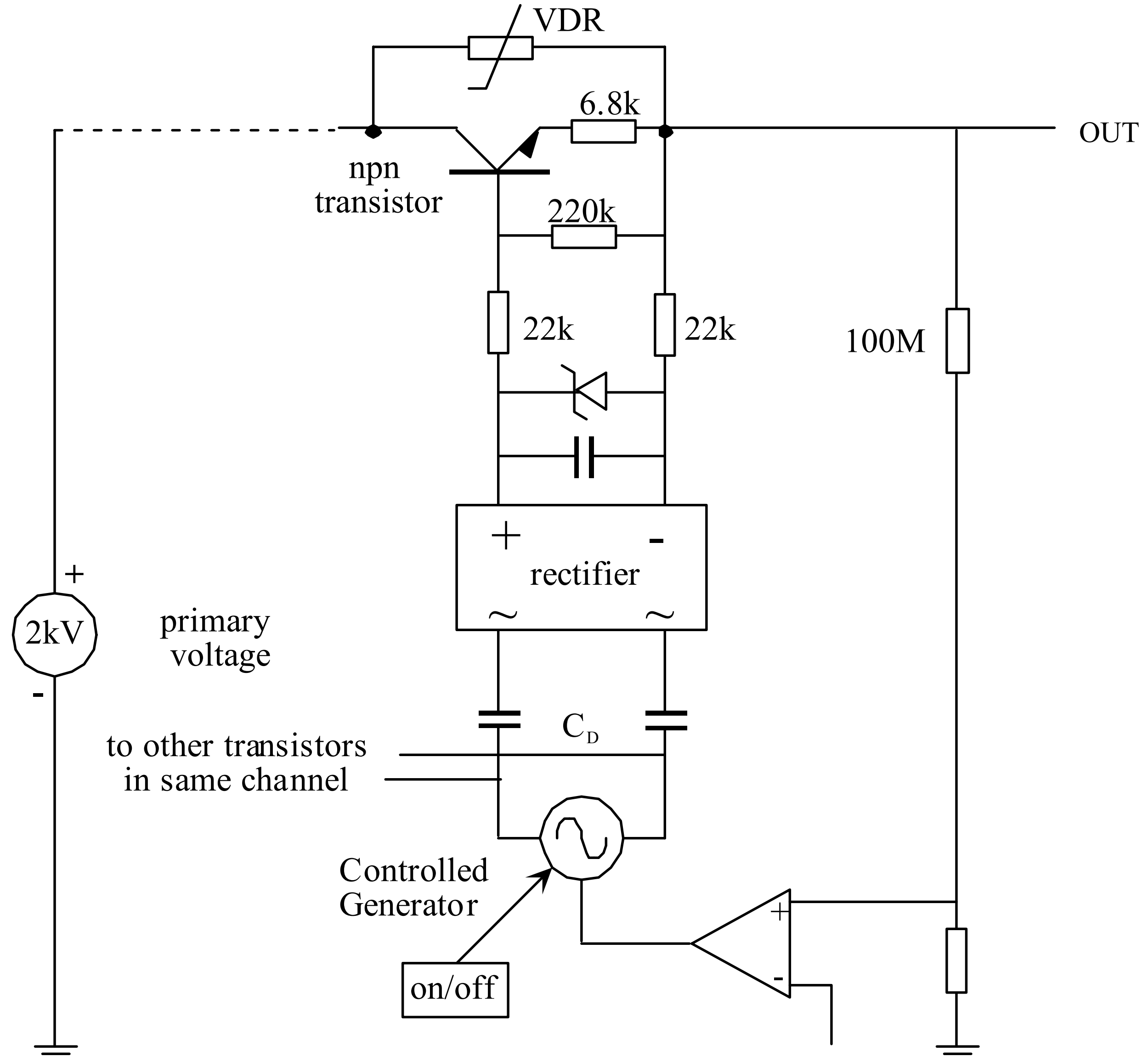


fig. 3a S channel with HV Transistor regulator

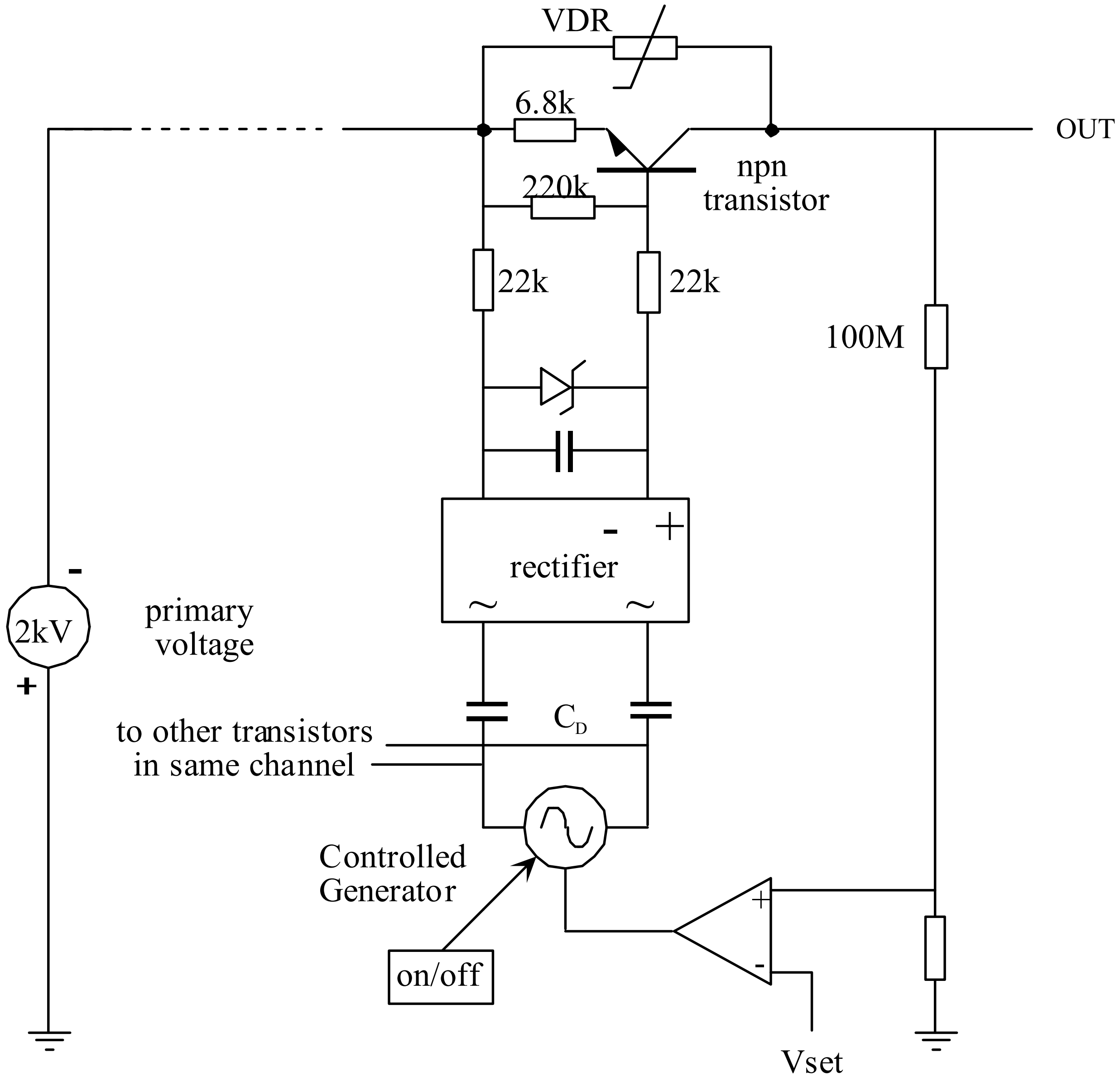


fig. 3b C channel with HV Transistor regulator

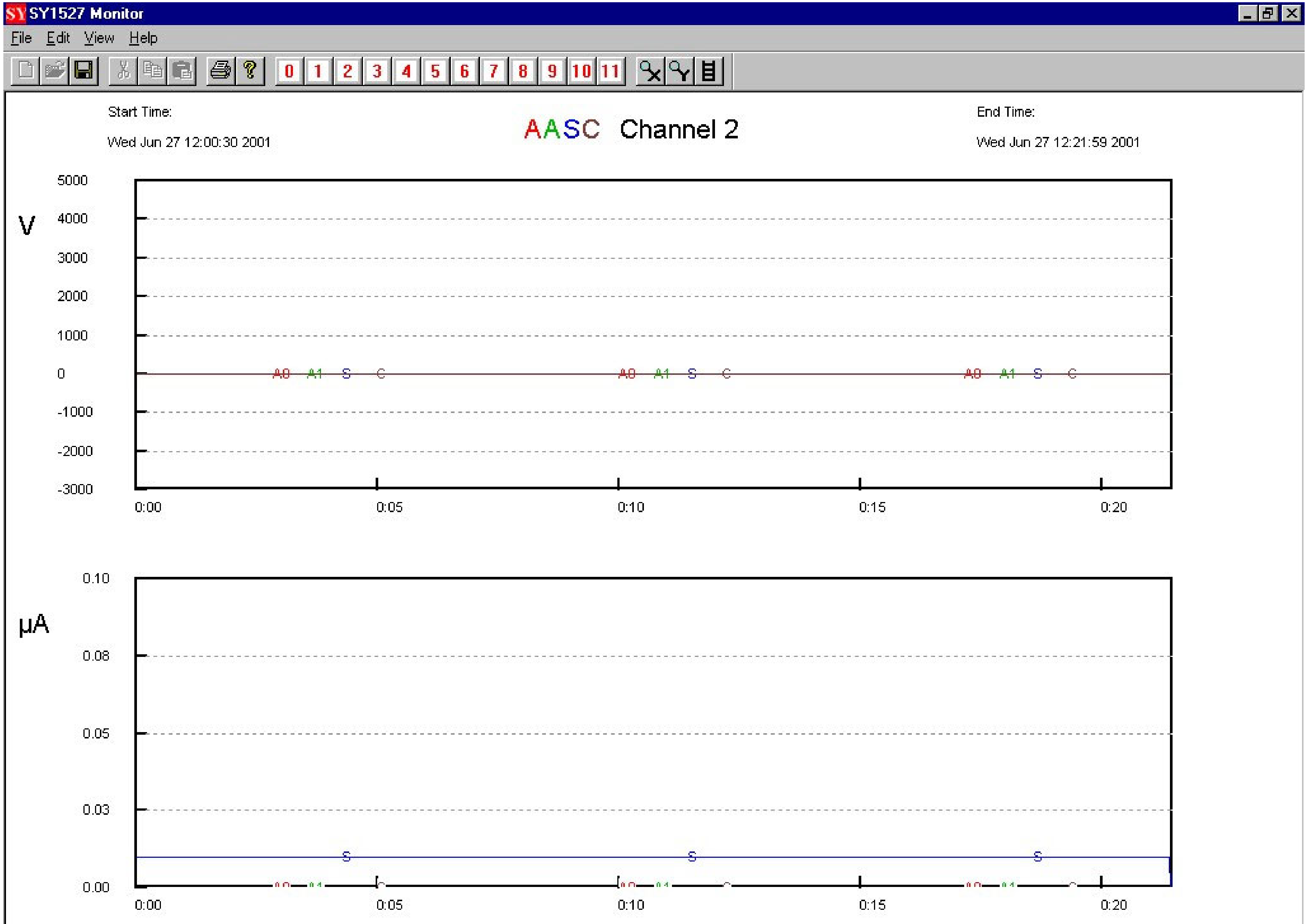
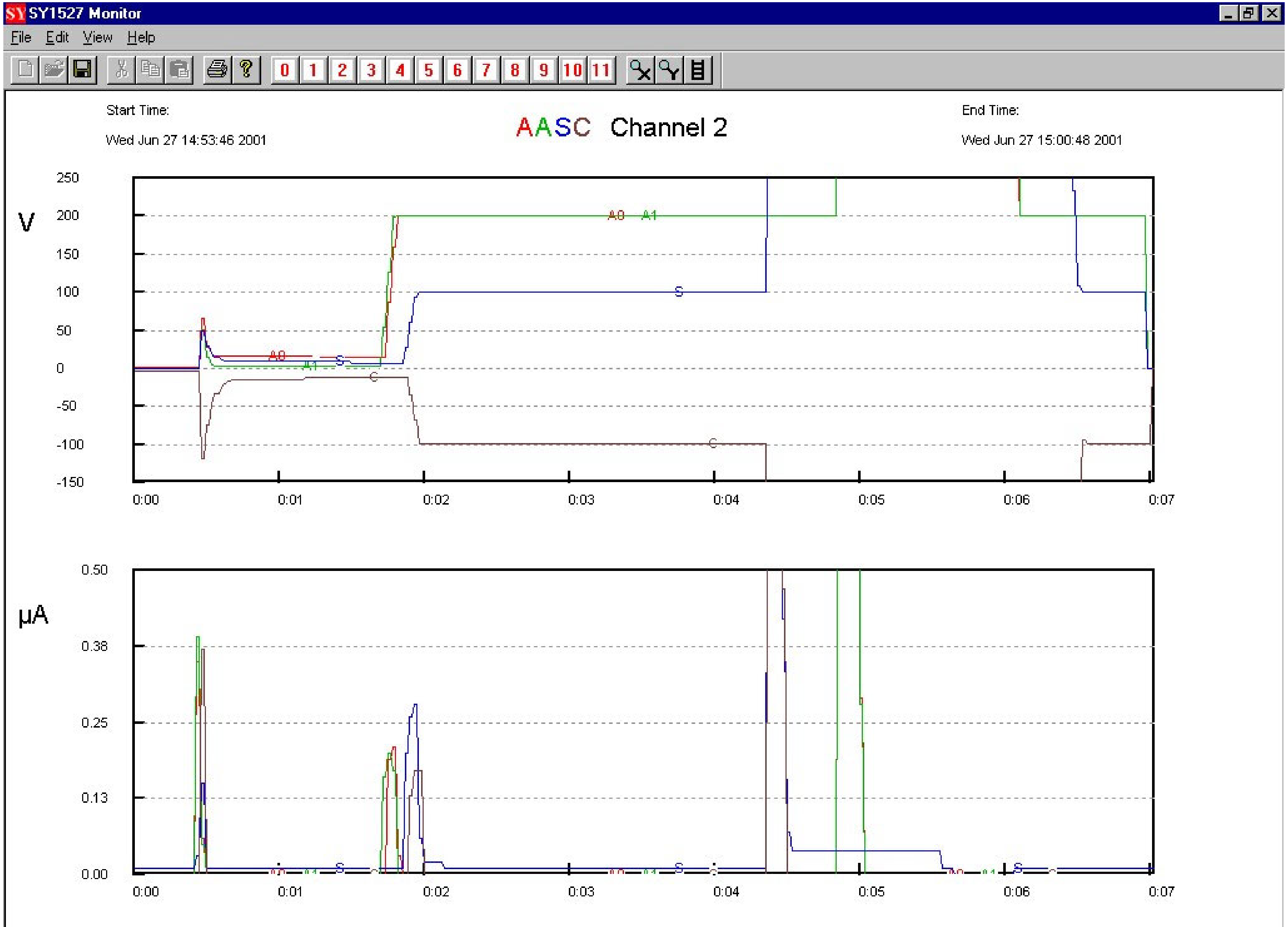


Fig. 4: Channels offsets with only LV on



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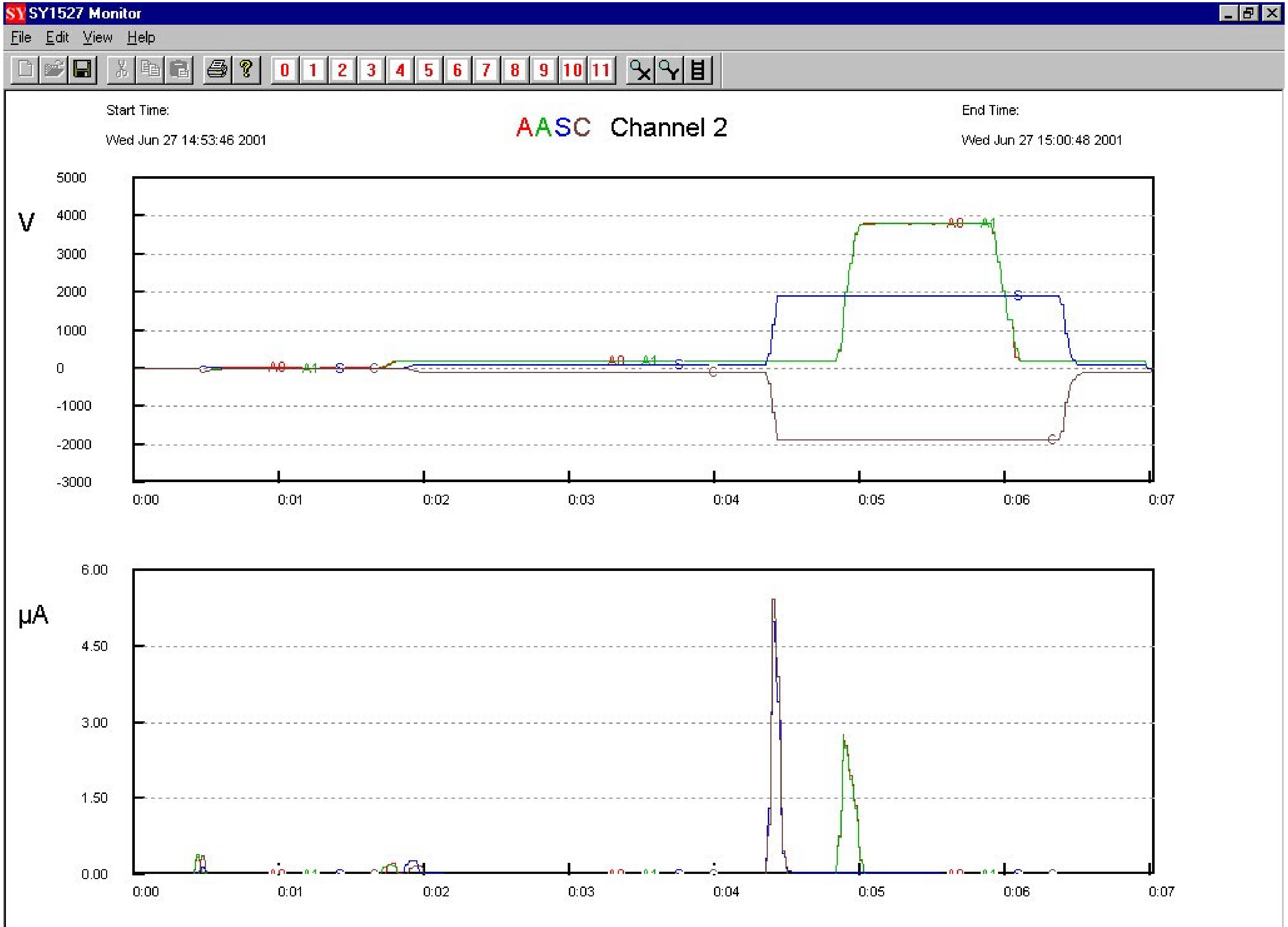
End Time:
Wed Jun 27 15:00:48 2001

Fig. 5: current offsets at test voltages



Start Time:
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AASC Channel 2

End Time:
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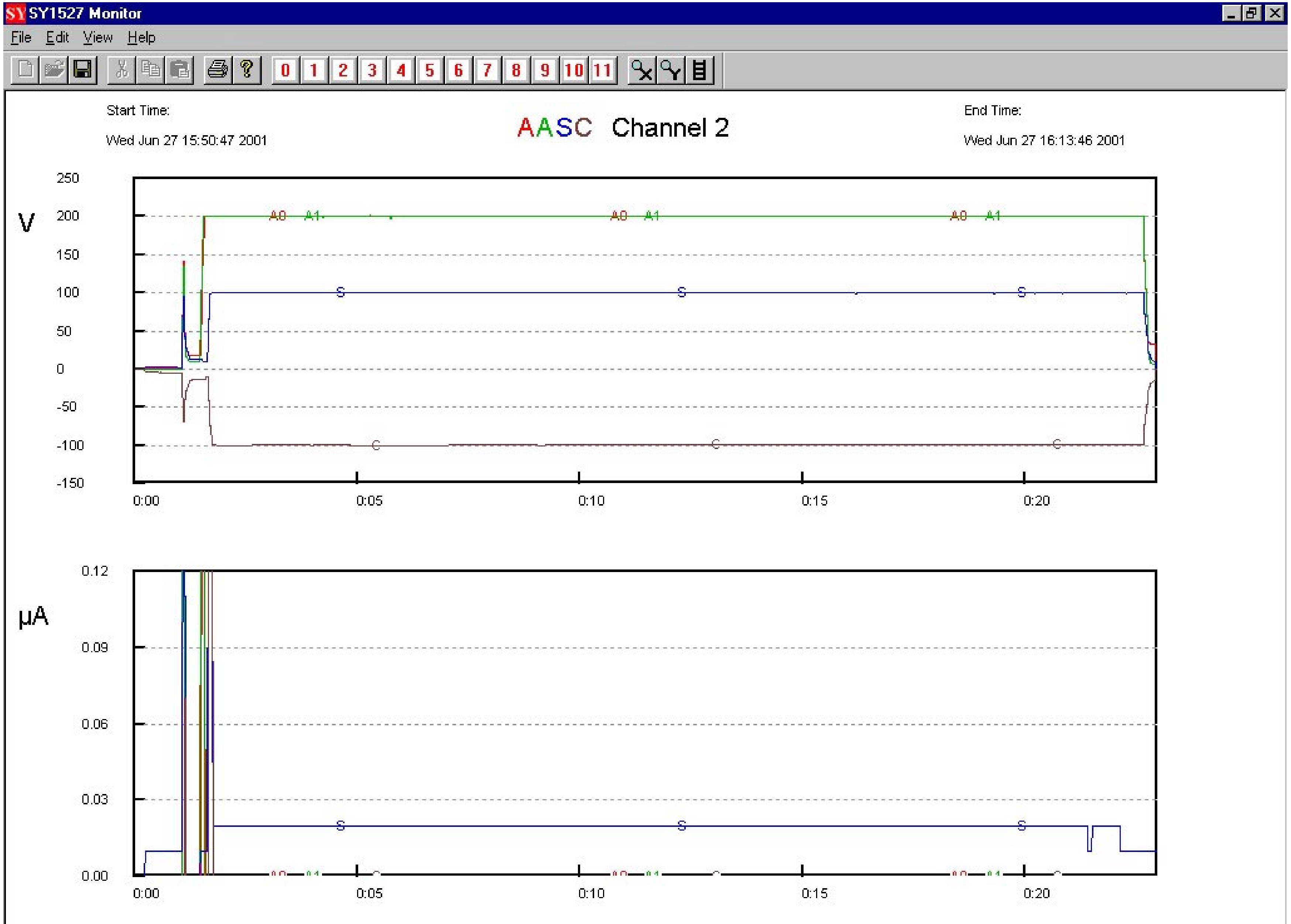
Fig. 6: current offsets at nominal voltages



Start Time:
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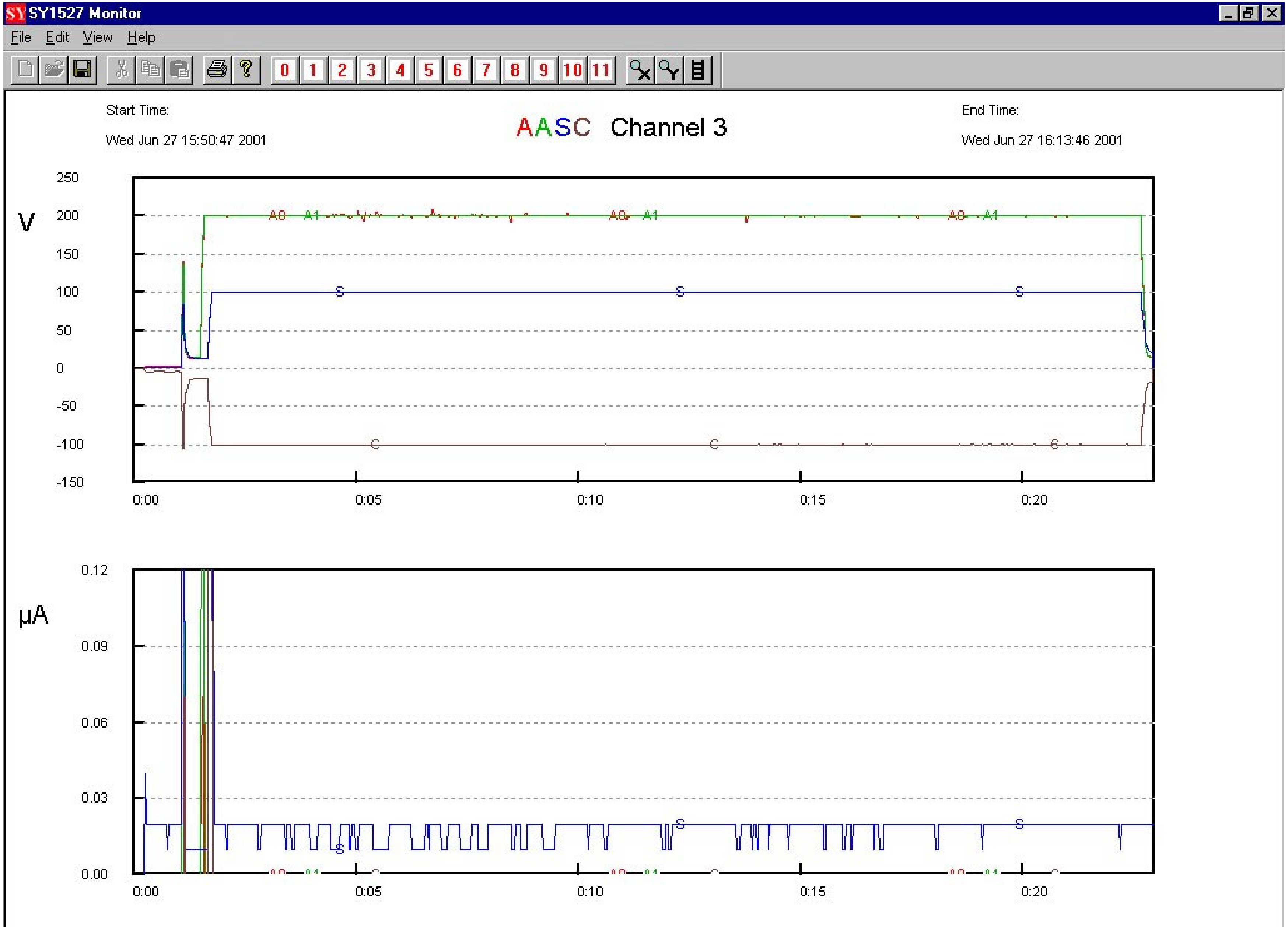
End Time:
Wed Jun 27 16:13:46 2001

Fig. 7: MCH2 currents at test voltages Step II



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End Time:
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Fig. 8: MCH3 currents at test voltages Step II

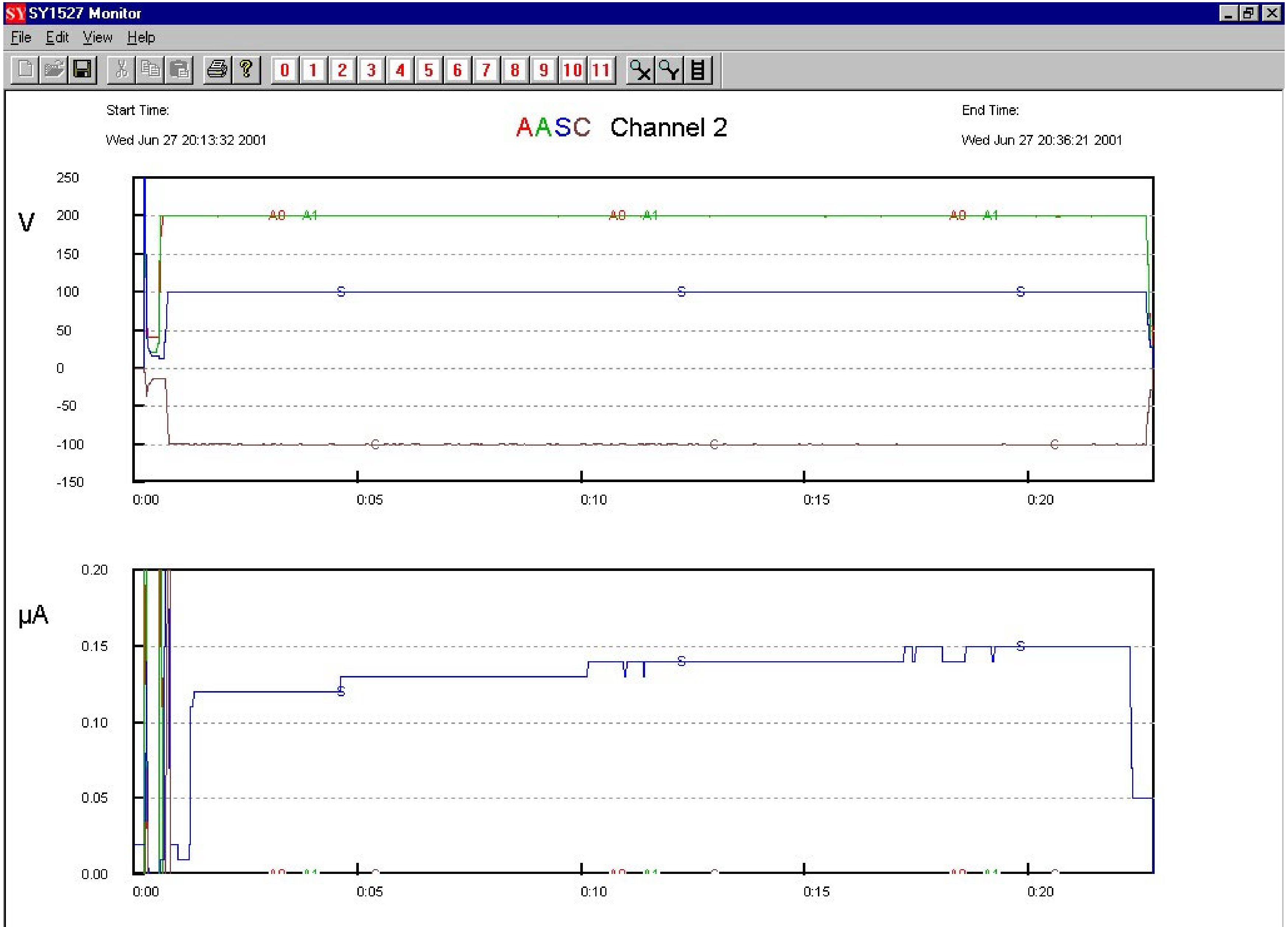

Fig. 9: MCH2 currents at test voltages Step XI

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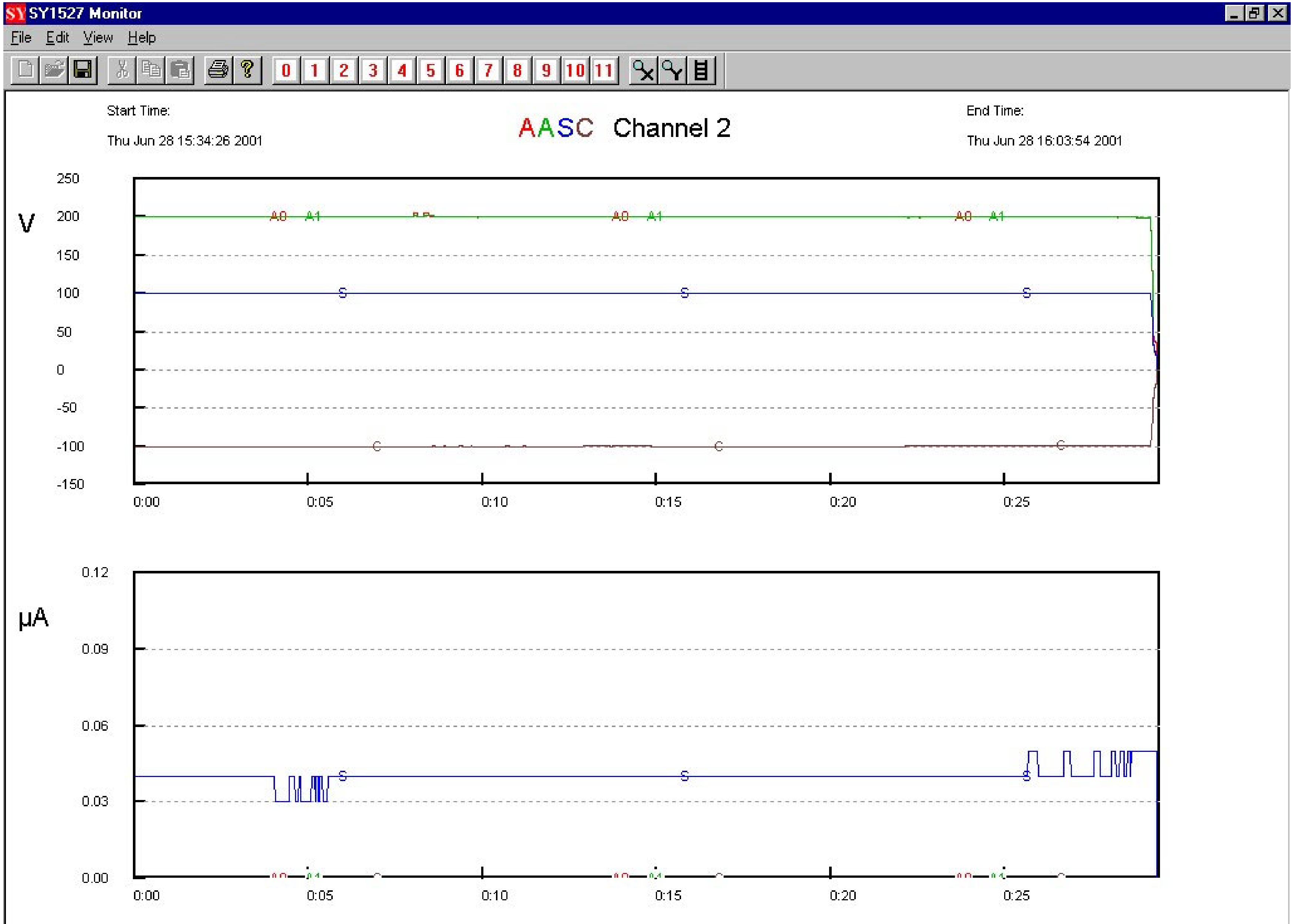
End Time: Wed Jun 27 20:36:21 2001

Fig. 10: MCH3 currents at test voltages Step XI



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End Time:
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Fig. 11: MCH2 currents at test voltages Step α

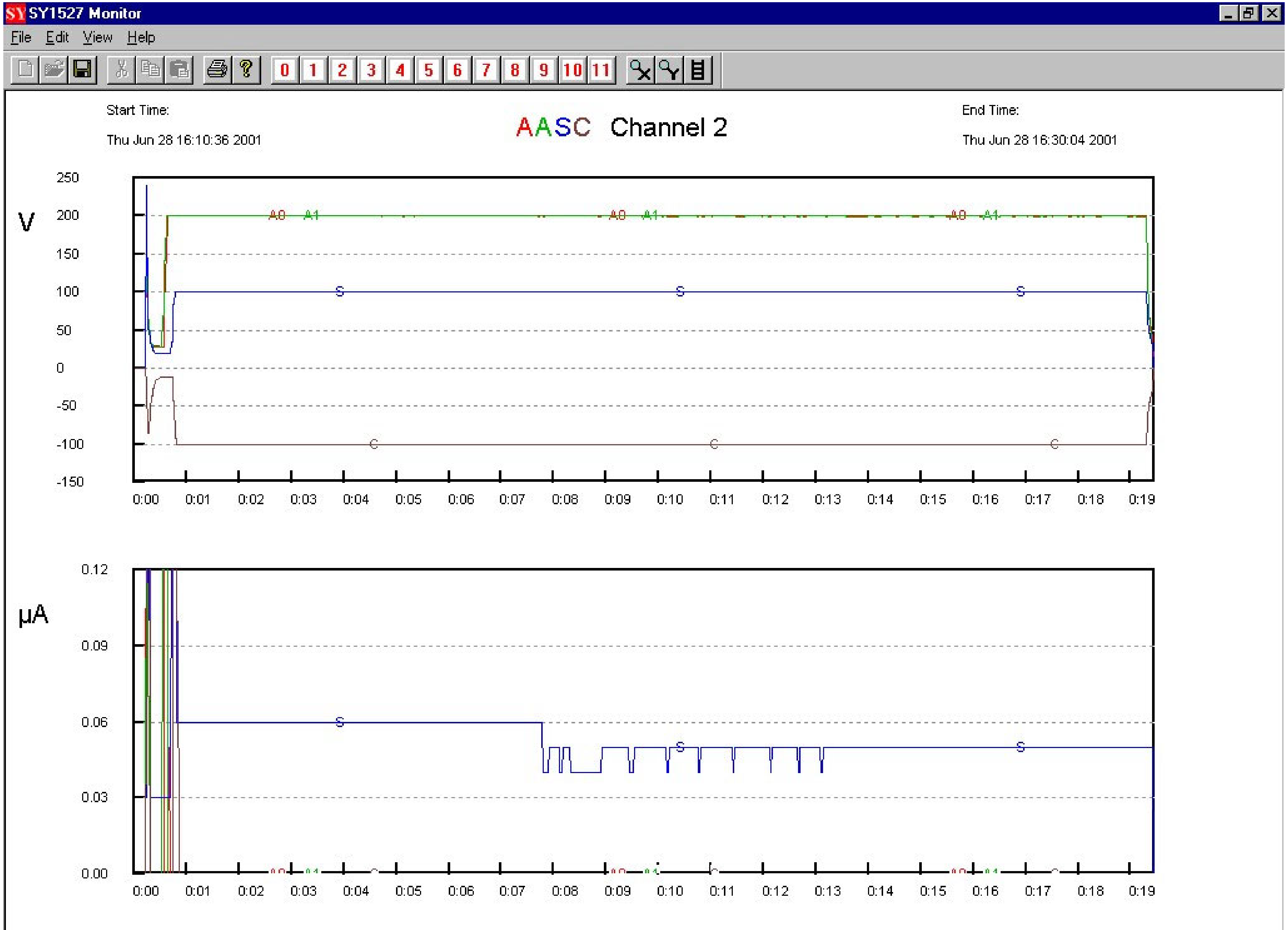
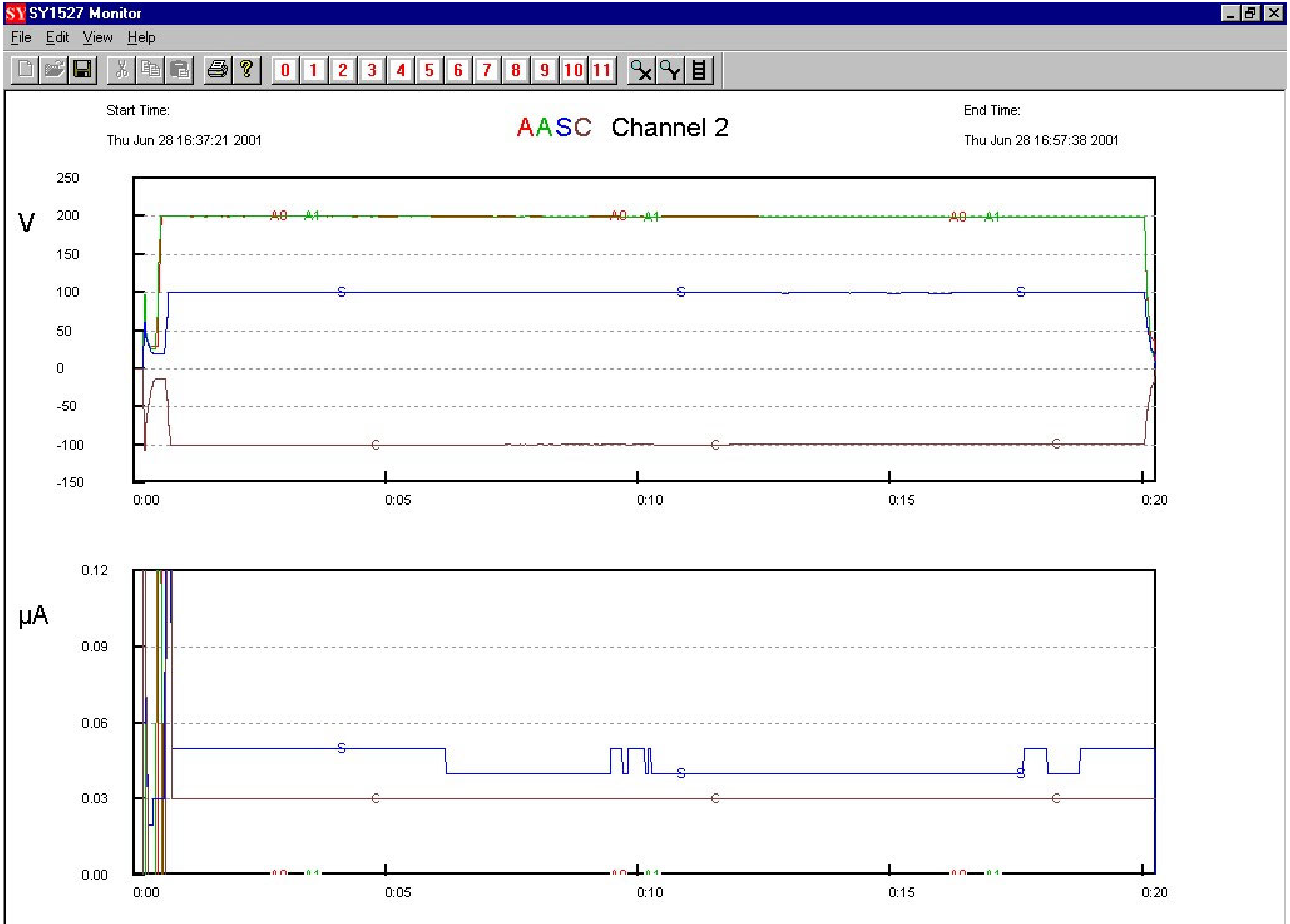


Fig. 12: MCH2 currents at test voltages Step β



AASC Channel 2

Start Time:
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End Time:
Thu Jun 28 16:57:38 2001

Fig. 13: MCH2 currents at test voltages Step γ

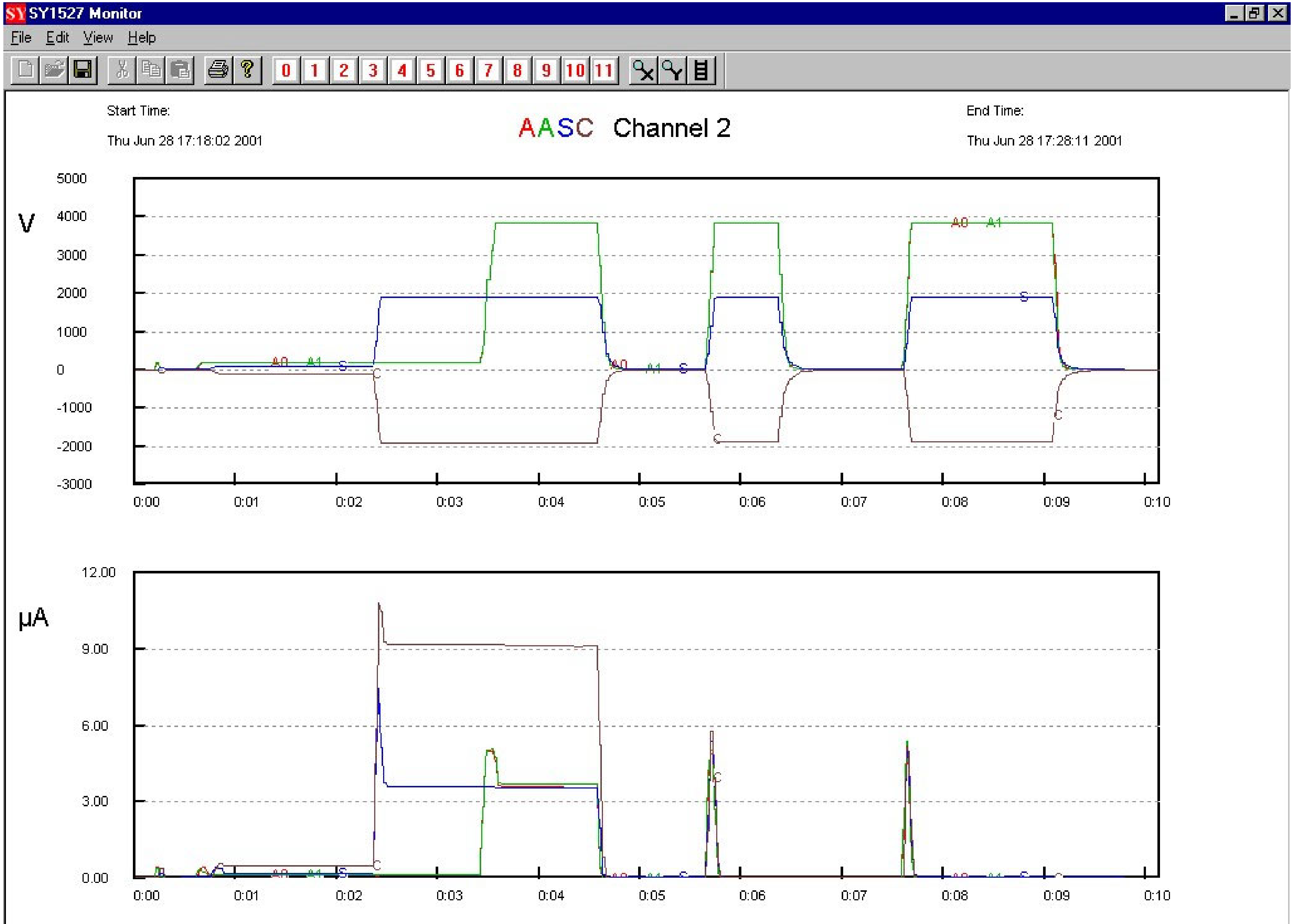

Fig. 14: MCH2 currents in post-irradiation test at full scale voltages and load

Fig. 15: MCH7 currents in post-irradiation test at full scale voltages and load

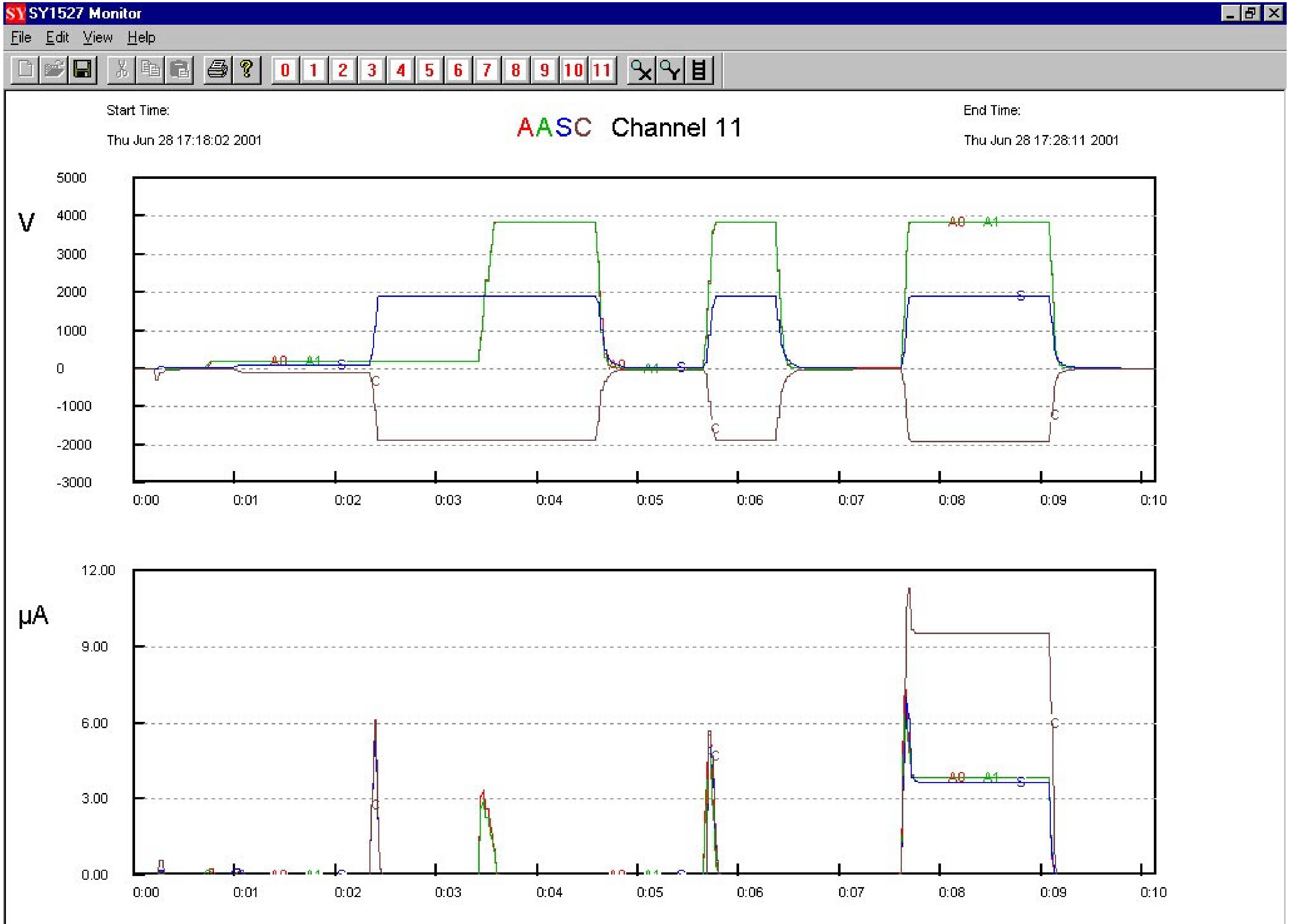

Fig. 16: MCH11 currents in post-irradiation test at full scale voltages and load