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## FINAL REPORT

### ON-BOARD DATA MANAGEMENT STUDY FOR EOPAP

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# Systems Analysis

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ON-BOARD DATA MANAGEMENT STUDY FOR EOPAP

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## ON-BOARD DATA MANAGEMENT STUDY FOR EOPAP

### 1. Summary

A study of the requirements, implementation techniques and mission analysis associated with on-board data management for EOPAP has been performed. SEASAT-A has been used as a baseline with reference [1] used as the primary source of information for the spacecraft configuration. The storage requirements, data rates, and information extraction requirements have been investigated for each of the following proposed SEASAT sensors: a short pulse 13.9 GHz radar, a long pulse 13.9 GHz radar, a synthetic aperture radar, a multispectral passive microwave radiometer facility and an infrared/visible very high resolution radiometer (VHRR). The short pulse radar is used for altimetry and the determination of wave height and wave directional spectra. Primary consideration in this study was given to this sensor based on data provided by the GSFC technical officer. The long pulse radar is used for measuring wind speeds by scatterometry. The synthetic aperture radar provides side-looking coherent imagery. The passive microwave sensors are radiometers at 5, 13.9, 18, 22, 36, and 53 GHz which are used for correcting altimeter measurements, measuring surface roughness and sea ice. The VHRR sensor provides cloud cover maps and sea surface temperature information. Data management principles for the latter were included in the study based upon the results of the earlier study contract NAS5-21940 "ITOS VHRR On-Board Data Compression Study" (reference [2]) and extended to include the other SEASAT sensors.

Rate distortion theory was applied to determine theoretical minimum

data rates and compared with the rates required by practical techniques. It was concluded that practical techniques can be used which approach the theoretically optimum based upon an empirically determined source random process model.

Finally the results of the preceding investigations were used to recommend an on-board data management system. The purpose of the on-board data management system is for (1) data compression through information extraction, optimal noiseless coding, source coding with distortion, data buffering and data selection under command or as a function of data activity, (2) for command handling, (3) for spacecraft operation and control, and (4) for experiment operation and monitoring. It was concluded that an on-board general purpose programmable computer should be used and that the advanced on-board processor (AOP) developed by NASA GSFC is suitable for the tasks required.

Section 2 is a review of the SEASAT sensors studied and their data rate requirements. Section 3 presents rate distortion theoretic considerations. Section 4 is a discussion of the data reduction and estimation techniques applied to aircraft samples of the short pulse radar type and the computer programs developed in this study for the analysis. Section 5 presents results for the VHRR data. Finally section 6 discusses an on-board data management system.

## 2. SEASAT Sensor Data Processing

### 2.1 Short Pulse Radar

The short pulse radar is used to measure the mean altitude of the spacecraft and the rms wave height in a nadir-looking mode with a .6 m dish. It also can be used with a 2 m dish in an off-nadir conical scan mode to measure wave directional spectra. The radar uses linear chirp FM transmission to attain the required resolution ( $\approx 3$  nsec compressed pulse length) in altitude, wave height, and wave directional spectra. On-board processing can be used to estimate and transmit these parameters at a low bit rate relative to the bit rate required for the unprocessed received radar data. The actual bit rate resulting depends on the number of read-outs per second of the processed estimates which can be controlled by the on-board data management system. The control can be through read-out rate selection under ground station control or under data control as a function of data activity. In either case, data compression can be used for further bit rate reduction by sending encoded changes in the parameters rather than the parameters themselves. In this method noiseless coding is used to take advantage of the lowered entropy of the difference sequence.

Further details regarding the processing of the radar data for parameter estimation appears in section 4 based upon samples of aircraft data supplied by the NASA GSFC contract technical officer.

## 2.2 Long Pulse Radar

The long pulse 13.9 GHz radar is used as a scatterometer to measure wind speed and direction. The scatterometer shares the 2 m dish with the short pulse radar in a conical scan mode and operates on the principle that the radar cross section of the sea surface depends on the wind speed and direction. Atmospheric calibration is provided by the 13.9 GHz passive radiometer. As for the short pulse radar, on-board processing can be used to reduce the received radar data into estimates of wind speed and direction so that arbitrarily low bit transmission rates can be attained depending upon the read out rate desired, and/or the data activity and/or the use of data compression on the sequence of parameter estimates.

## 2.3 Synthetic Aperture Radar

A synthetic aperture radar is provided for side-looking coherent imaging. Waves on the ocean can be analyzed from the imagery to determine wave spacing and direction (except for a  $180^\circ$  ambiguity). From the wave periodicity the rms wave height can be found through the known deterministic relation between the two parameters. Furthermore information on icebergs, shoals, kelp beds, tides, oil slicks, etc. can be provided. The major drawback in the useage of this technique is the high data rate. This data rate can be reduced by selective coverage through the on-board processor and through prefiltering and buffering operations to 8 Mbps. Because of the high data rate and the inherent redundancy of images, particularly the synthetic aperture type, the signal is an ideal candidate for data compression. Using rate distortion theory (see section 3),



and empirical experience with images, it is estimated that the bit rate could be reduced to 1 Mbps with acceptable quality by using a combination of line-to-line and sample-to-sample compression techniques. If further degradation is allowed so that only the essential information is retained (wave locations, edges of land or iceberg or other significant formations, etc) a reduction to .5 Mbps or less may be possible.

#### 2.4 Passive Microwave Radiometer Facility

The passive microwave radiometers provide atmospheric path length corrections for the short pulse radar altimeter, sea surface temperature measurements, surface wind speed measurements, and rain area and cloud water content determinations. The bit rate requirement for this data is 3.7 kbps. This can be substantially reduced by data compression using the inherent redundancy of the data (see section 3).

#### 2.5 Very High Resolution Radiometer

A two channel very high resolution infrared/visible radiometer (VHRR) provides cloud cover pictures and surface temperature measurements in the 10.5 to 12.5 micrometer infrared band and in the 0.6 to 0.7 micrometer visible band. This instrument is essentially identical to that used for ITOS-D. The scan voltage is a 35 kHz low pass signal which requires on the order of 1 Mbps for full-resolution, uncoded transmission. However, undersampling, line deletion, data formatting, and data compression under control of the on-board processor can be used to substantially reduce the required bit rate. Detailed methods of compression for this source data appear in Systems Analysis report no. 75100, "ITOS VHRR On-

Board Data Compression" prepared under NASA GSFC contract NAS5-21940. A summary of the essential results appears in section 5 of this report.

### 3. Rate Distortion Theory

The rate-distortion function of a source with a given probability distribution determines the minimum channel capacity required to transmit the source output (or the storage capacity required to store the source output per unit time) as a function of the desired maximum average distortion, where the distortion function (sometimes called fidelity criterion) is a measure of the agreement between the source output and the end user output as specified by the the user. The concept originated with Shannon who calculated the rate-distortion function for certain sources including in particular a Gaussian discrete time random process. This was later extended to more complicated sources and applied to performance bounding by other authors.

Figure 3.1 presents a highly simplified communication system block diagram. The system designer is given a source and wishes to encode the source in such a way that the channel capacity (or storage) requirement is minimized. To make this minimum as small as possible, he is willing to tolerate some average distortion (typically average error power) between the source output and the decoder output. The problem addressed by rate distortion theory is the minimization of the channel capacity requirement while holding the average distortion at or below an acceptable level.

To be slightly more specific, in figure 3.1 let the average information transmitted from the source to the decoder output be denoted by the function  $I(X,Y)$ , more information corresponding to larger values of

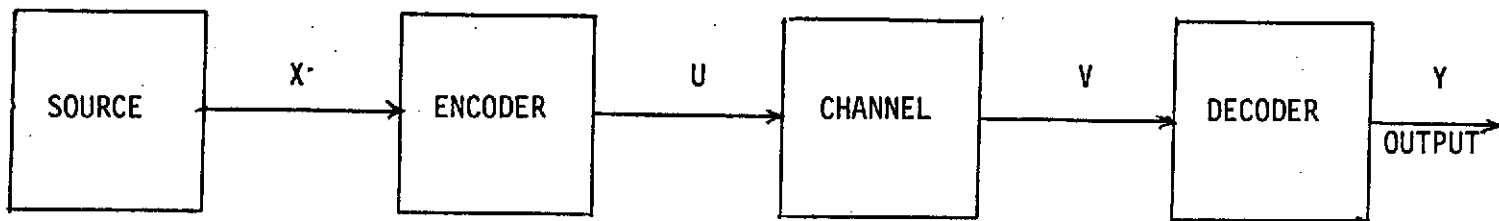


FIGURE 3.1. A SIMPLIFIED COMMUNICATION BLOCK DIAGRAM

$I(X,Y)$ . Let the analogous average information transmitted from the encoder output to the channel output be denoted  $I(U,V)$ . The channel capacity  $C$  is defined as the maximum of  $I(U,V)$  over all possible input devices. It is obvious that in figure 3.1, the intervening nature of  $U$  and  $V$  implies  $I(X,Y) \leq I(U,V) \leq C$  if the function  $I(\cdot, \cdot)$  is properly defined. Shannon defined the correct function for information and defined the rate distortion function  $R(D)$  as the minimum value of  $I(X,Y)$  for a given distortion level  $D$ . He also showed that  $R(D) < C$  assures the possibility of attaining average distortion  $D$  by coding at rate  $C$  with a sufficiently complicated encoder.

To look at the problem from a different angle, the encoding and decoding can be separated into two parts—source coding and channel coding. The job of the source coder is to remove source redundancy, whereas the job of the channel coder is to insert controlled redundancy to combat noise. How well channel coding can perform is established by Shannon's noisy coding theorem which states that transmission without channel errors is possible if and only if the rate at which messages are presented to the channel coder from the source coder does not exceed channel capacity. With this constraint on the source coder, at a given channel capacity the source coding must result in a loss of quality—i.e. some distortion must result. The rate distortion function  $R(D)$  is the minimum source coder rate (minimum required channel capacity) for an average distortion level  $D$ .

An analytically convenient source model to use is the Gaussian which frequently is a good model in practice, in particular for the image data found on SEASAT. Consider the problem of encoding a source which

generates a sequence of statistically independent Gaussian random variables with a squared error distortion measure. This source is characterized by a known mean (i.e. dc) value, which does not affect coding rate because it is a simple shift, and a variance (power)  $\sigma^2$ . Let the source output be the  $N$  values  $\{x_i, i=1, 2, \dots, N\}$  and the decoder output be  $\{y_i, i=1, 2, \dots, N\}$ . The distortion is taken as

$$d(X, Y) = \sum_{i=1}^N (x_i - y_i)^2$$

so that the average distortion is the average mean square error (error power):

$$D = \frac{1}{N} \sum_{i=1}^N E(x_i - y_i)^2$$

It can be shown that the rate distortion function is given by

$$R(D) = \begin{cases} \frac{1}{2} \log \frac{\sigma^2}{D} = \log \sqrt{\frac{\sigma^2}{D}} & \sigma^2 > D \\ 0 & \sigma^2 \leq D \end{cases} \quad (3.1)$$

That is, the rate distortion function is one-half the logarithm of the signal power-to-distortion(noise) ratio. It is achieved conceptually by encoding in such a way that the output error is Gaussian with variance  $D$  on each sample value and is sample-to-sample independent, but not necessarily signal independent. Actually there are no known practical methods for achieving a Gaussian error distribution or for achieving the rate distortion bound of (3.1). Instead one must be content with quantization methods which can be made to be within approximately .25 of a bit or so of the bound by choosing the quantization levels properly and using variable length coding on the quantized values.

In terms of quantizing schemes the rate distortion function has the following rough intuitive justification. The noise standard deviation as a fraction of the signal amplitude is inversely proportional to the number of quantization levels. Therefore, the number of levels should be proportional to  $\sigma/\sqrt{D}$  and the number of information bits should therefore be the logarithm (base 2) of this quantity. This is what is stated in (3.1). If the allowed distortion is greater than the signal power, i.e.  $D > \sigma^2$ , the minimum transmission rate and hence rate distortion function must be zero since nothing need be transmitted at all to achieve error power equal to signal power. This is also stated in (3.1).

The preceding was for a source of independent values. Suppose now the source contains memory as in most physical sources. In particular, suppose the source output is Markov (which means roughly that the future depends only on present values and not the past) with correlation coefficient  $\rho$ ,  $|\rho| < 1$ . This is a model which has found good agreement in practice, in particular for video data of the VHRR and synthetic aperture radar type. The value  $\rho$  is the correlation between adjacent values on a scan line. If  $\rho = 1$ , then each value is the same as the last. If  $\rho = 0$ , the values are independent as before. For this model it can be shown that (3.1) for low distortion levels becomes

$$R(D) = \frac{1}{2} \log \frac{\sigma^2(1-\rho^2)}{D} \quad (3.2)$$

The typical range of the parameter  $\rho$  is .95 to .99. Thus the number of bits can be reduced by  $\frac{1}{2} \log(1-\rho^2)$ , or something up to 3 bits, for a given mean square error  $D$  over coding for independent values. This performance can be approached through differential coding methods whereby successive sample differences are encoded by a variable length code. For

image data further gains can be made by using line-to-line effects. Assuming the same correlation model between lines, another gain of up to 3 bits can be attained assuming sufficient random access storage is available to store one whole line of data (in addition to the present line).

Rate distortion theory is most useful in practice in providing a bound on the performance of practical data compression methods. This is the primary way it has been used in this study. Consider for example differential variable length coding wherein the successive sample differences are quantized and encoded by a variable length code. Assuming fine quantization, the variance of the difference between the present quantized value and the next sample is approximately

$$2(1-\rho) \approx (1+\rho)(1-\rho) \approx 1-\rho^2 \quad (3.3)$$

Allowing .25 bit for the optimum quantized value code over the best that can be done as shown by (3.1) and (3.2), it is seen that the differential method comes within the .25 bit of the optimum up to the approximation of fine quantization and the approximations of (3.3)



## 4. Short Pulse Radar Data Reduction

### 4.1 Introduction

Extensive studies were performed on the extraction of rms wave height and wave periodicity based on off-nadir looking aircraft radar measurements provided by the NASA GSFC contract technical officer on digital 9 track tape. Two aircraft runs were provided, the first being from the JONSWOP experiment with the NRL altimeter used in an off-nadir mode by banking the aircraft. In this experiment a 10 nsec pulse width was used with a  $6^\circ$  beamwidth antenna. The aircraft was banked so that the beam center pointed about  $10^\circ$  and  $15^\circ$  off-nadir on passes in various turning configurations. The aircraft was at an altitude of approximately 11,000 feet. Similar data was provided by an NRL experiment in January 1974, the primary differences being a doubled sampling rate, a fixed bearing rather than a turning course by the aircraft, and less noisy data.

The sampled data provided in each of the experiments consisted of 6 digital tape files corresponding to each of 6 aircraft passes under different conditions. Each pass consisted of 8192 signal traces measured by sampling the pulse returns sequentially 160 times with increasing delay on each pulse across a total sampled time interval of one microsecond for the JONSWOP data and 500 nsec for the NRL data. A typical pulse appears in figure 4.1.1 and is seen to comprise the total returned energy from the sea surface plus noise with noise only preceding and following the return signal.

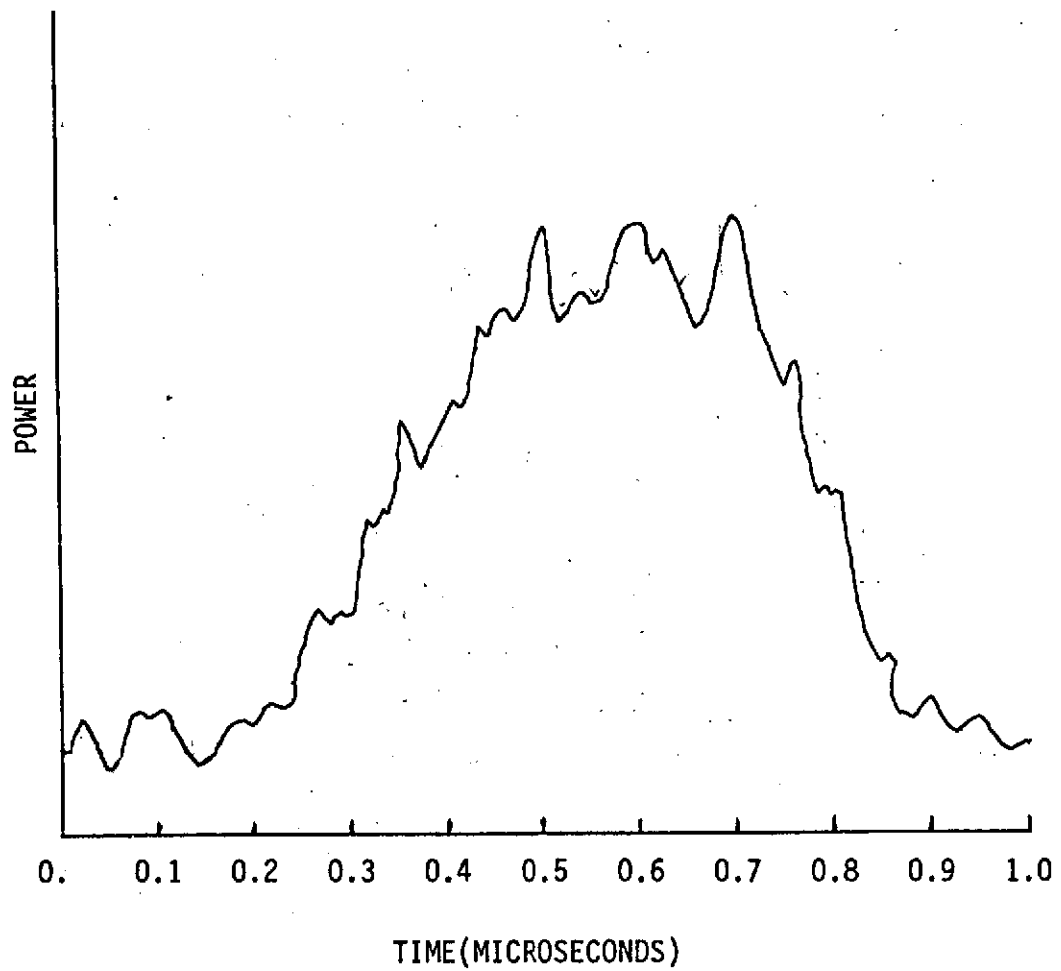


FIGURE 4.1.1. TYPICAL SIGNAL RETURN (JONSWOP DATA)

Computer programs were developed for the analysis of the sampled data and are included in listed form as a portion of this report. These are in Interdata assembly language and FORTRAN IV. The analysis programs include an Interdata assembly language program for inputting the data from the digital tape under a FORTRAN call and a master program with the ability under input control to print out individual signal traces or averages of signal traces, the ability to print out the Fourier transform amplitude spectra of the signal traces or their averages or the average of the Fourier amplitude spectra of the individual signal traces, using a fast Fourier transform routine written for the Interdata in FORTRAN, the ability to print out correlation functions and cross-correlation functions of the signal traces, and the ability to print out histograms of the signal trace peaks subject to a threshold on the signal level, including the calculated mean and rms values of the histogram. Except for the assembly language digital data input routine, FORTRAN IV was used exclusively so that the programs could be compiled on any machine, except, possibly for some minor modifications to conform with the particular compiler conventions.

Extensive computer program outputs of the various types were provided to NASA GSFC during the course of the contract for the purposes of analyzing the various approaches to determining the wave heights and/or wave periodicities from off-nadir short pulse radar data. The results to date appear promising but inconclusive, partly due to the limited amount of data, the noisiness of the data, the lack of resolution of the data, the necessity to construct one pulse from 160 sampled pulses, and the lack of ground truth values.

#### 4.2 Simplified Theory of Wave Height and Wave Periodicity Estimation

Many papers have been written on the theory of wave height and wave period estimation from radar sea scatter measurements. Some of these are listed in the references. In this section a brief review of the pertinent theory to off-nadir short pulse radar measurements is given in highly simplified form.

Consider a radar illuminating a periodic sea surface at an angle  $\alpha$  from nadir as shown below:

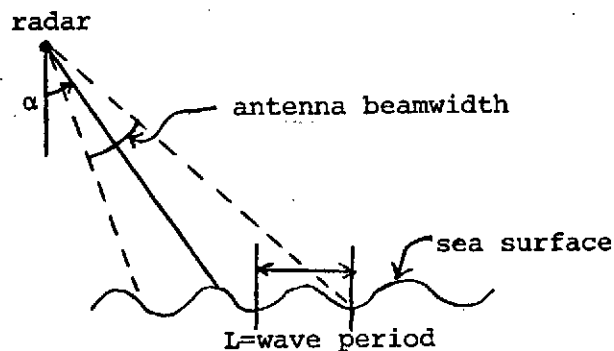


Figure 4.2.1. Short Pulse Radar Geometry

The returned signal power is the radar cross section as a function of propagation path length across the illuminated surface. If one assumes that the returns move linearly across the surface in time, the returned signal power contains an amplitude modulation component of frequency  $c/(2L\sin\alpha)$ . This conceptually can be extracted either directly from the returned power as a function of time or from the Fourier transform (spectrum) of the returned power by peak determination. Complicating the task, of course, is the non-pure periodicity of the sea surface, the nonlinearity of the range-time scale across the sea surface and the receiver noise. In the time domain the estimate could be extracted by a bank of

matched filters, incorporating the range-time base correction as a function of the off-nadir angle,  $\alpha$ . Alternately the data could be sampled non-uniformly or interpolated to correct the time base followed by a Fourier transform of the squared envelope. The peak of the spectrum (away from D.C.) represents the estimated amplitude modulation frequency.

Given the wave period estimate, the rms wave height estimate can be determined from the deterministic relation between the two. Alternately the wave height can be estimated and used to estimate the wave period through the same relationship. The average power return over a number of pulses is just the convolution of the transmitted pulse with the probability density function of the wave height integrated over range. The spectrum is the product of the transform of these factors. Thus the rms wave height can be extracted from the returned signal by finding the rms value of the probability density imbedded in the averaged returns. Reference [1] proposes doing this from the leading edge of the return which should be more or less spread out depending on wave height (actually [1] proposes using nadir measurements although the same analysis can be applied to small off-nadir observations). Levine [3,4] shows that the spectrum should be approximately proportional to

$$I(\nu) \exp \left[ -2 \left( \frac{2\pi\sigma_z}{c} \cos\alpha\nu \right)^2 \right] \text{sinc} \left( \frac{2\pi\ell}{c} \sin\alpha \right)$$

where:

$\nu$  = frequency

$I(\nu)$  = Fourier transform of the transmitted pulse squared

$\sigma_z$  = rms wave height

$\alpha$  = off-nadir angle

$l$  = illuminated surface length.

This is just the product of the transforms of the above referred to factors assuming the wave height distribution is Gaussian. Thus  $\sigma_z$  can be estimated by the rate of exponential decay of the spectrum.

Alternately, Levine [3] has shown that  $\sigma_z$  can be estimated from a histogram of the locations of peaks in the returned signal. In particular, he found that

$$\sigma_z^2 = \sec \alpha \left[ (c/2)^2 \overline{T_n^2} - \frac{(l \sin \alpha)^2}{12} \right]$$

where  $\overline{T_n^2}$  is the rms peak arrival time. Thus  $\sigma_z$  could be extracted from a peak histogram over several pulses.

Both of the preceding methods of extracting  $\sigma_z$  are theoretical results from a 2 dimensional model and involve approximations. Thus experimental results are needed to confirm the theory or point to needed modifications.

### 4.3 Computer Programs Developed for the Analysis

#### 4.3.1 Data Input Program

The data as supplied by the NASA GSFC technical officer is formatted on digital tape in 6 files of 257 records. The first record is a short header record for the file. Each succeeding record consists of 32 signal traces, formatted with 14 header bytes followed by 160 2-byte signal sample values. Thus one record consists of  $32 \times 167 = 5344$  2-byte (halfword) values. Each file of 256 data records comprises one aircraft pass.

The program written to read these values into a FORTRAN array is written in Interdata assembly language and appears as appendix A. The program is called by:

```
CALL ECKERM(INP)
```

where  $INP(N)$  is a (2-byte) integer array of dimension not less than 5344. All 5344 values from the next record on tape are unpacked sequentially in the array  $INP$ , including the header values.

#### 4.3.2 Fast Fourier Transform

A fast Fourier transform was used extensively for data analysis and is listed in Appendix B. It was written in Interdata FORTRAN IV and is a subroutine called by:

```
CALL FOUR1T(DATA,N,S,ISIGN)
```

where:

$DATA(I)$  = complex array of  $N$  values

$S$  = table of sines of dimension not less than  $N/2 + 1$

ISIGN is used as follows:

sign(ISIGN) = sign of the exponent in the Fourier transform

If  $|ISIGN| \neq 1$ , the sine tables are set up in S

If ISIGN = 0, tables are set up only.

The quantity calculated is:

$$\sum_{k=1}^N \text{DATA}(k) \exp \left( i \frac{2\pi}{N} (k-1) (n-1) \text{sign}(ISIGN) \right) ; \quad n=1,2,\dots,N$$

The results appear in DATA(n) in place of the original data. Note that no normalization by N occurs.

#### 4.3.3 Analysis Program

The listing of the main analysis program appears in Appendix C as it is currently configured. Many modifications were made to the program as the contract progressed to conform to the various analytical approaches and data requests by NASA GSFC. Certain classes of outputs can be generated by an appropriate input to the program from the teletype keyboard as the program now stands. Others can be generated by simple program modifications and re-compilation. The following outputs have been generated to date:

- (1). A printout of individual signal traces squared (i.e. power) or the average of a number of signal traces squared, with the number under input control, and the centroid of the printed quantity. An example of this printout appears in Appendix D.
- (2). A printout of the log of the spectrum of the average in (1). An example appears in Appendix D where a 1024 point spectrum



appears, generated by setting all values to zero outside the return signal range. Fourier transform amplitude spectra can also be generated without the appended zeroes, in which case the values are windowed prior to transforming.

- (3). The average of the Fourier transform amplitude spectra of individual pulses.
- (4). Correlation functions of the signal traces and cross correlation functions between signal traces.
- (5). Numbers (2)-(4) with the range-time base corrected by interpolation to be linear.
- (6). Signal-to-noise ratio estimates.
- (7). Histograms of peaks exceeding an input threshold, including the mean and rms values of the histograms. An example of this printout appears in Appendix E.

To date the efficacy of the various estimation techniques remains unproven, although the results are promising. Upon the attainment of further data, the programs developed under this contract will be available for the analysis and the development of an optimal technique.

## 5. VHRR Data Compression

The VHRR signal appears as in figure 5.1 with the timing as indicated in table 5.1. The voltage range is 6 volts which is contained within a lowpass bandwidth of 35 kHz nominal. Using a sampling rate on the order of 100 kHz (1.43 times the Nyquist rate) and something like 8 bit sample quantization results in a bit rate on the order of 1 Mhz for a straightforward PCM transmission system. However, an examination of table 5.1 reveals that 40 % of the data can be essentially eliminated by transmitting the temperature and calibration values as single digital values rather than as long repetitive steps and by synchronizing on and selecting out the earth scan data only. It is shown in the results of an earlier study [2] that another 3 bits can be removed from the 8 bit quantized values in the earth scan data by using variable length coding on the sample differences as described in section 3 of this report. Thus the compressed-buffered bit stream requires a channel capacity on the order of  $(8-5) \text{ bits} \times 60\% \times 100\text{kHz} \approx 300 \text{ kHz}$ . Further details can be found in the reference [2].

As indicated in section 3, a further reduction in bit rate can be achieved by using line-to-line effects, perhaps to as low as 100 kHz if enough storage is allocated to hold the last line. Still further reduction in the average rate can be attained by selecting out only the intervals of time of particular interest or by deleting samples and/or lines on a regular basis. In this case digital filtering should be used to prevent aliasing on reconstruction.

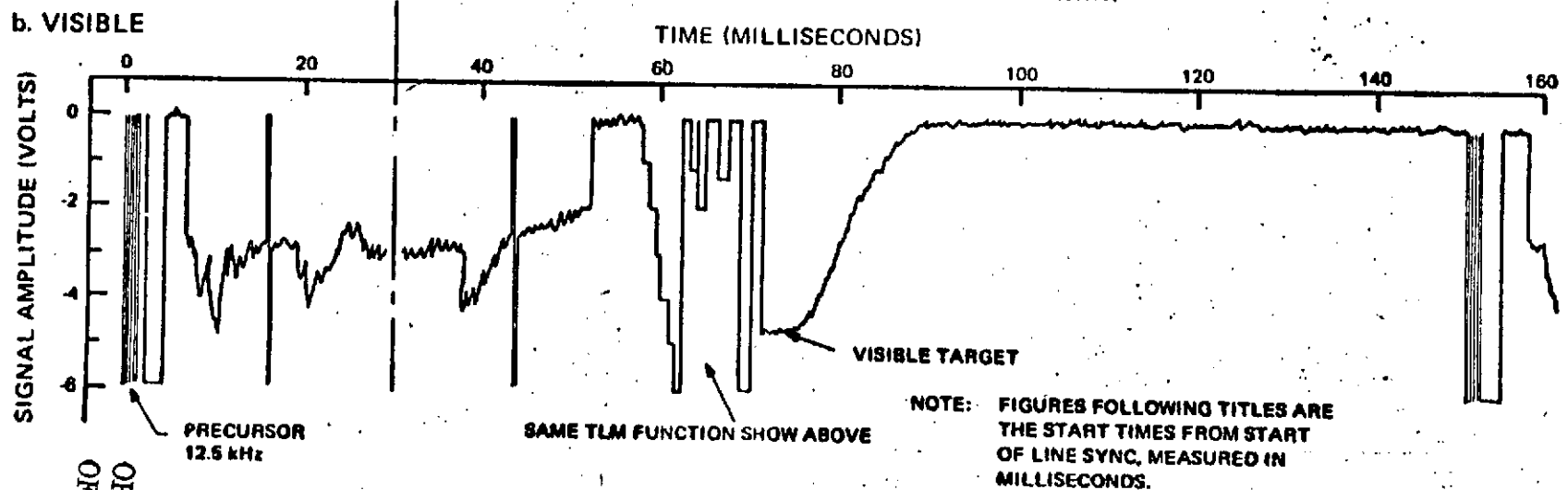
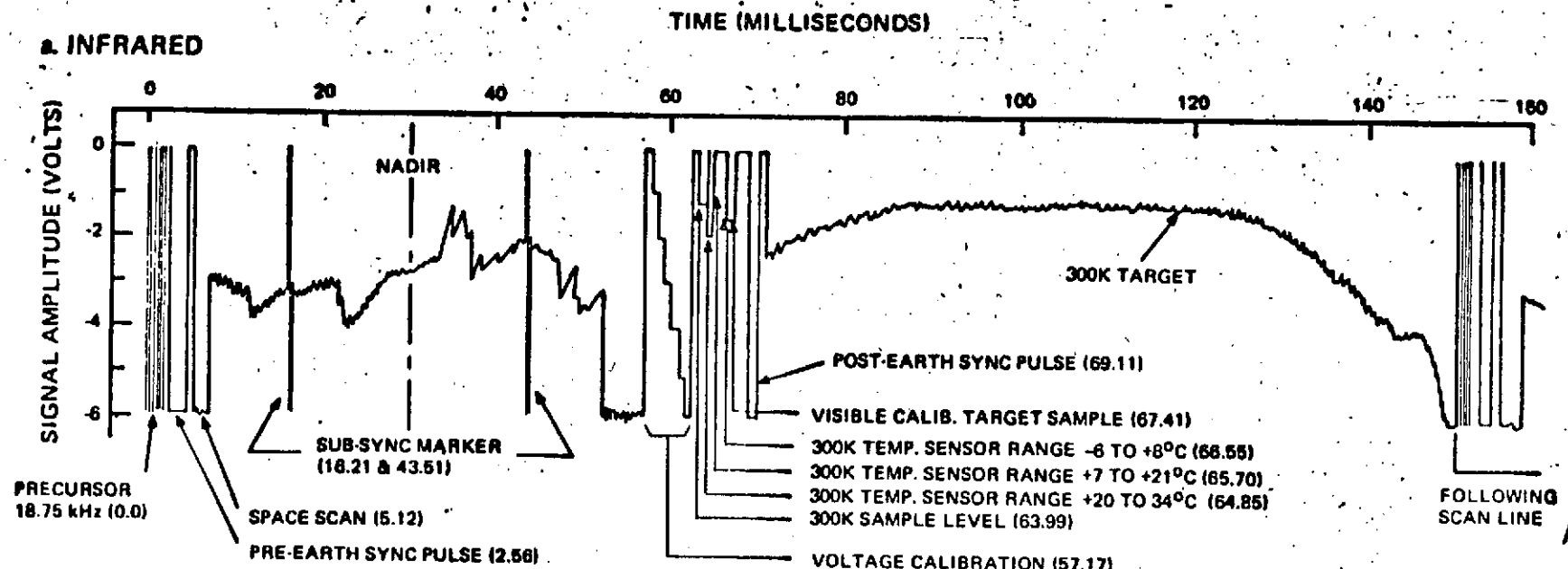


FIGURE 5.1. VHRR Signals

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Function	After Start of IR Precursor		Duration		Signal Characteristics
	Counts*	Time (msec)	Counts	Time (msec)	
Precursor IR	0	0	5.2	1.71	18.75 kHz square wave, 0 to 100% amplitude starts $72 \pm 1^\circ$ before nadir
Pre-earth Synchronization signal					
Front Porch	521	1.71	256	0.85	Amplitude 0%
Sync Pulse	768	2.56	512	1.71	Amplitude 100%. Starts $65.8 \pm 1^\circ$ before the nadir
Back Porch	1280	4.27	256	0.85	Amplitude 0%
Space scan	1536	5.12	Not clock controlled	2.08†	Amplitude 100% period varies with spacecraft altitude & attitude
Earth scan		7.20†	Not clock controlled	45.32†	Amplitude varies over range 0% to 100% (0% Hot, 100% Cold). Period, varies from 43.68 msec @900 n.mi. to 48.64 msec @600 n.mi.
1st Sub-Sync marker	4864	16.21	16	0.05	Two level signal starting at 0% amplitude for $\frac{1}{4}$ the period when switching to 100% for the remainder of the period
2nd Sub-Sync marker	13056	43.51	16	0.05	Same as 1st Sub-Sync marker
Space scan (post earth)	Not clock controlled	32.52	--	4.64†	Amplitude is undefined as signal may be influenced by the visible channel calibration target
Voltage Calibration	17152	57.17	1792	5.97	Seven levels increasing in amplitude from 0 to 100%. Zero level following 7th step.
Visible calibration	18944	63.14	256	0.85	Normal range when target is illuminated by sun is about 20% amplitude
Radiance calibration 300K target	19200	63.99	256	0.85	Amplitude about 20%. Varies with target's actual temperature

TABLE 5.1-VHRR TIMING

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Function	After Start of IR Precursor Counts*	IR Precursor Time (msec)	Duration		Signal Characteristics
			Counts	Time (msec)	
Temperature Sensor 300K target (expanded range +20 to +34°C)	19456	64.85	256	0.85	For normal temperature range amplitude will be between 0 and 80%. (If the temperature is out of this range, the signal will either be 0 or between 85% and 100%)
Temperature Sensor (expanded) range +7 to +21°C)	19712	65.70	256	0.85	Same as above
Temperature Sensor (expanded range -6 to +8°C)	19968	66.55	256	0.85	Same as above
<b>Post-earth Synchronization</b>					
Front Porch	20224	67.41	1024	3.41	Amplitude 0%
Sync Pulse	21248	70.82	256	0.85	Amplitude 100%
Back Porch	21504	71.67	256	0.85	Amplitude 0%
End of IR scan	21760	72.53			
Precursor Vis	22523*	75.00±1.00	512	1.71	12.50kHz square wave, 0 to 100% amplitude. Starts 72±10 before nadir
<b>Pre-earth Synchronization Signal</b>					
Front Porch	23035	76.78	256	0.85	Same as IR signal
Sync Pulse	23291	77.63	512	1.71	Same as IR signal
Back Porch	23803	79.34	256	0.85	Same as IR signal
Space scan (pre-earth)	24059	80.19	Not clock controlled	2.08†	Amplitude 0%. Period varies identically with IR signal

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TABLE 5-1 (cont)

Function	After Start of IR Precursor		Duration		Signal Characteristics
	Counts*	Time (msec)	Counts	Time (msec)	
Earth scan	Not clock controlled	82.27†	Not clock controlled	45.32†	Amplitude varies over range of 0% to 100%. (0% Black, 100% White). Period varies identically with IR channel.
1st Sub-Sync marker	27387	91.28	16	0.05	Same as IR signal
2nd Sub-Sync marker	35579	118.58	16	0.05	Same as IR signal
Space scan (post earth)	Not clock controlled	127.59	Not clock controlled	4.64†	Same as IR signal
Voltage calibration	39675	132.24	1792	5.97	Same as IR signal
Visible calib. target	41467	138.22	256	0.85	Same as IR signal
Radiance calibration 300°K target	41723	139.00	256	0.85	Same as IR signal
Temperature sensor (+20 to 34°C)	41979	139.93	256	0.85	Same as IR signal
Temperature sensor (+7 to +21°C)	42235	140.78	256	0.85	Same as IR signal
Temperature sensor (-6 to +8°C)	42491	141.64	256	0.85	Same as IR signal
<b>Post-earth Synchronization Signal</b>					
Front Porch	42747	142.49	1024	3.41	Same as IR signal
Sync Pulse	43771	145.90	256	0.85	Same as IR signal
Back Porch	44027	146.76	256	0.85	Same as IR signal
Multiplex tolerance safety zone	44283	147.61	--	~2.39	
End of Scan		150.00			

\*A count is one cycle of 300-kHz square wave.

†Spacecraft at 790 n.mi., 0° roll error, and nominal position for start of precursor

‡Nominal value for switchover from IR to Visible Scan. All following times assume that this switchover is nominal.

TABLE 5.1. (cont)

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## 6. On-Board Data Management System

It is clear from the preceding that the on-board processing requires a great deal of flexibility and computation which can be best performed by an on-board programmable computer, the programs for which can be loaded under ground station control. Such programs can be used to select and multiplex the sensors, to reduce the data to the desired parameter estimates, select sampling rates, encode the data and buffer it for transmission and/or storage at a constant rate from variable rate input values.

The primary considerations in the selection of an on-board processor are the computation speed, instruction repertoire and storage capacity. Also important, of course, are the power consumption, weight and volume. An investigation of the NASA GSFC-developed advanced on-board processor (AOP) indicates that it is suitable for SEASAT. It is a 1 microsecond cycle time machine with 16K 2 microsecond cycle time memory banks. There are 11 load/store and 9 arithmetic instructions plus various I/O, interrupt, branching, and test instructions.

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2. R.M. Gray and L.D. Davisson, "ITOS VHRR On-Board Data Compression Study," Systems Analysis Report no. 75100, January 1975.
3. David M. Le Vine, "Monitoring the Sea Surface with a Short Pulse Radar,"
4. David M. Le Vine, "Spectrum of Power Scattered by a Short Pulse From a Stochastic Surface," NASA GSFC Report X-952-74-299, August 1974.
5. K. Tomiyasu, "Short Pulse Wide Band Scatterometer Ocean-Surface Signature," IEEE Trans. Geoscience Electronics, v. GE-9, 1971, pp 175-177.
6. G.T. Ruck, D.E Barrick and T. Kaliszewski, "Bistatic Radar Sea State Monitoring," Batelle report, June 1972.



## APPENDIX A

## Data Input Program

PAGE 1

READ ECKERMAN TAPE INTO FORTRAN 5/74

```

0000R          ENTRY ECKERM
0000R          EXTRN .0
          *
          * CALL IS:
          *   CALL ECKERM(INP)
          * INP(N) IS A FIX PT ARRAY
          * N.GE. 5344
          *
          * LDD 5/74
          * MOD FOR 2 BYTE 10/74
          *
0000R D0A0      ECKERM  STM  10,REG          SAVE USER REGS
          0088R
0004R 48AF          LH  10,0(15)          CK NUMB ARGS
          0000
0008R 27A4          SIS  10,4
000AR 2337          BZS  OK
000CR C8B0          LHI  11,C'33'
          3333
0010R 41F0          BAL  15,.0          SEND ERR MESS
          0000F
0014R E130          SVC  3,0          & STOP
          0000
0018R 48AF          OK  LH  10,2(15)          GET A(INP)
          0002
001CR 08DA          LHR  13,10          SAVE FOR LATER
001ER 40A0          STH  10,INPUT+4          SET UP SVC
          009AR
0022R CAA0          AHI  10,10687          END ADDR
          29BF
0026R 40A0          STH  10,INPUT+6
          009CR
002AR 24E2          LIS  14,2
002CR C8FD          LHI  15,10686(13)          LAST ADDR
          29BE
0030R E110          GO  SVC  1,INPUT          READ TAPE IN
          0096R
0034R 4800          LH  0,INPUT+2          CK STAT
          0098R
0038R 4230          BNZ  NOGO
          0064R
003CR D3BD          LOOP LB  11,0(13)          GET MSP
          0000
0040R C7B0          XHI  11,X'10'          MAKE ALL +
          0010
0044R C4B0          NHI  11,X'1F'          MASK OUT INS BIT
          001F
0048R D3AD          LB  10,1(13)          GET LSP
          0001
004CR C4A0          NHI  10,X'1F'          MASK OUT INS BIT
          001F
0050R 91B5          SLLS 11,5          LINE UP
0052R 06BA          OHR  11,10          PACK
0054R 40BD          STH  11,0(13)          STORE AWAY
          0000
0058R C1D0          BXLE 13,LOOP          GET NEXT

```

READ ECKERMAN TAPE INTO FORTRAN 5/74

PAGE 2

```

003CR
005CR D1A0          LM      10,REG      RETURN IF DONE
0088R
0060R 430F          B        4(15)
0004
0064R E120          NOGO     SVC      2,UNPAK      UNPACK &
0074R
0068R E120          SVC      2,LIST      PRINT STAT
0078R
006CR E120          SVC      2,PAUSE     WAIT
0094R
0070R 4300          B         GO        TRY AGAIN
0030R
0074R 0006          UNPAK    DC        6,MESS
0084R
0078R 0007          LIST     DC        7,12,C'I/O ERR
000C
492F
4F20
4552
5220
0084R MESS           DS         4
0088R REG           DS        12
0094R PAUSE        DC         1
0096R 4801          INPUT    DC        X'4801',0,0,0 LU 1 RD IN
0000
0000
0000
009ER          END

```

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READ ECKERMAN TAPE INTO IFORTRAN 5/74

PAGE 3

NO ERRORS

* .O	0012R
* ECKERM	0000R
GO	0030R
INPUT	0096R
LIST	0078R
LOOP	0030R
MESS	0084R
NOGO	0064R
OK	0018R
PAUSE	0094R
REG	0088R
UNPAK	0074R

## Fast Fourier Transform

```

SUBROUTINE FOUR1T(DATA,NN,S,ISIGN)
C DATA=COMPLEX ARRAY
C NN=NUMB COMPLEX VALS
C S=SIN TBL, DIM=DIM(DATA)/2+1
C ISIGN=SIGN IN FOURIER
C IF ABS(ISIGN).NE.1, TABLES SETUP
C IF EQ. 0, TABLES ONLY
C NO NN NORMALIZATION
C DIMENSION DATA(1),S(1)
N=NN+NN
NN2=NN/2
NN21=NN2+1
NN22=NN2+2
NNP2=NN+2
XN=NN
IF(IABS(ISIGN).EQ.1) GO TO 1
DO 4 I=1,NN21
THETA=3.1415926535*FLOAT(I-1)/XN
4 S(I)=SIN(THETA)
IF(ISIGN.EQ.0) RETURN
1 J=1
DO 5 I=1,N,2
IF(I.GE.J) GO TO 2
TEMPR=DATA(J)
TEMPI=DATA(J+1)
DATA(J)=DATA(I)
DATA(J+1)=DATA(I+1)
DATA(I)=TEMPR
DATA(I+1)=TEMPI
2 M=N/2
3 IF(J.LE.M) GO TO 5
J=J-M
M=M/2
IF(M.GE.2) GO TO 3
5 I=J+M
MMAX=2
6 ISTEP=MMAX+MMAX
NMAX=N/MMAX
DO 8 M=1,MMAX,2
IND=((M-1)*NMAX)/2+1
IF(IND.GT.NN21) GO TO 2
WI=S(IND)
IND=NN22-IND
WR=S(IND)
GO TO 9
7 IND=NNP2-IND
WI=S(IND)
IND=NN22-IND
WR=-S(IND)
9 CONTINUE
IF(ISIGN.LE.0) WI=-WI
DO 8 I=M,N,ISTEP

```

```

      J=I+MMAX
      TEMPR=WR*DATA(J)-WI*DATA(J+1)
      TEMPI=WR*DATA(J+1)+WI*DATA(J)
      DATA(J)=DATA(I)-TEMPR
      DATA(J+1)=DATA(I+1)-TEMPI
      DATA(I)=DATA(I)+TEMPR
      DATA(I+1)=DATA(I+1)+TEMPI
      MMAX=ISTEP
      IF(MMAX.LT.N) GO TO 6
      RETURN
      END

```

```

FOUR1T 0024R FUNC/SUB
FOUR1T 0574R FUNC VAR
Q       0000R EXT FUNC
P       0000R EXT FUNC
DATA   002AR FORM PAR
NN     002CR FORM PAR
S      002ER FORM PAR
ISIGN  0030R FORM PAR
N      057CR INT4 VAR
NN2    0580R INT4 VAR
NN21   0588R INT4 VAR
NN22   0590R INT4 VAR
NNP2   0594R INT4 VAR
XN     0598R REAL VAR
W      0000R EXT FUNC
IABS   0000R EXT FUNC
1      012ER LABEL
4      00E4R LABEL
I      059CR INT4 VAR
THETA  05A0R REAL VAR
FLOAT  0000R EXT FUNC
SIN    0000R EXT FUNC
J      05B4R INT4 VAR
5      027CR LABEL
2      0228R LABEL
TEMPR  05B8R REAL VAR
TEMPI  05BCR REAL VAR
M      05C0R INT4 VAR
3      023AR LABEL
MMAX   05C4R INT4 VAR
6      02A2R LABEL
ISTEP  05C8R INT4 VAR
NMAX   05CCR INT4 VAR
8      04EAR LABEL
IND    05D0R INT4 VAR
7      033CR LABEL
WI     05D4R REAL VAR
WR     05D8R REAL VAR
9      038CR LABEL

```

0000 ERRORS

## APPENDIX C

## Main Analysis Program

```

0001 C THIS PROGRAM IS TO ANALYZE AND DISPLAY EOPAP SEASAT
0002 C SHORT PULSE RADAR DATA. DEPENDING ON THE PROGRAM
0003 C MODE SELECTED, PULSES, PULSE SPECTRA OR PEAK
0004 C HISTOGRAMS CAN BE DISPLAYED. EITHER THE AVERAGE
0005 C SPECTRA OR THE AVERAGE OF THE SPECTRA CAN BE
0006 C SELECTED. MEANS AND RMS VALUES CAN BE EVALUATED.
0007 C DATA ARE ADJUSTED FOR POWER.
0008 C
0009 0004R      IMPLICIT INTEGER*2 (I-N)
0010 0004R      DIMENSION IPR(168)
0011 0004R      DIMENSION INP(5344),TBL(1024),DAT(50),PULSE(256)
0012 0004R      DIMENSION XLAB(6),PLOT(101),PAV(256),WIND(256)
0013 0004R      COMPLEX Z(1024),CMPLX
0014 0004R      EQUIVALENCE (Z(1),INP(1))
0015 0004R      DATA PI,N,NTUP,LO,IHI/3.1415927,128,1024,23,150/
0016 0014R      DATA DOT,STAR,BLANK,SLASH,ES,AA,PEE/1H.,1H*,1H,1H/,1HS,1HA,1
0017 0030R      CALL FOURIT(Z,NTUP,TBL,0)
0018 C READ IN MODE DESIRED
0019 003ER 101 WRITE (0,100)
0020 0056R 100 FORMAT(11H ENTER MODE)
0021 006AR READ(0,2) MODE
0022 008AR N2=N/2
0023 0090R N21=N2+1
0024 00A8R NTUP21=NTUP/2+1
0025 00BER N1=N+1
0026 00CAR XN=N
0027 00D8R XM=PI/XN
0028 C CALCULATE WINDOW WEIGHTS
0029 00E4R DO 42 I=1,N
0030 00ECR 42 WIND(I)=1.-.83636364*XCOS(FLOAT(I-1)*XM)
0031 C GET LABEL FOR SPECTRA
0032 013ER DO 23 K=1,6
0033 0146R 23 XLAB(K)=FLOAT(K-1)
0034 C NOW GET INPUT PARAMETERS
0035 017CR WRITE(0,4)
0036 0194R 4 FORMAT(6H LABEL)
0037 01A2R READ(0,5) DAT
0038 01C4R 5 FORMAT(50A1)
0039 01CER WRITE(0,30)
0040 01E6R 30 FORMAT(13H ANGLE,MICSEC)
0041 01FCR READ(0,31) ANGLE,DUR
0042 0224R 31 FORMAT(8F5.1)
0043 0230R WRITE(3,6) DAT
0044 0252R 6 FORMAT(1H1,50A1)
0045 0260R ANG=ANGLE*PI/180.
0046 0270R DELTA=160./((DUR*FLOAT(NTUP)))
0047 0288R WRITE(0,1)
0048 02A0R 1 FORMAT(7H FILE=?,7HITHRESH)
0049 02BAR READ(0,2) IFILE,ITHRSH
0050 02E2R 2 FORMAT(8I5)
0051 02ECR WRITE(3,3) IFILE,ANGLE,DUR
0052 031CR 3 FORMAT(6H FILE ,I3,5X,F6.1,8H DEGREES,5X,F6.2,7H MICSEC)

```

```

0053 0352R      WRITE(3,99) ITHRSH
0054 0372R 99   FORMAT(15H THRESHOLD = ,I5)
0055 038ER      WRITE(0,7)
0056 03A6R 7    FORMAT(12H BLOCKS,SIZE)
0057 03BCR      READ(0,2)IBLKS,ISIZE
0058 03E4R      SIZE=ISIZE
0059 03F2R 8    FORMAT(1H ,I5,32H AVG SQUARED PULSES,LOG SPECTRUM)
0060 0422R 41   FORMAT(31H SPECTRA OF AVG=S,AVG SPECTRA=A )
0061          C BLOCKS ARE INPUT IN 32 TRACE BLOCKS
0062 044AR      KOUNT=33
0063 0452R      DO 9 IIII=1,IBLKS
0064 045AR      WRITE(3,10)IIII
0065 047AR 10   FORMAT(7H BLOCK ,I4)
0066 048CR      DO 15 K=LO,IHI
0067 0494R      IL=K+1-LO
0068 04A4R      PAV(IL)=0.
0069 04B8R      IPR(K)=0
0070 04CAR 15   PULSE(K)=0.
0071          C
0072 04F0R      WRITE(3,22) XLAB
0073 04F8R      CALL BKS(1)
0074 0500R      CALL ECKERM(INP)
0075 0508R      DO 12 I=1,ISIZE
0076 0514R      KOUNT=KOUNT+1
0077 0526R      IF(KOUNT.LE.32)GO TO 13
0078          MIN=2**14
0079          C GET NEXT INPUT BLOCK OF 32 TRACES
0080 053AR      CALL ECKERM(INP)
0081 0542R      DO 11 III=1,32
0082 054AR      IJ=(III-1)*167
0083 055AR      DO 11 K=LO,IHI
0084 0562R      J=IJ+K
0085 056ER 11   MIN=MIN0(MIN,INP(J))
0086 05B4R      KOUNT=1
0087 05BCR 13   IJ=(KOUNT-1)*167
0088 05CCR      DO 14 K=LO,IHI
0089 05D4R      J=IJ+K
0090 05E0R      X=INP(J)-MIN
0091 05FCR      XX=X*X
0092          C
0093          C
0094 0608R 14   Z(KL)=CMPLX(XX,0.)*WIND(KL)
0095 063ER      PULSE(K)=PULSE(K)+XX
0096          IF(MODE.NE.1)GO TO 12
0097          C CALCULATE PEAK HISTOGRAM FOR VALUES ABOVE THRESHOLD
0098 0650R      DO 70 K=LO,IHI
0099 0658R      J=IJ+K
0100 0664R      IF(INP(J).LT.ITHRSH) GO TO 70
0101 0680R      IF(INP(J).GT.INP(J-1).AND.INP(J).GT.INP(J+1))IPR(K)=IPR(K)+1
0102 06F0R 70   CONTINUE
0103 0702R      GO TO 12
0104          C GET PULSE FOURIER TRANSFORM
0105 0706R      CALL FOUR1T(Z,N,TBL,1)
0106 0714R      DO 40 K=1,N21

```

```

0105 071CR 40 PAV(K)=PAV(K)+CABS(Z(K))
0106 076AR 12 CONTINUE
0107 077CR DO 62 I=1,101
0108 0784R 62 PLOT(I)=BLANK
0109 07AAR IF(MODE.NE.1)GO TO 72
0110 07BCR WRITE(3,74) ISIZE
0111 07DCR 74 FORMAT(1H ,15,15H PEAK HISTOGRAM )
0112 C CALCULATE MEAN,RMS FOR HISTOGRAM
0113 07FCR SUMNRM=0.
0114 0804R CNTROD=0.
0115 080CR SUMSQ=0.
0116 0814R TMIN=5000.
0117 081CR TMAX=0.
0118 0824R DO 97 I=LO,IHI
0119 082CR XK=I
0120 083AR IF(IPR(I).GT.0) TMIN=AMIN1(TMIN,XK)
0121 0860R IF(IPR(I).GT.0) TMAX=AMAX1(TMAX,XK)
0122 0886R X=IPR(I)
0123 089ER SUMNRM=SUMNRM+X
0124 08AAR CNTROD=CNTROD+X*XX
0125 08BAR SUMSQ=SUMSQ+X*XX*XX
0126 08CER 97 CONTINUE
0127 08E0R CNTROD=CNTROD/SUMNRM
0128 08E6R SUMSQ=SUMSQ/SUMNRM
0129 08F8R RMS=SQRT(SUMSQ-CNTROD*CNTROD)
0130 0918R WRITE(3,98)CNTROD,RMS
0131 0940R 98 FORMAT(13H CENTROID = ,F5.0,7H RMS = ,F5.0)
0132 096AR GO TO 102
0133 096ER SIGZ=RMS*RMS-((TMAX-TMIN-1.)*2)/12.
0134 099ER SIGZP=DUR*150.*SQRT(ABS(SIGZ))/(160.*COS(ANG))
0135 09DER WRITE(3,96)SIGZP
0136 09FER 96 FORMAT(15H SIGMA Z = ,F12.5)
0137 0A1CR IF(SIGZ.LT.0.)WRITE(3,95)
0138 0A42R 95 FORMAT(12H NEGATIVE )
0139 0A58R 102 CONTINUE
0140 0A58R DO 73 K=LO,IHI
0141 0A60R IX=FLOAT(IPR(K))/SIZE*100.+5
0142 0A90R PLOT(IX)=PEE
0143 0AA4R WRITE(3,75) K,IPR(K),PLOT
0144 0AE8R 75 FORMAT(1H ,2I5,10I1)
0145 0AF0R PLOT(IX)=BLANK
0146 0B10R 73 CONTINUE
0147 0B22R GO TO 76
0148 C NOW PLOT PULSE AVG, SPECTRUM
0149 0B26R 72 XMAX=0.
0150 0B2ER CNTROD=0.
0151 0B36R SUMNRM=0.
0152 0B3ER DO 64 K=LO,IHI
0153 0B46R CNTROD=CNTROD+PULSE(K)*FLOAT(K)
0154 0B66R SUMNRM=SUMNRM+PULSE(K)
0155 0B7ER 64 XMAX=AMAX1(XMAX,PULSE(K))
0156 0BB2R CNTROD=CNTROD/SUMNRM

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0157 0BBER      ICNTR=CNTR0D+.5
0158 0BD0R      WRITE(3,8) ISIZE
0159 0BF0R      WRITE(3,65) ICNTR
0160 0C10R      65  FORMAT(13H CENTROID = ,I5)
0161 0C2AR      XNORM=100./XMAX
0162 0C36R      DO 16 K=1,N
0163 0C3ER      IJ=L0+K-1
0164 0C4ER      IX=PULSE(IJ)*XNORM+.5
0165 0C70R      PLOT(IX)=PEE
0166 0C84R      WRITE(3,61)IJ,PLOT
0167 0CAER      61  FORMAT(1H ,I3,101A1)
0168 0CC0R      PLOT(IX)=BLANK
0169 0CD4R      16  Z(K)=CMPLX(PULSE(IJ)/SIZE,0.)
0170 0D10R      DO 60 K=N1,NTUP
0171 0D24R      60  Z(K)=CMPLX(0.,0.)
0172 0D54R      CALL FOURIT(Z,NTUP,TBL,1)
0173 C           WRITE(2,200) (Z(KK),KK=1,N)
0174 0D62R      200  FORMAT(4E20.9)
0175 0D6ER      WRITE(3,22) XLAB
0176 0D90R      22  FORMAT(10H FREQUENCY ,4X,IHS,3X,5(F4.1,16X),F4.1)
0177 0DBER      DO 18 K=1,NTUP21
0178 C           PAV(K)=PAV(K)/SIZE
0179 0DC6R      D=FLOAT(K-1)*DELTA
0180 0DE2R      X=CABS(Z(K))/XN
0181 0E06R      X=ALOG10(X)
0182 0E12R      IX=20.*X+.5
0183 0E28R      IX=MIN0(MAX0(1,IX+1),101)
0184 C           Y=ALOG10(PAV(K))
0185 C           IY=20.*Y+SIGN(.5,Y)
0186 C           IY=MIN0(MAX0(1,IY+1),101)
0187 0E54R      PLOT(1)=SLASH
0188 0E60R      DO 19 I=2,101
0189 0E68R      PLOT(I)=BLANK
0190 0E70R      IF(((I-1)/4)*4.EQ.I-1)PLOT(I)=DOT
0191 0EB6R      19  CONTINUE
0192 C           PLOT(IY)=AA
0193 0EC8R      PLOT(IX)=ES
0194 0EDCR      WRITE(3,20) D,X,PLOT
0195 0F0ER      20  FORMAT(1H ,F6.2,4X,F7.4,2X,101A1)
0196 0F2ER      18  CONTINUE
0197 0F40R      76  WRITE(3,21)
0198 0F58R      21  FORMAT(1H1)
0199 0F62R      9   CONTINUE
0200 C NOW GET NEXT INPUT
0201 0F74R      GO TO 101
0202 0F78R      END
U      0000R      EXT FUNC
IPR     0F70R      INT2 VAR
INP     10CCR      INT2 VAR
Z       10CCR      CMPX VAR
TBL     3A8CR      REAL VAR
DAT     4A8CR      REAL VAR

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PULSE	4B54R	REAL VAR
XLAB	4F54R	REAL VAR
PLOT	4F6CR	REAL VAR
PAY	5100R	REAL VAR
WIND	5500R	REAL VAR
CMPLX	0000R	EXT FUNC
PI	0008R	REAL VAR
N	000CR	INT2 VAR
NTUP	000ER	INT2 VAR
LO	0010R	INT2 VAR
IHI	0012R	INT2 VAR
DOT	0014R	REAL VAR
STAR	0018R	REAL VAR
BLANK	001CR	REAL VAR
SLASH	0020R	REAL VAR
ES	0024R	REAL VAR
AA	0028R	REAL VAR
PEE	002CR	REAL VAR
FOUR1T	0000R	EXT FUNC
101	003ER	LABEL
100	0056R	LABEL
@H	0000R	EXT FUNC
2	02E2R	LABEL
MODE	5904R	INT2 VAR
N2	5906R	INT2 VAR
N21	590CR	INT2 VAR
NTUP21	5912R	INT2 VAR
N1	5914R	INT2 VAR
XN	5916R	REAL VAR
W	0000R	EXT FUNC
XM	591AR	REAL VAR
42	00ECR	LABEL
I	591ER	INT2 VAR
COS	0000R	EXT FUNC
FLOAT	0000R	EXT FUNC
23	0146R	LABEL
K	5938R	INT2 VAR
4	0194R	LABEL
5	01C4R	LABEL
30	01E6R	LABEL
31	0224R	LABEL
ANGLE	593AR	REAL VAR
DUR	593ER	REAL VAR
6	0252R	LABEL
ANG	5942R	REAL VAR
DELTA	594AR	REAL VAR
1	02A0R	LABEL
IFILE	5952R	INT2 VAR
ITHRSH	5954R	INT2 VAR
3	031CR	LABEL
99	0372R	LABEL
7	03A6R	LABEL

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IBLKS	5956R	INT2 VAR
ISIZE	5958R	INT2 VAR
SIZE	595AR	REAL VAR
8	03F2R	LABEL
41	0422R	LABEL
KOUNT	595ER	INT2 VAR
9	0F62R	LABEL
IIII	5964R	INT2 VAR
10	047AR	LABEL
15	04CAR	LABEL
IL	5966R	INT2 VAR
BKS	0000R	EXT FUNC
ECKERM	0000R	EXT FUNC
12	076AR	LABEL
13	05BCR	LABEL
MIN	5970R	INT2 VAR
I	0000R	EXT FUNC
11	056ER	LABEL
III	5976R	INT2 VAR
IJ	5978R	INT2 VAR
J	597ER	INT2 VAR
MIN0	0000R	EXT FUNC
14	0608R	LABEL
X	5980R	REAL VAR
XX	5984R	REAL VAR
70	06F0R	LABEL
40	071CR	LABEL
CABS	0000R	EXT FUNC
62	0784R	LABEL
72	0B26R	LABEL
74	07DCR	LABEL
SUMNRM	5988R	REAL VAR
CNTROD	598CR	REAL VAR
SUMSQ	5990R	REAL VAR
TMIN	5994R	REAL VAR
TMAX	599CR	REAL VAR
97	080ER	LABEL
XK	59A0R	REAL VAR
AMIN1	0000R	EXT FUNC
AMAX1	0000R	EXT FUNC
RMS	59A4R	REAL VAR
SQRT	0000R	EXT FUNC
98	0940R	LABEL
102	0A58R	LABEL
SIGZ	59A8R	REAL VAR
R	0000R	EXT FUNC
SIGZP	59B0R	REAL VAR
ABS	0000R	EXT FUNC
96	09FER	LABEL
95	0A42R	LABEL
73	0B10R	LABEL
IX	59C0R	INT2 VAR

.V	0000R	EXT FUNC
75	0A68R	LABEL
76	0F40R	LABEL
XMAX	59C4R	REAL VAR
64	0B7ER	LABEL
ICNTR	59CER	INT2 VAR
65	0C10R	LABEL
XNORM	59D0R	REAL VAR
16	0CD4R	LABEL
61	0C8ER	LABEL
4P	0000R	EXT FUNC
60	0D24R	LABEL
200	0D62R	LABEL
22	0D90R	LABEL
18	0F2ER	LABEL
D	59D4R	REAL VAR
ALOG10	0000R	EXT FUNC
MAX0	0000R	EXT FUNC
19	0EB6R	LABEL
20	0F0ER	LABEL
21	0F58R	LABEL
.V	0000R	EXT FUNC

0000 ERRORS



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