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ON-BOARD DATA MANAGEMENT STUDY FOR EOPAP

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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 (≈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° 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 prefilitering 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

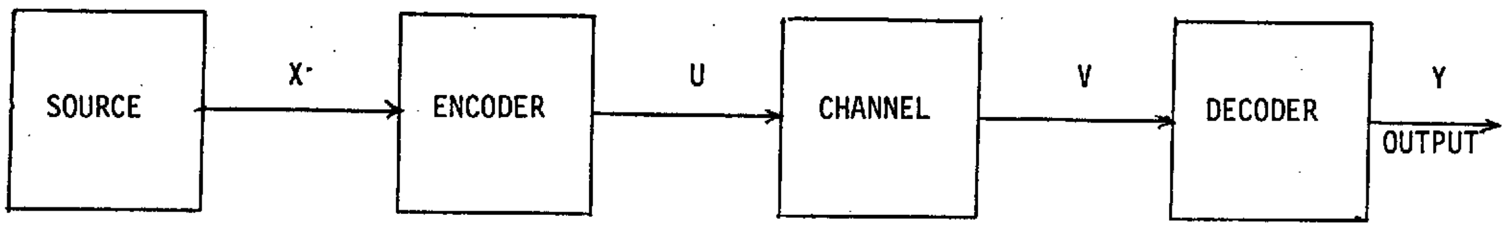

FIGURE 3.1. A SIMPLIFIED COMMUNICATION BLOCK DIAGRAM

$I(X,Y)$. 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 $R(D)<C$ issures 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 <u>controlled</u> 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) σ^2. Let the source output be the N values $\{x_i, i=1,2,\ldots N\}$ and the decoder output be $\{y_i, i=1,2,\ldots N\}$. 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 ρ, $|\rho| < 1$. 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 ρ 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

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

The typical range of the parameter ρ is .95 to .99. Thus the number of bits can be reduced by $\tfrac{1}{2} \log(1-\rho^2)$, 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

$$2\ (1-\rho) \approx (1+\rho)\ (1-\rho) \approx 1-\rho^2 \tag{3.3}$$

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° beamwidth antenna. The aircraft was banked so that the beam center pointed about 10° and 15° 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.

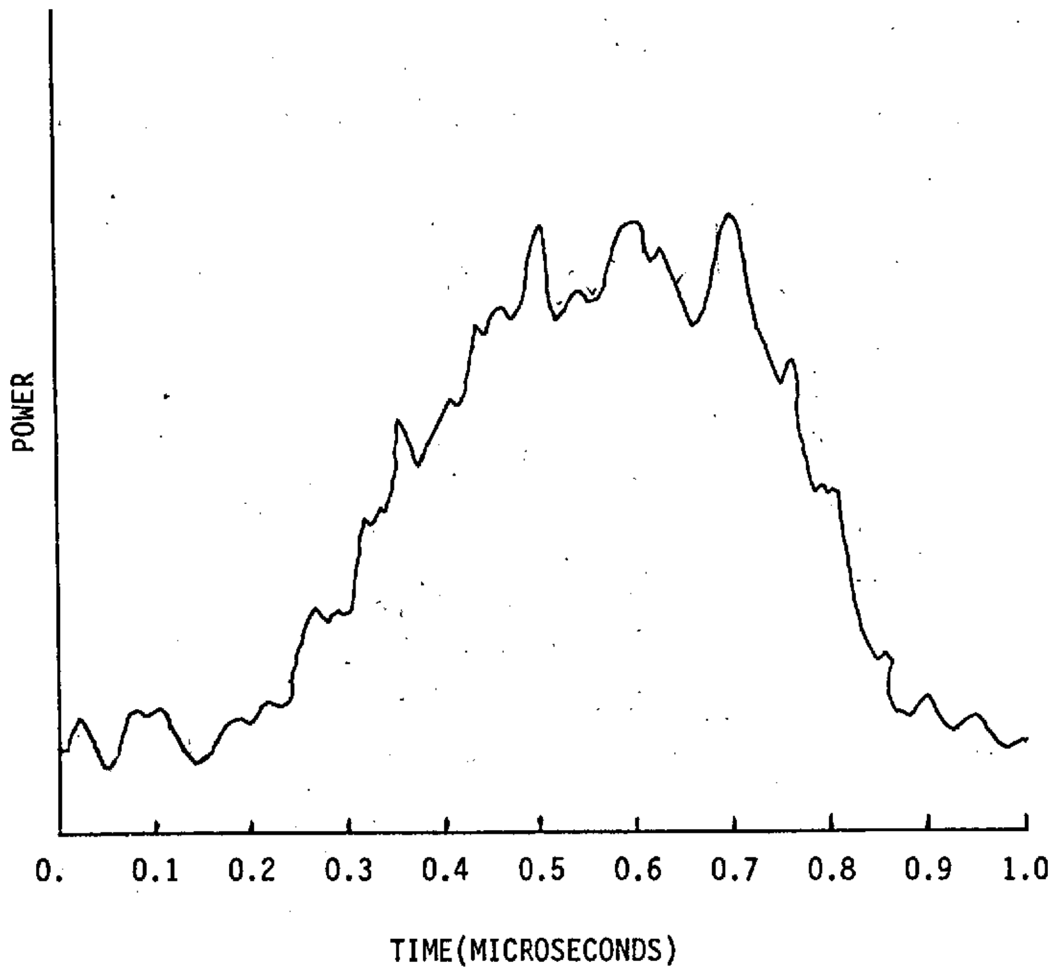

FIGURE 4.1.1. TYPICAL SIGNAL RETURN (JONSWOP DATA)

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 writen 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 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 α from nadir as shown below:

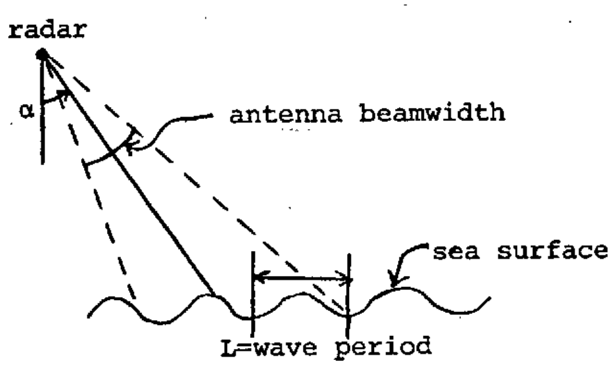

Figure 4.2.1. Short Pulse Radar Geometry

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, α . 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

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

where:

ν = frequency

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

σ_z = rms wave height

α= 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 σ_z can be estimated by the rate of exponential decay of the spectrum.

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

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

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

Both of the preceding methods of extracting σ_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 x 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 writen 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:

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

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-compilitation. 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 developement 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) bits x 60% x 100kHz $\approx$ 300 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.

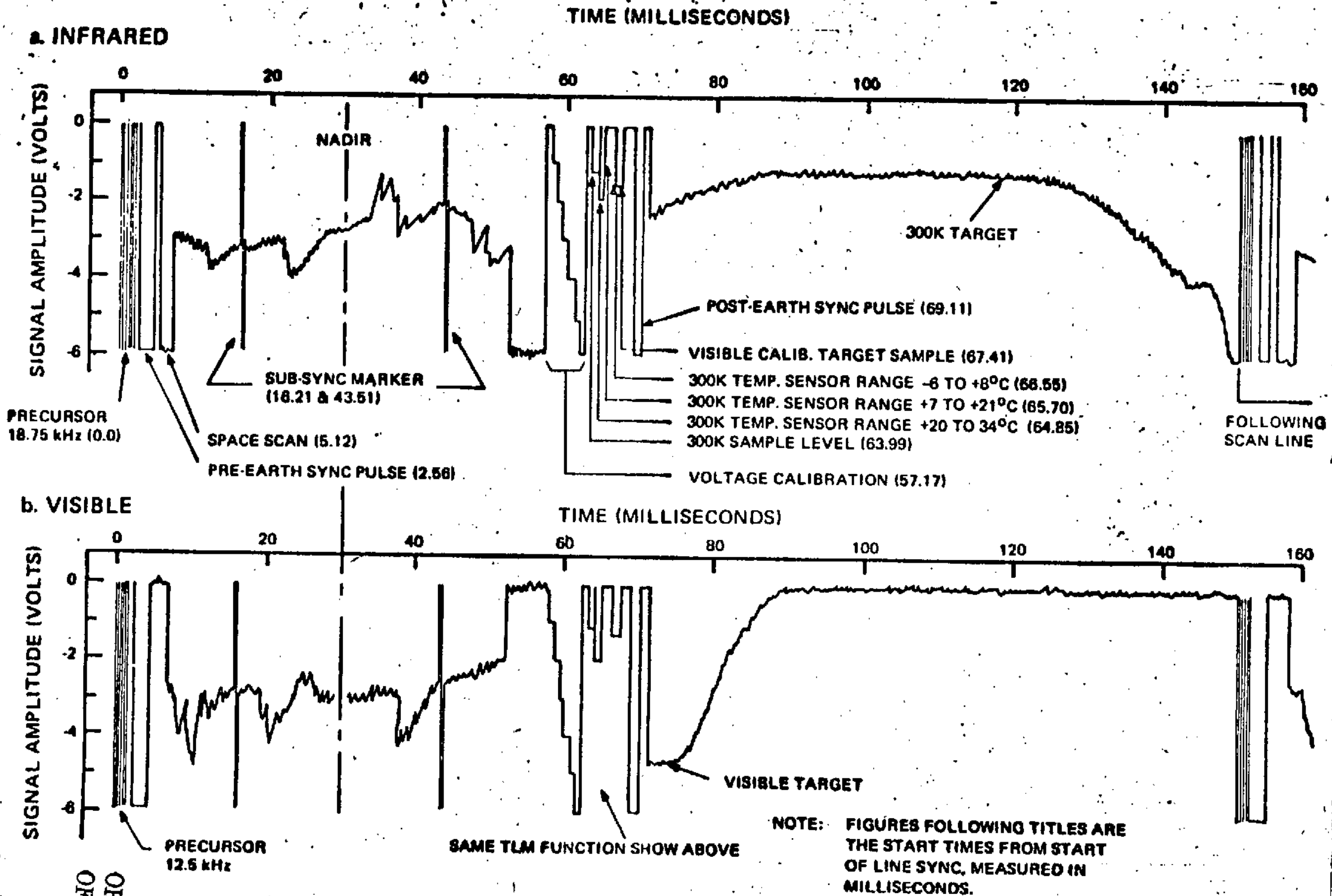

FIGURE 5.1. VHRR Signals

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 ± 1° 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 ±1° 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 ½ 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	52.52	--	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

Function	After Start of IR Precursor Counts*	After Start of IR Precursor Time (msec)	Duration Counts	Duration Time (msec)	Signal Characteristics
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
Post-earth Synchronization					
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
Pre-earth Synchronization Signal					
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

TABLE 5-1 (cont)

Function	After Start of IR Precursor Counts*	Time (msec)	Duration Counts	Time (msec)	Signal Characteristics
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
Post-earth Synchronization Signal					
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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OF POOR QUALITY

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.

REFERENCES

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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

```
 READ ECKERMAN TAPE INTO FORTRAN 5/74                                PAGE    1

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
```

```
       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 0001     PAUSE     DC    1
0096R 4801     INPUT     DC    X'4801',0,0,0    LU 1 RD IN
       0000
       0000
       0000
009ER                    END
```

```
NO ERRORS

* .O      0012R
* ECKERM  0000R
  GO      0030R
  INPUT   0096R
  LIST    0078R
  LOOP    003CR
  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
      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     J=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 7
      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
8     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

```
            C THIS PROGRAM IS TO ANALYZE AND DISPLAY EOPAP SEASAT
            C SHORT PULSE RADAR DATA. DEPENDING ON THE PROGRAM
            C MODE SELECTED, PULSES,PULSE SPECTRA OR PEAK
            C HISTOGRAMS CAN BE DISPLAYED. EITHER THE AVERAGE
            C SPECTRA OR THE AVERAGE OF THE SPECTRA CAN BE
            C SELECTED. MEANS AND RMS VALUES CAN BE EVALUATED.
            C DATA ARE ADJUSTED FOR POWER.
            C
0004R             IMPLICIT INTEGER*2 (I-N)
0004R             DIMENSION IPR(168)
0004R             DIMENSION INP(5344),TBL(1024),DAT(50),PULSE(256)
0004R             DIMENSION XLAB(6),PLOT(101),PAV(256),WIND(256)
0004R             COMPLEX Z(1024),CMPLX
0004R             EQUIVALENCE (Z(1),INP(1))
0004R             DATA PI,N,NTUP,LO,IHI/3.1415927,128,1024,23,150/
0014R             DATA DOT,STAR,BLANK,SLASH,ES,AA,PEE/1H.,1H*,1H ,1H/,1HS,1HA,1
0030R             CALL FOURIT(Z,NTUP,TBL,0)
            C READ IN MODE DESIRED
003ER       101   WRITE (0,100)
0056R       100   FORMAT(11H ENTER MODE)
006AR             READ(0,2) MODE
008AR             N2=N/2
009CR             N21=N2+1
00A8R             NTUP21=NTUP/2+1
00BER             N1=N+1
00CAR             XN=N
00D8R             XM=PI/XN
            C CALCULATE WINDOW WEIGHTS
00E4R             DO 42 I=1,N
00ECR       42    WIND(I)=1.-.83636364*COS(FLOAT(I-1)*XM)
            C GET LABEL FOR SPECTRA
013ER             DO 23 K=1,6
0146R       23    XLAB(K)=FLOAT(K-1)
            C NOW GET INPUT PARAMETERS
017CR             WRITE(0,4)
0194R       4     FORMAT(6H LABEL)
01A2R             READ(0,5) DAT
01C4R       5     FORMAT(50A1)
01CER             WRITE(0,30)
01E6R       30    FORMAT(13H ANGLE,MICSEC)
01FCR             READ(0,31) ANGLE,DUR
0224R       31    FORMAT(8F5.1)
0230R             WRITE(3,6) DAT
0252R       6     FORMAT(1H1,50A1)
0260R             ANG=ANGLE*PI/180.
0270R             DELTA=160./(DUR*FLOAT(NTUP))
0288R             WRITE(0,1)
02A0R       1     FORMAT(7H FILE=?,7HITHRESH)
02BAR             READ (0,2) IFILE,ITHRSH
02E2R       2     FORMAT(8I5)
02ECR             WRITE(3,3) IFILE,ANGLE,DUR
031CR       3     FORMAT(6H FILE ,I3,5X,F6.1,8H DEGREES,5X,F6.2,7H MICSEC)
```

```
0352R          WRITE(3,99) ITHRSH
0372R    99    FORMAT(15H THRESHOLD =    ,I5)
038ER          WRITE(0,7)
03A6R    7     FORMAT(12H BLOCKS,SIZE)
03BCR          READ(0,2)IBLKS,ISIZE
03E4R          SIZE=ISIZE
03F2R    8     FORMAT(1H ,I5,32H AVG SQUARED PULSES,LOG SPECTRUM)
0422R    41    FORMAT(31H SPECTRA OF AVG=S,AVG SPECTRA=A )
         C BLOCKS ARE INPUT IN 32 TRACE BLOCKS
044AR          KOUNT=33
0452R          DO 9 IIII=1,IBLKS
045AR          WRITE(3,10)IIII
047AR    10    FORMAT(7H BLOCK ,I4)
048CR          DO 15 K=LO,IHI
0494R          IL=K+1-LO
04A4R          PAV(IL)=0.
04B8R          IPR(K)=0
04CAR    15    PULSE(K)=0.
         C     WRITE(3,22) XLAB
04F0R          CALL BKS(1)
04F8R          CALL ECKERM(INP)
0500R          DO 12 I=1,ISIZE
0508R          KOUNT=KOUNT+1
0514R          IF(KOUNT.LE.32)GO TO 13
0526R          MIN=2**14
         C  GET NEXT INPUT BLOCK OF 32 TRACES
053AR          CALL ECKERM(INP)
0542R          DO 11 III=1,32
054AR          IJ=(III-1)*167
055AR          DO 11 K=LO,IHI
0562R          J=IJ+K
056ER    11    MIN=MIN0(MIN,INP(J))
05B4R          KOUNT=1
05BCR    13    IJ=(KOUNT-1)*167
05CCR          DO 14 K=LO,IHI
05D4R          J=IJ+K
05E0R          X=INP(J)-MIN
05FCR          XX=X*X
         C     KL=K+1-LO
         C     Z(KL)=CMPLX(XX,0.)*WIND(KL)
0608R    14    PULSE(K)=PULSE(K)+XX
063ER          IF(MODE.NE.1)GO TO 12
         C CALCULATE PEAK HISTOGRAM FOR VALUES ABOVE THRESHOLD
0650R          DO 70 K=LO,IHI
0658R          J=IJ+K
0664R          IF(INP(J).LT.ITHRSH) GO TO 70
0680R          IF(INP(J).GT.INP(J-1).AND.INP(J).GT.INP(J+1))IPR(K)=IPR(K)+1
06F0R    70    CONTINUE
0702R          GO TO 12
         C GET PULSE FOURIER TRANSFORM
0706R          CALL FOUR1T(Z,N,TBL,1)
0714R          DO 40 K=1,N21
```

```
071CR   40     PAV(K)=PAV(K)+CABS(Z(K))
076AR   12     CONTINUE
077CR          DO 62 I=1,101
0784R   62     PLOT(I)=BLANK
07AAR          IF(MODE.NE.1)GO TO 72
07BCR          WRITE(3,74) ISIZE
07DCR   74     FORMAT(1H ,I5,15H PEAK HISTOGRAM )
             C CALCULATE MEAN,RMS FOR HISTOGRAM
07FCR          SUMNRM=0.
0804R          CNTROD=0.
080CR          SUMSQ=0.
0814R          TMIN=5000.
081CR          TMAX=0.
0824R          DO 97 I=LO,IHI
082CR          XK=I
083AR          IF(IPR(I).GT.0) TMIN=AMIN1(TMIN,XK)
0860R          IF(IPR(I).GT.0) TMAX=AMAX1(TMAX,XK)
0886R          X=IPR(I)
089ER          SUMNRM=SUMNRM+X
08AAR          CNTROD=CNTROD+X*XK
08BAR          SUMSQ=SUMSQ+X*XK*XK
08CER   97     CONTINUE
08E0R          CNTROD=CNTROD/SUMNRM
08ECR          SUMSQ=SUMSQ/SUMNRM
08F8R          RMS=SQRT(SUMSQ-CNTROD*CNTROD)
0918R          WRITE(3,98)CNTROD,RMS
0940R   98     FORMAT(13H CENTROID =  ,F5.0,7H RMS =  ,F5.0)
096AR          GO TO 102
096ER          SIGZ=RMS*RMS-((TMAX-TMIN-1.)**2)/12.
099ER          SIGZP=DUR*150.*SQRT(ABS(SIGZ))/(160.*COS(ANG))
09DER          WRITE(3,96)SIGZP
09FER   96     FORMAT(15H SIGMA Z =      ,F12.5)
0A1CR          IF(SIGZ.LT.0.)WRITE(3,95)
0A42R   95     FORMAT(12H NEGATIVE    )
0A58R   102    CONTINUE
0A58R          DO 73 K=LO,IHI
0A60R          IX=FLOAT(IPR(K))/SIZE*100.+.5
0A90R          PLOT(IX)=PEE
0AA4R          WRITE(3,75) K,IPR(K),PLOT
0AE8R   75     FORMAT(1H ,2I5,101A1)
0AFCR          PLOT(IX)=BLANK
0B10R   73     CONTINUE
0B22R          GO TO 76
             C NOW PLOT PULSE AVG, SPECTRUM
0B26R   72     XMAX=0.
0B2ER          CNTROD=0.
0B36R          SUMNRM=0.
0B3ER          DO 64 K=LO,IHI
0B46R          CNTROD=CNTROD+PULSE(K)*FLOAT(K)
0B66R          SUMNRM=SUMNRM+PULSE(K)
0B7ER   64     XMAX=AMAX1(XMAX,PULSE(K))
0BB2R          CNTROD=CNTROD/SUMNRM
```

```
0BBER              ICNTR=CNTROD+.5
0BD0R              WRITE(3,8) ISIZE
0BF0R              WRITE(3,65) ICNTR
0C10R     65       FORMAT(13H CENTROID =    ,I5)
0C2AR              XNORM=100./XMAX
0C36R              DO 16 K=1,N
0C3ER              IJ=LO+K-1
0C4ER              IX=PULSE(IJ)*XNORM+.5
0C70R              PLOT(IX)=PEE
0C84R              WRITE(3,61)IJ,PLOT
0CAER     61       FORMAT(1H ,I3,101A1)
0CC0R              PLOT(IX)=BLANK
0CD4R     16       Z(K)=CMPLX(PULSE(IJ)/SIZE,0.)
0D1CR              DO 60 K=N1,NTUP
0D24R     60       Z(K)=CMPLX(0.,0.)
0D54R              CALL FOUR1T(Z,NTUP,TBL,1)
          C        WRITE(2,200) (Z(KK),KK=1,N)
0D62R     200      FORMAT(4E20.9)
0D6ER              WRITE(3,22) XLAB
0D90R     22       FORMAT(10H FREQUENCY ,4X,1HS,3X,5(F4.1,16X),F4.1)
0DBER              DO 18 K=1,NTUP21
          C        PAV(K)=PAV(K)/SIZE
0DC6R              D=FLOAT(K-1)*DELTA
0DE2R              X=CABS(Z(K))/XN
0E06R              X=ALOG10(X)
0E12R              IX=20.*X+.5
0E28R              IX=MIN0(MAX0(1,IX+1),101)
          C        Y=ALOG10(PAV(K))
          C        IY=20.*Y+SIGN(.5,Y)
          C        IY=MIN0(MAX0(1,IY+1),101)
0E54R              PLOT(1)=SLASH
0E60R              DO 19 I=2,101
0E68R              PLOT(I)=BLANK
0E7CR              IF(((I-1)/4)*4.EQ.I-1)PLOT(I)=DOT
0EB6R     19       CONTINUE
          C        PLOT(IY)=AA
0EC8R              PLOT(IX)=ES
0EDCR              WRITE(3,20) D,X,PLOT
0F0ER     20       FORMAT(1H ,F6.2,4X,F7.4,2X,101A1)
0F2ER     18       CONTINUE
0F40R     76       WRITE(3,21)
0F58R     21       FORMAT(1H1)
0F62R     9        CONTINUE
          C NOW GET NEXT INPUT
0F74R              GO TO 101
0F78R              END
  .U        0000R   EXT FUNC
  IPR       0F7CR   INT2 VAR
  INP       10CCR   INT2 VAR
  Z         10CCR   CMPX VAR
  TBL       3A8CR   REAL VAR
  DAT       4A8CR   REAL VAR
```

```
PULSE    4B54R   REAL VAR
XLAB     4F54R   REAL VAR
PLOT     4F6CR   REAL VAR
PAV      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
```

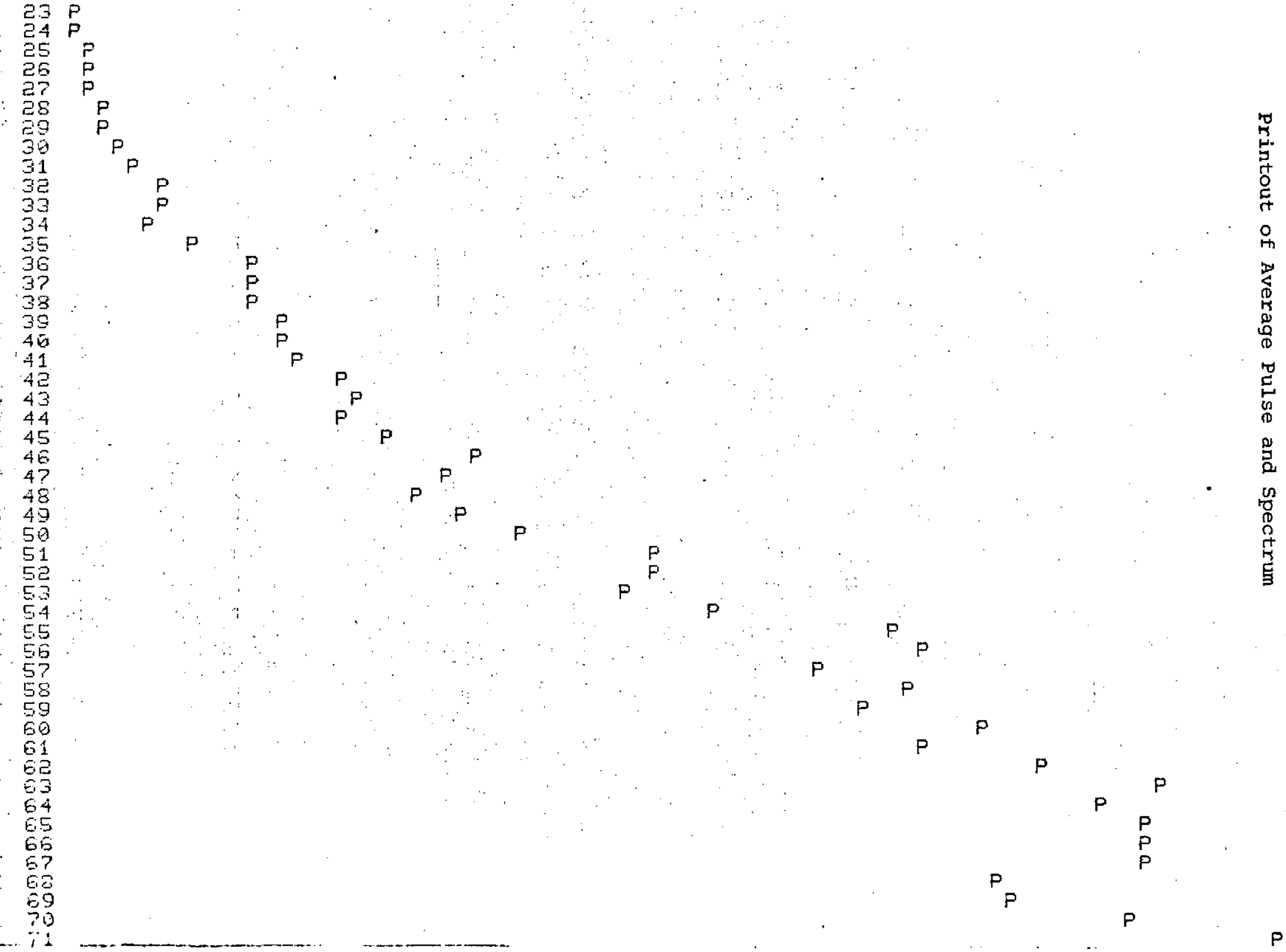
```
IBLKS   5956R   INT2 VAR
ISIZE   5958R   INT2 VAR
SIZE    595AR   REAL VAR
8       03F2R   LABEL
41      0422R   LABEL
KOUNT   595ER   INT2 VAR
9       0F62R   LABEL
IIII    5964R   INT2 VAR
10      047AR   LABEL
15      04CAR   LABEL
IL      5966R   INT2 VAR
BKS     0000R   EXT FUNC
ECKERM  0000R   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      08CER   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
```

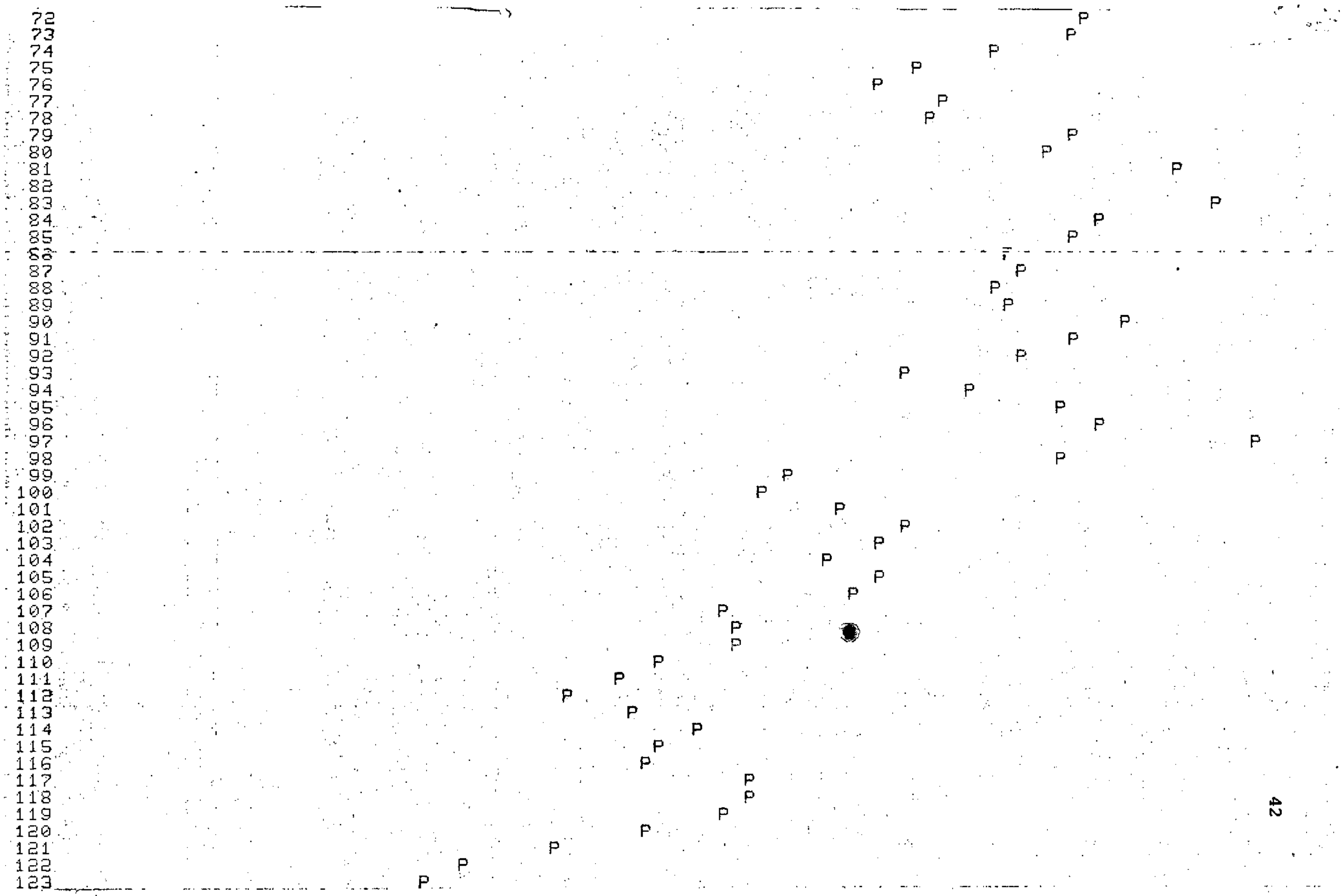
```
 .Y      0000R  EXT FUNC
 75      0AE3R  LABEL
 76      0F40R  LABEL
 XMAX    59CAR  REAL VAR
 64      0B7ER  LABEL
 ICNTR   59CER  INT2 VAR
 65      0C10R  LABEL
 XNORM   59D0R  REAL VAR
 16      0CD4R  LABEL
 61      0CAER  LABEL
 $P      0000R  EXT FUNC
 60      0D24R  LABEL
 200     0D62R  LABEL
 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
```

APPENDIX D

Printout of Average Pulse and Spectrum

```
NRL DATA OF 1/74 BY SYSTEMS ANALYSIS 1/75
FILE   1       10.0 DEGREES        0.50 MICSEC
THRESHOLD =     512
BLOCK    1
   64 AVG SQUARED PULSES,LOG SPECTRUM
CENTROID =      89
```

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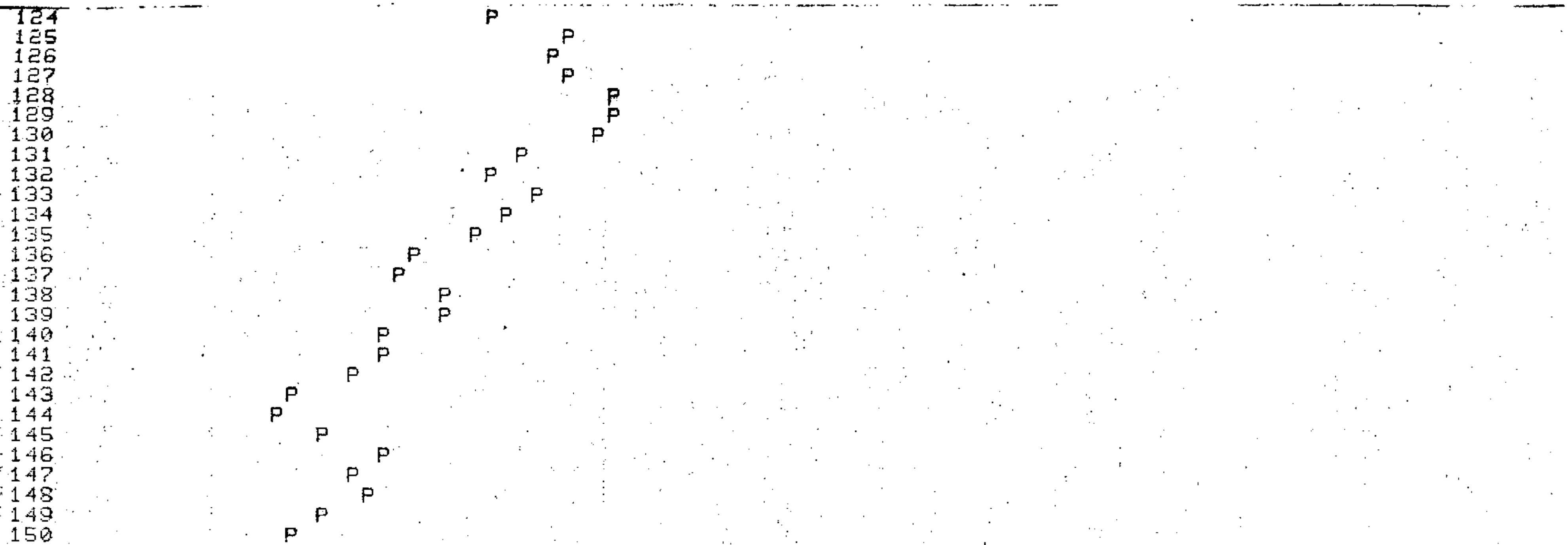
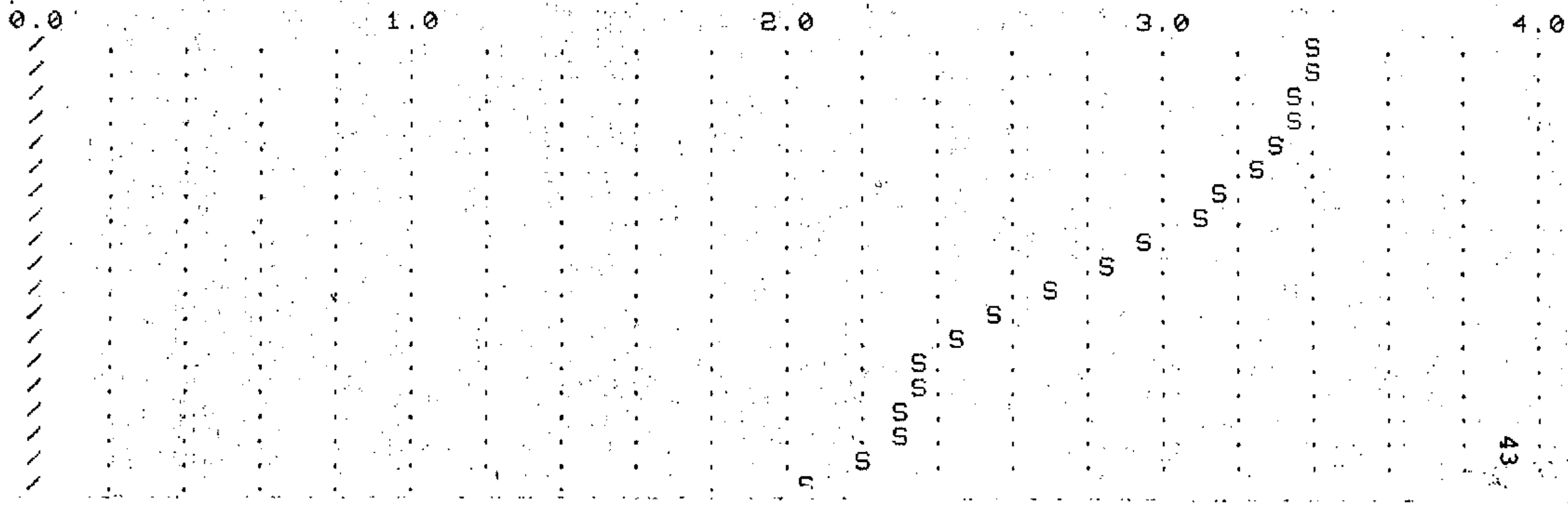
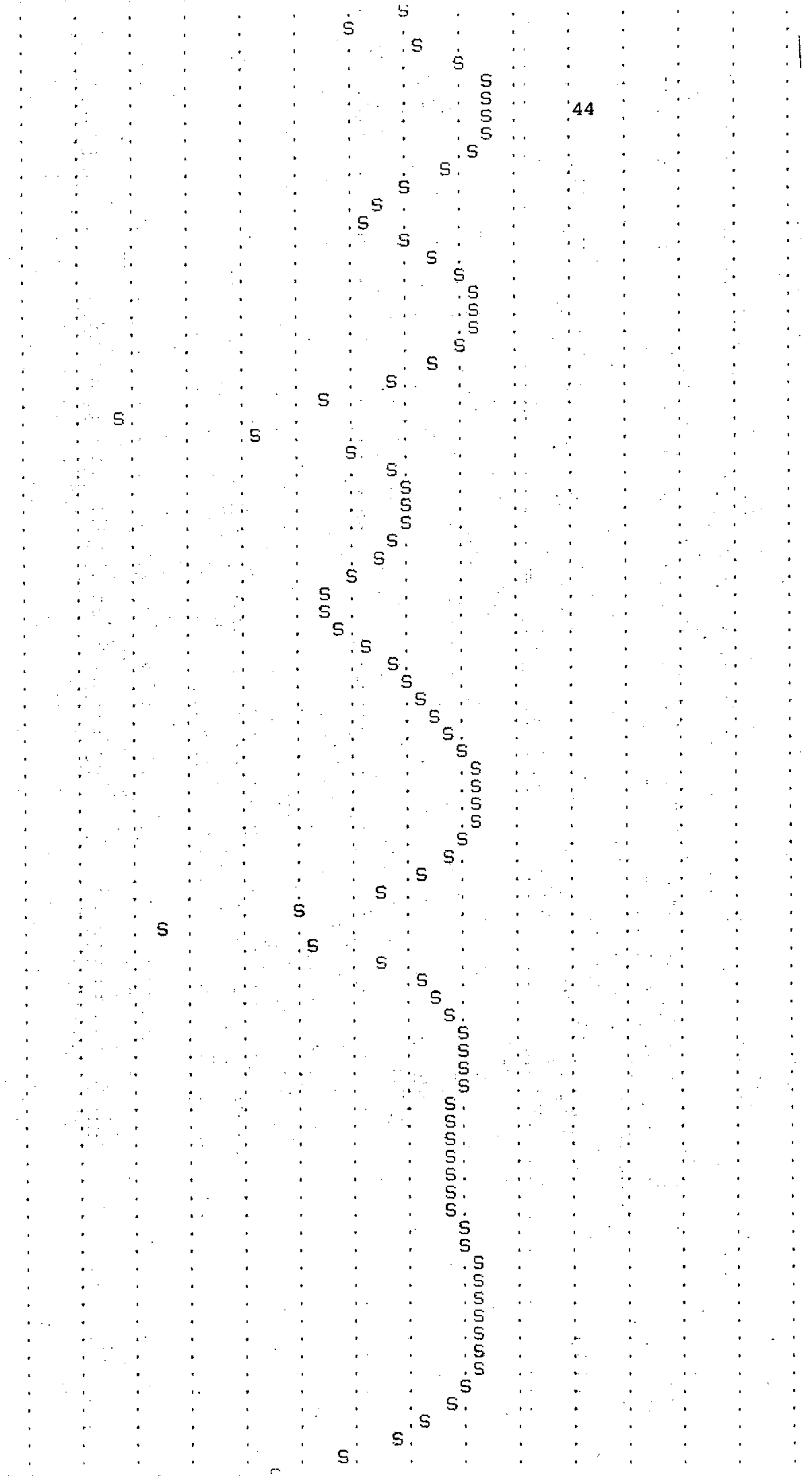
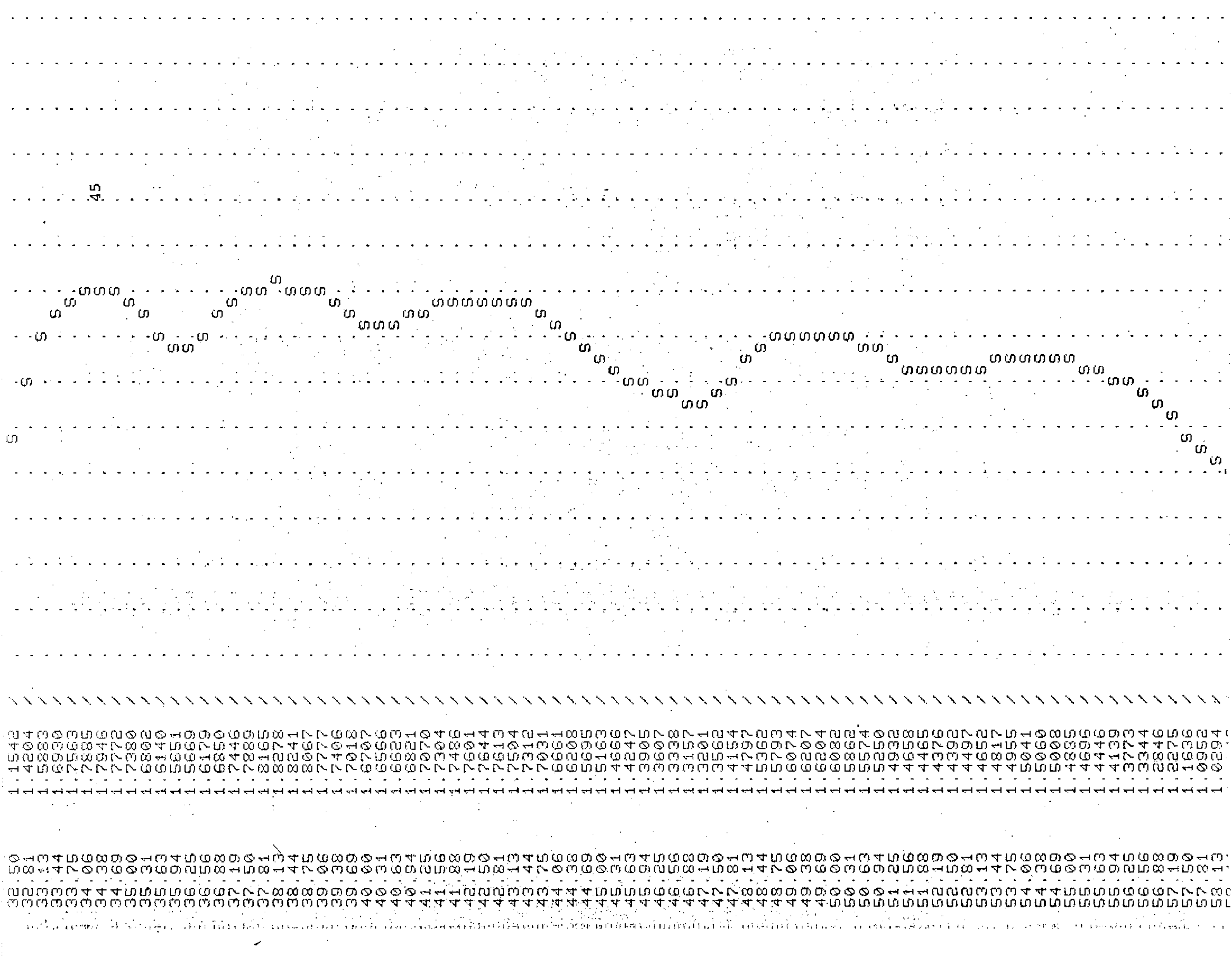


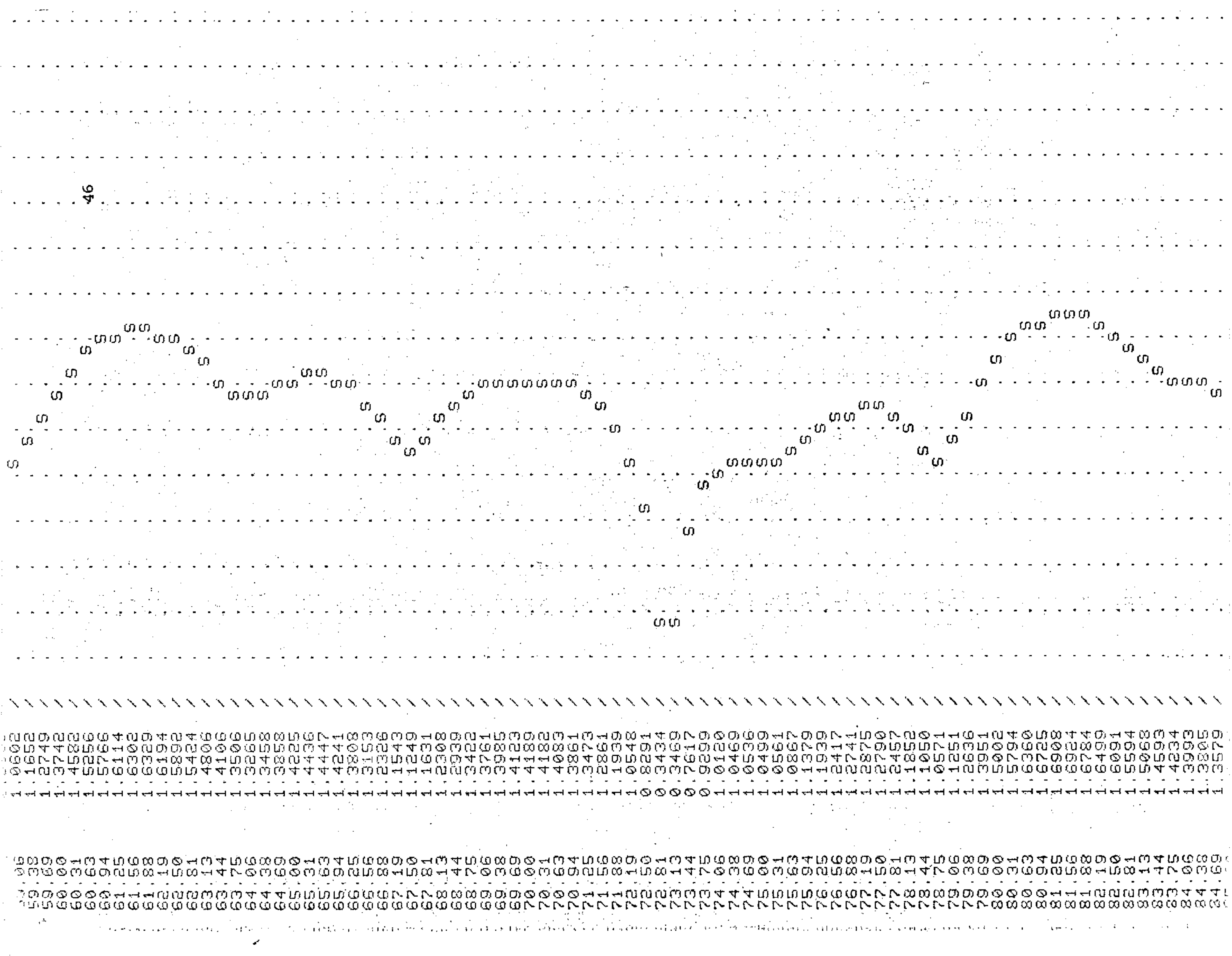
FREQUENCY	S
0.00	3.3895
0.31	3.3836
0.63	3.3657
0.94	3.3356
1.25	3.2927
1.56	3.2362
1.88	3.1650
2.19	3.0777
2.50	2.9726
2.81	2.8483
3.13	2.7058
3.44	2.5551
3.75	2.4275
4.06	2.3602
4.38	2.3386
4.69	2.3187
5.00	2.2751
5.31	2.1967
5.63	2.0737



6.25	1.6060
6.56	1.4194
6.88	1.6450
7.19	1.8032
7.50	1.8852
7.81	1.9203
8.13	1.9218
8.44	1.8950
8.75	1.8396
9.06	1.7513
9.38	1.6242
9.69	1.4781
10.00	1.4516
10.31	1.5839
10.63	1.7152
10.94	1.8043
11.25	1.8544
11.56	1.8704
11.88	1.8540
12.19	1.8036
12.50	1.7124
12.81	1.5630
13.13	1.3023
13.44	0.5696
13.75	1.0655
14.06	1.3837
14.38	1.5253
14.69	1.5935
15.00	1.6161
15.31	1.6039
15.63	1.5617
15.94	1.4924
16.25	1.4037
16.56	1.3237
16.88	1.3090
17.19	1.3724
17.50	1.4617
17.81	1.5443
18.13	1.6139
18.44	1.6725
18.75	1.7228
19.06	1.7663
19.38	1.8029
19.69	1.8308
20.00	1.8477
20.31	1.8510
20.63	1.8374
20.94	1.8027
21.25	1.7411
21.56	1.6416
21.88	1.4808
22.19	1.1883
22.50	0.7024
22.81	1.2380
23.13	1.4920
23.44	1.6325
23.75	1.7179
24.06	1.7690
24.38	1.7963
24.69	1.8059
25.00	1.8025
25.31	1.7900
25.63	1.7722
25.94	1.7532
26.25	1.7375
26.56	1.7292
26.88	1.7314
27.19	1.7443
27.50	1.7652
27.81	1.7897
28.13	1.8136
28.44	1.8342
28.75	1.8497
29.06	1.8594
29.38	1.8631
29.69	1.8603
30.00	1.8498
30.31	1.8295
30.63	1.7959
30.94	1.7439
31.25	1.6652
31.56	1.5458
31.88	1.3574







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85.94	1.1225
86.25	1.0237
86.56	0.9271
86.88	0.8616
87.19	0.8468
87.50	0.8681
87.81	0.9010
88.13	0.9324
88.44	0.9569
88.75	0.9698
89.06	0.9652
89.38	0.9348
89.69	0.8656
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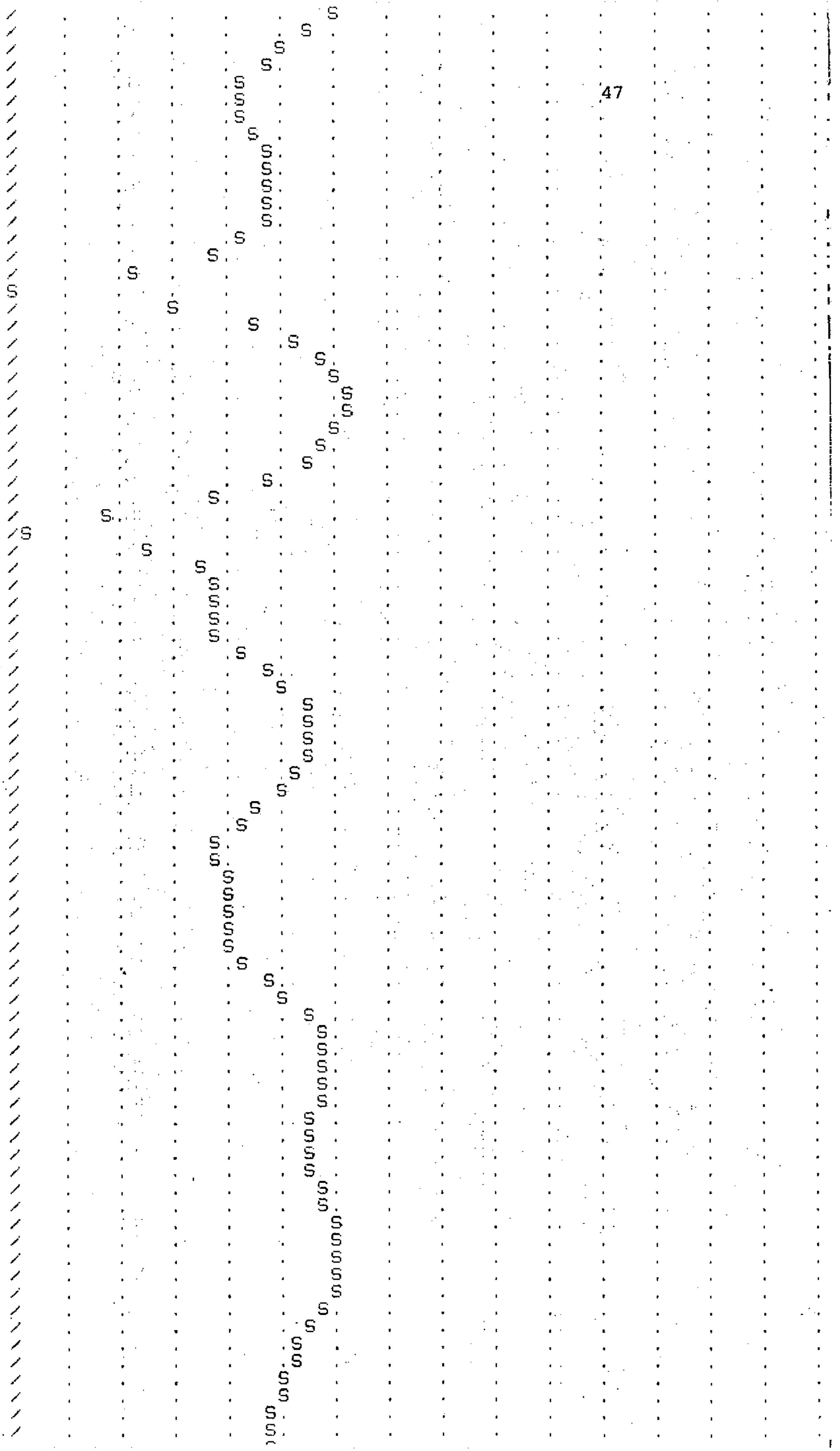
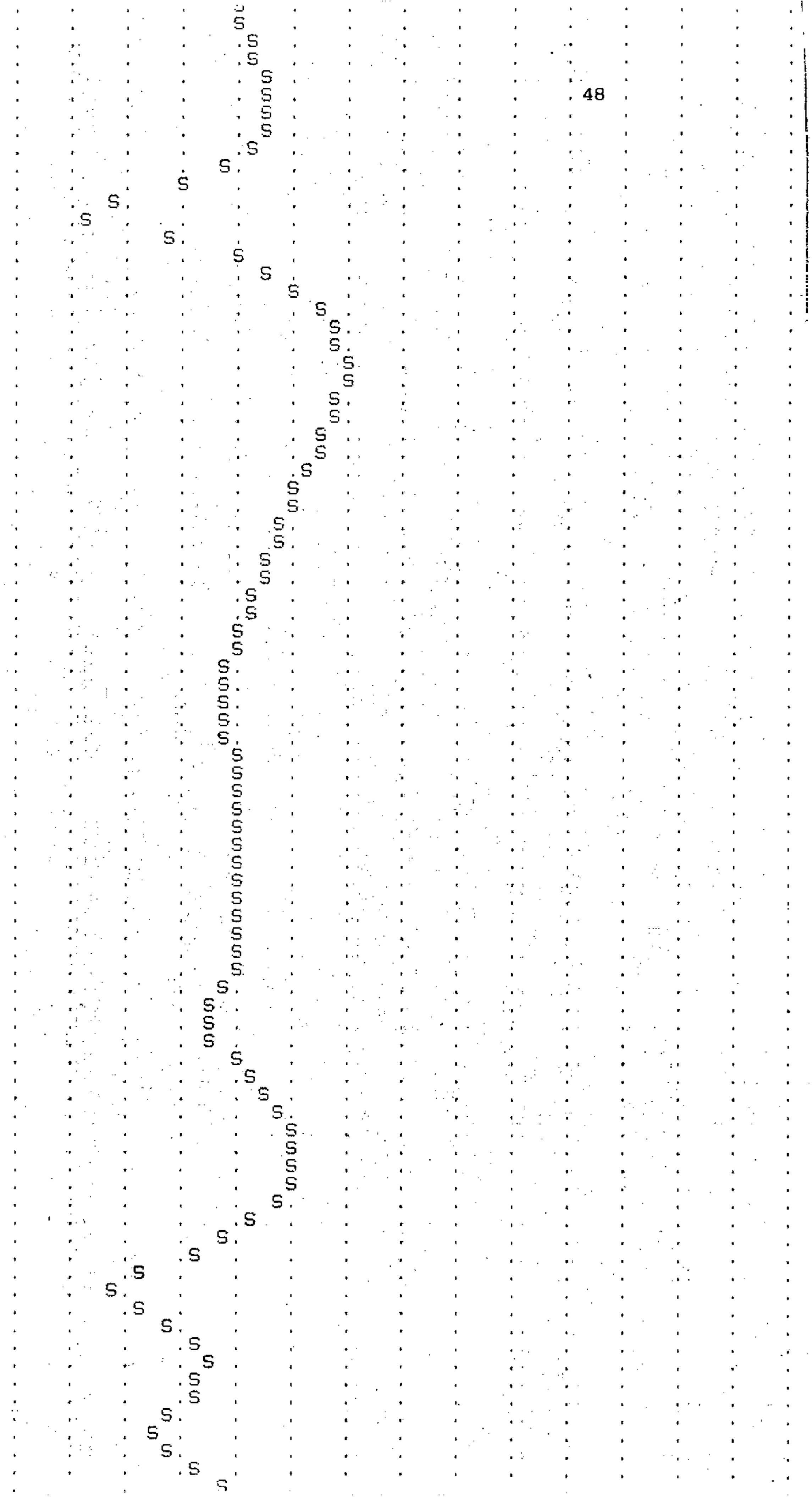
90.31	0.4420
90.63	-0.1591
90.94	0.6014
91.25	0.8785
91.56	1.0385
91.88	1.1400
92.19	1.2025
92.50	1.2343
92.81	1.2387
93.13	1.2165
93.44	1.1656
93.75	1.0807
94.06	0.9499
94.38	0.7444
94.69	0.3685
95.00	0.0739
95.31	0.5142
95.63	0.6835
95.94	0.7502
96.25	0.7630
96.56	0.7561
96.88	0.7746
97.19	0.8433
97.50	0.9356
97.81	1.0188
98.13	1.0794
98.44	1.1144
98.75	1.1239
99.06	1.1081
99.38	1.0671
99.69	1.0018
100.00	0.9168
100.31	0.8286
100.63	0.7707
100.94	0.7634
101.25	0.7816
101.56	0.7940
101.88	0.7913
102.19	0.7854
102.50	0.8036
102.81	0.8619
103.12	0.9430
103.44	1.0216
103.75	1.0846
104.06	1.1285
104.38	1.1533
104.69	1.1606
105.00	1.1533
105.31	1.1358
105.63	1.1148
105.94	1.0999
106.25	1.0994
106.56	1.1151
106.88	1.1410
107.19	1.1684
107.50	1.1907
107.81	1.2038
108.13	1.2060
108.44	1.1967
108.75	1.1764
109.06	1.1465
109.38	1.1093
109.69	1.0691
110.00	1.0310
110.31	0.9998
110.63	0.9779
110.94	0.9649
111.25	0.9599



111.87	0.9775
112.19	1.0028
112.50	1.0356
112.81	1.0692
113.13	1.0964
113.44	1.1114
113.75	1.1095
114.06	1.0858
114.38	1.0341
114.69	0.9434
115.00	0.7911
115.31	0.5354
115.63	0.4531
115.94	0.7649
116.25	0.9786
116.56	1.1198
116.87	1.2180
117.19	1.2869
117.50	1.3338
117.81	1.3629
118.12	1.3767
118.44	1.3772
118.75	1.3660
119.06	1.3449
119.38	1.3161
119.69	1.2824
120.00	1.2468
120.31	1.2127
120.63	1.1819
120.94	1.1548
121.25	1.1302
121.56	1.1062
121.88	1.0817
122.19	1.0563
122.50	1.0307
122.81	1.0060
123.13	0.9832
123.44	0.9640
123.75	0.9502
124.06	0.9444
124.37	0.9482
124.69	0.9603
125.00	0.9766
125.31	0.9917
125.63	1.0011
125.94	1.0026
126.25	0.9968
126.56	0.9871
126.88	0.9794
127.19	0.9790
127.50	0.9868
127.81	0.9983
128.13	1.0057
128.44	1.0026
128.75	0.9849
129.06	0.9531
129.37	0.9159
129.69	0.8958
130.00	0.9182
130.31	0.9799
130.62	1.0539
130.94	1.1200
131.25	1.1701
131.56	1.2021
131.88	1.2156
132.19	1.2105
132.50	1.1858
132.81	1.1398
133.13	1.0687
133.44	0.9665
133.75	0.8252
134.06	0.6500
134.37	0.5539
134.69	0.6520
135.00	0.7733
135.31	0.8495
135.63	0.8813
135.94	0.8735
136.25	0.8300
136.56	0.7626
136.88	0.7170
137.19	0.7618
137.50	0.8695
137.81	0.9739



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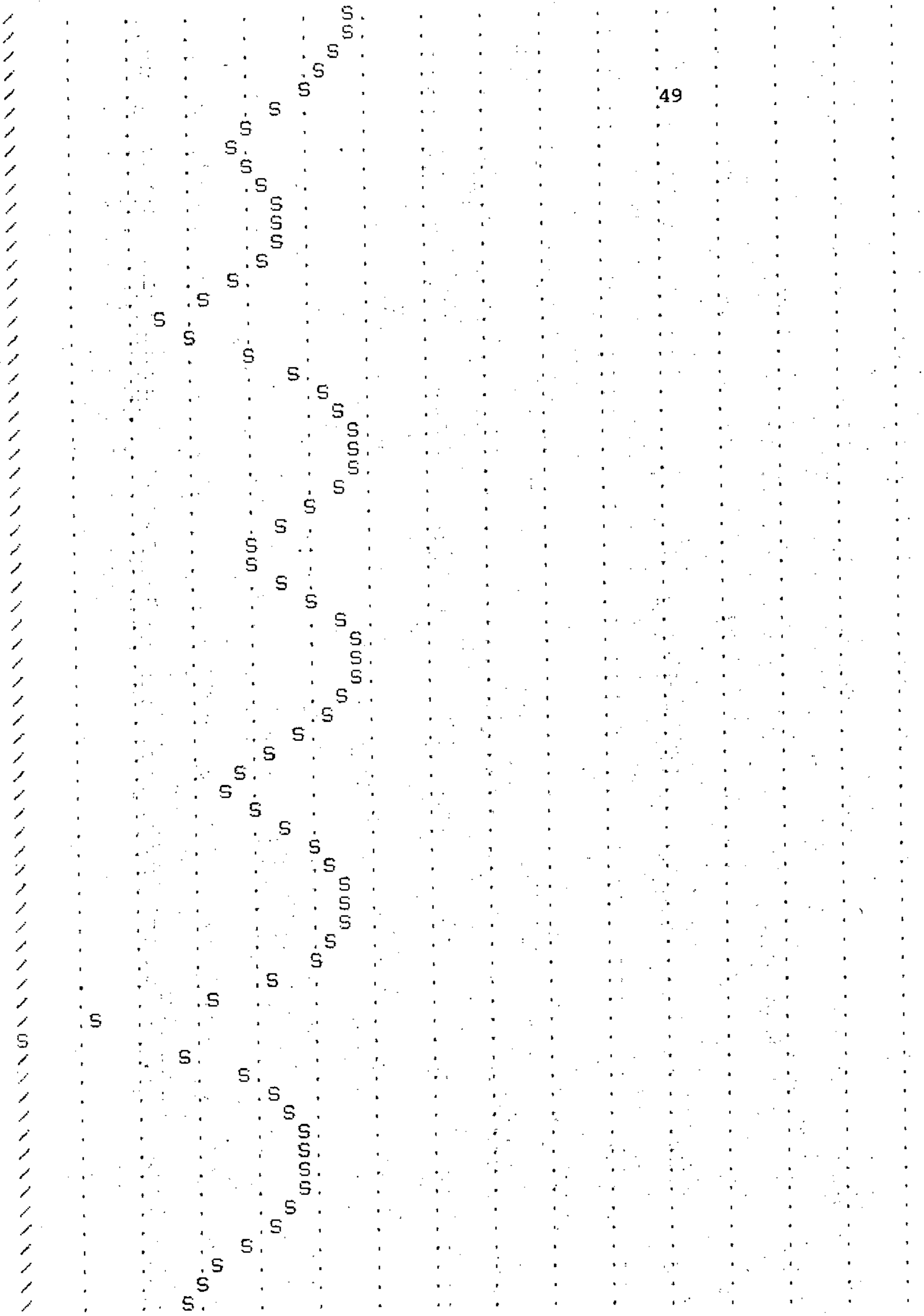
138.75	1.1273
139.06	1.1271
139.38	1.1029
139.69	1.0546
140.00	0.9824
140.31	0.8908
140.63	0.8003
140.94	0.7584
141.25	0.7880
141.56	0.8464
141.88	0.8937
142.19	0.9156
142.50	0.9071
142.81	0.8632
143.12	0.7747
143.44	0.6285
143.75	0.4752
144.06	0.5838
144.38	0.7938
144.69	0.9486
145.00	1.0533
145.31	1.1204
145.63	1.1564
145.94	1.1644
146.25	1.1449
146.56	1.0964
146.88	1.0166
147.19	0.9083
147.50	0.8079
147.81	0.8104
148.12	0.9091
148.44	1.0108
148.75	1.0843
149.06	1.1281
149.37	1.1453
149.69	1.1380
150.00	1.1069
150.31	1.0514
150.63	0.9696
150.94	0.8624
151.25	0.7521
151.56	0.7182
151.88	0.7985
152.19	0.9078
152.50	0.9973
152.81	1.0595
153.13	1.0956
153.44	1.1070
153.75	1.0935
154.06	1.0527
154.38	0.9790
154.69	0.8601
155.00	0.6645
155.31	0.2714
155.62	0.0245
155.94	0.5416
156.25	0.7478
156.56	0.8599
156.88	0.9230
157.19	0.9544
157.50	0.9625
157.81	0.9522
158.13	0.9261
158.44	0.8348
158.75	0.8280
159.06	0.7547
159.38	0.6662
159.69	0.5780
160.00	0.5364



APPENDIX E

Peak Histogram

```
NRL DATA OF 1/74 BY SYSTEMS ANALYSIS 1/75
FILE  1     :  10.0 DEGREES          0.50 MICSEC
THRESHOLD =      512
BLOCK      1
  32 PEAK HISTOGRAM
CENTROID =      90.  RMS =     26..
     23    0
     24    0
     25    0
     26    0
     27    0
     28    0
     29    0
     30    0
     31    0
     32    0
     33    0
     34    0
     35    0
     36    0
     37    0
     38    0
     39    0
     40    2      P
     41    1   P
     42    2      P
     43    2      P
     44    2      P
     45    1   P
     46    1   P
     47    0
     48    4            P
     49    0
     50    0
     51    3         P
     52    2      P
     53    2      P
     54    4            P
     55    3         P
     56    1   P
     57    1   P
     58    2      P
     59    1   P
     60    5               P
     61    5               P
     62    2      P
     63    1   P
     64    6                  P
     65    4            P
     66    3         P
     67    3         P
     68    3         P
     69    0
     70    3         P
     71    4            P
     72    5               P
     73    3         P
     74    4            P
     75    3         P
     76    2      P
     77    2      P
     78    5               P
     79    5               P
     80    8                        P
     81    3         P
     82    1   P
     83    6                  P
     84    4            P
     85    3         P
```

86	7							P	
87	2		P						
88	5					P			
89	5					P			
90	1	P							
91	2		P						
92	4				P				
93	3			P					
94	7							P	
95	7							P	
96	5					P			
97	2		P						
98	5					P			
99	1	P							
100	8								P
101	2		P						
102	8								P
103	5					P			
104	3			P					
105	5					P			
106	4				P				
107	2		P						
108	5					P			
109	2		P						
110	0								
111	0								
112	5					P			
113	2		P						
114	3			P					
115	3			P					
116	1	P							
117	1	P							
118	2		P						
119	0								
120	0								
121	3			P					
122	1	P							
123	2		P						
124	1	P							
125	2		P						
126	3			P					
127	2		P						
128	2		P						
129	0								
130	2		P						
131	2		P						
132	1	P							
133	2		P						
134	3			P					
135	3			P					
136	2		P						
137	0								
138	0								
139	0								
140	0								
141	1	P							
142	0								
143	1	P							
144	1	P							
145	2		P						
146	0								
147	2		P						
148	1	P							
149	2		P						
150	0								