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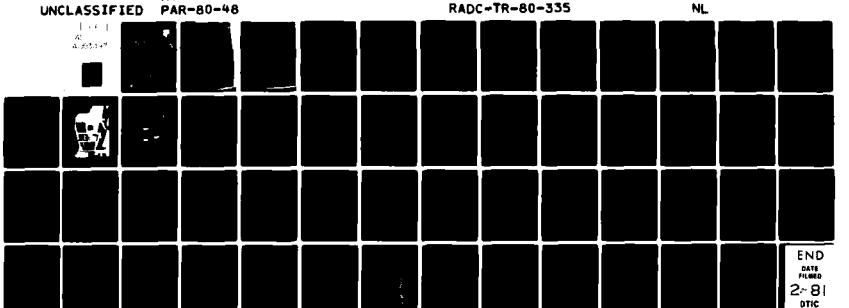

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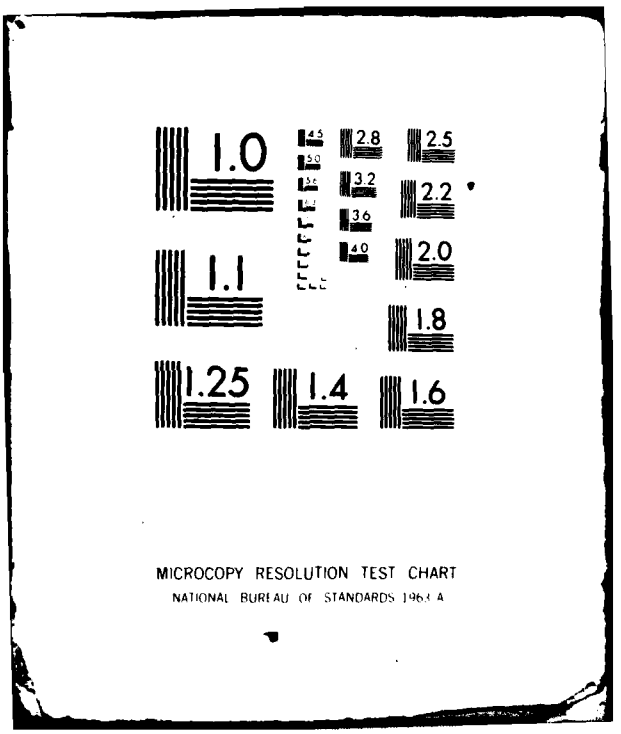
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Final Technical Report
November 1980

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SPECTRAL PROCESSING ANALYSIS SYSTEM (SPANS)

Pattern Analysis and Recognition Corporation

Robert E. Bozek

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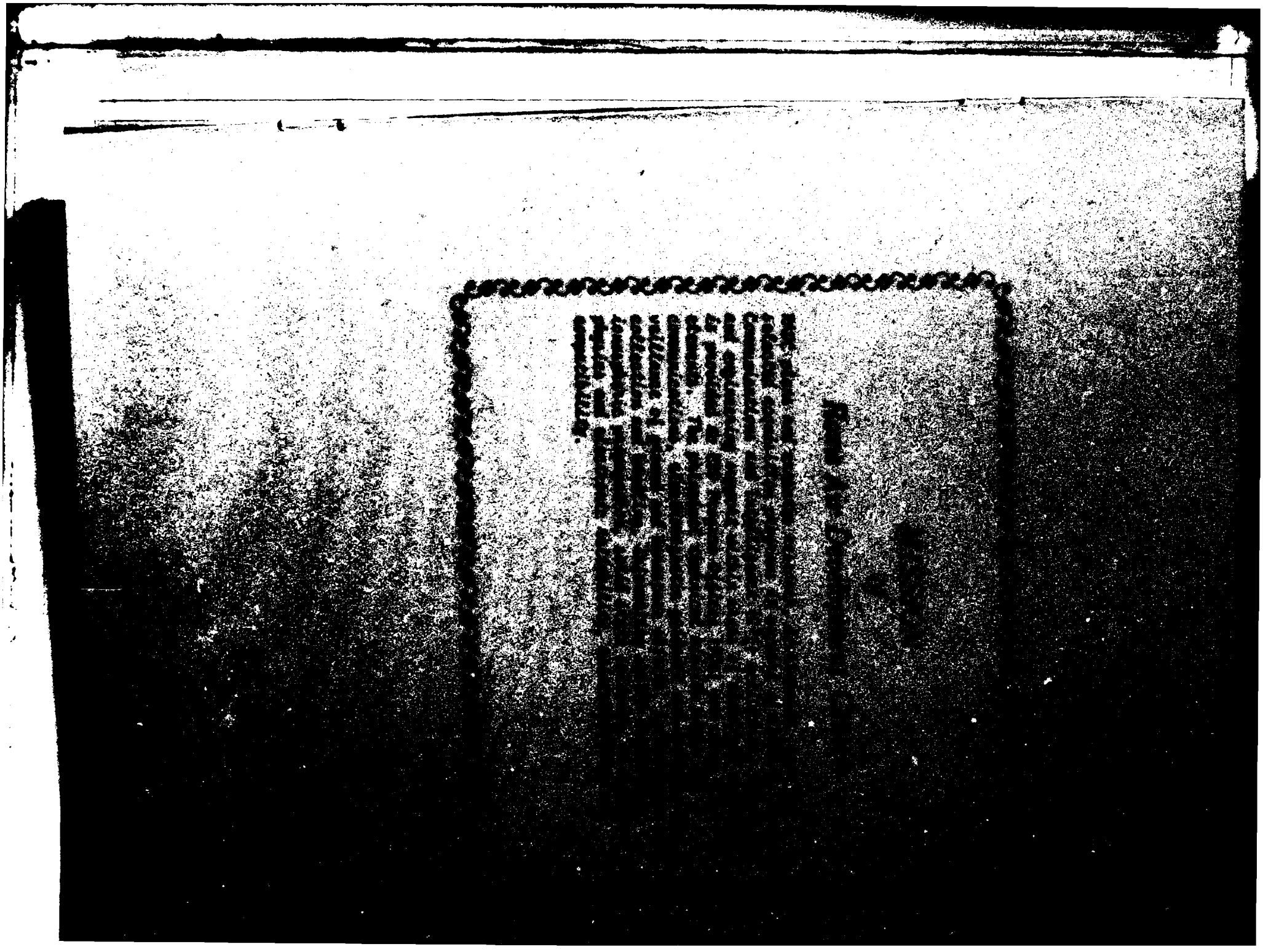

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This effort designed and developed a real-time on-line signal processing and analysis system. Capabilities include off-line/on-line signal processing to 100 KHz, time and frequency domain transformations, high speed and high resolution refresh graphics. This report is an introduction to the system's hardware and software capabilities.

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EVALUATION

Contract No.: F30602-79-C-0034, "Spectral Processing Analysis System (SPANS)

This contract was in support of TPO R1A, FTD Telemetry Intelligence Applications Support. FTD has the requirement to process large amounts of noisy data. This effort implemented a real-time, on-line signal processing system at FTD. Additional work is on-going and programmed to improve the system.

Melvin G Manor, Jr.

MELVIN G. MANOR, Jr.
Project Engineer

SECTION 1

INTRODUCTION

Under RADC Contract F30602-79-C-0034 Pattern Analysis and Recognition (PAR) Corporation has designed and developed a real-time Signal Processing and Analysis System (SPANS) for the Foreign Technology Division (FTD) of the Air Force located at Wright Patterson Air Force Base in Dayton, Ohio. The objective of SPANS was to enhance existing signal processing capabilities at FTD.

Development of SPANS began in September 1978 with a set of system requirements termed the Statement of Work (SOW) being provided to PAR by RADC. The requirements were reviewed and the design of SPANS began. State-of-the-art digital processing equipment was purchased and configured into four racks of equipment and real-time software developed. The system software was developed to provide sophisticated waveform and spectral displays as well as an efficient means of making frequency and amplitude measurements. The effort culminated in June of 1980 with the successful installation of SPANS at FTD. Basic SPANS capabilities are listed in Table 1-1.

This report represents the final technical report delivered on the SPANS effort and is meant to be an introduction to the SPANS hardware and software capabilities. Detailed descriptions of SPANS can be found in the several reports generated during the effort.

On-Line/Off-Line Signal Processing to 100 KHz

An Off-Line Mode for Detailed Analysis

Time and Frequency Domain Transformations

High Resolution Refresh Graphics

On-Line and Off-Line Audio Monitoring

Automatic Control of Analog Recorder

Table 1-1 SPANS Capabilities

In Section 2 of this report a description of the SPANS hardware and software configuration is given. In Section 3 SPANS display capabilities are introduced. Finally, in Section 4 the reader is introduced to the various reports written during the course of the SPANS effort which contain more detailed information concerning SPANS that may not appear in this document.

SECTION 2

FUNCTIONAL DESCRIPTION OF SPANS

In this section is described the hardware and software which comprises the SPANS system. First we take a look at the hardware configuration in Section 2.1. and then discuss SPANS software in Section 2.2. Table 2-1 summarizes both hardware and software system parameters.

2.1. SPANS HARDWARE DESCRIPTION

Figure 2-1 is a photograph of the SPANS system. SPANS consists of four racks of analog and digital processing equipment, a disk and computer terminal. The entire configuration runs off a 3-phase, 5 wire power source. As indicated in Figure 2-2, the SPANS hardware can be logically divided into the following functional units:

- o System Control
- o Analog Preprocessing
- o Data Processing
- o Display Generation.

These functional units will now be described.

1. Basic Display Options

Wave	-	Input data after digitizing in time domain
Power	-	Power spectra in linear or log display
FFT	-	Fast Fourier Transform
Auto	-	Autocorrelation
Histogr	-	Histogram display of amplitude levels

2. Input impedence - of patch panel - 50 ohm

3. Maximum A-D input - 20v p-p 1KHz - 100KHz single channel

Overall:	L. 11' W. 4' H. 6'
Cubic Feet:	130
Weight:	Approximately 750 pounds
Temperature Range:	60 - 80 degrees Farenheit
Humidity:	40 - 70 percent (relative)
Duty Cycle:	Continuous
Power Requirements:	5 wire, 3 phase, 30 amp/phase
	voltage - 115-125 V.A.C. 60 Hz $\pm$ 5%
	current - peak 76 amps, continuous 46 amps
	power - 5344 Watts
	Phase balance < 15%

Table 2-1 SPANS System Parameters

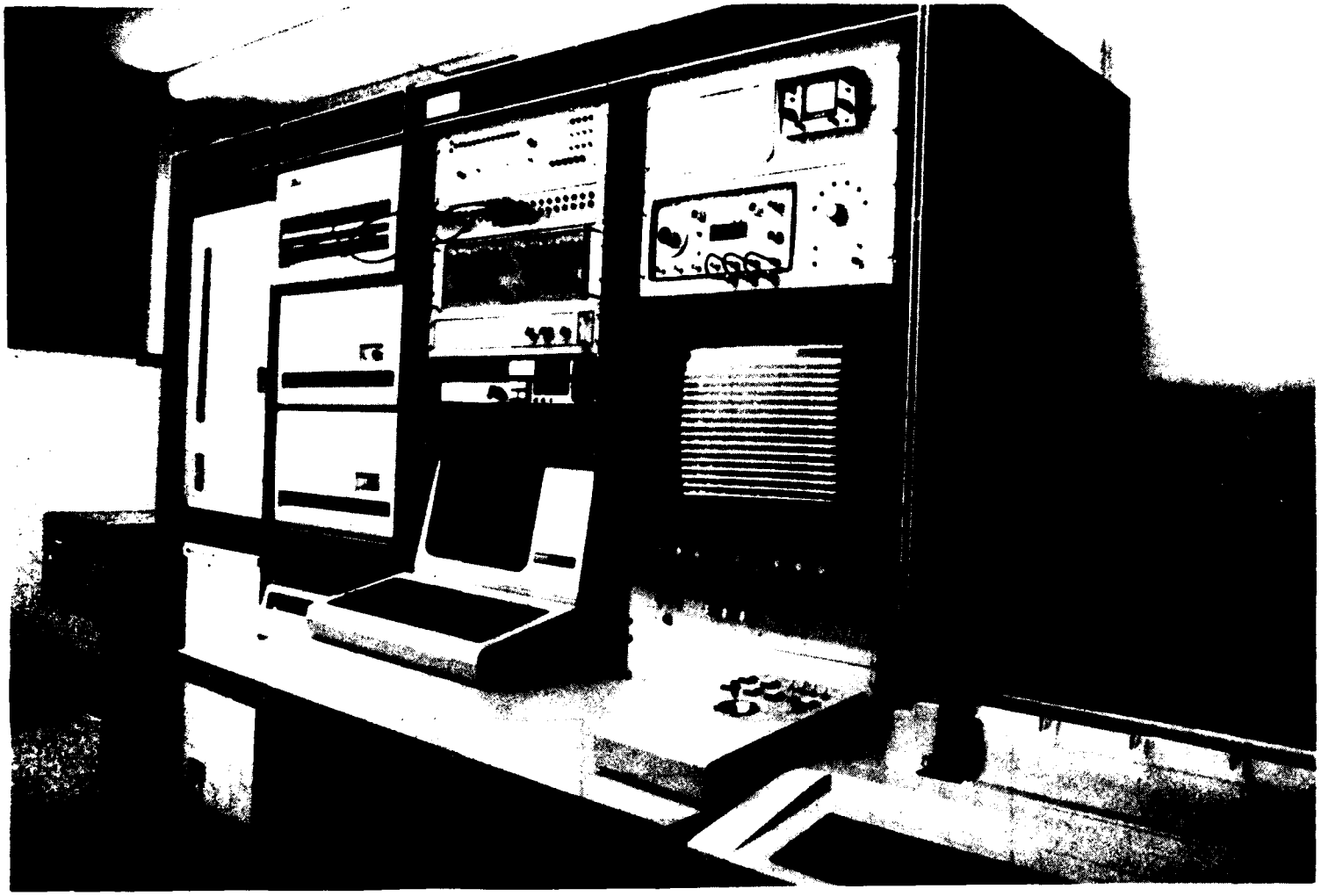


Figure 2-1 Photograph Showing Equipment Configuration

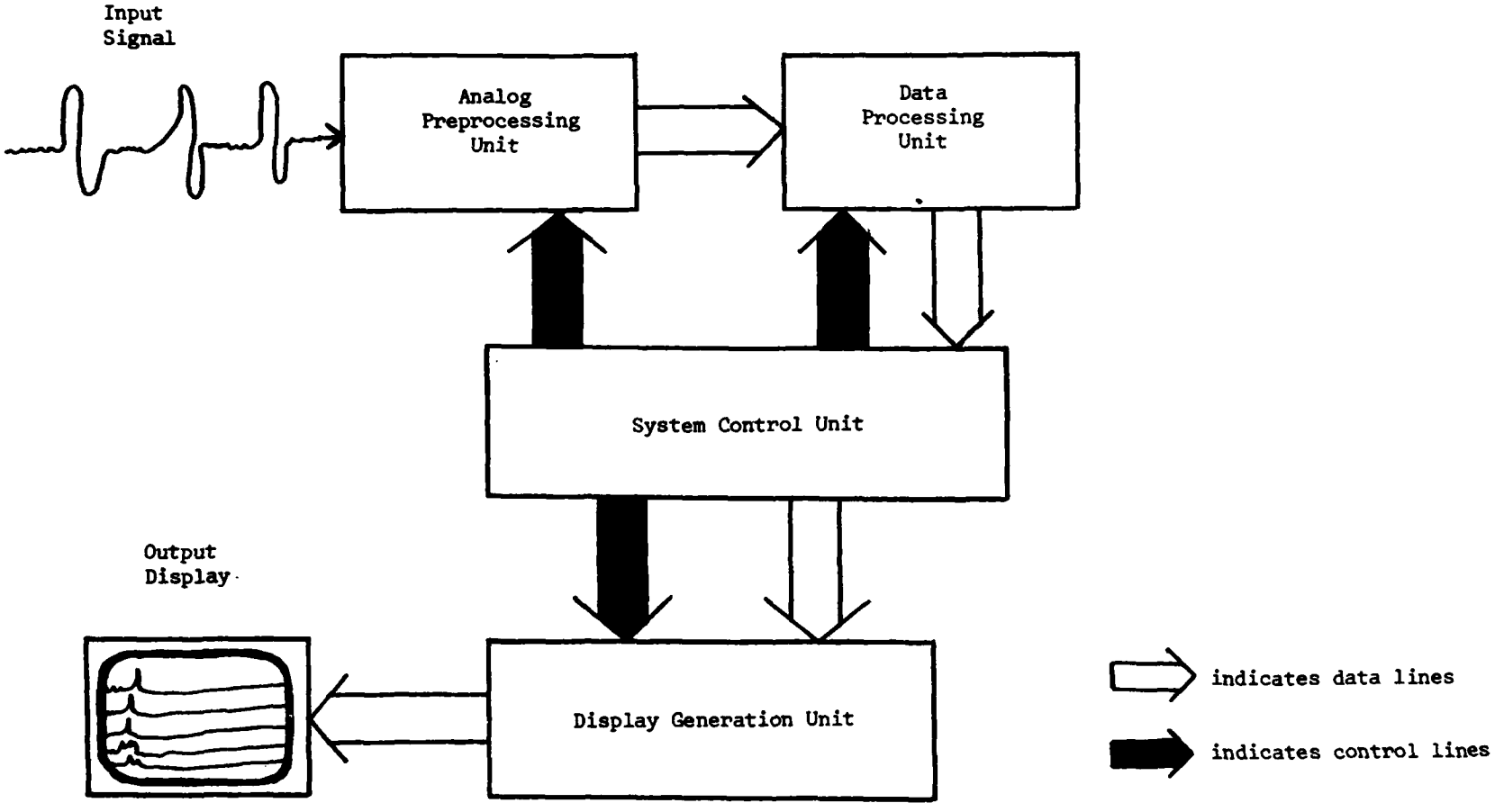


Figure 2-2 Functional Block Diagram of SPANS

System Control Unit

System control is provided by operator interaction with a Digital Equipment Corporation PDP-11/34 minicomputer. In addition to the 11/34 computer, this unit encompasses a VT-100 CRT which is the prime method of communication between the operator and the SPANS program, a LA36 Decwriter II terminal currently being used as a backup device, and two RL01 cartridge disk drives for program storage. The PDP-11/34 contains 32,768 words of fast MOS memory. Operator commands input on the VT-100 CRT are interpreted by software in the 11/34. The 11/34 then loads the appropriate software into memory and the appropriate action is taken.

Analog Preprocessing Unit

Input to the system is made via the Analog Preprocessing Unit which is comprised of a Trompeter 40 jack patch panel, Krohn Hite Model 3323 variable electronic filter, Preston XWB 8300 wideband adjustable amplifier, a 15 bit Preston GMAD1 analog-to-digital converter, signal monitors and digitizer clock control.

The analog time varying signal is patched to the filter to band limit signal frequency content prior to digitizing. The signal is band-limited to less than one half of the sample frequency to prevent the phenomenon termed in the literature as "aliasing." Aliasing comes about

when signal frequencies greater than one half the sample rate are digitized. These undersampled signals then take on the identity of lower frequency signals and thus the term "aliasing."

The output of the filter is then amplified by the Preston amplifier to match the signal level to the input range of the digitizer thus making use of the total dynamic range provided by the 15 bit converter.

Signal level monitoring is made possible by both a MINI oscilloscope and over and under voltage LED indicators.

Sampling rate is set in one of two ways. The first involves setting up the dials on a Wavetek frequency synthesizer. The other method is by inputting a reference signal into a clocking circuit developed by PAR. The circuit provides the capability of multiplying up the frequency of the reference by 1, 2, 4, 8, or 16 times and phase-locking the resulting output signal to the input reference signal. This latter method of digitizer clock generation is used when processing analog tapes on which a reference track has been recorded. By slaving the digitizing speed to the recorded reference, compensation is made for wow and flutter effects associated with tape recorder speed fluctuations.

In addition, the capability for audio monitoring of the input signal is provided by a Realistic audio amplifier, speaker/headphone combination and a DEC AA11-K 4 channel digital-to-analog converter which is necessary for monitoring data previously stored on disk.

Automatic control of an analog recorder is made possible by a Systron Donner 8154 tape reader/generator/search and control unit. This unit is used to automatically locate events of interest on analog tape on which a time code reference has been previously recorded. Time code format may be either 200 Hz or 1 KHz in the XR3 format.

Data Processing Unit

The data processing unit consists of a Floating Point System AP-120B array processor, interface to the Preston analog-to-digital converter, CDC disk drive and interface to the PDP-11/34 minicomputer. Program instructions for the AP-120B are loaded by the PDP-11/34. Typically, each new option selected by the operator initiates the loading of a new program into the program source memory of the AP.

In one mode of operation termed the on-line mode, the AP accepts data from the Preston analog-to-digital converter, performs various transformations on the data and transfers the resulting output data points to the PDP-11/34 minicomputer which passes the results to the

display generation unit. While data is being processed the raw data is also recorded on a mass storage device for subsequent off-line analysis.

In the off-line mode, data is input from disk storage and processed in a manner similar to that of the on-line mode.

The AP-120B contains 32K of fast 167 nanosecond main data memory, 1K of random access table memory, 1.5K of read only table memory, and 2K of program source memory. The arithmetic unit of the AP is essentially a pipeline processor. Multiplies and adds are performed simultaneously at up to 6 MHz rates. All computations are performed in 38 bit floating point for maximum accuracy.

Interface to the PDP-11/34 computer is through a standard host interface supplied by Floating Point Systems.

Direct interface to the analog-to-digital converter was made possible by use of the IOP16 digital I/O port provided as an option by FPS and control logic developed by PAR Corp.

The CDC disk drive is also interfaced directly to the AP. This was made possible by use of a Programmable Input Output Processor (PIOP) provided by FPS. The PIOP is actually a microprocessor which handles all protocol between the two devices.

The CDC disk drive has a 80 megabyte storage capacity. The disk controller was developed by Systems Industries Corp. In addition to providing control from the AP, the controller is also connected to the PDP-11/34. However, this link was not utilized for the SPANS development effort.

Display Generation Unit

The display generation unit consists of a Grinnell System GMR27 display controller, a CONRAC QQA17 high resolution black and white raster display monitor, a joystick cursor control unit, interface to the DEC PDP-11/34 computer, and hardcopy device.

Functionally, the Grinnell display controller accepts graphics commands from the PDP-11/34 and provides a video input signal to the CONRAC monitor. The Grinnell display controller contains two 1024 x 1024 bit memory planes. One is used for graphics and one for annotation.

Interface to the 11/34 is through a DEC DR11B direct memory access interface.

The video output (RS170) of the Grinnell is daisy chained through the CONRAC monitor and a Tektronix 4632 video hardcopy device. By pressing a button on the hardcopy device, any display on the CONRAC may be hardcopied in seconds.

A joystick cursor control unit works in conjunction with the Grinnell display control to provide x-y input to the 11/34 computer for frequency and amplitude measurements.

2.2. SPANS SOFTWARE DESCRIPTION

Software developed under the SPANS effort exists in five programming languages:

- o FORTRAN IV
- o PDP-11 ASSEMBLY
- o AP-120B ASSEMBLY
- o AP VECTOR FUNCTION CHAINER
- o PIOP ASSEMBLY.

The variety of programming languages was necessitated by the complexity of the hardware which involved three processors, the PDP-11, AP-120B array processor and PIOP microprocessor which communicates with the CDC disk drive.

The SPANS mainline program which interprets user commands and loads programs into the appropriate processors is written in FORTRAN IV for ease of maintenance and modification. PDP-11 assembly language was used as required for input/output communication with the various devices. Programs for the AP-120B exist in AP-120B assembly language

and a higher level compiler known as the Vector Function Chainer (VFC). Most application programs were written using VFC which "chains" together several subroutine calls from a library of subroutines into a single subroutine call. This has the effect of minimizing overhead since each subroutine call takes a fixed amount of processing time in communicating between the AP-120B and the PDP-11/34. AP assembly was used to develop new library functions which were not available in the standard math library which is provided by FPS with purchase of a AP-120B. PIOP assembler was used to program the microprocessor to control the disk drive. Modifications were necessary to the standard PIOP software provided by FPS.

The SPANS software runs under DEC's RT11 version 3B single job monitor. RT11 was chosen over DEC's other operating systems because of the low overhead of the RT11 which provides increased throughput over an operating system such as RSX-11M.

Software is "overlayed" since no one program can exceed 32K of memory including the operating system.

Operation of the SPANS software is similar to that of standard DEC commands. The user enters a command and one or more switch options. For example, if one types:

RUN SPANS

the software responds with the following:

SPANS>

which signifies that SPANS is awaiting a command. The user might then type:

POW /LIN:90/HAN/-AV

to get a power spectrum display with 90 lines displayed, a hanning weighting and turn off ("-") the average function. These "switches" following the command are the manner in which optional parameters are specified or turned off. Default values are maintained for all switch options so that no command is ever erroneously executed without required parameter settings specified.

Tables of legal commands and switches are maintained in tables in the SPANS mainline program. Then tables are easily modified or extended to permit the addition of new commands with a minimum of effort.

SPANS software also provides for error checking and reporting. Errors such as illegal commands and options as well as hardware malfunctions are detected by the software to elliminate uncontrolled system "crashes."

SECTION 3

SPANS DISPLAY CAPABILITIES

In this section we describe the various display options which are available to the SPANS analyst. First we will describe the individual commands and then describe a typical scenario which will demonstrate the power of the SPANS system.

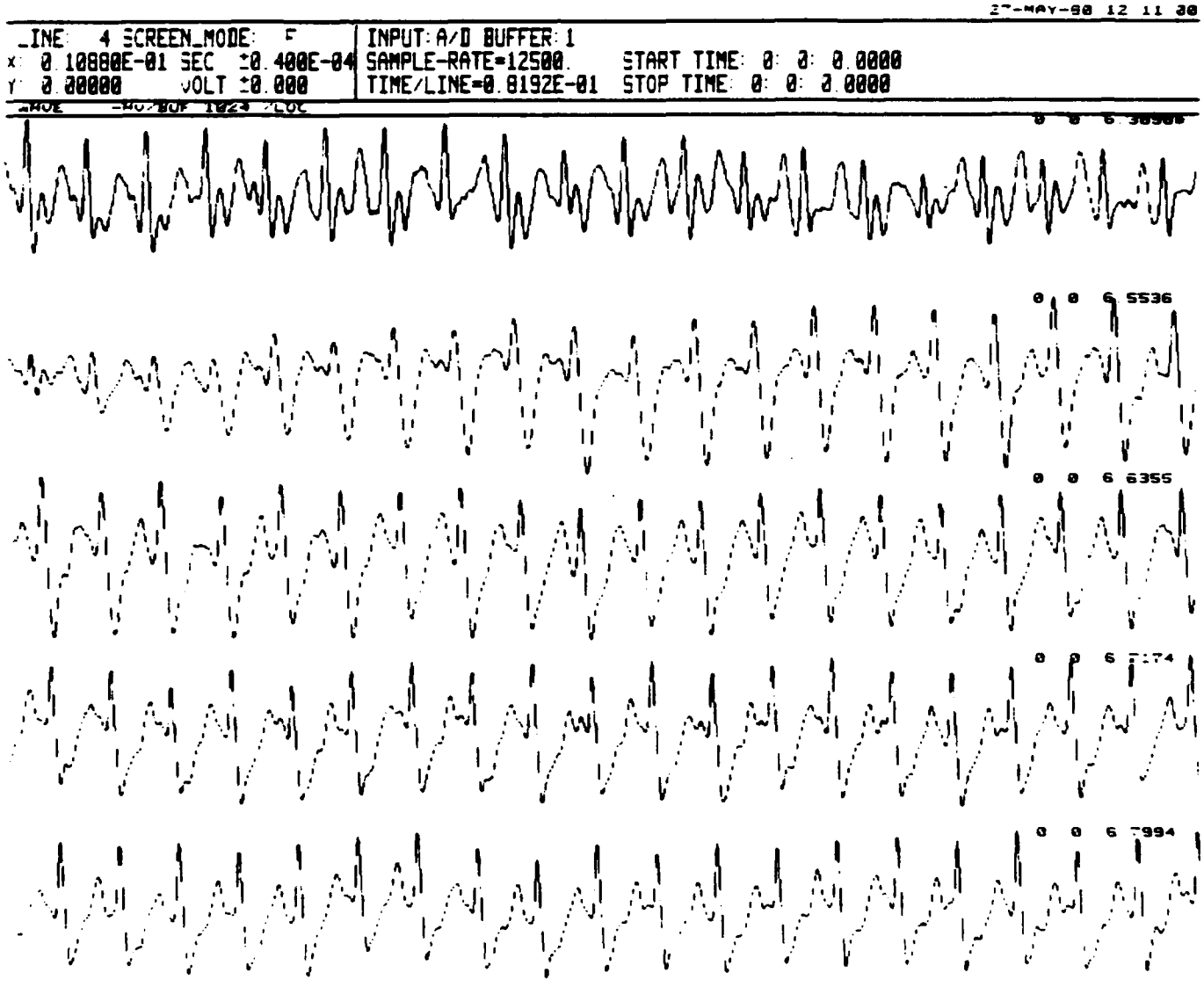
3.1. SPANS COMMANDS

The following is a description of the SPANS commands. As mentioned in a previous section, the system has two modes of operation, on-line and off-line. When on-line and a display command is selected, digitizing to disk and display of data occur simultaneously. In the off-line mode data to be displayed is read from disk storage. All commands may be selected by typing the first three characters of the command on the operator console.

WAVE

This command provides the user with a time domain or waveform display on the CONRAC monitor. Switch options include the ability to select the number of waveforms displayed per display frame, local or absolute scaling, number of display points per line and waveform averaging. A typical display is shown in Figure 3-1.

Figure 3-1 Waveform Display



POWER

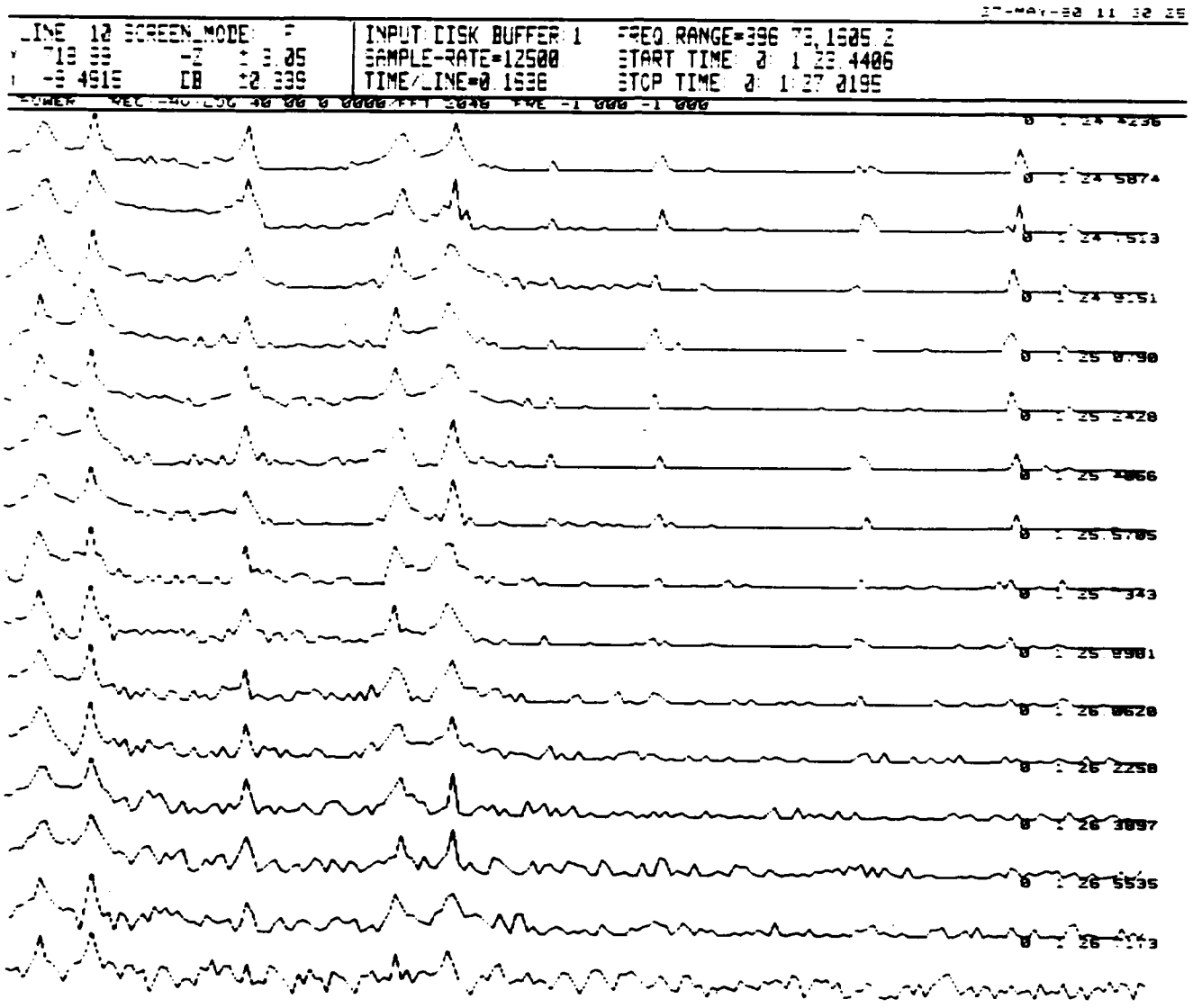
This command provides the user with a frequency domain or power spectrum display on the CONRAC monitor. Sampled time waveforms are transformed into the frequency domain using the Fast Fourier Transform (FFT) algorithm. The power spectrum is then computed as the magnitude squared of the complex FFT output. The display then is power versus frequency. An excellent discussion on the FFT can be found in [1]. This paper also touches on some of the problems associated with digital spectral analysis such as "aliasing".

Options include the ability to change the number of spectra displayed in one frame, the size of the FFT, the number of spectra to average, display scale and frequency range displayed. Windowing options include rectangular or the Hanning window. The Hanning window is used to suppress sidelobes in the vicinity of strong spectral lines at the expense of increased mainlobe width. A tutorial on windowing techniques can be found in [2]. In this paper the need for windows is made clear and several window types are compared. A sample spectrum display is shown in Figure 3-2.

FFT

The FFT option provides the user with a frequency domain display on the CONRAC. However, unlike the Power spectrum option described above,

Figure 3-2 Power Spectrum Display



the output of the FFT algorithm itself and not the magnitude squared function is displayed. Options include the ability to change the number of spectra displayed and the FFT size. The operator must also choose to display either the real part or imaginary component of the FFT. Hanning weighting is also available with this option.

AUTO

This command provides the user with an autocorrelation display where the vertical axis corresponds to the degree of correlation and the horizontal axis corresponds to a time delay or lag. The autocorrelation function is most often used in the computation of the power spectrum since the power spectrum is defined as the fourier transform of the autocorrelation function. It is a measure of the similarity or coherence between a signal and a delayed replica of the signal.

The autocorrelation function can be used to identify periodicities in the data. For example, for a sine wave input, the autocorrelation would also be repetitive showing a high degree of correlation at lags equal to the period of the waveform. In the case of white noise, a high degree of correlation is found at zero lag only with the remaining lags showing little correlation. For a more detailed discussion of the autocorrelation function see for instance [3].

Available options include the ability to change the number of autocorrelation functions displayed, the number of lags displayed and the number of points of the input waveform to consider. A typical autocorrelation display is shown in Figure 3-3.

HISTOGR

This command provides the user with a time domain histogram of the input signal amplitude levels. The horizontal axis of the display represents amplitude levels or bins. The vertical axis corresponds to the number of samples which fall into each amplitude bin. A histogram is most often used to estimate the amplitude distribution of an input waveform. When computed continuously at fixed intervals in time, the histogram is a good way of locating high amplitude events or identify saturation of a signal in an analog-to-digital converter.

Options include the ability to change the number of histograms displayed, the number of bins displayed, the range of the histogram, the number of waveform samples to be considered for each histogram calculated and the vertical scale of the histogram. A sample histogram display is shown in Figure 3-4.

DIGITIZE

The Digitize command provides the capability to digitize signals on-line without presenting a display on the CONRAC monitor. Input data samples are stored in a disk file designated by the SPANS operator.

Figure 3-3 Autocorrelation Display

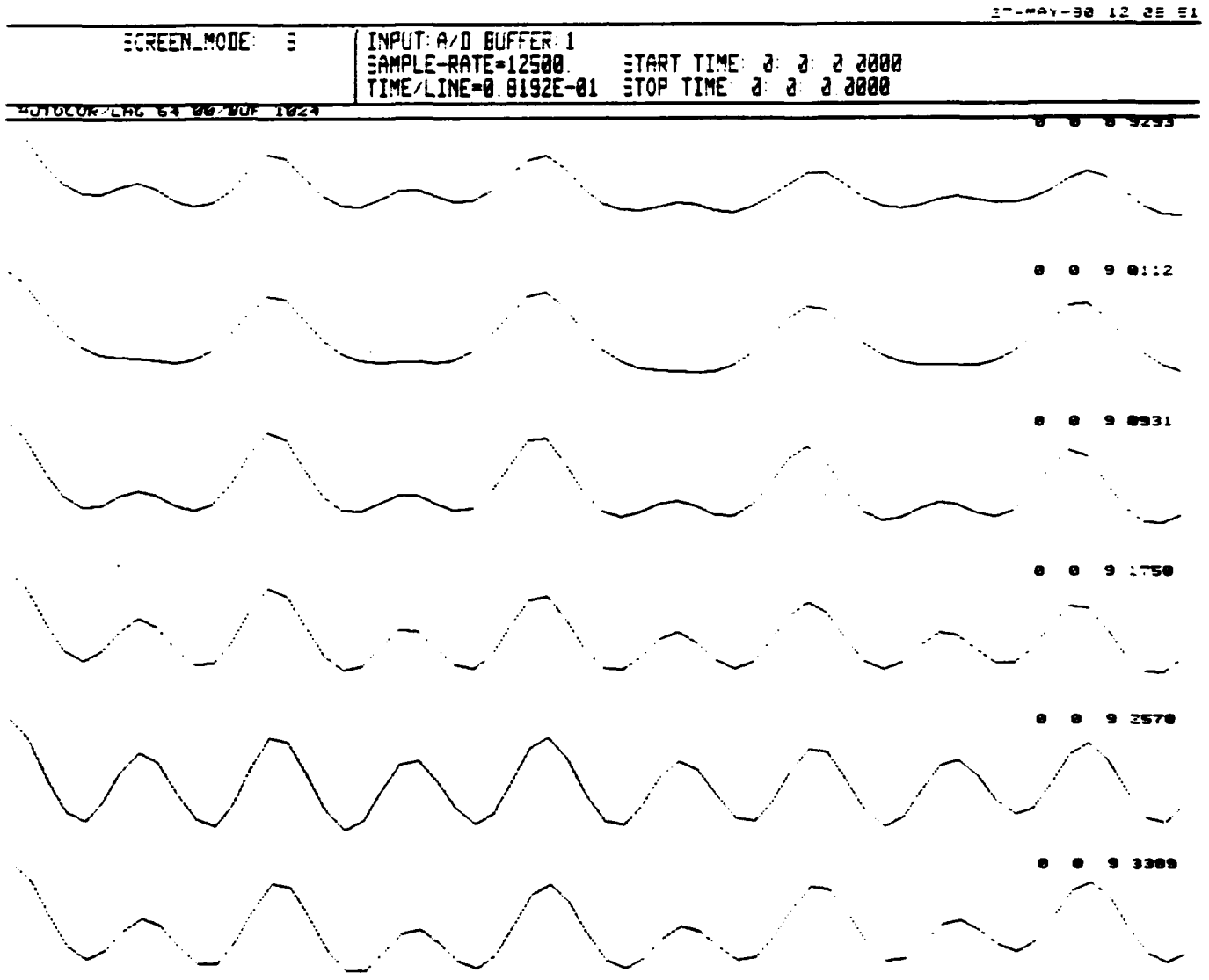
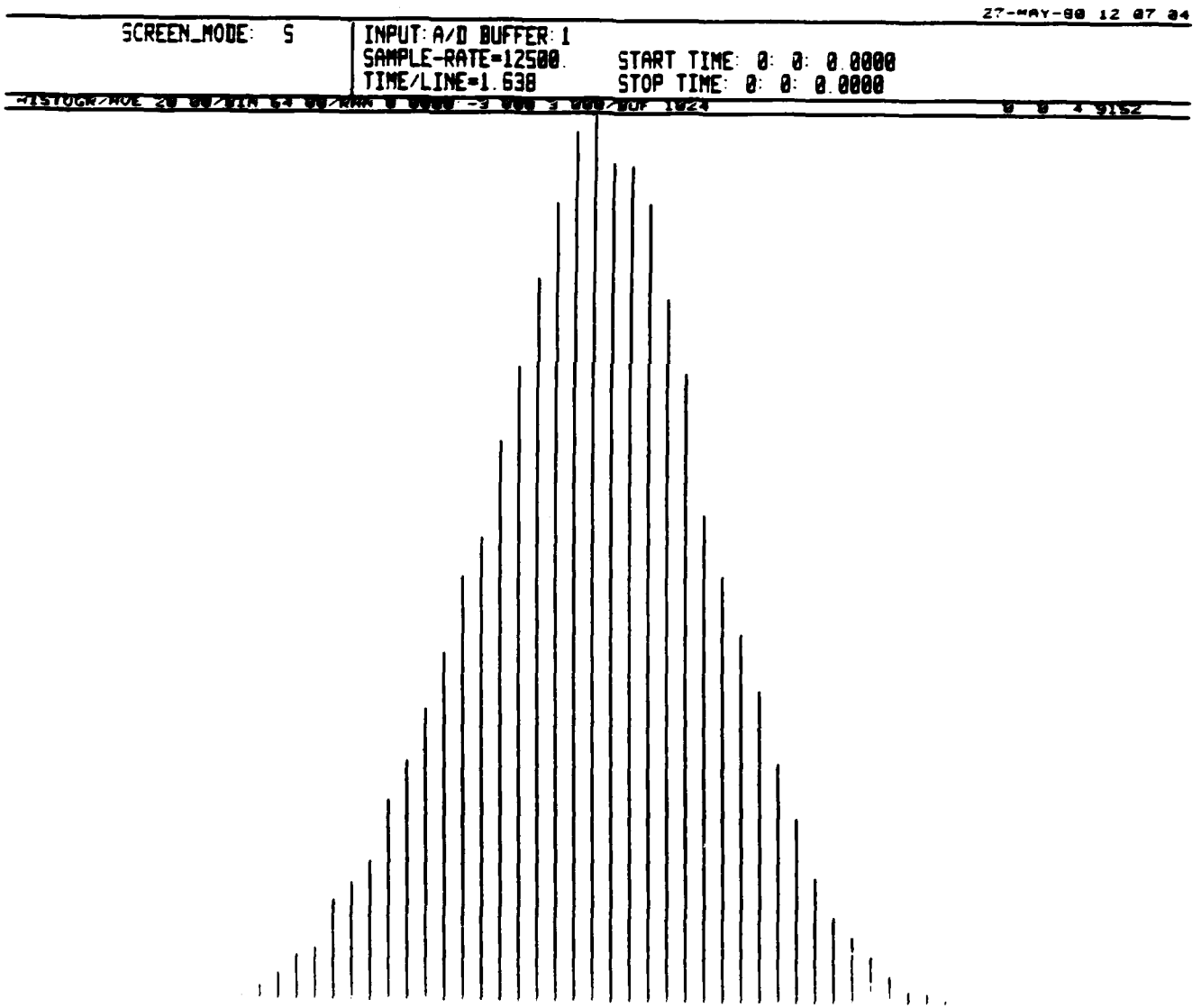


Figure 3-4 Histogram Display



PLAY

When this command is selected, digital data previously stored on disk is output to a digital-to-analog converter to recreate the analog input signal. This allows the operator to listen to waveforms which have been digitized. In the future this option may be selected to listen to processed data as well as the raw digital data. The operator can select the playback speed which can be different from the digitized speed and can also choose to repeat the sample n times.

SET

This is a utility command which is used to set system parameters without simultaneous display generation. In addition to switch options related to commands described above, there exists several additional switches which are useful for functions such as setting the position of the clock on the screen, purging disk files, changing default parameters and selecting display mode (e.g. dots or vectors). These switch options might normally be set with the SET command.

EXIT

This command is selected to exit from the SPANS software and return control to the RT11 monitor.

3.2. TYPICAL SPANS SCENARIO

This section is intended to give some insight into how SPANS can be used to solve a problem typical of that normally encountered by the FTD operator. An example is given in which a portion of an analog recording is input to SPANS on-line. While data is being input, a Power Spectrum is displayed. The SPANS operator is looking for spectral lines in a particular frequency band. When the line appears, the SPANS capabilities are exercised so that accurate measurements may be made on the signal of interest.

Assuming that the operator has powered up the system, booted the RT11 operating system and entered the correct data and time, he then runs the SPANS program with the following command:

"RUN SPANS"

SPANS then makes itself known by outputting the prompt:

"SPANS>"

to the VT-100 display. Assuming that input is to come from an analog tape, the operator must mount the tape on the recorder and patch in the data channel, time code channel and reference signal for the clock (if available). Signal levels should be adjusted so that the input to the ADC does not exceed $\pm$ 20 volts peak-to-peak.

The operator might then type in the following command:

"SET /SAM:12500/ONL:5/STA:0:3:5/STO:0:3:20/TS"

The "SET" command allows the operator to set up system parameters without actually executing a program. In this example, the "SAM" switch tells the system that a sample rate of 12,500 samples per second will be used for digitizing. It is important that this value agrees with the actual clock rate since the software has no other way of knowing what the clock was set to. If the value of "SAM" does not agree with the true clock rate, all frequency and time scales displayed will be in error. The next switch input "ONL:5" tells the system that we will be processing on-line and that data is to be recorded in disk buffer 5 (7 are available). The "STA" and "STO" switches define the start and stop times of the event to be processed (assuming time code has been recorded on tape). In the example, all data between 0 hour, 3 minutes and 5 seconds and 0 hour, 3 minutes and 20 seconds will be processed. The "TS" switch signifies that automatic control of the analog tape recorder is desired.

Processing and display is next initiated by the command:

"POW /LNE:0/-RE"

The "POW" command signifies that a power spectrum display is to be generated. The "LNE:0" switch is input to obtain a linear local line scaling thus overriding the default logarithm scaling option. The "-RE" switch is used since we will be exercising several power spectrum options. When this switch is used and the operator halts execution (with the ^F command) then control is not returned to the SPANS prompt but to the POW prompt. Thus the operator does not have to rerun the command "POW" on successive command lines; only the new switch options. Also, local switch options are not preserved if exit is made to the SPANS prompt. Once the command is executed, the analog tape recorder is automatically searched for the start time of 0:3:5. When the event is found, data is digitized and displayed in the form of a power spectrum on the CONRAC display. Default values for number of lines per display frame and FFT size are used since they were not specified in the "POW" command line. Figure 3-5 is a typical display.

The operator views the display on-line. When a spectral line appears as is shown in Figure 3-5, he may decide to freeze the display and measure the frequency of the line with the aid of the crosshair cursor. To freeze the display the operator types the "Control" and "F" keys simultaneously (^F). The display stops as does the analog recorder. The cursor is turned on and the vertical cursor is aligned with the spectra line of interest as shown in Figure 3-6. The frequency of the line as displayed in the upper left corner of the display is 2,978 Hz. Resolution is + or - 3 Hz.

Figure 3-5 Power Spectrum Display

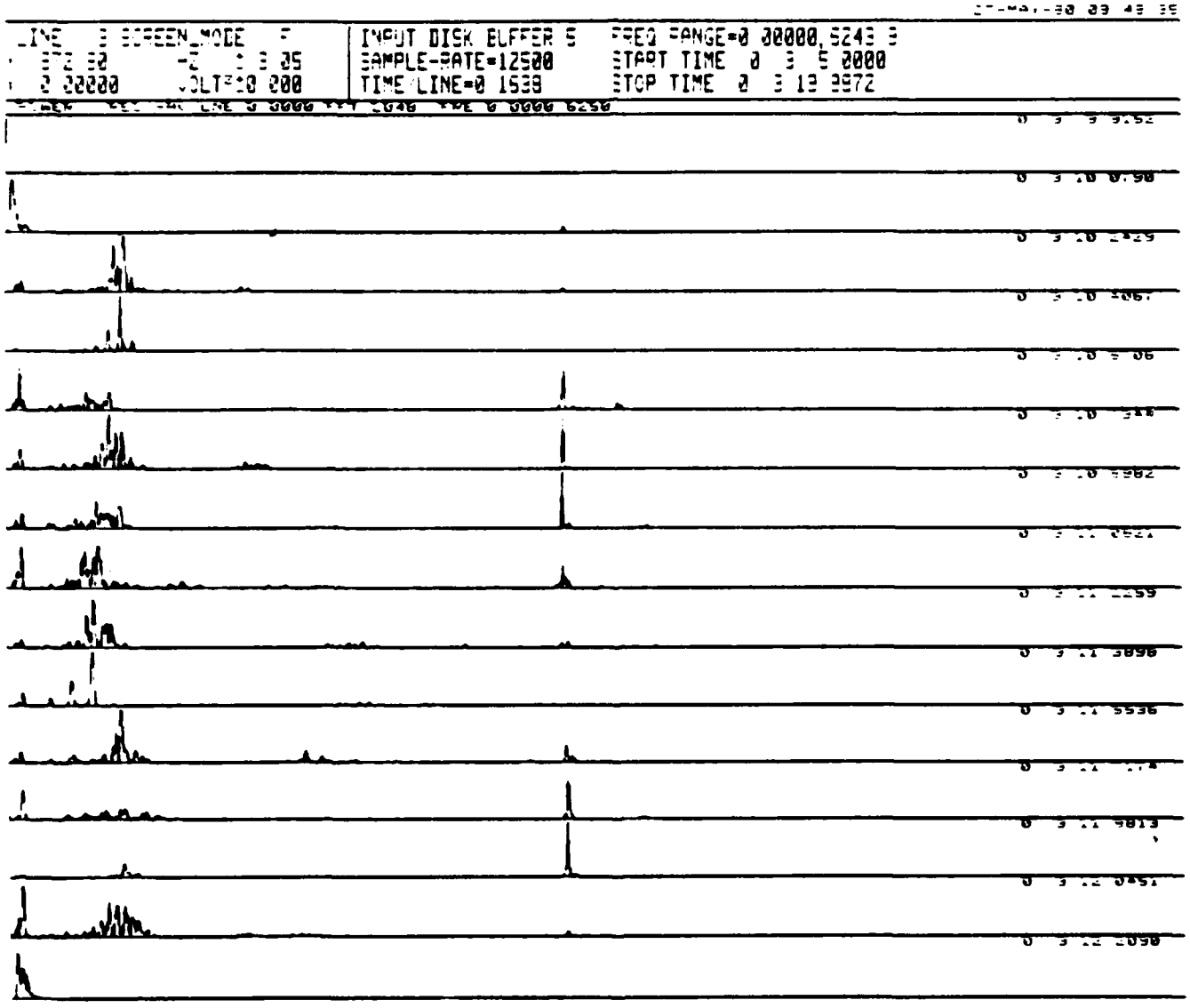
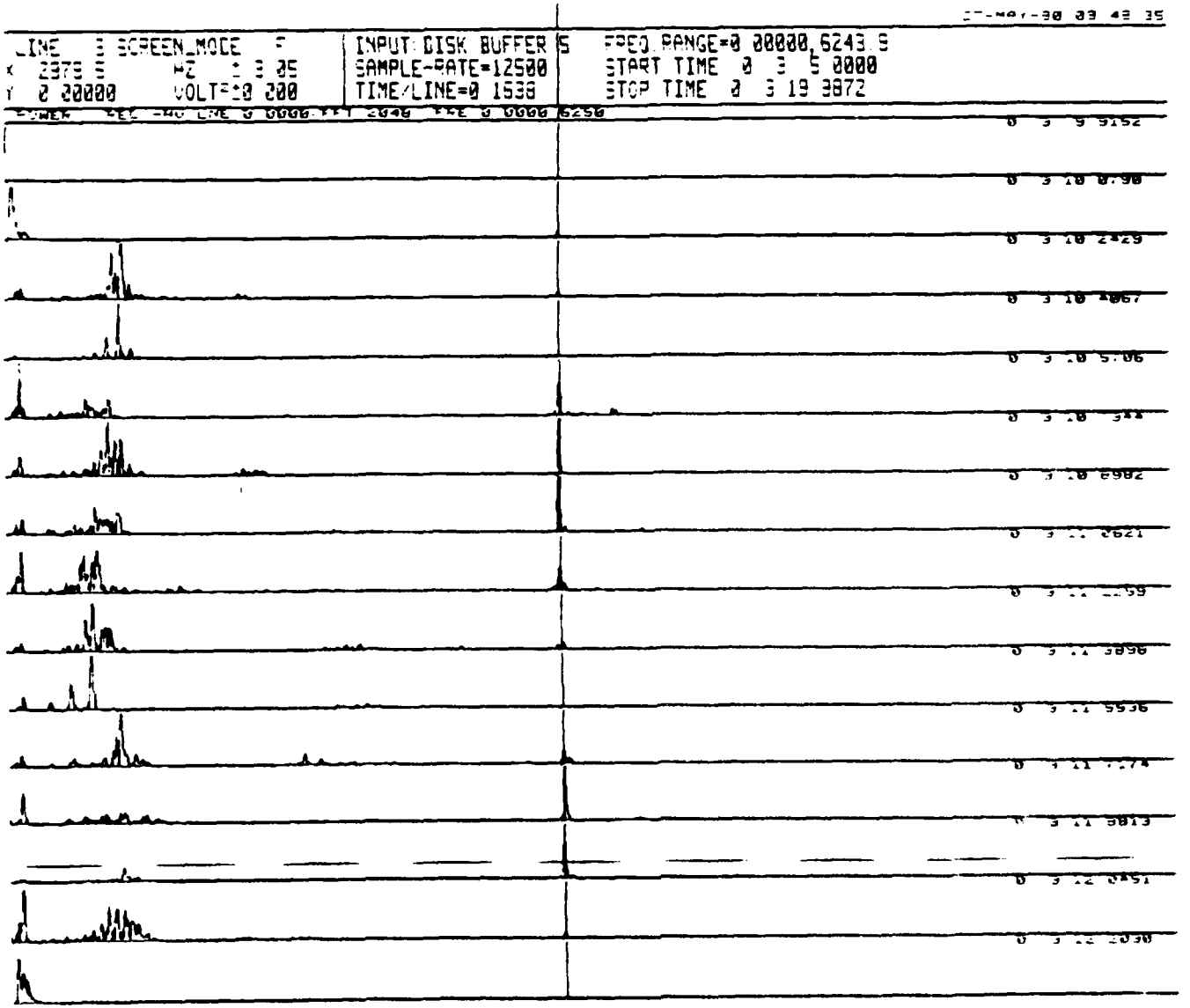


Figure 3-6 Making Frequency Measurement



The operator next decides to go off-line to process the segment of data containing the line in more detail. He types another ^F to get back to the "POW" prompt and then types the following:

"/OFF:5 /FRE:10:0"

The "OFF:5" switch tells SPANS that we wish to go off-line and process data in disk buffer 5. The "FRE" switch was used so that frequencies less than 10 Hz would not be displayed. This was used because a strong DC component was interfering with the display scale. In this example the operator wants to review all data in disk file number 5 and mark the start and end times of the spectral line with the cursor. He could accomplish this task just as easily by changing the start and stop times with the "STA" and "STO" commands respectively.

Display of the data then takes place. This time when the line appears, the operator types a "^E" to freeze the display, aligns the horizontal cursor with the start line of the event, the vertical cursor to the left of the line and types an "L" (see Figure 3-7). This marks the begin time and frequency of the lines. Once "L" is entered, the display then continues to scroll up as shown in Figure 3-8. The operator detects the end of the event at time 0:3:12.2090 and types a "^E" to again stop the display. He then realigns the cursor to mark the end time and end frequency and then types an "L" to record the cursor position. Start and end times and frequencies are now remembered by SPANS.

Figure 3-7 Marking Begin Time and Frequency

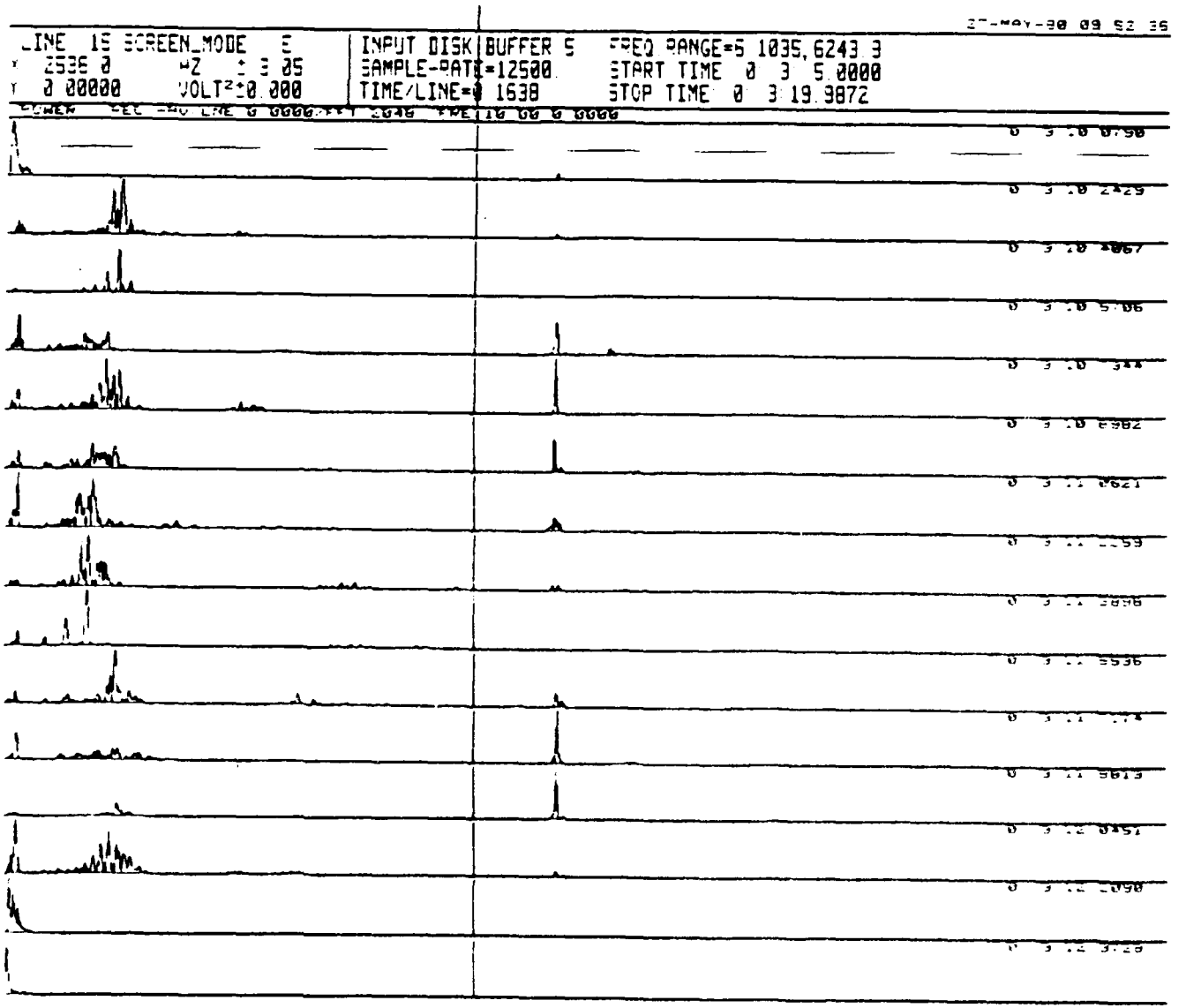
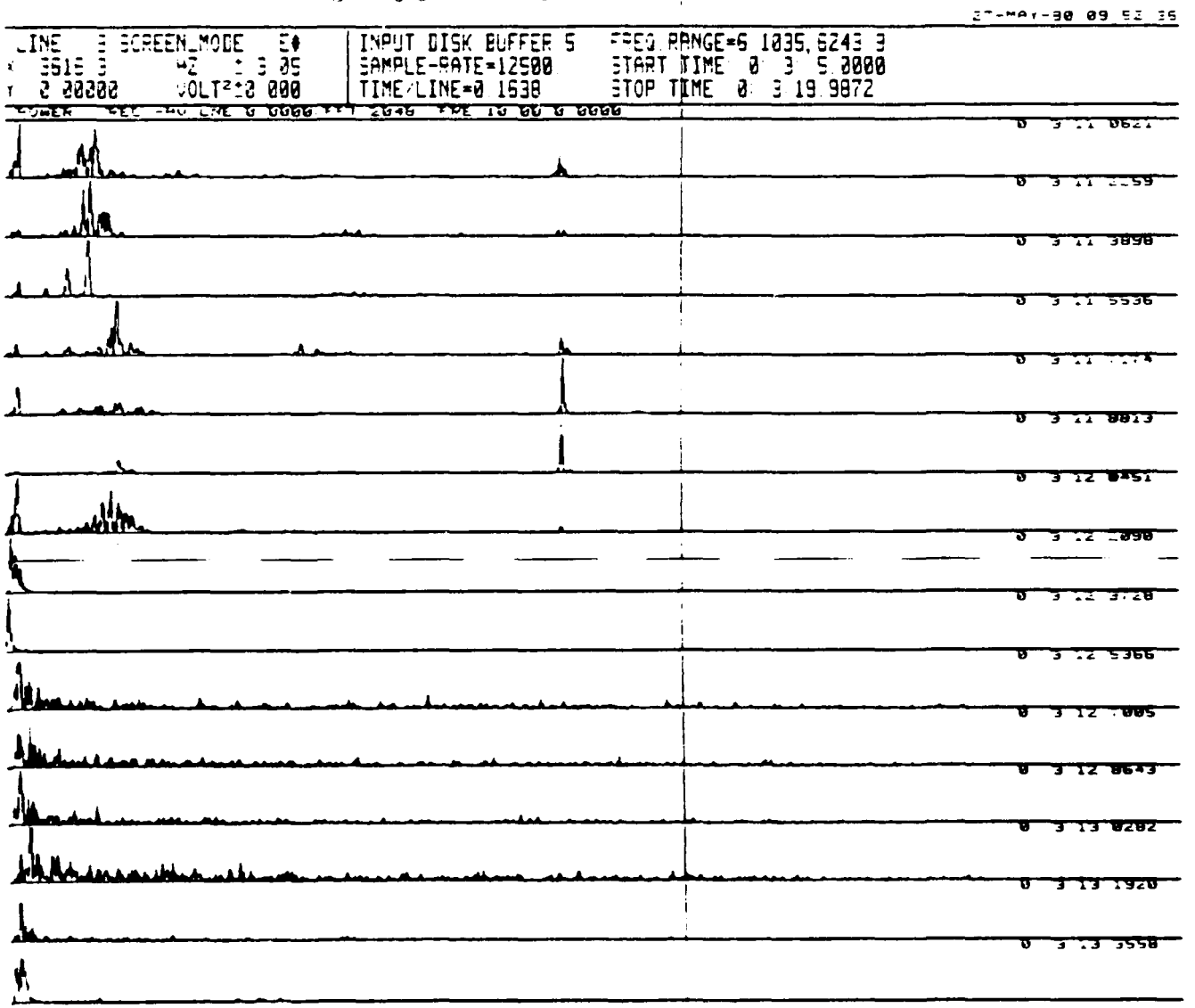


Figure 3-8 Marking End Time and Frequency



To check the start and end time markings, the operator then types a "^F" to stop the current display and then types the following:

"/EST/EET"

The power spectrum is then redisplayed but this time the Estimated Start Time (EST) and Estimated End Time (EET) as designated by the cursor is used and only the spectra containing the line of interest is displayed as shown in Figure 3-9.

The operator then wishes to display only those frequencies between the start and end frequencies. This is accomplished by typing "^F" and the following:

"/FRE: -1:-1"

The result is shown in Figure 3-10.

To enhance signal over noise, all spectra are then averaged together as shown in Figure 3-11 by typing a ":F" and the following:

"/AVE:-1/LIN:1"

To obtain the averaged spectrum on a logarithmic scale with a 40 db dynamic range displayed and referenced to the peak the user types "^F" and the following:

Figure 3-9 Power Spectra Display Between Begin and End Times

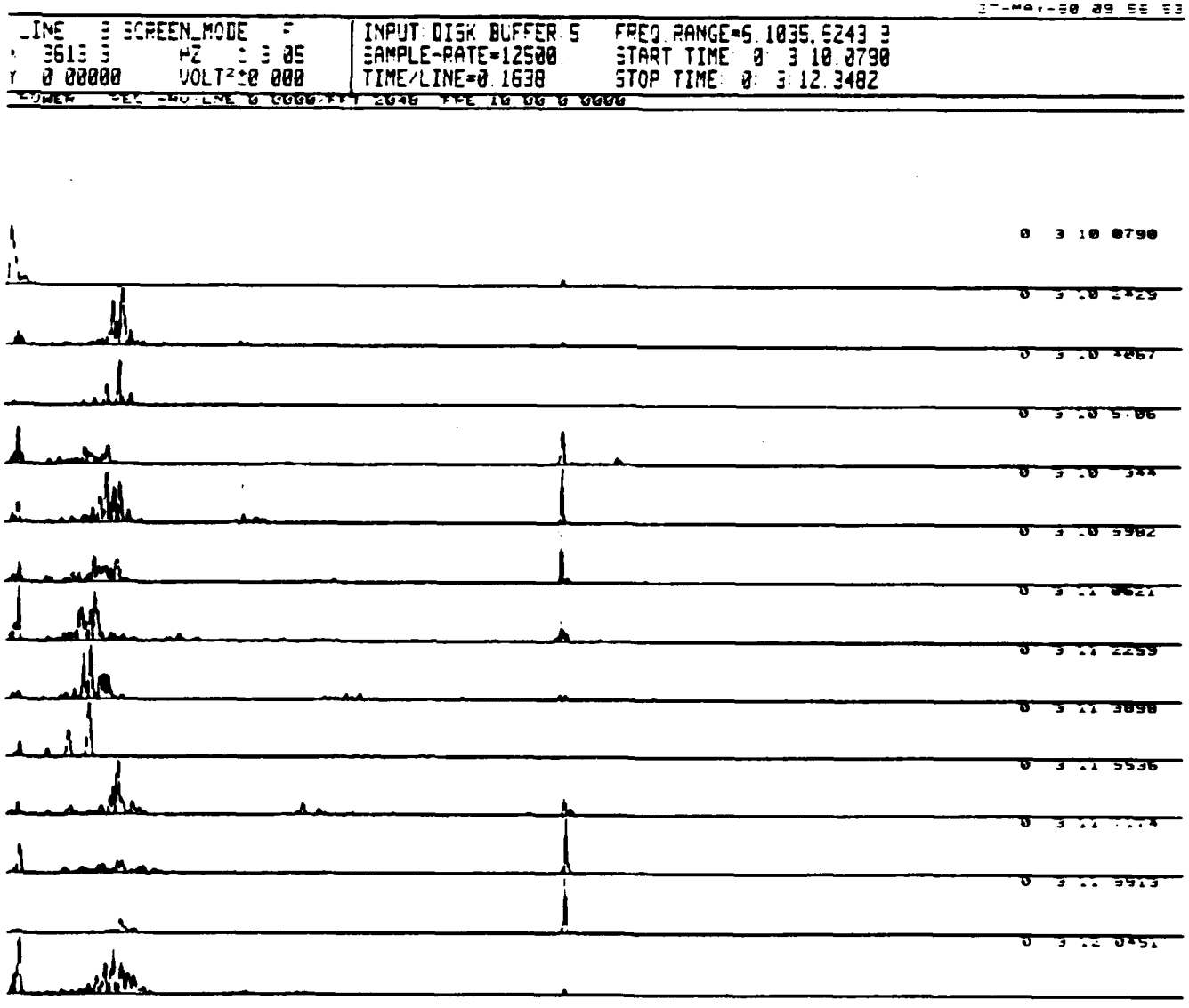


Figure 3-10 Power Spectra Display Between Begin and End Times and Frequencies

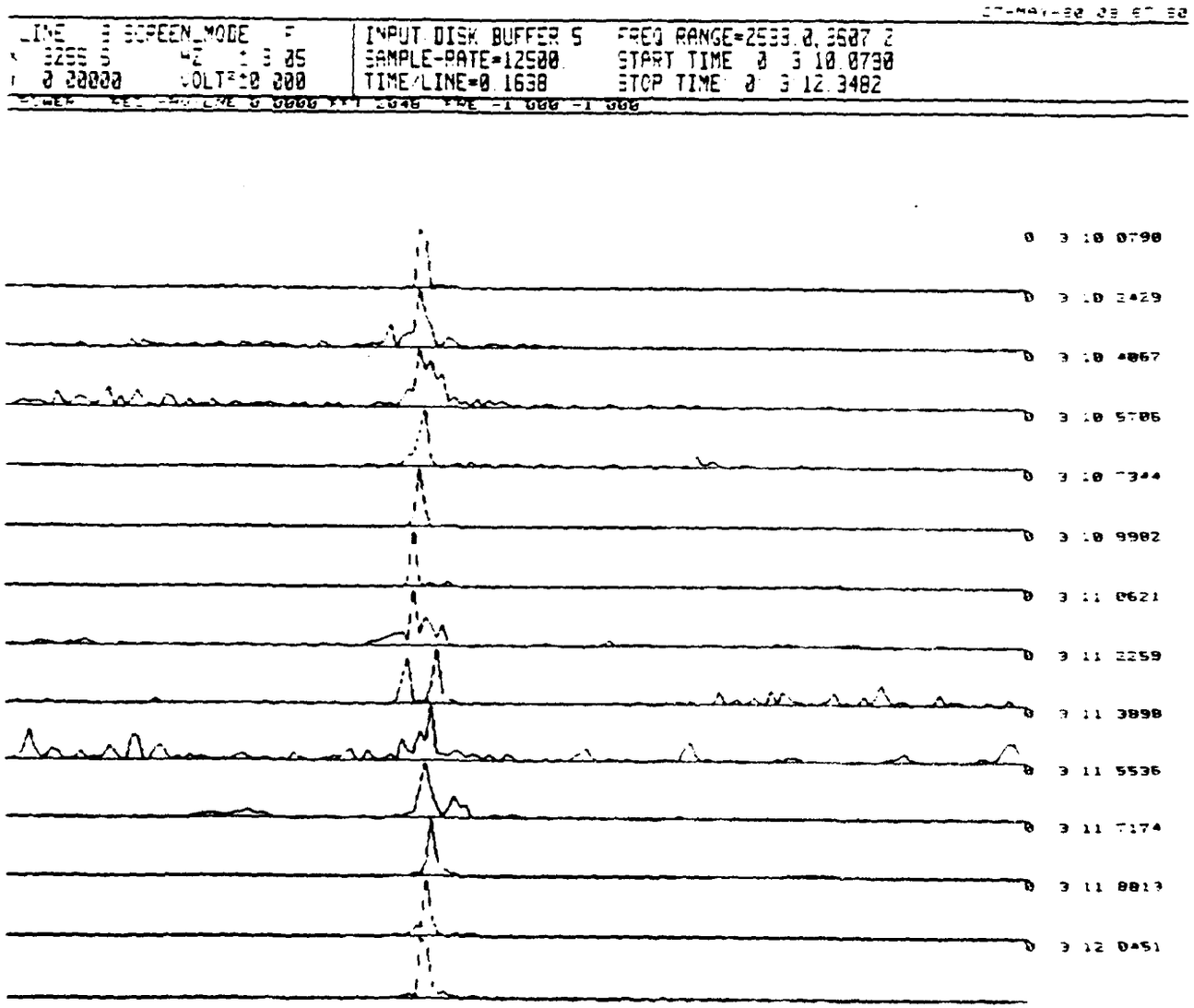
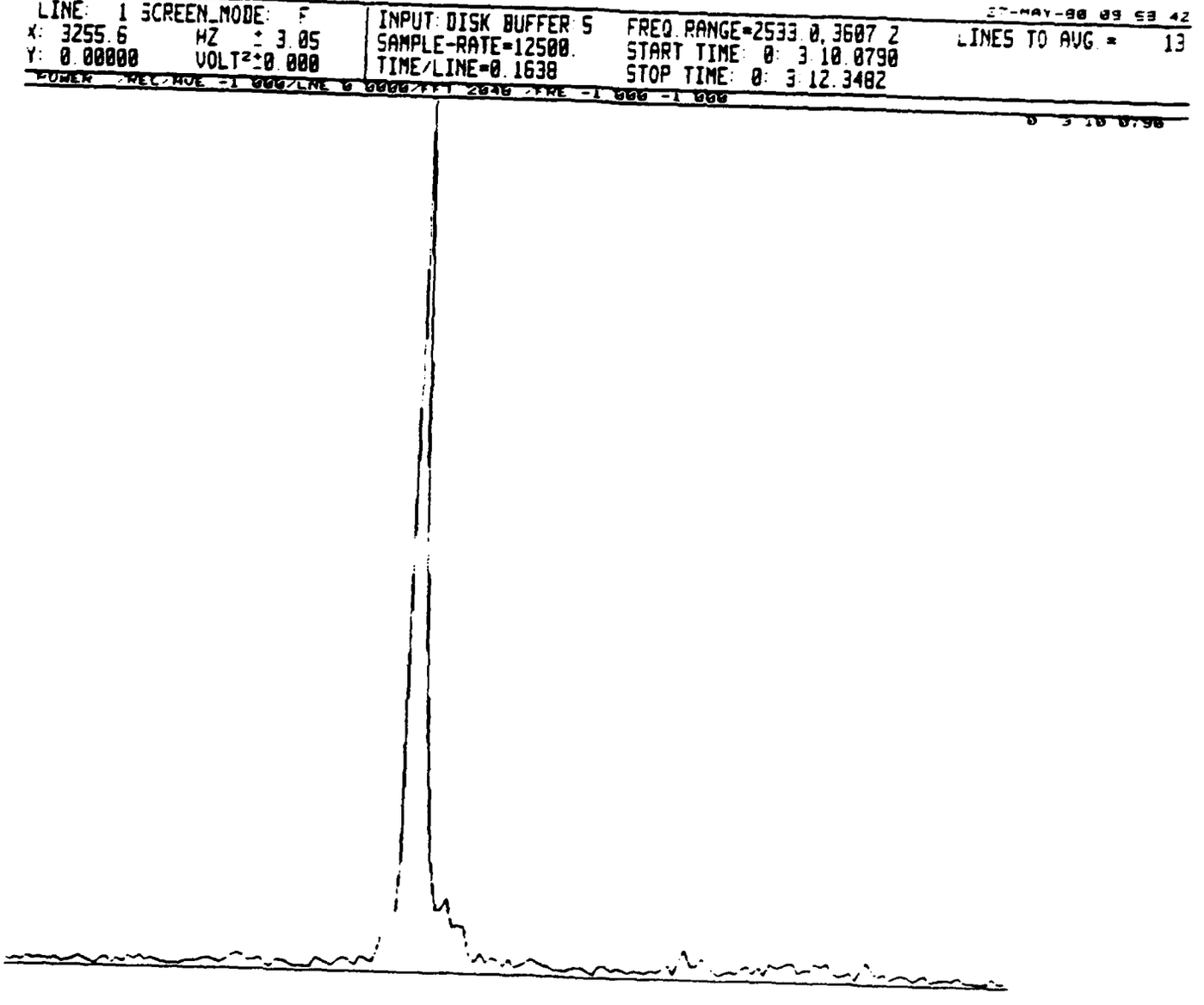


Figure 3-11 Averaged Spectrum



"/LOG:40:0"

The result is shown in Figure 3-12.

To obtain more frequency resolution, the operator then selects a larger FFT size. He types "^F" and:

"/FFT:8192"

As shown in Figure 3-13 frequency resolution is now + or - 0.7 Hz.

To see how far down in amplitude the spectra line is from the other components he then types "^F" and:

"/FRE:0:0/FFT:2048/RET"

The zeros entered in conjunction with the "FRE" switch signify that the maximum bandwidth be displayed. A smaller FFT was used to allow display of the entire bandwidth. The result is shown in Figure 3-14. The cursor is turned on and the horizontal cursor is aligned with the spectral line. As indicated in the annotation at the top left corner of the display, the peak is down only 2.7 db from a speech related peak. The "RET" switch provides return to the SPANS prompt with the completion of the current command.

Figure 3-12 Averaged Spectrum on Log Scale

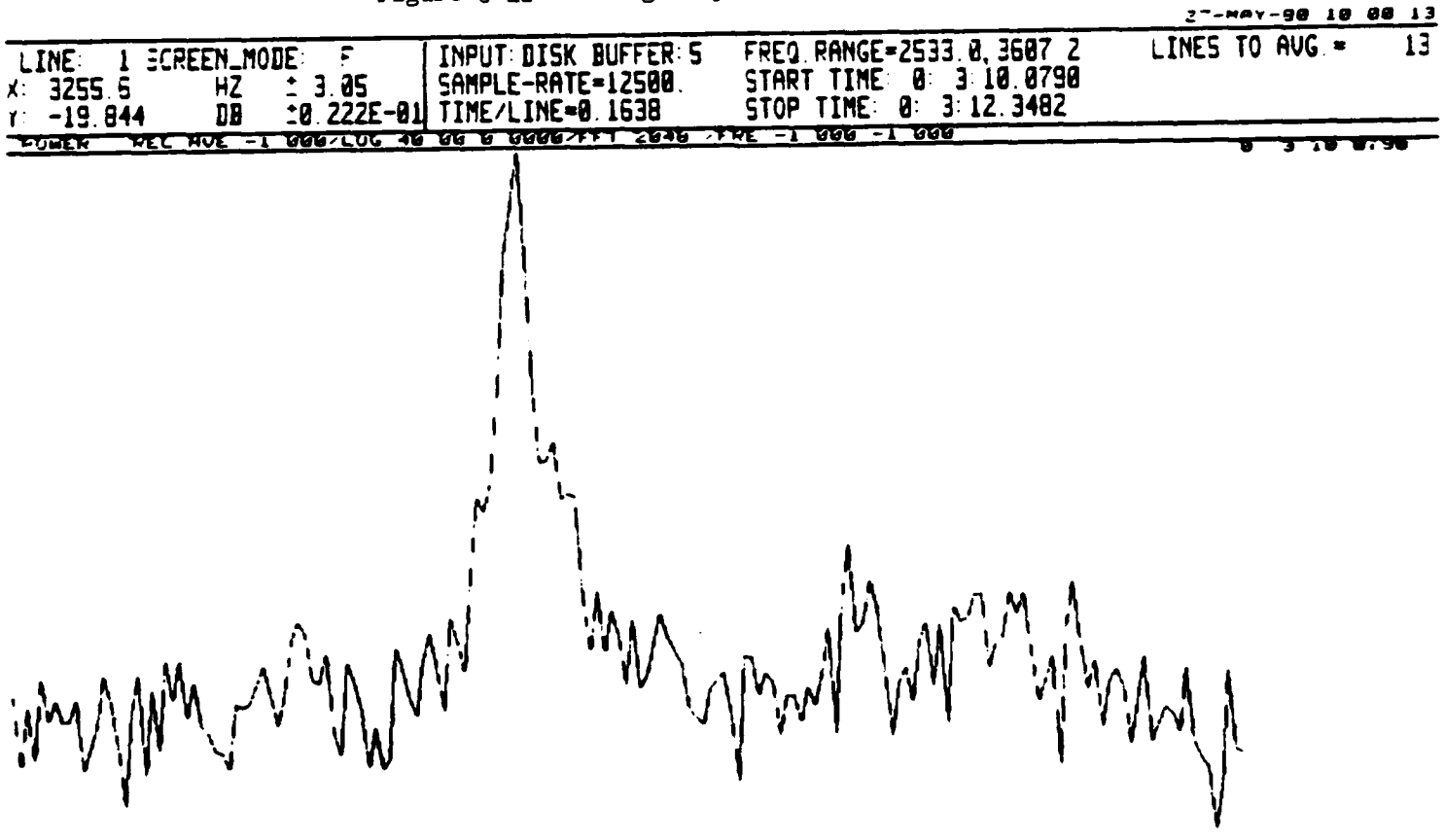


Figure 3-13 8192 Point FFT

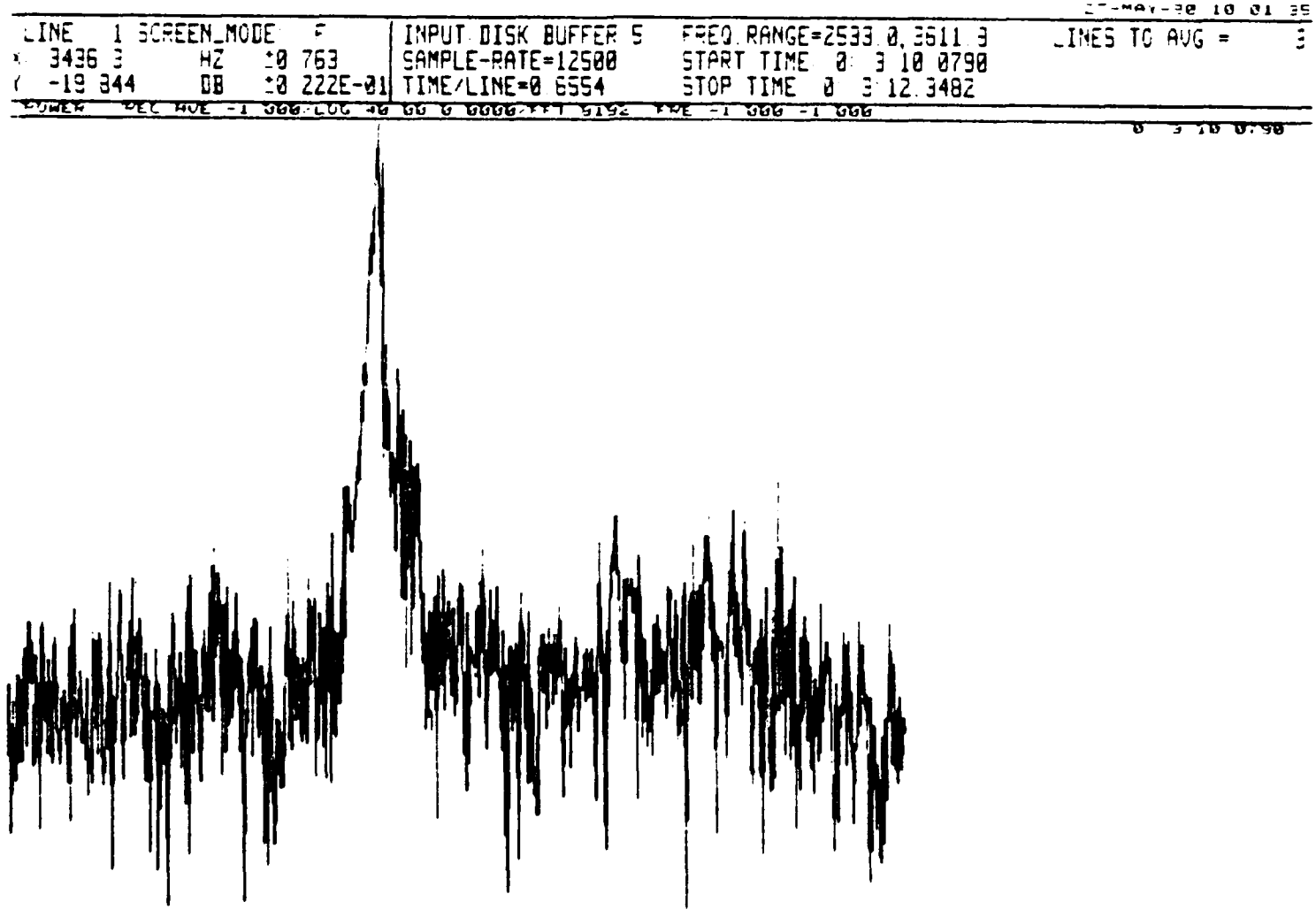
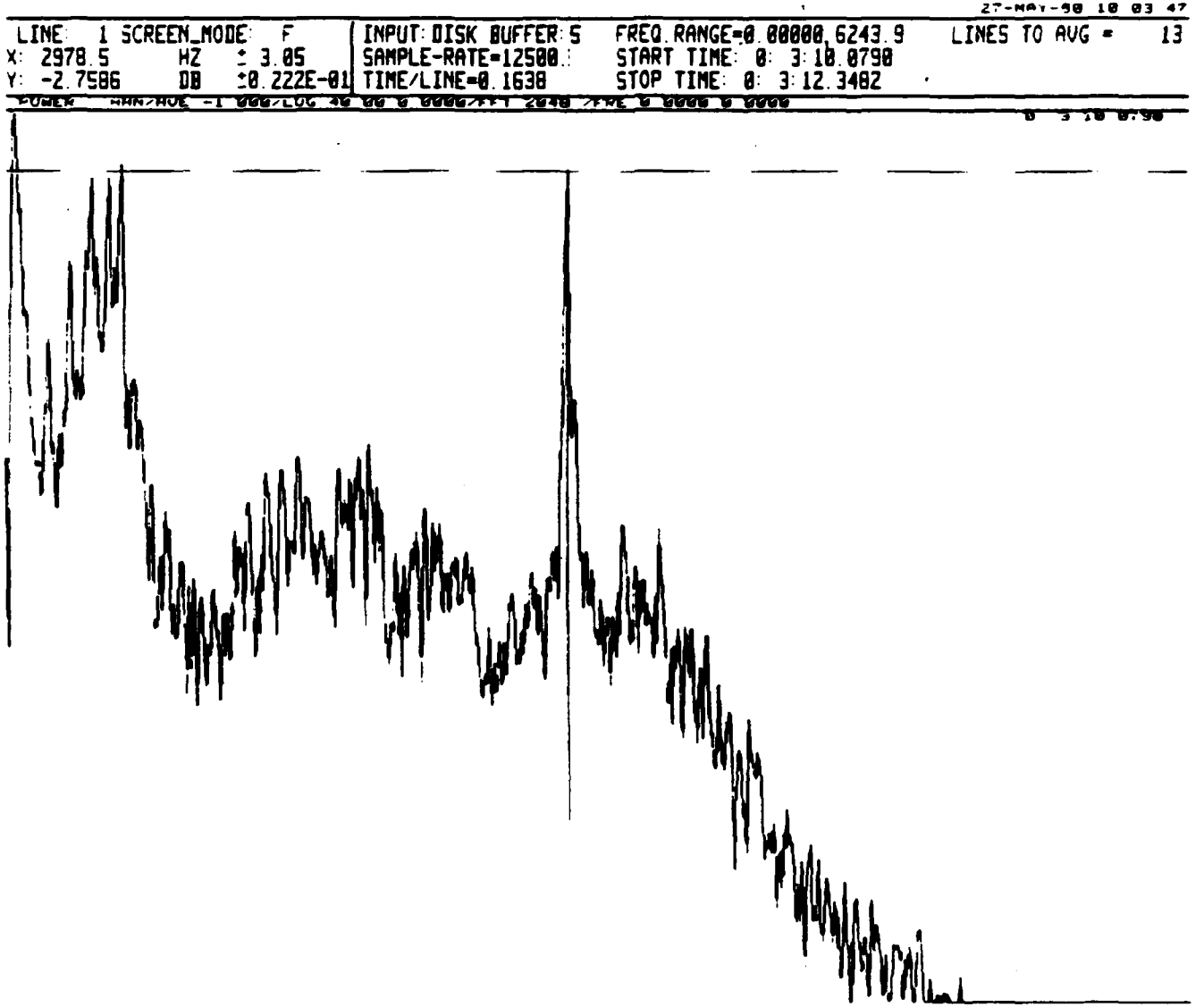


Figure 3-14 Making Power Measurement



At this time, the operator has completed the spectrum analysis and wishes to listen to the event. Since the "RET" switch was entered in the last command line, a "^F" will return control to the "SPANS" prompt. To listen to the digital event, the operator then types:

"PLA /EST/EET"

All data between the start and end times previously entered by the cursor is then played back at the digitized rate through the digital-to-analog converter (DAC). Assuming that the DAC output is appropriately filtered and patched to the speaker Channel B, the event will be heard through the speaker.

Once the event has been heard, return is made to the "SPANS" prompt. Exit from SPANS is then accomplished by input of the command:

"EX"

SECTION 4

SPANS REPORTS

This section gives a brief introduction to the various reports generated during the course of the SPANS development effort.

Reliability and Maintainability Analysis for Exploratory Advanced Development Model

This report presented the results of a reliability and maintainability analysis performed as required under this effort. The reliability analysis was performed in accordance with MIL-STD-756A entitled "Military Standard Reliability Prediction." The maintainability analysis was performed in accordance with Procedure IV of MIL-STD-472 entitled "Maintainability Prediction."

Operating Hazard Analysis

This report identified the safety considerations associated with personnel, procedures and equipment involved in the operation of SPANS. This analysis was performed in accordance with Paragraph 6 of DI-H-3278.

Test Plan/Procedures

This report described a plan for testing the operating characteristics of the SPANS system to verify that the Statement of Work was met.

The tests were divided into two parts, hardware tests and software tests. Preliminary tests were run at PAR prior to delivery of SPANS. Final testing was then successfully completed at FTD following installation.

Operating and Maintenance Manual

This manual describes the detailed operating and maintenance procedures required to run and maintain the SPANS equipment. The manual is divided into seven sections. Section 1 presents an overview of SPANS. Section 2 presents detailed system specifications and functions of individual equipments making up the system. In Section 3, all information necessary for unpacking and installing the equipment on site and detailed instructions for repacking equipment for shipping are given. Section 4 provides "turn-on" and calibration procedures as well as describing the various user commands and display options. Section 5 describes preventative maintenance procedures, software diagnostics and a trouble shooting chart for recognizing, isolating, and repairing minor malfunctions. In Section 6, hardware developed by PAR as well as modifications made by PAR to commercial hardware are described. Finally, Section 7 consists of system layouts, schematics, and wiring diagrams necessary for operation and maintenance of SPANS.

Program Documentation

Program documentation consists of a programmers' maintenance manual and detailed program write-ups for each program unit. In the programmers'

manual, a high level flowchart of SPANS is described. Each box of the flowchart then refers to a specific program unit which is numbered for easy reference.

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1. Bergland, G.D., "A Guided Tour of the Fast Fourier Transform," IEEE Spectrum, Vol. 6, pp 41-52, July 1969.

2. Harris, F.J., "On the Use of Windows for Harmonic Analysis with Discrete Fourier Transform," Proc. IEEE, Vol. 66, No. 1, January 1978.

3. Ziener and Tranter, "Principles of Communications," Houghton Mifflin Company, Ch. 2, pp 46-50 and pp 224-230.

DAT
FILM