Analysis of Pre-Flight Modulator Voltage Calibration Data for the Voyager Plasma Science Experiment

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1. Introduction

The digitized readout (DN = data number) of the low-voltage signal (MV) which is proportional to the potential (V) on the high-voltage modulator grids, is a part of the routine calibration sequence on the Voyager Plasma Science (PLS) experiment. Theoretically, in producing the modulator voltage, the voltage is stepped through one decade from 60 to 600 volts and then through the same steps with a multiplication factor of 10 to sweep from 600 to 6000 volts. To this voltage is added an offset of −50 volts.

The voltage monitors measure a voltage between 0.1 and 10 volts (a constant fraction of the voltage swept) which is then input into the fast A/D converter. This voltage is converted to a binary number from which the highest order bit is discarded. Thus, for MV sweeping from 0.1 to 1.0, a number between 0 and 255 is returned; for MV sweeping from 1.0 to 10 volts, again, a number between 0 and 255 is returned. To know which decade is being read out, one must either rely on the "proper sequence" or an "educated guess."

For more information on MVM Interpretation, see Voyager Memorandum #161 by R. L. McNutt, Jr. (attached).

2. An Outline of the PLS Calibration Data Analysis

The PLS Modulator Calibration (MVM) Data Analysis was undertaken in order to check the correctness of the fast A/D converter formulas that connect low-voltage monitor signals (MV) with digital outputs (DN), to determine the proportionality constants between the actual modulator grid potential (V) and the monitor voltage (MV), and to establish an algorithm to link the digitized readouts (DN) with the actual grid potential (V). The data used for the DN-MV analysis were from the calibration tests for the PLS-Prototype run at MIT CSR (included as Appendix A of Voyager Memo #161). The MV-V analysis used the results of the power supply tests, made by Matrix Research and Development Corp. for both PLS instruments to be flown on the Voyager 1 and Voyager 2 spacecraft (in the further text referred to as "test results"). The Matrix data was obtained between 11/11/76 and 11/15/76 for "Flite 1," and between 12/21/76 and 12/27/76 for "Flite 2." Drawings containing this data are labeled "M.J.S. Power Supply" (there are no drawing numbers). These are stored in the filing cabinet next to the outer wall, second drawer from the top in N52-367. Note that there is some potential confusion about which unit is which: if Flite 1 is SN002, then it is the instrument actually flown on Voyager 1. SN002 was put on Voyager 1 and SN003 which was supposed to have gone on Voyager 2 was not flown. When these data were taken, Flite 2 probably referred to SN003 which has remained at M.I.T. as the flight spare. SN001 was actually flown on Voyager 2.

All calibration tests and power supply tests were entered into a sequence of files. The method that was used in both analyses, i.e., DN-MV and MV-V, is an improved version of a least squares fit algorithm, implemented in several FORTRAN 77 programs (see, for example section 14.2 of *Numerical Recipes: The Art of Scientific Computing, Press, W. H., B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, Cambridge University Press, New York, 1986*).

3. Description of the Files

All of the files related to the investigation can presently be found on the directory /usr4/ojn. The file suffixes have the following meanings:

.dat .... data files
.mon .... mongo source code files
.f .... FORTRAN 77 source code files

The DN-MV test data and mongo files have filenames of the form:

p[mode][mvr #].[suffix]

The MV-V test data and mongo files have filenames of the form:

f[flite #]-[temperature]-[mode].[suffix]

where:

mvr # = 1 if $0.1 \leq MV \leq 1.0$
mvr # = 2 if $1.0 \leq MV \leq 10$

flite # = 1 for Voyager 1 PLS Instrument
flite # = 2 for Voyager 2 PLS Instrument

temperature = 5 for Temp = -5°C
temperature = 10 for Temp = 10°C
temperature = r for Temp = room-temp
temperature = 30 for Temp = 30°C
temperature = 40 for Temp = 40°C

(The temperature is that to which the instrument was exposed during the test.)

mode = l for the L-mode
mode = m for the M-mode
mode = e1 for the E1-mode
mode = e2 for the E2-mode

suffix = dat if the file is a data file
suffix = mon if the file is a mongo source code

Note that there are no files of the form f2-30-[mode].[suffix] due to lack of this information.

The files of the form:

tl[mvr #].f and tl[mvr #].dat

are FORTRAN 77 source code and output data files produced by their corresponding source code programs which make/contain the data from the theoretical fast A/D formulas for MV-DN conversion.

The FORTRAN 77 source code files that actually perform the analysis are:

dns-code.f ..... DN-MV analysis
mvs-code.f ..... MV-V analysis
mvs-tc-code.f ..... MV-V analysis combining the data files
that differ only by temperature

These source code files use the following driver files:

dns-driver.dat
mvs-driver.dat
mvs-tc-driver.dat

The analysis generates the following files:

dns-output.dat ..... DN-MV analysis results
vs-output.dat ..... MV-V analysis results
mvs-tc-out.dat ..... MV-V temperature-combined analysis results

4. Data File Organization

All data files are organized as matrices of numbers and/or strings. Their row structure is as follows:

p[mode][mvr #].dat and tl[mvr #].dat:

dn mv
where: dn are the data numbers
mv are the corresponding monitor voltages

f[flight #]-[temperature]-[mode].dat:

channel# hvdcout mvu mvl vl vu
where : channel# is the channel number
hvdcout is the dc high voltage output
mvl/mvu are the monitor low voltages at the lower/upper channel edge
vl/vu are the actual grid potentials corresponding to the mvl/mvu

dns-driver.dat:

filename mvr[mvr #] lines#
where : filename is the name of a file.
mvr[mvr #] is a character string that can be either mvr1 or mvr2 depending on what range the value of MV belongs to.
lines# is the number of lines in the file.

mvs-driver.dat:

filename startline-1 endline-1 startline-2 endline-2

where : startline-[chr #]/endline-[chr #] are the starting/ending line numbers for parts of the f[ ]-[ ]-[ ].dat data files that correspond to different channel ranges as follows:

chr # = 1 if $0 \le$ channel# ≤ 7 and mode = L or E2
.... $0 \le$ channel# ≤ 63 and mode = M
.... all channels and mode = E1
chr # = 2 if $8 \le$ channel# ≤ 15 and mode = L or E2

.... 64 ≤ channel# ≤ 127 and mode = M

mvs-tc-driver.dat: (Note: this file is a single-column file.)

mfilename#1
filename#1.1
filename#1.2
*
mfilename#2
filename#2.1

where : mfilename#[integer1] is a character string of the form:

f[flite #]-[mode].dat
which is found in the mvs-tc-output.dat file and labels the analysis results obtained by combining groups of f[ ]-[ ]-[ ].dat files that differ only by temperature.

filename#[integer1].[integer2] are the filenames of the f[ ]-[ ]-[ ].dat data files that were combined.

dns-output.dat:

filename mvr[mvr #] c1 c2 sqd pairs#

where : filename is the name of a file that labels the information obtained by its analysis.
mvr[mvr #] is as explained under dns-driver.dat.
c_1, c_2 are constants in the presumed function that fits the data.
sqd is the square deviation of the function.
pairs# is the number of analyzed data pairs.

mvs-output.dat:

filename chr[chr #] mvx-vx a b sqd siga sigb cov pairs#

where : chr[chr #] is a character string that can be either chr1 or chr2. chr # has a meaning as explained under mvs-driver.dat.
mvx-vx is a character string that can be either mvl-vl or mvu-vu. It specifies what monitor voltages were analyzed - those at the upper or

at the lower channel edge.
a, *b* are constants in the presumed function that
fits the data.
sqd, siga (σ_a), sigb (σ_b)are,
respectively, the square deviation
of the function, and the deviations of its
coefficients *a* and *b*.
cov (σ_{ab}) is the covariance of *a* and *b*.

mvs-tc-output.dat

mfilename chr[chr #] mvx-vx a b sqd siga sigb cov pairs#

where : mfilename is the character string that labels the analysis data, and contains information what files were combined for the analysis (see mvs-tc-driver).

5. Mongo Files

All files that have a suffix .mon are mongo source code files. There are two types of such files: p[ ][ ].mon and f[ ]-[ ]-[ ].mon files.

Every mongo file is used to create a hardcopy plot of the data file associated with the mongo file. A plot is obtained by typing:

mongo [mongo-filename]

p[mode][mvr #].mon plots include both the p[mode][mvr #].dat data (square dots) and the tl[mvr #].dat data (broken line). f[flite #]-[temperature]-[mode].mon files produce four plots out of the associated f[ ]-[ ]-[ ].dat data for different combinations of the channel range and choice of mvl-vl or mvu-vu pairs of data (square dots).

6. Fortran Files

Files that end with .f are FORTRAN 77 source code files. There are five such files: tl1.f, tl2.f, dns-code.f, mvs-code.f, and mvs-tc-code.f. The sequence of UNIX commands:

```
f77 -o execfile filename.f
execfile
```

performs a compilation of the source code and an execution of execfile, the generated object file.

tl1.f & tl2.f:

These programs generate the theoretical DN-MV pairs assuming the following exponential functions:

$$MV = e^{-(255-DN)t/\tau} \tag{1}$$

for tl1.f i.e. mvr# = 1

$$MV = 10\ e^{-(255-DN)t/\tau} \tag{2}$$

for tl2.f, i.e., mvr# = 2

where $t = 4.34\ \mu s$, $\tau = 482.55\ \mu s$ and $0 \le DN \le 255$ (From A. Mavretic's lab notebook labeled book 2, #254, July 1974). Note that $e^{t/\tau} = 10^{1/256.0167}$ for these values.

dns-code.f :

This program does a least squares fit by analyzing the p[ ][ ].dat data files, and presuming that MV and V are related by the following exponential relation:

$$MV = c_1\ e^{-(255-DN)\ c_2} \tag{3}$$

where c_1 and c_2 are constants that are determined by the fitting procedure.

The program produces the file dns-output.dat. The algorithm used is a modification of the general least squares algorithm that makes the round-off errors as small as possible.

mvs-code.f :

This program uses the same algorithm as the previous one. It presumes that MV and V are connected with the following relation:

$$V = a\ MV + b \tag{4}$$

where a and b are constants that are determined by the fit.

The program analyses the f[ ]-[ ]-[ ].dat data files, dividing each file into four parts using the driver file. Every part is characterized by a unique channel range and mv range (mvr). The analysis, i.e., the least squares fit is carried out independently for each part. The file mvs-output.dat contains the results from the analysis.

The formulae used to calculate the deviations of the obtained coefficients are:

$$\sigma_a = \left[\frac{\sigma^2}{\Delta} \sum_i MV_i^2 \right]^{1/2} \tag{5}$$

$$\sigma_b = \left[N\, \sigma^2 / \Delta \right]^{1/2} \tag{6}$$

$$\sigma_{ab} = -\sum_i MV_i\, \sigma^2 / \Delta \tag{7}$$

where

$$\Delta \equiv N \sum_i MV_i^2 - \left[\sum_i MV_i \right]^2$$

and

$$\sigma^2 \equiv \frac{N}{N-2}\, sqd \tag{8}$$

with N the number of MV-V pairs.

mvs-tc-code.f :

This program employs the same least squares fit algorithm as the previous two. It presumes the same relation between MV and V, and performs the same analysis as mvs-code.f does, except that it internally combines the f[ ]-[ ]-[ ].dat data files that differ only by temperature. The results of the analysis are contained in the file mvs-tc-out.dat.

7. DN-MV Analysis

The primary goal of this analysis was to find out how much the theoretical DN-MV formulas are off from the true values. The only information available is from the calibration tests performed on the PLS-Prototype. This information was severely limited - only one test, at unknown temperature, per channel in each mode. Also, there is no information on the measurement uncertainties. Hence, the analysis results should be used with some caution. consideration.

The mongo plots of DN-MV data files (DN vs. log MV) show that DN and MV are related through an exponential relation. The DN-log(MV) pairs, as can be seen from the plots, lie on a straight line which, however, has a slightly different slope and y-axis intercept than the theoretical line. This suggested that there might be some non-linearity in the A/D conversion, if one assumes that DN's and MV's were measured at the same time. In addition, the slope and intercept shifts are bigger for mvr1 ($0.1 \le MV \le 1.0$) than the corresponding shifts for mvr2. This implies that the multiplication factor in the DN-MV formula for this range is not exactly 10.

The investigation of the plots sugested that the presumed function for the least square fit be:

$$MV = c_1\, e^{-(255\,-\,DN)\,c_2} \tag{9}$$

The program actually uses a linear least squares fit algorithm. If we take ln of the both sides of the equation, we obtain:

$$\ln MV = (DN-255)\,c_2 + \ln c_1 \tag{10}$$

which can be considered as a linear function $y = ax + b$ setting: $x = DN-255$; $y = \ln MV$; $a = c_2$; $b = \ln c_1$.

Before the data files were used for the analysis, all DN-MV pairs which were significantly off the imagined line that connects the other points on the mongo plots were deleted. They obviously represent a subjective reading, or even a writing, error.

The analysis results show that the presumed function yields a good approximation, since the square deviation is less than 10^{-6} in most cases. The multiplication factor c_1 ranges from:

1.02831 → 1.02864 instead of 1 for mvr1 (2.831% → 2.864%)
9.91158 → 9.92186 instead of 10 for mvr2 (−0.8842% → −0.7814%)

The range deviations for c_1 in percentages are:

mvr1: ± 0.016%
mvr2: ± 0.052%

is surprising that the c_1(mvr2)/c_1(mvr2) ratio is less than 10 ; it ranges from 9.63880 → 9.64560. This implies that PLS circuitry constants responsible for the multiplication factor might be off by ~3.5% from their nominal value(s).

The constant in the exponent, $c_2 = t\,/\,\tau$, ranges from :

$0.888580 \times 10^{-2} \rightarrow 0.889623 \times 10^{-2}$ instead of 0.899388×10^{-2} (1.201% → 1.085%).

The range deviation for c_2 is ± 0.058%.

If we consider t (the period of the fast A/D converter) as constant, then the time constant τ might be off (bigger) 1.085% → 1.201% from the nominal value of 482.55 µs, or, on an average, by ~ 1.15%.

8. MV-V Analysis

The goal of this analysis was to determine the proportionality constants between the monitor low voltage and high voltage (i.e., the actual grid potential). The low voltage is (nominally) proportional to the high voltage applied to the modulator grids (at least in the linear regime of the amplifiers). The theoretical value of this factor is not known, although it can, in principle, be derived from the circuit diagrams.

The analysis uses the results of the power supply test, conducted by Matrix Research and Development for two of the PLS instruments (refer to discussion in section 2). The tests were performed for several temperatures. Although all modes were incorporated in the measurements, the files were highly incomplete and difficult to read (handwritten). As is the case with the DN-MV analysis, there is no information on the measurement uncertainties.

All of the plots of MV-V data files clearly show that MV and V are linearly dependent. Since no information was readily available for the theoretical factor of proportionality, the plots do not include any theoretical graphs. A simple linear function was presumed for the least squares fit:

$$V = a\,MV + b \tag{11}$$

Similar to the DN-MV analysis, all MV-V points with unusually large deviations from this function were deleted from the files.

Throughout the analysis, every file is divided into four parts (with an exception of mode E1 files which are divided into two parts with respect to mvr). Each part has a unique channel range (chr1 or chr2), and monitor monitor voltage range (mvr1 or mvr2). These parts are processed independently.

The analysis results (file mv-output.dat) are somewhat surprising. First, the square deviation ranges from roughly 10^{-5} to over 350 (considering least squares fits of more than 2 data pairs). This might be evidence of harsh measurement errors during the test or strong non-linear influences in the PLS circuit. The random distribution of the square deviation values shows that the errors or influences are not dependent on factors such as: temperature, mode, voltage or channel range. The deviations obtained for *a* and *b*, as well as the covariance of *a* and *b*, show a much more stable picture; their median values are, roughly, as follows:

$\sigma_a \sim 0.1$
$\sigma_b \sim 0.1$
$\sigma_{ab} \sim -10^{-2}$

It is interesting that the values obtained for *a* and *b* show an obvious dependence on various factors, although, ideally, they should not. If one looks at the values for the slope *a*, it can be seen that in 90% of the cases:

a(mvl-vl) > a(mvu-vu)

There are only eight cases where this relation does not hold true; since these cases appear to be totally random with respect to any factors that might have influenced them (temperature, specific mode, etc.), the observed property may serve as an evidence that some circuit constants change when switching from the lower to the upper channel edge.

The ratio a(chr2)/a(chr1) randomly oscillates around the value of 10, which is the nominal value for the multiplication voltage factor when the instrument switches from the first channel range to the second channel range. The stability of this multiplication factor shows that the circuit constants for the appropriate part of the circuit are close to their nominal values.

This situation, however, changes in considering the dependence of the slope of *a* on the mode. The values of *a* for various modes vary roughly as follows:

l-mode ..... a = 60.5; 605.1
m-mode ..... a = 60.3; 603.5
e1-mode .... a = 67.2
e2-mode .... a = 68.1; 672.1

The slight difference between a(l-mode) and a(m-mode) can be noticed in many cases, especially considering values of *a* which correspond to a smaller square deviation and larger number of analyzed MV-V pairs. On the average, a(l-mode) is 0.33% larger than a(m-mode). Following the same criterion, one notices that a(e1-mode) and a(e2-mode) differ more drastically from a(l-mode) and a(m-mode). The percentage increase from a(m-mode) turns out to be, roughly:

a(e1-mode) 11.45%
a(e2-mode) 12.93%

This suggests that some circuit constants in both E modes differ from their nominal values.

The last consideration for the slope values is whether or not they are temperature dependent. It is important to note, once again, that the analysis was limited to five different temperatures. The values of *a* do not show any dependence on temperature; they tend to oscillate randomly as the temperature increases. This observation is consistent with the theoretical expectations.

The values of *b*, which represent the y-axis intercept or the voltage offset are much more randomly distributed than are the slope values. In fact, *b* values vary so much that no dependence property can be uniquely established.

The values of *b* vary from -40 to +40; however, most of them are between -5 to 0. In roughly 90% of cases the values are negative. Theoretically, the values of b should be close to 0. Typical values for *b* are (roughly):

-0.4 ... for chr1
-1.5 ... for chr2

9. MV-V Temperature-combined Analysis

Since the slope values did not show any dependence on temperature, all families of files that differed only by temperature were collapsed, and the data from the corresponding parts of these files combined for the least squares fit. The result of this analysis is the file mvs-tc-out.dat. First, it can be noticed that the lower edge of the square deviation range has moved toward larger values (from $\sim 10^{-5}$ to $\sim 10^{-3}$). The square deviations for *a* and *b*, and the covariances are, for the most part, in the same range as in the previous analysis.

The relation:

a(mvl-vl) > a (mvu-vu)

still holds true for 80% of cases (there are three cases when it does not).

The ratio a(chr2)/a(chr1) oscillates around 10 (the theoretical value) as in the MV-V analysis.

This analysis also confirms that there is a definite dependence of a on the mode. Some spot checks suggest the following percentage differences (with respect to a(m-mode)):

a(l-mode) 0.13%
a(e1-mode) 11.75%
a(e2-mode) 12.12%

(The median value for a(m-mode) is 60.13.)

The values of *b* are, again, very randomly distributed, so that no firm property or dependence can be established. For example, b_{ave} = -4.631 volts. However, if the first four large values of *b* are not considered (since they range from -20 to -30), the new, restricted average value of b becomes: $b_{ave\ res} = -1.153$ volts.

This example clearly shows that it is very difficult to derive any major conclusion about b from the analysis results obtained.

10. Conclusions

The analysis results are surprising in that the derived conversion constants deviate by fairly significant amounts from their nominal values. However, it must be kept in mind that the test results which were used for analysis may be very imprecise. Even if we assume that the test result errors are very large, they do not appear to be capable to account for all discrepancies between the theoretical expectations and the results of the analysis. Measurements with the flight spare instrument appear to be the only means of investigating these effects further.

It is very clear that is impossible to create one simple algorithm that for given DN will return V - the actual grid potential. The MV-V slope dependence on the channel range is what was expected. However, the MV-V slope dependence on whether we have the top or the bottom of the channel, and a dependence of the MV-V slope on the mode, precludes a unique algorithm for all cases.

In order to convert a given DN into the V, we need the following auxiliary information:

1 - the mode
2 - the decade the modulator is sweeping through (mvr#)
3 - the channel range (chr#)
4 - the channel edge the DN corresponds to (mvl-vl or mvu-vu)

Given the stated information (for 2 and 3 we must rely on the "proper sequence" or an "educated guess"), one can pick up the corresponding constants from the files dns-output.dat and mvs-tc-out.dat, and substitute them in the general formula:

$$V = a\, c_1\, e^{-c_2\,(255-DN)} + b \tag{12}$$

to obtain the actual grid potential V. The error in the value obtained will be as large as the errors in the test results the DN-MV-V analysis is based on.

For example: Flite# = 2 ; Mode = M ; mvr# = 2 ; chr# = 1 ; channel edge = lower (mvl-vl). The values of the constants in the general DN-V formula, are:

$c_1 = 9.91168 \qquad c_2 = 0.888609 \times 10^{-2}$
$a = 60.13527 \qquad b = 0.71937 \times 10^{-1}$

If the value returned from the PLS instrument is DN = 73, then the grid potential is 118.3 volts.

It is important to note that the general DN-V formula only yields magnitudes; the actual potentials in the E1 and E2 modes will be negative.

11. Description of Tables

Tables 1,2, and 3 are, respectively, hardcopies of the files dns-output.dat, mvs-output.dat, and mvs-tc-out.dat.

12. Description of Graphs

The first set of graphs contains hardcopy plots of p[ ][ ].mon mongo files. The second set of graphs contains hardcopy plots of f[ ]-[ ]-[ ].mon mongo files (see section 5).

13. Description of Source Code used in the Analysis

Hardcopy listings (with comments) of the files dns-code.f, mvs-code.f, and mvs-tc-code.f are included.

14. Voyager Memorandum #161

Voyager Memorandum #161 is appended.

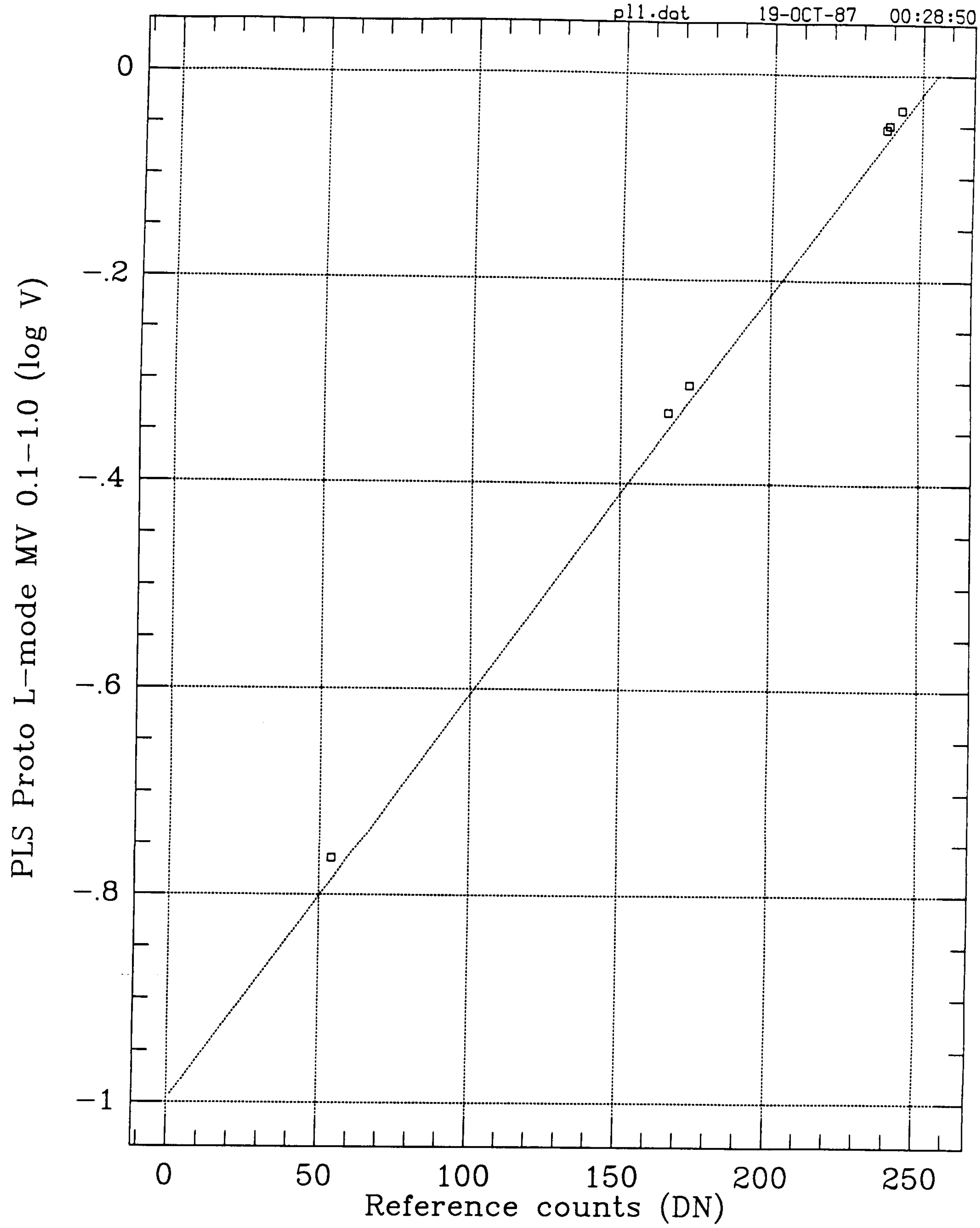
filename	mvr#	c1	c2	sqd	#pairs
p11.dat	mvr1	1.02839	-.889588e-02	.390305e-07	6
p12.dat	mvr2	9.91158	-.888580e-02	.808982e-08	25
pm1.dat	mvr1	1.02831	-.888749e-02	.744256e-06	27
pm2.dat	mvr2	9.91168	-.888609e-02	.161969e-07	112
pe11.dat	mvr1	1.02864	-.889413e-02	.952267e-06	6
pe12.dat	mvr2	9.92186	-.889096e-02	.110472e-07	5
pe21.dat	mvr1	1.02835	-.889623e-02	.169905e-07	4
pe22.dat	mvr2	9.91175	-.888633e-02	.911977e-08	8

filename	chr#	mvx-vx	a	b	sqd	siga	sigb	cov(a,b)	#pairs
fl-5-l.dat	chr1	mvl-vl	60.51235	-.615136	.997313e-01	0.608705e-01	0.201473	-.942402e-02	8
fl-5-l.dat	chr1	mvu-vu	60.02615	-.100870e-02	.302430e-02	0.791282e-02	0.367145e-01	-.229867e-03	8
fl-5-l.dat	chr2	mvl-vl	604.11932	-5.96604	8.40119	0.561085	2.18834	-1.03286	8
fl-5-l.dat	chr2	mvu-vu	600.65253	-.150051e-01	.186472	0.621079e-01	0.325927	-.170259e-01	8
fl-5-m.dat	chr1	mvl-vl	60.34817	-.341069	.473071	0.988696e-01	0.297130	-.168811e-01	10
fl-5-m.dat	chr1	mvu-vu	60.08419	-.824708e-01	.763699e-04	0.120710e-02	0.379316e-02	-.265612e-05	10
fl-5-m.dat	chr2	mvl-vl	602.49585	-5.08361	11.1661	0.273505	1.33931	-.264441	15
fl-5-m.dat	chr2	mvu-vu	600.31244	1.04457	.188948e-01	0.108204e-01	0.550362e-01	-.429496e-03	15
fl-5-e1.dat	chr1	mvl-vl	67.21983	-1.27390	.679980e-01	0.130648	0.137156	-.154335e-01	16
fl-5-e1.dat	chr1	mvu-vu	67.11500	-1.45989	.311056e-01	0.820973e-01	0.967405e-01	-.693560e-02	16
fl-5-e2.dat	chr1	mvl-vl	67.87886	-1.98333	.302277	0.123319	0.364760	-.332262e-01	7
fl-5-e2.dat	chr1	mvu-vu	67.47765	-1.71838	.929421e-02	0.161561e-01	0.667698e-01	-.823703e-03	7
fl-5-e2.dat	chr2	mvl-vl	678.63385	-26.3247	2.47177	0.341567	1.19437	-.344043	8
fl-5-e2.dat	chr2	mvu-vu	675.54791	-26.4225	2.26864	0.244052	1.14571	-.235929	8
fl-10-l.dat	chr1	mvl-vl	60.45045	-.426117	.316743e-01	0.597866e-01	0.230206	-.872973e-02	3
fl-10-l.dat	chr1	mvu-vu	72.17496	-8.81379	4.87331	0.556180	2.95382	-1.09155	3
fl-10-l.dat	chr2	mvl-vl	603.90668	-7.29915	.617473	0.290085	1.54953	-.387409	3
fl-10-l.dat	chr2	mvu-vu	600.80804	0.303848e-01	.282393e-02	0.145803e-01	0.104803	-.131706e-02	3
fl-10-m.dat	chr1	mvl-vl	59.32479	0.597509e-01	.635764e-03	0.556788e-01	0.288852e-01	-.138911e-02	5
fl-10-m.dat	chr1	mvu-vu	60.11923	-.648625e-01	.108634e-04	0.711466e-02	0.397385e-02	-.248202e-04	5
fl-10-m.dat	chr2	mvl-vl	597.16608	45.2825	.594443	0.191781	1.47048	-.240137	3
fl-10-m.dat	chr2	mvu-vu	598.60986	18.8517	.265741	0.124042	0.988455	-.104615	3
fl-10-e1.dat	chr1	mvl-vl	67.14627	-.985689	.103264	0.239544	0.278146	-.543871e-01	6
fl-10-e1.dat	chr1	mvu-vu	67.00823	-1.18625	.526322e-01	0.158861	0.206007	-.271838e-01	6
fl-10-e2.dat	chr1	mvl-vl	66.29117	-.783868	.566844e-01	0.898739e-01	0.309146	-.177230e-01	3
fl-10-e2.dat	chr1	mvu-vu	66.24818	-.879849	.676344e-02	0.231628e-01	0.110463	-.170817e-02	3
fl-10-e2.dat	chr2	mvl-vl	679.05194	-23.9143	1.63895	0.531040	2.53468	-1.16171	3
fl-10-e2.dat	chr2	mvu-vu	674.69830	-24.5234	1.28637	0.349951	2.24837	-.679375	3
fl-r-l.dat	chr1	mvl-vl	60.55255	-.827384	.187547	0.837044e-01	0.276299	-.177728e-01	8
fl-r-l.dat	chr1	mvu-vu	60.03791	-.179914	.405232e-03	0.289560e-02	0.134355e-01	-.307771e-04	8
fl-r-l.dat	chr2	mvl-vl	605.07617	-9.88383	8.46190	0.564280	2.19736	-1.04325	8
fl-r-l.dat	chr2	mvu-vu	600.67584	-1.54748	.312340	0.803605e-01	0.421933	-.285218e-01	8
fl-r-m.dat	chr1	mvl-vl	60.30745	-.339155	.691204e-01	0.347300e-01	0.882699e-01	-.156537e-02	14
fl-r-m.dat	chr1	mvu-vu	60.08812	-.311307e-01	.587022e-04	0.972897e-03	0.258471e-02	-.130124e-05	14
fl-r-m.dat	chr2	mvl-vl	603.22913	-7.25629	10.6580	0.296681	1.32739	-.277331	14
fl-r-m.dat	chr2	mvu-vu	600.50580	0.712475	.156099	0.344893e-01	0.160388	-.388917e-02	14
fl-r-e1.dat	chr1	mvl-vl	67.27860	-1.34343	.614586e-01	0.124567	0.130295	-.139753e-01	16
fl-r-e1.dat	chr1	mvu-vu	67.02419	-1.53669	.315467e-01	0.827581e-01	0.974193e-01	-.704037e-02	16
fl-r-e2.dat	chr1	mvl-vl	68.02900	-1.65146	.260379	0.110855	0.327331	-.279894e-01	8
fl-r-e2.dat	chr1	mvu-vu	67.37809	-1.91325	.194067e-01	0.224682e-01	0.935669e-01	-.166936e-02	8
fl-r-e2.dat	chr2	mvl-vl	680.25678	-24.7925	.949734	0.212501	0.739772	-.132532	8
fl-r-e2.dat	chr2	mvu-vu	673.82123	-30.7932	139.077	1.90430	8.97744	-14.4294	8
fl-30-l.dat	chr1	mvl-vl	60.48734	-.266280	.314025e-01	0.596379e-01	0.229132	-.866265e-02	3
fl-30-l.dat	chr1	mvu-vu	60.04224	-.429275e-01	.105712e-03	0.257825e-02	0.137505e-01	-.235406e-04	3

f1-30-l.dat	chr2	mvl-vl	604.69434	-7.22915	.903369	0.351400	1.87357	-.567367	3
f1-30-l.dat	chr2	mvu-vu	599.10309	-5.48300	376.736	5.31187	38.3271	-175.552	3
f1-30-m.dat	chr1	mvl-vl	59.30324	0.111777	.211677e-03	0.352405e-01	0.186906e-01	-.549909e-03	4
f1-30-m.dat	chr1	mvu-vu	60.12197	-.617451e-01	.207063e-04	0.107766e-01	0.614458e-02	-.564131e-04	4
f1-30-m.dat	chr2	mvl-vl	603.03278	-6.80254	.361189e-01	0.477435e-01	0.365954	-.149311e-01	3
f1-30-m.dat	chr2	mvu-vu	600.50073	1.25235	.185133	0.103871	0.827574	-.734290e-01	3
f1-30-e1.dat	chr1	mvl-vl	67.19112	-.931211	.105990	0.243170	0.281414	-.558214e-01	6
f1-30-e1.dat	chr1	mvu-vu	66.98763	-1.24480	.452411e-01	0.147369	0.190932	-.233684e-01	6
f1-30-e2.dat	chr1	mvl-vl	68.03098	-1.07653	.181260	0.161272	0.552319	-.567428e-01	3
f1-30-e2.dat	chr1	mvu-vu	67.39749	-1.87342	.128202e-01	0.318398e-01	0.152103	-.323376e-02	3
f1-30-e2.dat	chr2	mvl-vl	680.48627	-22.8291	.129155	0.149537	0.711206	-.917747e-01	3
f1-30-e2.dat	chr2	mvu-vu	673.84424	-24.1930	1.47295	0.373767	2.40569	-.776356	3
f1-40-l.dat	chr1	mvl-vl	60.57846	-.693189	.216349	0.900174e-01	0.296572	-.205067e-01	8
f1-40-l.dat	chr1	mvu-vu	60.02045	-.120726	.203734e-03	0.205234e-02	0.952460e-02	-.154625e-04	8
f1-40-l.dat	chr2	mvl-vl	605.86938	-10.3675	6.98169	0.513211	1.99546	-.861557	8
f1-40-l.dat	chr2	mvu-vu	600.11243	0.102392	.378934	0.884640e-01	0.464641	-.345730e-01	8
f1-40-m.dat	chr1	mvl-vl	60.30112	-.378115	.104426	0.427041e-01	0.108467	-.236343e-02	14
f1-40-m.dat	chr1	mvu-vu	60.08394	-.546729e-01	.491939e-04	0.890818e-03	0.236544e-02	-.108951e-05	14
f1-40-m.dat	chr2	mvl-vl	603.44074	-7.98325	3.84319	0.160787	0.786015	-.912654e-01	15
f1-40-m.dat	chr2	mvu-vu	600.43164	1.11681	.162244	0.317138e-01	0.161213	-.368610e-02	15
f1-40-e1.dat	chr1	mvl-vl	67.32028	-1.35274	.710135e-01	0.134095	0.139741	-.161221e-01	16
f1-40-e1.dat	chr1	mvu-vu	66.96509	-1.64349	.352477e-01	0.874581e-01	0.102907	-.785773e-02	16
f1-40-e2.dat	chr1	mvl-vl	68.10291	-1.25709	.167670	0.891462e-01	0.262077	-.179932e-01	8
f1-40-e2.dat	chr1	mvu-vu	67.30157	-2.43097	.543690e-01	0.375483e-01	0.156757	-.467641e-02	8
f1-40-e2.dat	chr2	mvl-vl	672.17169	-7.41316	264.967	3.59806	12.9298	-38.4482	7
f1-40-e2.dat	chr2	mvu-vu	674.56934	-36.9362	118.502	1.80264	8.73213	-13.0675	7
f2-5-l.dat	chr1	mvl-vl	60.17648	0.155520	.158251e-01	0.242317e-01	0.800396e-01	-.148761e-02	8
f2-5-l.dat	chr1	mvu-vu	59.97764	0.327712	.113892e-03	0.153694e-02	0.712142e-02	-.865788e-05	8
f2-5-l.dat	chr2	mvl-vl	602.28113	0.769367	1.07762	0.200297	0.780893	-.131373	8
f2-5-l.dat	chr2	mvu-vu	600.51239	1.64362	.207434e-01	0.207467e-01	0.108788	-.189894e-02	8
f2-5-m.dat	chr1	mvl-vl	60.12848	0.194878	.160125e-01	0.166489e-01	0.425381e-01	-.362899e-03	14
f2-5-m.dat	chr1	mvu-vu	59.99821	0.337415	.113653e-03	0.135012e-02	0.360352e-02	-.253099e-05	14
f2-5-m.dat	chr2	mvl-vl	601.54022	1.04488	1.53489	0.101451	0.497178	-.364544e-01	15
f2-5-m.dat	chr2	mvu-vu	600.61743	1.81879	.142007	0.297158e-01	0.151269	-.324961e-02	15
f2-5-e1.dat	chr1	mvl-vl	67.23154	-1.66764	.730523e-01	0.135980	0.141911	-.166099e-01	16
f2-5-e1.dat	chr1	mvu-vu	67.03916	-1.83544	.349447e-01	0.873001e-01	0.102438	-.780712e-02	16
f2-5-e2.dat	chr1	mvl-vl	67.91608	-2.17327	.249580	0.108755	0.320576	-.268985e-01	8
f2-5-e2.dat	chr1	mvu-vu	67.46211	-2.36739	.194963e-01	0.226216e-01	0.938107e-01	-.168543e-02	8
f2-5-e2.dat	chr2	mvl-vl	681.04962	-27.1815	1.94795	0.305059	1.06044	-.272830	8
f2-5-e2.dat	chr2	mvu-vu	676.60834	-30.1168	10.6877	0.530712	2.48825	-1.11451	8
f2-10-l.dat	chr1	mvl-vl	60.17376	0.129080	.797190e-02	0.299889e-01	0.115361	-.219066e-02	3
f2-10-l.dat	chr1	mvu-vu	59.97874	0.353142	.303788e-04	0.138394e-02	0.736847e-02	-.676795e-05	3
f2-10-l.dat	chr2	mvl-vl	602.62256	-1.88010	.155082e-07	Inf	Inf	-Inf	2
f2-10-l.dat	chr2	mvu-vu	600.47296	2.04455	.288050e-07	Inf	Inf	-Inf	2
f2-10-m.dat	chr1	mvl-vl	59.73257	0.269767	.865535e-03	0.656626e-01	0.335781e-01	-.190192e-02	5
f2-10-m.dat	chr1	mvu-vu	59.96705	0.304995	.102931e-03	0.219277e-01	0.121490e-01	-.233392e-03	5

f2-10-m.dat	chr2	mvl-vl	601.76184	-1.26277	.452630e-01	0.533998e-01	0.409339	-.186743e-01	3
f2-10-m.dat	chr2	mvu-vu	600.48962	2.33135	.134320	0.885304e-01	0.704928	-.533099e-01	3
f2-10-el.dat	chrl	mvl-vl	67.05306	-1.38256	.131341	0.335011	0.336182	-.881515e-01	5
f2-10-el.dat	chrl	mvu-vu	66.92881	-1.67638	.666050e-01	0.221553	0.249634	-.443746e-01	5
f2-10-e2.dat	chrl	mvl-vl	67.89469	-1.49594	.206411	0.172474	0.589408	-.647614e-01	3
f2-10-e2.dat	chrl	mvu-vu	67.45460	-2.13037	.170298e-01	0.368446e-01	0.175278	-.431136e-02	3
f2-10-e2.dat	chr2	mvl-vl	681.01978	-24.7361	.316632e-09	Inf	Inf	-Inf	2
f2-10-e2.dat	chr2	mvu-vu	672.09674	-21.5260	.146668e-08	Inf	Inf	-Inf	2
f2-r-l.dat	chrl	mvl-vl	60.23248	0.562140e-02	.188177e-01	0.264582e-01	0.872465e-01	-.177006e-02	8
f2-r-l.dat	chrl	mvu-vu	59.94294	0.242753	.218799e-03	0.213005e-02	0.986386e-02	-.166129e-04	8
f2-r-l.dat	chr2	mvl-vl	603.13892	-1.40088	1.10748	0.203300	0.791702	-.135192	8
f2-r-l.dat	chr2	mvu-vu	600.17041	1.19110	.376552	0.883839e-01	0.463304	-.344461e-01	8
f2-r-m.dat	chrl	mvl-vl	60.13647	-.192660e-02	.178065e-01	0.175701e-01	0.448361e-01	-.403117e-03	14
f2-r-m.dat	chrl	mvu-vu	59.97662	0.171016	.204702e-03	0.181242e-02	0.483296e-02	-.454875e-05	14
f2-r-m.dat	chr2	mvl-vl	602.05994	-1.53841	1.24895	0.102893	0.456330	-.332072e-01	14
f2-r-m.dat	chr2	mvu-vu	600.52539	1.63030	.678163	0.729389e-01	0.336138	-.173336e-01	14
f2-r-el.dat	chrl	mvl-vl	67.21871	-1.39276	.711585e-01	0.134445	0.139702	-.161524e-01	16
f2-r-el.dat	chrl	mvu-vu	67.98734	-3.88276	23.5436	2.26806	2.65358	-5.25083	16
f2-r-e2.dat	chrl	mvl-vl	67.97079	-1.85405	.236677	0.106083	0.311734	-.254891e-01	8
f2-r-e2.dat	chrl	mvu-vu	67.40055	-2.23466	.240213e-01	0.250822e-01	0.104047	-.207171e-02	8
f2-r-e2.dat	chr2	mvl-vl	681.10181	-25.1177	.488952	0.153081	0.530736	-.684924e-01	8
f2-r-e2.dat	chr2	mvu-vu	675.00739	-27.2256	5.02141	0.362954	1.70376	-.521682	8
f2-40-l.dat	chrl	mvl-vl	60.24822	0.434202e-02	.237725e-01	0.297514e-01	0.980322e-01	-.223596e-02	8
f2-40-l.dat	chrl	mvu-vu	59.92659	0.220377	.100471e-02	0.456249e-02	0.211298e-01	-.762113e-04	8
f2-40-l.dat	chr2	mvl-vl	603.48999	-1.99360	.797637	0.172470	0.671553	-.972650e-01	8
f2-40-l.dat	chr2	mvu-vu	599.88709	1.75730	.331916	0.829803e-01	0.434984	-.303635e-01	8
f2-40-m.dat	chrl	mvl-vl	60.14411	0.114325e-01	.298870e-01	0.227636e-01	0.580779e-01	-.676222e-03	14
f2-40-m.dat	chrl	mvu-vu	59.97903	0.205800	.304463e-02	0.698926e-02	0.186347e-01	-.675945e-04	14
f2-40-m.dat	chr2	mvl-vl	602.09229	-1.60779	1.00080	0.819617e-01	0.401471	-.237822e-01	15
f2-40-m.dat	chr2	mvu-vu	600.43127	2.79594	6.06477	0.194096	0.987730	-.138488	15
f2-40-el.dat	chrl	mvl-vl	67.22803	-1.45360	.709771e-01	0.134294	0.139461	-.161038e-01	16
f2-40-el.dat	chrl	mvu-vu	66.98215	-1.66388	.366907e-01	0.895093e-01	0.104703	-.817530e-02	16
f2-40-e2.dat	chrl	mvl-vl	67.97550	-1.77854	.235044	0.105775	0.310553	-.253129e-01	8
f2-40-e2.dat	chrl	mvu-vu	67.39137	-2.29253	.277553e-01	0.269500e-01	0.111853	-.239312e-02	8
f2-40-e2.dat	chr2	mvl-vl	681.06494	-24.4491	2.80381	0.366699	1.27099	-.392918	8
f2-40-e2.dat	chr2	mvu-vu	674.79327	-26.2589	8.06381	0.459808	2.15908	-.837513	8

mfilename	chr#	mvx-vx	a	b	sqd	siga	sigb	cov(a,b)	#pairs
f1-1.dat	chr1	mvl-vl	60.52104	-.610043	.164336	0.331425e-01	0.113269	-.157042e-01	30
f1-1.dat	chr1	mvu-vu	61.98012	-3.78736	301.191	1.05781	5.06098	-.126347e-01	30
f1-1.dat	chr2	mvl-vl	604.74603	-8.13411	10.7494	0.269372	1.13736	-.223076e-01	30
f1-1.dat	chr2	mvu-vu	600.16797	-.973543e-01	58.6173	0.466305	2.65526	-.165305e-01	30
f1-m.dat	chr1	mvl-vl	60.31631	-.353374	.170454	0.296164e-01	0.714492e-01	-.603742e-02	47
f1-m.dat	chr1	mvu-vu	60.08471	-.510478e-01	.505415e-03	0.154998e-02	0.391030e-02	-.591564e-02	47
f1-m.dat	chr2	mvl-vl	602.76862	-4.90454	52.3157	0.293152	1.52384	-.597133e-02	50
f1-m.dat	chr2	mvu-vu	600.36346	1.54410	5.37263	0.902943e-01	0.487818	-.572787e-02	50
f1-e1.dat	chr1	mvl-vl	67.24926	-1.24871	.875493e-01	0.690395e-01	0.738429e-01	-.478687e-01	60
f1-e1.dat	chr1	mvu-vu	67.03070	-1.48414	.661700e-01	0.556784e-01	0.669305e-01	-.470001e-01	60
f1-e2.dat	chr1	mvl-vl	67.72772	-1.22783	3.10232	0.162477	0.496514	-.176905e-01	29
f1-e2.dat	chr1	mvu-vu	67.19755	-1.67142	2.24984	0.102853	0.441530	-.142202e-01	29
f1-e2.dat	chr2	mvl-vl	678.07275	-21.2894	124.611	1.03011	3.92660	-.252968e-01	29
f1-e2.dat	chr2	mvu-vu	674.68091	-30.3143	106.165	0.707489	3.63723	-.189183e-01	29
f2-1.dat	chr1	mvl-vl	60.21009	0.735942e-01	.239714e-01	0.138893e-01	0.467219e-01	-.187701e-01	27
f2-1.dat	chr1	mvu-vu	59.95467	0.264793	.223082e-01	0.100075e-01	0.471735e-01	-.151654e-01	27
f2-1.dat	chr2	mvl-vl	602.88281	-.773320	2.68548	0.149835	0.601851	-.257683e-01	26
f2-1.dat	chr2	mvu-vu	600.25501	1.39881	2.25701	0.102482	0.553832	-.193295e-01	26
f2-m.dat	chr1	mvl-vl	60.13527	0.719373e-01	.265907e-01	0.116207e-01	0.281091e-01	-.590580e-02	47
f2-m.dat	chr1	mvu-vu	59.98359	0.245631	.822439e-02	0.621848e-02	0.157195e-01	-.580673e-02	47
f2-m.dat	chr2	mvl-vl	601.85620	-.658335	2.10953	0.628142e-01	0.313642	-.646934e-02	47
f2-m.dat	chr2	mvu-vu	600.52618	2.08670	2.36698	0.640338e-01	0.332164	-.622361e-02	47
f2-e1.dat	chr1	mvl-vl	67.20400	-1.48642	.900689e-01	0.776666e-01	0.805384e-01	-.570088e-01	53
f2-e1.dat	chr1	mvu-vu	67.27348	-2.35832	7.48046	0.656644	0.766262	-.560609e-01	53
f2-e2.dat	chr1	mvl-vl	67.94134	-1.87212	.298369	0.553911e-01	0.166032	-.214916e-01	27
f2-e2.dat	chr1	mvu-vu	67.42473	-2.28871	.418198e-01	0.154045e-01	0.650145e-01	-.172369e-01	27
f2-e2.dat	chr2	mvl-vl	681.07147	-25.5305	2.97343	0.178696	0.639013	-.295865e-01	26
f2-e2.dat	chr2	mvu-vu	674.81555	-26.0345	31.2612	0.429203	2.07553	-.219703e-01	26



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100
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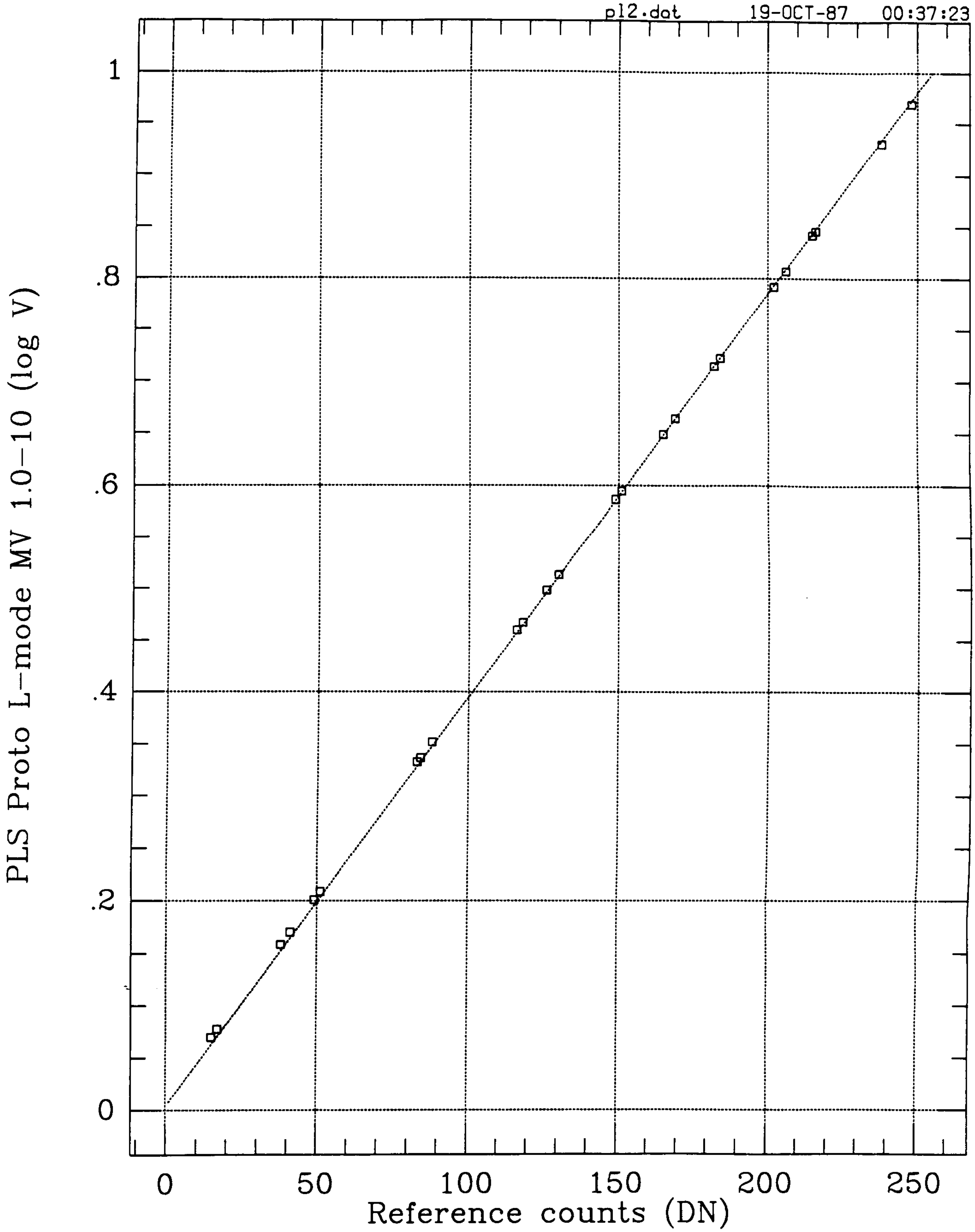
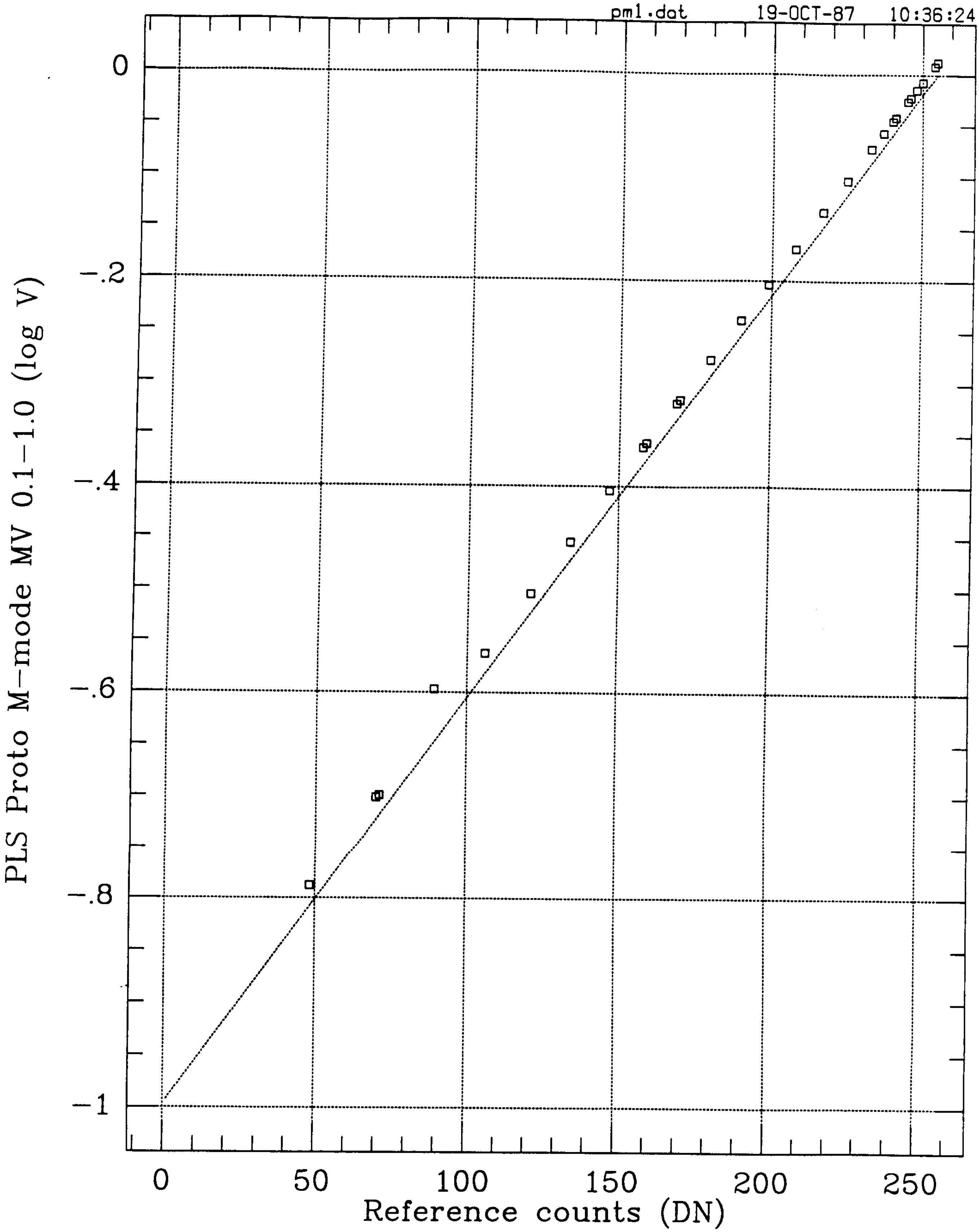
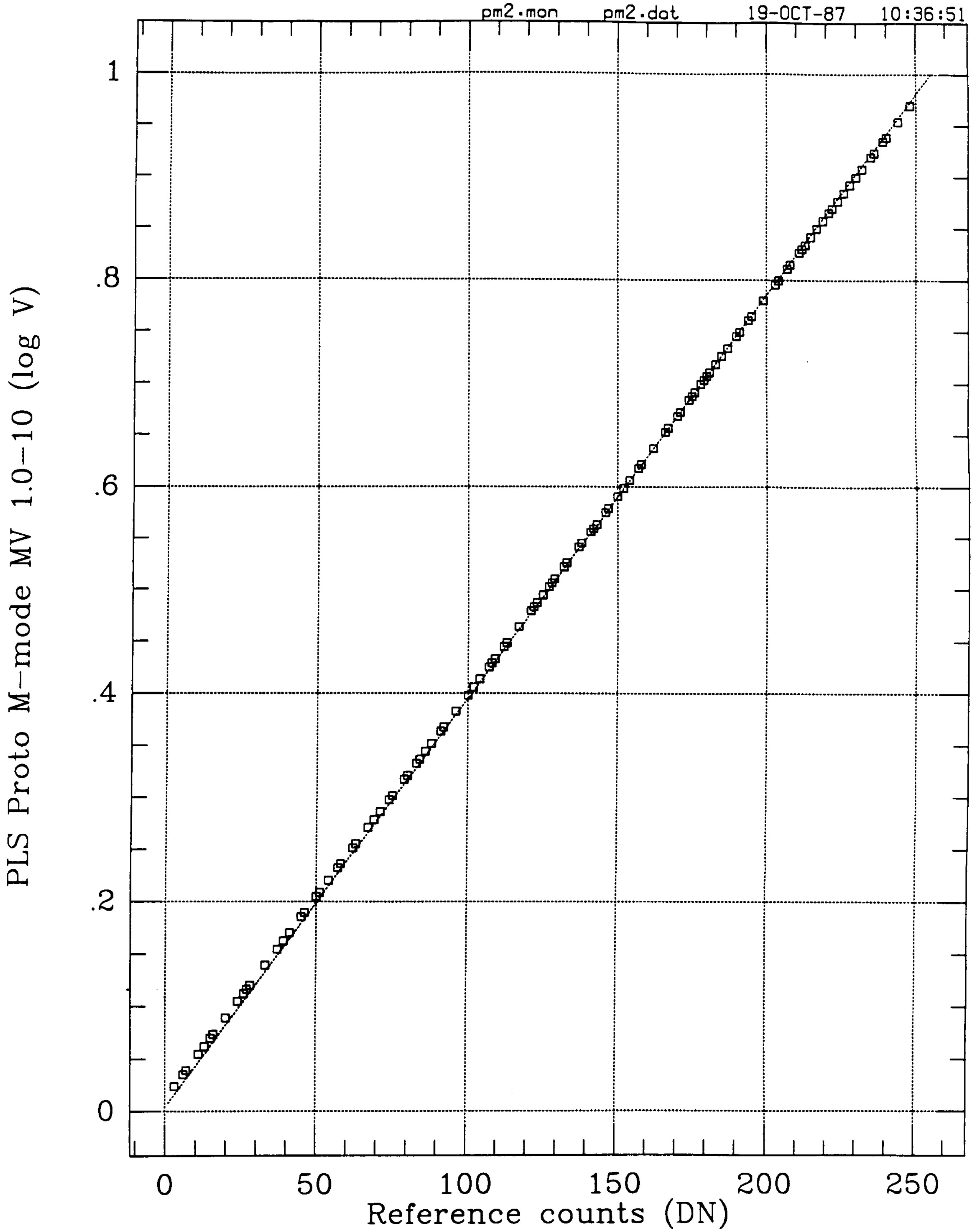
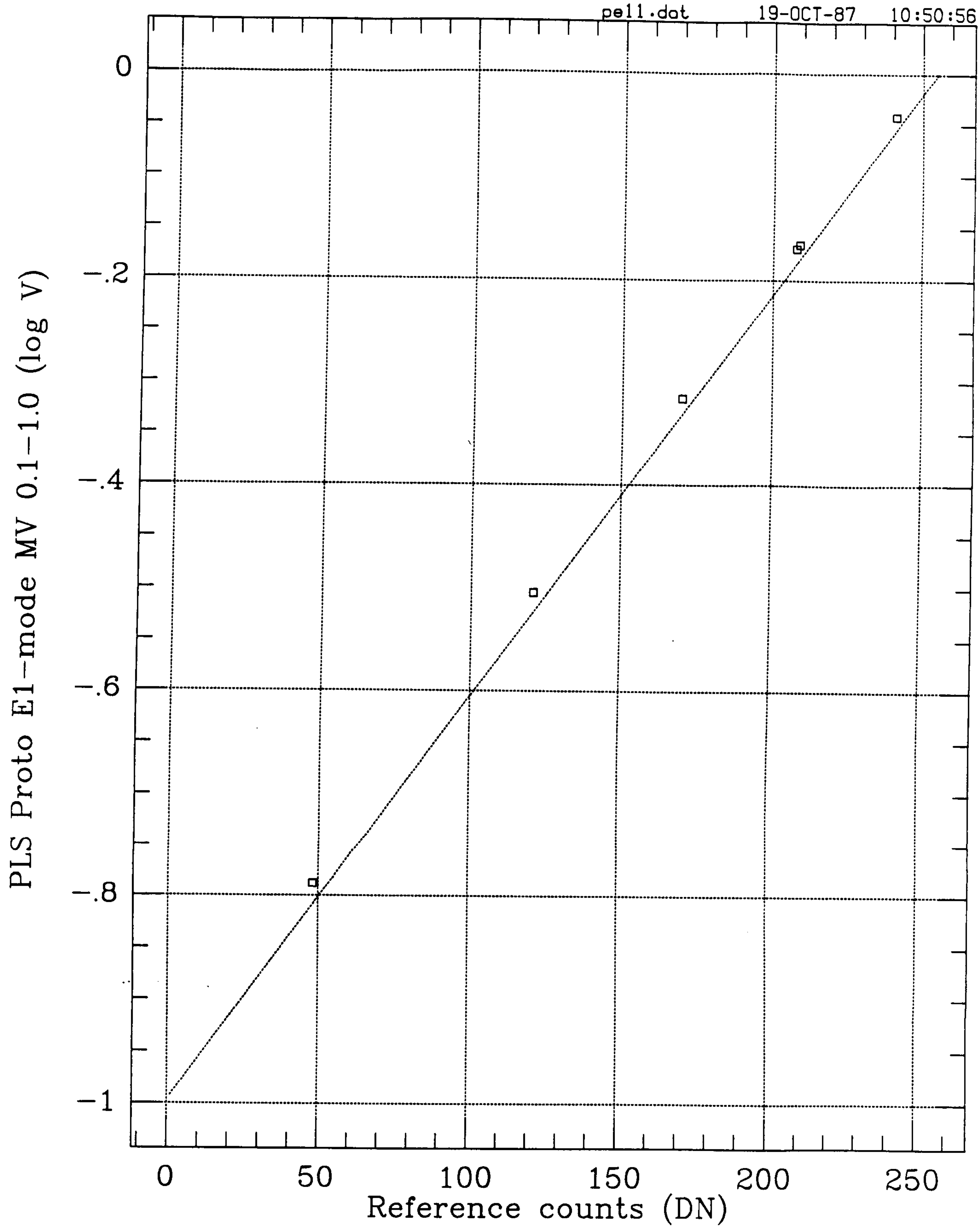
Reference counts (DN)

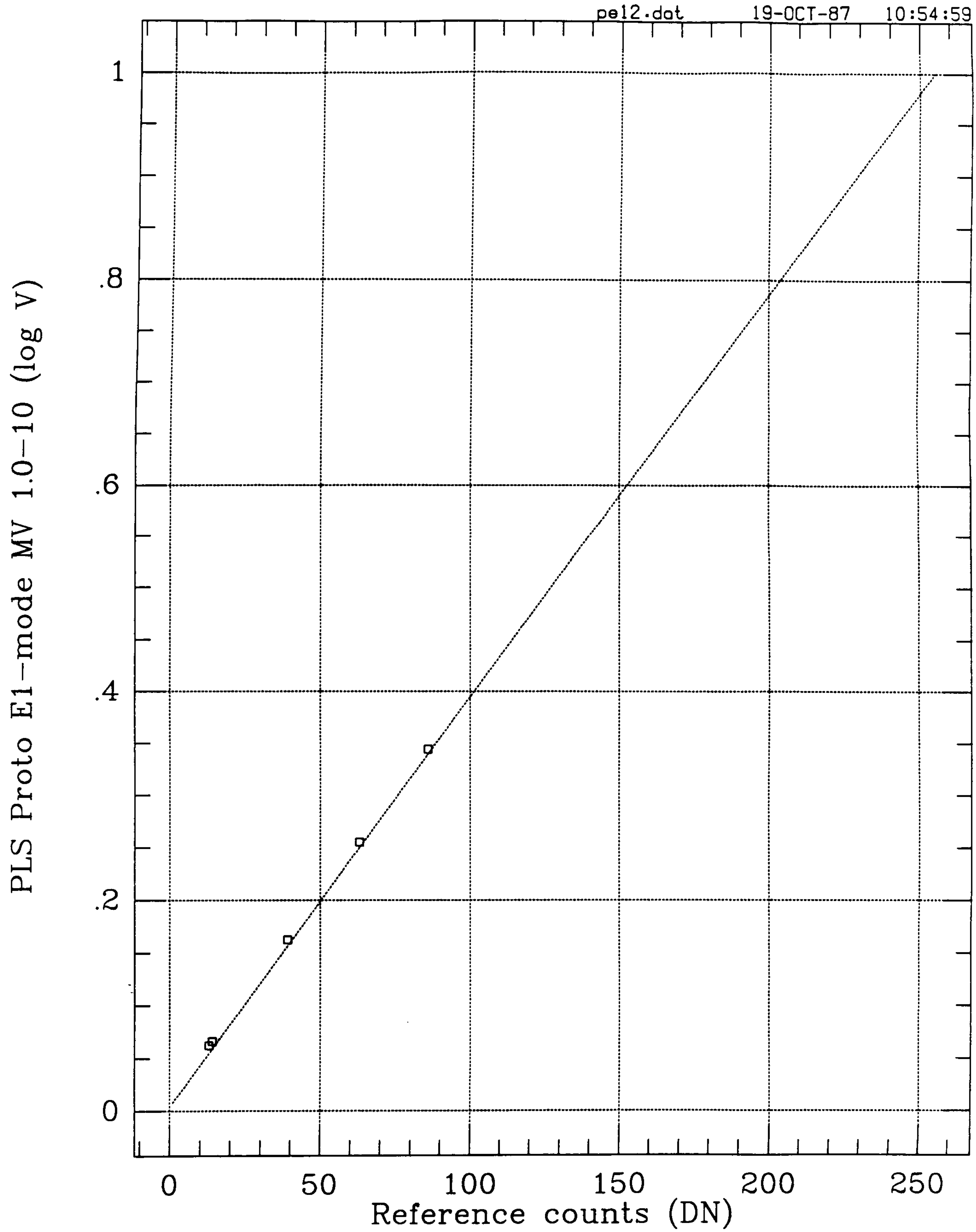

pl2.dat
19-OCT-87
00:37:23
PLS Proto L-mode MV 1.0-10 (log V)
Reference counts (DN)
0
50
100
150
200
250
.2
.4
.6
.8
1



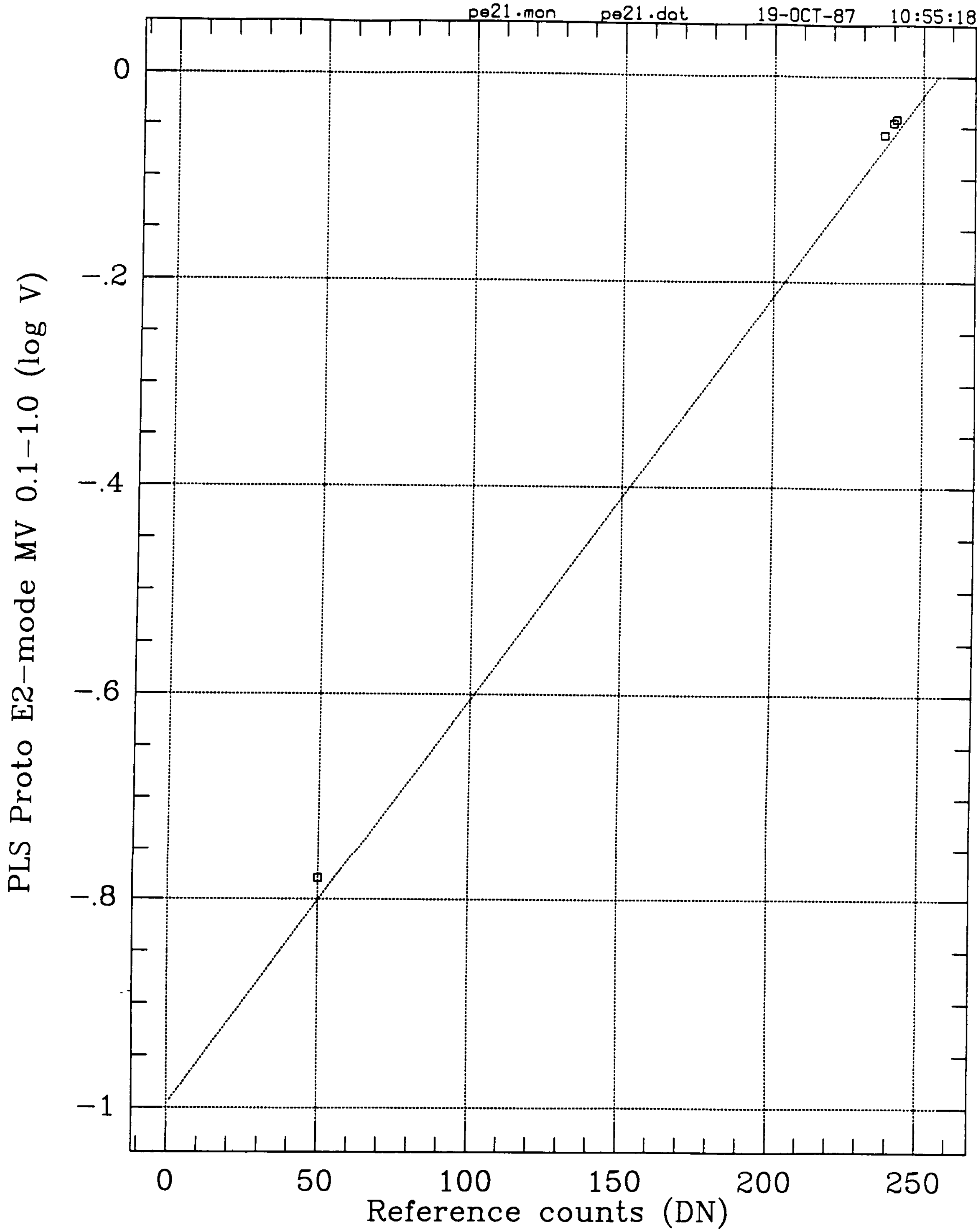
pm1.dat
19-OCT-87
10:36:24
0
-.2
-.4
-.6
-.8
-1
PLS Proto M-mode MV 0.1-1.0 (log V)
0
50
100
150
200
250
Reference counts (DN)

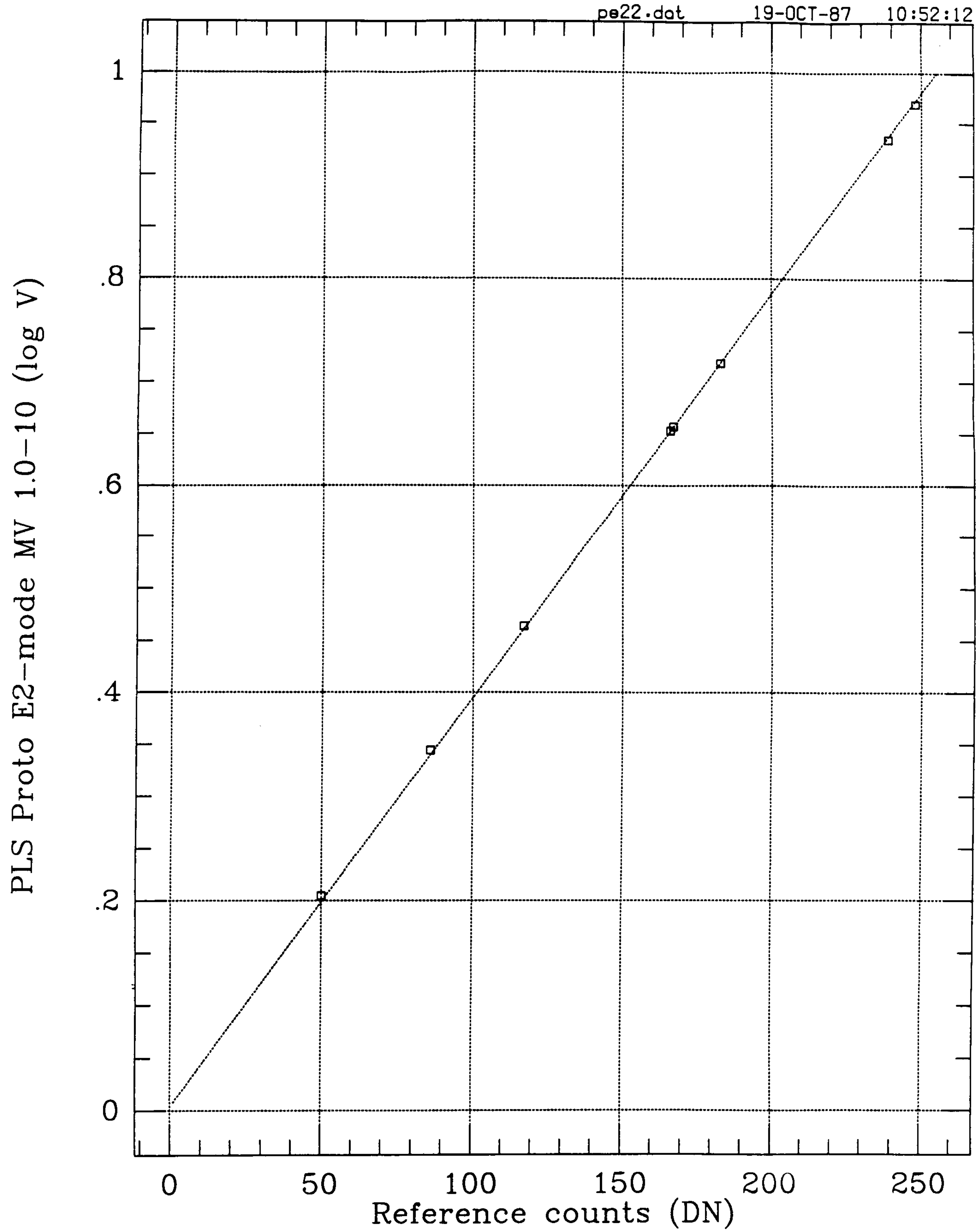

pm2.mon
pm2.dat
19-OCT-87
10:36:51
PLS Proto M-mode MV 1.0-10 (log V)
1
.8
.6
.4
.2
0
0
50
100
150
200
250
Reference counts (DN)

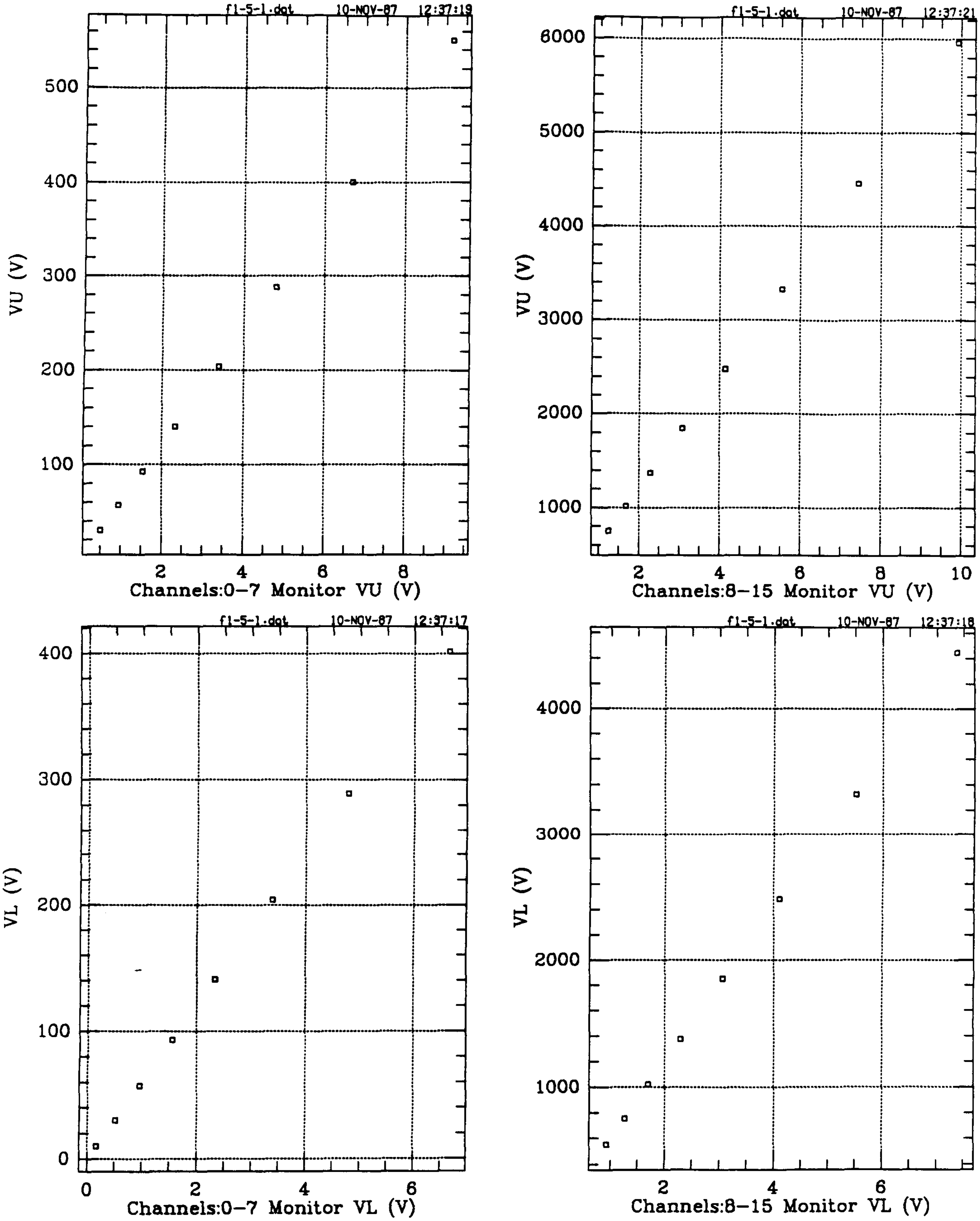

pe11.dat
19-OCT-87
10:50:56
0
-.2
-.4
-.6
-.8
-1
PLS Proto E1-mode MV 0.1-1.0 (log V)
0
50
100
150
200
250
Reference counts (DN)



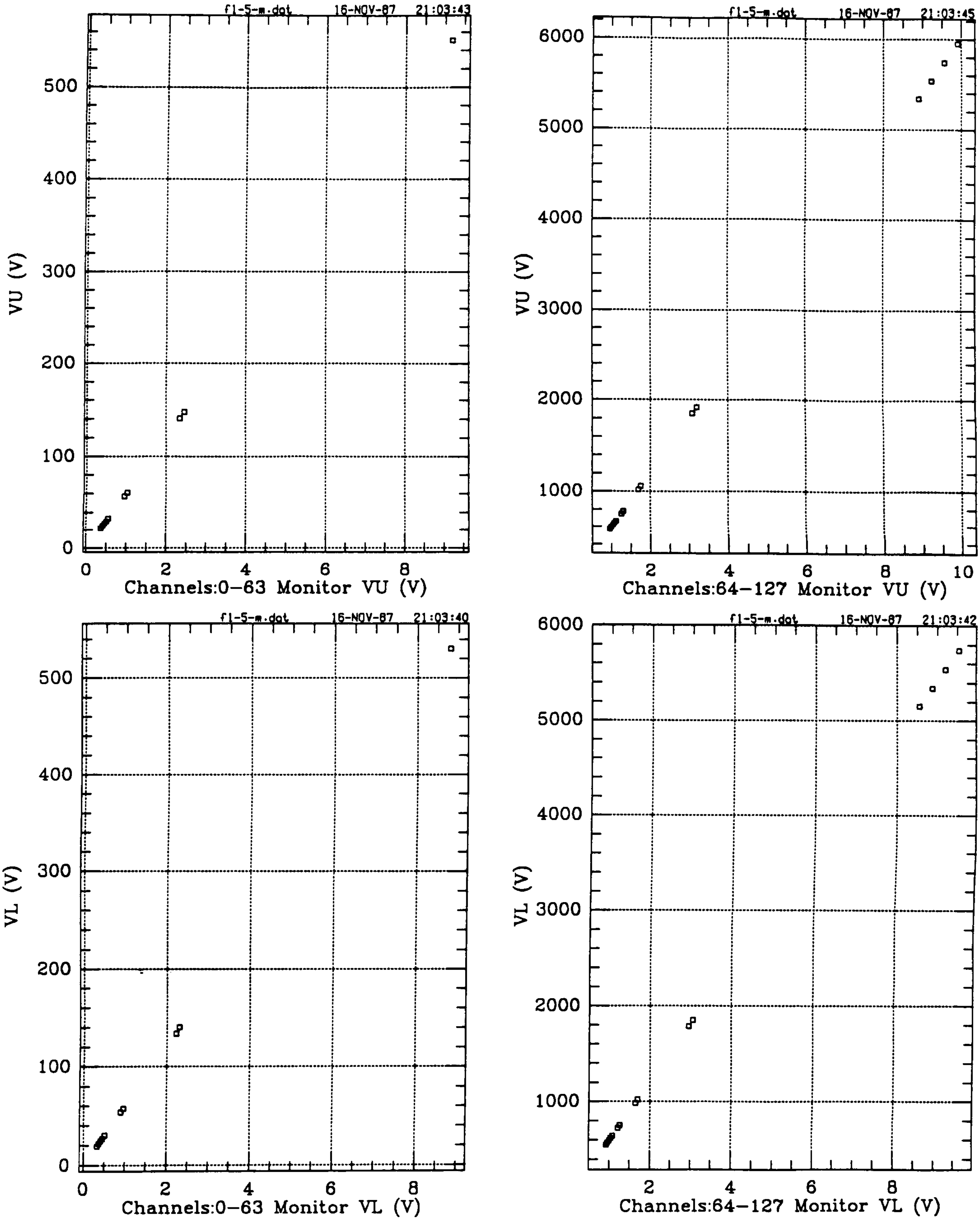
pe12.dat 19-OCT-87 10:54:59
PLS Proto E1-mode MV 1.0-10 (log V)
Reference counts (DN)
0
.2
.4
.6
.8
1
0
50
100
150
200
250


pe21.mon
pe21.dat
19-OCT-87
10:55:18
0
-.2
-.4
-.6
-.8
-1
PLS Proto E2-mode MV 0.1-1.0 (log V)
0
50
100
150
200
250
Reference counts (DN)

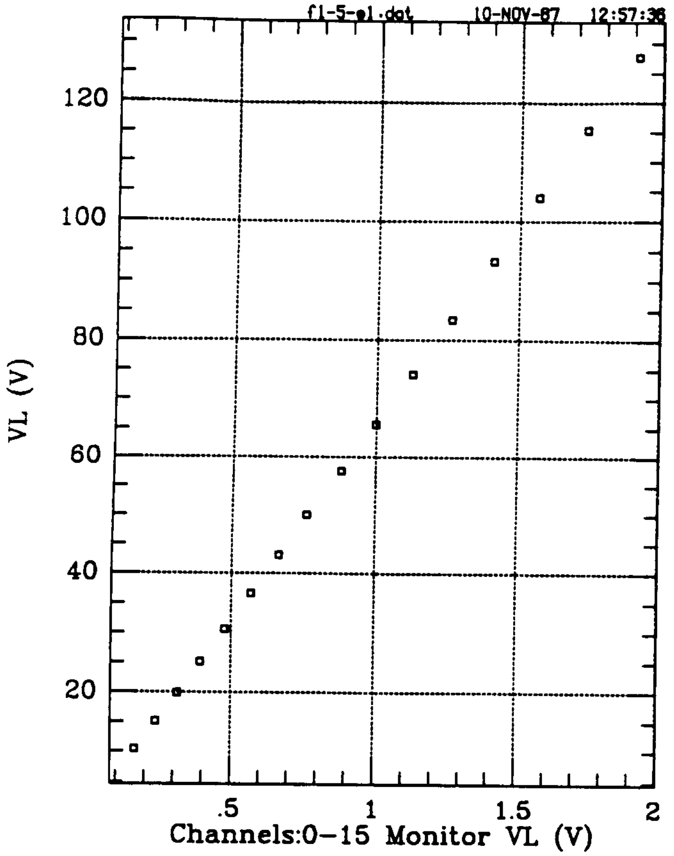

pe22.dat 19-OCT-87 10:52:12
PLS Proto E2-mode MV 1.0-10 (log V)
Reference counts (DN)
0
.2
.4
.6
.8
1
0
50
100
150
200
250

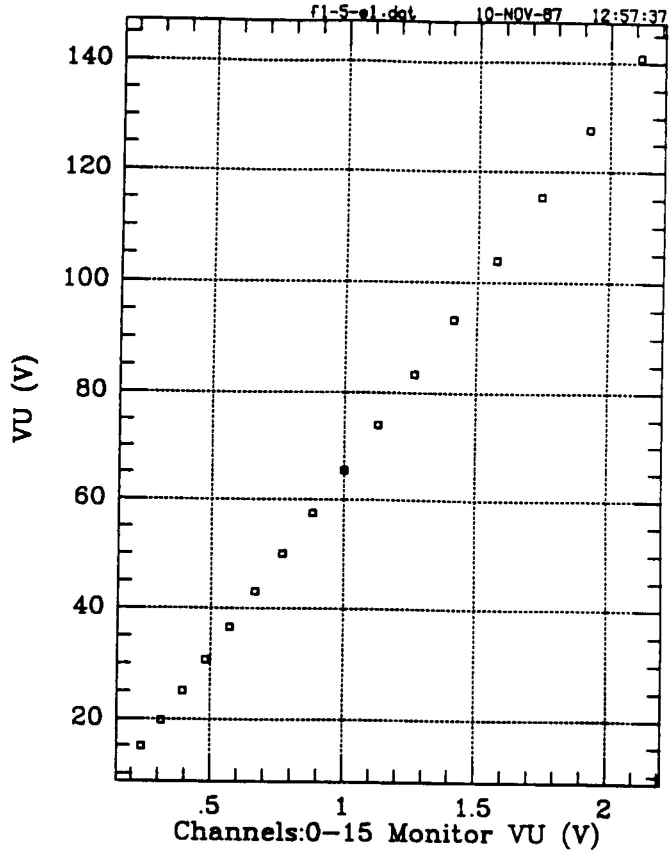


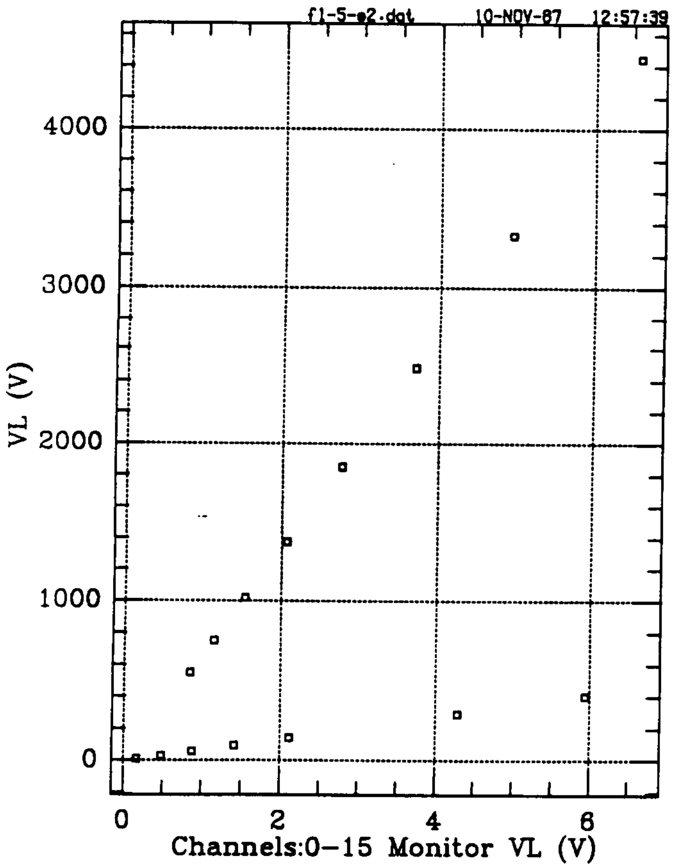
Flite:1 Temp:−5C Mode:L

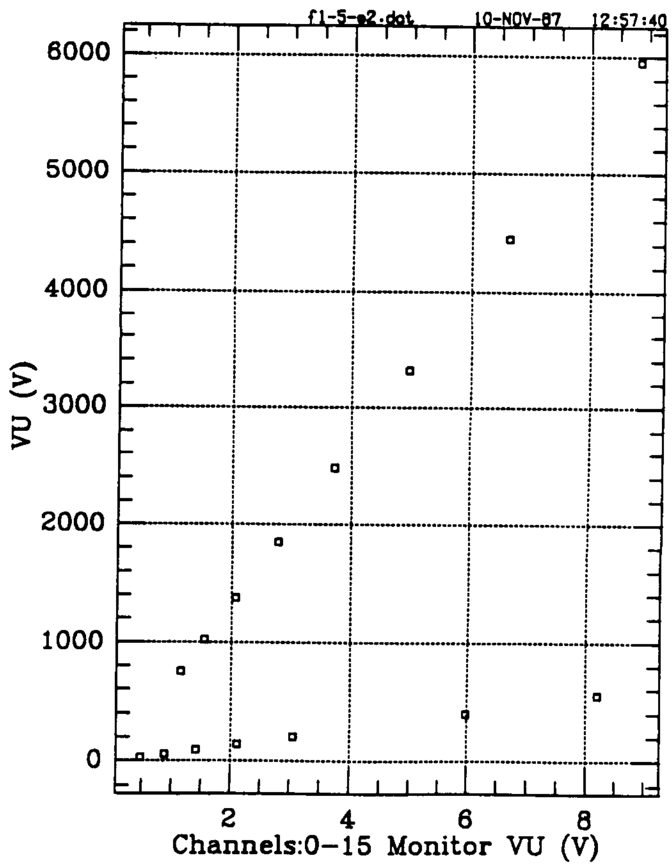


Flite:1 Temp:–5C Mode:M

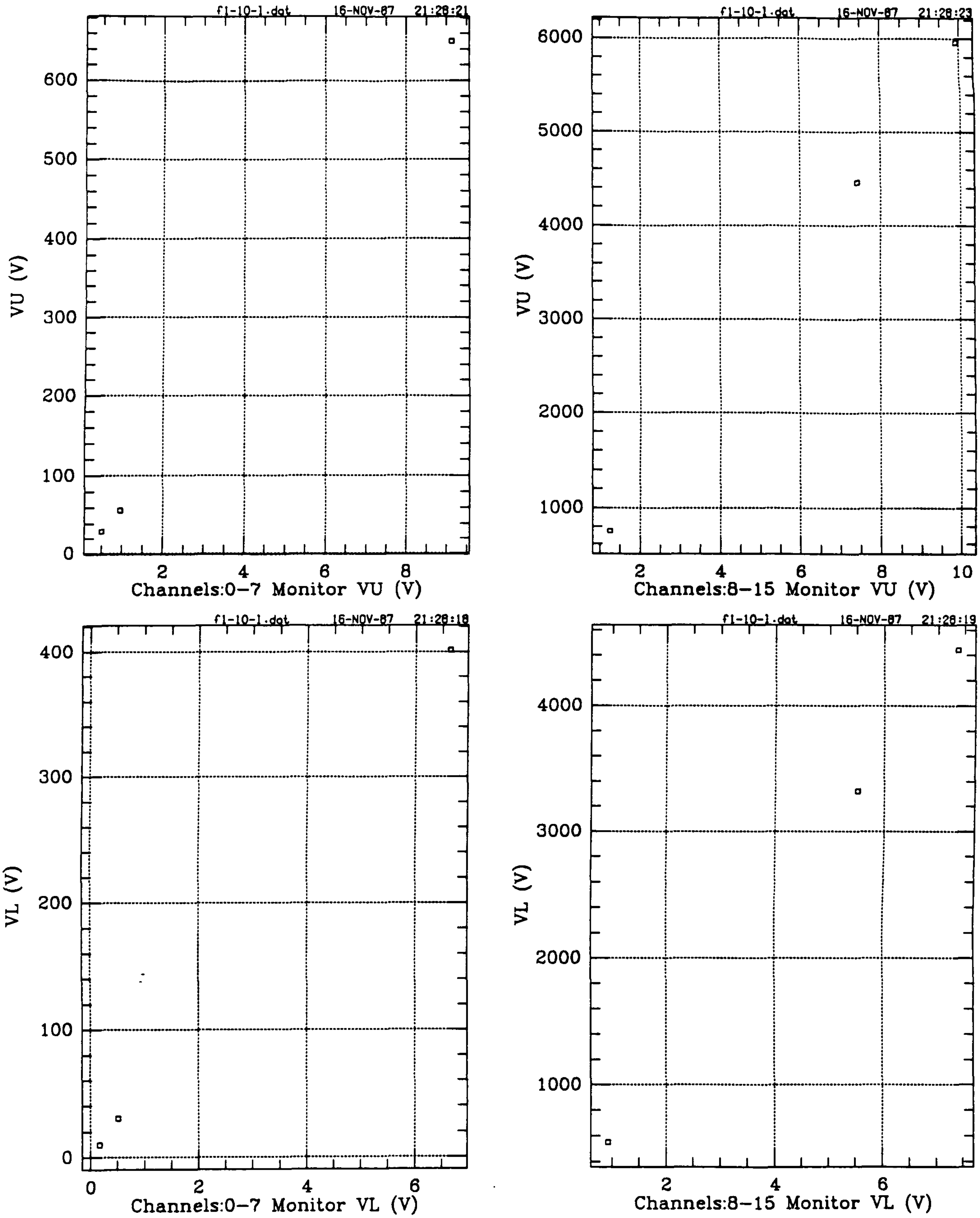




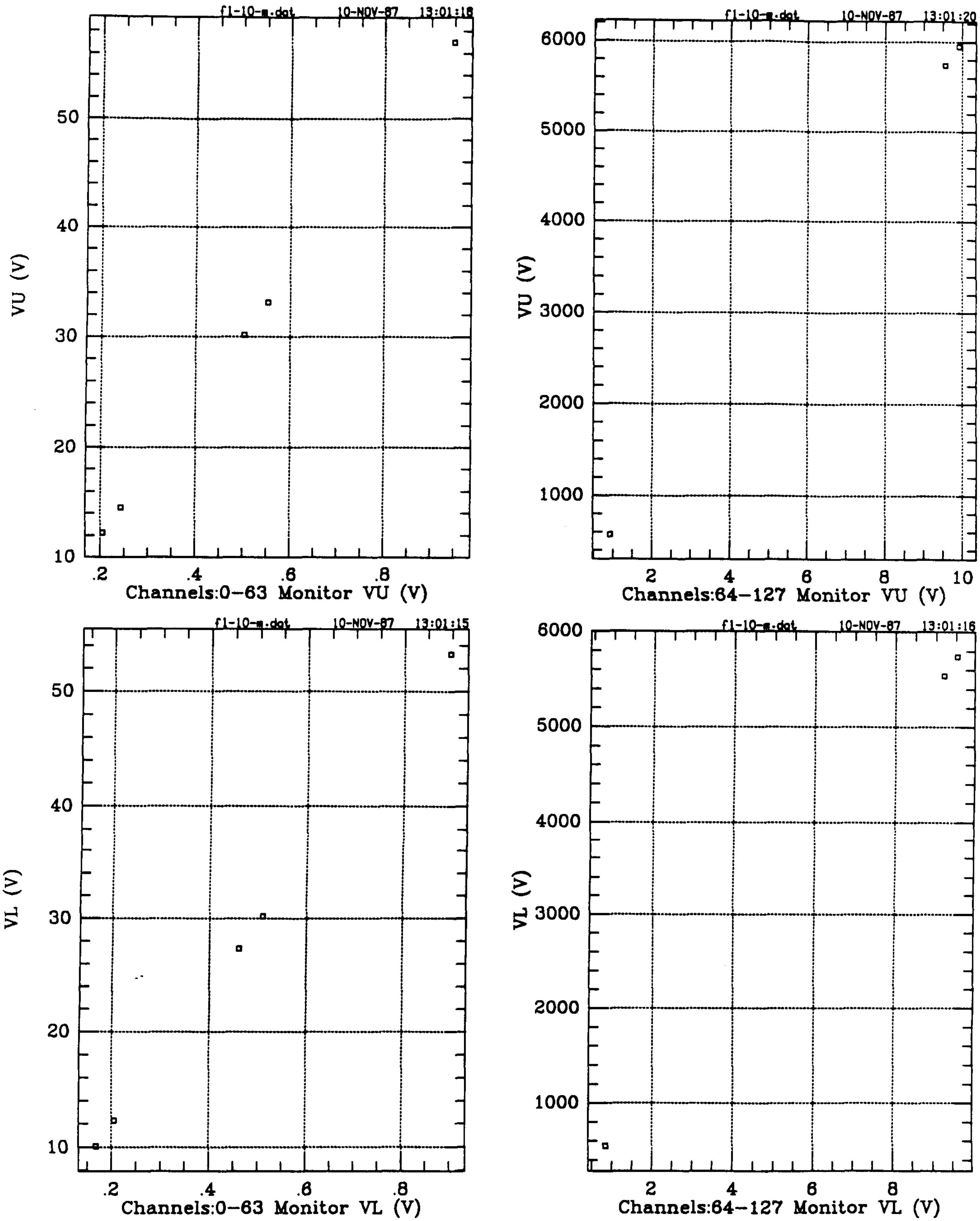




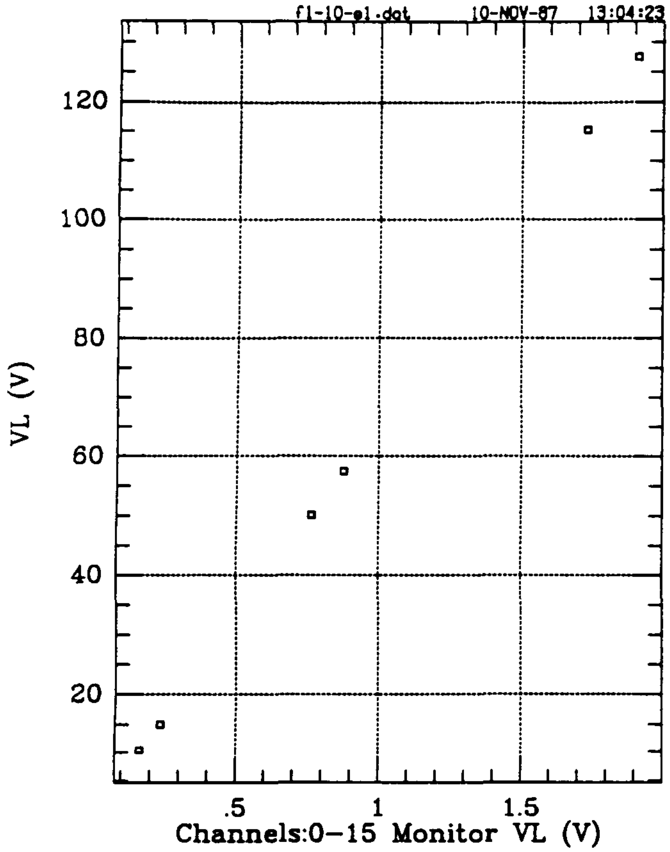
Flite:1 Temp:−5C Mode:E1 & E2

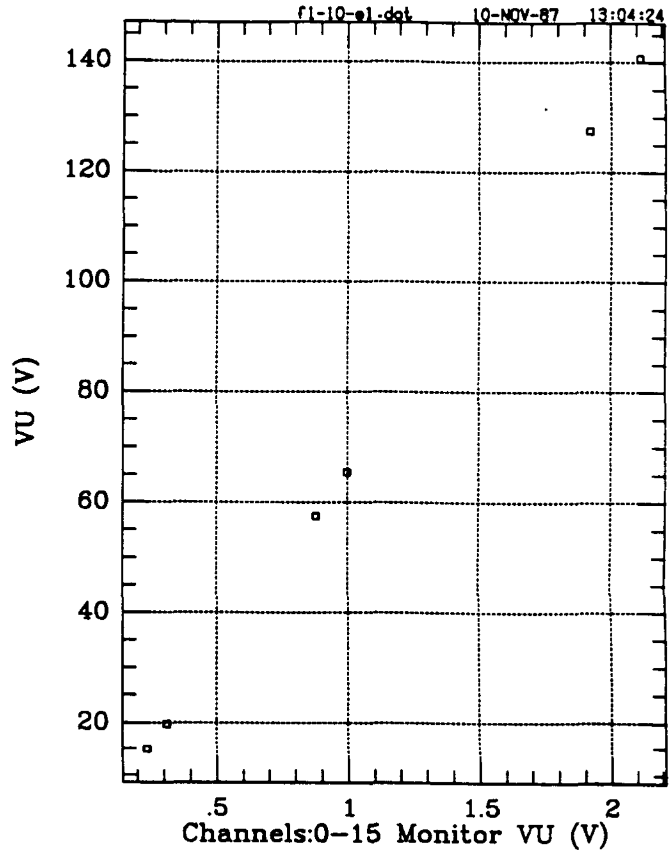


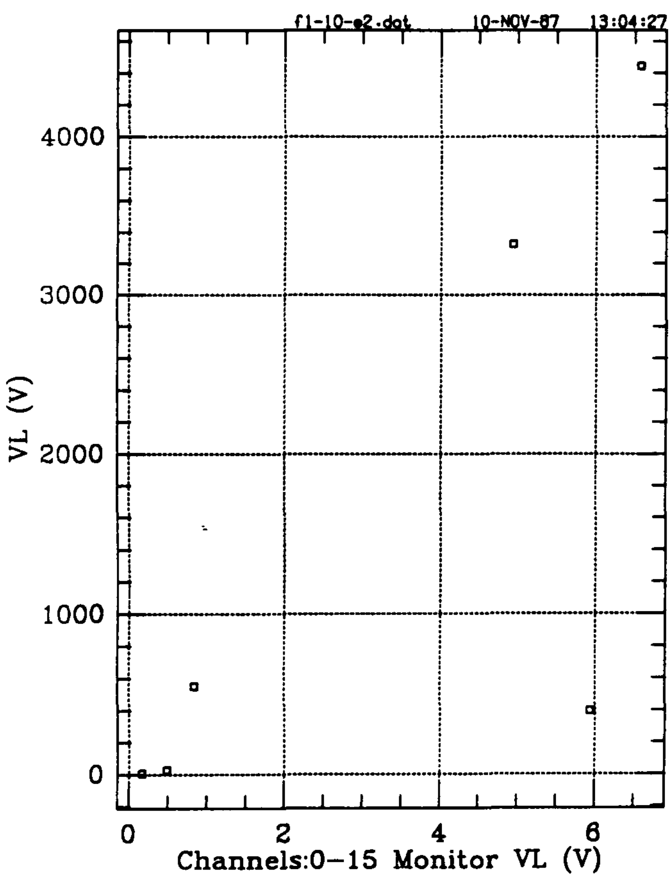
Flite:1 Temp:10C Mode:L

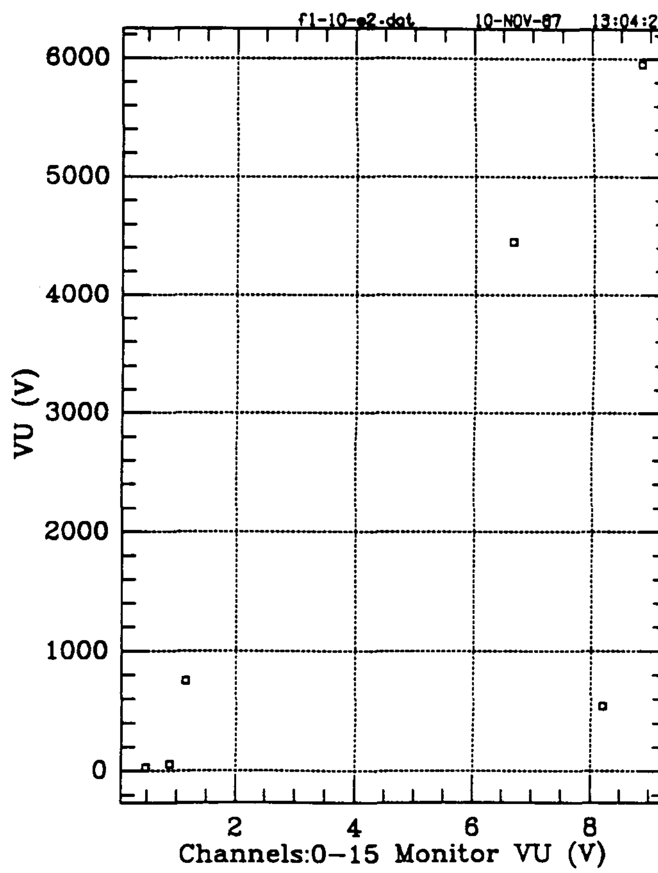


Flite:1 Temp:10C Mode:M

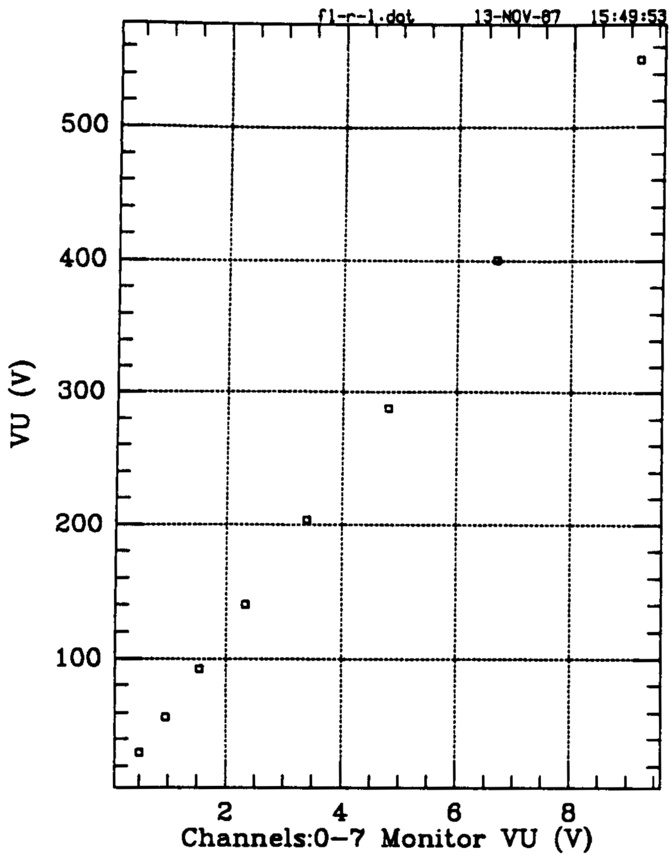


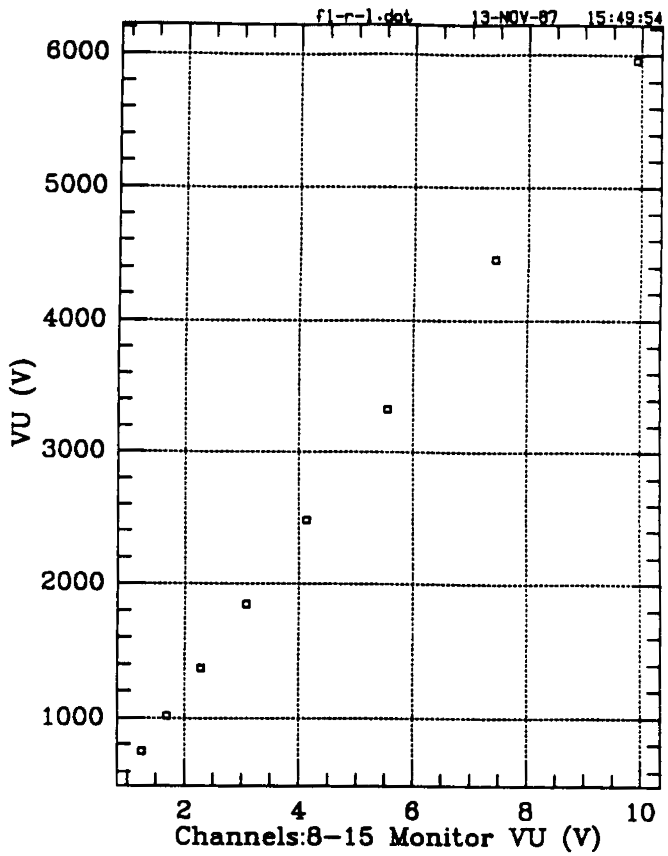


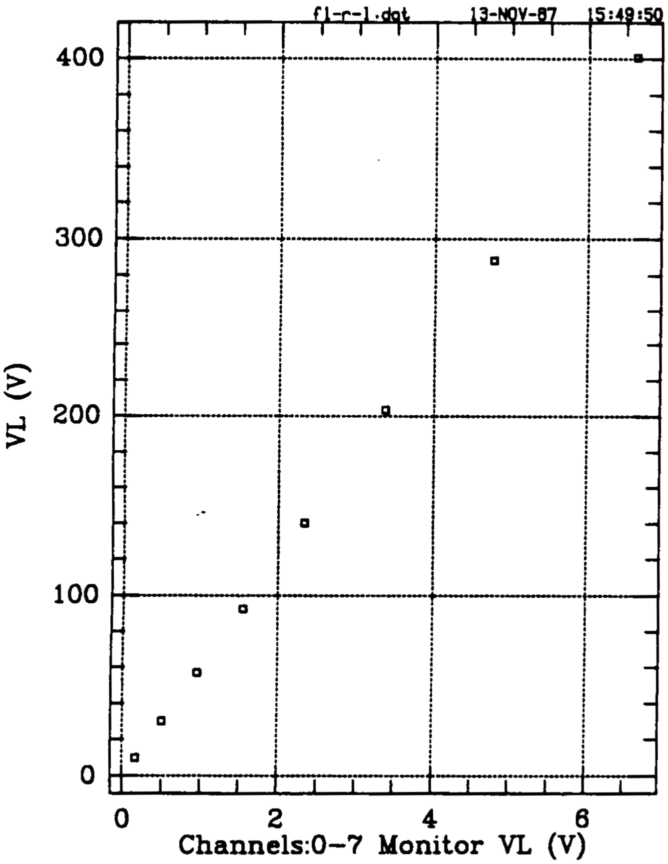


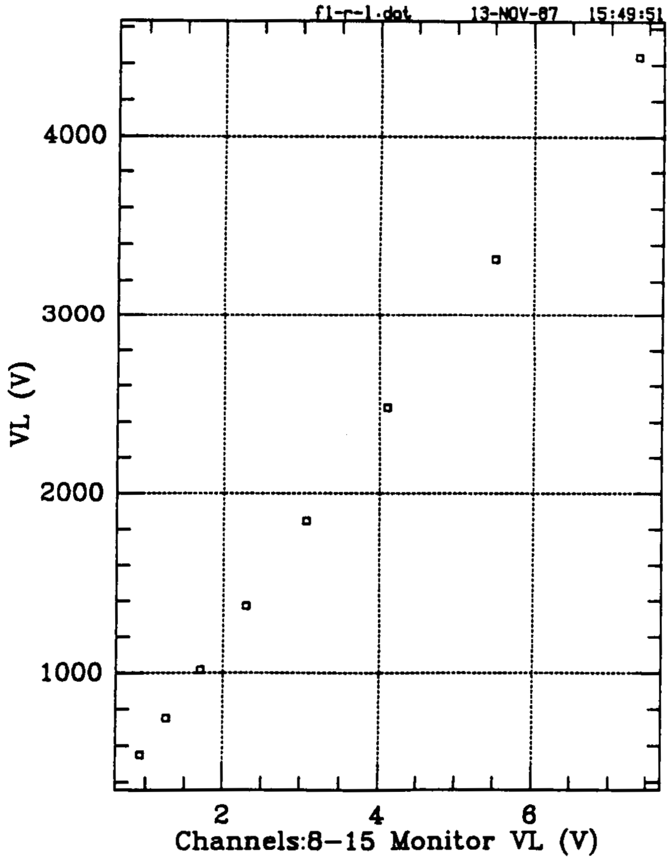


Flite:1 Temp:10C Mode:E1 & E2

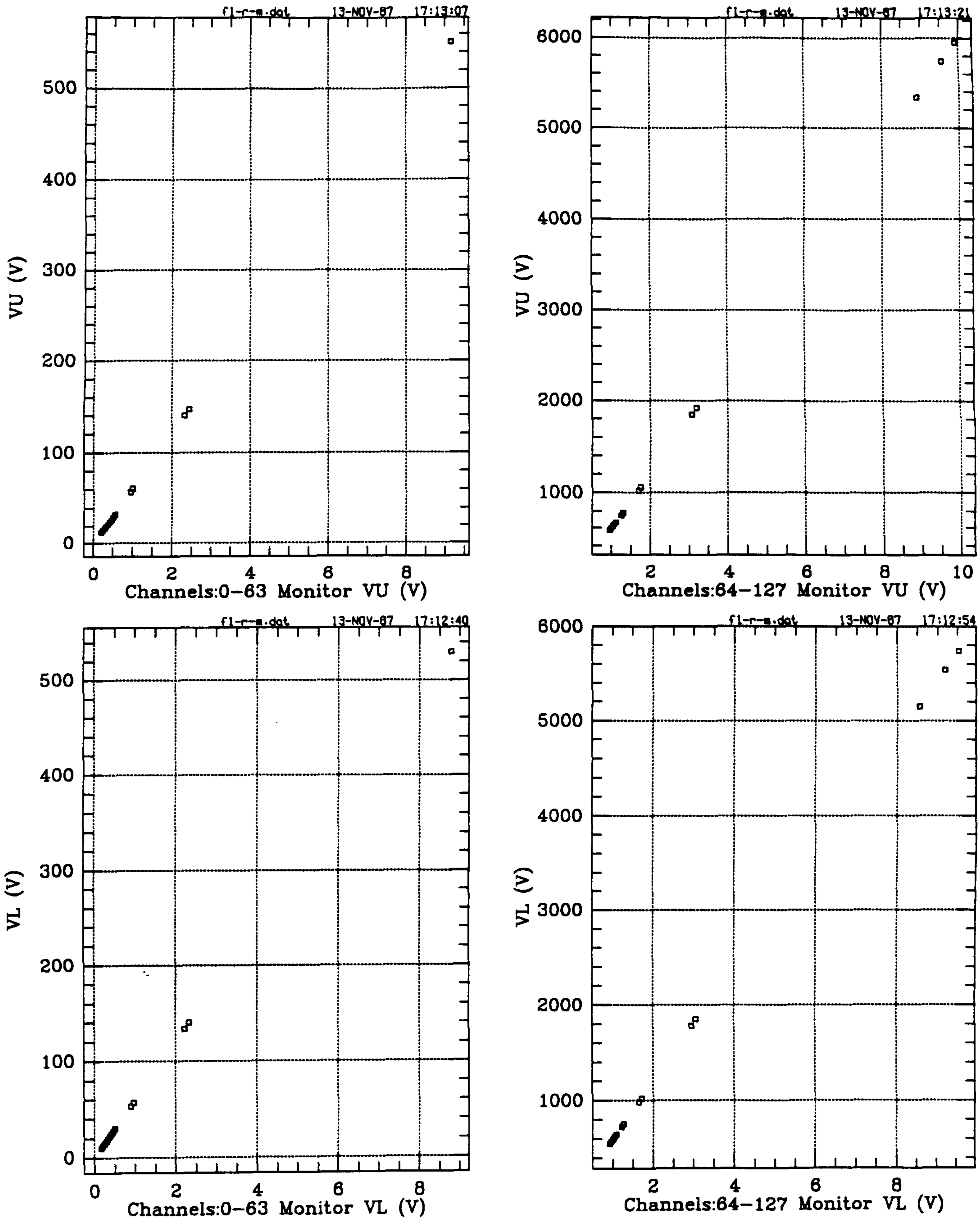




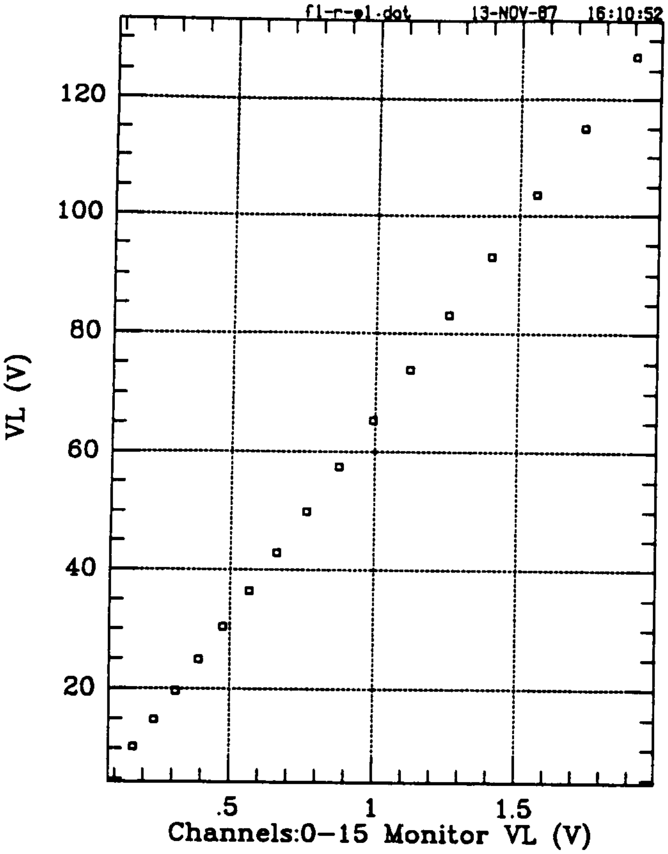


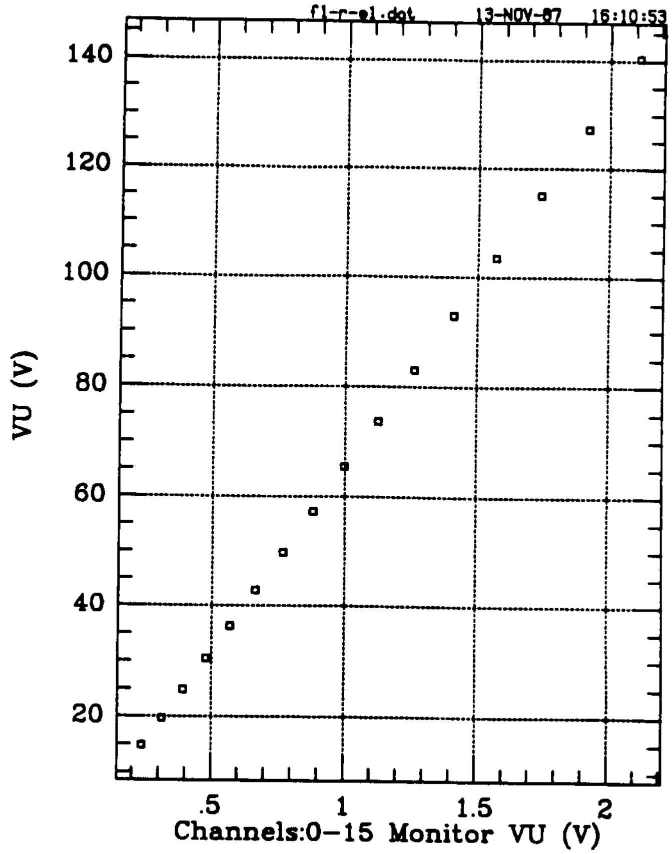


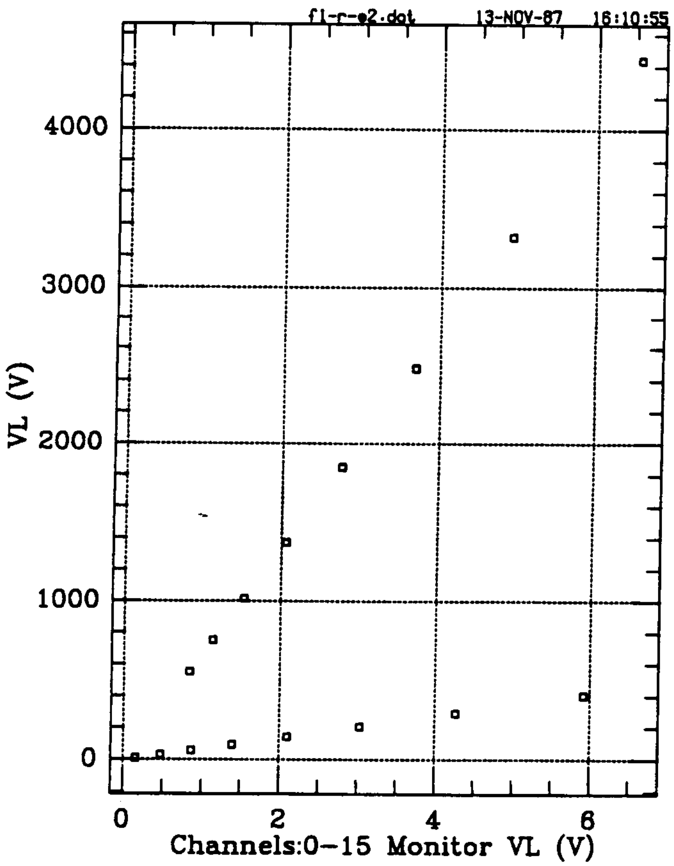
Flite:1 Temp:Room Mode:L

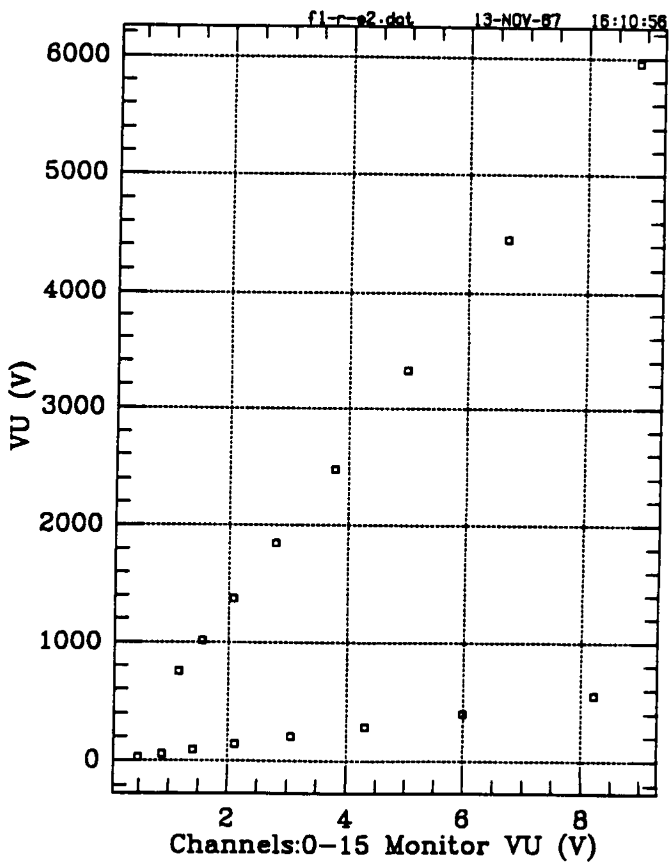


Flite:1 Temp:Room Mode:M

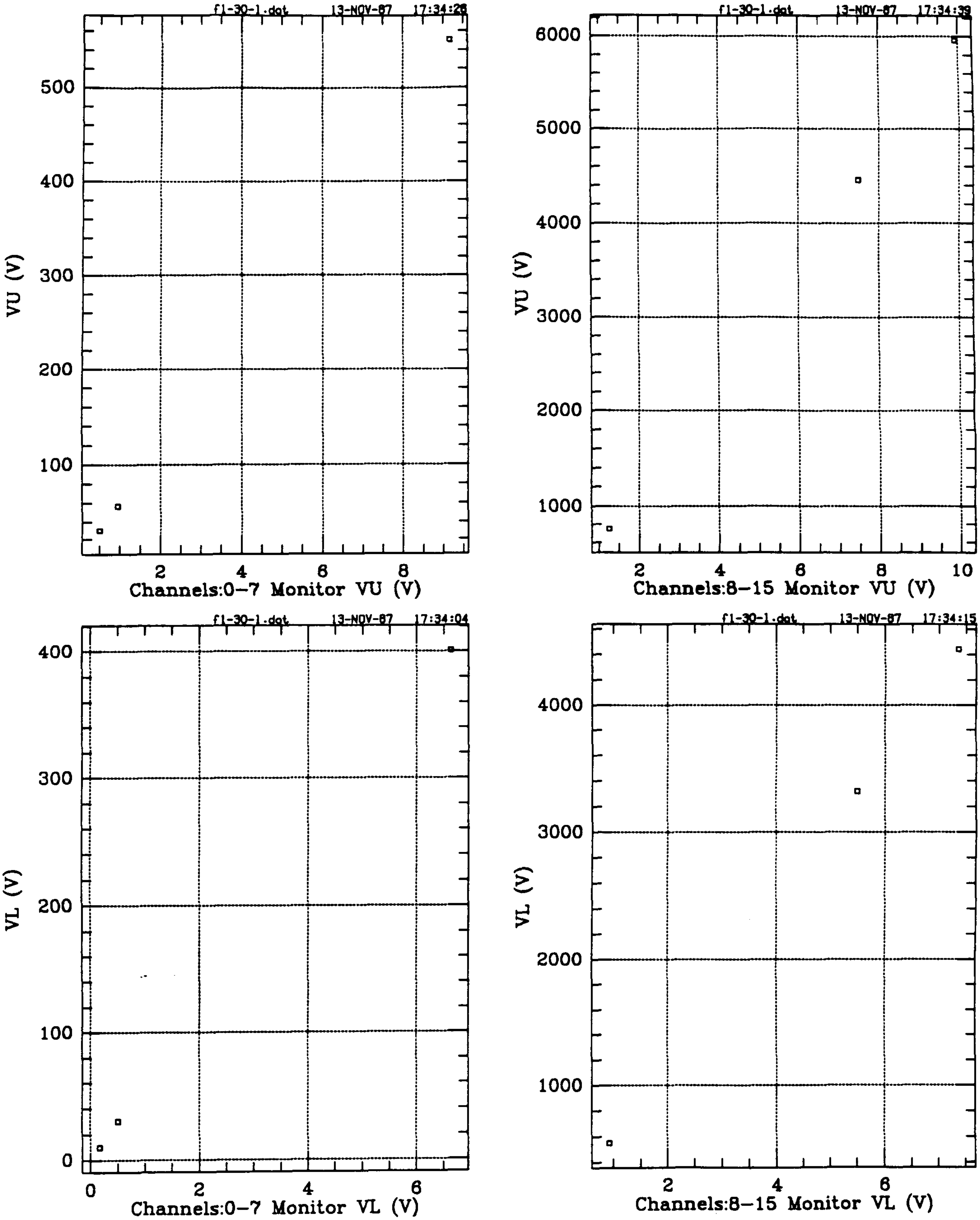




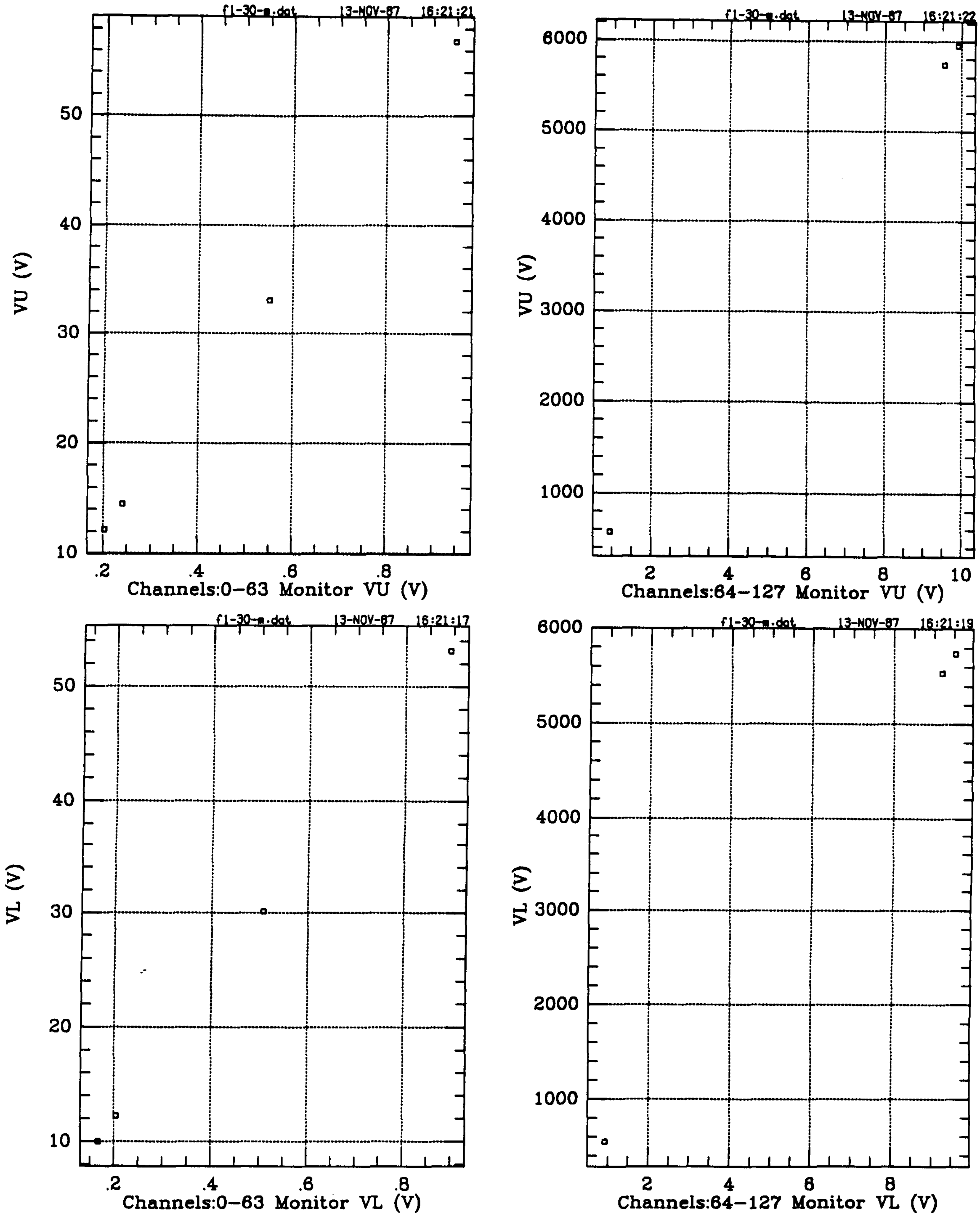




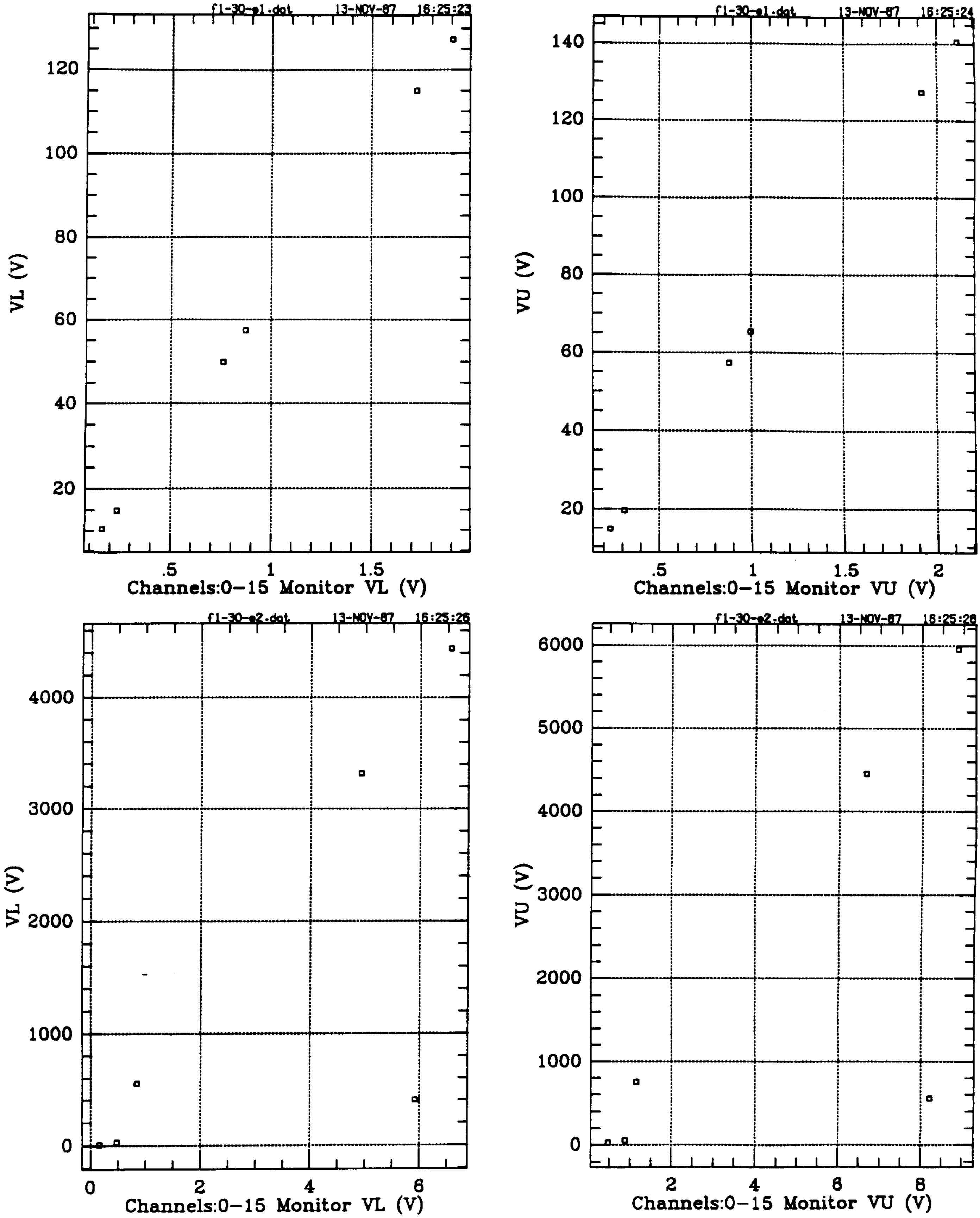
Flite:1 Temp:Room Mode:E1 & E2



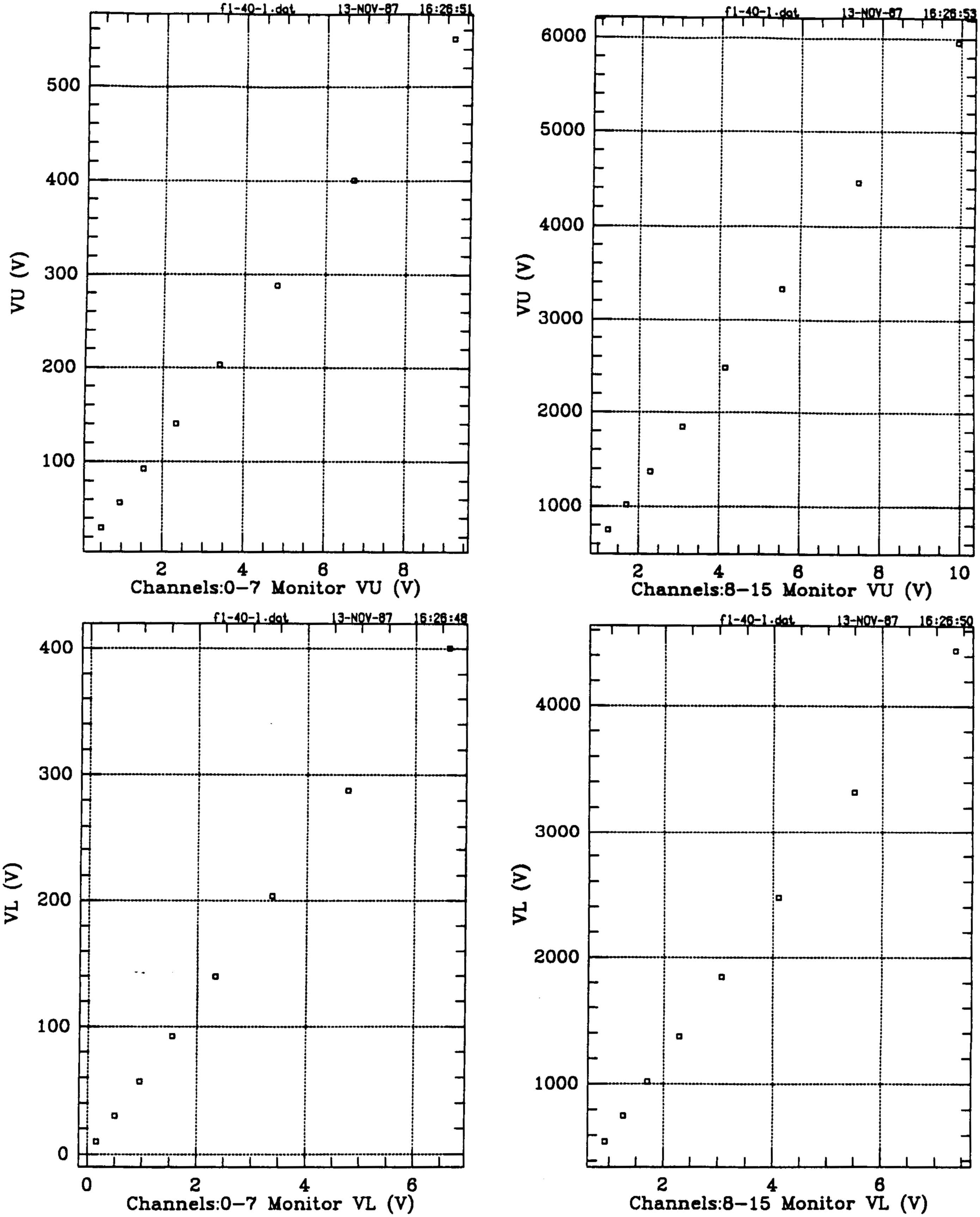
Flite:1 Temp:30C Mode:L



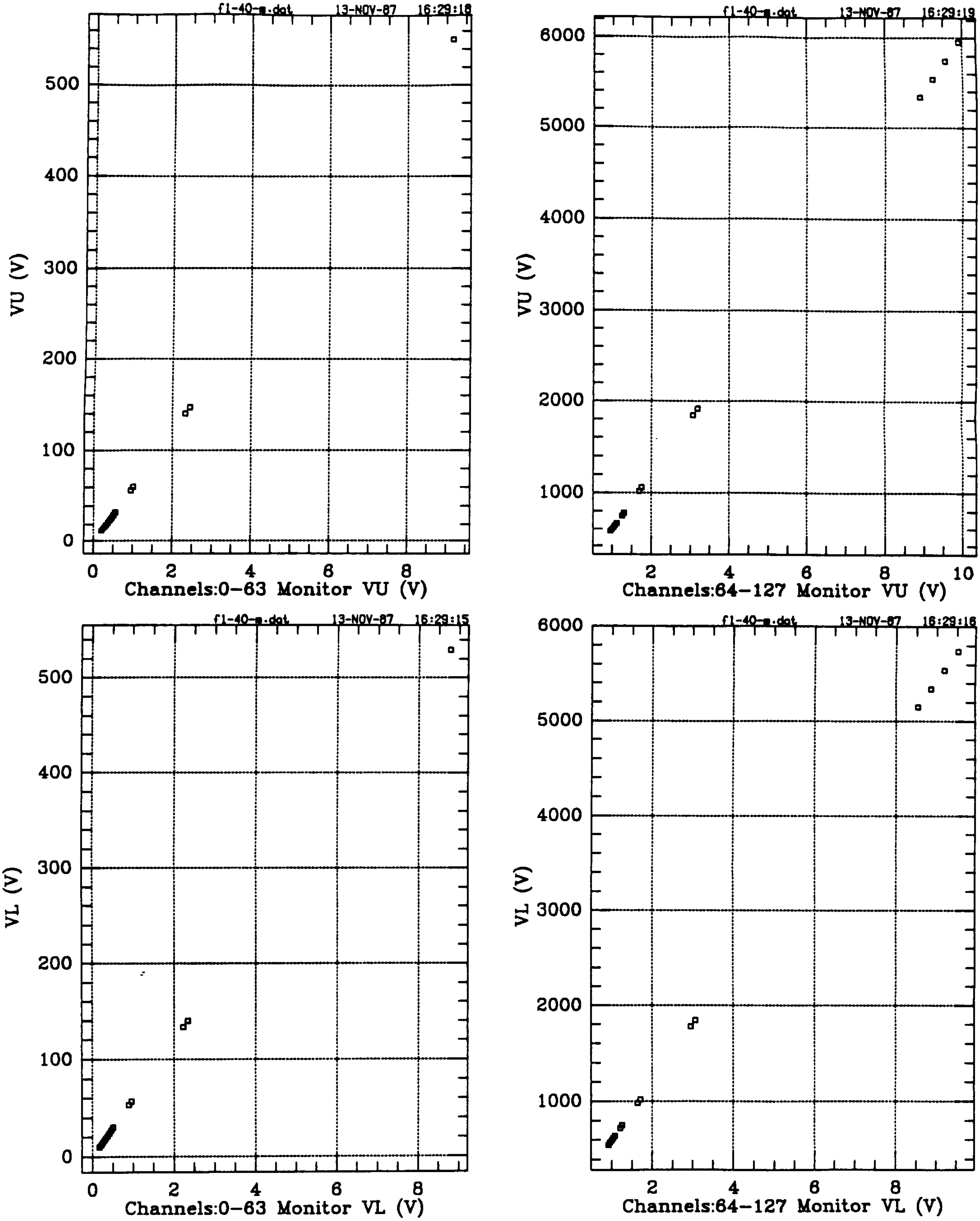
Flite:1 Temp:30C Mode:M



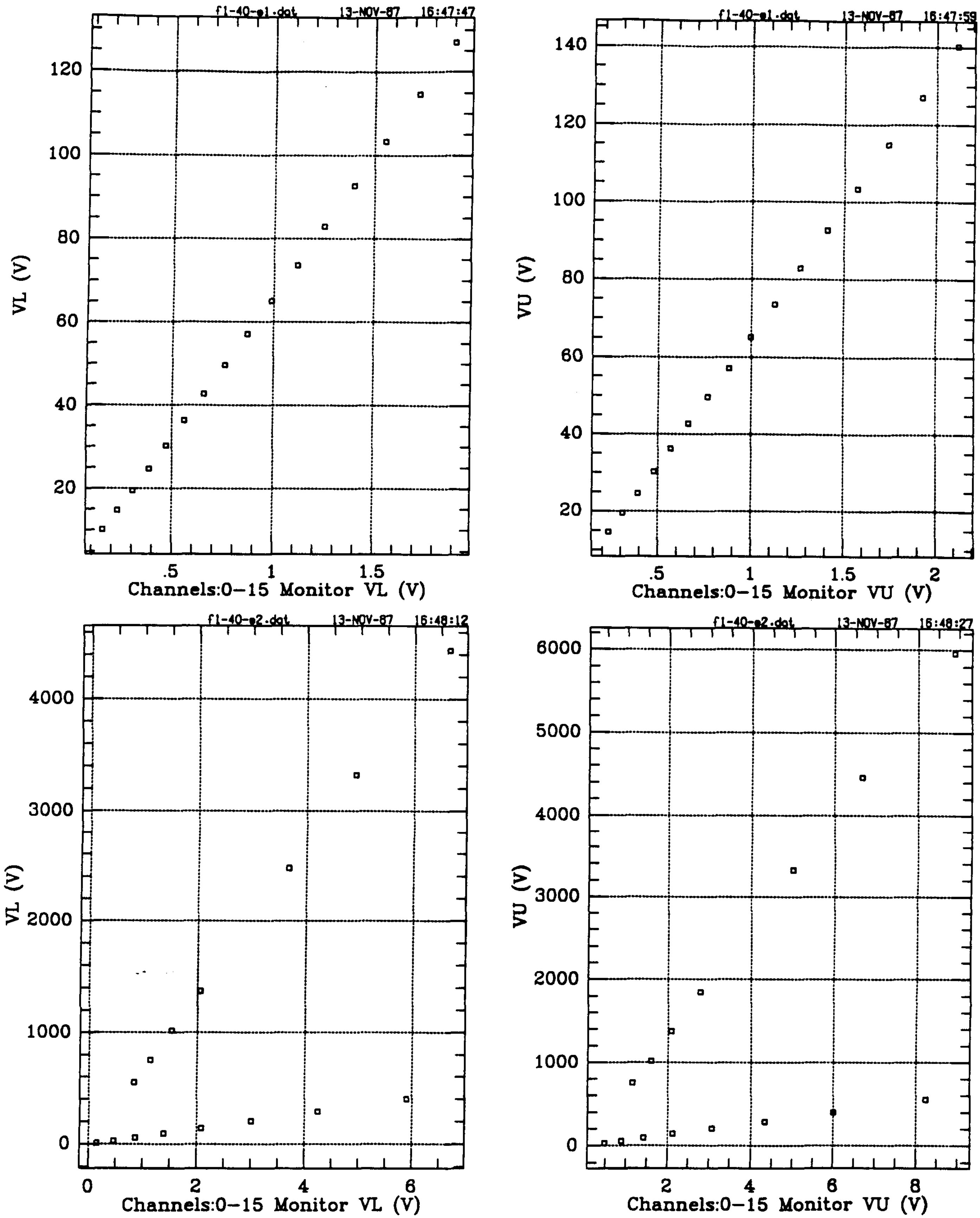
Flite:1 Temp:30C Mode:E1 & E2



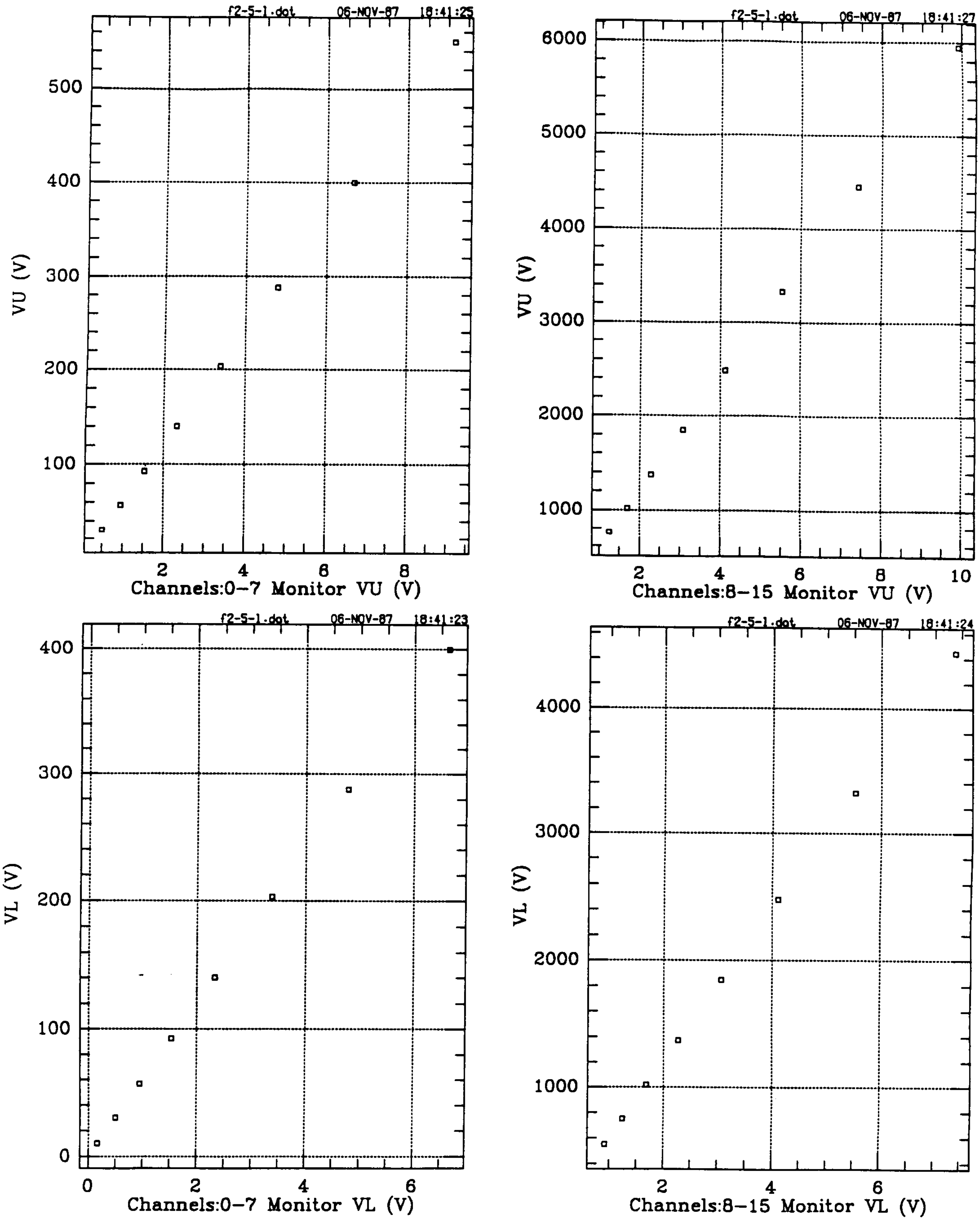
Flite:1 Temp:40C Mode:L



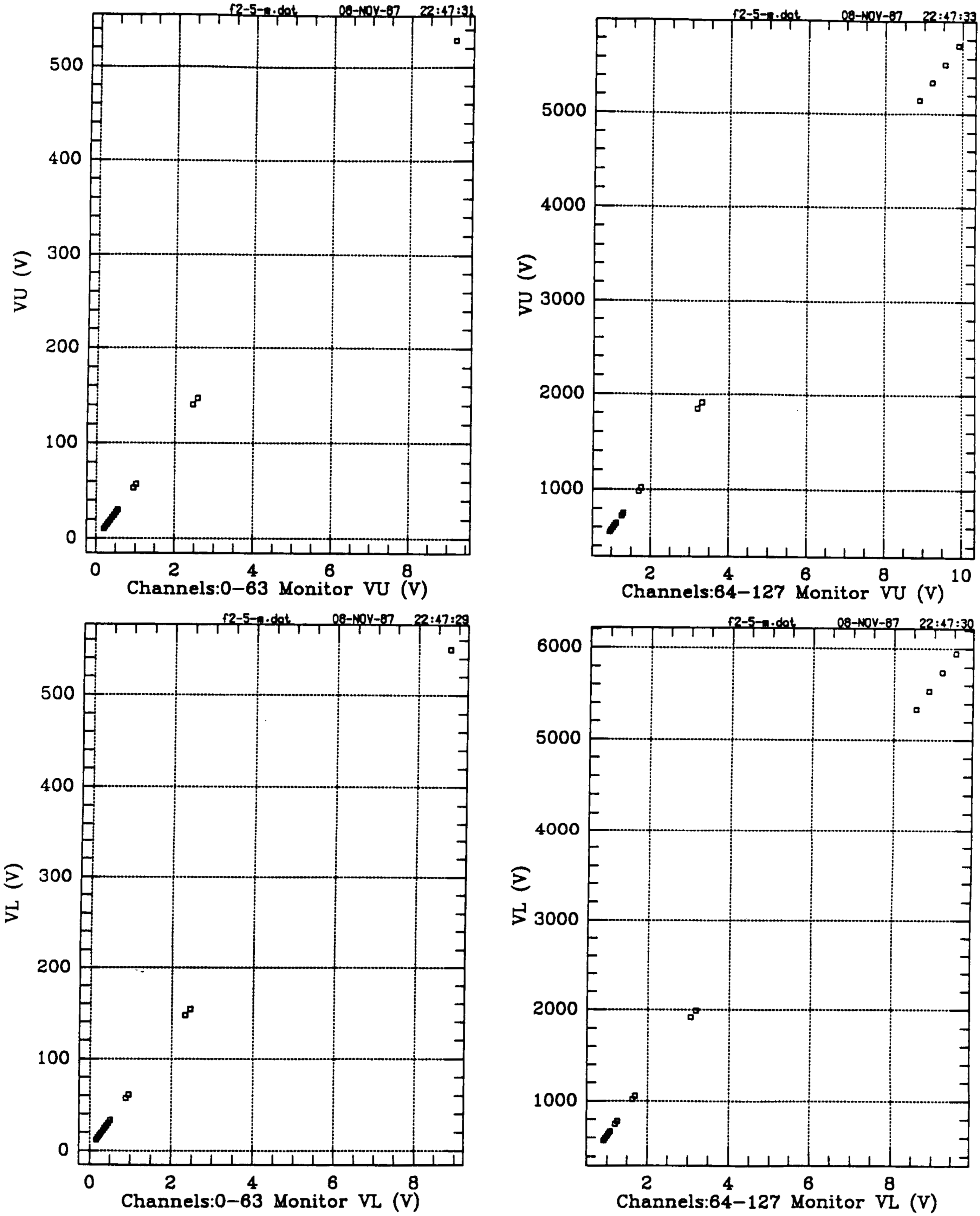
Flite:1 Temp:40C Mode:M



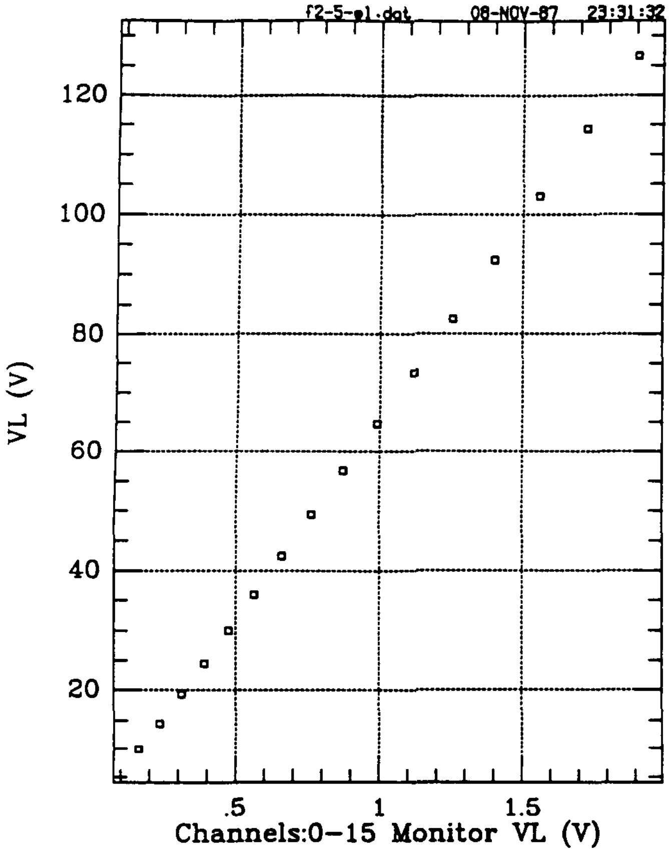
Flite:1 Temp:40C Mode:E1 & E2

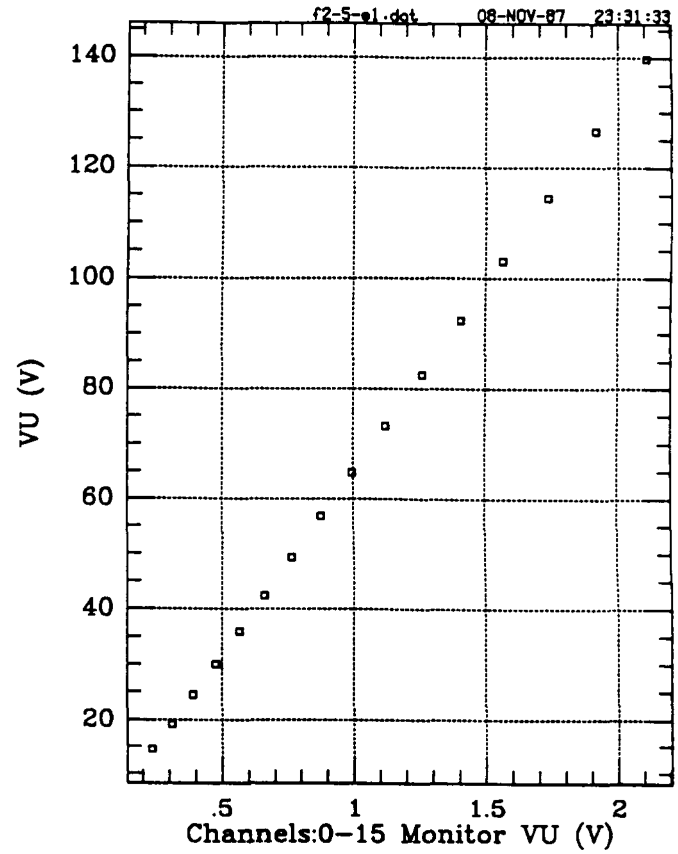


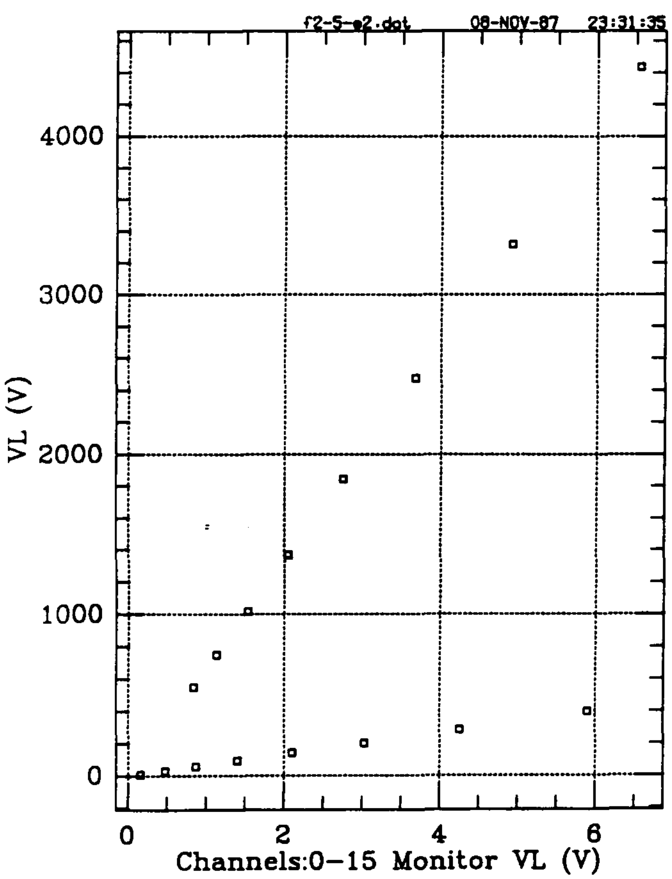
Flite:2 Temp:−5C Mode:L

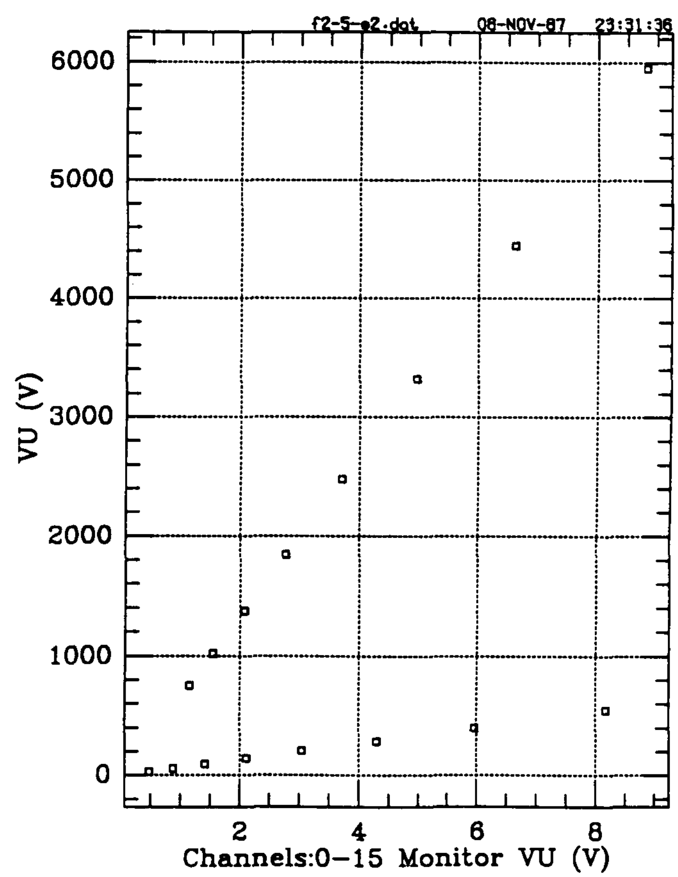


Flite:2 Temp:−5C Mode:M

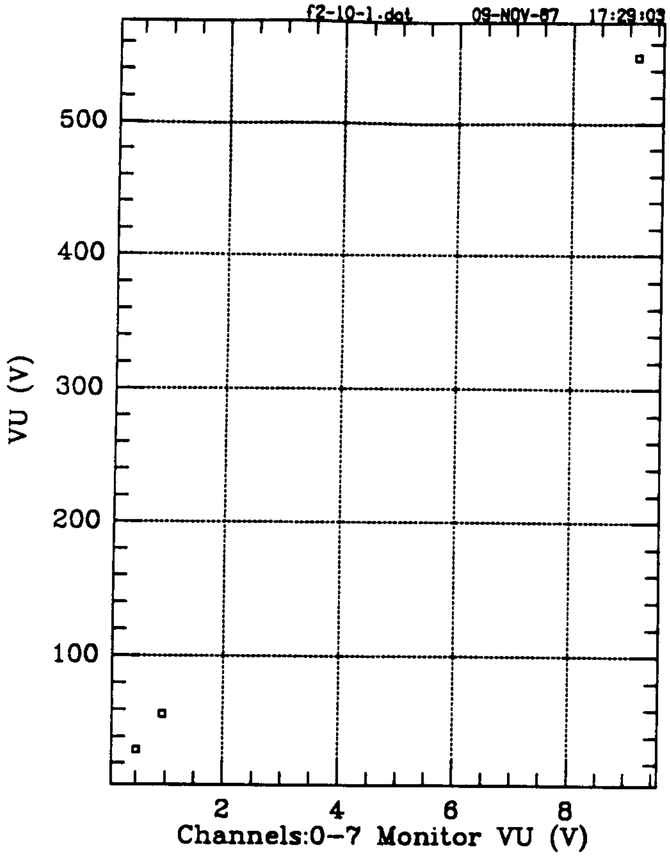


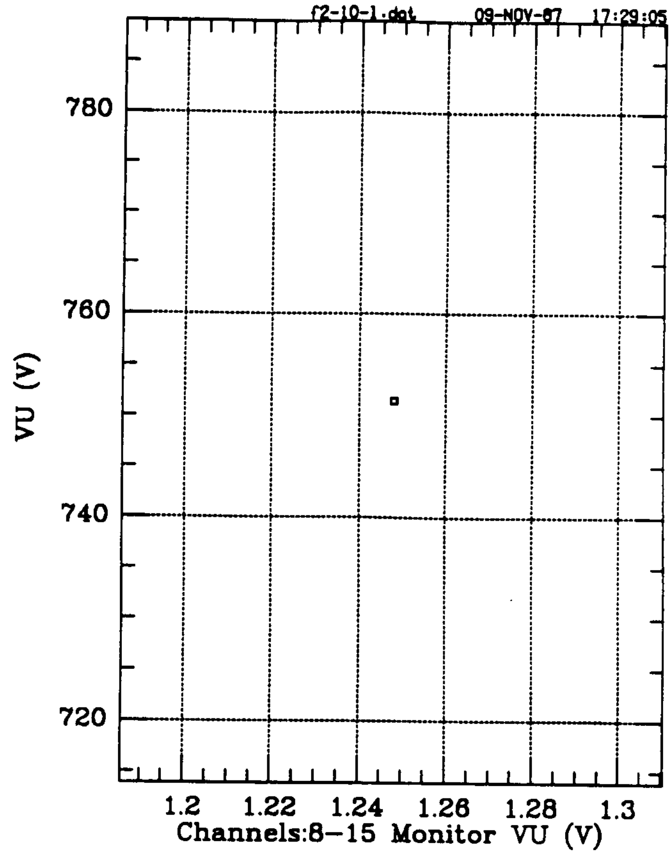


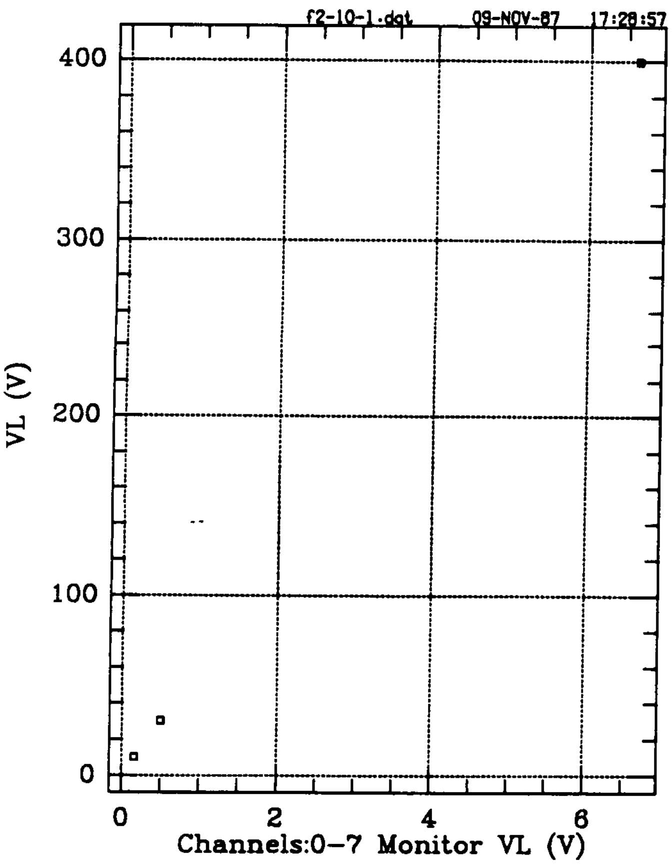


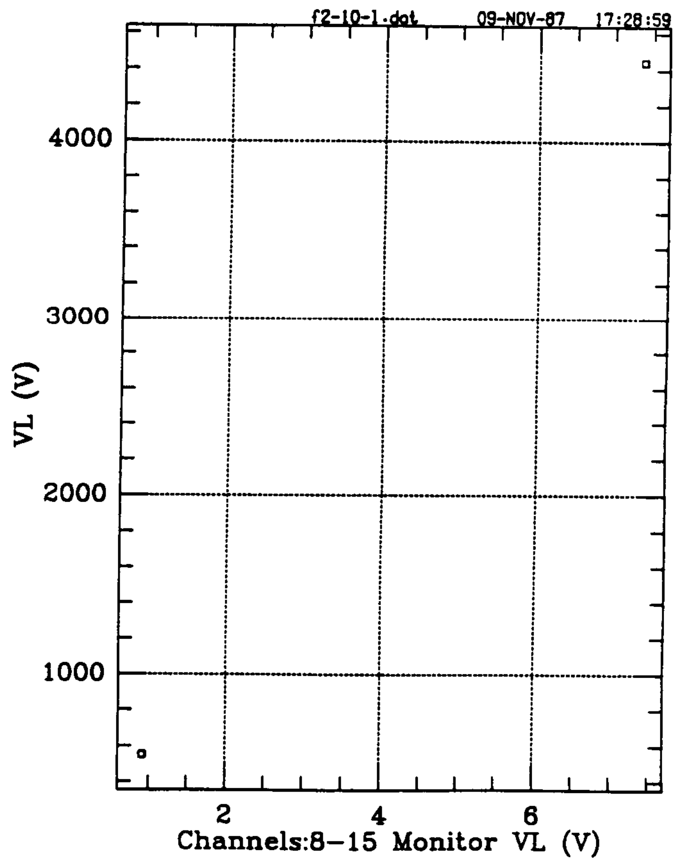


Flite:2 Temp:–5C Mode:E1 & E2

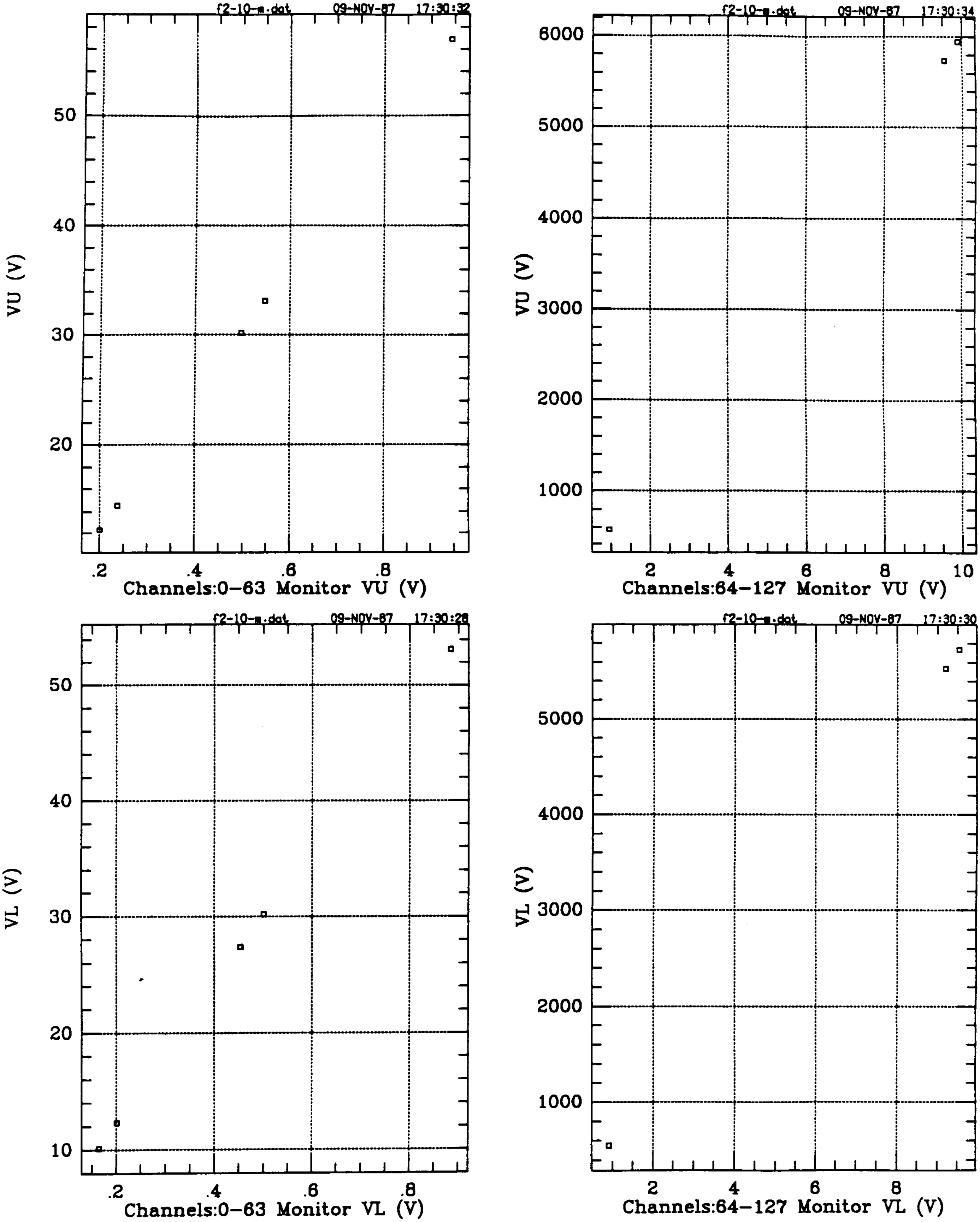




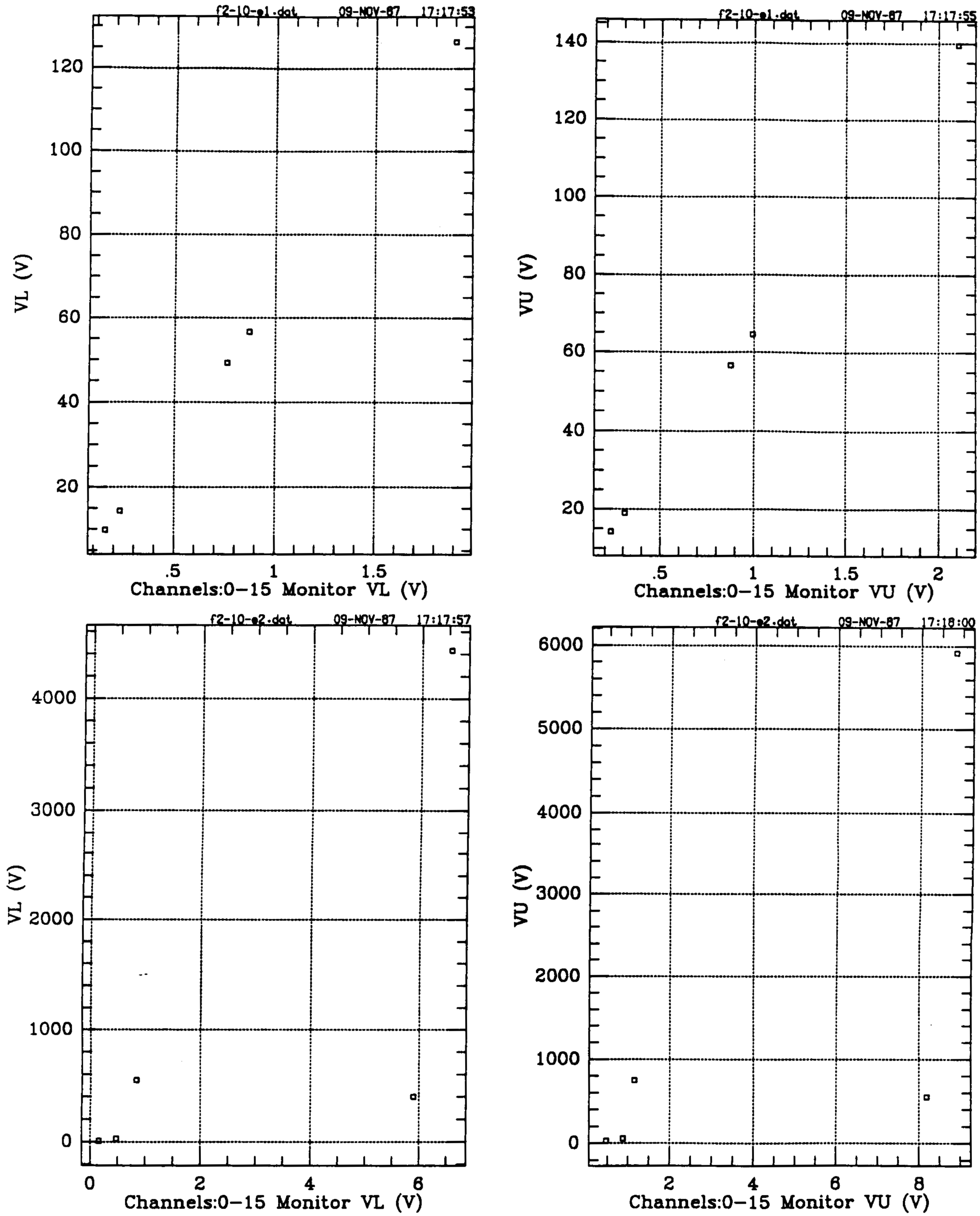




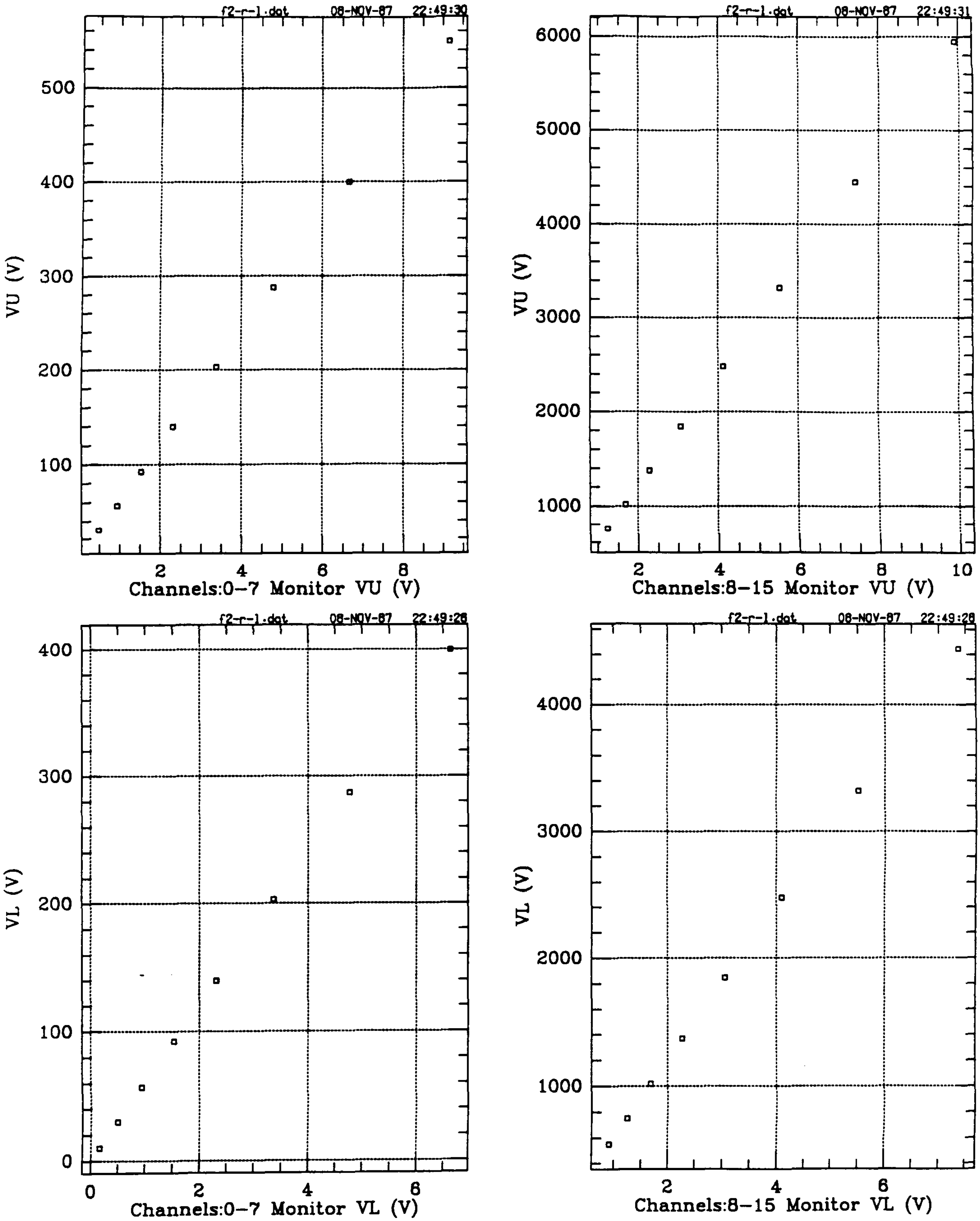
Flite:2 Temp:10C Mode:L



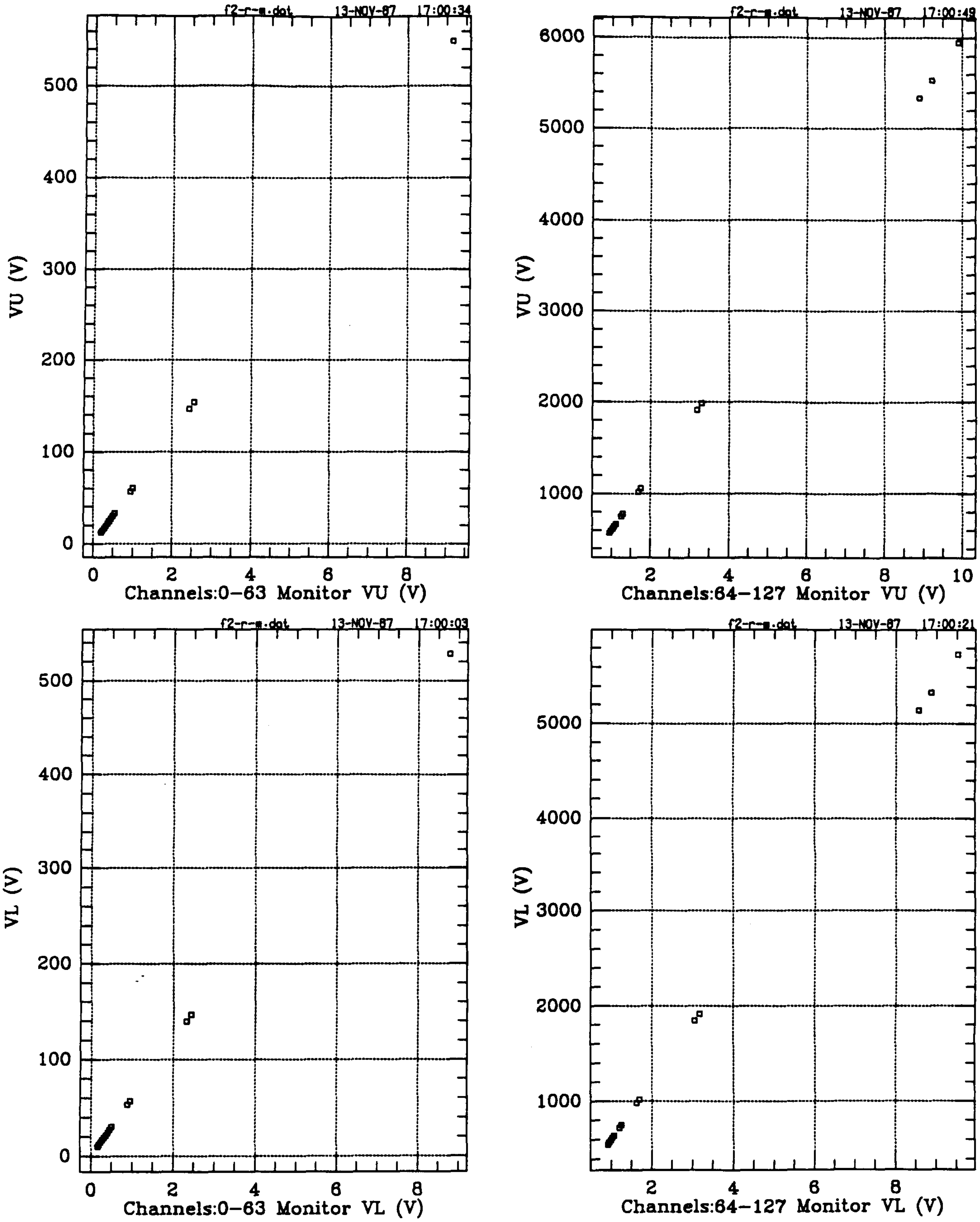
Flite:2 Temp:10C Mode:M



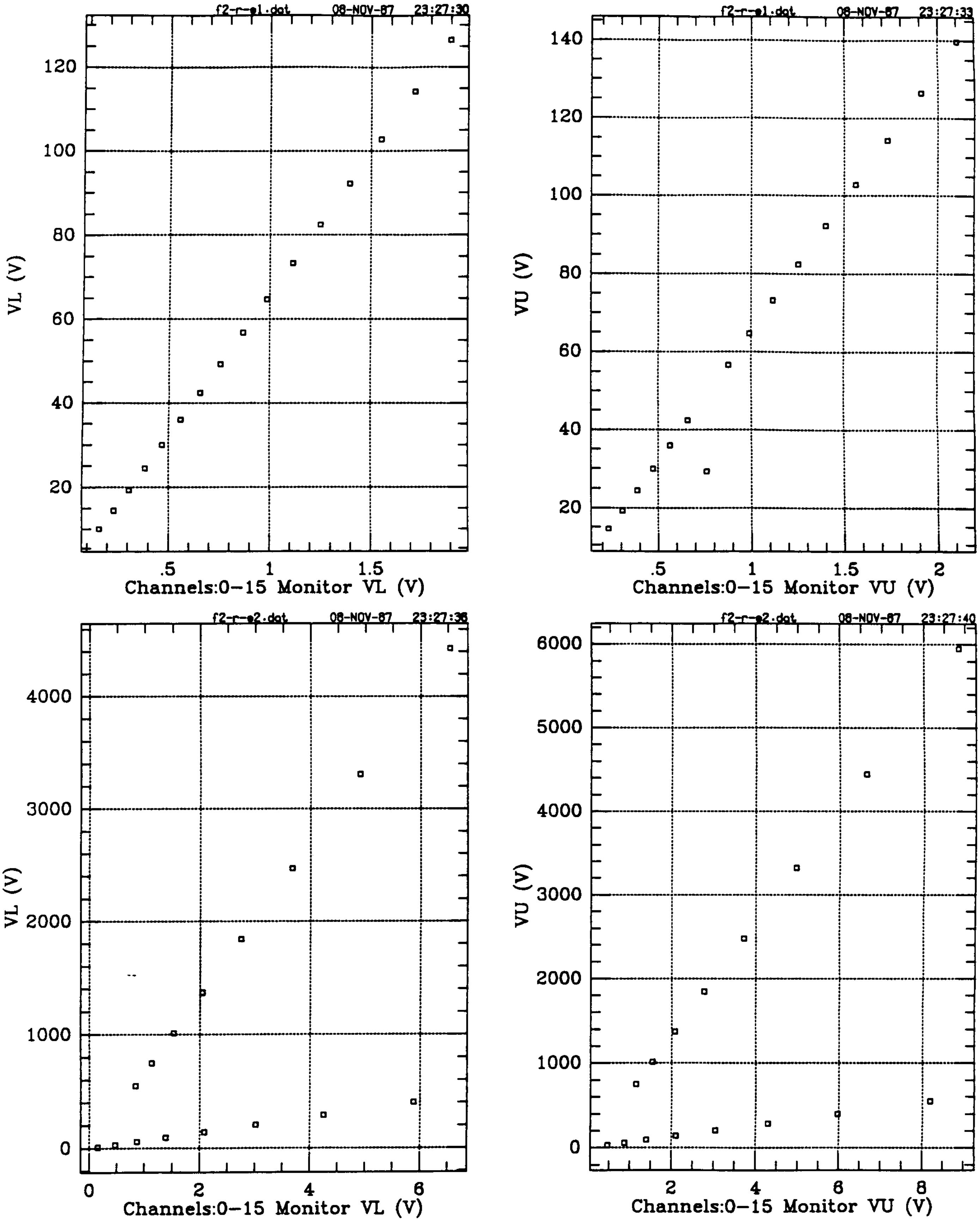
Flite:2 Temp:10C Mode:E1 & E2



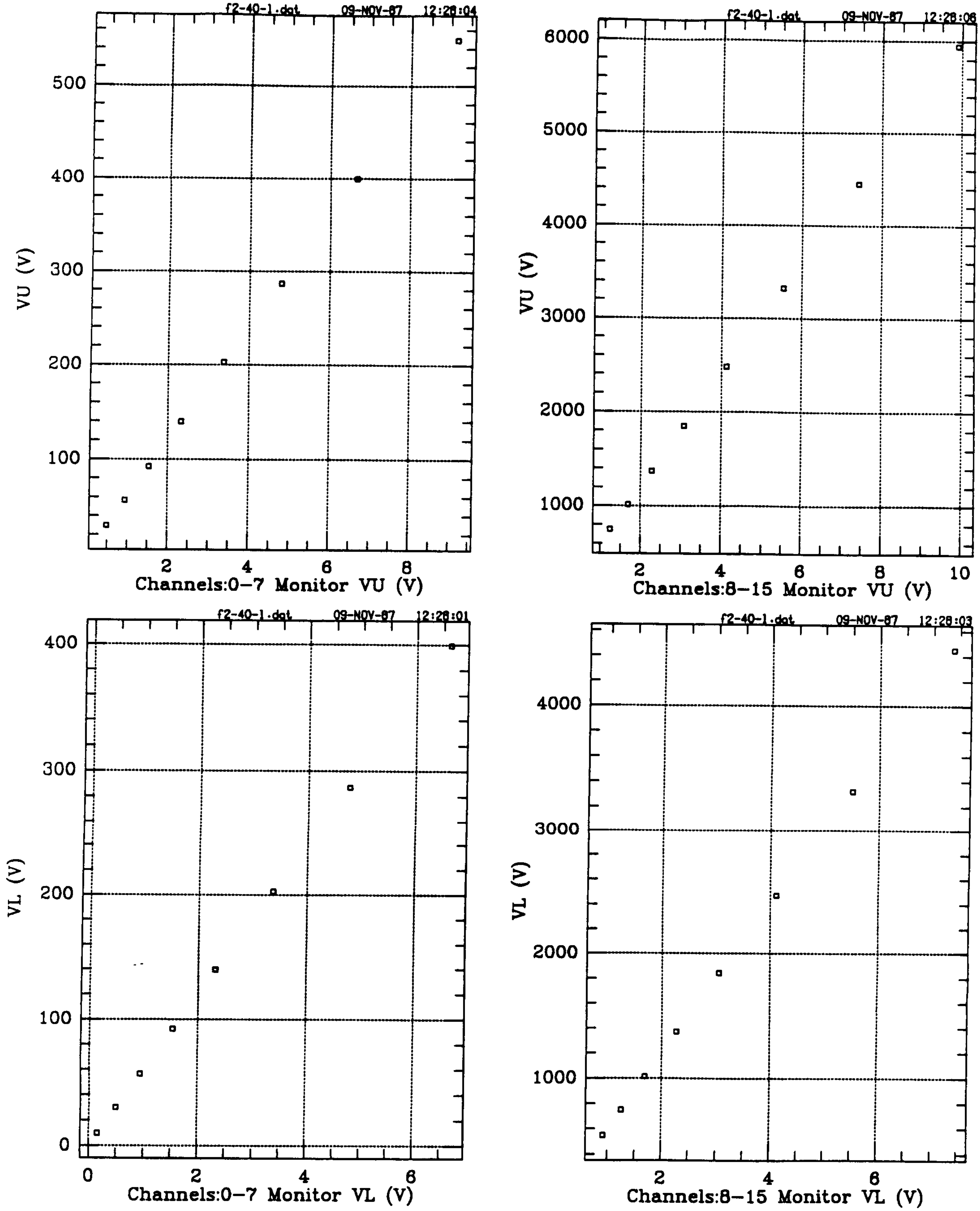
Flite:2 Temp:Room Mode:L



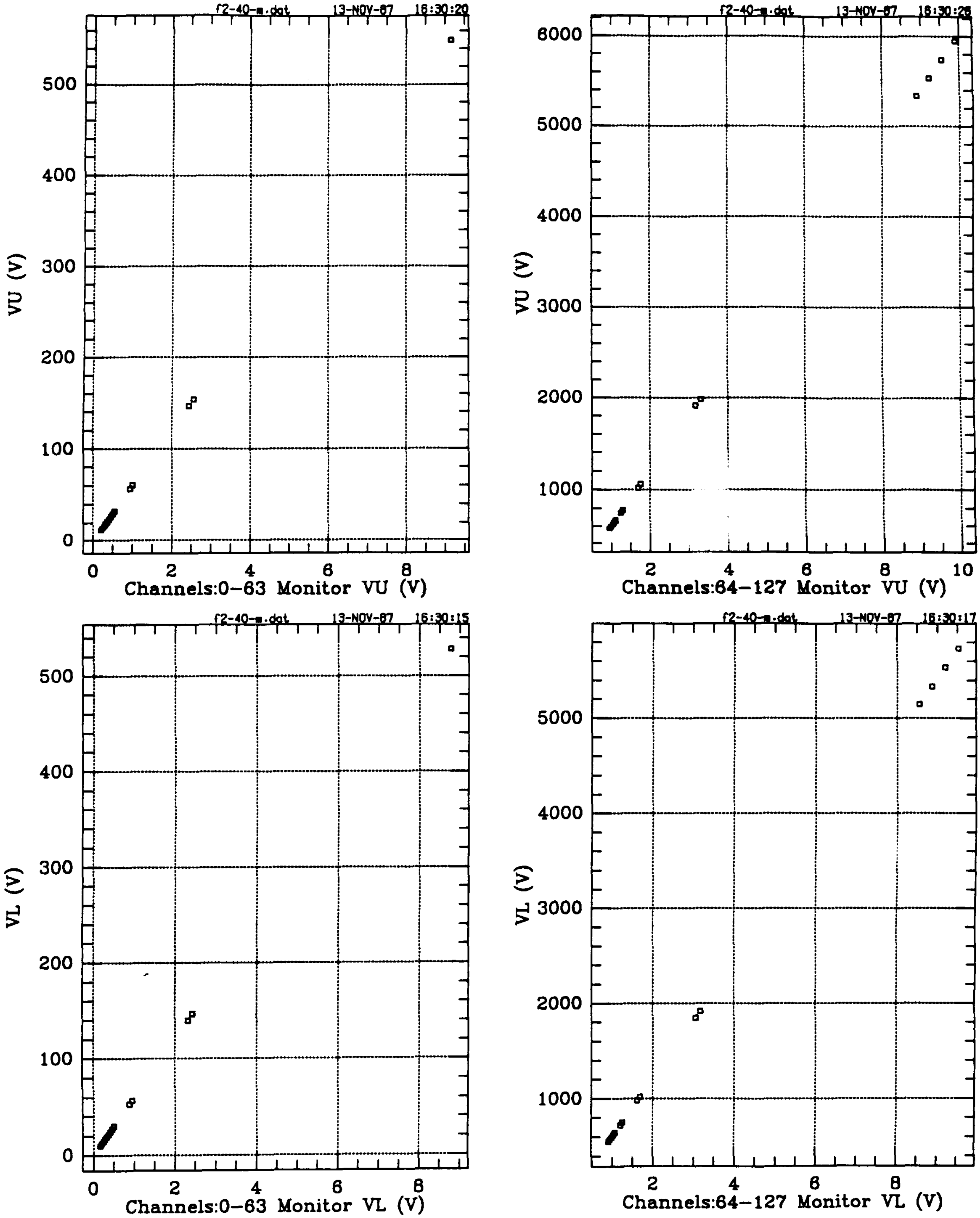
Flite:2 Temp:Room Mode:M



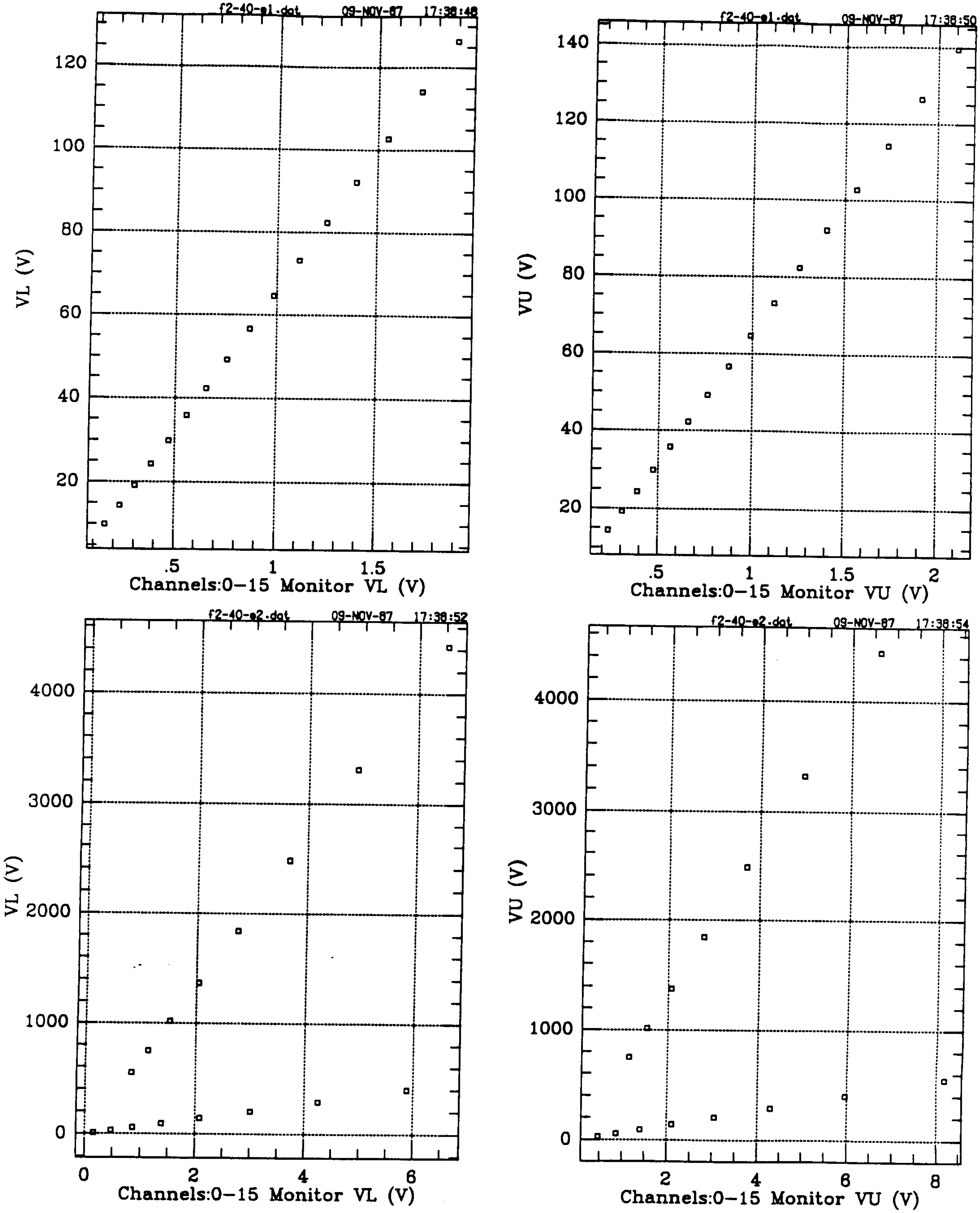
Flite:2 Temp:Room Mode:E1 & E2



Flite:2 Temp:40C Mode:L



Flite:2 Temp:40C Mode:M



Flite:2 Temp:40C Mode:E1 & E2

```
c       DNS-CODE.F analyses the PLS Prototype data.
c       ------------------------------------------
c       Author: Ognen Nastov , MIT undergraduate, Nov 1987
c       ------------------------------------------
c       leastsq does a least square approximation
c               and minimizes the round-of errors.
c               n = # of x-y pairs
c               A = (1 / sum(t**2)) * sum (t*y)
c               B = (sum(y) - A*sum(x)) / n
c               where t(i) = x(i) - sum(x) / n
        subroutine leastsq (filename, depth,
     +          a, b, sqd)
        integer depth, dn
        real a, b, mv, x, y, sumx, sumy,
     +          t(120), u(120), v(120), sumtsq, sumty, sqd
        character*8 filename
        sumx = 0
        sumy = 0
        sumtsq = 0
        sumty = 0
        open (1, file=filename, form='formatted')
        rewind (1)
        do 1010 counter = 1, depth
                read (1, *) dn, mv
                x = 255 - dn
                y = log (mv)
                sumx = sumx + x
                sumy = sumy + y
                u(int(counter)) = x
                v(int(counter)) = y
1010            continue
        do 1020 i = 1, depth
                t(i) = u(i) - sumx / depth
                sumtsq = sumtsq + t(i)*t(i)
                sumty = sumty + t(i)*v(i)
1020            continue
        a = sumty / sumtsq
        b = (sumy - a*sumx) / depth
        call sqdev (a, b, depth, u, v, sqd)
        close (1)
        return
        end

c       Sqdev calculates the square deviation
c               by definition.
        subroutine sqdev (a, b, n, u, v, sqd)
        integer n
        real a, b, u(120), v(120), sqd
        sqd = 0
        do 2000 i = 1, n
                sqd = sqd + (a*u(i) + b - v(i))**2
2000            continue
        sqd = sqd / n
        return
        end

c       The MAIN program body.
c       It produces one line of output for each input file.
c       The program uses a special driver file
c               dns-driver.dat.
        integer pairs
        real a, b, c1, c2
        character*8 filename
        character*4 mvr
        open (2, file='dns-driver.dat', form='formatted')
```

```
        open (3, file='dns-output.dat', form='formatted')
        rewind (2)
        print *, 'Creating file: ', 'dns-output.dat', '...'
c
50      read (2, *) filename, mvr, pairs
        print *, 'Processing file: ', filename, '...'
        call leastsq (filename, pairs, a, b, sqd)
        c1 = exp (b)
        c2 = a
        write (3, fmt=200) filename, mvr, c1, c2, sqd, pairs
100     if (filename .ne. 'pe22.dat') go to 50
        close (2)
        close (3)
        print *, 'File: dns-output.dat created.'
200     format (a8, tr2, a4, tr2, g12.6, tr2, g12.6, tr2,
   +            g11.6, tr2, i3)
        end
```

```
c       MVS-CODE.F analyses the PLS calibration data for both flites.
c       ------------------------------------------------------------
c       Author: Ognen Nastov, MIT undergraduate, Nov 1987
c       ------------------------------------------------------------
c       leastsq does a least square approximation
c               | sum(x**2)A + sum(x)B = sum(xy)
c               | sum(x)A + nB = sum(y)
c               where n = # of x-y pairs
        subroutine leastsq (filename, voltrange, startline, endline,
     +          a, b, sqd, depth)
        integer channel, startline, endline, skip, depth
        real a, b, mvu, mvl, vl, vu, hvdcout, x, y, sumxsq, sumx, sumxy,
     +          sumy, sumysq, sqd
        character*6 voltrange
        character*12 filename
        sumxsq = 0
        sumx = 0
        sumxy = 0
        sumy = 0
        sumysq = 0
        open (1, file=filename, form='formatted')
        rewind (1)
        skip = startline - 1
        do 500 counter = 1, skip
                read (1,*) channel, hvdcout, mvu, mvl, vl, vu
500             continue
        depth = endline - startline + 1
        do 600 counter = 1, depth
                read (1, *) channel, hvdcout, mvu, mvl, vl, vu
                if (voltrange .eq. 'lower') then
                        x = mvl
                        y = vl
                else
                        x = mvu
                        y = vu
                endif
                sumxsq = sumxsq + x*x
                sumx = sumx + x
                sumxy = sumxy + x*y
                sumy = sumy + y
                sumysq = sumysq + y*y
600             continue
        call solvesys (sumxsq, sumx, sumxy, sumx, depth, sumy,
     +          a, b)
        call sqdev (a, b, depth, sumx, sumy, sumxy,
     +          sumxsq, sumysq, sqd)
        close (1)
        return
        end

c       lsq2 does a least square approximation
c               and also minimizes round-of errors
c               n = # of x-y pairs
c               A = (1 / sum(t**2)) * sum (t*y)
c               B = (sum(y) - A*sum(x)) / n
c               where t(i) = x(i) - sum(x) / n
        subroutine lsq2(filename, voltrange, startline, endline,
     +          a, b, sqd, sqda, sqdb, cov, depth)
        integer channel, startline, endline, skip, depth
        real a, b, mvu, mvl, vl, vu, hvdcout, x, y, sumx, sumy,
     +          t(20), u(20), v(20), sumtsq, sumty, sqd,
     +          sqda, sqdb, cov, del, sumxsq
        character*6 voltrange
        character*12 filename
        sumx = 0
```

```
          sumy = 0
          sumtsq = 0
          sumty = 0
          sumxsq = 0
          open (1, file=filename, form='formatted')
          rewind (1)
          skip = startline - 1
          do 1000 counter = 1, skip
                  read (1, *) channel, hvdcout, mvu, mvl, vl, vu
1000              continue
          depth = endline - startline + 1
          do 1010 counter = 1, depth
                  read (1, *) channel, hvdcout, mvu, mvl, vl, vu
                  if (voltrange .eq. 'lower') then
                          x = mvl
                          y = vl
                  else
                          x = mvu
                          y = vu
                  endif
                  sumx = sumx + x
                  sumy = sumy + y
                  sumxsq = sumxsq + x*x
                  u(int(counter)) = x
                  v(int(counter)) = y
1010              continue
          do 1020 i = 1, depth
                  t(i) = u(i) - sumx / depth
                  sumtsq = sumtsq + t(i)*t(i)
                  sumty = sumty + t(i)*v(i)
1020              continue
          a = sumty / sumtsq
          b = (sumy - a*sumx) / depth
          call sqd2 (a, b, depth, u, v, sqd)
          close (1)
          del = depth * sumxsq - (sumx)**2
          sqdb = sqrt (sumxsq / del * sqd * depth / (depth - 2))
          sqda = sqrt (depth / del * sqd * depth / (depth - 2))
          cov = - sumx / del * sqd *depth / (depth - 2)
          return
          end

c         sqd2 calculates the square deviation by definition
c                 sqd = (1 / n) * sum(Ax + B - y)**2
          subroutine sqd2 (a, b, n, u, v, sqd)
          integer n
          real a, b, u(20), v(20), sqd
          sqd = 0
          do 2000 i = 1, n
                  sqd = sqd + (a*u(i) + b - v(i))**2
2000              continue
          sqd = sqd / n
          return
          end

c         solvesys solves 2x2 linear systems using determinants
c                 a1*x+b1*y=c1
c                 a2*x+b2*y=c2
          subroutine solvesys (a1, b1, c1, a2, b2, c2, x, y)
          integer b2
          real a1, b1, c1, a2, c2, x, y, det, detx, dety
          det = a1*b2 -a2*b1
          detx = c1*b2 - c2*b1
          dety = a1*c2 - a2*c1
          x = detx/det
```

```
      y = dety/det
      return
      end

c     sqdev calculates the square deviation expanding
c             the sum:
c             sqd = (1 / n) * sum(Ax + B - y)**2
      subroutine sqdev (a, b, n, sumx, sumy, sumxy,
     +        sumxsq, sumysq, sqd)
      integer n
      real a, b, sumx, sumy, sumxy, sumxsq, sumysq, sqd
      sqd = a*a*sumxsq + n*b*b + sumysq + 2*a*b*sumx -
     +        2*a*sumxy - 2*b*sumy
      sqd = abs (sqd / n)
      return
      end

c     The MAIN program body.
c     It produces four lines of output for each input file.
c     The program makes use of the lsq2 and sqd2 subroutines.
c     It uses the file mvs-driver.dat to get the info
c             essential to analyse only the appropriate chunks
c             of data.
      integer stl1, edl1, stl2, edl2, pairsl, pairsu
      real al, bl, sqdl, sqdal, sqdbl, covl,
     +        au, bu, sqdu, sqdau, sqdbu, covu
      character*6 voltrange
      character*12 filename
      open (2, file='mvs-driver.dat', form='formatted')
      open (3, file='mvs-output.dat', form='formatted')
      rewind (2)
      print *, 'Creating file: ', 'mvs-output.dat', '...'
c     analyze the first channel range...
50    read (2, *) filename, stl1, edl1, stl2, edl2
      print *, 'Processing file: ', filename, '...'
      voltrange = 'lower'
      call lsq2 (filename, voltrange, stl1, edl1,
     +        al, bl, sqdl, sqdal, sqdbl, covl, pairsl)
      voltrange = 'upper'
      call lsq2 (filename, voltrange, stl1, edl1,
     +        au, bu, sqdu, sqdau, sqdbu, covu, pairsu)
      write (3, fmt=200) filename, 'chr1', 'mvl-vl', al, bl,
     +        sqdl, sqdal, sqdbl, covl, pairsl
      write (3, fmt=200) filename, 'chr1', 'mvu-vu', au, bu,
     +        sqdu, sqdau, sqdbu, covu, pairsu
c     analyze the second channel range...
      if (stl2 .eq. 0) go to 100
      voltrange = 'lower'
      call lsq2 (filename, voltrange, stl2, edl2,
     +        al, bl, sqdl, sqdal, sqdbl, covl, pairsl)
      voltrange = 'upper'
      call lsq2 (filename, voltrange, stl2, edl2,
     +        au, bu, sqdu, sqdau, sqdbu, covu, pairsu)
      write (3, fmt=200) filename, 'chr2', 'mvl-vl', al, bl,
     +        sqdl, sqdal, sqdbl, covl, pairsl
      write (3, fmt=200) filename, 'chr2', 'mvu-vu', au, bu,
     +        sqdu, sqdau, sqdbu, covu, pairsu
100   if (filename .ne. 'f2-40-e2.dat') go to 50
      close (2)
      close (3)
      print *, 'File: mvs-output.dat created.'
200   format (a12, tr2, a4, tr2, a6, tr2, f9.5, tr2, g12.6, tr2,
     +        g11.6, tr2, g12.6, tr2, g12.6, tr2, g12.6, tr2, i2)
      end
```

```
c       MVS-TC-CODE.F
c       ------------------------------------------------------
c       Author: Ognen Nastov, MIT undergraduate, Nov 1987
c       ------------------------------------------------------

c       lsq2 does a least square approximation
c               and also minimizes round-of errors
c               n = # of x-y pairs
c               A = (1 / sum(t**2)) * sum (t*y)
c               B = (sum(y) - A*sum(x)) / n
c               where t(i) = x(i) - sum(x) / n
        subroutine lsq2(filenames, filenum, voltrange, startlines,
     +          endlines, a, b, sqd, sqda, sqdb, cov, totdep)
        integer channel, startlines(6), endlines(6), skip,
     +          depth(5), curfile, totdep, filenum
        real a, b, mvu, mvl, vl, vu, hvdcout, x, y, sumx, sumy,
     +          t(100), u(100), v(100), sumtsq, sumty, sqd,
     +          sqda, sqdb, cov, del, sumxsq
        character*6 voltrange
        character*12 filenames(6)
        sumx = 0
        sumy = 0
        sumtsq = 0
        sumty = 0
        sumxsq = 0
        curfile = 1
        totdep = 0
500     open (1, file=filenames(curfile), form='formatted')
        rewind (1)
        skip = startlines(curfile) - 1
        do 1000 counter = 1, skip
                read (1, *) channel, hvdcout, mvu, mvl, vl, vu
1000            continue
        depth(curfile) = endlines(curfile) - startlines(curfile) + 1
        do 1010 counter = (totdep + 1), (totdep + depth(curfile))
                read (1, *) channel, hvdcout, mvu, mvl, vl, vu
                if (voltrange .eq. 'lower') then
                        x = mvl
                        y = vl
                else
                        x = mvu
                        y = vu
                endif
                sumx = sumx + x
                sumy = sumy + y
                sumxsq = sumxsq + x*x
                u(int(counter)) = x
                v(int(counter)) = y
1010            continue
        close (1)
        totdep = totdep + depth(curfile)
        curfile = curfile + 1
        if (curfile .le. filenum) go to 500
        do 1020 i = 1, totdep
                t(i) = u(i) - sumx / totdep
                sumtsq = sumtsq + t(i)*t(i)
                sumty = sumty + t(i)*v(i)
1020            continue
        a = sumty / sumtsq
        b = (sumy - a*sumx) / totdep
        call sqd2 (a, b, totdep, u, v, sqd)
        del = totdep * sumxsq - (sumx)**2
        sqdb = sqrt (sumxsq / del * sqd * totdep / (totdep - 2))
        sqda = sqrt (totdep / del * sqd * totdep / (totdep - 2))
        cov = - sumx / del
```

```
        return
        end

c       sqd2 calculates the square deviation by definition
c               sqd = (1 / n) * sum(Ax + B - y)**2
        subroutine sqd2 (a, b, n, u, v, sqd)
        integer n
        real a, b, u(20), v(20), sqd
        sqd = 0
        do 2000 i = 1, n
                sqd = sqd + (a*u(i) + b - v(i))**2
2000            continue
        sqd = sqd / n
        return
        end

c       The MAIN program body.
c       It combines the files that are corresponding to the same
c       temperature, and produces four lines of output per each
c       combination. The program uses two driver files:
c       mvs-driver.dat and mvs-tc-driver.dat. The lsq2 subroutine
c       has been modified in order to be able to combine several
c       files for analysis.
        integer stl1(6), edl1(6), stl2(6), edl2(6), pairsl, pairsu,
     +          filnum, i
        real al, bl, sqdl, sqdal, sqdbl, covl,
     +          au, bu, sqdu, sqdau, sqdbu, covu
        character*6 voltrange
        character*12 filenames(6), mfile, file
        open (2, file='mvs-driver.dat', form='formatted')
        open (3, file='mvs-tc-out.dat', form='formatted')
        open (4, file='mvs-tc-driver.dat', form='formatted')

50      i = 0
        read (4, *) mfile
100     i = i + 1
        read (4, *) filenames(i)
        if (filenames(i) .ne. '*') go to 100
        filnum = i - 1

        do 200 i = 1, filnum
                rewind (2)
300             read (2, *) file, stl1(i), edl1(i),
     +                  stl2(i), edl2(i)
                if (file .ne. filenames(i)) go to 300
200             continue

        print *, 'Processing master-file: ', mfile, '...'
        voltrange = 'lower'
        call lsq2 (filenames, filnum, voltrange, stl1, edl1,
     +          al, bl, sqdl, sqdal, sqdbl, covl, pairsl)
        voltrange = 'upper'
        call lsq2 (filenames, filnum, voltrange, stl1, edl1,
     +          au, bu, sqdu, sqdau, sqdbu, covu, pairsu)
        write (3, fmt=2000) mfile, 'chr1', 'mvl-vl', al, bl,
     +          sqdl, sqdal, sqdbl, covl, pairsl
        write (3, fmt=2000) mfile, 'chr1', 'mvu-vu', au, bu,
     +          sqdu, sqdau, sqdbu, covu, pairsu

c       analyze the second channel range ...
        if (stl2(1) .eq. 0) go to 500
        voltrange = 'lower'
        call lsq2 (filenames, filnum, voltrange, stl2, edl2,
     +          al, bl, sqdl, sqdal, sqdbl, covl, pairsl)
        voltrange = 'upper'
```

```
      call lsq2 (filenames, filnum, voltrange, stl2, edl2,
     +           au, bu, sqdu, sqdau, sqdbu, covu, pairsu)
      write (3, fmt=2000) mfile, 'chr2', 'mvl-vl', al, bl,
     +           sqdl, sqdal, sqdbl, covl, pairsl
      write (3, fmt=2000) mfile, 'chr2', 'mvu-vu', au, bu,
     +           sqdu, sqdau, sqdbu, covu, pairsu
500   if (mfile .ne. 'f2-e2.dat') go to 50
      close (2)
      close (3)
      print *, 'File: mvs-tc-out.dat created.'
2000  format (a12, tr2, a4, tr2, a6, tr2, f9.5, tr2, g12.6, tr2,
     +           g11.6, tr2, g12.6, tr2, g12.6, tr2, g12.6, tr2, i2)
      end
```

M E M O R A N D U M

Massachusetts Institute of Technology
Center for Space Research

September 24, 1987

VOYAGER MEMORANDUM # 161:

From: Ralph L. McNutt, Jr.

To: Voyager Internal

Subject: Modulator Calibrations (Modcal or MVM): Interpretation

NORMAL OPERATION

As part of the routine calibration sequence on the Voyager Plasma Science (PLS) experiment, there is a digitized readout of the low voltage signal which is proportional to the potential on the modulator grids. This is accomplished via a set of Modulator Voltage Monitors; these measurements are referred to by MVM on Summary or EDR tape logs. In many of the engineering notebooks they are referred to as "Modcal" measurements or mode (as compared to "Curcal" or current calibration measurements. In producing the modulator voltage, the voltage is stepped through one decade from 60 to 600 volts and then through the same steps with a extra gain of $\times$ 10 switched into the circuit to sweep from 600 to 6000 volts. To this voltage is added an offset of 50 volts. Hence, the L and M modes sweep from +10 V to +5950 V and the E2 mode sweeps from -10 V to -5950 V (the E1 mode sweeps from -10 V to -- 140 V by using a different step size). Thus, the true voltage ranges across 2.8 decades.

The voltage monitors measure a voltage which is a constant fraction of the voltage swept which does not include the factor of 10 gain change. The monitors measure a voltage between 0.1 and 10 volts which is then input into a fast A/D converter. This voltage is then converted to a binary number from which the highest order bit is discarded. Thus, as the low voltage sweeps between 0.1 and 1.0 the digital output sweeps from 0 to 255; as the voltage sweeps from 1.0 to 10.0 volts, the output again sweeps from 0 to 255, although retention of the highest order bit would give a digital output from 256 to 511. Hence, the voltage monitor output can correspond to 4 orders of magnitude although, again, the factor of 10 gain change is not explicitly incorporated in this measurement. To know which decade is actually being read out, one must either rely on a "proper sequence" (the case for nominal operation for which the MVM readout presumably yields voltages close to the nominal values) or an "educated guess" (for interpreting the MVM readouts from the PLS instrument on Voyager 1 after the failure).

NOMINAL VOLTAGE LEVELS

The nominal conversion between channel number (or "step number") is employed in all analysis (both in the VGRANL and MJSANL software packages). The conversion between channel number and voltage is discussed in *Bridge et al.* [1977]. Let n be the channel number, which can take on values of 1 to 16 for the E1, E2, and L modes and 1 to 128 for the M mode. Let M be an integer with values of 8 for the E2 and L modes, 32 for E1 and 64 for M. Then the potential ϕ_n at the lower edge ("bottom") of channel n (also referred to below as $V_{L,\ HV}$), which is equal to the voltage at the upper edge ("top") of channel $n + 1$ (also referred to below as $V_{U,\ HV}$), (the upper edge potentials follow from considering "channel" 129 for the M mode and 17 for the other modes), is given by

$$\phi_n = 60 \cdot 10^{n/M} - 50 \tag{1}$$

where ϕ_n is in volts. This formula only yields magnitudes, of course, the actual potentials in the E1 and E2 modes being negative.

It is important to note that the 50 volt offset makes the channel spacing only quasi-logarithmic; at lower channel numbers, the channel widths are larger than if they were logarithmically spaced.

NOMINAL FAST A/D VOLTAGE CONVERSION

Information on the analog-to-digital converter is contained in Anton Mavretic's lab notebook labeled book 2, number 254 (starting date of July, 1974). On page 142 (dated 7/25/75), we find for analog voltage v running from 0.1 to 10, the digital count number N running from 0 to 127. Anton gives the constitutive relation as

$$v = V_{REF}\, e^{-\frac{(127-N)\,T}{\tau}} \tag{1}$$

and values $V_{REF} = 10$ V, $T = f_{AD}^{-1} = 1/\ 57.6\ \text{kHz} = 17.36\ \mu\text{s}$, $\tau = 482.55\ \mu\text{s}$. Transforming to base 10, this yields

$$v = 10 \times 10^{-\frac{(127-N)}{64.00008}} \tag{2}$$

where the denominator in the exponent is usually approximated as the integer 64.

On page 143, formulas are given for the fast A/D conversion. Anton lists

$$v = V_{REF}\, e^{-\frac{(255-N)\,T}{\tau}}, \quad 1.0 < v < 10. \tag{3a}$$

and

$$v = V_{REF}\ /\ 10\, e^{-\frac{(255-N)\,T}{\tau}}, \quad 0.1 < v < 1.0. \tag{3b}$$

with $T = f_{fast\ AD}^{-1} = 1/\ 230.4\ \text{kHz} = 4.34\ \mu\text{s}$, $\tau = 482.55\ \mu\text{s}$. Transforming to base 10, this yields the combination

$$v = 10 \times 10^{-\frac{(255-N)}{256}}, \quad 1.0 < v < 10. \tag{4a}$$

and

$$v = 10^{-\frac{(255-N)}{256}}, \quad 0.1 < v < 1.0. \tag{4b}$$

Although not explicitly stated, these are *apparently* the nominal, rather than measured, conversion formulas.

Nominal Monitor Operation

In the usual MVM mode, the data numbers (DN) produced by running the low voltage monitor outputs through the fast A/D converter are returned as a function of channel number. In the L and M modes, the DNs corresponding to V_L are returned in the space occupied by A cup plasma measurements in the usual plasma measurement mode; similarly, the DNs corresponding to V_H are returned in the space occupied by the B cup plasma measurements. The C cup and D cup contain currents corresponding to normal plasma currents *but with DN values obtained from the fast A/D converter*. Hence, for the L and M modes, there is a measure of the contiguity of neighboring channels (gaps and/or overlaps in coverage).

For the E1 and E2 modes, there are only 16 slots available in the data sequence for each mode, so compromises were made in deciding which DN values would be included in the telemetry stream. For odd channel numbers (counting from 1 to 16), the DN corresponding to V_L is returned. For even channel numbers, the DN corresponding to V_U is telemetered. Hence, both absolute value and contiguity are checked, but only for every other channel. For example, there are MVM measurements for V_{L1}, V_{U2}, V_{L3}, V_{U4}, V_{L5}, etc., but there is no calibration information for the boundaries between channels 1 and 2, 3 and 4, etc.

In nominal operation, note that we should have $V_{U,\ n} = V_{L,\ n+1}$. Indication of where the V_Us and V_Ls come in the data is given in the VOYPRT appended to Voyager Memorandum 158 as Figure 6.

Relationship Between Modulator Potential and Monitor Voltages

Figure 1 (from J. Binsack) shows a simplified block diagram of the high voltage modulator circuit for the PLS instrument; indicated on the figure is the location of the suspected failed circuit in the Voyager 1 PLS instrument. The low voltage monitor voltages are measured at the point indicated with the arrow and labeled "$V_{fb} = CAL$. This low voltage is (nominally) directly proportional to the high voltage applied to the modulator grids (at least in the linear regime of the amplifiers). The DC gain of the Cockcroft-Walton amplifiers ("C. W.") and the AC gain of the transformer in the feedback loop are unknown as of this writing, so a theoretical value of the proportionality factor is not known (but could be derived from the appropriate circuit diagrams, J. Binsack, private communication, 1987). Data shown in Appendix A (see below) suggests that this factor is ~ 60.

The subcontractor responsible for the high voltage power supply, Matrix Research and Development Corporation, measured both the voltage to ground from the modulator grid leads and the low voltage monitor outputs for all three modulators (on SN001, SN002, and SN003) for all channels in all modes. Work has begun to combine this information with other information to develop an algorithm to link the measured DNs in the MVM mode with the actual modulator potential. It is important to note that all modulator potential measurements were actually made with high impedance probes to the modulator grid leads, terminated with capacitances to approximate the electrical characteristics of the grids themselves (R. Butler, private communication, 1987). In no case were potential measurements made on the grids themselves with the grids in place in the cups; this is not possible as a probe cannot physically be inserted into the assembly.

Before the PLS instruments were to delivered to JPL for integration with the Voyager spacecraft, extensive calibration tests were run at the MIT Laboratory for Space Experiments using the Bench Checkout Equipment (BCE). The modulator was stepped through all channels in all modes and the DNs (or "decimal counts") were recorded as a function of step number, equal to the channel number minus one (channel 1 corresponds to step 0).

In Appendix A, the reference counts are listed as a function of step number for each mode (labeled for the prototype rather than for one of the flight units). Corresponding voltages from the voltage monitors are also given. *Note that these are the counts measured with the BCE.* For example, the nominal value of $V_{L,\,HV}$ for step 0 is +10 V in L and M modes and -10 V in E1 and E2 modes. The reference counts for the L, E1, E2, and M modes are, respectively, 54, 48, 50, 48. The fraction values for V_L are, presumably, the measured low voltage monitor outputs (they are not nominal values as the nominal value should be the same in for all of these). The applicable equation relating the monitor voltages and the reference counts is (4b). However, applying (4b) to values of 0.172, 0.163, 0.166, 0.163, yields DNs of 59.3, 53.3, 55.3, and 53.3, respectively. This suggests that the theoretical A/D algorithms are off (if the reference counts and monitor voltages were really measured simultaneously). Note that (4b) is off by about a factor of $10^{5/256} = 1.046$, but not quite.

The agreement is better at the other end of the scale for V_U of step 15 of E2 and L and step 127 of M, the counts are 248 and the monitor voltage is 9.314 V. Using 9.314 volts and equation (4a) yields a DN of 247.1. Again, if the counts and monitor voltages were measured at the same time (which is not known), there is some nonlinearity in the A/D converter, not currently accounted for. A spot check suggests that a simple DC offset voltage also does not account for the discrepancy.

I have searched through all of Anton's notebooks stored in Herb's office and through all of the files in N-52 and have not been able to locate any documentation (other than that mentioned above) on the performance of the A/D converter. To put all of this in perspective, at the higher voltages in the M mode, the reference counts for V_U and V_L are separated by 4 DN. This implies that a determination of the true potentials on the modulator grids to an accuracy of better than 1% should, in principal, be possible.

Attached as Appendix B are similar modulator calibration data from the Flight 1 unit (on Voyager 1, i.e., SN002). Most of the measurements are dated 4/22/77, less than 5 months before the launch. Unfortunately, simultaneous high voltage, monitor voltage, and DN were not recorded. It is worth noting that for step 127 of the M mode, the measured value of V_U was 6010 volts, as compared to a nominal value of 5950 volts, a deviation from nominal of 1%. This suggests that such deviations are not uncommon.

MODULATOR VOLTAGES FOR THE VOYAGER 1 PLS INSTRUMENT AFTER THE FAILURE

The assumed circuit failure on the Voyager 1 PLS instrument pegged the value of V_L at some value greater than 6000 V, and caused the values of V_U to increase with step number, but in a spurious way (J. Binsack, private communication, 1987), i.e., the phase of the modulated current is shifted 180°. Hence, the solar wind can no longer be detected in the normal plasma mode because the current is detected synchronously, and the failure introduced the incorrect phasing.

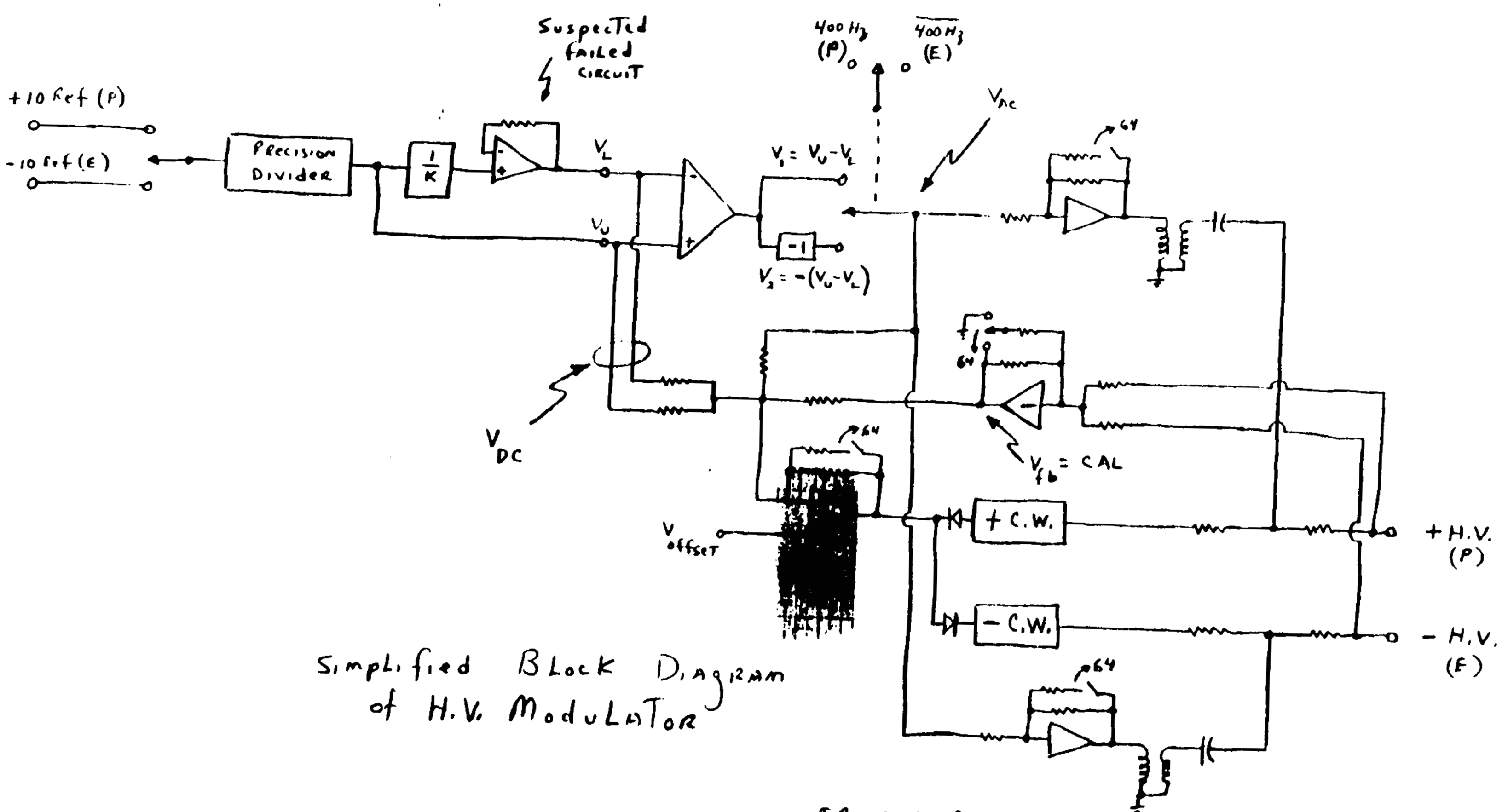
If the value of V_L is pegged to a large value, then the solar wind is always excluded from the detector for half of a measurement. If the value of V_U is low enough, then the solar wind should be admitted for the other half, unless V_U steps to a large enough value to also exclude the solar wind.

The DC return measurements from the Voyager 1 instrument after the failure show changes in all 16 channels which vary with time; this presumably gives some measure of the solar wind flux (see Voyager Memorandum 157). There is a "break" in the DN numbers in the DC return mode above channel 8, suggesting that V_U for the first 8 channels (in the L mode) is always low enough to allow the solar wind access to the collector plate. The DNs decrease for the top 8 channels suggesting that more of the solar wind is gradually being excluded, but the lack of variation in this pattern could mean that this is another instrumental effect instead. The interpretation is also complicated by the fact that there is a factor of 10 gain change internally in going from the voltages for channel 8 to those of channel 9, so the break at this point may actually be related to this change.

From the L mode spectrum in Figure 6 of Voyager Memorandum 158 (referred to previously), the MVM data numbers change from 190 to 93 for the first 8 channels of the L mode (at 1980-346/0103:23.735) with a "fold" occurring between channels 2 and 3. If the DNs can be interpreted as before the failure, then the fold could occur at ~6, 60, 600, or 6000 V. The value of 6000 V must be excluded on the basis of the detection of the solar wind. At channel 8, the DN of 93 could be ~14 or 140 V; higher values are again excluded because the solar wind is detected.

In the top 8 channels, the DNs run from 90 to 136. If no "folds" are present (and none are apparent), this could correspond to ~140 V to 210 V or some multiple of 10 times these limits. These potentials would allow the solar wind to be admitted in all channels, but for speeds of 400 km/s, similar to those detected by Voyager 2 at these distances, no decrease in DC current with channel number should be present. Multiplying the limits by a factor of 10 would exclude the solar wind from the top channel, unless its speed exceeded ~600 km/s, and speeds of this magnitude were not detected just prior to the failure, so something is not consistent.

To understand the post-failure measurements by the instrument on Voyager 1, a more detailed investigation is clearly required. Such an investigation is now underway.



Simplified Block Diagram of H.V. Modulator

J.B. 30 Dec 80

(2)

FIGURE 1

APPENDIX A

MVM Measurements for Prototype

ORIGINAL PAGE IS
OF POOR QUALITY

PLS-PROTOTYPE
HIGH VOLTAGE MONITORS

DEC. COUNTS — L-Mode — S.C. = 960 ms

Step	Reference Counts $+V_L$	Reference Counts $+V_U$	$+V_L$ [V]	$+V_U$ [V]
0	054	166	0.172	0.466
1	173	239	0.496	0.892
2	243	038 + 255 (1)	0.924	1.441
3	041	084	1.480	2.169
4	088	126	2.247	3.150
5	130	165	3.264	4.455
6	169	202	4.616	6.189
7	206 + 255	238 + 255	6.413	8.522
8	238 Carl	015 + 255 (1)	0.894	1.175
9	017 + 255	049	1.196	1.589
10	051	083	1.619	2.150
11	084	116	2.169	2.882
12	118	149	2.934	3.864
13	151	182	3.934	5.181
14	184	215	5.274	6.947
15	216	248 + 255	7.009	9.314

Least square approximation!

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PLS-PROTOTYPE
HIGH VOLTAGE MONITORS

DEC. COUNTS | E1-Mode | S.C. = 960 ms

Step	Reference Counts		$-V_L$ CONV.	$-V_u$ CONV.	lower reading
	$-V_L$	$-V_U$			
0	048		0.163		3.9%
1		121		0.313	
2	121		0.313		
3		170		0.483	3.9%
4	170		0.483		3.9%
5		209		0.683	
6	208		0.677		4.8%
7		241		0.908	4.3%
8	241		0.908		
9		014		1.164	
10	013		1.154		6.0%
11		039		1.454	
12	039		1.454		5.9%
13		063		1.800	
14	063		1.800		5.9%
15		086		2.208	5.5%

PLS-PROTOTYPE

HIGH VOLTAGE MONITORS

DEC. COUNTS E2-Mode S.C. = 960 ms

Step	Reference Counts $-V_L$	Reference Counts $-V_U$	$-V_L$ [v]	$-V_u$ [v]
0	050		0.166	
1		240		0.900
2	241		0.908	
3		086		2.208
4	086		2.208	
5		166		4.494
6	167		4.535	
7		239 +255		8.598
8	237		0.876	
9		050 +255		1.603
10	050		1.603	
11		117		2.908
12	117		2.908	
13		183		5.227
14	183		5.227	
15		248		9.314

PLS-PROTOTYPE
HIGH VOLTAGE MONITORS

DEC. COUNTS — M-Mode — S.C. = 960 ms

Step	Reference Counts +VL	Reference Counts +VU	+VL [V]	+VU [V]	-							
0	048	071	0.163	0.200								
1	070	089	0.199	0.253	off			0.121				
2	089	106	0.253	0.274	off			0.225				
3	106	121	0.274	0.313				+0.262				
4	121	134	0.313	0.351								
5	134	147	0.351	0.394								
6	147	158	0.394	0.434								
7	159	169	0.438	0.479								
8	170	180	0.483	0.528								
9	180	190	0.528	0.577								
10	190	199	0.577	0.625								
11	199	208	0.625	0.677								
12	208	217	0.677	0.734								
13	217	225	0.734	0.788								
14	225	233	0.788	0.846								
15	233	240	0.846	0.900								
16	241	248	0.908	0.966								
17	248	255	0.966	1.028								
18	255	006 +255	1.028	1.084								
19	006 +255	013	1.084	1.154								
20	013	020	1.154	1.228								
21	020	026	1.228	1.275								
22	027	033	1.307	1.379								
23	033	039	1.379	1.454								
24	039	045	1.454	1.534								
25	045	051 +255	1.534	1.618								

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PLS-PROTOTYPE
HIGH VOLTAGE MONITORS

DEC. COUNTS

M-Mode

S.C. = 960 ms

Step	Reference Counts $+V_L$	$+V_U$	$+V_L$ [V]	$+V_U$ [V]
26	051 +255	057 +255	1.618	1,706
27	057	063	1,706	1,800
28	063	069	1,800	1,898
29	069	074	1.898	1,984
30	075	080	2,002	2,093
31	080	086	2,093	2,208
32	086	091	2,208	2,308
33	091	096	2,308	2,413
34	096	102	2,413	2,545
35	102	107	2,545	2,661
36	107	112	2,661	2,782
37	112	117	2,782	2,908
38	117	122	2,908	3,040
39	123	127	3,067	3.178
40	128	132	3.207	3,323
41	133	137	3,352	3,473
42	138	142	3,504	3,631
43	143	147	3,664	3.796
44	147	152	3.796	3,969
45	152	157	3,969	4,149
46	157	162	4,149	4,338
47	162	166	4,338	4,494
48	167	171	4,535	4,679
49	171	176	4,679	4.912
50	176	180	4,912	5,090
51	181 +255	185 +255	5,135	5.321

PLS-PROTOTYPE
HIGH VOLTAGE MONITORS

DEC. COUNTS M-Mode S.C. = 960 ms

Step	Reference Counts $+V_L$	Reference Counts $+V_U$	$+V_L$ [V]	$+V_U$ [V]								
52	185+255	190+255	5,321	5,563								
53	190	194	5,563	5,764								
54	195	199	5,816	6,026								
55	199	203	6,026	6,244								
56	204	208	6,300	6,528								
57	208	212	6,528	6,764								
58	213	217	6,824	7,071								
59	217	221	7,071	7,327								
60	222	226	7,392	7,660								
61	226	230	7,660	7,937								
62	230	235	7,937	8,298								
63	235+255	239+255	8,298	8,598								
64	237	241	0,876	0,908								
65	241	245	0,908	0,941								
66	246	250	0,949	0,983								
67	250	254	0,983	1,019								
68	254	003+255	1,019	1,056								
69	003+255	007	1,056	1,094								
70	007	011	1,094	1,134								
71	011	015	1,134	1,175								
72	016	020	1,185	1,228								
73	020	024	1,228	1,273								
74	024	028	1,273	1,319								
75	028	033	1,319	1,379								
76	033	037	1,379	1,428								
77	037-255	041+255	1,428	1,480								

HIGH VOLTAGE MONITORS

DEC COUNTS | M-Mode | S.C. = 960 ms

Step	Reference Counts +V_L	Reference Counts +V_U	+V_L [V]	+V_U [V]
78	041+255	045+255	1,480	1,534
79	046	050	1,547	1,603
80	050	054	1,603	1,661
81	054	058	1,661	1,721
82	058	062	1,721	1,784
83	062	067	1,784	1,865
84	067	071	1,865	1,932
85	071	075	1,932	2,002
86	075	079	2,002	2,075
87	079	083	2,075	2,150
88	084	088	2.169	2.247
89	088	092	2,247	2,329
90	092	096	2,329	2,413
91	096	100	2.413	2,500
92	100	104	2,500	2,591
93	104	108	2,591	2,684
94	109	112	2.708	2.782
95	113	117	2.806	2.908
96	117	121	2.908	3.013
97	121	125	3,013	3.122
98	125	129	3.122	3.235
99	129	133	3.235	3.352
100	133	137	3.352	3.473
101	137	141	3.473	3.599
102	142	146	3.631	3.763
103	146 [illegible]	150 [illegible]	3.763	3.899

HIGH VOLTAGE MONITORS

DEC. COUNTS | M-Mode | S.C. = 960 ms

Step	Reference Counts +V_L	Reference Counts +V_U	+V_L [V]	+V_U [V]
104	150 +255	154 +255	3,899	4,040
105	154	158	4,040	4,186
106	158	162	4,186	4,338
107	162	166	4,338	4,494
108	166	170	4,494	4,657
109	170	174	4,657	4,826
110	175	178	4,869	5,000
111	179	183	5,045	5,227
112	183	187	5,227	5.417
113	187	191	5,417	5,613
114	191	195	5,613	5,816
115	195	199	5,816	6,026
116	199	203	6,026	6,244
117	203	207	6,244	6,470
118	207	211	6,470	6,704
119	211	215	6,704	6,947
120	215	219	6,947	7,198
121	219	224	7,198	7,525
122	224	228	7,525	7,797
123	228	232	7,797	8,079
124	232	236	8,079	8.372
125	236	240	8,372	8.675
126	240	244 [illegible]	8,675	8,989
127	244 +255	248 +255 [illegible]	8,989	9,314

APPENDIX B

MVM Measurements for Flight 1
(SN 002)

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Ser # 002

PLS-~~PROTOTYPE~~ F1
HIGH VOLTAGE MONITORS

1/20/76
Tested with MIT made h.v. tester

DEC. COUNTS

Ref.

L-Mode

S.C. = 960 ms

Step	Reference Counts +V_L	Reference Counts +V_U	V_{DC}	V_U	V_L	V_D	V_U	V_L	V_u	V_L		
0	054	166	70	30.0	10.							
1	173	239	93.35	56.7	30.0		55	28				
2	243	038	124.5	92.3	56.7		90	54	92	56		
3	041	084	166.01	139.7	92.3		138	90				
4	088	126	221.38	203.0	139.7		202	138	200.	135		
5	130	165	295.21	287.4	203.0		287	202				
6	169	202	393.67	399.94	287.4	[illegible]	401	288				
7	206	238		550.0	399.9		552	401				
8	238	015		750.1	550.0		752	552	749	549		
9	017	049		1017.0	750.1		1016	751				
10	051	083		1372.8	1017.0		1374	1020				
11	084	116		1847.	1372.8		1848	[illegible]76	[illegible]			[illegible]
12	118	149		2480.	1847.		2492	[illegible]56	2493	1859		114 mA
13	151	182		3324	2480.		[illegible]55	[illegible]2				
14	184	215		4449.	3324.		[illegible]491	3351				
15	216	248		5950.	4449.		[illegible]	4481	4462	5980		170 mA
							[illegible]	[illegible]				

4/22/77

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PLS ~~PROTOTYPE~~ Ser. #002
HIGH VOLTAGE MONITORS

DEC. COUNTS

L-Mode

S.C. = 960 ms

Step	Reference Counts $+V_L$	Reference Counts $+V_U$	Voltage		$+V_L$	$+V_U$	$+V_L$	$+V_U$					
0	054	166			53	173	52	173					
1	173	239			172	243	172	243					
2	243	038			243	41	243	42					
3	041	084			41	88	41	88					
4	088	126			87	129	87	129					
5	130	165			129	168	129	168					
6	169	202			168	205	167	205					
7	206	238			204	240	204	240					
8	238	015			239	18	239	18					
9	017	049			17	52	17	52					
10	051	083			51	85	51	85					
.	084	116			86	118	85	118					
12	118	149			118	151	118	151					
13	151	182			151	184	151	184					
14	184	215			183	216	183	216					
15	216	248			216	249	216	249					
					Before TPL								

F1 PLS-~~PROTOTYPE~~ Ser #002 4/22/77

HIGH VOLTAGE MONITORS

DEC. COUNTS Reference E1-Mode S.C. = 960 ms

Step	Reference Counts $-V_L$	Reference Counts $-V_U$	$-V_L$ Voltage	$-V_u$
0	048		-10	-14.5
1		121	-14.5	-19.3
2	121		19.3	24.5
3		170		
4	170		30	36
5		209		
6	208		42.4	49.3
7		241		
8	241		56.7	64.66
9		014		
10	013		73.21	82.40
11		039		
12	039		92.28	102.59
13		063		
14	063		114.31	126.56
15		086	126.56	139.74

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PLS ~~PROTOTYPE~~ Ser. # 002
HIGH VOLTAGE MONITORS

4/22/77

DEC. COUNTS   E2-Mode   S.C. = 960 ms

Step	Reference Counts $-V_L$	Reference Counts $-V_U$	Measured Voltage $-V_L$	$-V_u$	measured $-V_L$	measured $+V_U$	$-V_L$	$-V_u$	$-V_L$	$-V_u$			
0	050		-10	-30			49		46				
1		240						239		239			
2	241		56.70	92.28	55	91	238		237				
3		086						83		83			
4	086		139.74	203.02			82		82				
5		166						163		163			
6	167		287.41	399.94			162		162				
7		239						237		237			
8	237		550.00	750.11	547	757	234		234				
9		050						47		47			
10	050		1016.97	1372.83			46		46				
11		117						114		114			
12	117		1847.37	2480.18	1833	2499	113		113			105 mA	
13		183						179		179			
14	183		3324.05	4449.37			178		178				
15		248	4449.37	5950.0	4445	6025		246		246		150 mA	
							ATP Before JPL		AFTER JPL				

In blue measured values
Red = reference   with home made instrument

PLS-~~PROTOTYPE~~ Ser. # 002 4/22/7?

HIGH VOLTAGE MONITORS

DEC. COUNTS ~~Measured~~ References M-Mode Measured S.C. = 960 ms

Step	Reference Counts $+V_L$	Reference Counts $+V_U$	References $+V_L$ Voltage	References $+V_u$	M-Mode Measured $+V_L$	M-Mode Measured $+V_u$
0	048	071				
1	070	089				
2	089	106	14.5	16.8	13	15
3	106	121				
4	121	134				
5	134	147				
6	147	158				
7	159	169				
8	170	180				
9	180	190				
10	190	199				
11	199	208				
12	208	217				
13	217	225				
14	225	233				
15	233	240				
16	241	248	56.7	60.6	52	57
17	248	255				
18	255	006				
19	006	013				
20	013	020				
21	020	026				
22	027	033				
23	033	039				
24	039	045				
25	045	051				

PLS-~~PROTOTYPE~~ Ser. #002 4/22/77

HIGH VOLTAGE MONITORS

DEC. COUNTS   Ref ~~Measured~~   M-Mode Measured   S.C. = 960 ms

Step	Reference Counts												
	$+V_L$	$+V_U$	$+V_L$ ~~Voltage~~	$+V_U$ ~~$+V_L$~~	$+V_U$	$+V_L$							
26	051	057											
27	057	063											
28	063	069											
29	069	074											
30	075	080											
31	080	086	133.0	139.7									
32	086	091	139.7	146.7	144	137							
33	091	096	146.7	153.9									
34	096	102											
35	102	107											
36	107	112											
37	112	117											
38	117	122											
39	123	127											
40	128	132											
41	133	137											
42	138	142											
43	143	147											
44	147	152											
45	152	157											
46	157	162											
47	162	166											
48	167	171											
49	171	176											
50	176	180											
51	181	185											

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PLS-~~PROTOTYPE~~ Ser. # 002

HIGH VOLTAGE MONITORS

9/22/77

DEC. COUNTS

M-Mode

S.C. = 960 ms

Step	Reference Counts		Measured Voltage										
	$+V_L$	$+V_U$											
52	185	190											
53	190	194											
54	195	199											
55	199	203											
56	204	208											
57	208	212											
58	213	217											
59	217	221											
60	222	226											
61	226	230											
62	230	235											
63	235	239											
64	237	241	550.0	571.99	548	572							
65	241	245											
66	246	250											
67	250	254											
68	254	003											
69	003	007											
70	007	011											
71	011	015											
72	016	020											
73	020	024											
74	024	028											
75	028	033											
76	033	037											
77	037	041											

PLS-~~PROTOTYPE~~ Ser. # 002 4/22/77

HIGH VOLTAGE MONITORS

DEC COUNTS Measured M-Mode measured S.C. = 960 ms

ep	Reference Counts		Voltage		$+V_L$	$+V_n$							
	$+V_L$	$+V_U$											
78	041	045											
79	046	050											
80	050	054											
81	054	058											
82	058	062											
83	062	067											
84	067	071											
85	071	075											
86	075	079											
87	079	083											
88	084	088											
89	088	092											
90	092	096											
91	096	100											
92	100	104											
93	104	108											
94	109	112											
95	113	117											
96	117	121	1847.4	1916.9	1929	1858							
97	121	125											
98	125	129											
99	129	133											
100	133	137											
1	137	141											
102	142	146											
103	146	150											

PLS-~~PROTOTYPE~~ Ser. #002

HIGH VOLTAGE MONITORS

4/22/77

DEC. COUNTS Measured M-Mode S.C. = 960 ms

ep	Reference Counts												
	$+V_L$	$+V_U$	Voltage		$+V_L$	$+V_U$							
104	150	154											
105	154	158											
106	158	162											
107	162	166											
108	166	170											
109	170	174											
110	175	178											
111	179	183											
112	183	187											
113	187	191											
114	191	195											
5	195	199											
116	199	203											
117	203	207											
118	207	211											
119	211	215											
120	215	219											
121	219	224											
122	224	228											
123	228	232											
124	232	236											
125	236	240											
126	240	244											
7	244	248	5738	5950	5799	6010							