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THE FORTH PROGRAM FOR SPECTRAL LINE OBSERVING ON NRAO'S 36 ft TELESCOPE

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The computer system for spectral line observing at the 26 ft mm–wavelength telescope at Kitt Peak is unusually flexible and complete: flexible in that the observer has extensive control over his observing program, and complete in that a very full range of on-line data reduction capabilities exist. The system is written in FORTH, a high-level language designed for real-time interactive applications. It runs on an 12K Honeywell 316 computer with a Tektronix 4002 terminal including a graphics scope and hard copy unit, a PEC 32K drum and 7–track tape. (Until August, 1972, the system ran in 8K, with almost its current range of capabilities, using 1 overlay). A diagram of the system is shown in figure 1.

There are two main observing programs, which differ in that one computes effective antenna temperatures using a formula based on (S–R)/R, and the other uses (S–R)/C (where S = Signal, R = Reference and C = Calibration). Three calibration routines implement an automatic noise-tube and two semi-automatic chopper wheels. A routine is available for computing the LO setting for the frequency synthesizer, including the Doppler offset to the local standard of rest. The program can control automatic antenna switching on and off the source. Such position switching may be combined with beam or frequency switching. Since the temperatures are computed as the data is taken, the intermediate data may be displayed in units of °K, as well as processed data. At the end of each scan, the temperatures in each channel are stored on drum and eventually copied to tape. Figure 2 shows a typical scan. There are many optional display formats; this one shows the 1.2 MHz bandwidth filter to full scale, with the .25 MHz filter data superimposed on it at the same scale. If the latter data is smoothed, it will show good resolution of the central portion. The horizontal axis shows MHz, the vertical axis °K.

Data reduction techniques may be used while data taking is in progress. The observer may obtain a graphical display of incoming data or any past scan; he may select up to 50 past scans and combine them in several ways, obtaining a display of the results. Figure 3 shows a group of scans entered in the "scan stack" for this purpose, and displayed with a vertical offset. Options include averaging the entire group, weighted by integration times; aligning the scans in the group in frequency before averaging; folding one group of scans into another; displaying the residuals after averaging, etc. If desired, the observer may apply a 7–point smoothing function to the data. The displays may be in a number of formats, including plotting with lines, points or histograms, or with error bars. The range of the vertical scale may be changed easily. The horizontal scale may be in units of velocity, frequency, or channels. Frequency and velocity units are computed from the bandwidth of the filter, the peculiar velocity of the source, the center frequency, and the velocity of the local standard of rest (which is computed on-line). Since hard copies of these displays are available, in most cases no later data reduction is necessary.

A general purpose fitting routine allows any function to be fitted to the data, using up to five variables for the fit. Figures 4 and 5 show a single gaussian and a flipped gaussian fitted to data which was displayed with points and error bars. The numbers printed show the center position, half width at half maximum and peak height, each with its rms error, and a computed percentage of the standard deviation of the points. These two gaussian functions are built into the program; any other function may be easily added.

The FORTH program is kept in source form on tape. Compiling (including loading) takes about 30 sec. This enables non-trivial modifications to be made, using a built-in text editor, and the program re-compiled for testing in a very short time. Although in practice only the programmers actually modify the program, special functions may be defined on-line to suit particular needs.

Figure 6 shows an example of the type of functions that casual observers define for themselves. The colon begins the definition of SPLOT, which will plot with points, draw a 1 σ shadow band, draw and label the axes and print the values plotted. The definition terminates with a semi-colon. The computer's OK indicates acceptance of the definition. This definition has now been compiled into the dictionary in memory; that is, the dictionary searches have been made for the words (POINTS, etc.) and their addresses included in an entry that is executed when SPLOT is typed. The picture shows the result.

In an attempt to convey how a user gets along with the system, we have included on each of these pictures the words typed to produce the picture. Italics indicate what the user typed. Figure 7 shows the status display that appears when the program is loaded. The user has entered the date and time, and reset several parameters.

The structure and philosophy of FORTH is an essential part of this system. It is theoretically possible to make a program with many of the superficial aspects of this one using conventional techniques; but it would require far longer to implement, would require considerably more memory and an elaborate overlay structure, and would be very much less flexible. The fact that, over the 20 months that this system has been operational, it has been able to grow through constant interaction with many users, both sophisticated and naive, has made it reflect their needs in a remarkable way. Moreover, since FORTH is unusually computer independent, many of our techniques are available for any other FORTH system without modification.

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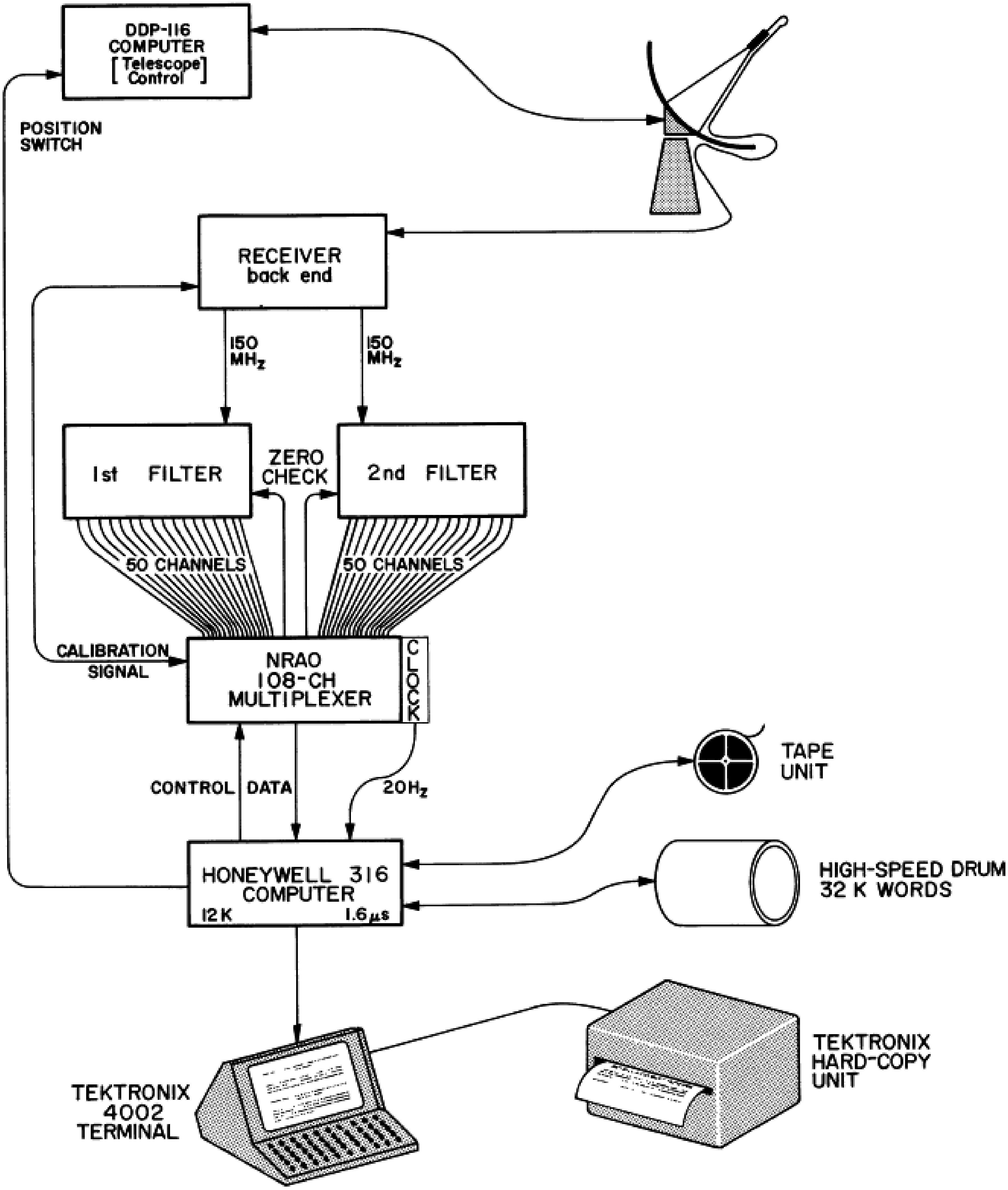
DDP-116
COMPUTER
[Telescope Control]
POSITION
SWITCH
RECEIVER
back end
150
MHz
150
MHz
1st FILTER
ZERO
CHECK
2nd FILTER
50 CHANNELS
50 CHANNELS
CALIBRATION
SIGNAL
NRAO
108-CH
MULTIPLEXER
CLOCK
CONTROL
DATA
20Hz
TAPE
UNIT
HONEYWELL 316
COMPUTER
12K
1.6μs
HIGH-SPEED DRUM
32 K WORDS
TEKTRONIX
4002
TERMINAL
TEKTRONIX
HARD-COPY
UNIT

Figure 1

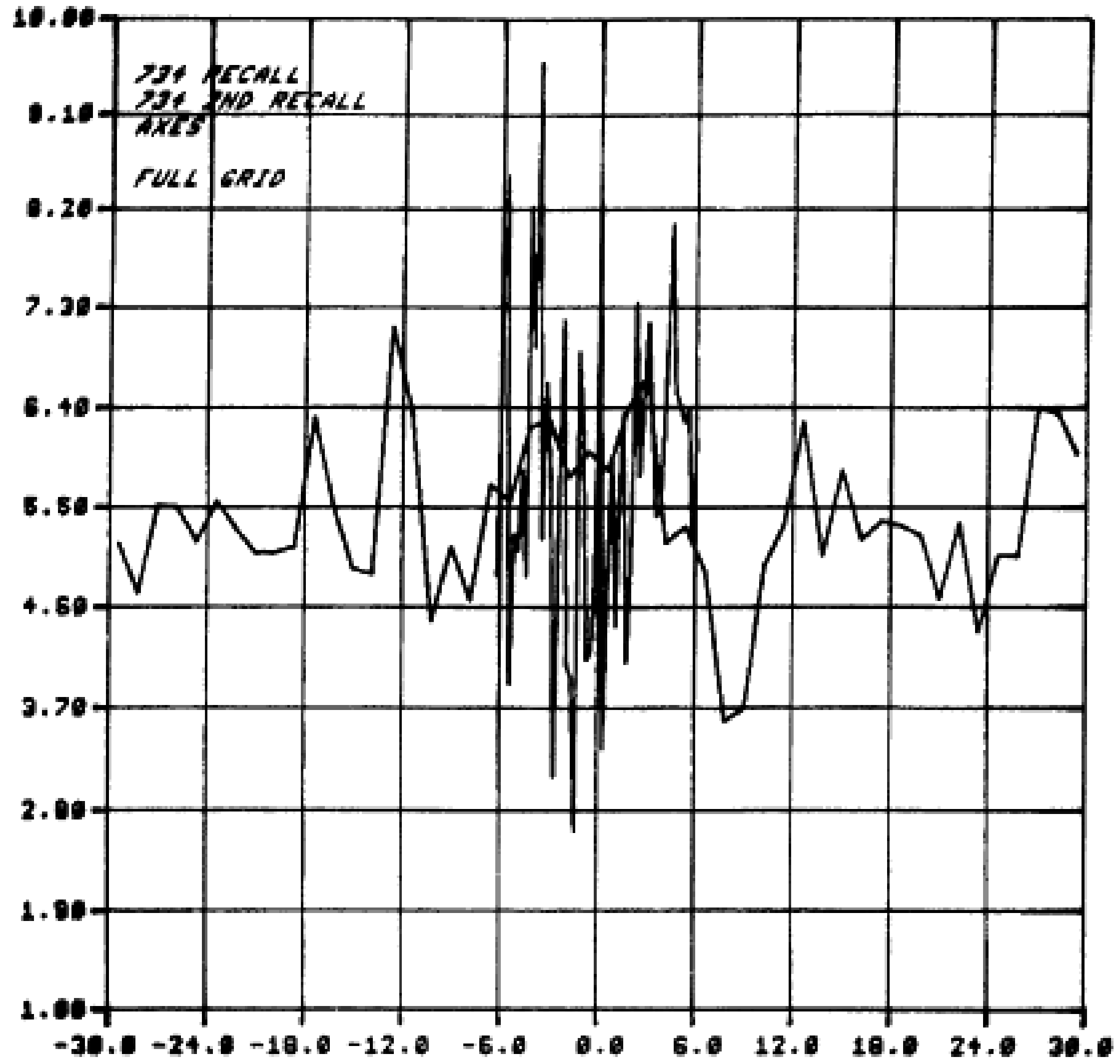

Figure 2

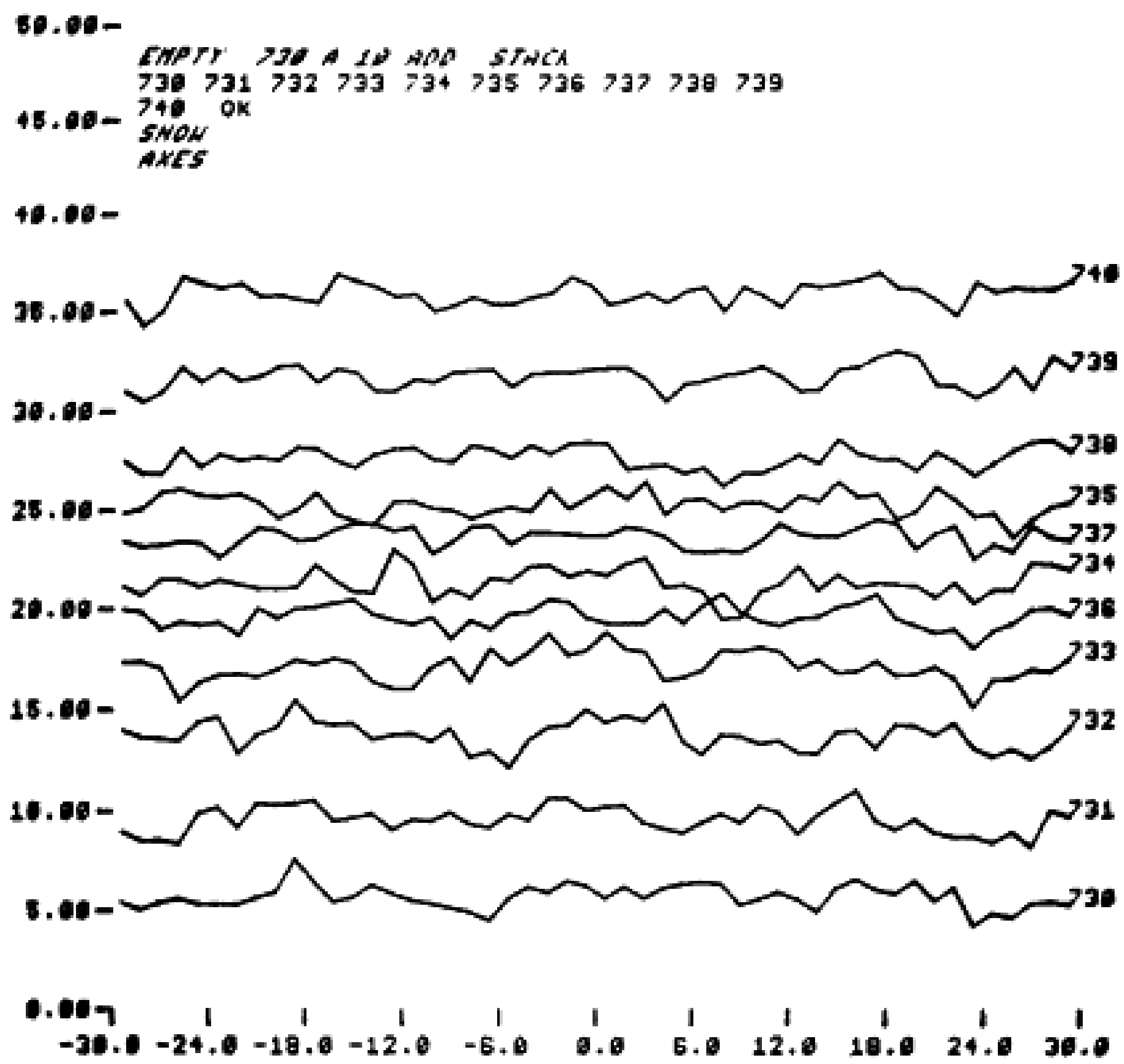

Figure 3

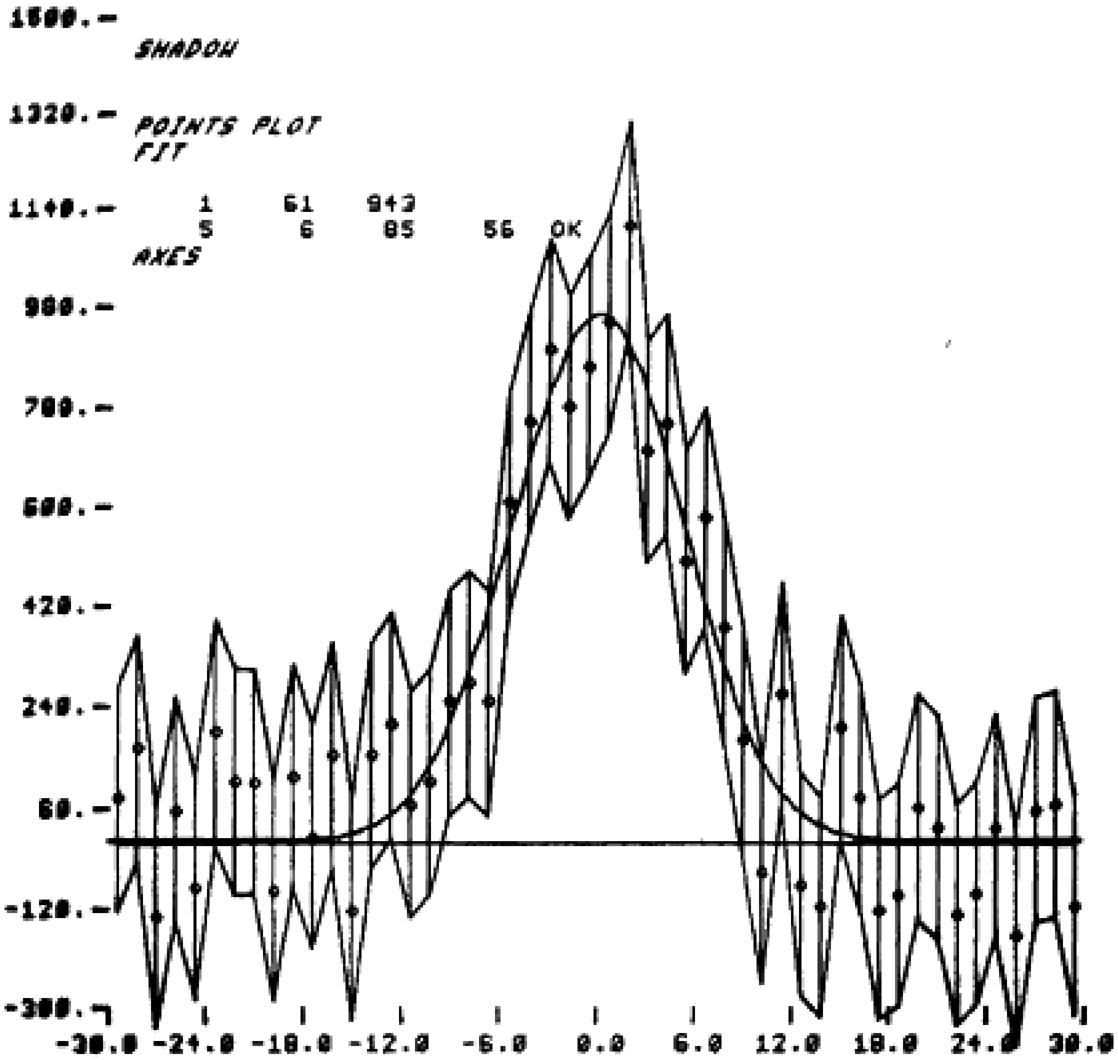

Figure 4

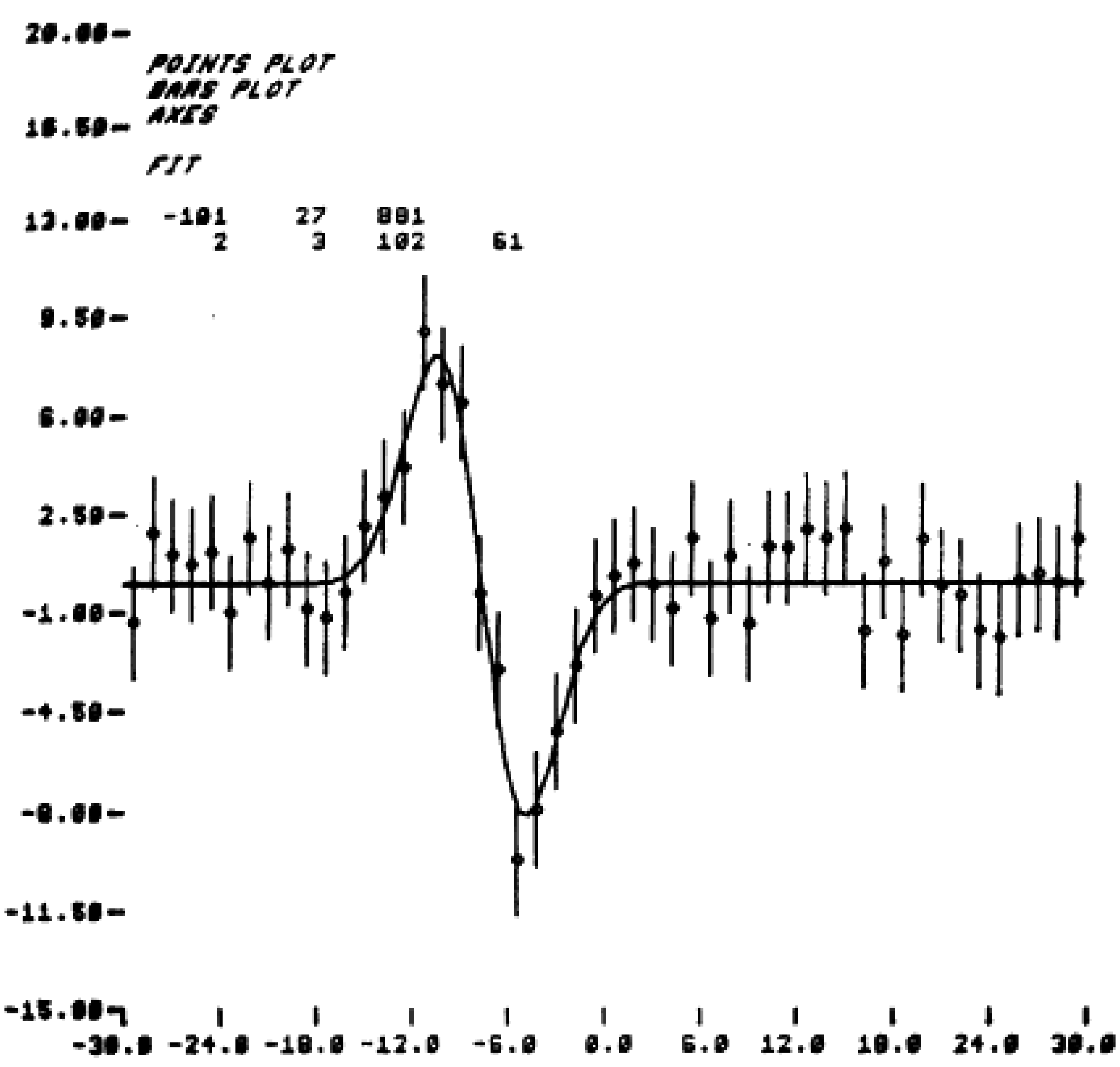

Figure 5

```
: SPLOT   POINTS PLOT  SHADOW  AXES  PRINT ; OK
SPLOT
```

0.87	0.51	0.67	0.97	1.02
1.16	0.85	1.18	1.16	1.58
1.46	1.34	1.23	1.02	1.11
1.14	0.75	0.94	0.82	1.00
0.90	1.35	1.72	1.64	1.64
1.55	1.49	1.42	0.98	0.86
1.00	0.93	0.90	1.08	1.10
1.07	0.93	1.56	1.57	1.50
1.19	1.11	0.93	0.91	0.12
0.51	0.64	0.96	1.34	1.31

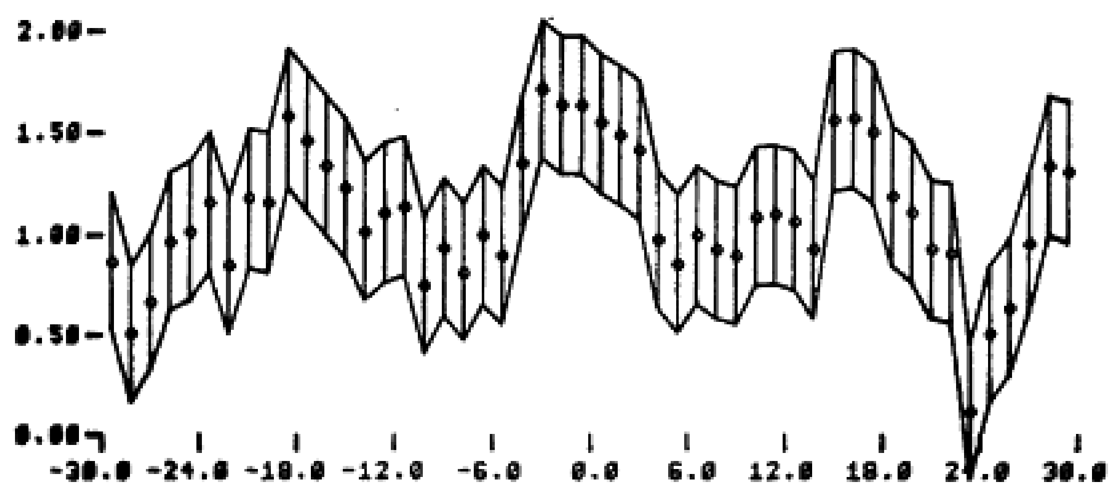

Figure 6

```
PARAMETERS: 100 CHANNELS. 50 FIRST 50 SECOND
TC = 0 K (CALIBRATION TEMP., SSB)
TS = 4000 K (SYSTEM TEMPERATURE., SSB)
1ST BANDWIDTH 1.200 MHz
2ND           0.250
VEL = 0.0 Km/S (SOURCE VELOCITY)
SEC = 30   DUR = 30 PAUSE = 6 (SECONDS)
1 ON-OFF = 10 REPEATS. OR 12:00 TOTAL TIME
NEXT HEADER NO. = 400

31 MAY     0:00 UT  OK

1 NOV   20:33 UT! OK

100 TC !   10 DUR !   4 PAUSE !   1126 HEADER ! OK
```

Figure 7