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MEMORANDUM REPORT BRL-MR-3680

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COMPUTER IMPLEMENTATION OF ALGORITHM FOR THE ANALYSIS OF RADAR DOPPPLER FROM PROJECTILES

SUSAN A. COATES

JULY 1988

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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During the course of studying projectiles and gun dynamics, data is recorded from firings on indoor and outdoor ranges. Data recorded during firings consists of the following types of data: guntube strain, guntube acceleration, chamber pressure, and doppler radar from the flight of the projectile both in-bore and in free flight. Currently there are four sets of analysis programs resident on a Hewlett Packard 1000 F Series minicomputer (HP1000) with the operating system RTE 6/VM for use when analyzing this data. These programs are used specifically for the acquisition and the analysis of strain, pressure, acceleration, and doppler radar data. This report will concentrate on the digitization and analysis of radar data.

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I. INTRODUCTION

During the course of studying projectiles and gun dynamics, data are recorded from firings on indoor and outdoor ranges. Data recorded during firings consist of the following: guntube strain, guntube acceleration, chamber pressure, and doppler radar from the flight of the projectile both in-bore and in free flight. Currently there are four sets of analysis programs resident on a Hewlett Packard 1000 F Series minicomputer (HP1000) with the operating system RTE 6/VM for use when analyzing this data. These programs are used specifically for the acquisition and the analysis of strain, pressure, acceleration, and doppler radar data. The HP1000 minicomputer was choosen since the driver used with the digitizer allowed any size data record to be digitized as long as the disk designated to receive the data is large enough to accomodate the data. The data from these test firings can range in time from a few milliseconds to a few seconds. A record that is three seconds long can contain up to 7,200,000 samples if the highest sampling rate and largest tape speed factor are used. The highest sampling frequency generally is only used when digitizing doppler radar files. The techniques for sampling data will be discussed in Part III, Computer Implementation of Radar Analysis; Section A, Data Digitization. This report will concentrate on the digitization and analysis of radar data as opposed to strain, pressure, or acceleration data.

II. OVERVIEW OF DATA FILE STRUCTURE

There are three main types of files: an acquisition file for strain, pressure, and acceleration data; an analysis file for strain, pressure, and acceleration data; and a radar file. These files different in their formats but seem relatively similar to the user.

An aquisition file contains digitized strain, pressure, or acceleration data. The aquisition file is created in the acquisition set of programs when data are digitized and then stored on the disk. Before digitization occurs the data may be passed through a filter and the gain (amplitude) of the data may be increased. This file has a header record that contains the file name, label information supplied by the user, and other information that will be used for later analysis such as sample rate, tape speed factor, and the number of points in the file. In the digitization program for strain, pressure, and acceleration data, the option exists to digitize multiple channels simultaneously. When two channels are digitized simultaneously, the first digitized datum is from channel one, the second digitized datum is from channel two, and the pattern repeats. The acquisition file for strain, pressure, and acceleration data is large enough to contain all the digitized data which can be hundreds of thousands of points. This large number of data points may occur under one or several different conditions. These conditions are (1) one to fourteen channels of data are digitized in one pass, (2) a large sampling frequency is used, or (3) a long time span is recorded. The data in this file are equally spaced in time with only the actual data point being stored. The time at which each data point occurs is computed from information in the header.

An analysis file is created by the analysis programs. The analysis programs for strain, pressure, and acceleration data work with up to 30,000 data points equally spaced in time. For the type of analysis done with the analysis programs generally 30,000 or less points is a sufficient quantity for analysis. These points are all resident in memory at one time. These data points may be recovered from an acquisition or an analysis type file. When recovering data from a file the user chooses how many points are to be used (up to 30,000). As mentioned before, more than 30,000 points may be digitized and stored in an acquisition file when several channels are digitized at once. In the process of retrieving the file only one channel of data is retrieved and this is generally less than 30,000 points. When a long time span is digitized, usually only a part of that is the data of interest. The user will have to find this particular part of the data by either incrementing the data or knowing from observing the oscilloscope while digitizing that the data occurred at the beginning, end, or middle of the record. When storing a file from these programs an analysis type file is created. An analysis file also has one header record that contains the file name, label information supplied by the user, and information needed for future analysis. The rest of the file is filled with data records where the data are equally spaced in time.

The set of programs for the acquisition and analysis of doppler radar data uses only radar files. Radar data are digitized one channel at a time. These data are stored in a file that has one header record containing the file name, label information, and information needed for future analysis; and up to several thousand data records which contain equally spaced data points in time, 1024 points per record. Again, this file may also contain hundreds of thousands of points. When analyzing radar records all of these points are needed for the analysis but they can not all be resident in memory at one time; therefore, usually only one record of data is in memory at a time.

Three sets of programs have already been mentioned. A fourth set of programs, Zeroing Programs, are used in the analysis of radar doppler data. These programs only work with analysis type files; therefore, the radar files need to be converted to analysis files. This will all be discussed in Part III, Computer Implementation of Radar Analysis; Section E, Zeroing Programs.

This is all transparent to the user and the four sets of interactive programs appear very similar to the user. Each set of programs has a main menu list similar to the one shown in Figure 1. Under each of the options is either a process to be used or another menu list similar to Figure 2. Figure 2 is option three of the main menu list shown in Figure 1. Figure 3 shows how the different types of data and programs are related. For all types of tests the data are recorded on analog tape and then passed through antialiasings filters. Strain, pressure, or acceleration data are digitized with the aquisition programs and an acquisition file is created. These data are then used with the analysis programs and analysis files are created. Radar data are digitized and analyzed with the radar programs. The zeroing programs are used for certain types of analysis of the radar data. For one special case the analysis programs are used with radar data. The rest of this report will concentrate on the digitization and analysis of radar data. More information on the analysis of strain, pressure, and acceleration data may be found in reference 1.

```
OPTIONS:
   0 - END PROCESSING
   1 - DATA DIGITIZATION
   2 - TARGET TRACKING AND ANALYSIS
   3 - SIDEBAND AND SPECTRAL ANALYSIS
   4 - TRAJECTORY AND DRAG COMPUTATION
   5 - UTILITY PROGRAMS
```

Figure 1. Main Menu List

```
THE DISK IS 78% FULL.


OPTIONS:
       0 - END PROCESSING
       1 - TRANSFER DATA RECORD TO OR FROM THE hp9845
       2 - DATA FILE ACCESS (TAPE OR DISK)
       3 - ADJUST ZERO LEVEL OR # OF BLOCKS TO PROCESS
       4 - AM SIDEBAND DETECTION AND REMOVAL
       5 - HIGH RESOLUTION (MESA) SPECTRAL ANALYSIS
       6 - FOURIER SPECTRAL ANALYSIS
       7 - DIGITAL FILTER DESIGN/APPLICATION
       8 - ANNOTATED PLOTS
       9 - WATERFALL SPECTRUM PLOTS
      99 - SUSPEND PROGRAM
```

Figure 2. Secondary Menu List

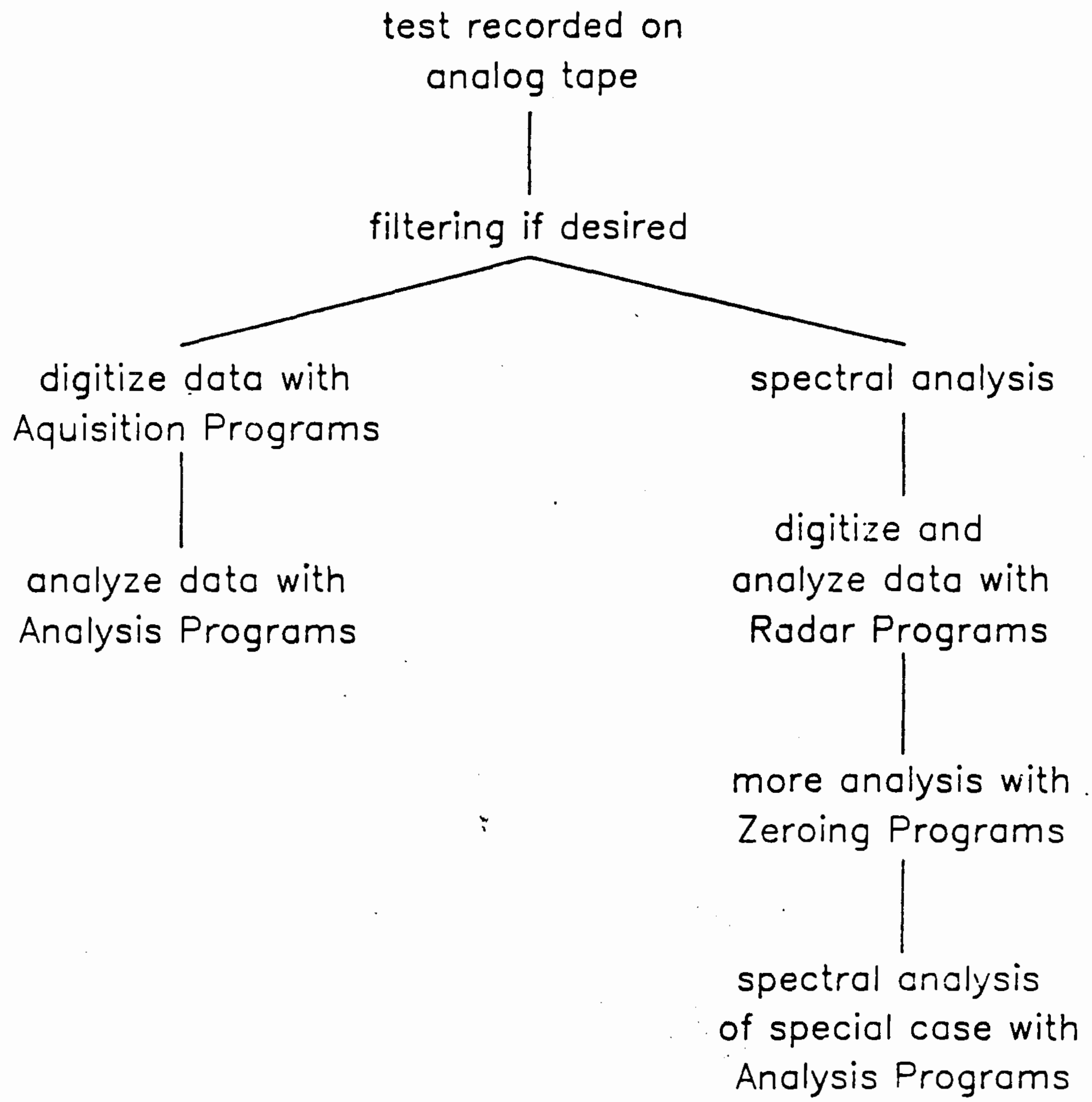

Figure 3. Relationship of Data Types to Programs

III. COMPUTER IMPLEMENTATION OF RADAR ANALYSIS

Figure 4 shows the breakdown of the different sets of radar programs as well as the interaction with the zeroing programs and analysis programs. The radar data are recorded on analog tape, passed through a filter and spectral analyzer, and then digitized with option one of the radar programs. Once the data are digitized one of four different options can be choosen as shown and each will be discussed in detail later in this section.

A. Data Digitization

The first step in the analysis of doppler radar data is to acquire the data digitally (number one in the option list of Figure 1). This particular option has no menu list under it, only questions to be answered by the user. The data have already been recorded on analog tape either at an indoor or outdoor range. On the current system data may be digitized at a sampling rate of up to 40kHz; doppler radar data, however, requires a higher sample rate for analysis. This is accomplished by slowing the tape speed down. The tape recorder used for recording data and for playing back data has tape speeds ranging from 0.9375 to 120 inches per second (ips). The data have usually been recorded at either 60 ips or 120 ips. For example, suppose the data were recorded at 60 ips and the tape is played back at 7.5 ips; the tape speed factor is eight (60ips / 7.5ips = 8). If a sampling frequency of 40kHz was used, this results in a real time sample rate of 320kHz (40kHz * 8 = 320kHz). Filtering, as well as increasing the gain (amplitude) of the data, may be done immediately before digitizing. The data is run through a set of antialiasing filters where the gain may be set at one, two, five, or ten and different filter settings may also be used. Usually the filters are set at 150kHz which effectively allows all frequencies to pass through for digitizing. The data may also be passed through a spectrum analyzer which allows the user to time how long the record lasts and to see if there are any irregularities in the record. An example of such an irregularity, a piece of projectile breaking off, can be seen in the waterfall plot of Figure 5 taken directly from the spectrum analyzer. Peaks occur in the waterfall plot corresponding to the frequency content of the data. The frequency with the highest peak has the most power within the window. As the velocity of the projectile decreases so does the frequency since velocity is approximately proportional to frequency (see reference 2). On these waterfall plots the frequency increases to the right on the horizontal axis and time increases upward on the vertical axis. In this particular plot peaks are seen at approximately 11,000Hz indicated by A in Figure 5. About one third of the way up the plot (point B in Figure 5) the frequency of the peaks starts decreasing in a parabolic path. At the same time there are peaks to the far left where the frequency is also decreasing in a parabolic path. This is the piece that has broken off the projectile. The piece broken off slows down at a much faster rate then the projectile and the track of this ends at point C in Figure 5.

The first question the user must answer is, "Enter the number of channels to be digitized." The user must enter one because only one channel of radar data may be digitized at a time. This question is in here for the program to be expanded at a future date. The second question is, "Enter the desired sampling rate." The user enters a sampling frequency of less than or equal to 40,000 Hz as discussed earlier. All numbers entered by the user are entered without commas or units. Commas are used to separate numbers when more than one number is needed for an answer. The console then echoes what the user entered and

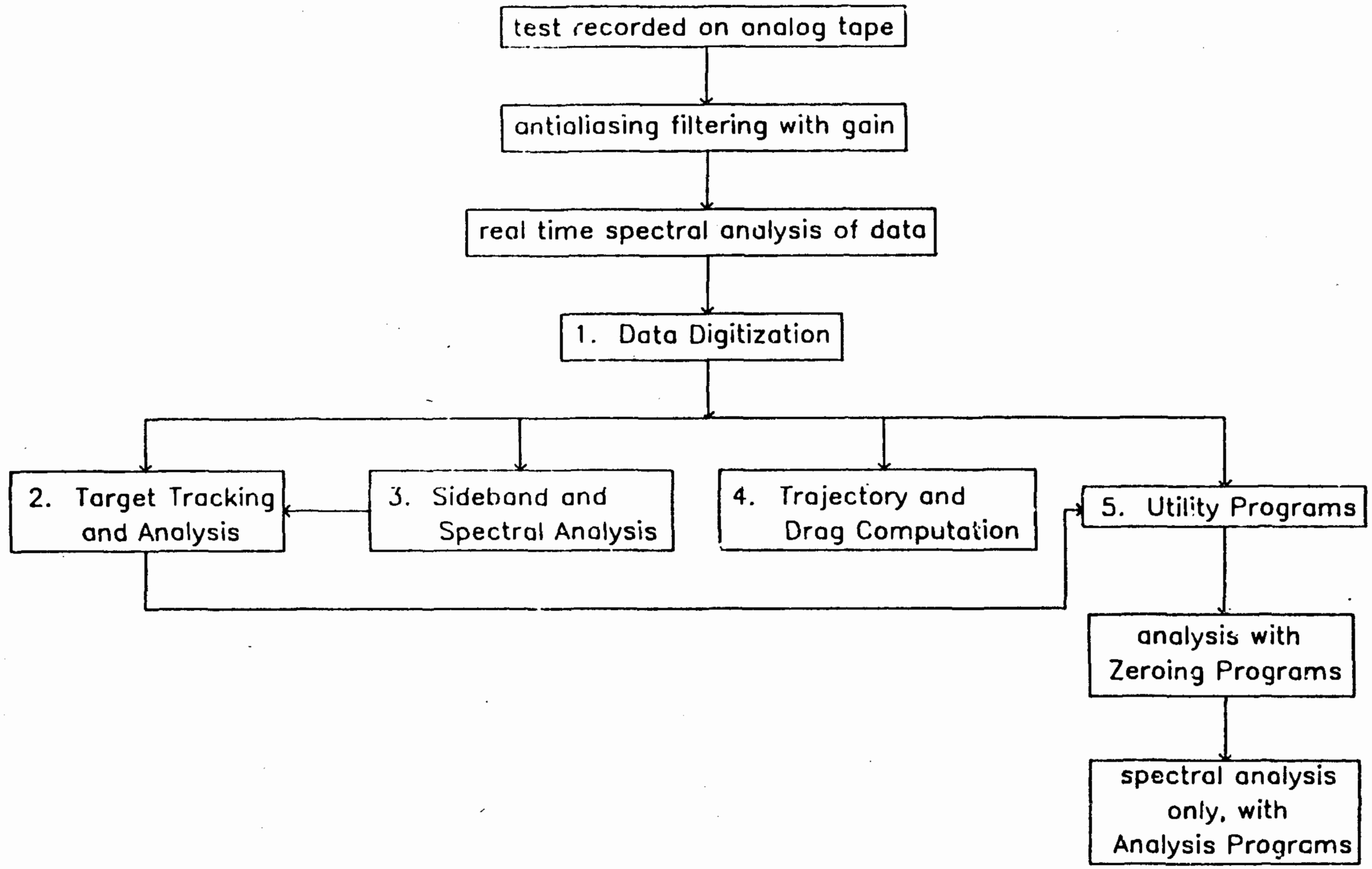

Figure 4. Breakdown of Radar Programs

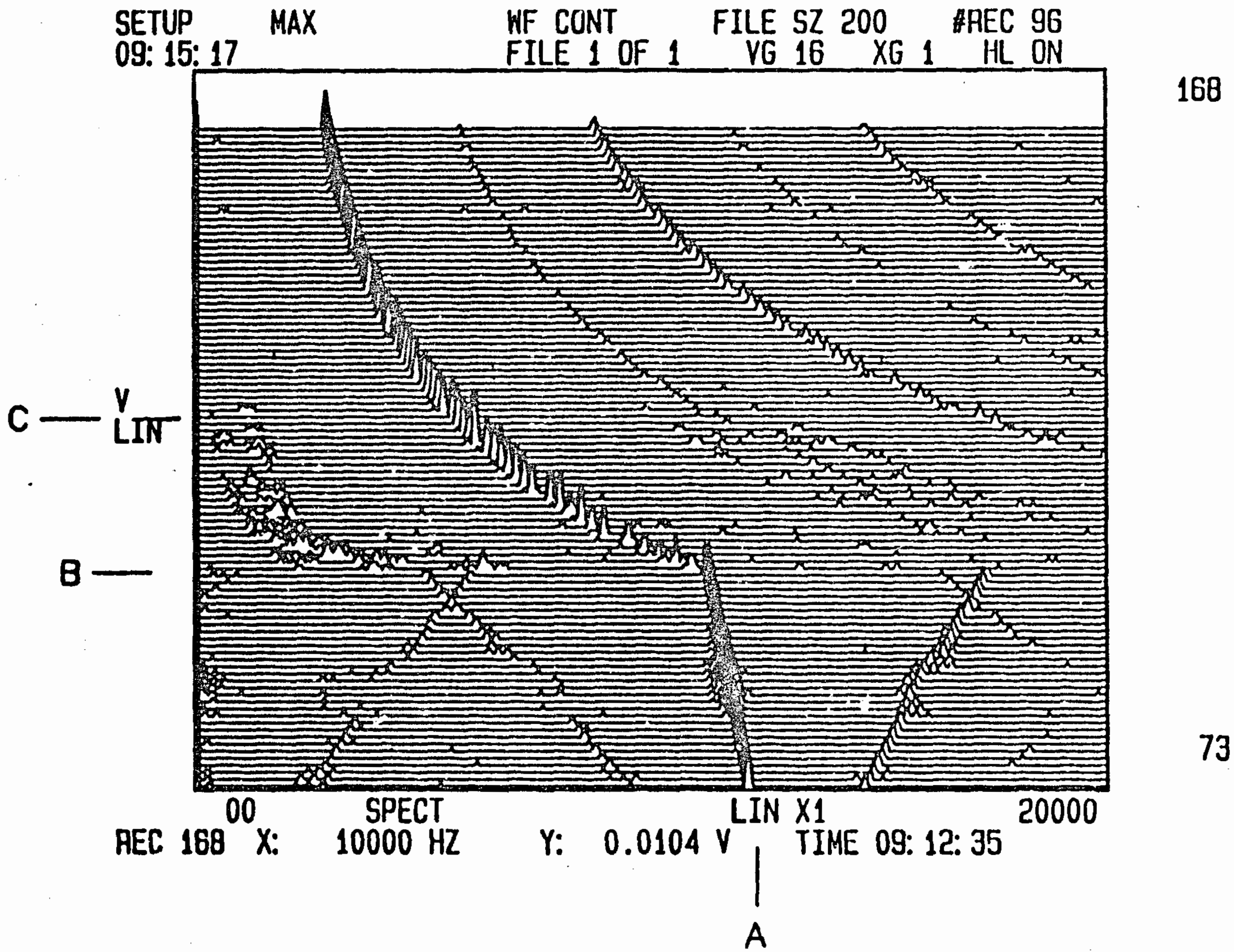

Figure 5. Plot from the Spectrum Analyzer with a Piece Breaking Off the Projectile

asks, "Do you want to change these? (YE or NO)." If the answer is YE, the user re-answers the first two questions. If the answer is NO, the program goes on. The user is now asked for playback time in seconds. This is answered appropriately as discussed earlier. Next the user is asked the mode for triggering (starting to digitize). On this system there are two ways to trigger: manually or automatically. If data are digitized by triggering manually, the digitization process starts when the user presses the return key on the computer console. If the digitization is automatically triggered, a channel of data is run through the triggering device and digitization starts when the voltage reaches a preset level. The data channel used for automatic triggering may be the channel of actual data or it may be another channel of data recorded simultaneously that contains some type of pulse to indicate the start of data. When triggering automatically the user may enter a time delay which delays the start of digitization until after the specified voltage has been reached. As these data are digitized they are written onto a disk. After digitization is completed the user is asked, "Okay to proceed? (YE or NO)." If for some reason there was an error the user may enter NO and re-digitize; otherwise YE is entered. The user now enters a file number between 1 and 9999. The program will automatically name the file DRxxxx where xxxx indicates the number choosen by the user. The user now enters any information about the file in a 72 character label. The tape speed factor must be entered as discussed earlier. The user is asked if the status word should be monitored. If YE is entered each datum that has been digitized is checked to see that no problems occured with the digitizer. If something was wrong with the digitizer the status bit would be set to indicate there was a problem. Usually NO is entered. See Appendix A for a complete example of the questions and answers for digitizing. The data is now written in a readable form to another disk file. The raw doppler data is shown in Figure 6.

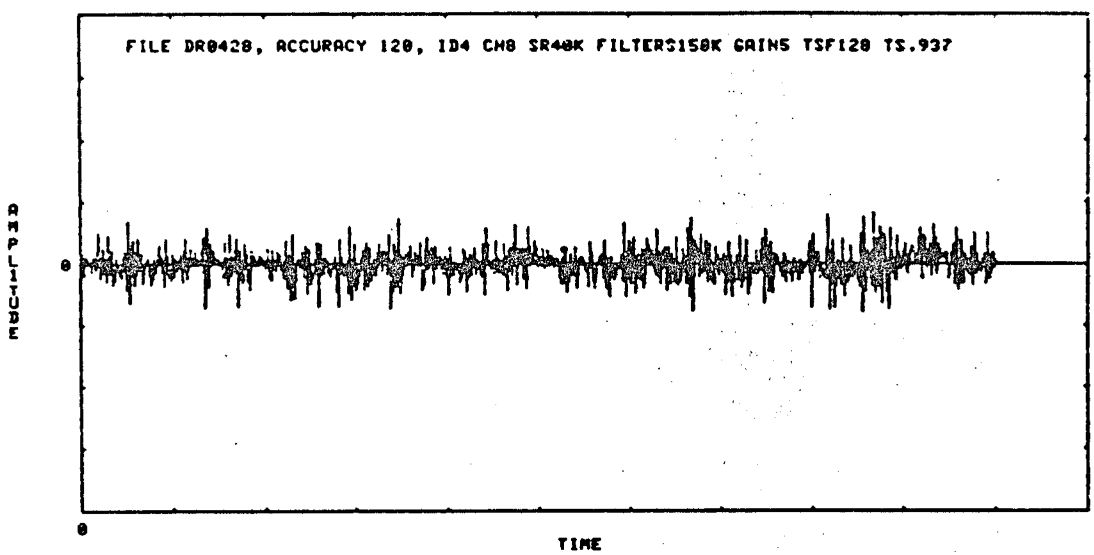

Figure 6. Raw Doppler Data

Once the raw doppler data have been digitized and stored on disk (option one of Figure 1) there are four other options that may be choosen in order to analyze the data (options two through five of Figure 1). This report will cover options two, three, and five. Option four, Trajectory and Drag Computation, has been covered in reference 2.

B. Target Tracking and Analysis

Option two of Figure 1, Target Tracking and Analysis, deals with tracking the data and analyzing it. When option two is selected, another menu list appears on the screen (Figure 7). There are eight options in this menu list.

```
OPTIONS:
  0 - END PROCESS
  1 - COMPUTE RADIAL VELOCITY TIME DATA
  2 - CREATE MULTIPLE TARGET TRACK PROFILE
  3 - EDIT RADIAL VELOCITY DATA
  4 - SPLINE FIT OF VELOCITY DATA
  5 - LIST RADIAL VELOCITY TIME POINTS
  6 - COMPUTE TRAVEL DATA
  7 - PLOT RAW DIGITAL DATA
  8 - PLOT TRAVEL, VELOCITY OR ACCELERATION vs TIME
```

Figure 7. Target Tracking and Analysis Menu List

Option one of Figure 7 generates a radial velocity-time file or velocity profile. Radial velocity is the velocity of the projectile with respect to the radar along the radial line (reference 2). This can be accomplished in two different ways. The first is to generate the radial velocity-time file directly from the raw doppler file. A spectral analysis of each block of raw doppler data is done as the program progresses. This is a raw fast Fourier transform (FFT) which will be discussed in Section C, Sideband and Spectral Analysis. The second way to generate a radial velocity-time file is to use an existing FFT file created under option three of Figure 1. This program essentially tracks the highest peaks that are created as the spectral analysis is being performed on each block of data or the program tracks the highest peaks that have already been created when an existing FFT file is being used. The user enters a minimum starting velocity and bounds for the projectile. These bounds indicate whether the velocity will be going up, down, or both and how much it may change in one step. The user also decides how the velocity points are accepted: check all the points (the user decides if the point is good or not), check consecutive rejections (points will be accepted if they are within the bounds, the first point outside the bounds will be rejected, a consecutive point outside the bounds is left up to the user to accept or reject), and reject all points outside the bounds. The user also has the option of using an automatic change mode. The following is an example of the automatic change mode:

A	accepted - within bounds
B	accepted - within bounds but A is not equal to B
A	out of bounds but last point accepted before B; therefore, change to B and accept

A velocity-time profile is stored as time, data, time, data. This is a minor type of data file. The time between points may not be the same and usually is not. A velocity-time profile usually looks like a step function since this is a discrete process (Figure 8). Since the velocity did not change in discrete steps this curve may be edited in two ways to make it smooth. The first is by linear editing (Figure 9) done within option one. In Figure 9 the X indicates an actual data point. The equation of the line between the first point of one step and first point of the next step is determined. A point on the line between steps is found at the correct time for each data point. These points are indicated by the small circles. The other way to edit a velocity-time file is to use a cubic spline, option 3. Again, the first point of each step is found. A cubic spline is determined using three points. Between the first two points used in the spline a data point is found on this curve at the appropriate time. Then the last two points used for the spline and a new point is used to find the next spline. The velocity-time file that was just created may be plotted using option eight (Figure 8) as well as listed on a line printer (Figure 10), listed to the consol, or written in ASCII to tape so the data may be transferred to another computer, option five. The integral may also be taken to obtain the travel of the projectile (option six). Also under this heading the raw doppler data may be plotted as was shown in Figure 6.

Option four is a test program of another type of spline fit. This test program has not been released for general use.

Option two, Multiple Target Track Profile, was created in order to track projectiles that were fired in a burst such as a five round burst from a machine gun. This option is similar to option one. The user goes into the option and enters the name of the file to be processed. The user then decides how many peaks to track; in the above example five peaks can be tracked. The program finds the maximum amplitudes for the number of peaks choosen and writes this information out to the screen. The user must decide whether to accept the points or change them. There is no automatic acception or automatic change as in option one.

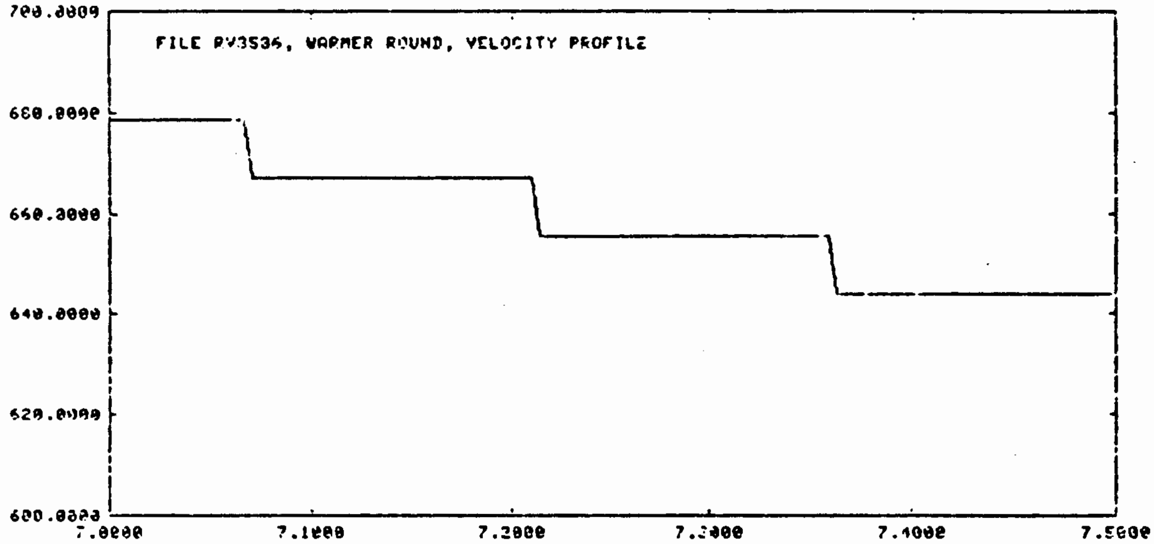

Figure 8. Section of Velocity-Time File

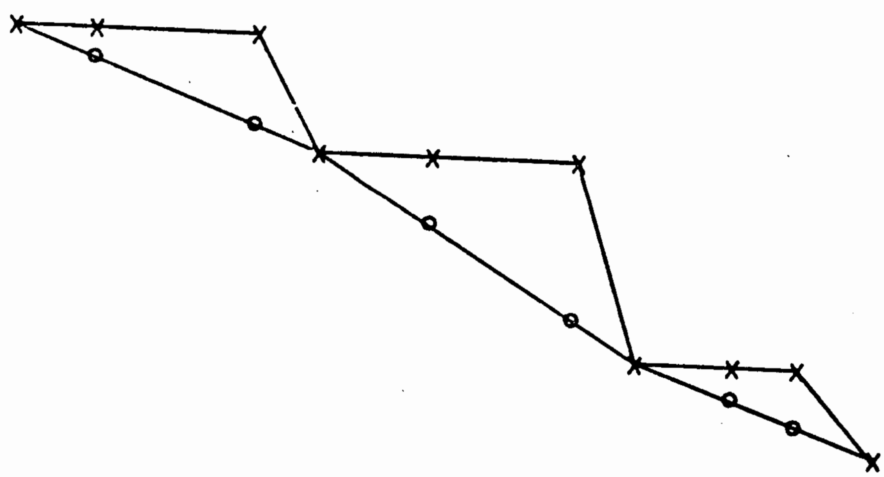

Figure 9. Linear Editing

FILE. 707596

WARNER ROUND, VELOC Y

TIME, SEC.	RAD. VEL., F/S	TIME, SEC.	RAD. VEL., F/S	TIME, SEC.	RAD. VEL., F/S	TIME, SEC.	RAD. VEL., F/S
.000000E+00	.510593E+04	.844800E-02	.511743E+04	.211200E-01	.515193E+04	.253440E-01	.514975E+04
.295680E-01	.514043E+04	.337920E-01	.512795E+04	.380160E-01	.511747E+04	.422400E-01	.511201E+04
.464640E-01	.510593E+04	.506880E-01	.509443E+04	.549120E-01	.508293E+04	.591360E-01	.507036E+04
.633600E-01	.505993E+04	.675840E-01	.505451E+04	.718080E-01	.504943E+04	.760320E-01	.503693E+04
.902560E-01	.502543E+04	.844800E-01	.501393E+04	.887040E-01	.500243E+04	.929280E-01	.499668E+04
.971520E-01	.499093E+04	.101376E+00	.497943E+04	.105600E+00	.496793E+04	.109824E+00	.495643E+04
.114048E+00	.494493E+04	.118272E+00	.493918E+04	.122496E+00	.493343E+04	.126720E+00	.492193E+04
.130944E+00	.491043E+04	.135168E+00	.489893E+04	.139392E+00	.488743E+04	.143616E+00	.488171E+04
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.232320E+00	.468609E+04	.236544E+00	.468043E+04	.240768E+00	.466893E+04	.244992E+00	.465743E+04
.249216E+00	.465175E+04	.253440E+00	.464593E+04	.257664E+00	.463443E+04	.261888E+00	.462293E+04
.266112E+00	.461143E+04	.270336E+00	.459993E+04	.274560E+00	.459421E+04	.278784E+00	.458843E+04
.283008E+00	.457633E+04	.287232E+00	.456543E+04	.291456E+00	.455393E+04	.295680E+00	.454809E+04
.299904E+00	.454244E+04	.304128E+00	.453094E+04	.308352E+00	.451944E+04	.312576E+00	.451378E+04
.316800E+00	.450794E+04	.321024E+00	.449644E+04	.325248E+00	.448494E+04	.329472E+00	.447344E+04
.333696E+00	.446766E+04	.337920E+00	.446194E+04	.342144E+00	.445044E+04	.346368E+00	.443894E+04
.350592E+00	.442744E+04	.354816E+00	.441594E+04	.359040E+00	.441045E+04	.363264E+00	.440444E+04
.367488E+00	.439294E+04	.371712E+00	.438695E+04	.375936E+00	.438144E+04	.380160E+00	.436994E+04
.384384E+00	.435844E+04	.388608E+00	.434694E+04	.392832E+00	.434109E+04	.397056E+00	.433544E+04
.401280E+00	.432394E+04	.405504E+00	.431244E+04	.409728E+00	.430678E+04	.413952E+00	.430094E+04
.418176E+00	.428944E+04	.422400E+00	.427794E+04	.426624E+00	.426644E+04	.430848E+00	.426059E+04
.435072E+00	.425494E+04	.439296E+00	.424344E+04	.443520E+00	.423194E+04	.447744E+00	.422652E+04
.451968E+00	.422044E+04	.456192E+00	.420894E+04	.460416E+00	.420296E+04	.464640E+00	.419744E+04
.468864E+00	.418594E+04	.473088E+00	.417444E+04	.477312E+00	.416294E+04	.481536E+00	.415742E+04
.485760E+00	.415144E+04	.489984E+00	.413994E+04	.494208E+00	.413365E+04	.498432E+00	.412844E+04
.502656E+00	.411694E+04	.506880E+00	.410544E+04	.511104E+00	.410002E+04	.515328E+00	.409394E+04
.519552E+00	.408244E+04	.523776E+00	.407636E+04	.528000E+00	.407094E+04	.532224E+00	.405944E+04
.536448E+00	.404794E+04	.540672E+00	.404252E+04	.544896E+00	.403644E+04	.549120E+00	.402494E+04
.553344E+00	.401886E+04	.557567E+00	.401344E+04	.561791E+00	.400194E+04	.566015E+00	.399044E+04
.570239E+00	.398502E+04	.574463E+00	.397894E+04	.578687E+00	.396744E+04	.582911E+00	.396136E+04
.587135E+00	.395594E+04	.591359E+00	.394444E+04	.595583E+00	.393294E+04	.599807E+00	.392755E+04
.604031E+00	.392144E+04	.608255E+00	.390994E+04	.612479E+00	.390422E+04	.616703E+00	.389844E+04
.620927E+00	.388694E+04	.625151E+00	.388119E+04	.629375E+00	.387544E+04	.633598E+00	.386395E+04
.637822E+00	.385817E+04	.642046E+00	.385244E+04	.646270E+00	.384095E+04	.650494E+00	.383487E+04
.654718E+00	.382945E+04	.658942E+00	.381795E+04	.663166E+00	.380645E+04	.667390E+00	.379920E+04
.671614E+00	.379495E+04	.675838E+00	.379092E+04	.680062E+00	.378345E+04	.684286E+00	.377195E+04
.688510E+00	.376631E+04	.692734E+00	.376045E+04	.696958E+00	.374895E+04	.701182E+00	.374320E+04
.705405E+00	.373745E+04	.709629E+00	.372595E+04	.713853E+00	.372008E+04	.718077E+00	.371445E+04
.722301E+00	.370295E+04	.726525E+00	.369531E+04	.730749E+00	.369145E+04	.734973E+00	.368758E+04
.739197E+00	.367995E+04	.743421E+00	.366845E+04	.747645E+00	.366281E+04	.751869E+00	.365495E+04
.756093E+00	.364845E+04	.760317E+00	.363958E+04	.764541E+00	.363395E+04	.768765E+00	.362245E+04
.772989E+00	.361491E+04	.777213E+00	.361095E+04	.781436E+00	.360708E+04	.785660E+00	.359945E+04
.789884E+00	.358795E+04	.794108E+00	.359223E+04	.798332E+00	.357645E+04	.802556E+00	.356495E+04
.806780E+00	.355779E+04	.811004E+00	.355345E+04	.815226E+00	.354770E+04	.819452E+00	.354195E+04
.823676E+00	.353761E+04	.827900E+00	.353045E+04	.832124E+00	.351895E+04	.836348E+00	.351317E+04
.840572E+00	.350745E+04	.844796E+00	.349595E+04	.849020E+00	.348835E+04	.853243E+00	.348445E+04
.857467E+00	.348049E+04	.861691E+00	.347295E+04	.865915E+00	.346145E+04	.870139E+00	.345441E+04
.874363E+00	.344995E+04	.878587E+00	.344419E+04	.882811E+00	.343845E+04	.887035E+00	.343402E+04
.891259E+00	.342695E+04	.895483E+00	.341545E+04	.899707E+00	.340829E+04	.903931E+00	.340395E+04

Figure 10. Partial Listing of a Velocity-Time File

C. Sideband and Spectral Analysis

Option three, Sideband and Spectral Analysis, deals with spectral analysis, waterfall plots, and sideband analysis. Figure 2 shows the secondary menu of option three. To use any of the options in this secondary menu the data must be "retrieved" by going into option two where there is yet another menu list (Figure 11). Within this menu list the user may open and close a data file, transfer and restore data files from tape, purge a data file on disk, and catalog data files. All of this is accomplished by choosing the appropriate option and then answering the questions as they appear on the screen. When option two, open a data file, is chosen, the following questions need to be answered. "Is the mass storage device the disk or magnetic tape? What is the name of the file to be accessed? Should a new file be created or should this file replace the current file?" Most of the time a new file does not need to be created. This is only used when part of the file is needed and this can usually be accomplished within other programs. "Should the label information be changed?" Usually this does not need to be changed unless a mistake was made when originally typing the label. A complete example of this option with all the questions and answers is in Appendix B. The name of the file and the header information contained in the first record are brought into memory. The actual data points are brought into memory only when needed by the program. The other options within this menu have similar questions that need to be answered. The radar files are fairly large and, depending on the actual size and the number of other data files stored on the disk, sometimes only a few additional files may be stored. The user must be able to store these files on tape and then purge them from disk. When option three of the main menu list was choosen, the current capacity of the disc was shown (Figure 2) allowing the user to decide if any more files may be stored on the disk.

```
OPTIONS:
   0 - RETURN TO MENU LIST
   1 - CLOSE A DATA FILE
   2 - OPEN A DATA FILE
   3 - TRANSFER A DATA FILE TO TAPE
   4 - RESTORE A DATA FILE FROM TAPE
   5 - PURGE A DISK FILE
   6 - CATALOG THE DATA FILES
```

Figure 11. Data File Access Menu List

The process used most often is option six, Fourier Spectral Analysis, also known as FFT's. For this program the user must retreive the data and then select option six. Once in option six the user must select on which blocks of data to perform the spectral analysis. Usually for the first FFT all the blocks of data are used. The user is given the option of changing the time between spectra. This time is computed from the header information. The user might want to change the time if there was a mistake made when answering the questions after digitization or if the user would like to change the units from seconds to milliseconds or microseconds. In doing this a problem can be created when labeling plots since some plots, particularly waterfall plots are pre-labeled and depend on the time being in seconds. The user must decide what transform expansion factor to use. Usually one is chosen as a transform expansion factor. By choosing a different transform expansion factor the user can change the size of the block of data being transformed. A transform expansion factor of one means 1024 (1024 * 1 = 1024) data points will be used; a transform expansion factor of two means that 2048 (1024 * 2 = 2048) data points will be used. If the transform expansion factor is negative the number of points (1024) is divided. If the transform expansion factor is a negative two the number of points to transform is 512 (1024 / 2 = 512). Different window types may be used: rectangular, Hanning, Hamming, and Gaussian. For most of the analysis done rectangular windowing is chosen, since the data recorded for use with this analysis package usually has a bandwidth much wider than the bandwidth of the phenomenon of interest. The resolution of the transform may be changed by entering a resolution factor other than one. If a resolution factor, is entered higher resolution is obtained by zero fill, periodic continuation, or periodic expansion. With zero fill zeroes are put at the beginning, end, or beginning and end of a file to increase the number of points thereby increasing the resolution. With periodic continuation the file is repeated using odd periodic continuation until the correct number of points is obtained. The periodic expansion option is being used to test another option and is currently not working. The user is asked whether zero mean correction is desired. The answer is NO; this was put in for a specific set of data that was offset. The user must also decide what the starting frequency should be. When in-bore data is being analyzed the starting frequency is zero since the starting velocity is zero and frequency and velocity are approximately proportional. When analyzing data from free flight the starting frequency needs to be tailored to the velocity of the projectile and frequency of the radar used. The user also needs to decide on an overlap. An overlap allows for a smoother progression of peaks by not using a completely new set of points for each new FFT. There is an example of this complete process in Appendix C. After all the questions have been answered the FFT routine essentially takes a spectral analysis of a segment of data, then takes a spectral analysis of the next segment of data, and this continues until all the data desired has been transformed. These data are then plotted as a waterfall plot, option nine.

Option five, High Resolution Spectral Analysis, allows the user to perform a Maximum Enthropy Spectral Analysis (MESA) on the data. This method has not proved very successful for analysis of radar data and will not be discussed here.

Both these spectral analysis processes may be plotted as waterfall plots. Again when plotting a waterfall plot, the data must have already been retrieved before entering the plotting option. The user selects option nine and chooses what type of plotter is to be used for the waterfall plot. The waterfall plot may be plotted on a Hewlett Packard 2648A (HP2648A) graphics terminal or on several different types of plotters. If the HP2648A graphics terminal is choosen the user must be working there. The user then answers the questions presented. The user designates whether these are Fourier spectra or MEM (Maximum Enthropy Method) spectra. The option exists to plot only part of the frequency data and the user must decide which part to plot. On a first plot it is usually helpful to plot all 512 points on the frequency axis and on subsequent plots to plot only the points where the data is located. The spectra type must be decided upon; normal indicates that all frequency peaks will show up and line mode indicates that only the largest peak will appear. The user must also decide which spectra to plot. Again, as with the points on the frequency axis, it is usually advantageous to plot all the spectra and then limit the number on additional plots with the exception that if the plot is to be displayed on the HP2648A terminal sixty spectra is really the limit to what can be seen. The number of spectra for scaling is usually a few (five) more than the number actually being plotted since this keeps the last peaks from being chopped off. The spectra may be normalized to the first or independently. If they are normalized independently, the highest peak of each line will be the same height. If they are normalized with respect to the first, the height of the peaks will vary with the strength of the doppler return. The vertical scale expansion factor indicates how tall the highest peak is to be if independent normalization is used or how tall the first peak is to be if the spectra are normalized to the first. A good height to use is six. This means the peak will be six spectra high. The peaks may be clipped if looking for secondary peaks and the clipping height will be required. The peaks may be aligned and the advantages of this will be discussed in Example 2: Fast Fourier Transforms and Waterfall Plots. Last there is an option to draw the axes if desired.

The first option in Figure 2 allows data transfer between the HP1000 and an HP9845, a desktop computer. This is done to allow analysis to be done on a remote computer. This is not used very often since the HP9845 is a slower machine and there are large amounts of data to process with radar data.

Option three goes into yet another menu list (Figure 12). Within this menu the file size may be adjusted, the zero level of the data adjusted, the data plotted, and the mean and standard deviation of the data found. All of this is accomplished by asking the user which points to perform the specified function on and then the program returns when the function is finished. When the user is finished with all options needed, a zero is entered to return the user to the next menu list up.

```
OPTIONS:
  0 - RETURN TO MENU LIST
  1 - PLOT OF DATA WITH CURSOR READOUT
  2 - ZERO LEVEL ADJUSTMENT
  3 - ADJUST # OF DATA BLOCKS
  4 - MEAN AND STD DEV OF ALL OR PART OF DATA
  5 - MODIFY DATA INCREMENT
```

Figure 12. Adjust Zero Level or Number of Blocks to Process Menu List

Option four looks at the amplitude modulation and treats this as a time varing signal. This process has not been very succesful and is not recommended for use.

Option seven allows the user to filter the data by designing lowpass filters, highpass filters, or bandpass filters. Again, this is accomplished by asking the user specific questions about the filter being designed. Option eight is only in the menu list to test some trial plotting programs and is of no use to the user.

D. Utility Programs

In option five of the main menu list of Figure 1 there are various utility programs available for use (Figure 13). Three of these options convert files to a different type of file: one from a raw doppler file to a data-time file, one from a data-time file to an analysis file, and the other from an analysis file to a time-data file. In these three options the user is asked such questions as the name of the file to be converted, the name of the new file, the time between samples, and what blocks or points are to be processed. The only reason the time between samples is asked is in case of an error in answering questions or in case of round off error. The time between samples is found by subtracting the actual times between to data points and this can cause a round off error. For example, the times can be stored in such a way that when subtracted the time between points is 0.49999999 when it should actually be 0.5.

```
OPTIONS:
  0 - END PROCESS
  1 - COMBINE TIME DATA FILES
  2 - CONCATENATE TIME DATA FILES
  3 - CONVERT RAW DATA TO TIME DATA
  4 - IN-BORE WAVELENGTH CORRECTION
  5 - RE-ZERO AND SCALE TIME DATA
  6 - TRUNCATE TIME DATA FILE
  7 - COPY A FILE
  8 - VELOCITY CORRECTION
  9 - CONVERT TIME-DATA FILES TO ANALYSIS FILES
 10 - CONVERT ANALYSIS FILE TO TIME-DATA FILE
```

Figure 13. Utility Programs Menu List

Time-data files are combined in different ways using options one and two. Option one takes the data part of file one and makes it the x value of the new file. It takes the data part of file two and makes it the y value of the new file. In option two, file two is appended at the end of file one to make a new file. Both of these options ask for the name of each of the two files to be combined as well as the name of a new file to be created. There is no error checking. When files are appended by option two, there is no check to see that the time continues to increase; therefore the user must be sure the values make sense.

An in-bore wavelength correction may be done with option four. This is used since there is a shift in the waveguide wavelength of the radar from in-bore to freespace at muzzle exit (see reference 3).

Option five allows the units on a time data-file to be changed. The user enters three variables. The first variable entered is subtracted from the data. The data is multiplied by the second variable entered and divided by the third variable entered.

Option six truncates a time data-file while option seven copies a time-data file. Option eight corrects a velocity-time file to zero velocity when the velocity does not start at zero.

E. Zeroing Programs

Sometimes after a velocity profile is completed it is advantageous to see what types of sinusoidal motion are superimposed on the data. The main program for doing this is the spectral analysis program which was already written for use with strain, pressure, and acceleration data; therefore, the easiest way to perform a spectral analysis is to convert the data to analysis type data. Once a velocity-time file has been converted to an analysis file the spectral content may be determined. A spectral analysis may not be performed directly on this data because there is an oscillation about the velocity, not about zero. This curve needs to be zeroed so that the oscillations appear about zero on the horizontal axis and this is where the Zeroing Programs are used. This is a relatively simple set of programs that has only one menu list (Figure 14). The first two options allow the user to store and retrieve data similar to the options in the radar programs. Data must be retrieved before going into any of the other options. In this particular set of programs the data files contain less then 30,000 points; therefore, all the data is in memory at one time. With the HP1000 30,000 is about the limit as to the number of points that can be in memory with out running out of memory. Option three is the first step in the zeroing process which is to fit a parabola to the data. Three points are choosen for the fit; usually the user chooses the first, last, and an approximate middle point. The user is asked to enter the index of the points used for the fit and has the opportunity to change them if he makes a mistake. Option five plots these two curves to see if a good fit has been obtained (Figure 15). If a good fit has not been obtained the user may return to option three and choose three different points for the fit. Once this is done the parabola is subtracted from the original data using option four. In doing this an S curve is introduced. This curve may be filtered out, if desired, and the data plotted using option six (Figure 16). The spectral content can now be determined by using the analysis set of programs. If a closer look is needed, more points may be added back into the file and the file may be converted to a radar file (option seven) so that an FFT and waterfall plot may be done. There are two other options that allow the user to increment the data or combine two data file. These two processes are

```
OPTIONS:
  0 - END PROCESSING
  1 - STORE DATA
  2 - RETRIEVE DATA
  3 - PARABOLIC FIT
  4 - ZERO DATA CURVE
  5 - PLOT OF PARABOLA AND DATA CURVE
  6 - PLOT OF ZEROED DATA CURVE
  7 - CONVERT FILE TO RADAR FILE
  8 - ADJUST INCREMENT OR SIZE OF DATA FILE
  9 - MULTIPLE DATA FILE MANIPULATION
```

Figure 14. Zeroing Programs Menu List

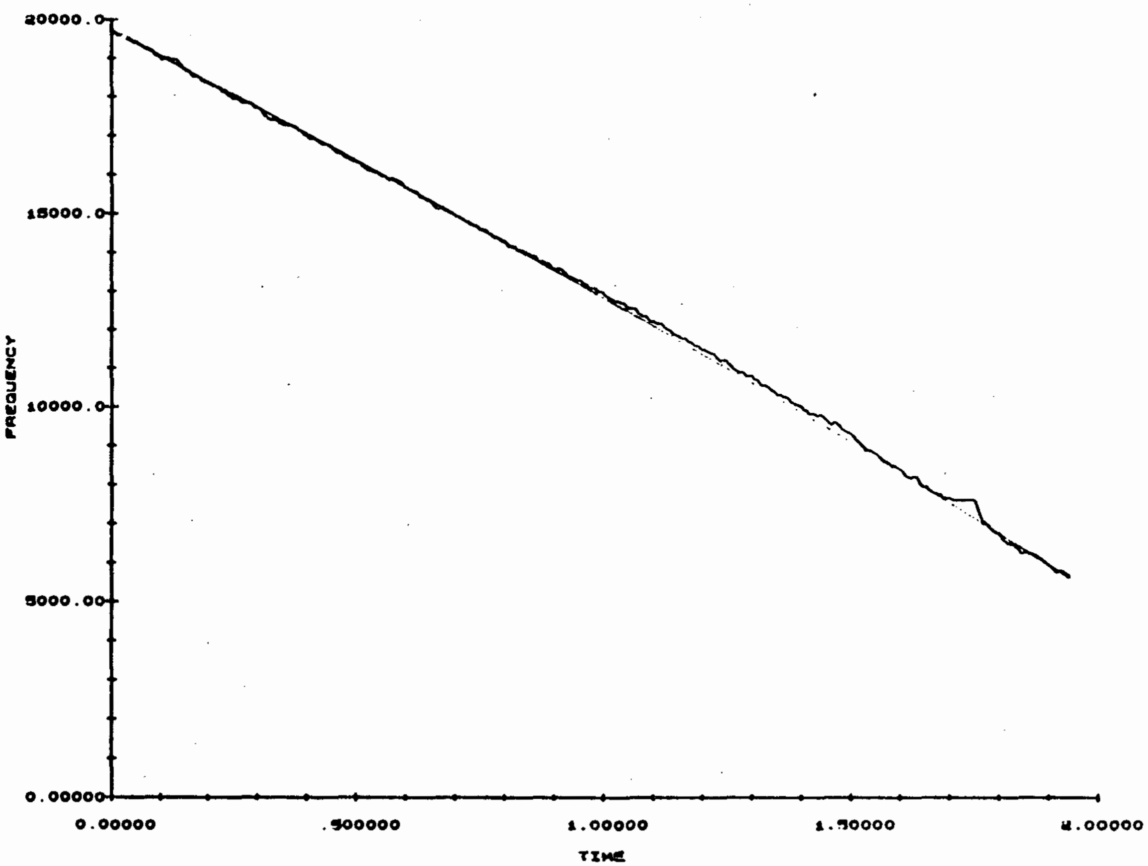

Figure 15. Data with a Parabolic Fit

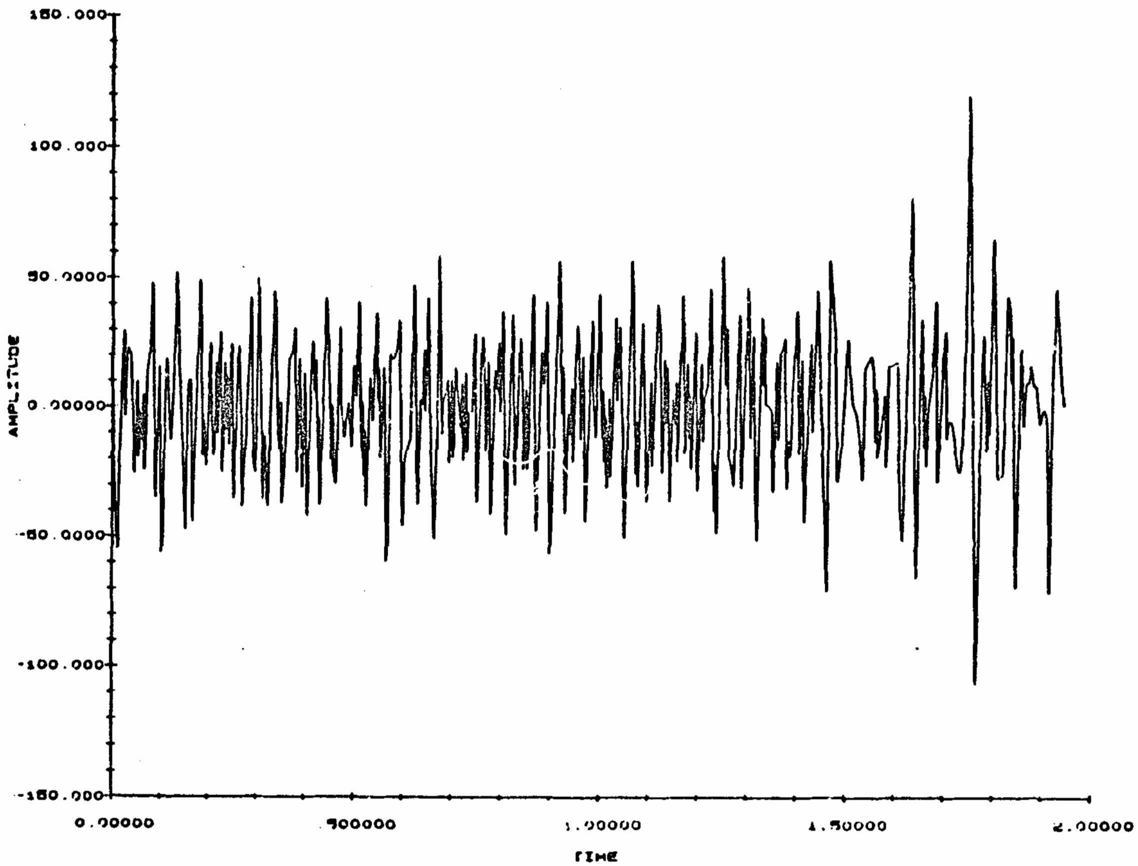

Figure 16. Zeroed Data

very similar to processes in the radar programs described in Section C, Sideband and Spectral Analysis and Section D, Utility Programs.

IV. EXAMPLE 1: OBTAINING A VELOCITY PROFILE

The data were recorded on analog tape at 60 ips. Within the A/D system the data was passed through a wide band filter where the gain was increased to five. The spectrum analyzer was used to determine the start of the record and how long the record lasted (Figure 17). The data was sampled at 30,303Hz with the tape speed slowed down to 7.5ips or a slowdown factor of eight (60ips / 7.5ips = 8) giving a real time sample rate of 242,424Hz (30,303Hz * 8 = 242,424Hz). The record lasted approximately 60 seconds or 7.5 seconds (60sec / 8 = 7.5sec) in real time. On another channel an IR pulse was present indicating muzzle exit; therefore, an automatic trigger could be used. This channel of data with the IR pulse was run through the trigger, when the voltage reached a certain level the digitizer started. A small section of the digitized data is shown in Figure 18. Nothing can be seen from this plot of raw doppler radar data. The velocity profile may be determined directly from this data when a minimum starting velocity is known. The minimum starting velocity was approximately 5000 feet per second; therefore, the minimum starting velocity entered was 4900 feet per second. The bounds choosen were zero for the upper bound (implying the velocity would not increase) and 30 for the lower bound. Every block of data was processed with an overlap of one. Auto change was enabled and consecutive rejections were checked. Since this data was relatively smooth once the correct point in the beginning was accepted the program ran by itself and needed no interaction from the user. The velocity profile was then edited using a cubic spline to obtain a velocity curve (Figure 19). This data was then written to tape so that the data could be transfered to another machine.

V. EXAMPLE 2: FAST FOURIER TRANSFORMS AND WATERFALL PLOTS

A raw FFT has resolution of one and no overlap (also called an overlap of one). This means a spectral analysis is performed on the first 1024 points (one block of data as it has been stored), then on the second set of 1024 points, and so on. These data may now be plotted as a waterfall plot (Figure 20). Again, in a waterfall plot the frequency is on the horizontal axis increasing to the right and time is on the vertical axis increasing upward. The record can be seen starting at approximately 13 milliseconds and 40kHz. These peaks progress in a somewhat smooth manner and increase in frequency which means the projectile is increasing in velocity (frequency is approximately proportional to velocity). This particular waterfall plot is from the doppler radar of a projectile in-bore and does not show much more than where the data record is located. To generate more spectra and a smoother transgression of peaks, an overlap must be used. For example, if an overlap of four is used the first spectral analysis is performed on the first 1024 points. The following spectral analysis uses 768 points (three quarters of a block) from the previous spectra and 256 new points (one quarter of a block). The waterfall plot of this spectral analysis is seen in Figure 21. The resolution has not changed; therefore, the flight of the projectile may be seen but the frequency between points is the same and it is too large to see any characteristics of the flight of the projectile. The resolution

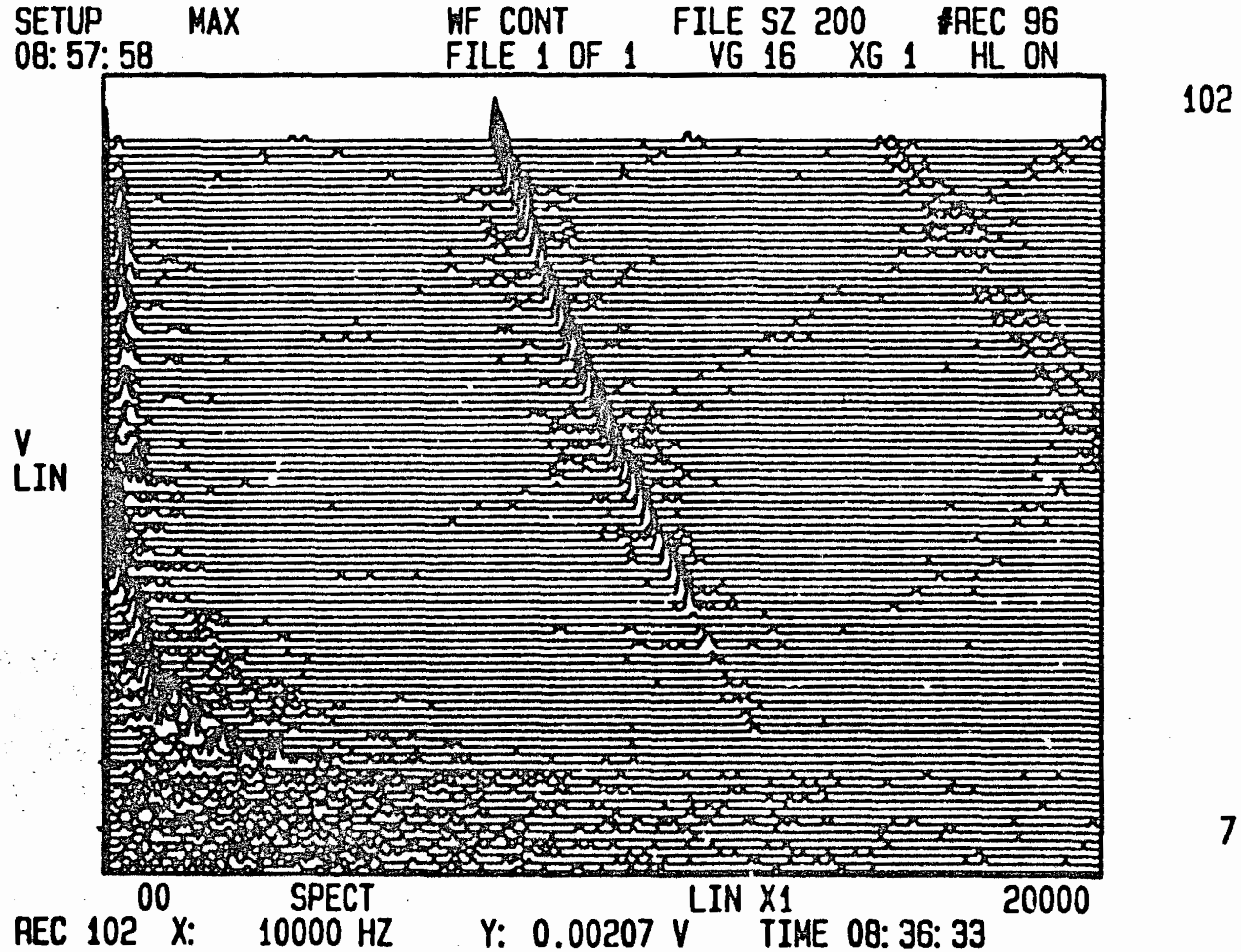

Figure 17. Start of Record

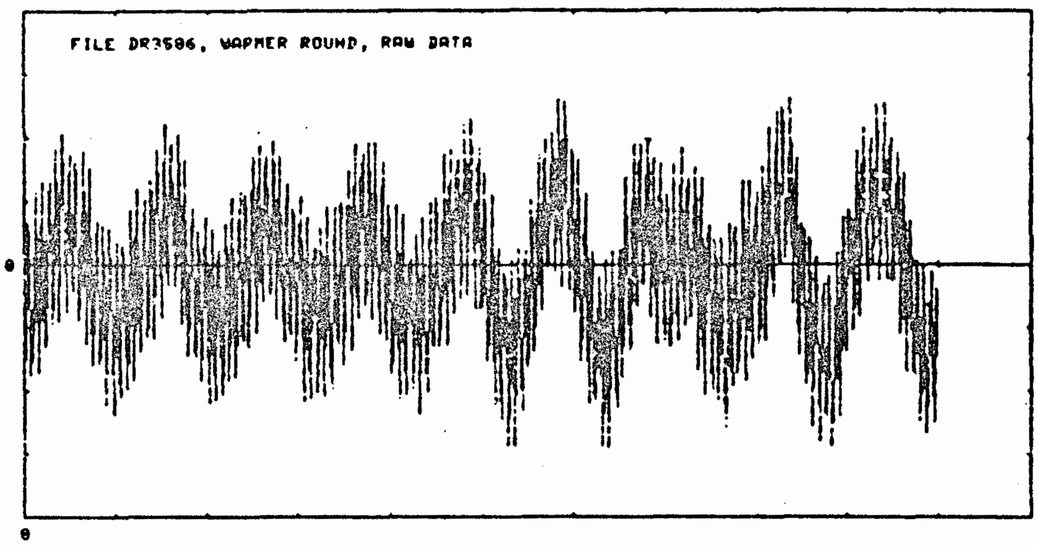

Figure 18. Digitized Data

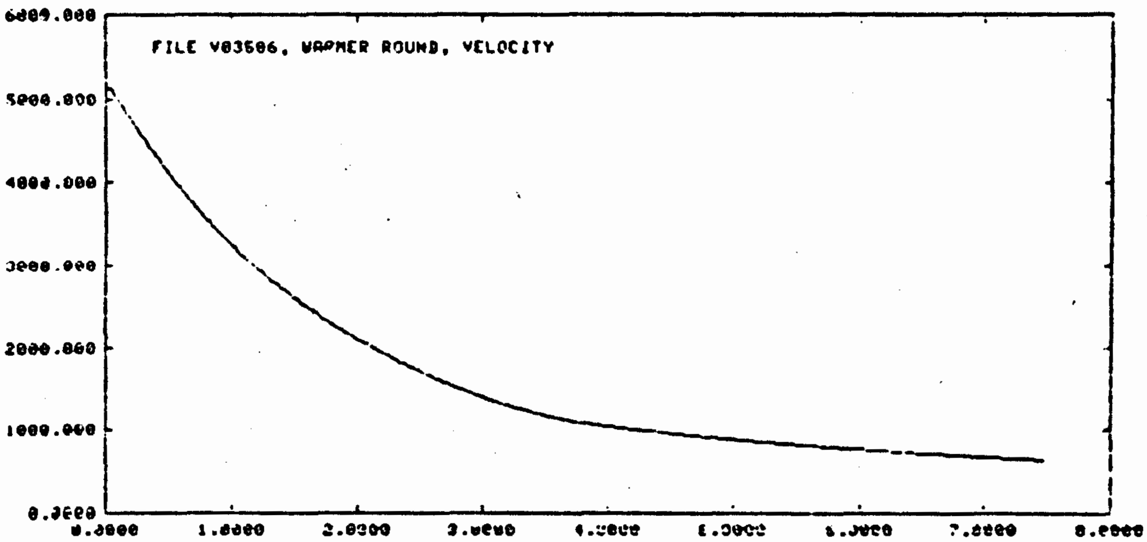

Figure 19. Velocity-Time Plot

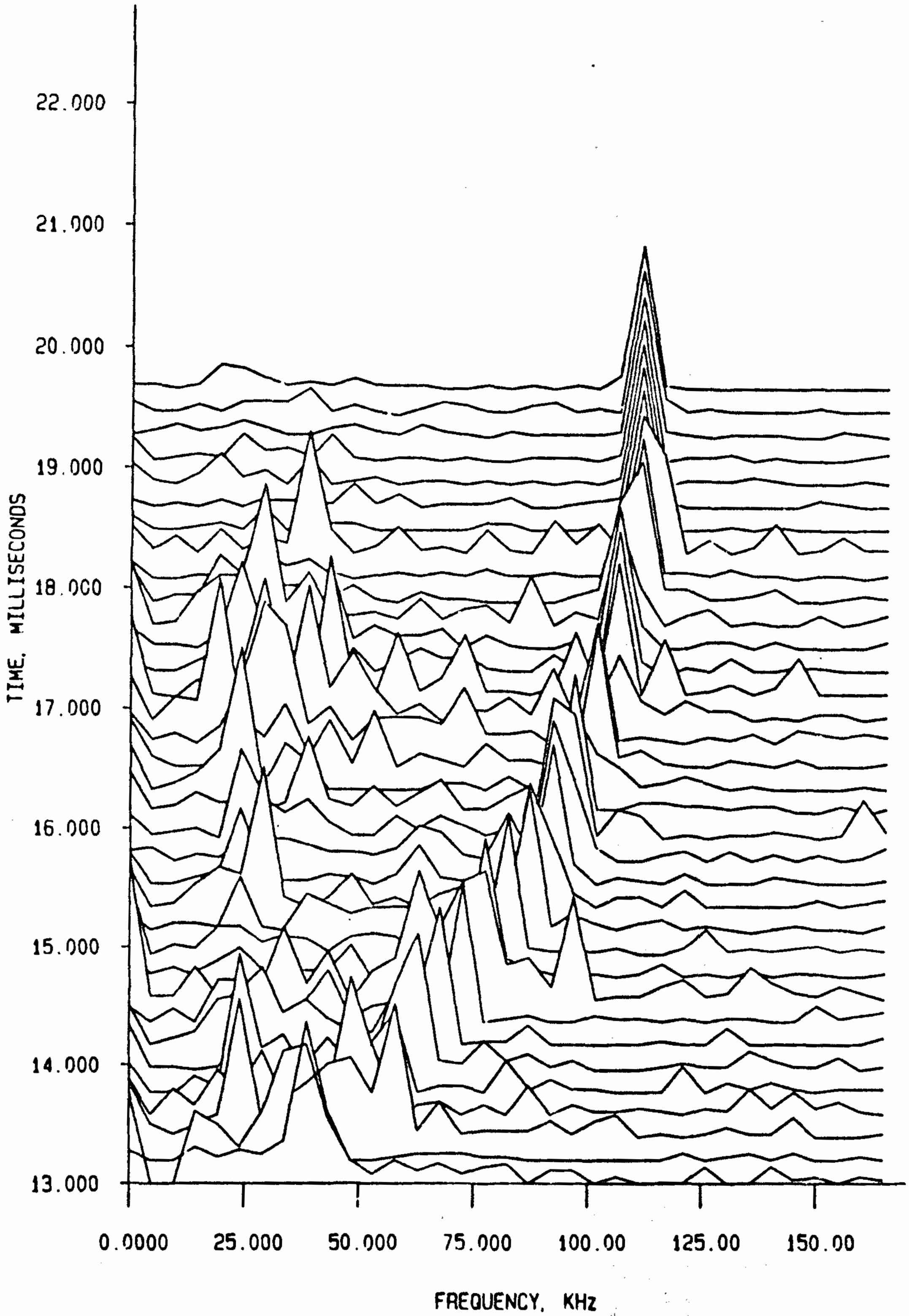

Figure 20. Raw FFT with Overlap 1 and Resolution 1

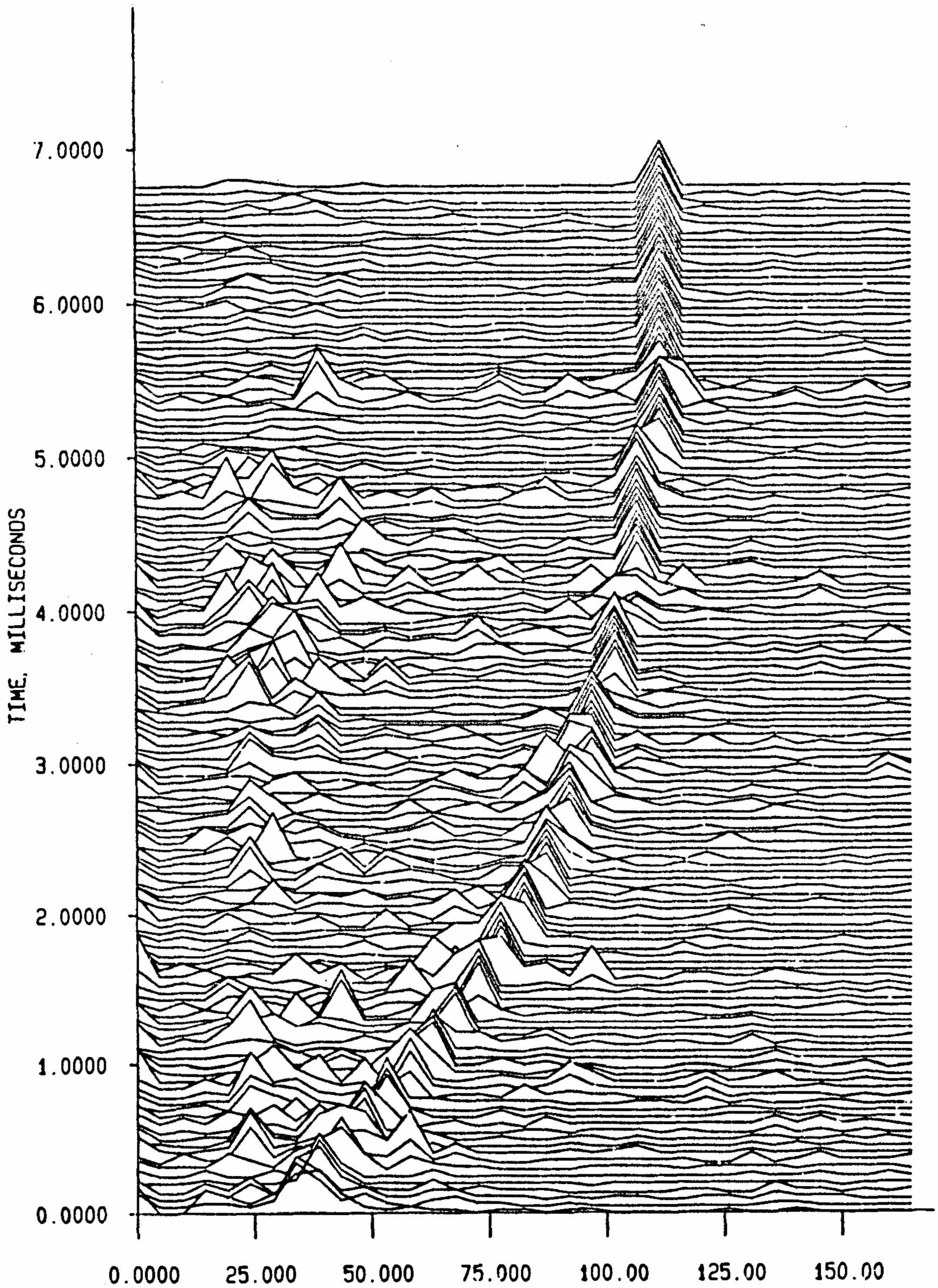

Figure 21. FFT with Over'ap 4 and Resolution 1

may also be increased so that there is less of a frequency change between points. If a resolution of 16 is used 15,360 ((16 - 1) * 1024 = 15,360) zeros are added to the end of each 1024 point segment before transforming it. The plot in Figure 22 shows more detailed frequency information that is obtained by this process. Some oscillation may be seen early in-bore (starting at 1.35 and continuing through 3.65 milliseconds) indicating balloting. The spectra are normalized independently in Figure 23 and they are normalized with respect to the first spectra in Figure 24. As can be seen when the spectra are normalized independently the highest peak of each line on the waterfall plot will be the same height. When the spectra are normalized with respect to the first, the height of the peaks varies with the varying strength of the doppler return. The data in Figure 25 are plotted by aligning the peaks which will sometimes allow the cyclic motion of the side lobes to be seen as in this figure.

VI. EXAMPLE 3: IN-BORE ANALYSIS

These data were digitized with a real time sample rate of 5120kHz; a raw (no resolution, no overlap) FFT was performed on all blocks of the data. When plotted these data show where the actual record begins and ends (Figure 26). The increase in velocity could be seen but no other details were visible. An FFT with resolution sixteen and overlap four was done (Figure 27). Now muzzle exit can be seen at approximately 7.5 milliseconds as well as some sinusoidal motion in-bore indicating balloting.

VII. CONCLUSIONS

The HP1000 has four sets of analysis programs resident on it. There are two sets used for doppler radar analysis: the Radar Programs and the Zeroing Programs. One specific program, the spectral analysis program, from the Analysis Programs is used in special cases with radar data. These sets of programs are all run interactively on the HP1000 and look very similar to the user. The radar programs do not bring all the actual data into memory as the other programs do. This is the major difference between the program sets, but all of this is transparent to the user.

VIII. ACKNOWLEDGEMENTS

The author would like to acknowledge the asistance of James N. Walbert, VLD and Kathleen L. Zimmerman, IBD for suggestions and review of this report.

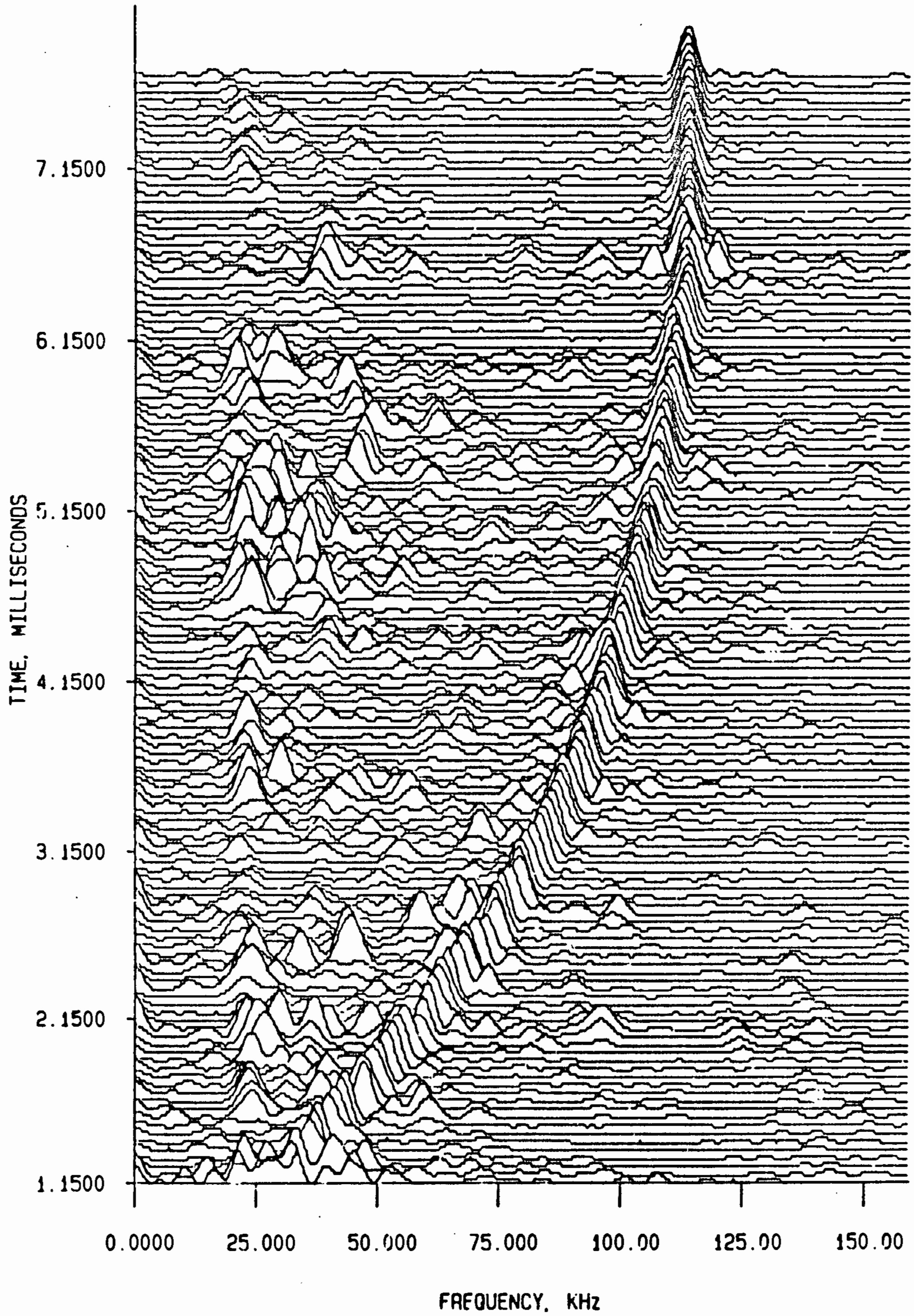

Figure 22. FFT with Overlap 4 and Resolution 16

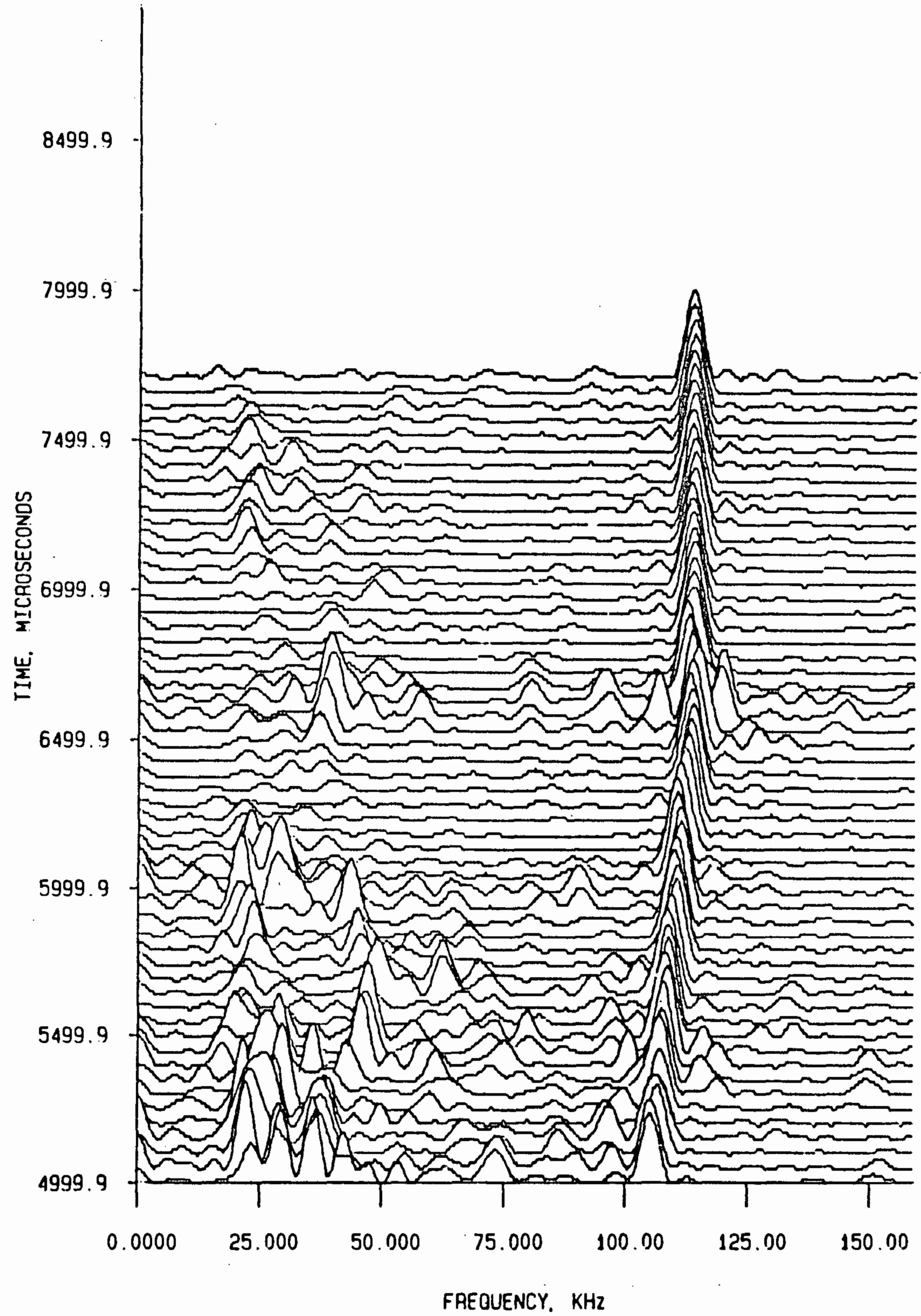

Figure 23. Spectra Normalized Independently

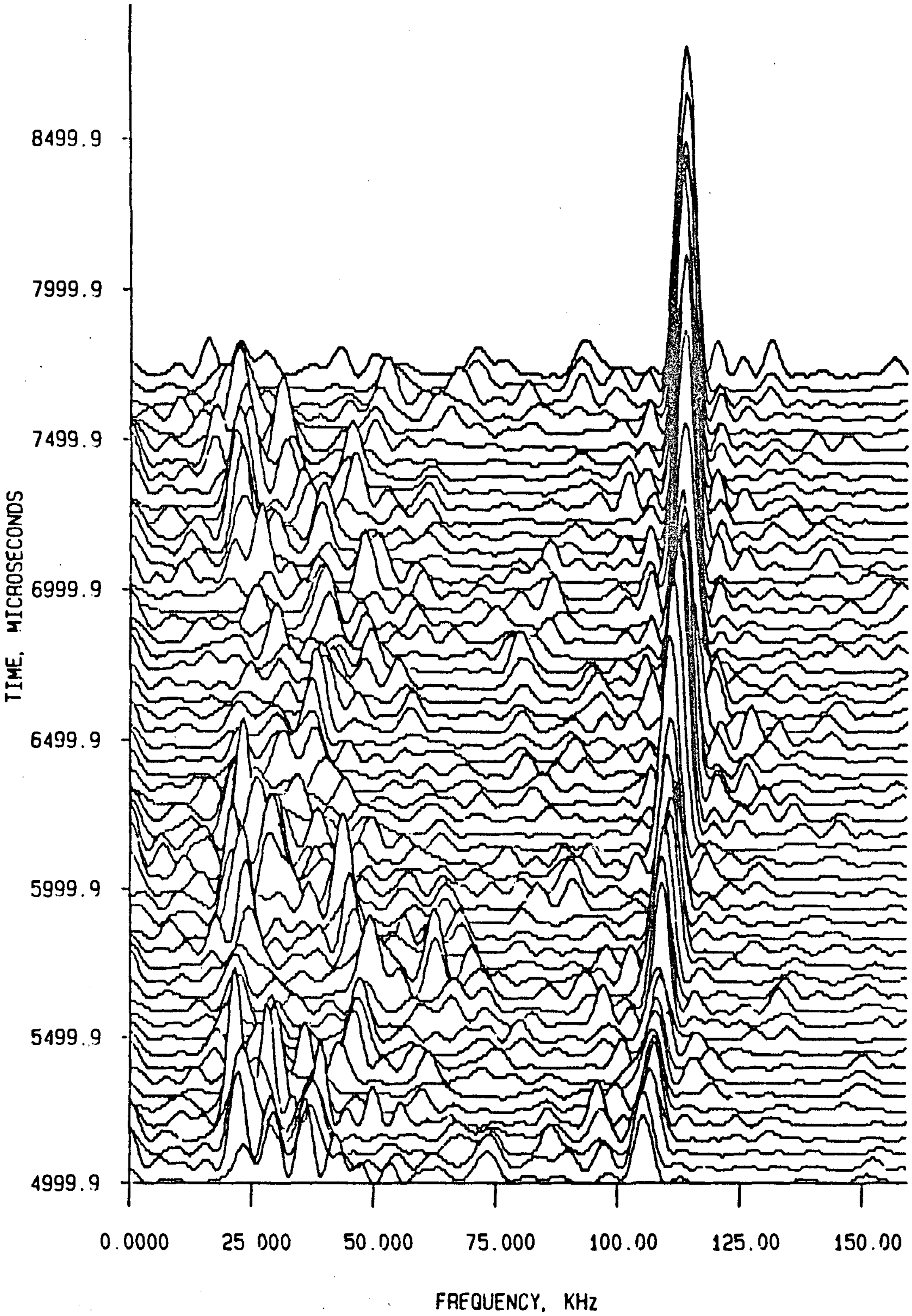

Figure 24. Spectra Normalized with Respect to the First

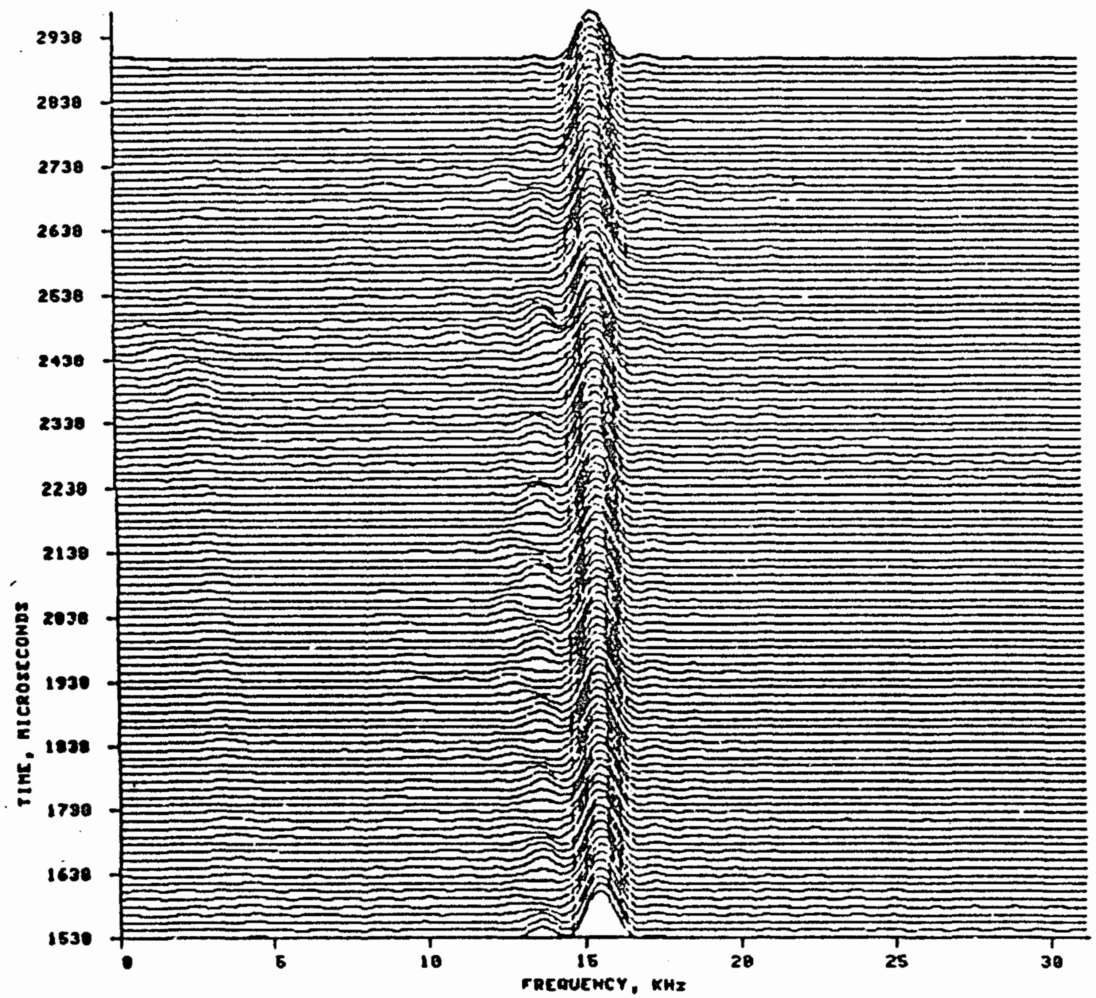

Figure 25. Waterfall Plot with the Peaks Aligned

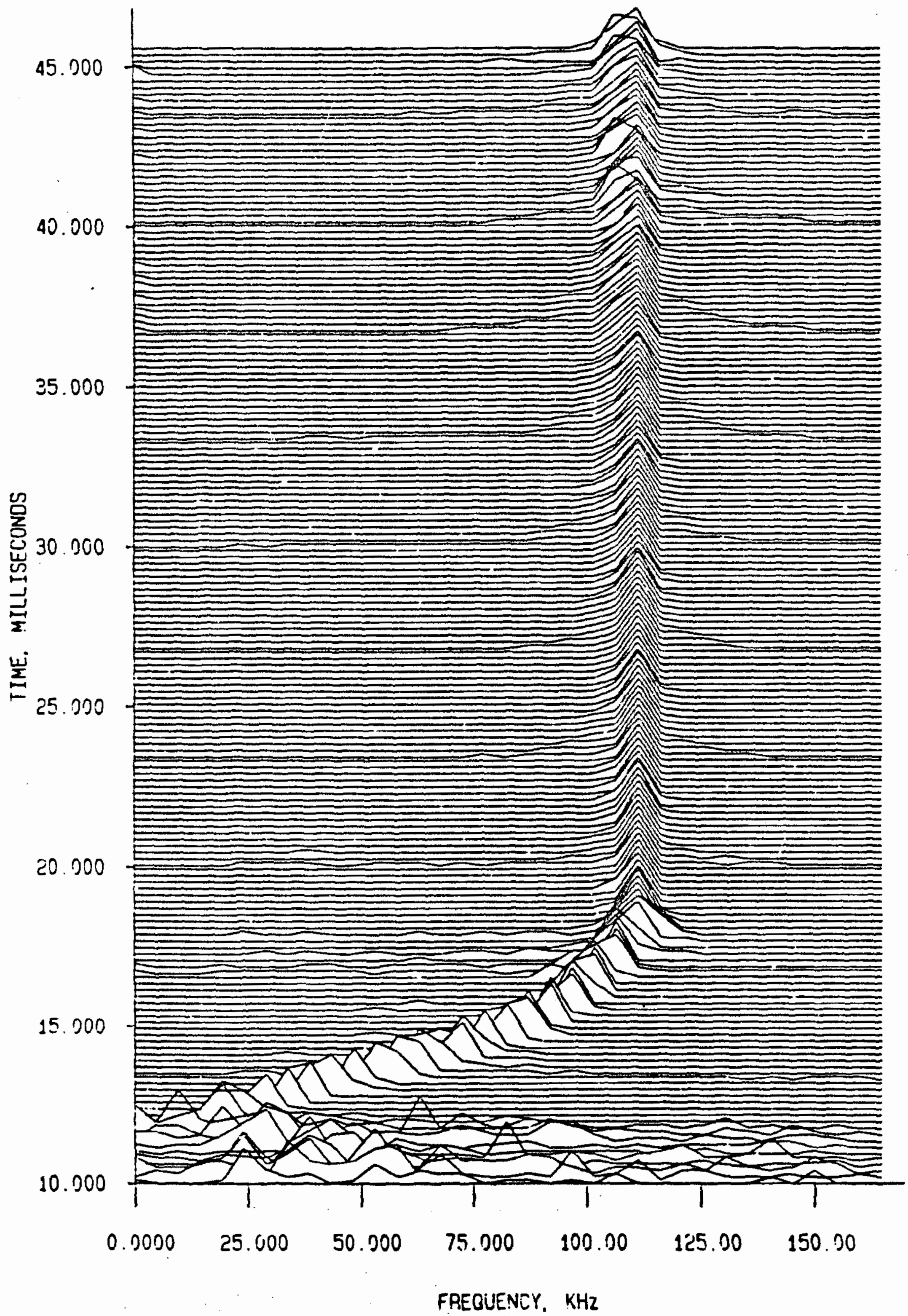

Figure 26. Raw FFT

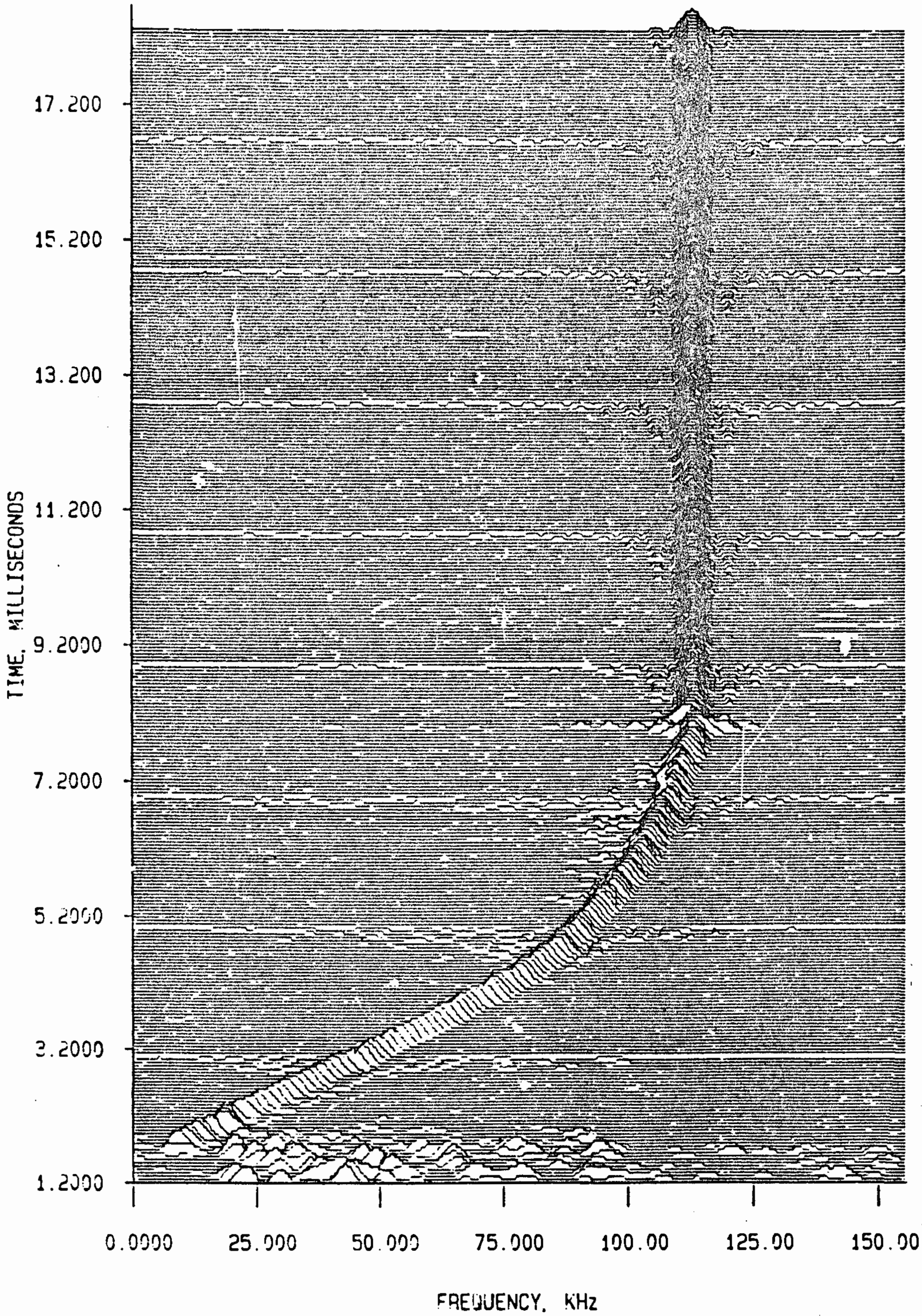

Figure 27. High Resolution FFT with Overlap 4 and Resolution 16

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3. S.F. Adam, *Microwave Theory and Applications*, Prentice-Hall, Inc., 1969

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APPENDIX A - DATA DIGITIZATION

```
OPTIONS:
   0 - END PROCESSING
   1 - DATA DIGITIZATION
   2 - TARGET TRACKING AND ANALYSIS
   3 - SIDEBAND AND SPECTRAL ANALYSIS
   4 - TRAJECTORY AND DRAG COMPUTATION
   5 - UTILITY PROGRAMS
1
ENTER THE NUMBER OF CHANNELS TO BE DIGITIZED:
1
ENTER THE DESIRED SAMPLING RATE:
40000
CURRENT DIGITIZING PARAMETERS ARE
      NUMBER OF CHANNELS:  1
      SAMPLING RATE:  40000.00
 DO YOU WANT TO CHANGE THESE? (YE or NO)
NO
 TIME DURATION (IN SECONDS) FOR DIGITIZING
   THIS FILE (ACTUAL TAPE PLAYBACK TIME - NOT EVENT TIME)
1
 IPACE=          25  MULT=      0
 NUMBF=           5  IRATE=    40
IBGN:          0        320          0          0
IERR ON CREATE =     0
ENTER THE MODE FOR TRIGGERING:
   0 - MANUAL
   1 - AUTOMATIC
0
 PRESS RETURN TO START DIGITIZING

DIGITIZING
 DVT77 STATUS = 0000
 DVR62 STATUS = 0000
OKAY TO PROCEED? (YE or NO)
YE
ENTER THE FILE NUMBER (1-9999): (ENTER 0 FOR CATALOG)
2222
IERR =     0 ON CREATE CALL FOR FILE DR2222
FILE NAME IS DR2222
ENTER THE LABEL INFORMATION (72 CHARACTERS MAXIMUM):
DIGITIZING FOR 1 SECOND AT 40KHZ
ENTER THE TAPE SPEED FACTOR
8
DATA IS NOW BEING CONVERTED AND TRANSFERRED
MONITOR STATUS WORD? (YE or NO)
NO
OPTIONS:
   0 - END PROCESSING
   1 - DATA DIGITIZATION
   2 - TARGET TRACKING AND ANALYSIS
   3 - SIDEBAND AND SPECTRAL ANALYSIS
   4 - TRAJECTORY AND DRAG COMPUTATION
   5 - UTILITY PROGRAMS
```

APPENDIX B - OPENING A DATA FILE

```
OPTIONS:
   0 - RETURN TO MENU LIST
   1 - CLOSE A DATA FILE
   2 - OPEN A DATA FILE
   3 - TRANSFER A DATA FILE TO TAPE
   4 - RESTORE A DATA FILE FROM TAPE
   5 - PURGE A DISK FILE
   6 - CATALOG THE DATA FILES
2
IS THE MASS STORAGE DEVICE THE DISK (0),
   OR A MAGNETIC TAPE (1)?
0
ENTER THE NAME OF THE FILE TO BE ACCESSED:
DR2222
FILE NAME IS DR2222

DIGITIZING FOR 1 SECOND AT 40KHZ

PARAMETERS:
   NUMBER OF CHANNELS =  1
   LOGICAL RECORD LENGTH = 2048
   NUMBER OF RECORDS =   41
     (1 HEADER RECORD PLUS   40 DATA RECORDS)
   SAMPLING RATE (Hz) = 40000.
   TAPE SPEED FACTOR =    8
   TIME (SEC) BETWEEN SAMPLES = .3125000E-05
 IS THIS THE CORRECT FILE? (YE or NO)
YE
CREATE NEW FILE (0), OR REPLACE CURRENT FILE (1)?
1
DO YOU WANT TO CHANGE THE LABEL INFORMATION?
NO
OPTIONS:
   0 - RETURN TO MENU LIST
   1 - CLOSE A DATA FILE
   2 - OPEN A DATA FILE
   3 - TRANSFER A DATA FILE TO TAPE
   4 - RESTORE A DATA FILE FROM TAPE
   5 - PURGE A DISK FILE
   6 - CATALOG THE DATA FILES
```

APPENDIX C - FOURIER SPECTRAL ANALYSIS

```
OPTIONS:
      0 - END PROCESSING
      1 - TRANSFER DATA RECORD TO OR FROM THE hp9845
      2 - DATA FILE ACCESS (TAPE OR DISK)
      3 - ADJUST ZERO LEVEL OR # OF BLOCKS TO PROCESS
      4 - AM SIDEBAND DETECTION AND REMOVAL
      5 - HIGH RESOLUTION (MESA) SPECTRAL ANALYSIS
      6 - FOURIER SPECTRAL ANALYSIS
      7 - DIGITAL FILTER DESIGN/APPLICATION
      8 - ANNOTATED PLOTS
      9 - WATERFALL SPECTRUM PLOTS
     99 - SUSPEND PROGRAM
6
FOURIER TRANSFORM OPTIONS:
     0 - RETURN
     1 - COMPUTE TRANSFORMS
1
THERE ARE   40 BLOCKS AVAILABLE. ENTER THE NUMBER
 TO TRANSFORM (START,STOP) 0 TRANSFORMS ALL:
0
DT IS  .312500E-05. DO YOU WANT TO CHANGE IT? (YE or NO)
NO
ENTER THE TRANSFORM EXPANSION FACTOR +/-(1,2,4,8,16):
1
ENTER THE DESIRED WINDOW TYPE:
   0 - RECTANGULAR
   1 - HANNING
   2 - HAMMING
   3 - GAUSSIAN
0
DATA BANDWIDTH IS .160000E+06 HERTZ
DELTA FREQUENCY IS .312500E+03
OKAY? (YE or NO)
NO
ENTER RESOLUTION FACTOR:  (1,2,4,8,16)
 (MAXIMUM ALLOWED IS   16)
2
DELTA FREQUENCY IS .156250E+03
OKAY? (YE or NO)
YE
ENTER THE MODE FOR HIGH RESOLUTION:
   0 - ZERO FILL
   1 - PERIODIC CONTINUATION
   2 - PERIODIC EXPANSION
0
ENTER THE TYPE OF ZERO FILL DESIRED:
   0 - FILL AT THE END
   1 - FILL AT BEGINNING AND END
   2 - FILL AT BEGINNING
0
CORRECT FOR ZERO MEAN? (0-NO,1-YES)
0
THERE ARE  2048 TRANSFORM POINTS COVERING
THE DATA BANDWIDTH OF .160000E+06 HERTZ.
ENTER THE DESIRED STARTING FREQUENCY
(1024 POINTS WILL BE RETAINED)
0
```

```
FREQUENCY RANGE (HZ): .000000E+00 TO .798438E+05 OKAY?
YE
ENTER THE OVERLAP FACTOR (1,2,4,8,16, OR MULTIPLES
 OF THESE UP TO  1024):
1
ENTER THE FFT FILE NAME:
FFT222
ENTER THE LABEL INFORMATION
FFT OF DR2222 REC WINDOW RES 2 OVERLAP1 FREQ RNG 0-79843.8
ENABLE PLOT OPTION? (0 - NO, 1 - YES)
0
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     1
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     2
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     3
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     4
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     5
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     6
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     7
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     8
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK     9
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    10
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    11
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    12
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    13
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    14
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    15
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    16
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    17
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    18
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    19
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    20
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    21
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    22
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    23
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    24
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    25
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    26
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    27
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    28
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    29
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    30
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    31
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    32
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    33
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    34
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    35
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    36
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    37
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    38
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    39
COMPUTING TRANSFORM NUMBER   1 OF DATA BLOCK    40
```

THE DISK IS 75% FULL.

OPTIONS:

```
       0 - END PROCESSING
       1 - TRANSFER DATA RECORD TO OR FROM THE hp9845
       2 - DATA FILE ACCESS (TAPE OR DISK)
       3 - ADJUST ZERO LEVEL OR # OF BLOCKS TO PROCESS
       4 - AM SIDEBAND DETECTION AND REMOVAL
       5 - HIGH RESOLUTION (MESA) SPECTRAL ANALYSIS
       6 - FOURIER SPECTRAL ANALYSIS
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      99 - SUSPEND PROGRAM
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