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Flattopÿ Frequency Studies for the VHF Cavity; Stability, Reproducibility, Resolution

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Subject Flattop Frequency Studies for the VHF Cavity; Stability, Reproducibility, Resolution

Introduction

The VHF cavity that will be used for controlled longitudinal phase space dilution is a narrow band cavity that must be synchronized to the AGS rf system during a short (~ 50 ms) flattop. This study investigated the stability of the rf frequency on a typical flattop. If the natural stability of the AGS frequency is not sufficiently high to keep the cavity drive frequency within the cavity bandwidth, then explicit control of the AGS rf frequency (by means of the radial loop) will have to be implemented. The required stability is ± 250 Hz over the duration of the flattop. The study found that the inherent stability is very good. The standard deviation of the frequency during the flattop was 250 Hz. However, the reproducibility from machine cycle to machine cycle was much worse, typically 2.8 kHz. Also, it was found that the time it takes to achieve the flattop condition was rather long, 50 ms.

Experimental Method

The data were taken using the HP-5371A Frequency and Time Interval Analyzer. The analyzer measures frequency (among other things) with very high precision as function of time over a very wide range of time intervals. It also performs statistical analysis of frequency measurements. The instrument was on loan from HP for evaluation purposes.

We found that the output of the spare STA3 (self-tracking amplifier) was the best signal to use as input to the analyzer as a measure of the frequency of the beam. The analyzer was triggered by "injection peaker" for all runs and was internally delayed to set the measurement point and duration. A typical run measured the frequency 1000 times in 50 microsecond intervals for a total measurement time of 50 milliseconds. With 50 microsecond measuring interval, the resolution of the frequency measurement was ± 25 Hz.

The magnetic field was flattopped with a Gauss Clock trigger at 4300 GCC via the parameter TRGAT. This gave a nominal frequency of 4.10 MHz and momentum of 2.25 GeV/c. The slope of the flattop was adjusted, while watching the frequency slope on the analyzer, via the parameter SESLD. Both time dependent frequency measurements and histograms of the frequency during the stable portion of the flattop were recorded.

Several histograms were taken, with the machine parameters fixed, to determine the cycle-to-cycle variation of the frequency. The cycle-to-cycle variation of the radius was measured on the flattop for 50 cycles with the IPM. The dependence of frequency on radius was measured by moving the radius of the beam with the radial offset by 5.0 mm.

The beam intensity for this study was 2 x 10^{12} ppp. The rf gap voltage was reduced to 128 keV/turn on the flattop.

Results

Figure 1 shows, on a gross scale, the frequency as the machine goes into the flattop, over a 150 ms period, beginning 60 ms after "peaker". A closer look at the "flat" portion in Figure 2 reveals a frequency slope of 14.7 Hz/ms. This corresponds to magnetic field slope, at constant radius, of 21.3 mGauss/ms.

By adjusting SESLD, the slope seen in Figure 2 could be reduced essentially to zero. In Figure 3, the vertical scale has been expanded by a factor of 3 and the slope is seen to be less than 1.9 Hz/ms. The average field drooped by less than 0.14 Gauss in 50 ms. This very good flatness was repeated shot after shot.

The fluctuations of the frequency during the flattop can be seen in Figure 4, which is a histogram of 1000 frequency measurements, taken at 50 microsecond intervals. These fluctuations would not be a problem in driving the VHF cavity because they amount to no more than 1/10 of the bandwidth of the cavity. However, Figure 5 shows an accumulated histogram of 10 consecutive machine cycles. It an be seen here that the frequency does not reproduce well on repeated shots. There are three peaks in this plot and Figures 5.a to 5.d show that the frequency does not jump from one peak to another during a shot. The separation between peaks is approximately 2.8 kHz, which corresponds to 4.0 Gauss out of 877 Gauss total. Figure 6 shows an accumulated histogram over 100 machine cycles and the same behavior occurs over the much longer sample. The IPM was used to measure the variations of the radius from shot to shot. Figure 7 shows that the radius varied by less than 0.2 mm over 50 consecutive shots.

The time required to get into the flattop was also studied. Figure 8 shows the 52 ms transient that occurs at the beginning of the flattop period. Frequency excursions during the transient were ± 6.7 kHz. An attempt was made to use the "spill servo trigger" to minimize this transient but it was found unworkable at the low voltage needed for 2.25 GeV/c. This transient is significant since it equals the time needed for a dilution and thereby reduces the efficiency by 50%.

A radial shifter was used to measure the dependence of the frequency on radius, df/dR, at fixed magnetic field. The following results were obtained:

Radius Shift (mm)	Frequency (MHz)
+ 12.25	4.100357
+ 14.25	4.101253
+ 17.0	4.102413

We conclude from these data that df/fR = 4.32×10^{-4} MHz/mm. This is close, but not equal to what one calculates from

$$dB/B = \gamma^2 \, df/f + (\gamma^2 - \gamma_{tr}^2) \, dR/R$$

$$df/dR = 3.1 \times 10^{-4} \text{ MHz/mm}.$$

The discrepancy is not understood, but is probably due to errors in the data for the radial shifts.

To test the settability, we measured frequency at three different values TRGAT. At each new value of TRGAT the slope parameter, SESLD, was adjusted for optimal flatness. The results are

TRGAT	SESLD	Frequency (MHz)
405	145	4.087214
415	149	4.103727
425	151	4.117618

Fitting these points to be best straight line gives a slope, df/d(TRGAT) = 1520 Hz/Count. Since one TRGAT count corresponds to ten Gauss Clock counts, we conclude that the settability is more than adequate for the VHF cavity.

Conclusion

The study has shown that the flatness of the flattops can be excellent and more than adequate for the requirements of the VHF cavity. However, the reproducibility from shot to shot of the flattop magnetic field value is not compatible with the requirements of the VHF cavity. It appears that the flattop field values are discrete with spacing of about 4 Gauss.

The transient upon going into the flattop is longer than one would like, especially in view of the fact that after the Booster comes on line we may need more than one dilution per cycle. It is possible, however, that some new circuitry analogous to the spill servo trigger could be built for VHF cavity operation. This question should be studied further and the likely improvement over the observed 50 ms transient estimated.

Discussion

It is clear that we must be prepared to run the VHF cavity with the Siemens control as it was in this study. This means that a frequency control loop will take over the radial loop during the dilutions to fix the machine frequency to the proper sub-harmonic of the VHF cavity. The crucial question is how much radial shift will be needed to offset the variations in the magnetic field from shot to shot. At 1.5 GeV kinetic, we have seen field variations of about 4 Gauss out of 877 Gauss. To hold the frequency fixed with this field variation would require a radial variation of $\pm$ 4.5 mm. At 3.5 GeV kinetic we have to estimate the field variation because this study did not look at a flattop at that energy. One assumption is that the size of the discrete field steps is the same at 3.5 GeV and hence the $\Delta B/B$ is smaller by a factor of 1.9, the momentum ratio. Under this assumption, the radial swing needed would be $\pm$ 2.8 mm. Assuming $\Delta B/B$ is constant, leads to a radial swing of $\pm$ 5.4 mm. The beam size during this study was measured with the IPM, see Figure 9. Clearly this beam could stand such excursions since 7 x sigma (99.95% of a Gaussian distribution) is only 35 mm.

What will happen at higher intensity leads to some open questions that will have to be addressed in future studies. The beam size will be bigger and will tolerate less radial shift to tune the frequency. The transient upon going into the flattop probably causes some radial excursions because the radial loop is not arbitrarily fast. Will they be too large? This effect was not measured in this study. The effect of the change in beam loading on the main rf system upon going into flattop is also an important question for high intensity operation.

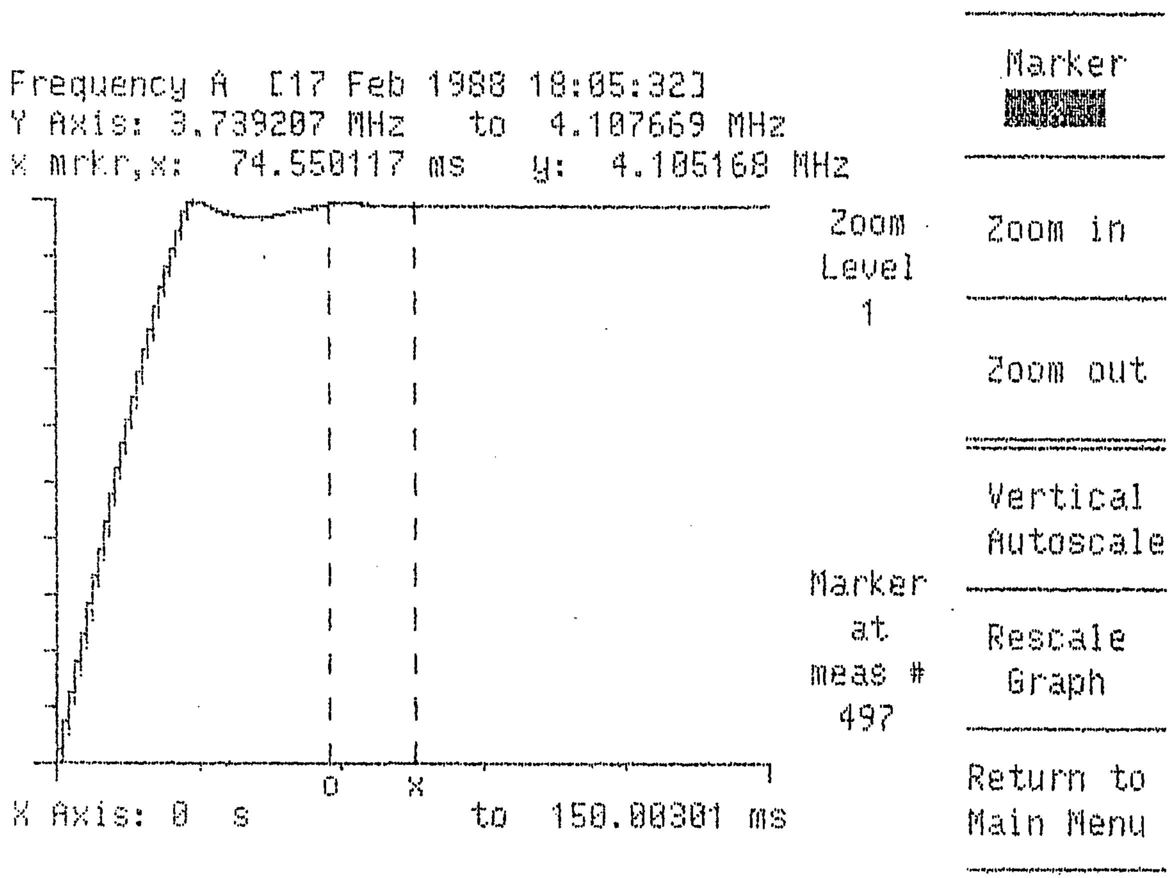
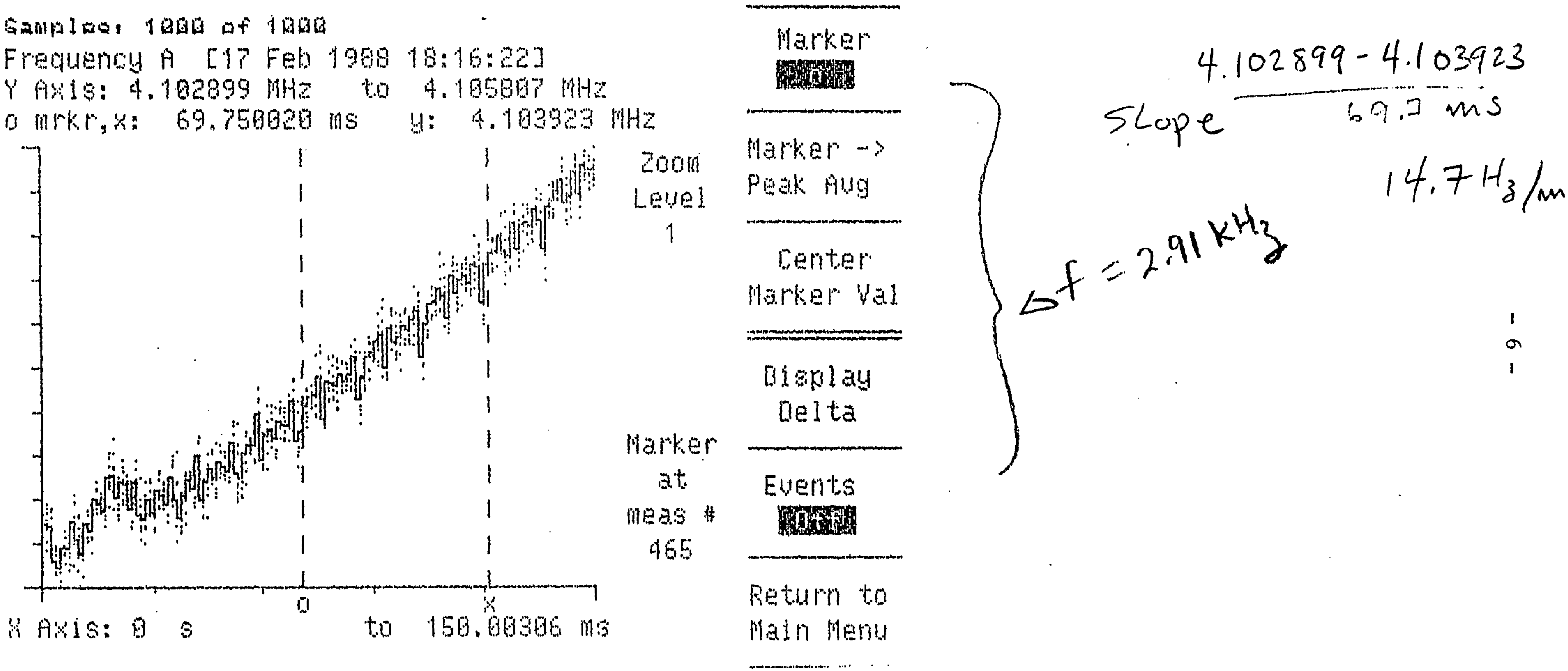

Frequency A [17 Feb 1988 18:05:32]
Y Axis: 3.739207 MHz to 4.107669 MHz
x mrkr,x: 74.550117 ms y: 4.105168 MHz
o
x
X Axis: 0 s to 150.00301 ms
Zoom
Level
1
Marker
at
meas #
497
Marker
Zoom in
Zoom out
Vertical
Autoscale
Rescale
Graph
Return to
Main Menu

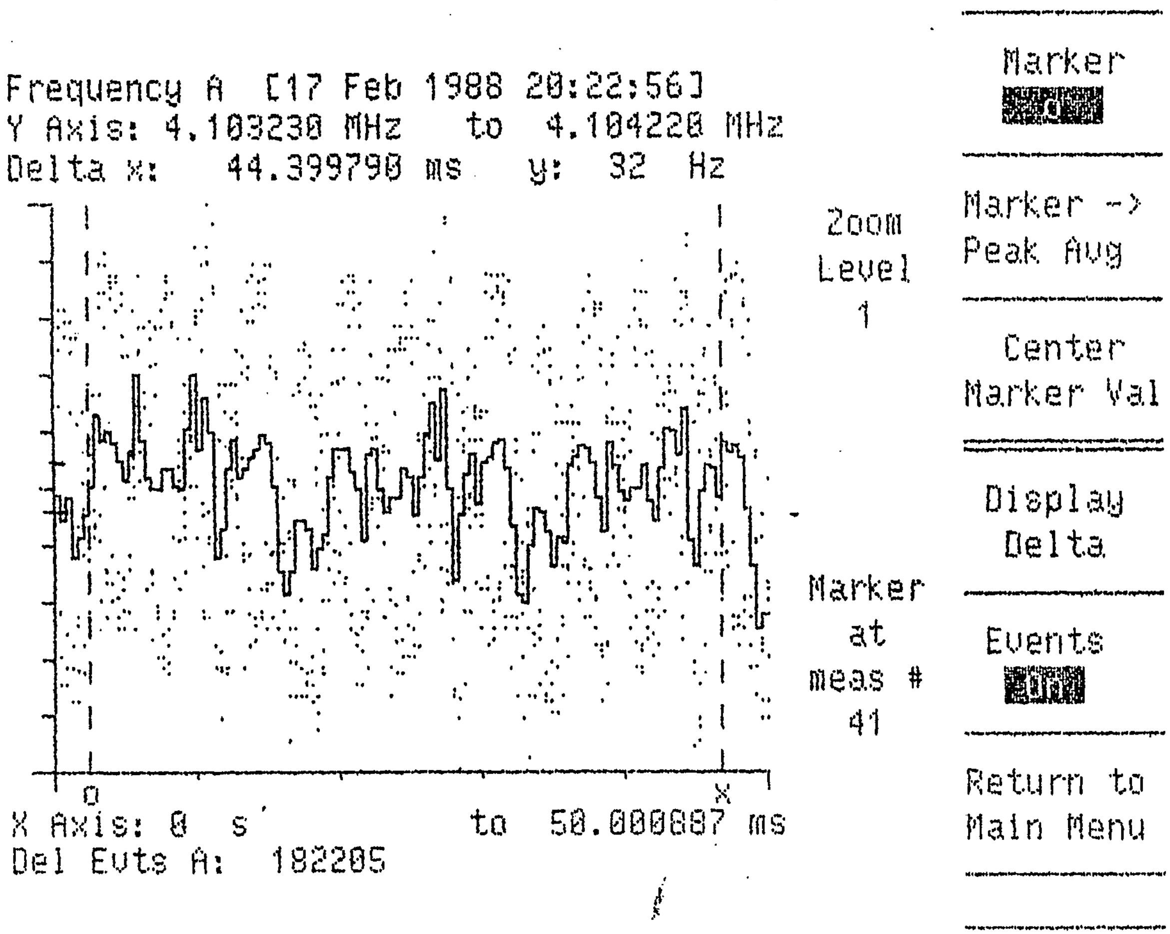
Fig. 1

005



Samples: 1000 of 1000
Frequency A [17 Feb 1988 18:16:22]
Y Axis: 4.102899 MHz to 4.105807 MHz
o mrkr,x: 69.750020 ms y: 4.103923 MHz
0
x
X Axis: 0 s to 150.00306 ms
Zoom
Level
1
Marker
at
meas #
465
Marker
Marker ->
Peak Avg
Center
Marker Val
Display
Delta
Events
Return to
Main Menu
4.102899 - 4.103923
Slope
69.7 ms
14.7 Hz/ms
Δf = 2.91 kHz

Fig 2



99 KHz = Δf range

5/52 999 = 16Hz

<20

Fig 3

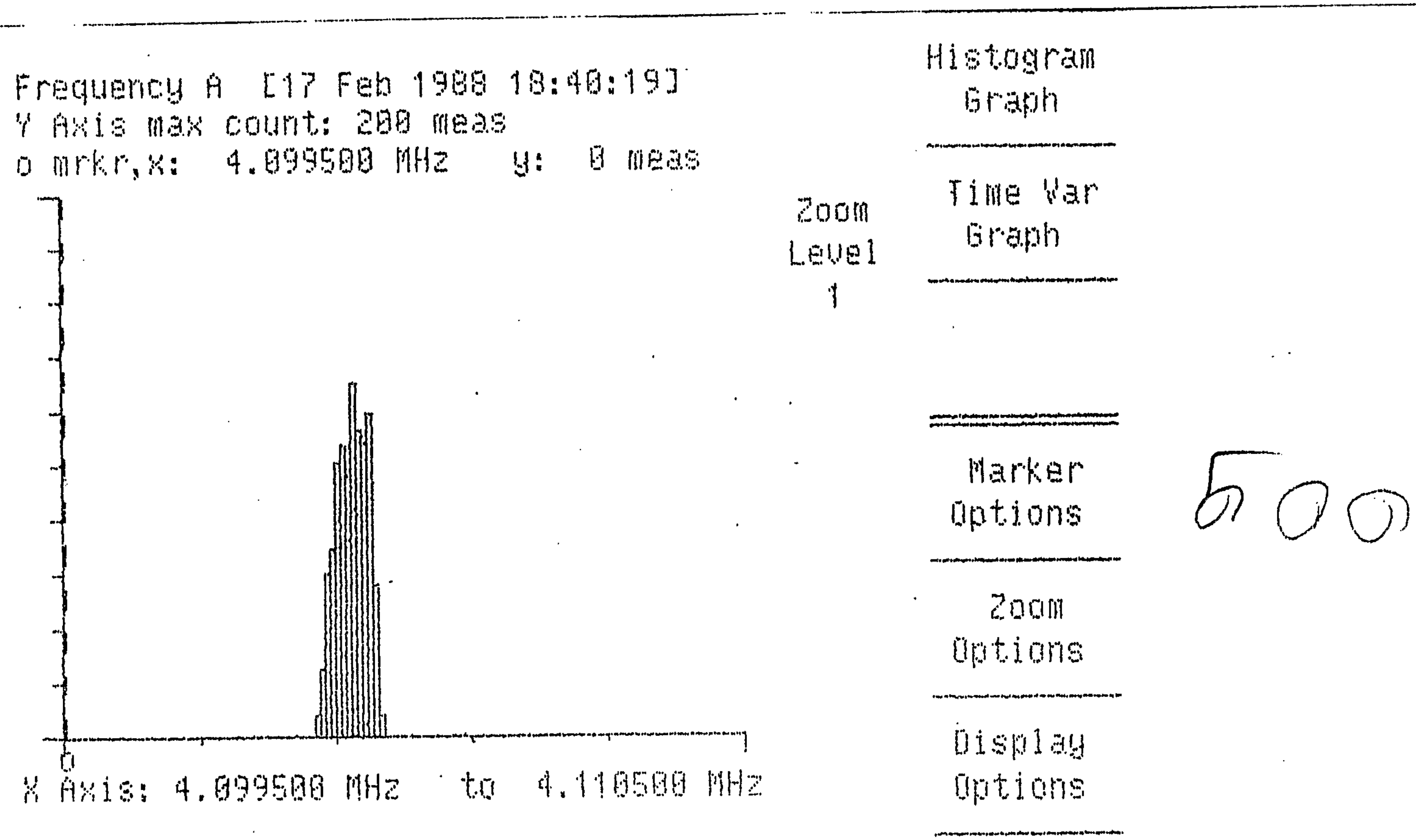
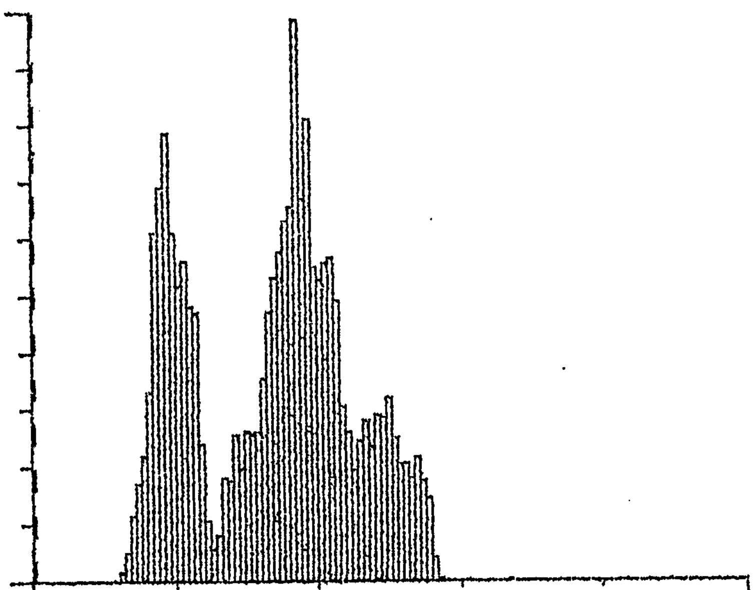

Frequency A [17 Feb 1988 18:40:19]
Y Axis max count: 200 meas
o mrkr,x: 4.099500 MHz y: 0 meas
0
X Axis: 4.099500 MHz to 4.110500 MHz
Zoom
Level
1
Histogram
Graph
Time Var
Graph
Marker
Options
Zoom
Options
Display
Options
500

Fig 4

Samples: 10000 of 10000
Frequency A [17 Feb 1988 18:50:37]
Y Axis max count: 500 meas
o mrkr,x: 4.099500 MHz y: 0 meas



X Axis: 4.099500 MHz to 4.110500 MHz

Zoom
Level
1

Histogram
Graph

Time Var
Graph

Marker
Options

Zoom
Options

Display
Options

Fig 5

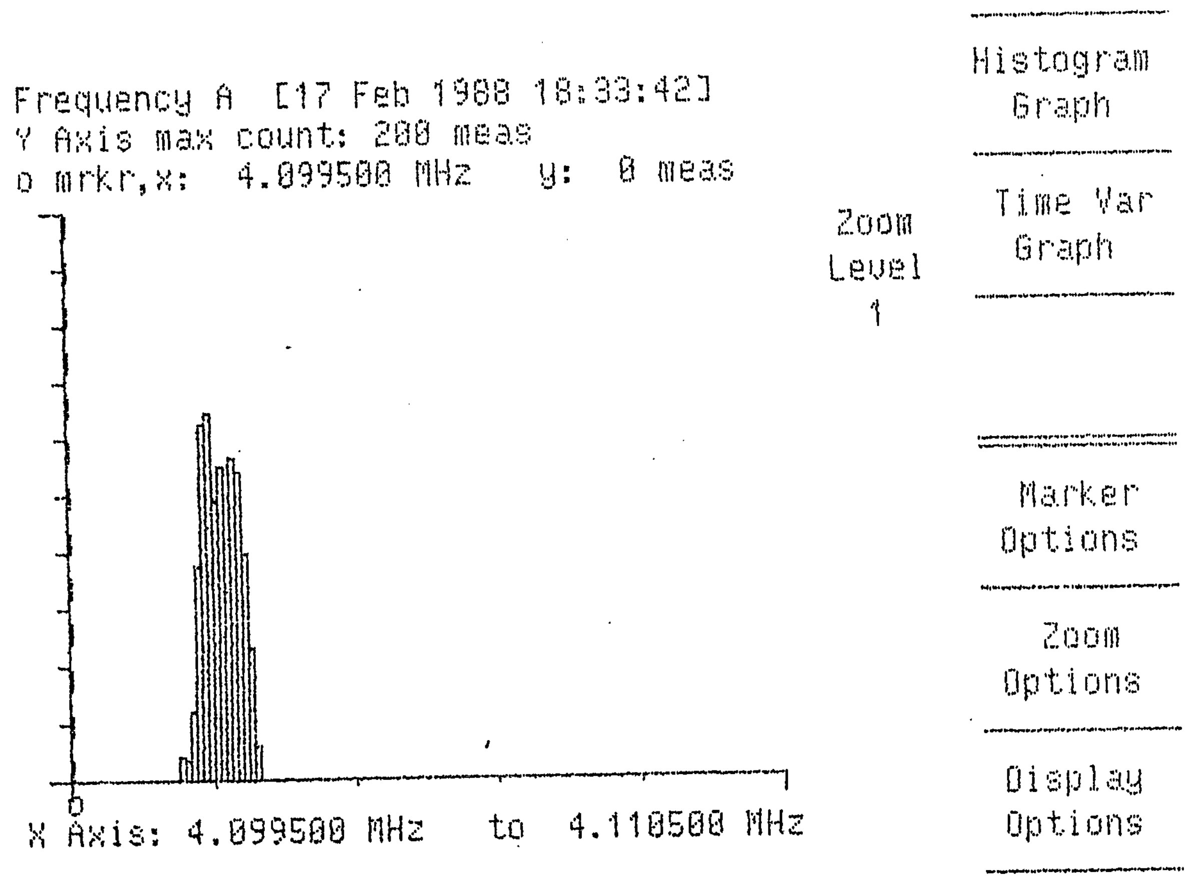

Frequency A [17 Feb 1988 18:33:42]
Y Axis max count: 200 meas
o mrkr,x: 4.099500 MHz y: 0 meas
0
X Axis: 4.099500 MHz to 4.110500 MHz
Zoom Level 1
Histogram Graph
Time Var Graph
Marker Options
Zoom Options
Display Options

Fig 5a

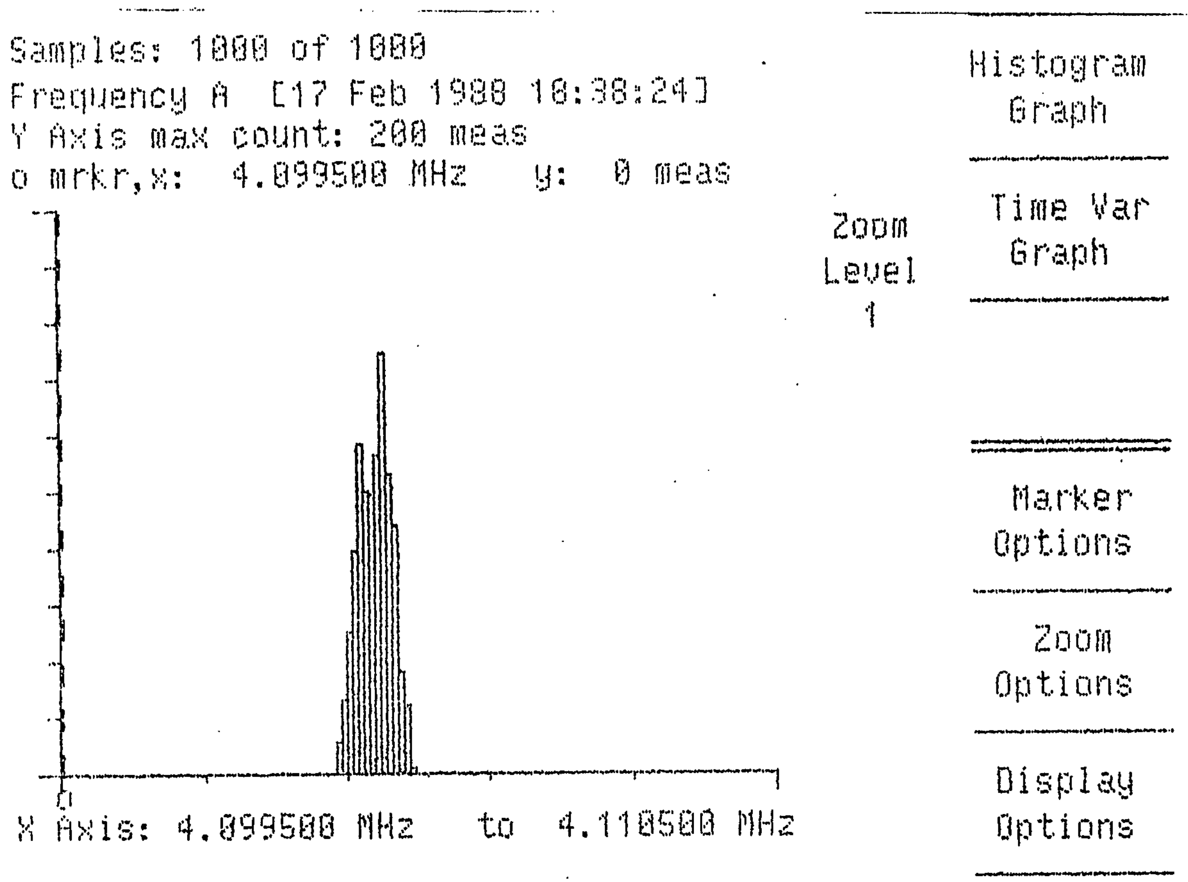

Samples: 1000 of 1000
Frequency A [17 Feb 1988 18:38:24]
Y Axis max count: 200 meas
o mrkr,x: 4.099500 MHz y: 0 meas
X Axis: 4.099500 MHz to 4.110500 MHz
Zoom
Level
1
Histogram
Graph
Time Var
Graph
Marker
Options
Zoom
Options
Display
Options

Fig 5b

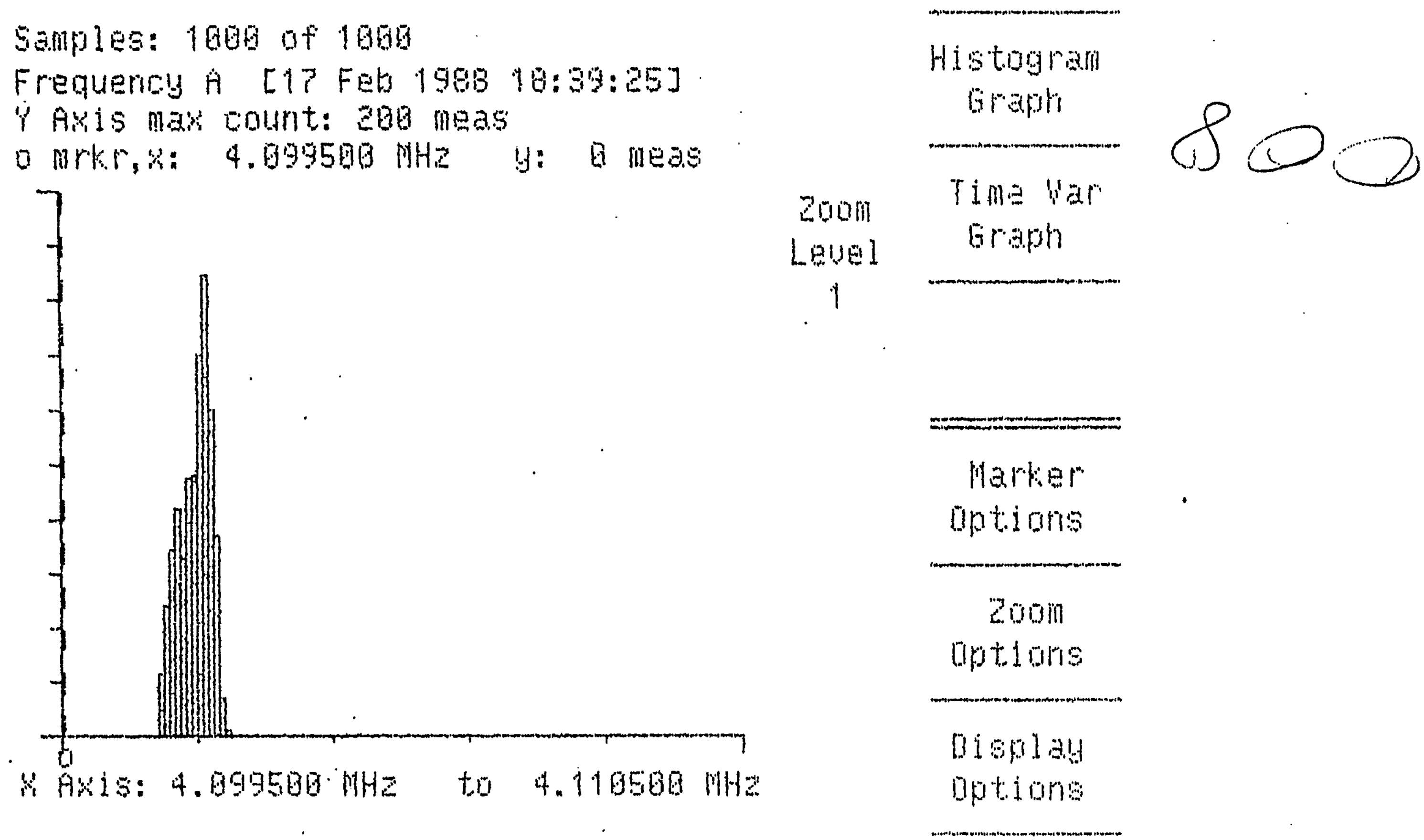
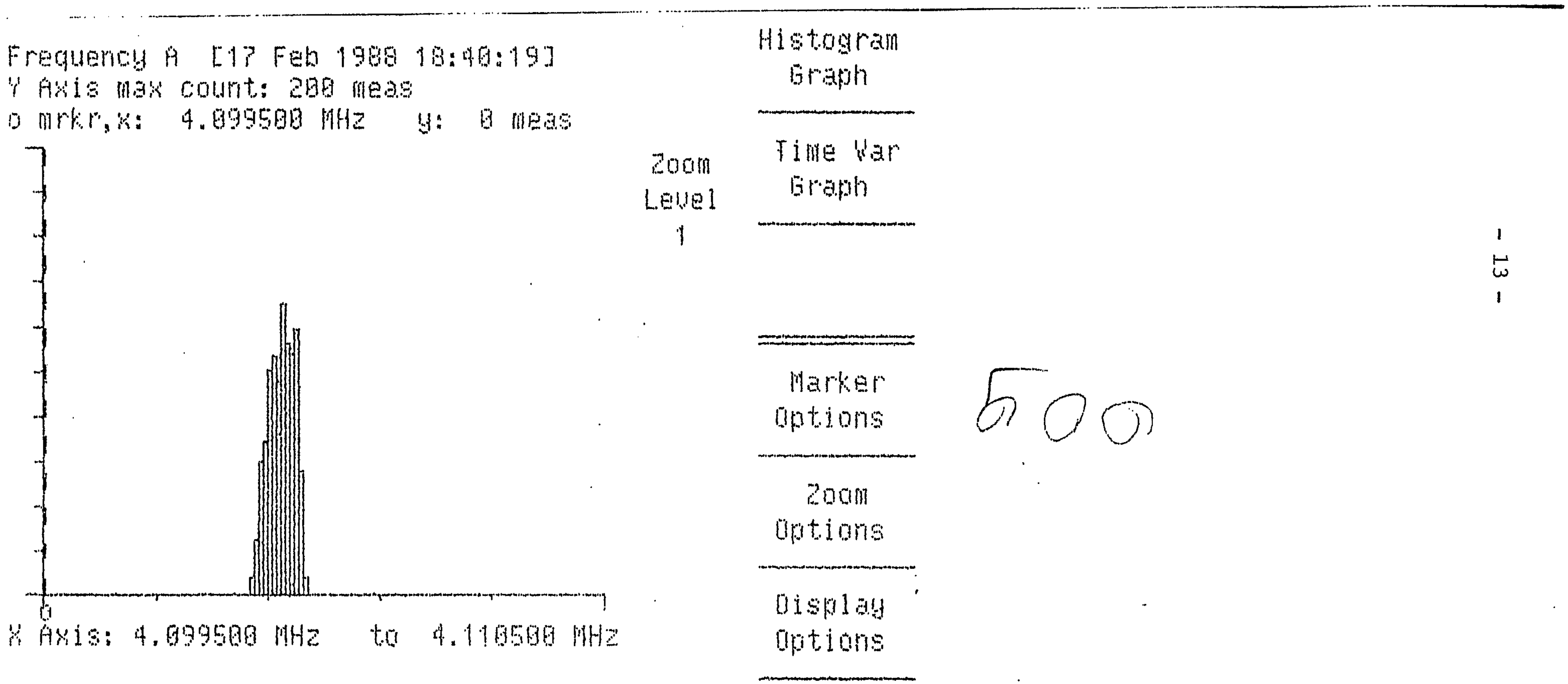

Samples: 1000 of 1000
Frequency A [17 Feb 1988 10:39:25]
Y Axis max count: 200 meas
o mrkr,x: 4.099500 MHz y: 0 meas
0
X Axis: 4.099500 MHz to 4.110500 MHz
Zoom Level 1
Histogram Graph
Time Var Graph
Marker Options
Zoom Options
Display Options
800

FIG 5c



Frequency A [17 Feb 1988 18:40:19]
Y Axis max count: 200 meas
o mrkr,x: 4.099500 MHz y: 0 meas
0
X Axis: 4.099500 MHz to 4.110500 MHz
Zoom
Level
1
Histogram
Graph
Time Var
Graph
Marker
Options
Zoom
Options
Display
Options
500

Fig 5d

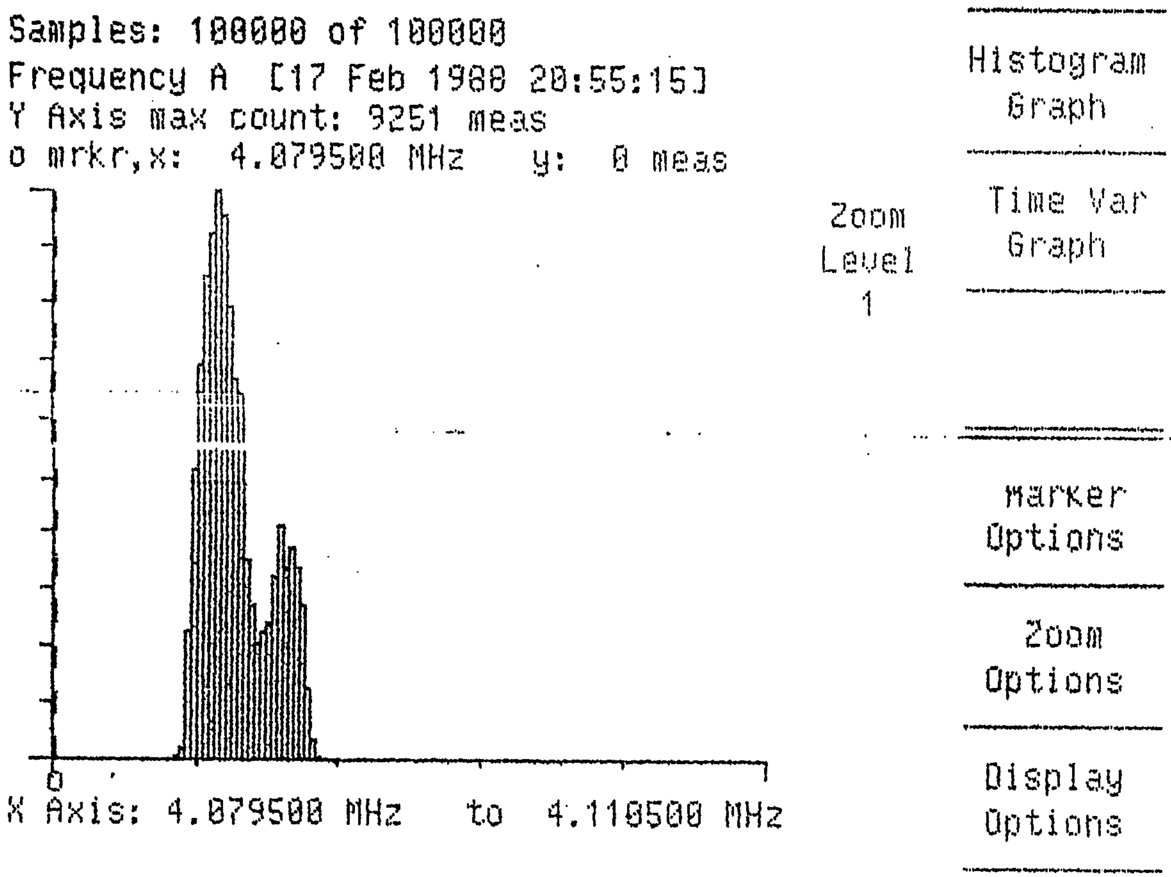

Samples: 100000 of 100000
Frequency A [17 Feb 1988 20:55:15]
Y Axis max count: 9251 meas
o mrkr,x: 4.079500 MHz y: 0 meas
0
X Axis: 4.079500 MHz to 4.110500 MHz
Zoom
Level
1
Histogram
Graph
Time Var
Graph
Marker
Options
Zoom
Options
Display
Options

FIG 6

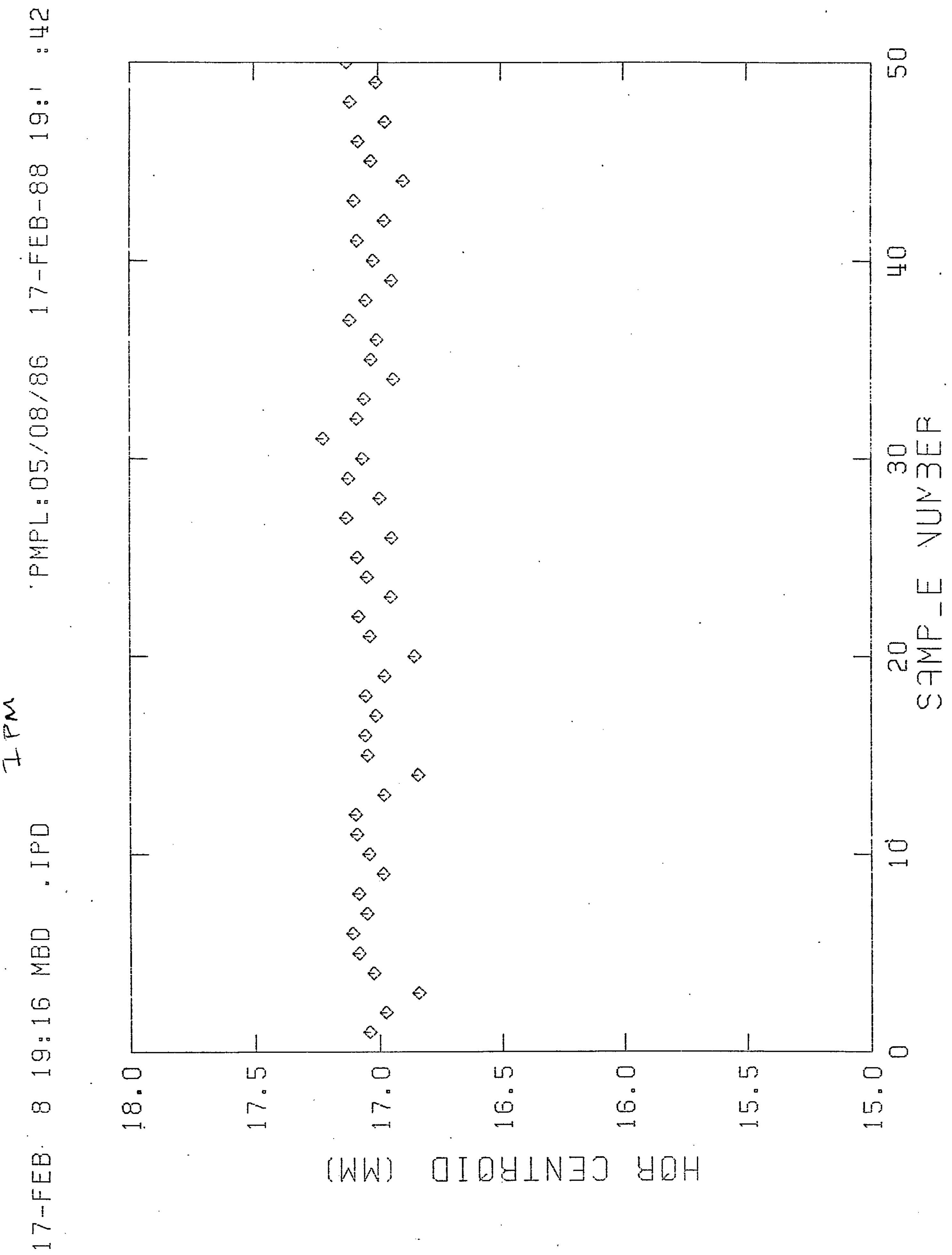

17-FEB 8 19:16 MBD .IPD 'PMPL:05/08/86 17-FEB-88 19:' :42
1 PM
HOR CENTROID (MM)
18.0
17.5
17.0
16.5
16.0
15.5
15.0
0
10
20
30
40
50
SAMPLE NUMBER

Fig 7

220

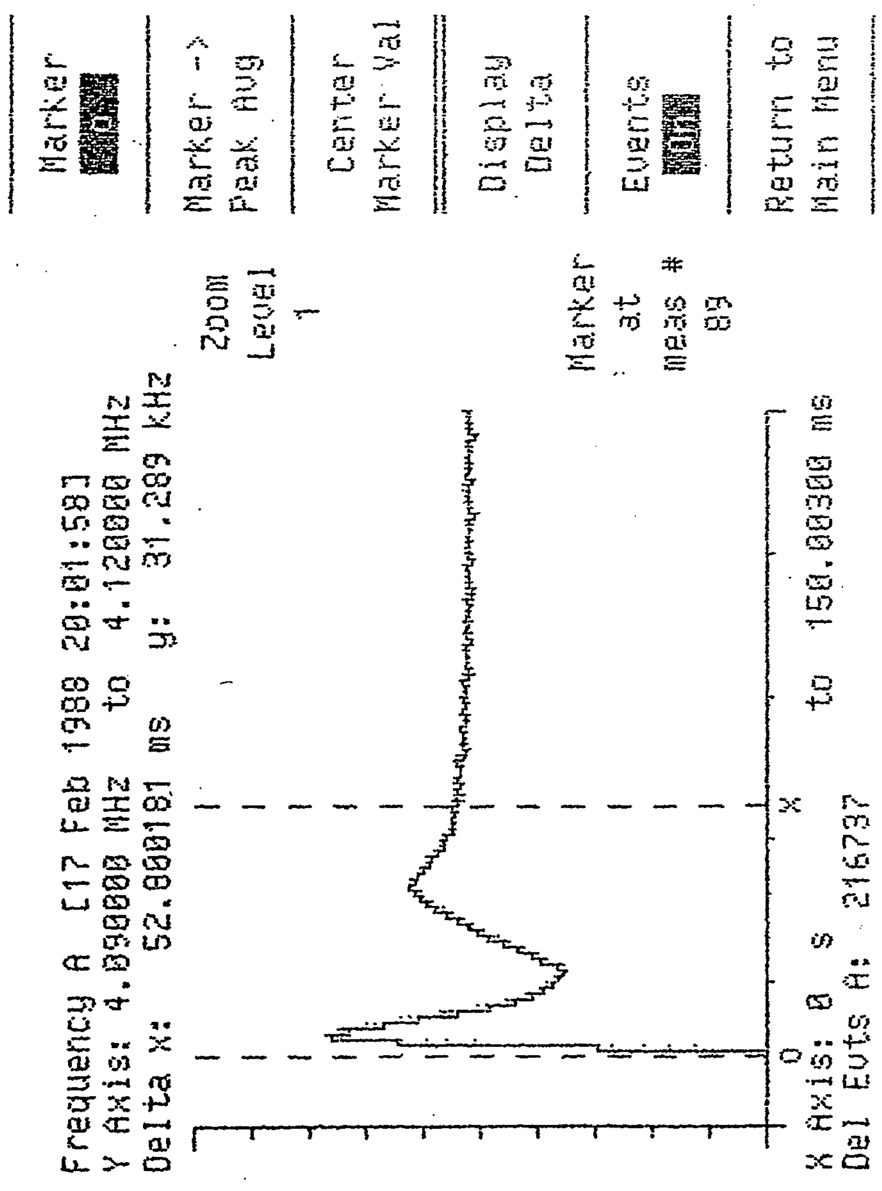
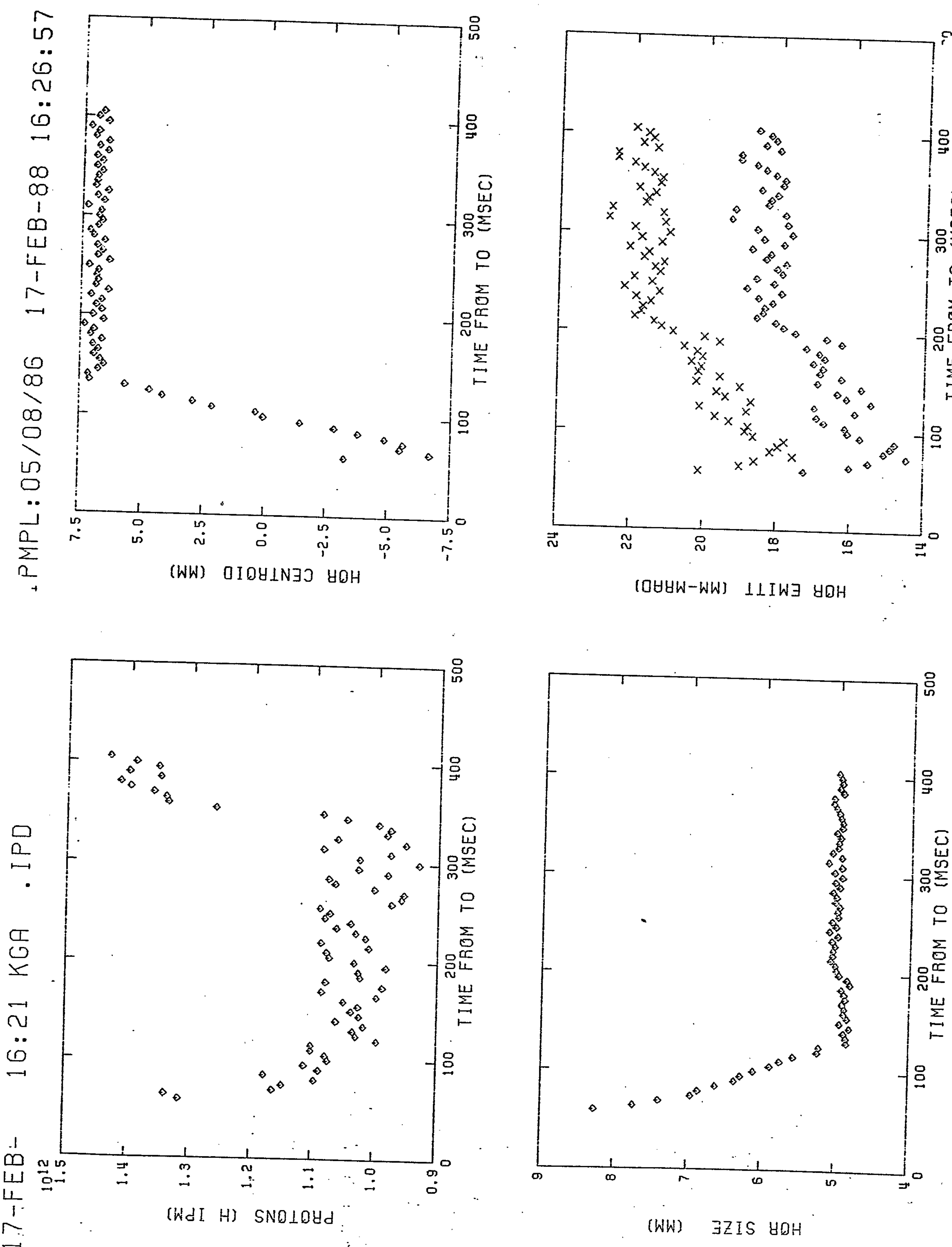

Frequency A [17 Feb 1988 20:01:58]
Y Axis: 4.090000 MHz to 4.120000 MHz
Delta x: 52.000181 ms y: 31.289 kHz
Zoom Level 1
Marker at meas # 89
0
x
X Axis: 0 s to 150.00300 ms
Del Evts A: 216737
Marker
Marker -> Peak Avg
Center Marker Val
Display Delta
Events
Return to Main Menu

FIG 8



17-FEB- 16:21 KGA .IPD
PMPL:05/08/86 17-FEB-88 16:26:57
HOR CENTROID (MM)
HOR EMITT (MM-MRAD)
PROTONS (H IPM)
HOR SIZE (MM)
TIME FROM TO (MSEC)

Fig. 9