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TITLE

FINAL REPORT: SOFTWARE DEVELOPMENT FOR A TRANSPORTABLE INTRAPULSE COLLECTION AND ANALYSIS FACILITY

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Atlantis Scientific
Systems Group Inc.

Specialists in Radar R&D

Final Report: Software Development for a Transportable Intrapulse Collection and Analysis Facility

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Under:

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Abstract

This report documents in detail the software packages developed under this contract. Two software packages have been developed for use with the Transportable Intrapulse Collection and Analysis Facility. The software aids the operator of this system to sort out the radar signal environment by graphically displaying the frequency, pulse repetition interval and pulse width of each emitter and by tracking the movement of radar emitters over time. The software also helps to determine if two emitters are from the same radar by applying various signal processing algorithms to the intrapulse data.

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1. Introduction

Two software packages have been developed in this contract for the Transportable Intrapulse Collection and Analysis Facility [1]. In this facility, a wide band radar ESM system (Phoenix) [1] is used to monitor the radar environment by providing the bearing, RF frequency, pulse repetition interval (PRI) and the pulse width of each radar emitter. Once a signal of interest is identified, a number of other intrapulse receivers [1] are used to provide fine measurements on the signal.

The first software package developed, the Polar Display Software, is used to help the operator sort out the radar signal environment and to graphically display information such as the frequency, PRI and pulse width. It is also used to track movements of radar emitters over time, in terms of bearing change.

The second software package developed is the Signal Processing Software. There are several specialized intrapulse receivers which are used to measure the fine structures of radar signals in terms of amplitude, frequency and phase as a function of time. This software package has three major functions. The first is to group several pulses according to the frequency, peak power and pulse width. The second is to determine the average and peak amplitude, frequency and phase of the pulses in the selected group. The third function is to select and compare two pulses, either from the same pulse train or from two different groups, to determine if they are from the same radar emitter.

All software written was developed using MATLAB 4.1. This report is written to document the software packages written under this contract.

2. Display Software

The display software graphically displays information from an Activity file and from a Pulse Descriptor Word (PDW) file created by [1] in either cartesian or polar coordinates. The structure of the display software is illustrated in the figures 1-3. Some of the features implemented into the software are

1. Load data from an Activity file and from a PDW file.
2. Plot Activity and PDW data in Cartesian coordinates.
3. Plot Activity and PDW data in polar coordinates.
4. Plot Activity and PDW data for a specified frequency range in polar coordinates.

These features are discussed in more detail below.

2.1. Loading Activity and PDW Data

The Activity and PDW data can be loaded and viewed in either polar or cartesian coordinates. When an updated Activity file is loaded the data is appended to the previous data and is grouped according to frequency, pulse repetition frequency (PRF) and the pulse width. When an updated PDW file is loaded the previous data is deleted and only the data from the new file is displayed.

2.2. Cartesian Coordinates

The possible cartesian plots from the Activity data are frequency, PRF and pulse width versus either monopulse bearing or DF bearing and either pulse width or PRF versus frequency. In order to incorporate a tracking feature, if more than one Activity file is loaded the new data is appended to the previous data. The data which have the same frequency, PRF and pulse width, plus or minus a corresponding window, are assumed to be from the same emitter and are therefore placed into the same group. The points from the same group are plotted using the same symbol and colour and are joined by a dotted line to identify the group. The last point entered is also identified.

The possible plots using the PDW data are frequency, monopulse bearing, DF bearing, pulse width and amplitude versus time of arrival.

2.3. Polar Coordinates

The DF bearing and the frequency from the Activity and PDW files can be viewed in polar coordinates. The same tracking feature incorporated into the cartesian coordinate display is also incorporated into the polar display, for the Activity data only.

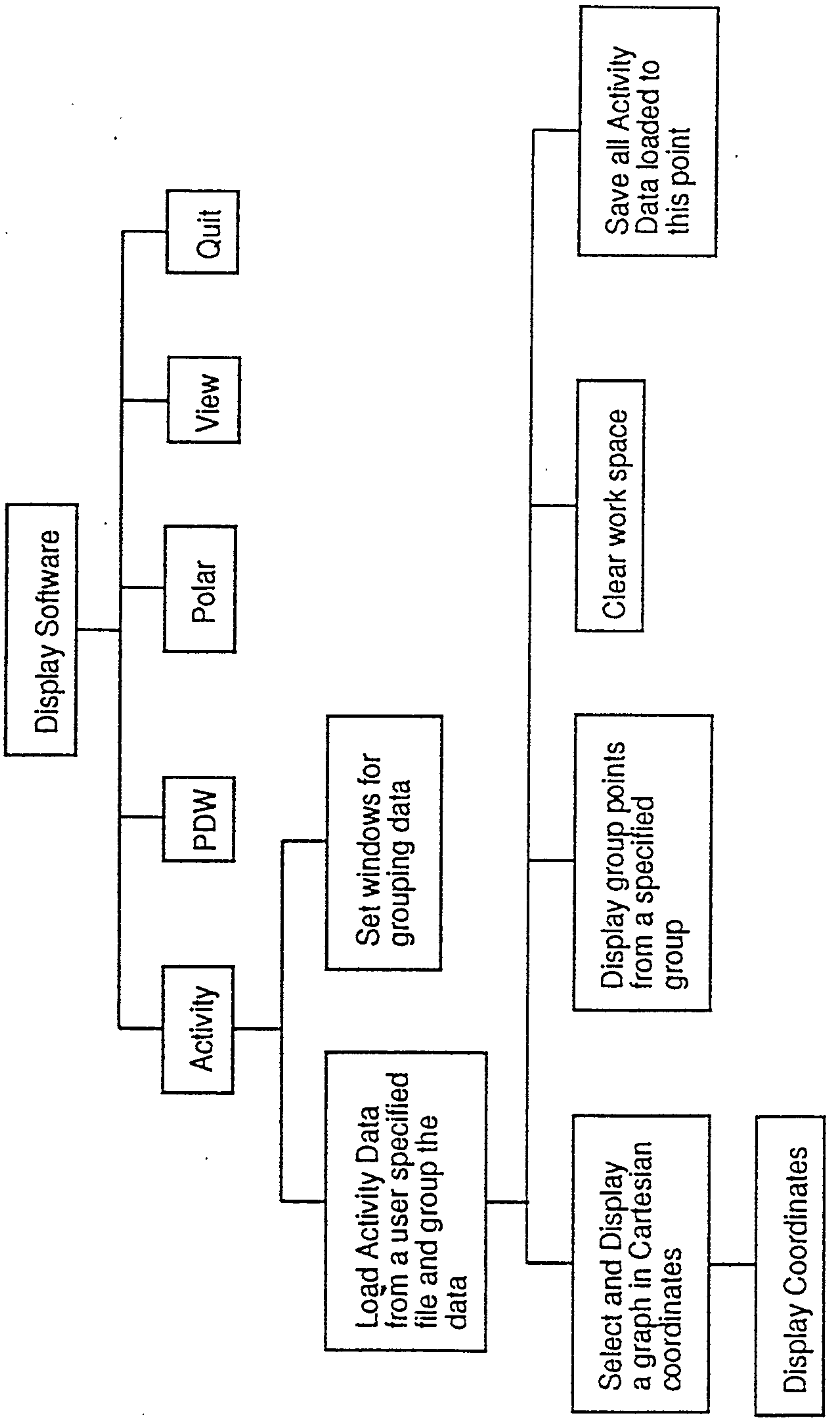


Figure 1 Structure of Display Software.

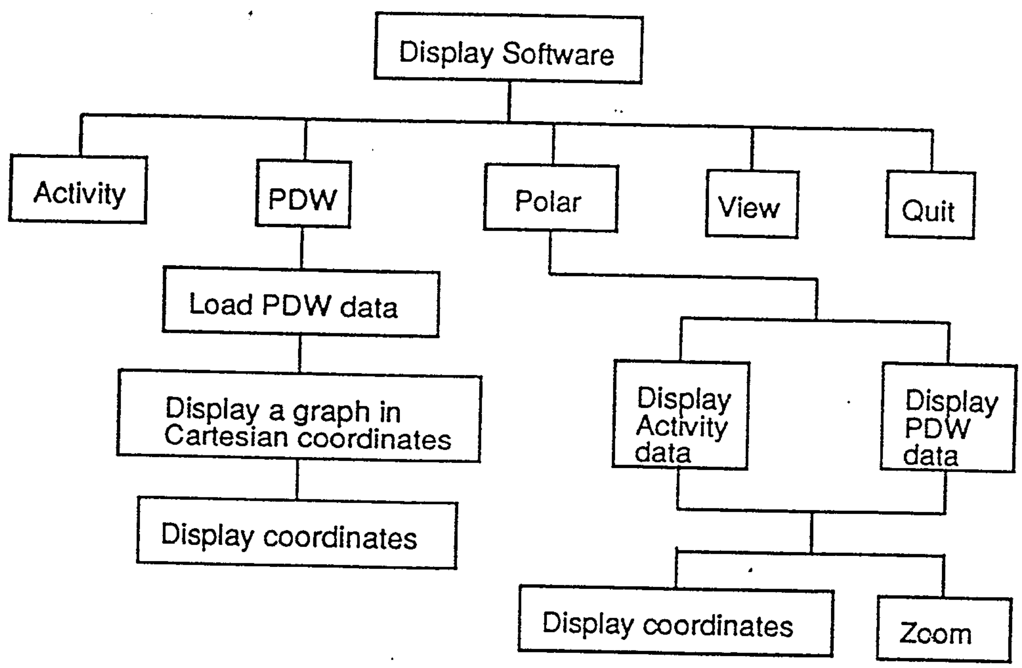


Figure 2 Structure of Display Software continued.

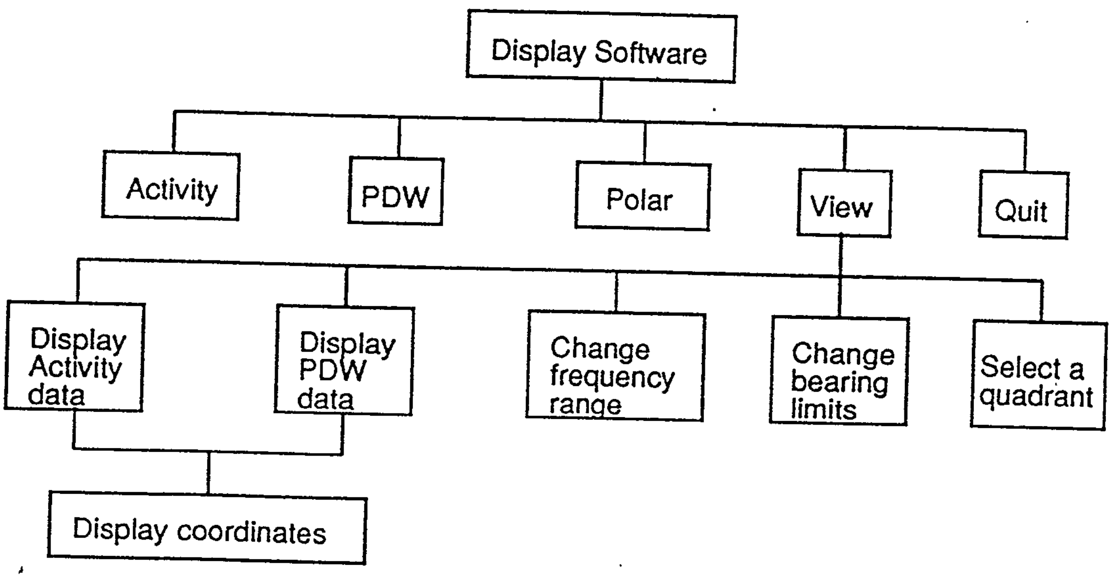


Figure 3 Structure of Display Software continued.

The user can determine the actual coordinates (bearing and frequency) of a specified point by using the mouse. The location of the button press is compared to the actual coordinates of the displayed points. All the coordinates of the points within a specified range of the indicated point are displayed. If the points are too close together the zoom-in feature may be used to view a portion of the polar plot up close. The zoom-in feature changes the limits of the x and y-axis and re-displays only the points within the new limits. Each time the zoom-in feature is selected the length of the new axes is half that of the previous. The first time the zoom-in feature is selected the length of the x and y-axis is set to 4 GHz, where the coordinates of the button press is the centre of the new graph.

Figure 4 shows the frequency and bearing of an Activity file in polar coordinates. The graph shows two radar emitters. The first one has a frequency of approximately 8.3 GHz and has moved from a bearing of 24 degrees to 36 degrees. The second radar emitter has a frequency of approximately 9.4 GHz and has moved from a bearing of 100 degrees to 118 degrees.

2.4. View Specific Range in Polar Coordinates

Since the data is predominantly in the frequency range of 9.3 to 9.5 GHz, the polar graph is modified to only display the points in this frequency range or a range specified by the user. In order to view the specified range in more detail, the graph for frequencies less than the minimum frequency is not drawn to scale. See figure 5. This polar axis is implemented by first drawing a polar graph from 0 to 10 GHz and drawing a circle with radius 1 centred at 0 GHz. All data in the user specified frequency range of $[f_{min}, f_{max}]$ is then mapped to the range [1, 10] using the linear transformation

$$T(x) = \left(\frac{9}{f_{max}-f_{min}}\right) x + 1 - f_{min}\left(\frac{9}{f_{max}-f_{min}}\right)$$

An option is also added to determine the coordinates of a specified point on the graph. Once the data points in the range $[f_{min}, f_{max}]$ are plotted in polar coordinates, the actual coordinates of the data can be retrieved using the inverse linear transformation

$$T^{-1}(x) = \left(\frac{f_{max}-f_{min}}{9}\right) x + f_{min} - \frac{f_{max}-f_{min}}{9}$$

This transformation maps the range [1, 10] to the range $[f_{min}, f_{max}]$.

Again, the same tracking feature is added for the Activity data only.

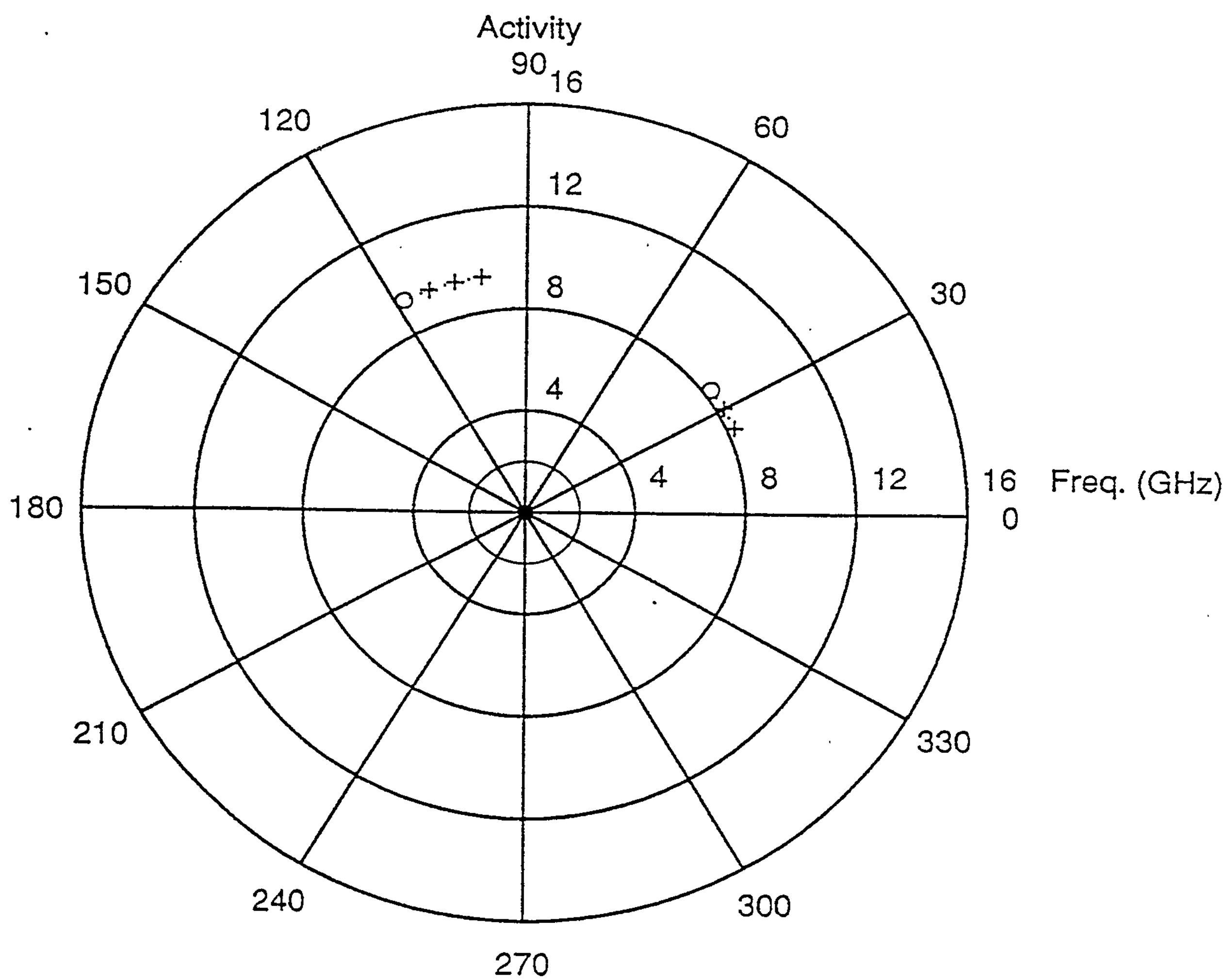


Figure 4 Graph of Activity file in polar coordinates.

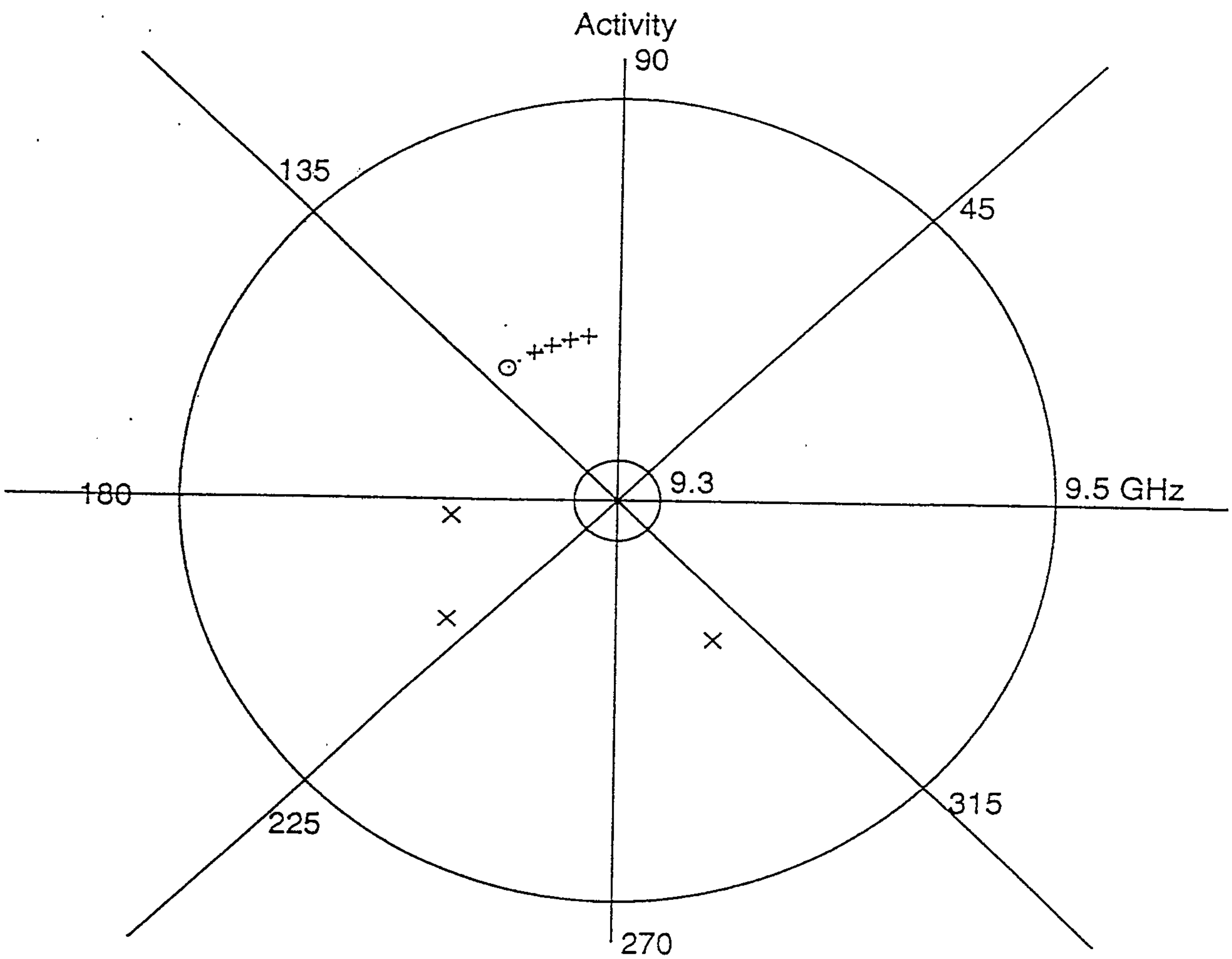


Figure 5 Polar coordinate graph for frequencies 9.3 to 9.5 GHz

3. Signal Processing Software

The purpose of the signal processing software is to compare the intrapulse information of two pulses using various techniques to determine if they are from the same radar emitter. The structure of this software is illustrated in the figures 6-8. The following is a list of some of the features currently implemented into the software.

1. Load the data of two pulses or a set of pulses.

2. Convert data in volts to either dBm or MHz.

3. Select a group of pulses from the loaded set of pulses according to frequency, peak power and pulse width.

4. Calculate the precision pulse repetition interval (PRI) on the group of pulses.

5. Select two pulses from the loaded set of pulses for comparison.

6. View the power, frequency and phase versus time graphs for the two pulses being compared.

7. Select a portion of each pulse and normalize its power, frequency and phase.

8. Perform the cross-correlation function.

9. Perform the discrete Fourier transform (FFT) using either the power, frequency or phase.

10. Calculate the RMS using either the power, frequency or phase.

11. Align the two loaded pulses.

12. Add weighting function (window) for FFT calculation.

These features are discussed in greater detail below.

3.1. Loading Data

Two different data formats can be loaded for analysis. The first format requires two files, one for each pulse being compared. Each file is in matrix form containing the time, power, frequency and phase (the phase data is optional).

The second format requires only one file. Several pulses can be stored in one file. The first nine numbers in the file represent the pulse number, number of points, time of

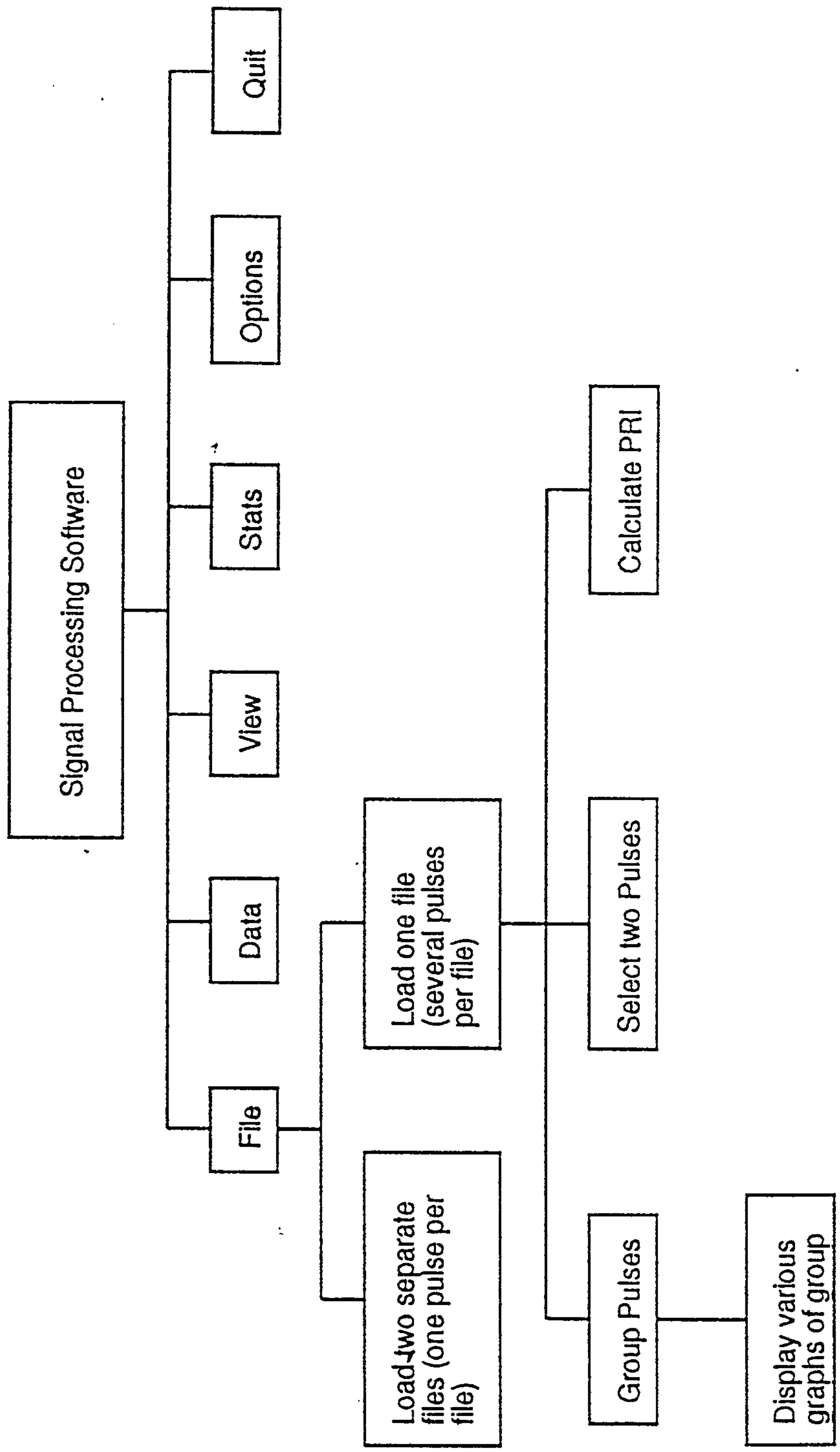


Figure 6 Structure of Signal Processing Software.

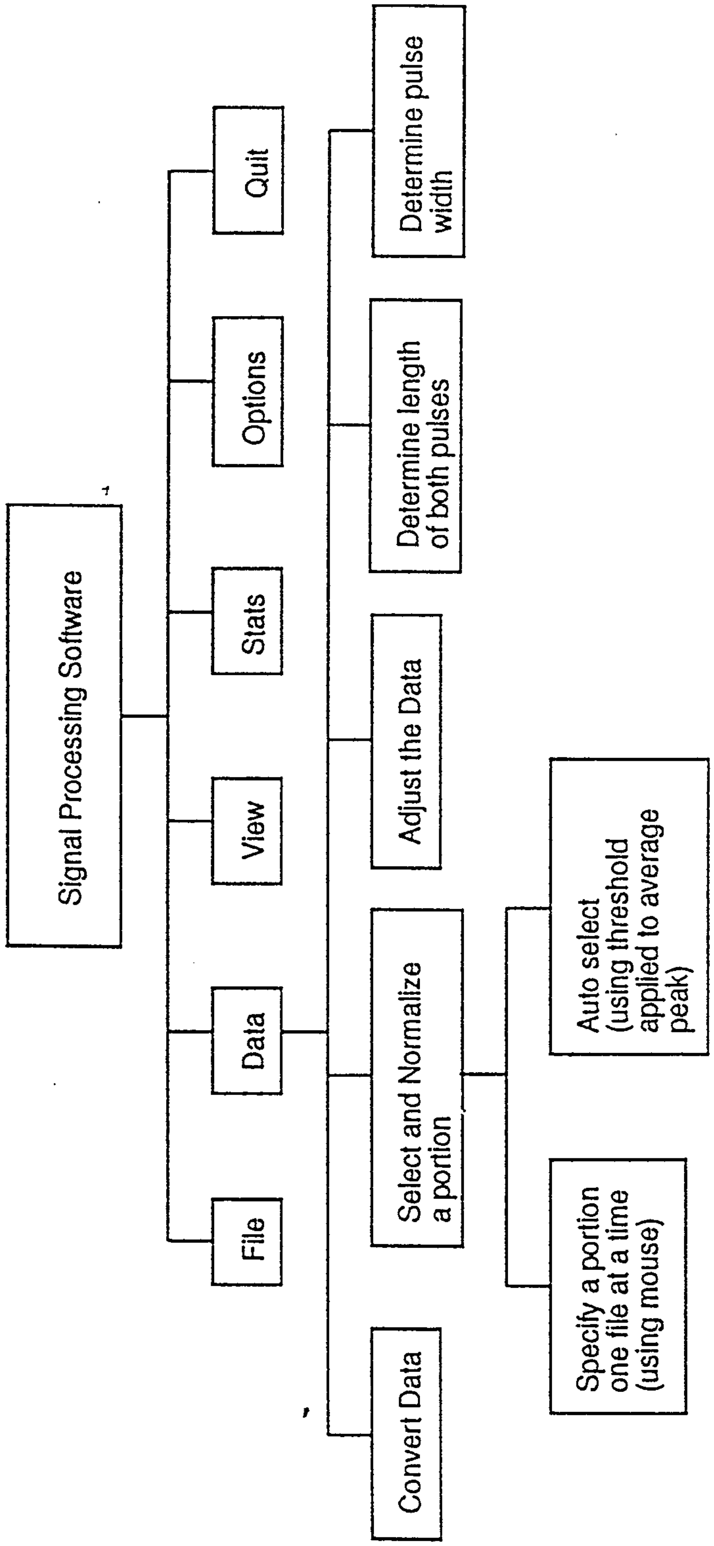


Figure 7 Structure of Signal Processing Software continued.

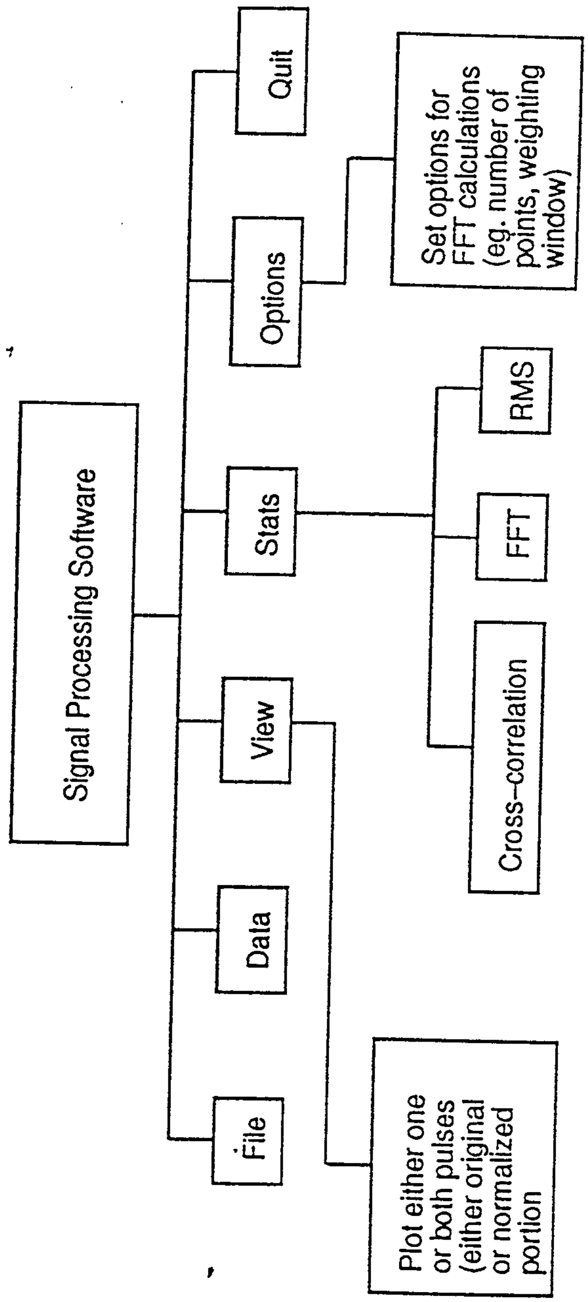


Figure 8 Structure of Signal Processing Software continued.

arrival, sampling rate, saturation indicator, peak power, peak frequency, pulse width and mean frequency, respectively. The next set of numbers represent the time vector followed by the power, frequency and phase vectors.

3.2. Converting Data

If the data loaded contains the frequency and power in volts instead of the required units of MHz and dBm respectively, this option will perform the necessary conversion using one of three different look-up tables. The three different look-up tables are Lockheed, g1000 and g160 [1]. The table selected should correspond to the type of intrapulse receiver used for data collection.

3.3. Select a Group of Pulses

If several pulses have been loaded, the pulses can be grouped using the frequency, peak power and pulse width as selection criteria. The pulses are grouped first by using a frequency window, entered by the user and applied to the first pulse. The grouping process can be summarized by the following steps.

Step 1: Enter a frequency window.
Step 2: Get the peak frequency of the first pulse and find all pulses with the same peak frequency plus or minus the frequency window.
Step 3: Form one group containing these pulses.
Step 4: Repeat steps 2 and 3 on the remaining pulses until there are no more pulses.

Once the groups are formed, one group is selected. Pulses can then be further eliminated from the selected group by using a threshold applied to the peak power and by using a window for the pulse width, or equivalently the number of points in the pulse. The number of points in a pulse which is used as a reference is specified by the user.

After a group of pulses has been determined, the mean and the RMS of the power, frequency and phase are calculated. The power is converted to linear units for both the mean and RMS calculations. The RMS for the frequency is calculated as follows

$$RMS_f = \sqrt{\frac{\sum_{i=1}^{m} (f_i - \overline{f})^2}{m}}$$

where f is the frequency vector of length m and $\bar{f}$ is the mean frequency. The RMS for the power and the phase is similarly calculated. Graphs can be displayed showing the mean, RMS-mean and RMS+mean for each of the three vectors. See figure 9.

An option has also been added to compare the average pulse to the peak pulse. The average pulse is a pulse with its power, frequency and phase equal to the mean power, mean frequency and mean phase, respectively, of all the pulses in the selected group. The peak pulse is the pulse with the greatest peak power.

3.4. Calculation of Precision PRI

In estimating the precision PRI, the mean PRI must first be calculated. The mean PRI is calculated by determining the difference in the time of arrival of consecutive pulses and averaging only the differences which are less than 1.8 times the minimum difference. This is to ensure that the average does not incorrectly take into account the cases where either a single pulses or two or more consecutive pulses are missing.

Multiple groups are detected if the difference in the time of arrival of two consecutive pulses is greater than a user specified time. If more than one group of pulses is detected, then two additional PRI estimates are reported using peak and centroid estimation.

When using peak estimation the peaks of each of the first two groups and the corresponding pulse numbers are determined. The PRI using peak estimation is calculated using the equation

$$PRI_p = \frac{T_{p_2} - T_{p_1}}{n}$$

The difference in the time of arrival of the two pulses, T_{p2}-T_{p1}, is divided by the number of pulses between the two peaks, n. This is calculated using the equation

$$n = round\left[\frac{T_{p_2} - T_{p_1}}{\overline{PRI}}\right]$$

The difference in the time of arrival of the two pulses is divided by the mean PRI and then rounded to the nearest integer to determine the number of pulses between the two

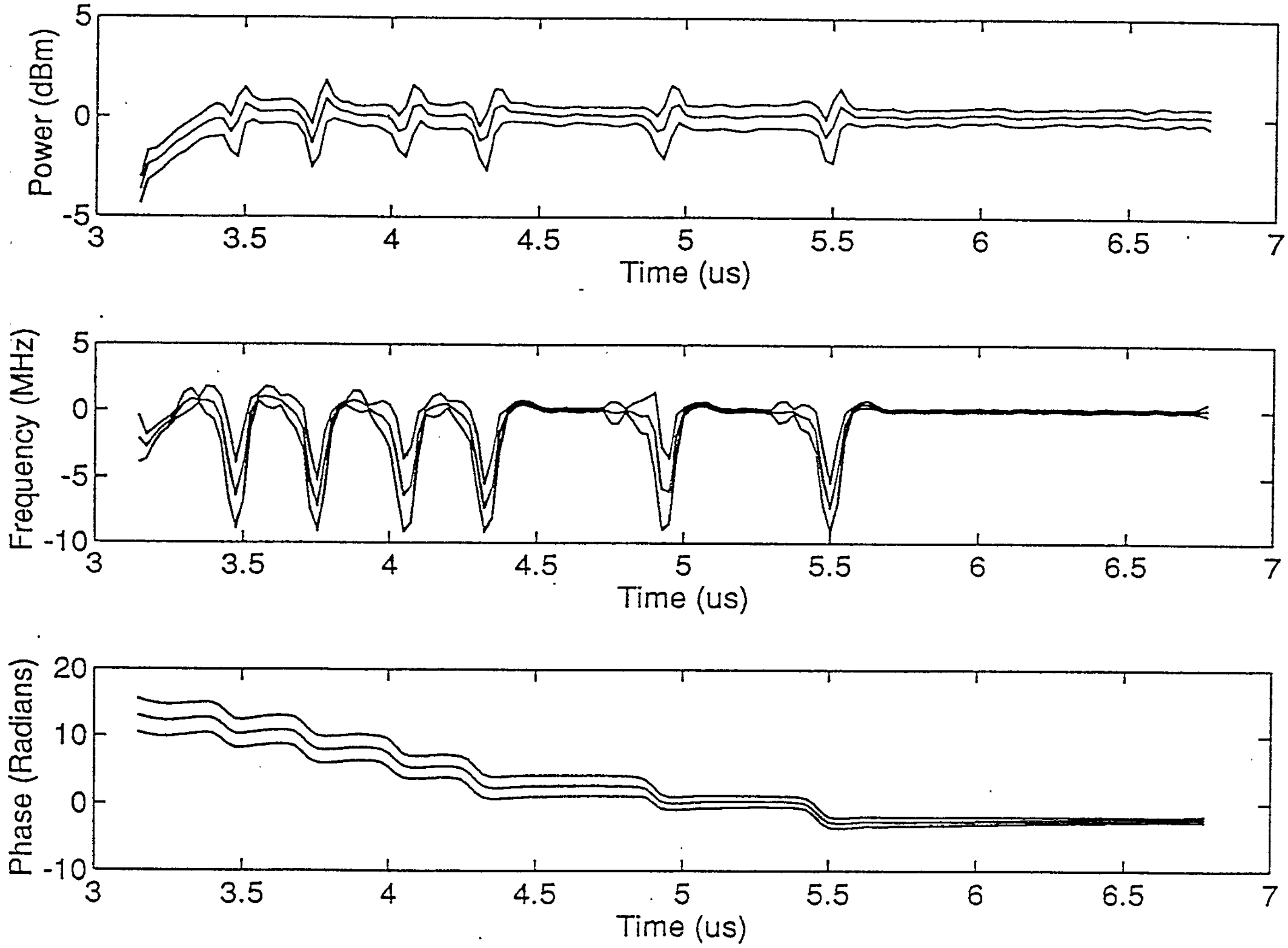


Figure 9 Mean, RMS-mean and RMS+mean.

peaks. This same process is repeated for centroid estimation using the centroid for each of the first two groups instead of the peak. The centroid is calculated as

$$C=\frac{\sum_{i=1}^{n} x_i f(x_i)}{\sum_{i=1}^{n} f(x_i)}$$

where n is the number of pulses being considered, x_i is the pulse number of the i^{th} pulse in the group and $f(x_i)$ is the peak power of pulse x_i.

To illustrate the calculation of the precision PRI consider the 100 pulses in figure 10. If the precision PRI is calculated using all 100 pulses with a time of 2 seconds distinguishing among groups, only the mean PRI of 191.299612 microseconds is reported. Figure 11 shows a group of pulses that have been selected from the original 100 pulses. If the precision PRI is now calculated using this group, with a time of 2 seconds distinguishing groups of pulses, the mean PRI is 172.566187 microseconds. The PRI using peak estimation is 172.561780 microseconds and the PRI using centroid estimation is 172.561785 microseconds. If the pulses in figure 12 are selected to form a group of pulses only the mean PRI of 219.875602 microseconds is reported.

3.5. Select Two Pulses

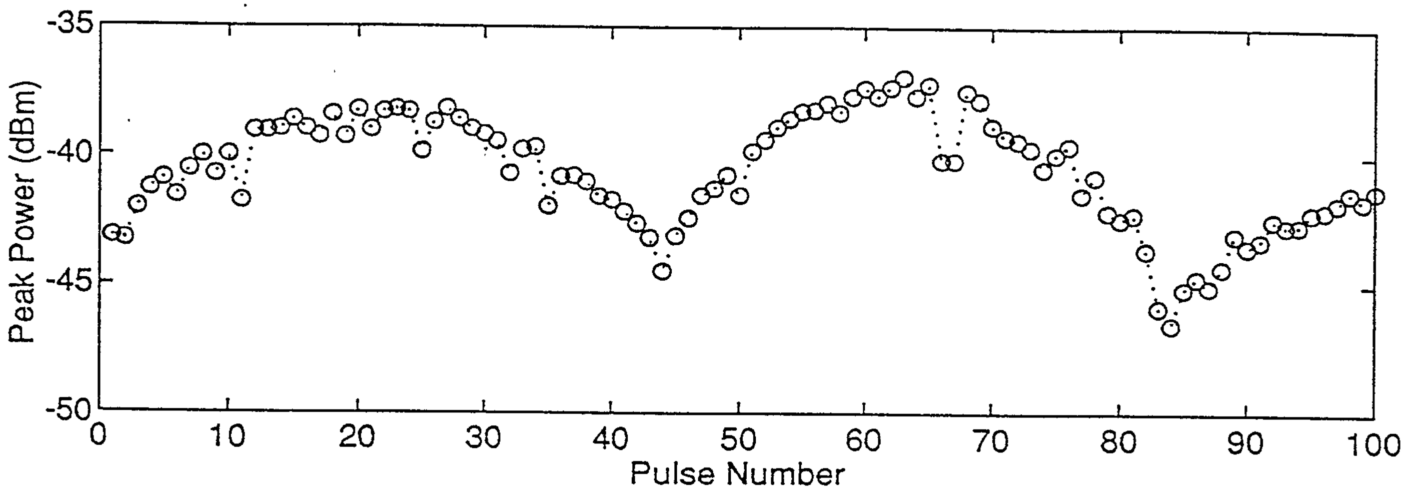
Since only two pulses can be compared at a time, this option is added to allow the user to select two pulses for further analysis. There are three different methods of selecting two pulses. The pulses may be selected using the mouse from the entire set of pulses or, if a group is selected, from the pulses in the selected group, or the pulses may be selected by entering the pulse number using the keyboard.

3.6. View Graphs

The view option allows the user to view the power, frequency and phase versus time graphs either one pulse at a time or both pulses at the same time. An option is also included to change the line style for plotting the curves.

3.7. Select/Normalize

Instead of using the entire pulse, a portion of the pulse may be selected and normalized



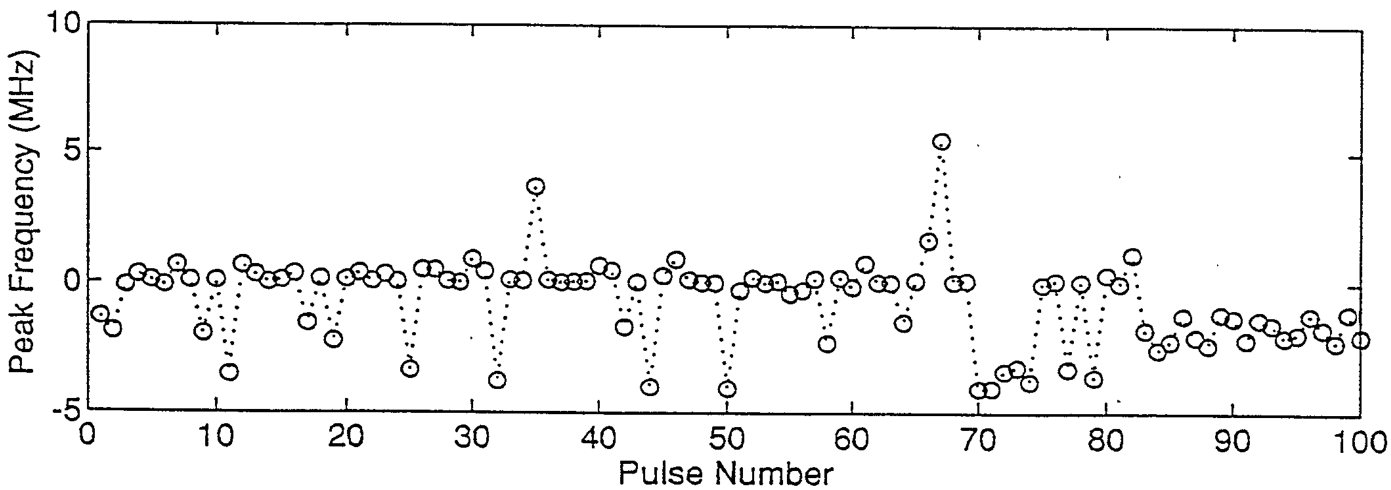


Figure 10 Peak power and peak frequency for 100 pulses.

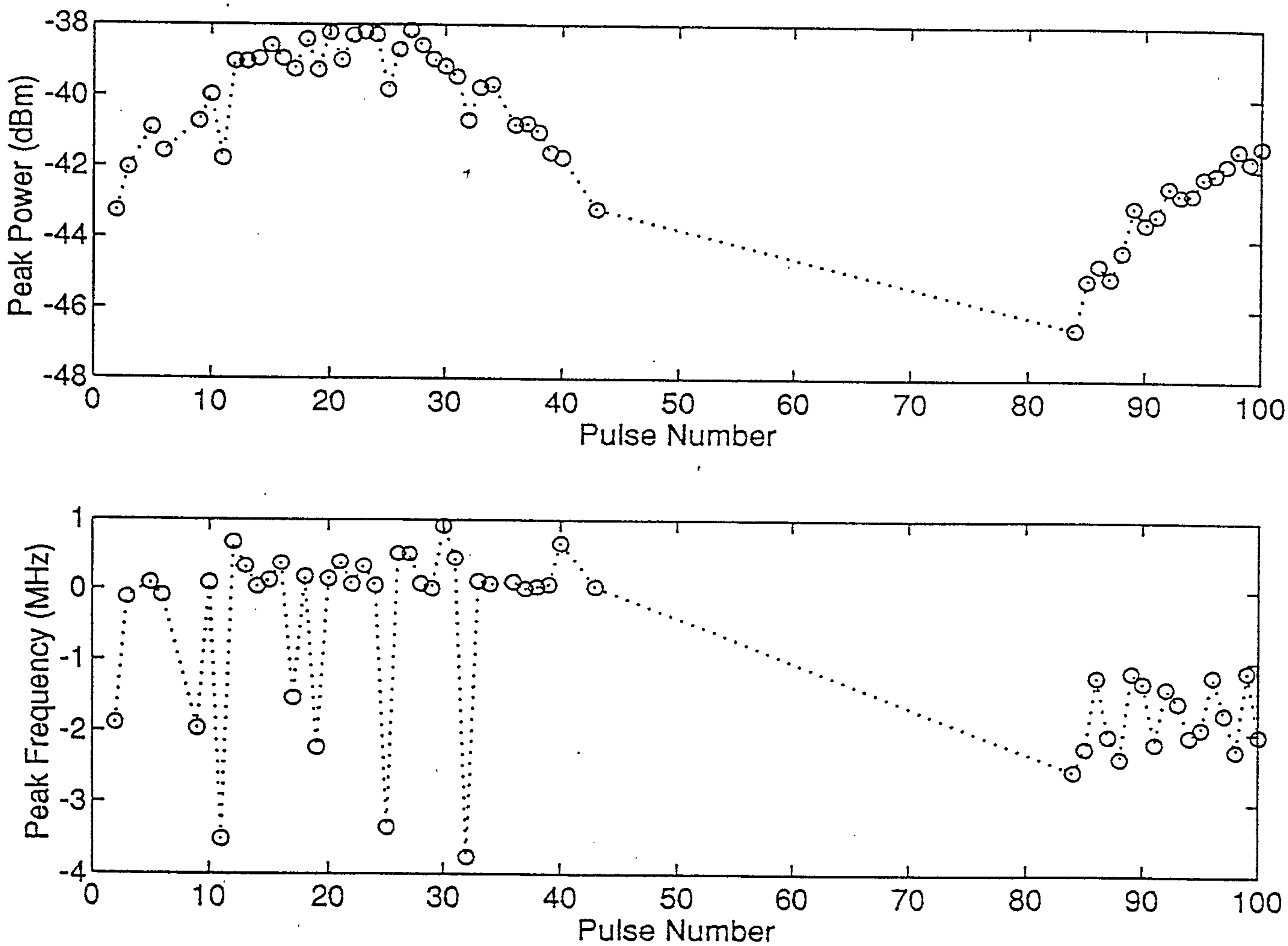


Figure 11 A group of selected pulses.

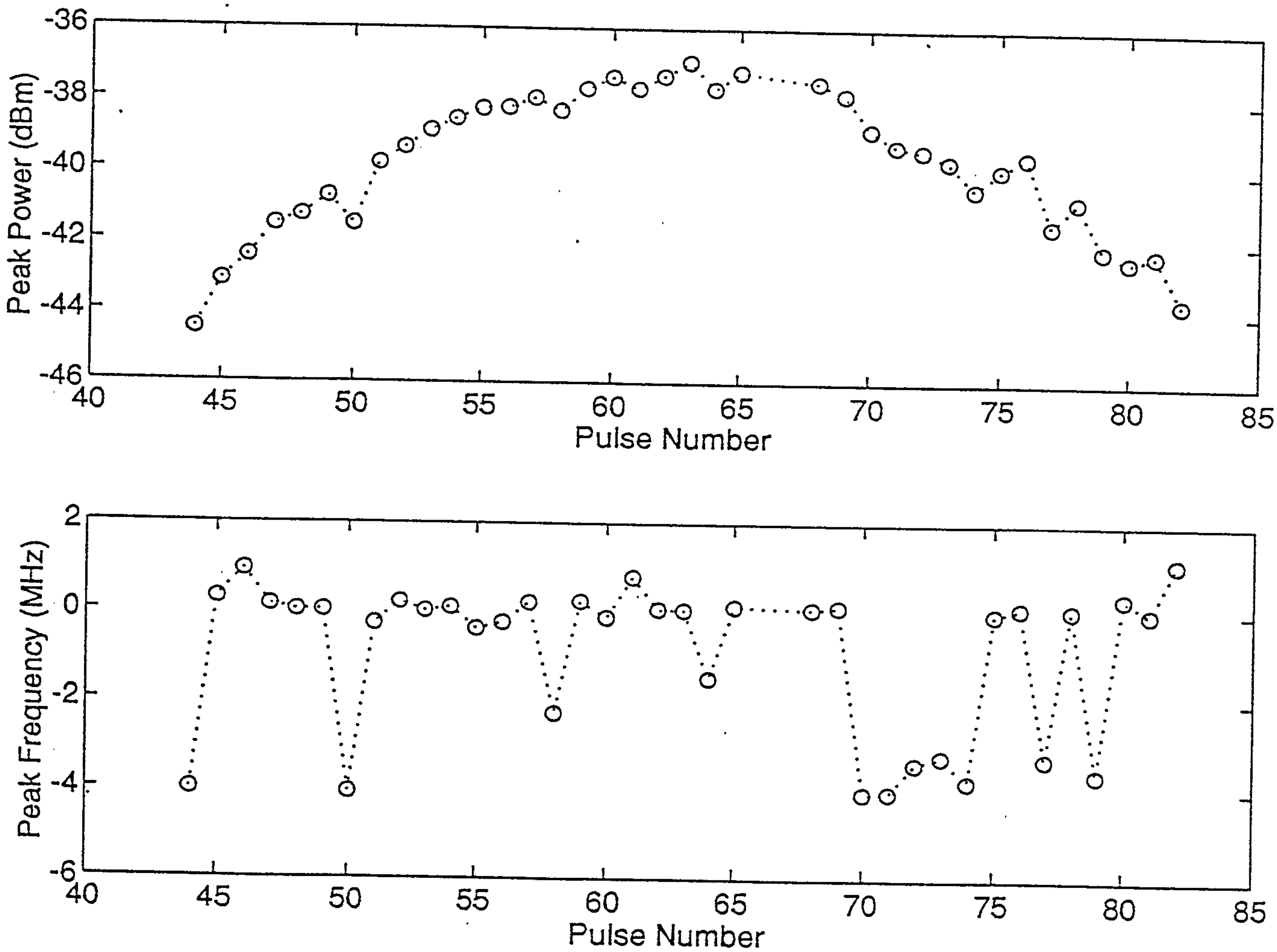


Figure 12 A group of selected pulses.

for further analysis. A portion may be selected from each pulse by either specifying a time range, for each pulse, or by specifying a relative power threshold in dB. If the threshold method is used, the relative threshold is subtracted from the average peak to determine the actual threshold. The average peak is defined as the average of the maximum power and the next four points. The beginning of the selected portion, t_1, is the time at which the first point is greater than the threshold. The end of the portion, t_2, is the time after the peak occurs, t_p, where the power first begins to be less than the threshold. See figure 13.

The power, frequency and phase are then normalized for the selected time range by subtracting the corresponding averages. Since the power is in logarithmic units the average is calculated after converting the power vector to linear units. Once the mean is calculated it is converted back to logarithmic units (dBm) and subtracted from the original power vector. The average power, P_{ave}, can be summarized by the equation

$$P_{ave} = 10\log_{10}\left[\frac{\sum_{i=1}^{m} 10^{P_i/10}}{m}\right]$$

where P is the power vector of length m in dBm.

3.8. Cross-correlation Function

The cross-correlation function determines how close two sequences of numbers $S_i[n]$ and $S_j[n]$ are to one another. The function is calculated using the MATLAB function XCORR which normalizes the output to between -1 and 1 [2]. MATLAB does not document how the output is normalized but initial software tests indicate that the following formula is used to arrive at a normalized version of the standard cross-correlation function.

$$CCF_{ij}[k] = \frac{\sum_{n=1}^{N} (S_i[n])(S_j[n+k])}{\sqrt{\sum_{n=1}^{N} (S_i[n])^2 \sum_{n=1}^{N} (S_j[n])^2}}$$

The two sequences of numbers, $S_i[n]$ and $S_j[n]$, in the equation are both of length N. If the output of this function is one then the two sequences are maximally correlated. An output of zero indicates that the two sequences are not correlated and an output of -1 indicates that the sequences are inverted in magnitude. The value of k for which the output attains a maximum is called the lag. A small lag most likely indicates that the two sequences are misaligned by the number of samples equal to the lag, but a large lag value usually indicates that the two sequences are different.

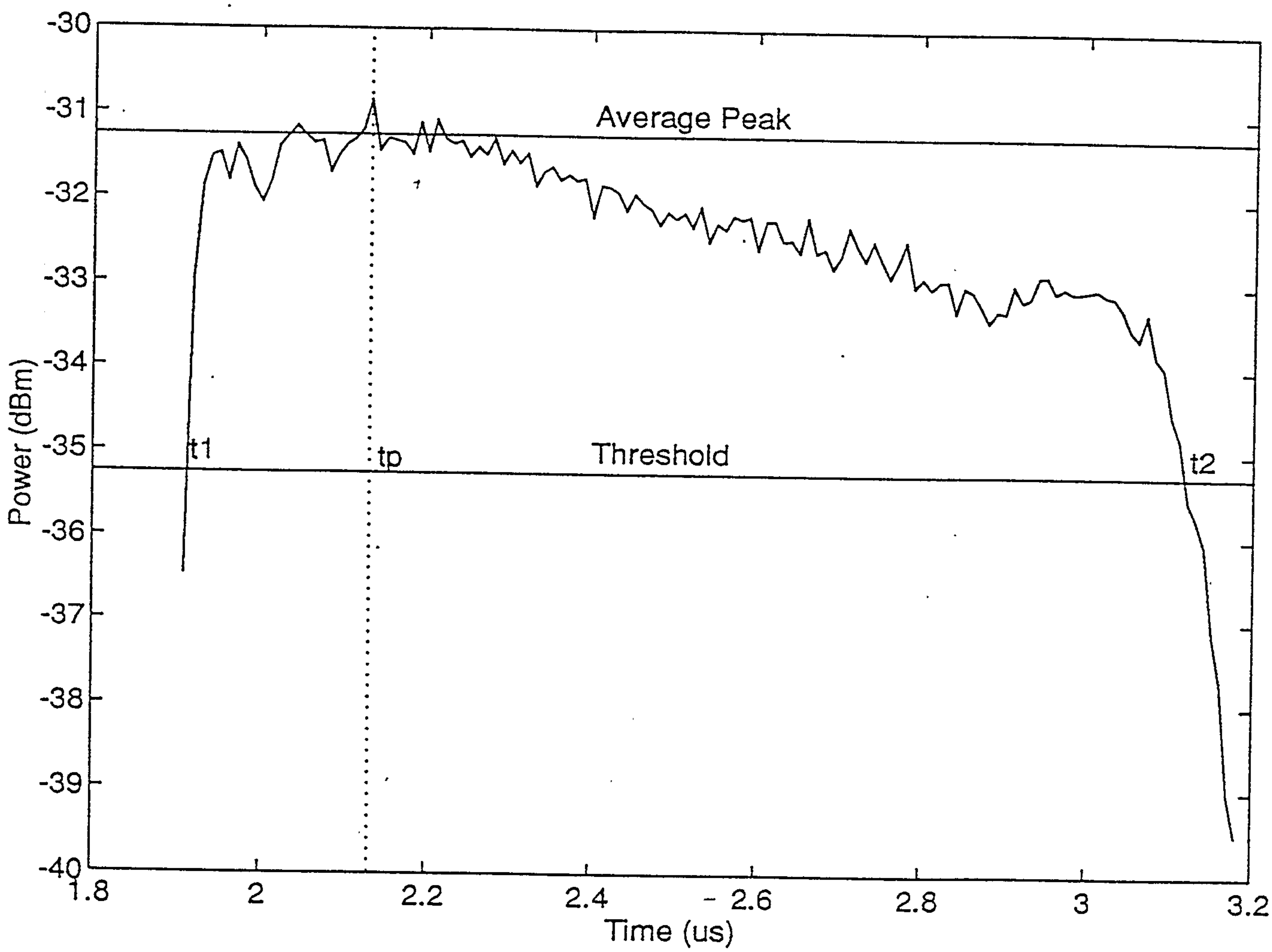


Figure 13 Portion of the power vector to be normalized.

As an example consider the power, frequency and phase of the two different pulses in figure 14. The result of the cross-correlation function (figure 15) shows that the two pulses are aligned since the lag, or the location of the peak, is zero for each of the three vectors. Figure 16 shows the same three vectors after being normalized using a relative threshold of 4 dB while figure 17 illustrates the result of the cross-correlation function on the normalized vectors.

3.9. Discrete Fourier Transform

The discrete Fourier transform is calculated using the MATLAB function FFT [2]. This function uses the fast Fourier transform algorithm when the number of points used in the calculation is of base two. The Fourier transform is given by the equation

$$X(k+1) = \sum_{n=0}^{N-1} x(n+1)\, e^{-j(2\pi\, kn/N)}$$

where N is the length of x. The FFT can be performed on either the power, frequency or the phase vector. Either the real part, the imaginary part or the magnitude of the complex result of the FFT can be graphed. The magnitude of the FFT is the power spectral density or the measurement of the energy at various frequencies. It is calculated using the equation

$$P = \frac{4y\bar{y}}{N^2}$$

where y is the complex result of the FFT on either the power, frequency or phase vectors and N is the number of points used in the FFT calculation. The three graphs are plotted against a frequency axis which is calculated using the equation

$$f = \frac{(bin-1)\, f_s}{N}$$

where bin is the bin number and f_s is the sample frequency. The number of points to use and the number of points to skip when calculating the FFT can be set by the user.

Figure 18 illustrates the results of taking the magnitude of the FFT on the frequency vectors of both pulses in figure 14. Both pulses have a length of 152 points. The FFT is calculated using 64 points and a rectangular weighting function. Figure 19 illustrates the same results for the two pulses in figure 16 which have been normalized using a relative power threshold of 4 dB.

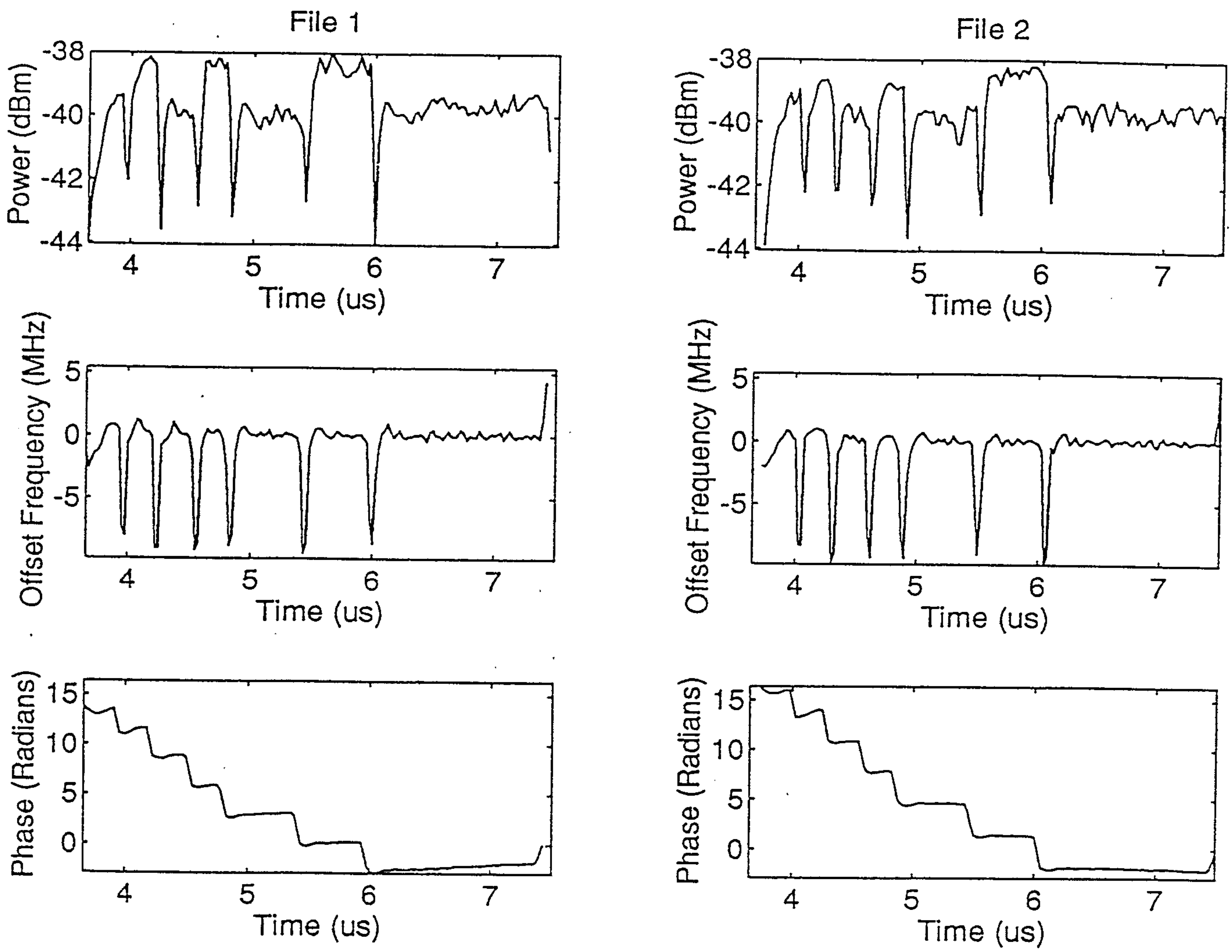


Figure 14 Power, frequency and phase for two selected pulses.

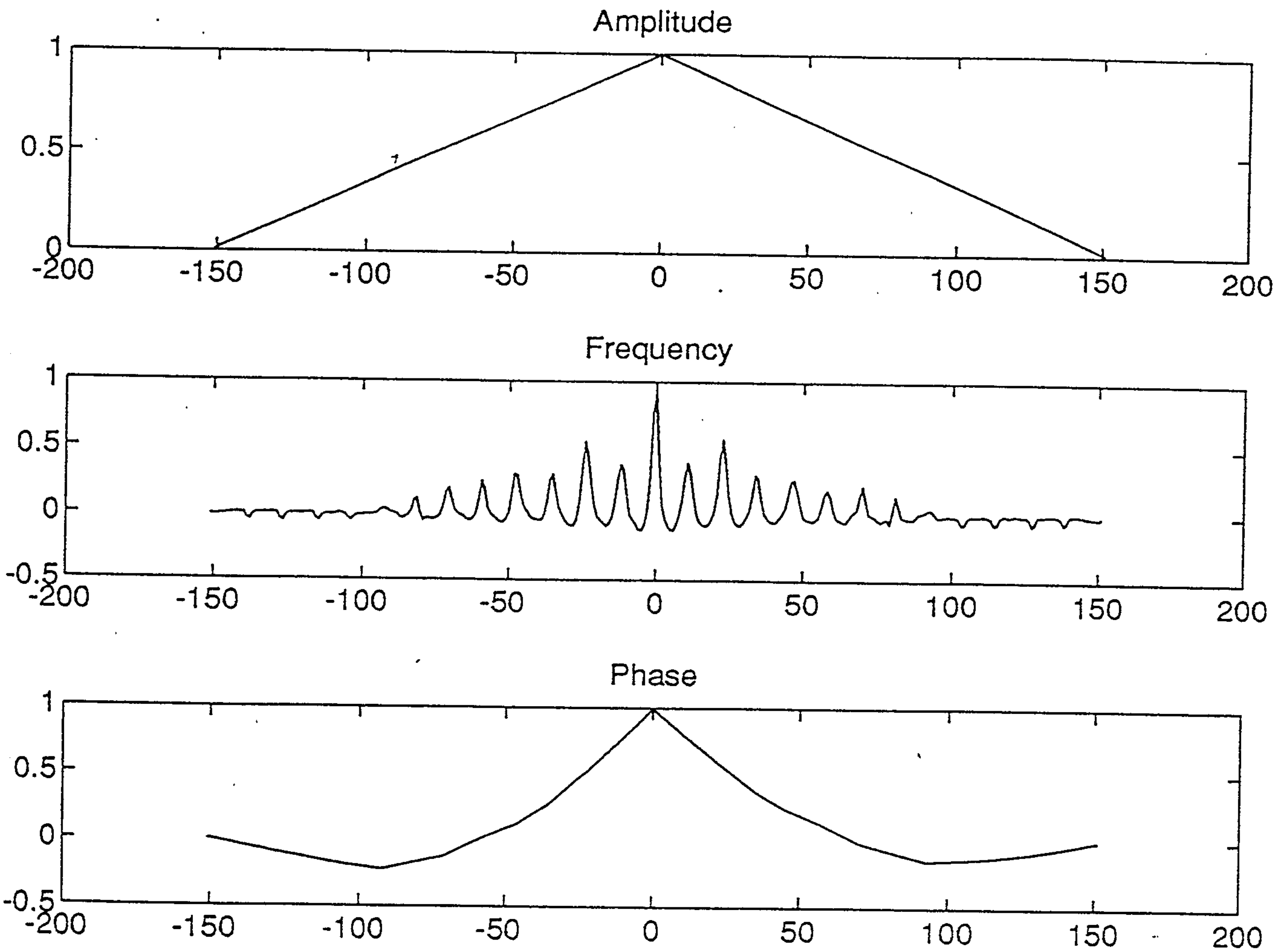


Figure 15 Cross-correlation of power, frequency and phase.

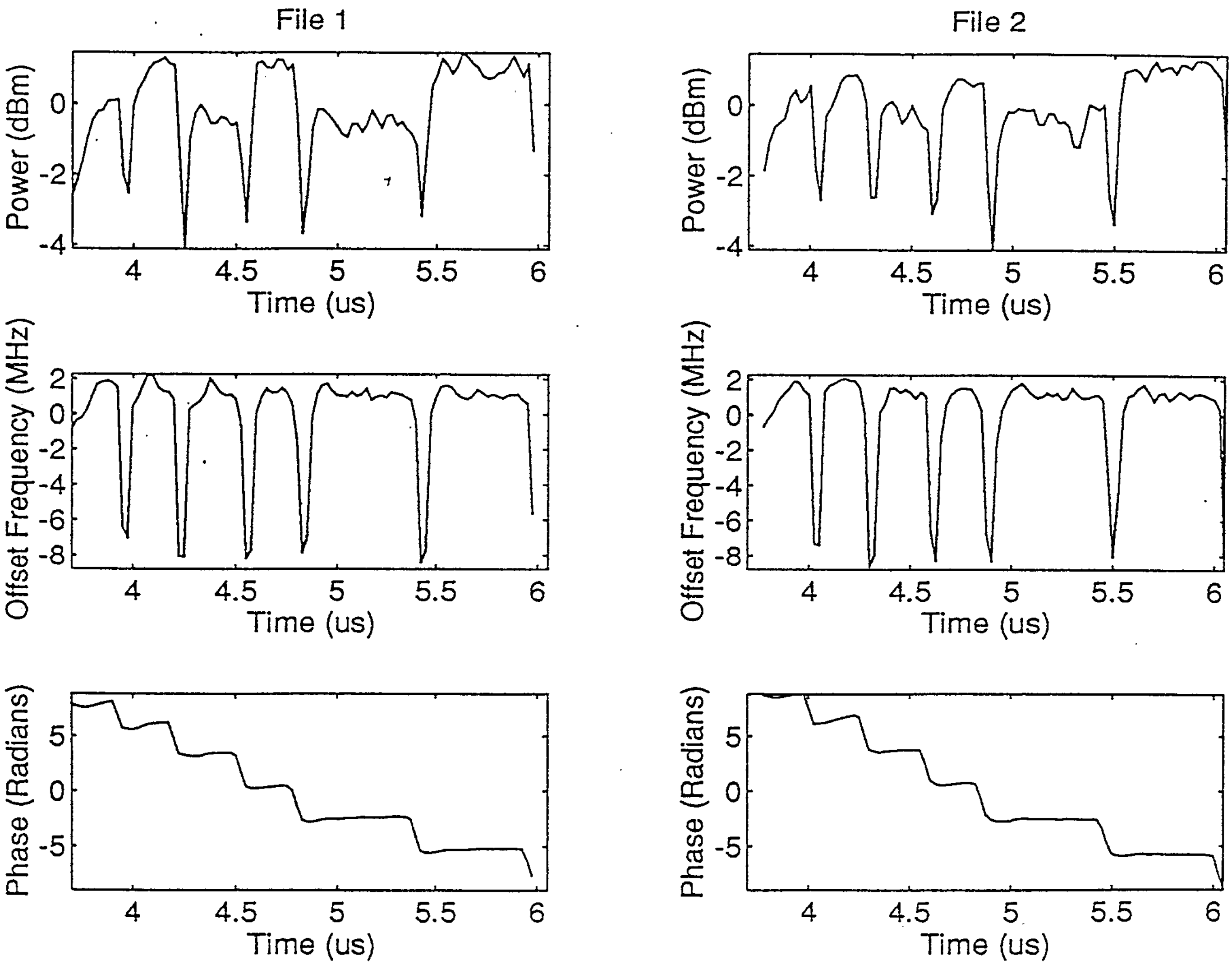


Figure 16 Power, frequency and phase after normalization.

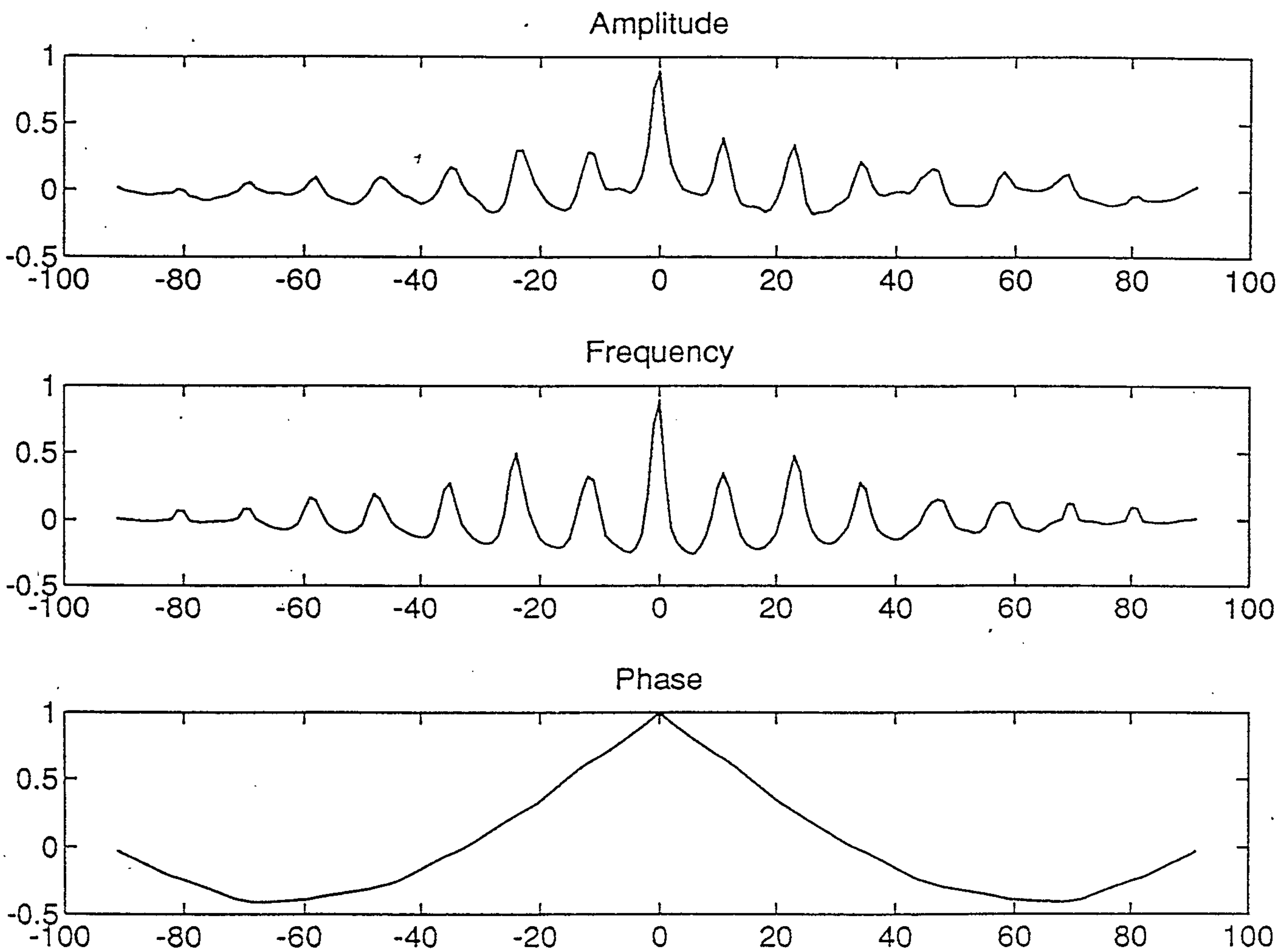


Figure 17 Cross-correlation using normalized vectors.

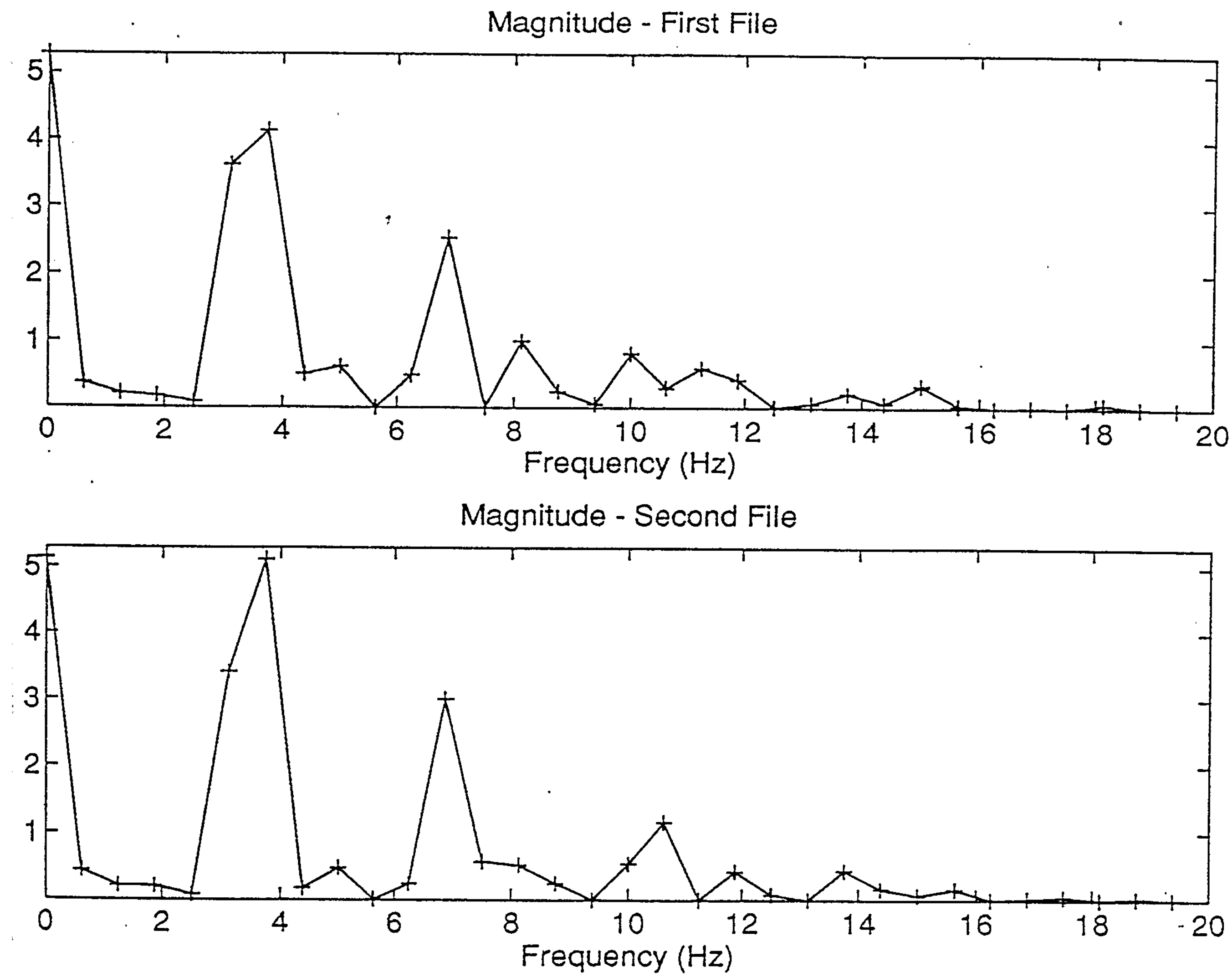


Figure 18 Magnitude of FFT of the frequency vectors.

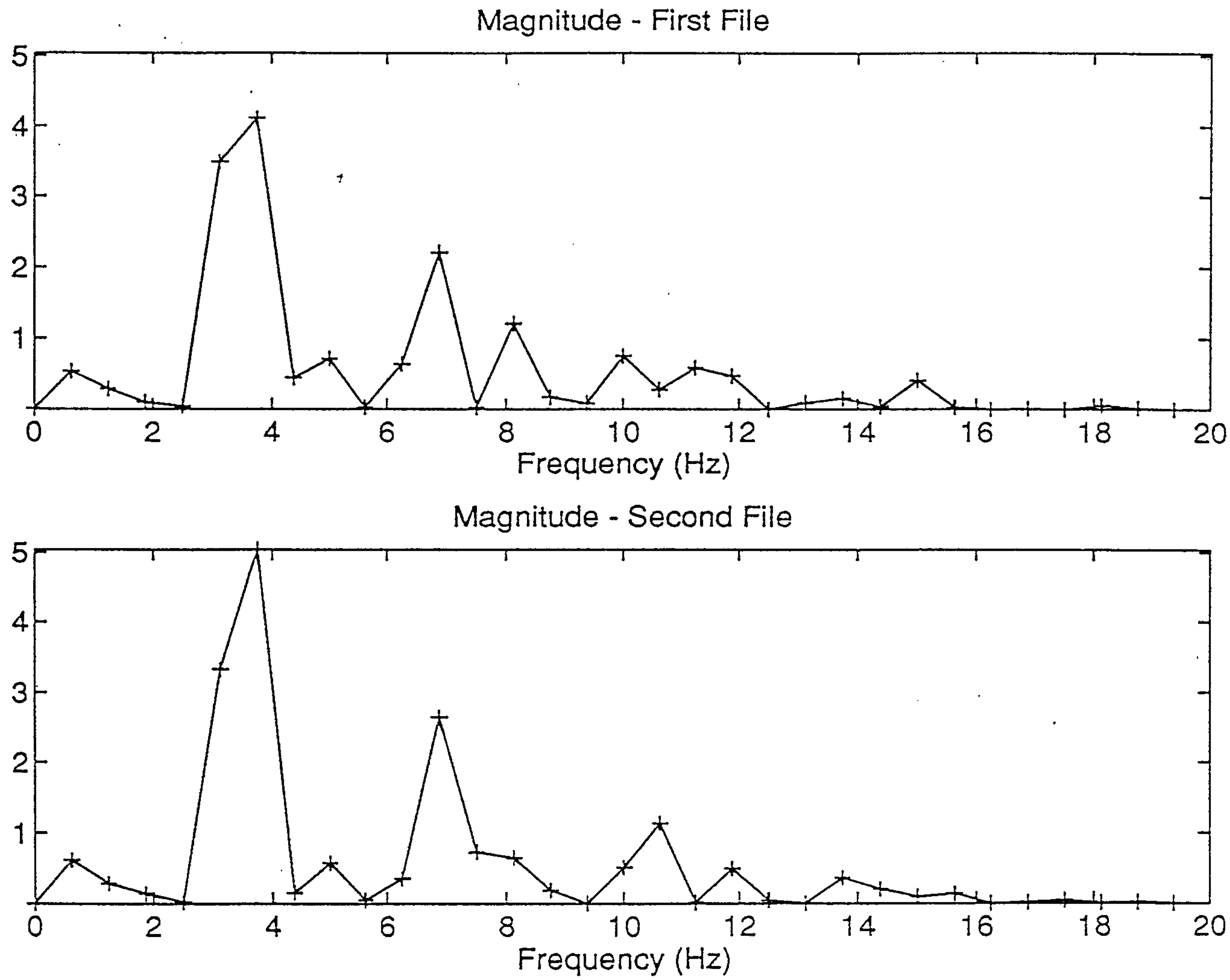


Figure 19 Magnitude of FFT using normalized frequency vectors.

4. Summary

The two software packages, the Display Software and the Signal Processing Software, were developed for use with the Transportable Intrapulse Collection and Analysis Facility. The Display Software's main function is to help the operator sort out the radar signal environment. This is accomplished by graphically displaying data such as the frequency and bearing of each radar emitter detected and by incorporating a tracking feature to show the movement of each radar emitter.

The Signal Processing Software is used once the amplitude, frequency and phase are determined for each pulse. This software package can be used to determine if two pulses are from the same radar emitter. Several different methods can be used to compare the two pulses such as, the cross-correlation function, the discrete Fourier transform and the RMS function. The Signal Processing Software can also be used to group several pulses according to the peak frequency, peak power and pulse width and to determine the precision pulse repetition interval.

References

[1] Lee, J.P., "Design and Development of an Intrapulse Collection and Analysis Facility", DREO technical report (to be published).

[2] "Signal Processing Toolbox User's Guide", The MathWorks, Inc.

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(U) This report documents in detail the software paackages developed under this contract. Two software packages have been developed for use with the Transportable Intrapulse Collection and Analysis Facility. The software aids the operator of this system to sort out the radar signal environment by graphically displaying the frequency, pulse repetition interval and pulse width of each emitter and by tracking the movement of radar emitters over time. The software also helps to determine if two emitters are from the same radar by applying various signal processing algorithms to the intrapulse data.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

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