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## Signal Analysis and Parametrization for EMP Data

September 1975

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>Presented are the theoretical background, program description,<br>and computer listings that describe the techniques to reduce and<br>analyze digital time-series data obtained in electromagnetic-pulse<br>testing of military communications systems. The topics treated<br>include data preprocessing, digital filtering, fast Fourier trans-<br>form, fast Walsh transform, refined spectral densities, autocor- |                       |                                                                                                                                      |

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relation functions, waveform representation by parametrized functions, and nonlinear, least squares techniques. Several examples of the data are analyzed and discussed.

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## 1. INTRODUCTION

This report presents the theoretical background and computer programs for the analysis techniques that were used in evaluating data obtained in the electromagnetic pulse (EMP) testing of military communication and weapons systems under the PREMPT program.<sup>1</sup>

The data presented are initially obtained as a voltage-versus-time trace photographed on Polaroid film. This trace is then digitized and a time series of digital values is produced. The data are then processed in a digital computer. The various techniques employed in reducing and transforming the data are grouped under the generic title "signal analysis." Section 2 of this report gives a detailed description of all the algorithms; also, it contains complete instructions on how to use the signal-analysis program.

Another technique used in the data-reduction process is to represent the EMP waveform by a set of parametrized functions. This technique involves a least-squares fitting procedure which is discussed in section 3. Also, section 3 contains complete instructions on the use of a least-squares fitting program.

This report is not intended to be exhaustive on the subject of signal analysis but rather to present to the EMP community a basic software package that will: (1) accomplish most of the data reduction for EMP work and (2) be easily modified to include any additional techniques.

## 2. SIGNAL ANALYSIS

This section presents the theoretical background and computer implementation of a number of techniques for reducing and transforming digital time series produced in EMP tests under the PREMPT program. A complete program listing annotated with comments is given in this section. Several versions of this program have been implemented on both the IBM 370-195 and CDC 6500 computers. All of the programming was done in FORTRAN. Some of the subroutines have been coded in assembly language for the NOVA minicomputer but are not reported here.<sup>2</sup>

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<sup>1</sup>The PREMPT program is a joint NMCSSC/DNA effort to determine the response of DCS to electromagnetic pulses generated by a high-altitude nuclear burst.

<sup>2</sup>Further details are presented in "The Interactive Digitization and Editing System (IDES)" by Dr. Thomas A. Tumolillo, USA Harry Diamond Laboratories, Adelphi, MD 20783, (Aug 1973).

## 2.1 Data Preprocessing

Under the generic title "Data Preprocessing" is included the many minute details that are necessary to prepare the raw input data as obtained from a digitization of the waveform, so that it is suitable for transformation to the frequency domain.

The following sections discuss the method of referencing the trace to the scope graticule, scaling the data, time ordering, bit reversal, and a few of the simpler interpolation schemes. The software for two of the simpler interpolators, the linear Lagrange, and the linear least squares are presented. Higher order interpolators have been used occasionally in the PREPMT program, but are not included here because the simpler methods usually work. Similarly, no techniques for time tying of digital records are given. Only the software are presented for the most commonly used grid and tablet referencing schemes, even though some of the more complicated procedures are discussed.

### 2.1.1 Referencing the Trace to Graticule and Digitization Tablet

One important function of the data reduction is the determination of the rotation angle of the scope graticule with respect to the digitization tablet, the zero point (origin) of the graticule, and the scale factors for the X and Y axes in the graticule (or grid) coordinate system. There are many possible schemes that can be used to determine these factors; the most general method will be discussed in this section. The software exists for the general procedure as well as for the simpler specific case implemented in this signal analysis package.

For simplicity, but with no loss of generality, let the grid points be symmetrical about the origin of the grid coordinate system (fig. 1); call this origin  $(X_o, Y_o)$ . In the grid coordinate system the measure grid points are designated by the arrays XG(I) and YG(I). In the tablet coordinate system the measured grid points are designated by the arrays XT(I) and YT(I). The coordinate systems are shown in figure 1.

The transformation equation between the two systems is

$$\begin{bmatrix} X_T \\ Y_T \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X_G \\ Y_G \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \end{bmatrix} \quad (1)$$

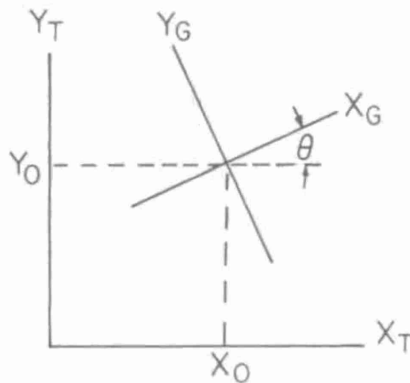


Figure 1. Diagram of coordinate systems.

Applying this transformation to the measured grid points, we have

$$\begin{bmatrix} \sum_{I=1}^N X_T(I) \\ \sum_{I=1}^N Y_T(I) \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \sum_{I=1}^N X_G(I) \\ \sum_{I=1}^N Y_G(I) \end{bmatrix} + \begin{bmatrix} \sum_{I=1}^N x_o \\ \sum_{I=1}^N y_o \end{bmatrix} \quad (2)$$

The points are symmetrical in the grid system; thus, we have

$$\sum_{I=1}^N X_G(I) = \sum_{I=1}^N Y_G(I) = 0$$

Therefore,  $(x_o, y_o)$  is given by

$$\begin{bmatrix} x_o \\ y_o \end{bmatrix} = \frac{1}{N} \begin{bmatrix} \sum_{I=1}^N X_T(I) \\ \sum_{I=1}^N Y_T(I) \end{bmatrix} \quad (3)$$

It is convenient to shift the origin of the tablet coordinate system to the point  $(X_O, Y_O)$ ; thus,

$$\begin{bmatrix} X'_T \\ Y'_T \end{bmatrix} = \begin{bmatrix} X_T - Y_O \\ Y_T - Y_O \end{bmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} X_G \\ Y_G \end{bmatrix} \quad (4)$$

For a specific set of points in the grid system, the above transformation can be linearized. Take the line defined by  $Y_G = 0$ ; then we have

$$X'_T = \cos\theta X_G, \quad Y_G = 0 \quad (5)$$

Let  $\alpha = \cos\theta$ , then  $X'_T = \alpha X_G$ . The best value of  $\theta$  can be estimated from the measured points along the grid X axis by using a least-squares technique. Let

$$\chi^2 = \sum_I [X_T(I) - \alpha X_G(I)]^2; \quad (6)$$

minimizing  $\chi^2$  with respect to  $\alpha$ , we have

$$\frac{\partial(\chi^2)}{\partial \alpha} = 0 \Rightarrow \alpha = \cos\theta = \frac{\sum_I X_T(I) * X_G(I)}{\sum_I X_G(I) * X_G(I)} \quad (7)$$

The  $\sum_I$  means that we only sum over those points on the grid X axis.

We could now suitably define other straight lines on subsets of the measured grid points and get further estimates of  $\theta$ . It is more convenient to use a nonlinear least-squares technique, and extract the best value of  $\theta$ , by using all the points at once.

$$\text{Let } \vec{Z}(I) = \begin{bmatrix} XT(I) \\ YT(I) \end{bmatrix}, \quad (8)$$

$$\vec{\phi}(\theta, I) = \begin{Bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{Bmatrix} \begin{bmatrix} XG(I) \\ YG(I) \end{bmatrix}, \quad (9)$$

and

$$\chi^2 = \sum_{I=1}^N |\vec{Z}(I) - \vec{\phi}(\theta, I)|^2. \quad (10)$$

We minimize  $\chi^2$  with respect to  $\theta$  by requiring  $\partial(\chi^2)/\partial\theta = 0$ ; thus, we have

$$\begin{aligned} \frac{\partial(\chi^2)}{\partial\theta} = \sum_{I=1}^N \left[ \frac{\partial \vec{\phi}^\dagger(\theta, I)}{\partial\theta} \cdot (\vec{Z}(I) - \vec{\phi}(\theta, I)) + (\vec{Z}(I) \right. \\ \left. - \vec{\phi}(\theta, I)) \cdot \frac{\partial \vec{\phi}(\theta, I)}{\partial\theta} \right] = 0. \end{aligned} \quad (11)$$

Here,  $\phi^\dagger$  is the adjoint of  $\phi$ .

Assume now that we have defined an iterative process for evaluating  $\theta$  and  $\phi$ , at the  $k^{\text{th}}$  iteration, we assume that  $\phi$  is given by

$$\begin{aligned} \vec{\phi}(\theta, I) \sim \vec{\phi}(\theta^k, I) + \frac{\partial \vec{\phi}(\theta^k, I)}{\partial\theta} \cdot \Delta\theta^k \\ \Delta\theta^k = \theta^{k+1} - \theta^k \end{aligned} \quad (12)$$

By substituting equation (12) into equation (11), a recursion relation is obtained for  $\theta$ . It can be shown after a slight algebraic manipulation that

$$\theta^{k+1} = \theta^k - C_1 \sin\theta^k + C_2 \cos\theta^k, \quad (13)$$

where

$$C_1 = \frac{\sum_{I=1}^N (XG(I)*XT(I) + YG(I)*YT(I))}{\sum_{I=1}^N (XG(I)*XG(I) + YG(I)*YG(I))} , \quad (14)$$

$$C_2 = \frac{\sum_{I=1}^N (XG(I)*YT(I) - YG(I)*XT(I))}{\sum_{I=1}^N (XG(I)*XG(I) + YG(I)*YG(I))} , \quad (15)$$

The recursion relation generally converges quickly, as long as the initial estimate for  $\theta$  is close to the true value. We used for  $\theta^1$  the value determined in equation (7). The program considers that the iterative scheme has converged as long as  $\Delta\theta^k < 10^{-3}$  and  $\chi^2(k+1) < \chi^2(k)$ .

The scale factors for the X and Y axes can be easily calculated. For illustrative purposes, suppose we measured 28 grid points as shown in figure 2.

Initially, the arrays XG and YG are defined in a DATA statement so that the points [XG(I), YG(I)] correspond to a grid so that

$$XG(I) \in \{-1., -.8, -.6, \dots, +.8, +1.\}$$

$$YG(I) \in \{-1., -.75, \dots, +.75, +1.\} ,$$

so that for example [XG(27), YG(27)] = (+.4, -.5). In the program, one of the initial redefinitions of the arrays we make is

$$XG(I) \rightarrow XS*XG(I)$$

$$YG(I) \rightarrow YS*YG(I)$$

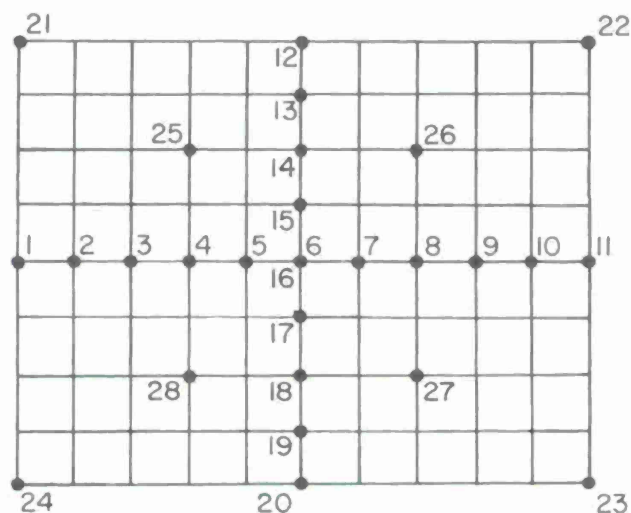


Figure 2. Measured grid points.

Scale factors  $X_S$  and  $Y_S$  must be determined (fig. 3).

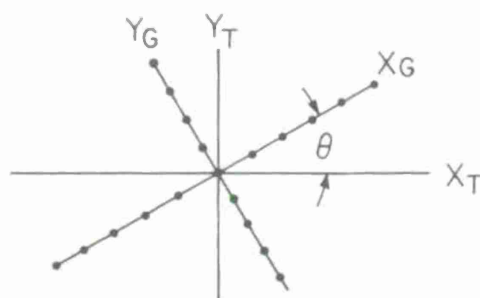


Figure 3. Rotation between G and T systems.

For the points on the  $X_G$  axis ( $I = 1, \dots, 11$ ), we have

$$[X_S \cdot X_G(I)]^2 = X_T(I) \cdot X_T(I) + Y_T(I) \cdot Y_T(I)$$

The average value for  $X_S$  is

$$XS = \sqrt{\frac{\sum_{I=1}^{11} (XT(I)*XT(I) + YT(I)*YT(I))}{\sum_{I=1}^{11} XG(I)*XG(I)}} \quad (16)$$

Similarly, from the points on the  $Y_G$  axis ( $I = 12, 20$ ), we have

$$YS = \sqrt{\frac{\sum_{I=12}^{20} (XT(I)*XT(I) + YT(I)*YT(I))}{\sum_{I=12}^{20} YG(I)*YG(I)}} \quad (17)$$

A complete grid measurement is rarely carried out as a routine operation in the reduction of EMP data. Occasionally, it will be done to test the linearity of the system. The most common method is to measure two points on each axis and calculate all quantities from these numbers. The following equations were implemented in the signal analysis package. The routine calculates the grid rotation angle, the scale factor, and the origin point from two measured points on both the X and Y grid axes. Initially, the program reads in the coordinates of the two points measured on the X axis--X1 and X2--and on the Y axis--Y1 and Y2. Then the four grid points are read in the same order that the coordinate locations were read in. The four grid points are stored in the arrays XT(I), YT(I),  $I = 1, 4$ . The origin of the grid (X0, Y0) is given by

$$\begin{aligned} X0 &= |X2*XT(1) - X1*XT(2)| / |X1 - X2| , \\ Y0 &= |Y2*YT(3) - Y1*YT(4)| / |Y1 - Y2| . \end{aligned} \quad (18)$$

The scale factors XS and YS are given by

$$\begin{aligned} XS &= \sqrt{(XT(2) - XT(1))^2 + (YT(2) - YT(1))^2} / (X2 - X1) , \\ YS &= \sqrt{(XT(4) - XT(3))^2 + (YT(4) - YT(3))^2} / (Y2 - Y1) . \end{aligned} \quad (19)$$

The rotation angle is determined by

$$\begin{aligned}\tan(\theta) &= 0.5 * \left( \frac{YT(2)-YT(1)}{XT(2)-XT(1)} - \frac{XT(4)-XT(3)}{YT(4)-YT(3)} \right) , \\ CT = \cos(\theta) &= 1./\sqrt{1+\tan(\theta)**2} , \\ ST = \sin(\theta) &= \cos(\theta)*\tan(\theta) .\end{aligned}\tag{20}$$

Then the subroutine reads scale factors T (nanosecond/grid division) and V (volts/grid division), then recomputes the scale factors as

$$T \leftarrow T/XS, \quad V \leftarrow V/XS ,\tag{21}$$

which have units nanoseconds/tablet counts and volts/tablet counts. Then the (x,y) coordinates of the trace are transformed as,

$$\begin{aligned}X(I) &\leftarrow (CT*(X(I)-X0) + ST*(Y(I)-Y0)-XZ)*T , \\ Y(I) &\leftarrow (-ST*(X(I)-X0) + CT*(Y(I)-Y0)-YZ)*V ,\end{aligned}\tag{22}$$

where (XZ, YZ) are the rotated coordinates of the "zero point of the trace," that is, the point on the trace at which the signal starts,

$$\begin{aligned}XZ &\leftarrow CT*(XZ-X0) + ST*(YZ-Y0) \\ YZ &\leftarrow -ST*(XZ-X0) + CT*(YZ-Y0)\end{aligned}\tag{23}$$

### 2.1.2 Time Ordering, Bit Reversal, and Interpolation Schemes

*Time ordering* of the array is a necessary procedure in order to remove errors introduced in the digitization process. Occasionally, there will be errors in the grid measurements that cause portions of the trace to fold back in the time sense after it is rotated. Similarly, inaccurate movement of the digitization operator's hand may also cause a few points to be folded back in the time sense. In some cases the digitization hardware will allow consecutive digital points to have the same time value. If these measurement ambiguities are not removed, they will cause considerable error in the high-frequency part of the transforms. This correction of the data is handled in subroutine CST OUT. This routine casts out those points in the array that are folded

back--that is, if  $XF$  is the input time array and  $XF(K) < XF(I)$  for  $K = I + 1, I + 2, \dots$  then  $SF(K)$  is deleted from the array. Similarly, if  $XF(K) = XF(I)$  for some set of  $K$  then the routine averages the amplitude  $YF(K)$  to create a single value at that value  $XF(I)$ .

*Bit reversal* of the array refers to a specific reordering of the elements of a digital time series prior to its entering the FFT subroutine. It is done so that after transformation the frequency domain arrays are in ascending order of the frequency value. The term *bit reversal* arises from representing the index of an array  $I$  in base-two notation. For example, suppose we have the 65th element of a 1024 element array, then  $65_{10} = 0001000001_2$ . The reverse of the number is  $1000001000_2 = 520_{10}$ . To bit reverse, we swap the elements 65 and 520 of the original array.

In subroutine `LNQ`, the Lagrangian methods for interpolation are used. A brief description of Lagrange interpolation is given here.

It is generally assumed that the function,  $f$ , interpolated here behaves like a polynomial; thus, in order to calculate  $f$  approximately at a point  $x$ , we find a polynomial approximation  $g$  for  $f$  good in the neighborhood of  $x$ . Lagrange showed that there is a unique polynomial of degree  $n$  having  $n + 1$  values  $f_i$  at  $n + 1$  distinct points  $x_i$ ,  $i = 0, \dots, n$ . That polynomial is  $g_n$ ,

$$g_n(x) = \sum_{i=0}^n f(x_i) \prod_{\substack{j=0 \\ j \neq i}}^n (x - x_j) / (x_i - x_j) . \quad (24)$$

For the software presented in this package,  $n$  is restricted to the value 1. Thus,

$$g_1(x) = \frac{f(x_1) - f(x_0)}{x_1 - x_0} x + \frac{x_1 f(x_0) - x_0 f(x_1)}{x_1 - x_0} \\ \equiv C1 \cdot x + C2 \quad (25)$$

In the program the function  $f$  is called  $YF(I)$ ,  $x_i$  is replaced by the time array  $XF(I)$ , and the interpolated values are put into the real part of the complex array  $YNYQA(K)$

$$\text{REAL } [\text{YNYQA}(K)] = C1 \cdot X + C2,$$

$$C1 = \frac{YF(I) - YF(I-1)}{XF(I) - XF(I-1)}, \quad C2 = \frac{XF(I) * YF(I-1) - XF(I-1) * YF(I)}{XF(I) - XF(I-1)} \quad (26)$$

In subroutine NYQST, a linear polynomial is fitted to a set of points in the arrays YF(I), XF(I), I = LB,...,LT. After determining the polynomial, the program evaluates it at the predetermined interpolation point.

The theory behind the least squares, polynomial fitting programs is straightforward. We need to minimize  $\chi^2$  with respect to the C(J) where

$$\chi^2 = \sum_{I=LB}^{LT} [YF(I) - \sum_{J=0}^M C(J) * XF(I) ** J]^2 \quad (27)$$

Setting  $\frac{\partial(\chi^2)}{\partial C(J)} = 0$  J = 0,...,M yields

$$\vec{B} = A \cdot \vec{C} \quad (28)$$

where the (K,L)<sup>th</sup> element of the matrix A is

$$A(K,L) = \sum_{I=LB}^{LT} XF(I) ** (K + L - 2), \quad K, L = 1, \dots, M, \quad (29)$$

the K<sup>th</sup> element of the vector  $\vec{B}$  is

$$\vec{B}(K) = \sum_{I=LB}^{LT} YF(I) * (XF(I) ** (K - 1)) \quad K = 1, \dots, M, \quad (30)$$

and the K<sup>th</sup> element of the vector  $\vec{C}$  is just the K<sup>th</sup> polynomial coefficient. Upon inversion we find the solution for  $\vec{C}$

$$\vec{C} = A^{-1} \cdot \vec{B} \quad (31)$$

Both of the interpolator subroutines take due account of the end points of the arrays and minimize the number of calculations when more than one interpolated point falls between the same time values.

## 2.2 Digital Filtering

This section briefly reviews the theory of digital filters. Frequently in EMP work, the signal is contaminated by high-frequency noise arising both from the nature of the measurements and the digitization process which reduces the continuous signal to a digital record. This high-frequency component can generally be eliminated by passing the digital record through a low-pass digital filter. Another useful application of low-pass filters is in reducing the number of digital values needed to accurately calculate the Fourier transform of a waveform at low frequencies. For example, if there is a signal with frequency content up to 250 MHz, the Nyquist criterion is satisfied by sampling the signal every 2.0 nsec. If the signal has a 2-μsec duration, then 1000 numbers must be stored for the Fourier transform routine. However, if most of the significant frequency content is contained in a frequency band up to say 50 MHz, then after filtering, only 200 numbers must be stored to adequately represent the signal and obtain the Fourier transform without worrying about foldover effects. Bandpass and high-pass digital filters have application in EMP work when one is interested in studying only a certain region of the frequency spectrum so that correlations between equipment upset and damage and the induced signal can be determined.

### 2.2.1 Theory of Digital Filtering and Z Transforms

In EMP work, there is generally (after interpolation or as a result of the digitization process) a sequence of numbers  $u(k)$ ,  $k=0, \dots, N$  that must pass through a linear discrete system (generally a difference equation) in order to limit, in some manner, the frequency content of the signal. The output of the linear system is denoted here by  $y(k)$ ,  $k=0, \dots, N$ . By a linear discrete system is meant a system in which the output  $y(k)$  is expressed as a linear combination of inputs and past outputs; thus,

$$y(k) + \sum_{j=1}^n a(j)y(k-j) = \sum_{l=0}^m b(l)u(k-l) , \quad (32)$$

and  $y(k), u(k) = 0, k < 0$ .

The Z transform is used to simplify the analysis and synthesis of the digital filter represented by equation (32)--for example, generate the set of constants  $a(j)$  and  $b(l)$ .

The Z transform of a sequence of numbers  $f(k)$ ,  $k=0, \dots, N$   $f(k) = 0$ ,  $k < 0$  is defined by

$$Z[f(k)] = F(z) = \sum_{k=0}^{\infty} f(k) z^{-k}, \quad (33)$$

where  $z$  is an arbitrary complex number.

The Z transform of the input-output signals are related to one another by

$$Y(z) = H(z) U(z), \quad (34)$$

where  $U(z)$  and  $Y(z)$  denote the Z transforms of the input and output signals respectively, and  $H(z)$  is the system transfer function, and is given by

$$H(z) = \sum_{l=0}^m b(l) z^l / \left( 1 + \sum_{j=1}^n a(j) z^{-j} \right) \quad (35)$$

Proof: Multiply each side of equation (32) by  $z^{-k}$  and sum over all  $k$ .

$$\sum_{k=0}^{\infty} y(k) z^{-k} + \sum_{j=1}^n a(j) \sum_{k=0}^{\infty} y(k-j) z^{-k} = \sum_{l=0}^m b(l) \sum_{k=0}^{\infty} u(k-l) z^{-k}. \quad (36)$$

Using the properties of the Z transform, this can be rewritten as

$$Y(z) + \sum_{j=1}^n a(j) z^{-j} Y(z) = \sum_{l=0}^m b(l) z^{-l} U(z); \quad (37)$$

or, as

$$Y(z) \left[ 1 + \sum_{j=1}^n a(j)z^{-j} \right] = \left[ \sum_{\ell=0}^m b(\ell)z^{-\ell} \right] U(z) . \quad (38)$$

Thus, equation (35) follows and may be rewritten as

$$H(z) = b \prod_{i=1}^r (z-z_i) / \prod_{i=1}^n (z-p_i) . \quad (39)$$

Here,  $z_i$  and  $p_i$  are called the zeros and poles of the system transfer function  $H(z)$ .

One of the most important properties of the transfer function is the fact that the location of the zeros and poles has an enormous effect on how the system transmits different types of inputs. Thus, a system can be synthesized that will pass some inputs and reject others by a proper selection of the zeros and poles.

Assume the application of a sinusoidal input  $u(k) = \sin(kwT)$   $k=0, 1, 2, \dots$  to our systems. Then the resultant steady-state response,  $y(k)$ , is given by

$$y(k) = \left| H(e^{iwT}) \right| \sin(kwT+\theta) . \quad (40)$$

Here, the sinusoidal response of the system is obtained by evaluating the system transfer function  $H(z)$  at  $z=e^{iwT}$ , where  $w$  is the radian frequency of the input sinusoid and  $T$  is the underlying sampling period.  $\theta$  is the phase angle of  $H(e^{iwT})$ --that is,  $H(e^{iwT}) = \left| H(e^{iwT}) \right| e^{i\theta}$ . To prove equation (40) let  $u(k) = \sin(kwT)$   $k = 0, 1, 2, \dots$ ; then,  $U(z)$  is given by

$$U(z) = \frac{z \sin wT}{(z-e^{iwT})(z-e^{-iwT})} \quad (41)$$

The Z transform of the system response is given by,

$$Y(z) = \frac{H(z)z\sin\omega T}{(z-e^{i\omega T})(z-e^{-i\omega T})} \quad (42)$$

Since only stable systems are considered, all the poles of  $H(z)$  must be inside the unit circle. Therefore, none of the poles of  $H(z)$  is at  $e^{i\omega T}$  or  $e^{-i\omega T}$ . A partial fraction expansion of equation (42) yields

$$Y(z) = \frac{az}{(z-e^{i\omega T})} + \frac{bz}{(z-e^{-i\omega T})} + \text{terms due to poles of } H(z), \quad (43)$$

where

$$a = H(e^{i\omega T})/2i \text{ and } b = -H(e^{-i\omega T})/2i.$$

Noting that  $H(e^{i\omega T}) = H(e^{-i\omega T})^*$  and writing  $H(e^{i\omega T}) = Me^{i\theta}$ , we find that

$$Y(z) = \frac{M}{2} \left[ \frac{ze^{i\theta}}{(z-e^{i\omega T})} - \frac{ze^{-i\theta}}{(z-e^{-i\omega T})} \right] + \text{terms due to poles of } H(z) \quad (44)$$

Taking the inverse Z transform of equation (44) we obtain

$$y(k) = \frac{M}{2i} \left[ e^{i(k\omega T + \theta)} - e^{-i(k\omega T + \theta)} \right] + \text{transient response generated by poles of } H(z); \quad (45)$$

or,

$$y(k) = M \sin(k\omega T + \theta) + y_{\text{transient}}(k) \quad (46)$$

In the steady-state  $y$  transient  $(k) \rightarrow 0$  as  $k$  becomes large. Thus

$$y(k) = |H(e^{i\omega T})| \sin(k\omega T + \theta) . \quad (47)$$

The quantity  $M = |H(e^{i\omega T})|$  is called the system gain factor. To filter out a given sinusoid, pick a system so that  $M \ll 1$ ; or, to amplify a given sinusoid, pick  $M \gg 1$ .

As has been observed in equation (39), the transfer function is a ratio of polynomials in the variable  $z$ . Therefore, the system gain factor that is equal to the magnitude of the transfer function evaluated at  $z = \exp(i\omega T)$  may always be expressed as a ratio of polynomials in the variables  $\cos(\omega T)$  and  $\sin(\omega T)$ . Thus, different filters can be synthesized by investigating ratios of trigonometric functions. For example, a low-pass filter with half-power point  $\omega$ , has the following squared gain factor,

$$|H(e^{i\omega T})|^2 = \frac{1}{1 + \frac{\tan^{2n}(\omega T/2)}{\tan^{2n}(\omega_1 T/2)}} . \quad (48)$$

By a considerable amount of algebraic manipulation equation (48) can be written as

$$|H(z)|^2 = \frac{\tan^{2n}(\omega_1 T/2) (1+z)^{2n}}{\left[ \tan^{2n}(\omega_1 T/2) + (-1)^n \right] \left[ (z-p_1)(z-p_2) \cdots (z-p_{2n}) \right]} , \quad (49)$$

where  $z = \exp(i\omega T)$ , and the  $2n$  poles  $p_i$  are given by

$$p_i = \frac{1 - \tan^2(\omega_1 T/2) + \sqrt{-1} \tan(\omega_1 T/2) \sin \theta_i}{1 - 2 \tan(\omega_1 T/2) \cos \theta_i + \tan^2(\omega_1 T/2)} , \quad (50)$$

where,

$$\begin{aligned}\theta_i &= (i-1) \pi/2, \text{ n odd} \\ &= (2i-1) \pi/2, \text{ n even} .\end{aligned}$$

It can be shown that of the  $2n$  poles,  $p_i$ , exactly  $n$  lie inside the unit circle and  $n$  outside. Let  $p_1, p_2, \dots, p_n$  denote the  $n$  poles inside the unit circle. The transfer function that has the desired squared-gain factor is given by

$$H(z) = \frac{b(1+z)^n}{(z-p_1)(z-p_2) \dots (z-p_n)} , \quad (51)$$

where  $b$  is chosen so that the steady-state, unit-step response has magnitude one,  $H(1)=1$ ; thus,

$$b = \frac{(1-p_1)(1-p_2) \dots (1-p_n)}{2^n} . \quad (52)$$

The remaining poles  $p_{n+1}, p_{n+2}, \dots, p_{2n}$  associated with  $|H(z)|^2$  can be shown to arise from the process of determining the squared-gain factor.

From the foregoing, a well-defined procedure exists for synthesizing a low-pass filter. It can be summarized in the following steps:

- (a) Determine the half-power point  $\omega_1$ ,
- (b) Determine the value  $n$ --using equation (17)--by specifying the gain at frequency  $\omega_2$ ,
- (c) Find the  $n$  roots  $p$  given by equation (49) which satisfy  $|p_i| < 1$ , and
- (d) Determine the difference equation which has the transfer function given by equations (51) and (52).

A squared-gain factor that corresponds to that of a high-pass filter is given by

$$\left| H(e^{i\omega T}) \right| = \frac{1}{1 + \frac{\cot^{2n}(\omega T/2)}{\cot^{2n}(\omega_2 T/2)}} \quad (53)$$

Here, the half-power point is denoted by  $\omega_2$ . Formulas analagous to equations (50) and (51) may be derived. Then, if the poles and zeros of a low-pass filter with half-power point  $(\pi/T - \omega_2)$  are rotated through  $\pi$  radians in the complex plane, the pole-zero pattern of a high-pass filter is obtained with half-power point  $\omega_2$  and the same gain-factor falloff outside its passband is obtained. Thus, if we have  $H(z)$  for the low-pass filter given by

$$H(z) = b(1+z)^n / \prod_{i=1}^n (z - p_i) \quad (54)$$

then the high-pass filter is given by  $H'(z)$

$$H'(z) = b'(z-1)^n / \prod_{i=1}^n (z + p_i) \quad (55)$$

### 2.2.2 Examples of Filtering EMP Data

To illustrate the implementation of the algorithms described in section 1, a typical EMP waveform was selected from the vast amount of data collected at the Polk City AUTOVON EMP tests and processed. Figure 4 plots the digitized waveform after it has been digitized, time ordered, and interpolated at 1.63-nsec intervals using a Lagrange interpolator.

Figure 5 plots the power spectrum after passing the digital record through a fast Fourier transform routine. All the power is contained in two peaks at 13.2 and 24.0 MHz. Several filters were then synthesized and the digital record passed through filters before processing it through the fast Fourier transform routines. Table I lists the half-power points,  $\omega_1$ , the gain at the higher frequency  $\omega_2$  used to determine  $n$ , and the filter coefficients  $a(j)$ ,  $j=1, \dots, n$ ,  $b(j)$ ,  $j=0, \dots, n$ , which were calculated for each synthesized filter. Figures 6 through 12 are plots of the power spectra obtained by using a fast Fourier transform routine on the filtered-time series. The general result is fairly evident from these plots--namely, that as the number of poles is increased and consequently the gain rolloff at the half-power point is increased, a sharper filtering is obtained.

Although it is not apparent from the plots of the power spectra presented, there is much greater definition of the peaks in the power spectrum relative to the noise background. The high-frequency noise was reduced by a factor of 100.

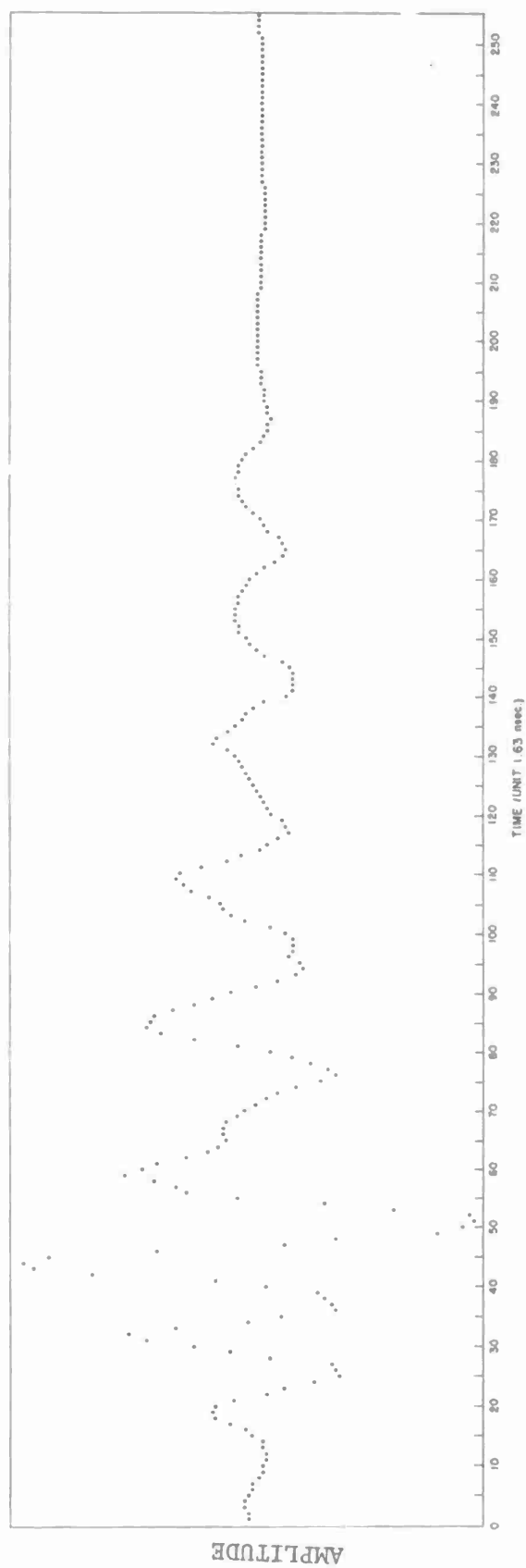


Figure 4. Plot of equispaced digital times series.

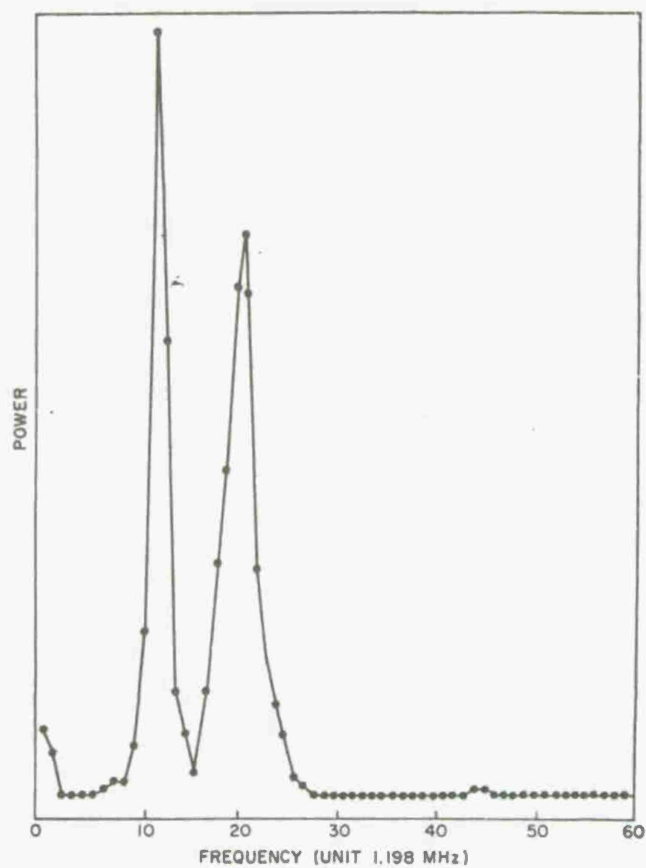


Figure 5. Plot of power spectrum obtained without filtering.

TABLE I. PARAMETERS CALCULATED FOR EACH SYNTHESIZED FILTER

| Filter No. | Half-power point $W_1$ (MHz) | Gain $W_2 = W_1$ | $W_2$ | Sampling Interval T (usec) | n | $a(j), j=1, \dots, n$                                                                                 | $b(j), j=1, \dots, n+1$                                                                                             |
|------------|------------------------------|------------------|-------|----------------------------|---|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| 1          | 20                           | 0.4              | 25    | 1.63                       | 1 | -0.8135657E00                                                                                         | +0.9321713E00<br>+0.9321713E00                                                                                      |
| 2          | 20                           | 0.2              | 25    | 1.63                       | 4 | -0.3465070E 01<br>0.4533676E 01<br>-0.2652045E 01<br>0.5848047E 00                                    | 0.8540331E-04<br>0.3416131E-03<br>0.5124197E-03<br>0.8540331E-04                                                    |
| 3          | 20                           | 0.1              | 25    | 1.63                       | 5 | -0.4337327E 01<br>0.7563597E 01<br>-0.6625226E 01<br>0.2913780E 01<br>-0.5145599E 00                  | 0.8235322E-05<br>0.4117661E-04<br>0.8235322E-04<br>0.8235322E-04<br>0.4117661E-04<br>0.8235322E-05                  |
| 4          | 20                           | 0.07             | 25    | 1.63                       | 6 | -0.5208673E 01<br>0.1135041E 02<br>-0.1324103E 02<br>0.8718896E 01<br>-0.3071778E 01<br>0.4523243E 00 | 0.7937438E-06<br>0.4762463E-05<br>0.1190616E-04<br>0.1587487E-04<br>0.1190616E-04<br>0.4762463E-05<br>0.7937438E-06 |
| 5          | 20                           | 0.05             | 25    | 1.52                       | 6 | -0.2848268E 01<br>0.3845003E 01<br>-0.2959958E 01<br>0.1351626E 01<br>-0.3426920E 00<br>0.3745000E-01 | 0.1299385E-02<br>0.7796306E-02<br>0.1949077E-01<br>0.2598769E-01<br>0.1949077E-01<br>0.7796306E-02<br>0.1299385E-02 |
| 6          | 18                           | 0.2              | 25    | 1.63                       | 3 | -0.2631725E 01<br>0.2328194E 01<br>0.6912119E 00                                                      | 0.6571114E-03<br>0.1971334E-02<br>0.1971334E-02<br>0.6571114E-03                                                    |
| 7          | 17.5                         | 0.05             | 25    | 1.63                       | 5 | -0.4420094E 01<br>0.7844978E 01<br>-0.6986225E 01<br>0.3120767E 01<br>-0.5592871E 00                  | 0.4385640E-05<br>0.2192819E-04<br>0.4385639E-04<br>0.4385639E-04<br>0.2192819E-04<br>0.4385640E-05                  |

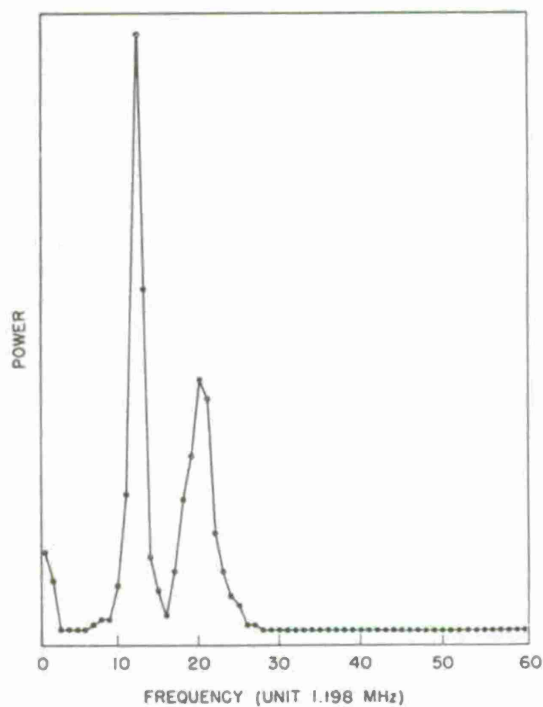
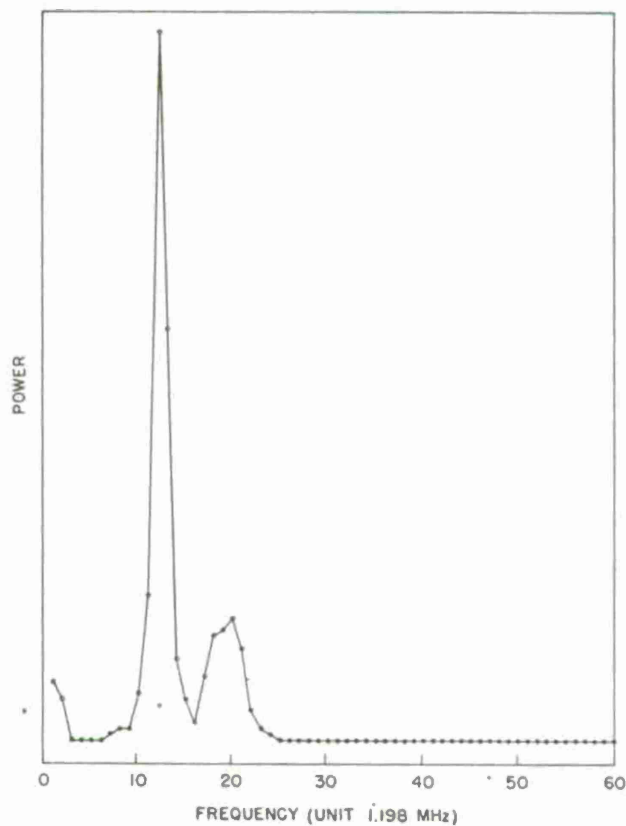


Figure 6. Plot of power spectrum obtained after passing the digital record through filter No. 1 (table I).

Figure 7. Plot of power spectrum obtained after passing the digital record through filter No. 2 (table I).



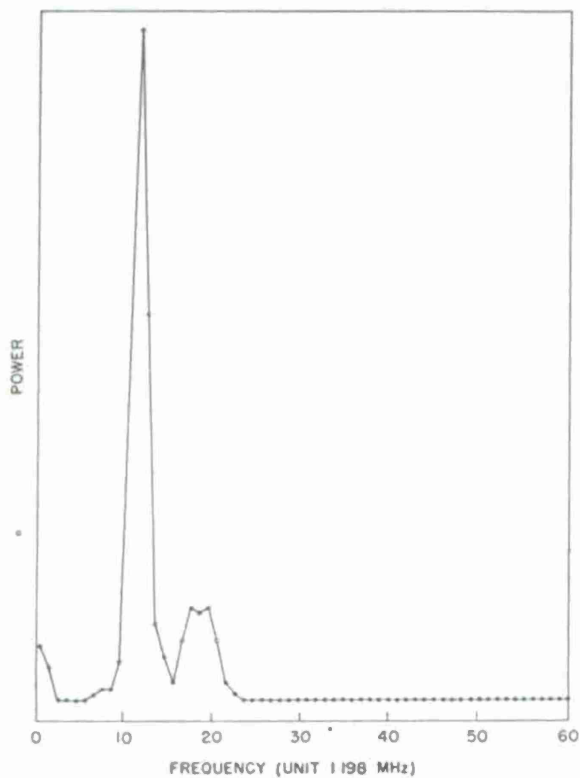
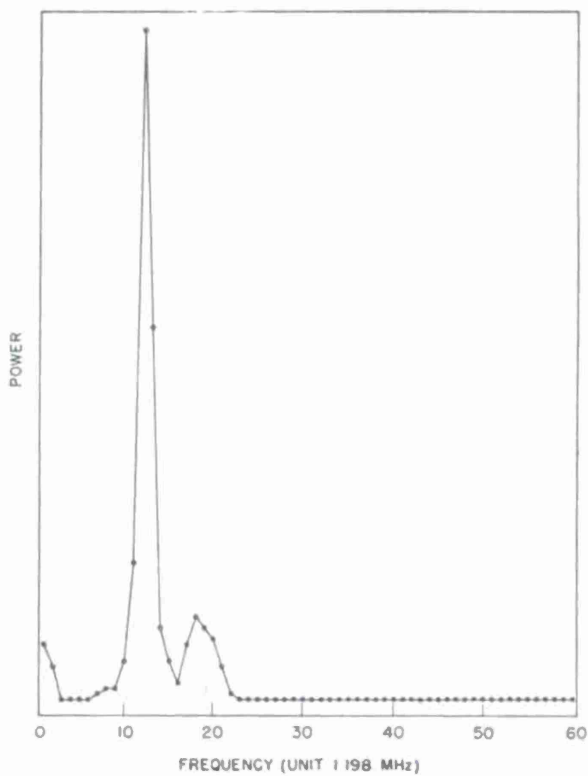


Figure 8. Plot of power spectrum obtained after passing the digital record through filter No. 3 (table I).

Figure 9. Plot of power spectrum obtained after passing the digital record through filter No. 4 (table I).



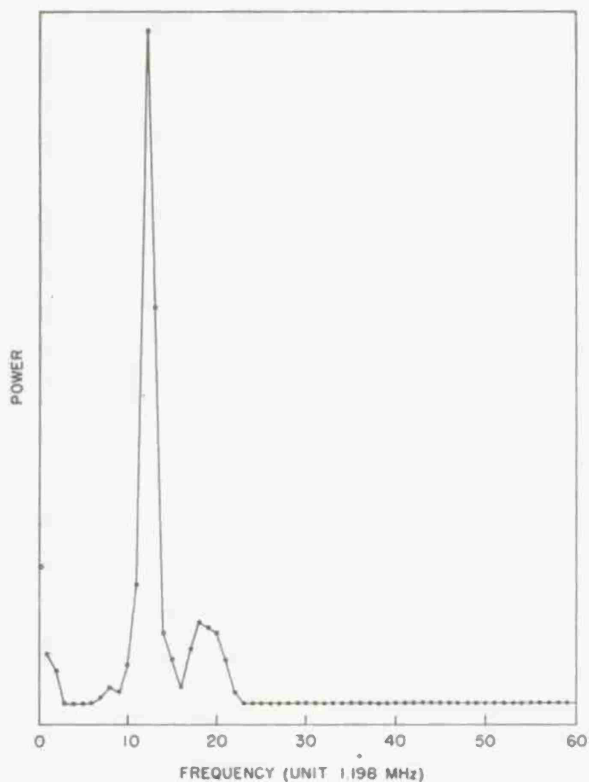
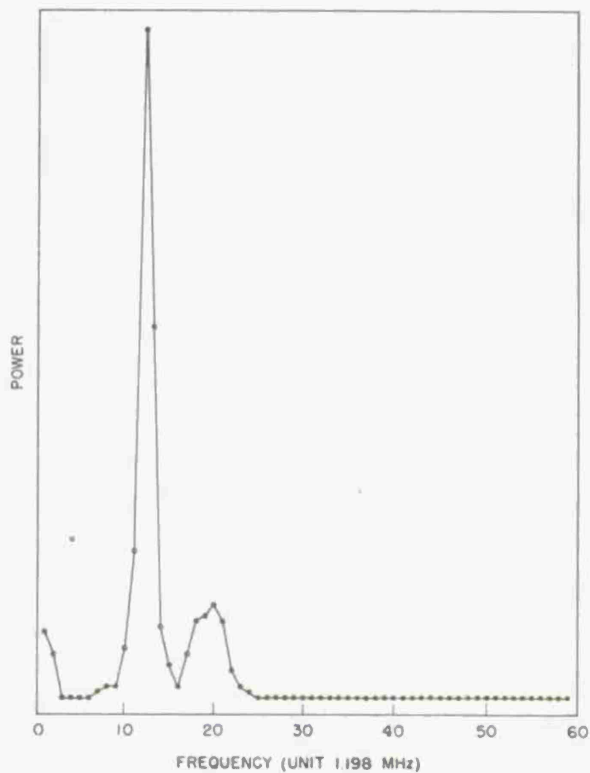


Figure 10. Plot of power spectrum obtained after passing the digital record through filter No. 5 (table I).

Figure 11. Plot of power spectrum obtained after passing the digital record through filter No. 6 (table I).



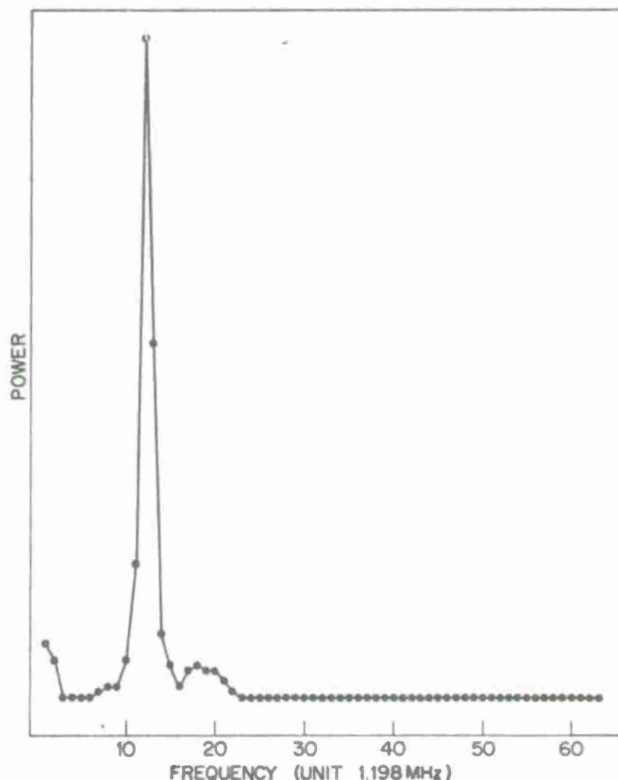


Figure 12. Plot of power spectrum obtained after passing the digital record through filter No. 7 (table I).

### 2.3 Transform Techniques

Three different popular transform techniques are discussed below.

#### 2.3.1 Fast Fourier Transform

The fast Fourier transform is by far the method most preferred for generating the Fourier transform of a digital-time series. A short discussion of the method is given in this section.

$F(\omega)$  of a function  $f(t)$  is defined as

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt \quad . \quad (56)$$

If  $f(t)$  is nonzero only over a finite time interval  $T$ , then it is a good approximation to write the Fourier transform as a discrete sum,

$$F(\omega) = \Delta t \sum_{k=0}^{N-1} f(k\Delta t) e^{-\omega k\Delta t}, \quad N\Delta t = T. \quad (57)$$

The inverse transform is

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{i\omega t} d\omega. \quad (58)$$

If  $F(\omega)$  has no (or a negligible) frequency content above  $\omega_{\max}$  the inverse transform can be written as

$$f(t) = \frac{\Delta\omega}{2\pi} \sum_{r=0}^{N-1} F(r\Delta\omega) e^{itr\Delta\omega}, \quad N\Delta\omega = 2\omega_{\max}. \quad (59)$$

For a band-limited signal, we know from the Nyquist criterion that the sampling interval  $\Delta t$  must be chosen so that  $\Delta t = 2\pi/2\omega_{\max}$ . Similarly, for a time-bounded signal, the frequency-sampling interval must be chosen so that  $\Delta\omega = 2\omega/T$ ,

$$\Delta t \Delta\omega \leq \frac{T}{N} \frac{2\pi}{T} = \frac{2\pi}{N}. \quad (60)$$

Thus,

$$F(r\Delta\omega) = \Delta t \sum_{k=0}^{N-1} f(k\Delta t) e^{-2\pi i r k / N}, \quad r=0, 1, \dots, N-1. \quad (61)$$

For notational convenience, we write  $F_r = F(r\Delta\omega)$ ,  $f_k = f(k\Delta t)$ ,  $W = e^{-2\pi i / N}$ , and drop the factor  $\Delta t$ .

$$F_r = \sum_{k=0}^{N-1} f_k W^{rk} \quad r = 0, \dots, N-1. \quad (62)$$

Divide the time series of points,  $f_k$ , into two functions  $g_k$  and  $h_k$ ,

$$\begin{aligned} g_k &= f_{2k}, \\ h_k &= f_{2k+1}, \end{aligned} \quad k = 0, 1, 2, \dots, \frac{N}{2} - 1 \quad (63)$$

The discrete Fourier transforms of  $g_k$  and  $h_k$  are  $G_r$  and  $H_r$ , respectively.

$$G_r = \sum_{k=0}^{(N/2)-1} g_k e^{-2\pi i r k / (N/2)}, \quad r = 0, 1, \dots, \frac{N}{2} - 1 \quad (64)$$

$$H_r = \sum_{k=0}^{(N/2)-1} h_k e^{-2\pi i r k / (N/2)}.$$

Equations (61) and (62) may be rewritten as

$$F_r = \sum_{k=0}^{(N/2)-1} f_{2k} e^{-2\pi i r k / (N/2)} + e^{-2\pi i r / N} \sum_{k=0}^{(N/2)-1} f_{2k+1} e^{-2\pi i r k / (N/2)} \quad (65)$$

Using equations (63) and (64), we have

$$\begin{aligned} F_r &= G_r + W H_r & 0 \leq r < N/2 \\ F_{r+N/2} &= G_r - W H_r & 0 \leq r < N/2 \end{aligned} \quad (66)$$

We may therefore compute the Fourier transform of a function sampled  $N$  times by evaluating two Fourier transforms of the function sampled  $N/2$  times. The computations of  $G_r$  and  $H_r$  can be reduced to the evaluation of sequences of  $N/4$  samples. If  $N = 2^n$ ,  $n$  such reductions can be made by applying equations (63) and (66) first for  $N$ , then  $N/2$ , and finally for a two-point function. The Fourier transform of a one-point function

is just the sample itself. Beside the obvious savings in computer running time by using this successive reduction scheme, the transform can also be done in place--that is, in each stage of reduction the intermediate results are written over the original array. This in-place reduction requires a rearrangement of the original array called *bit reversal* (subroutine SRTFUR). A complete rearrangement and overwriting sequence for an eight-point sampled function is illustrated in figure 13.

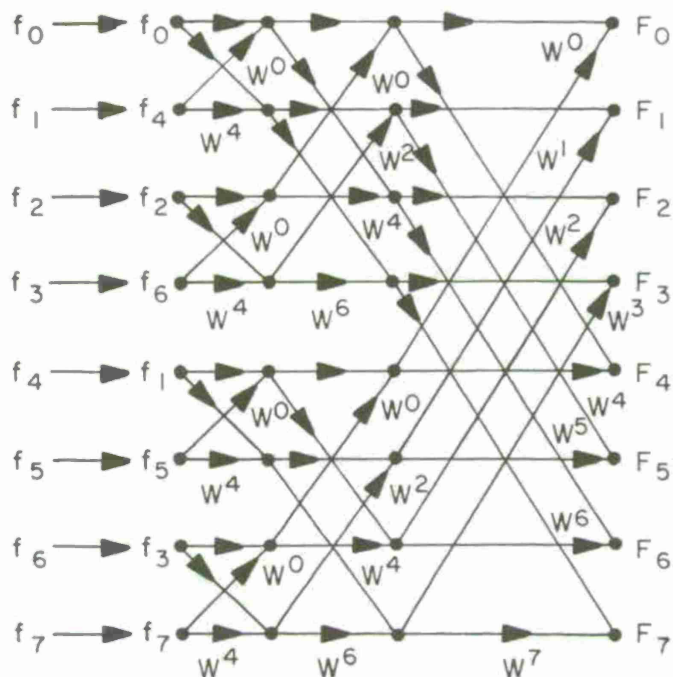


Figure 13. Rearrangement and overwriting sequence for an eight-point sampled function.

Each arrow in the diagram means that the term at the origin of the arrow must be added. A variable next to the arrow acts as a multiplier to the additive term. Thus, at the first overwriting, sequence  $f_0$  is replaced by  $f_0 + W_0 * f_4$  and  $f_4$  is replaced by  $f_0 + W_4 * f_4$ .

Subroutine FFT will compute the transform of any array with  $2^n$  elements as described above. The only restriction is that imposed by the finite memory size of the computer being used. Several examples of the power spectrum derived from the real and imaginary parts of the transform generated by FFT are shown in figures 5 through 12.

### 2.3.2 Fast Walsh Transform

The previous section transforms the digital-time series to the frequency domain by using a particular set of orthogonal functions--namely sines and cosines. Another set of orthogonal functions, which are used extensively in communications theory, are the Walsh functions that are used primarily to represent logic signals. Their most appealing feature is that the digital Walsh transform algorithm is about an order of magnitude faster than the Fourier transform algorithm.

The Walsh functions are  $wal(k, \theta)$ ,  $sal(k, \theta)$ , and  $cal(k, \theta)$ ,

$$wal(2k, \theta) = cal(k, \theta)$$

$$wal(2k-1, \theta) = sal(k, \theta)$$

They are defined on the time interval  $T$ ,  $\theta$  is the normalized time  $\theta = t/T$ , and  $k$  is called the sequency. The sequency is equal to the average number of zero crossings of the function per unit time. The functions  $sal$  and  $cal$  are similar to the sine and cosine functions. The sequency of the Walsh functions plays a similar role as the frequency for the sinusoidal functions. One definition of the Walsh functions is through a difference equation,

$$wal(2k+p, \theta) = (-1)^{[k/2] + p} \left[ wal \left[ k, 2 \left( \theta, \frac{1}{4} \right) \right] + (-1)^{k+p} wal \left[ k, 2 \left( \theta - \frac{1}{4} \right) \right] \right], \quad (67)$$

where

$$k = 0, 1, 2, \dots,$$

$[k/2]$  is the largest integer less than or equal to  $k/2$ ,

$p = 0$  or  $1$ , and

$$\begin{aligned} wal(0, \theta) &= 1 \quad \theta \leq \frac{1}{2} \\ &0 \quad \theta > \frac{1}{2} \end{aligned} \quad (68)$$

A few of the Walsh functions are shown in figure 14.

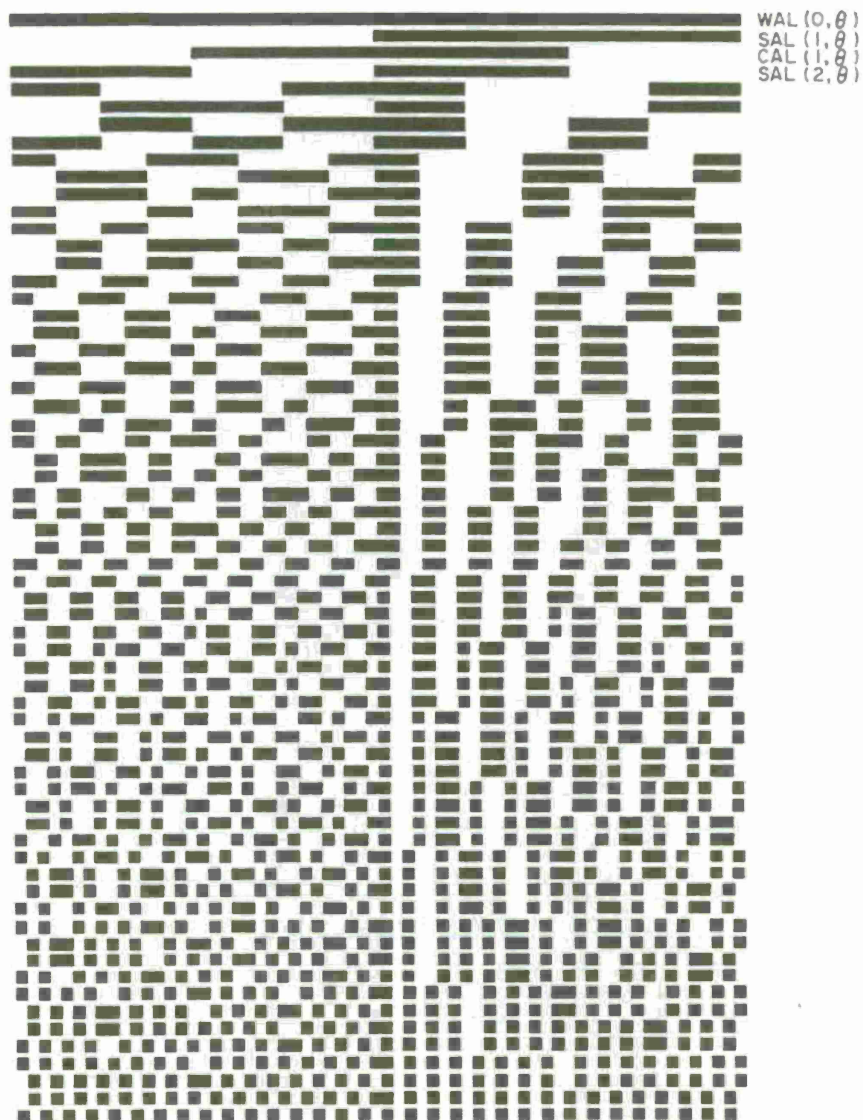


Figure 14. Examples of Walsh functions for interval  $-\frac{1}{2} < \theta < \frac{1}{2}$  (dark areas imply +1, light areas imply -1).

A signal  $f(t)$  may be expanded in a Walsh series

$$f(t) = a(o)wal(o,t) + \sum_{k=1}^{\infty} \left[ a_c(k)cal(k,t) + a_s(k)sal(k,t) \right] ,$$

$$a(o) = \int_{-T/2}^{T/2} f(t)dt ,$$

$$a_c(k) = \int_{-T/2}^{T/2} f(t)cal(k,t) dt ,$$

$$a_s(k) = \int_{-T/2}^{T/2} f(t)sal(k,t)dt . \quad (69)$$

Just as in a Fourier expansion, the sum of the squares of the expansion coefficients give the sequency energy spectrum. The Walsh power is

$$E(k) = a_c^2(k) + a_s^2(k) . \quad (70)$$

To evaluate the coefficients, a fast Walsh transform algorithm can be derived that is similar to the fast Fourier technique. The main difference is that the reduction cannot be done in place. The steps for an eight-point-sampled function is shown in figure 15. The arrows have the same meaning as in the overwriting sequence for the FFT. Thus, at the first overwrite,  $f_0$  is replaced by  $f_0 + f_1$ .

For the EMP data of figure 4, the Walsh power was calculated and the results plotted in figure 16. The same figure plots the Walsh power after filtering the data through filter No. 7, table I.

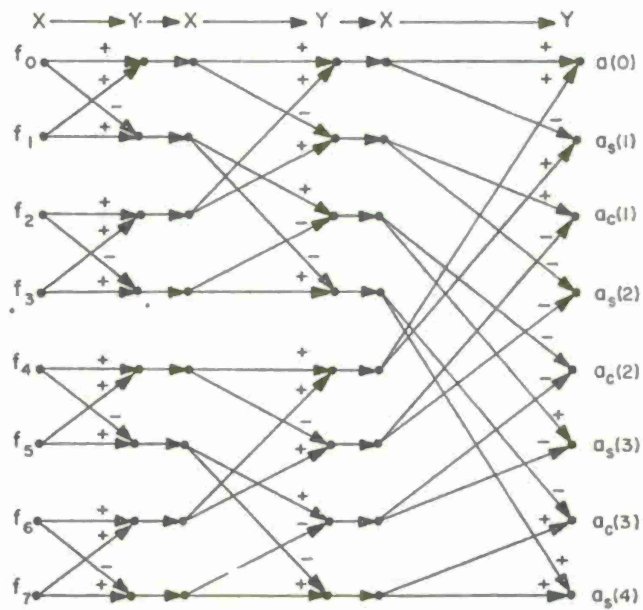


Figure 15. Overwriting sequence for Walsh transform.

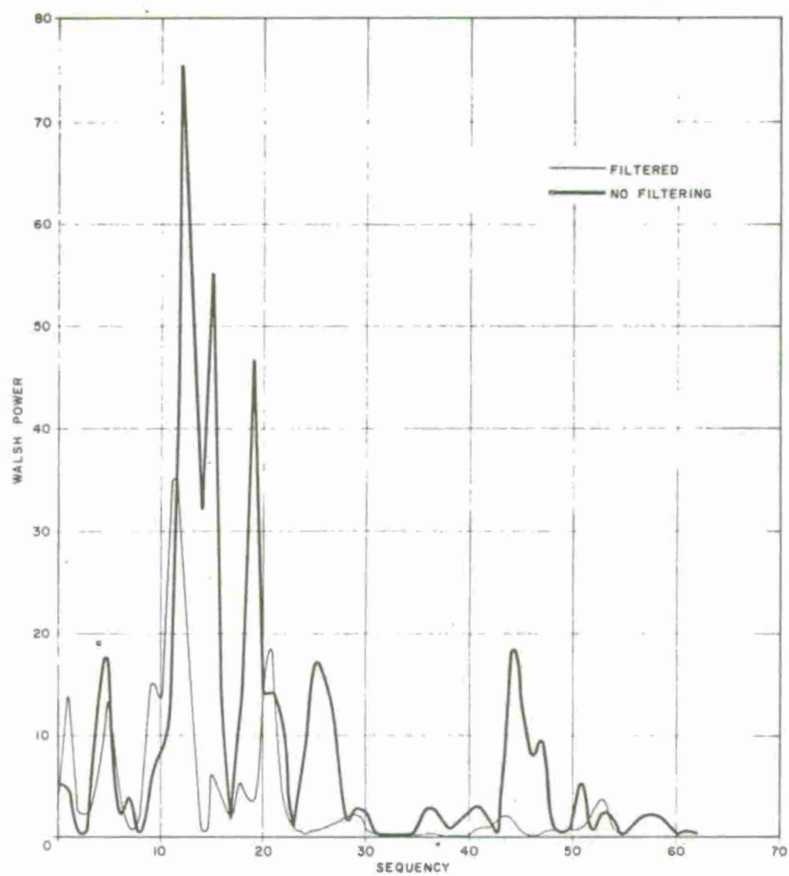


Figure 16. Walsh power for the time series of figure 4.

### 2.3.3 Refined Spectral Densities and Autocorrelation Function

In EMP work, there is a great need for implementing numerical algorithms for the processing and storage of digitized waveforms, which are the main output of all EMP tests. This subsection describes one algorithm to generate the power spectrum of a digital record from its autocorrelation function. The theory presented below is illustrated by several examples.

A procedure will now be defined for estimating the power spectrum of a uniformly spaced, discrete time series of finite length.

If  $C(\tau)$  is the autocovariance function for a time waveform  $X(t)$ , then by definition

$$C(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} X(t)X(t+\tau)dt \quad (71)$$

The power spectrum  $P(w)$  of the time waveform is then given by

$$P(w) = 2 \int_0^{\infty} \cos(w\tau) C(\tau) d\tau \quad (72)$$

For a uniformly spaced discrete-time series of finite length, denoted by  $X_0, X_1, \dots, X_n$  compute the mean lagged products,  $C_r$ , with lag interval  $\Delta\tau = h\Delta t$ , and  $\Delta t$  is the time interval between adjacent values of the time series.

$$C_r = \frac{1}{n-hr} \sum_{q=0}^{q=n-hr} X_q X_{q+hr}, \quad r=0, 1, \dots, m, \quad m \leq \frac{n}{h} \quad (73)$$

Next, compute the "raw spectral density estimates"  $V_r$ .

$$V_r = \Delta\tau \cdot \left[ C_0 + 2 \sum_{q=1}^{q=m-1} C_q \cos \frac{qr\pi}{m} + C_m \cos r\pi \right] \quad (74)$$

The frequency corresponding to  $r$  is  $r/2m\Delta\tau$ .

We next calculate the refined spectral density estimates according to

$$U_r = 0.23 V_{r-1} + 0.54 V_r + 0.23 V_{r+1} . \quad (75)$$

To illustrate the implementation of the algorithms given by equations (73), (74), and (75), refer once again to figures 4 and 5. Figure 4 plots the digitized waveform after it has been digitized, time ordered, and interpolated at 1.63-nsec intervals with a Lagrange interpolator. Figure 5 plots the power spectrum after passing the digital record through a fast Fourier transform routine. Most of the power is contained in the two peaks at 13.2 and 24.0 MHz.

Figures 17 through 23 are plots of the mean lagged products and spectral densities for different values of the lag interval,  $\Delta t$ . It is seen that all of the frequency content of the power spectrum is accurately calculated until the lag interval exceeds the Nyquist sampling rate,  $\Delta > t_N = 1/2f_{\max}$ , where  $f_{\max}$  is the largest expected frequency content of the record. For these data,  $\Delta t_N = 20$  nsec. Figure 22 shows the power spectrum clearly broadened and thus fold-over effects on the lower frequency peak. Since the autocorrelation function is close to zero for times greater than 0.5  $\mu$ sec, the power spectrum can be accurately calculated with a lag of 1.0 and a lesser number of mean lagged products (fig. 23).

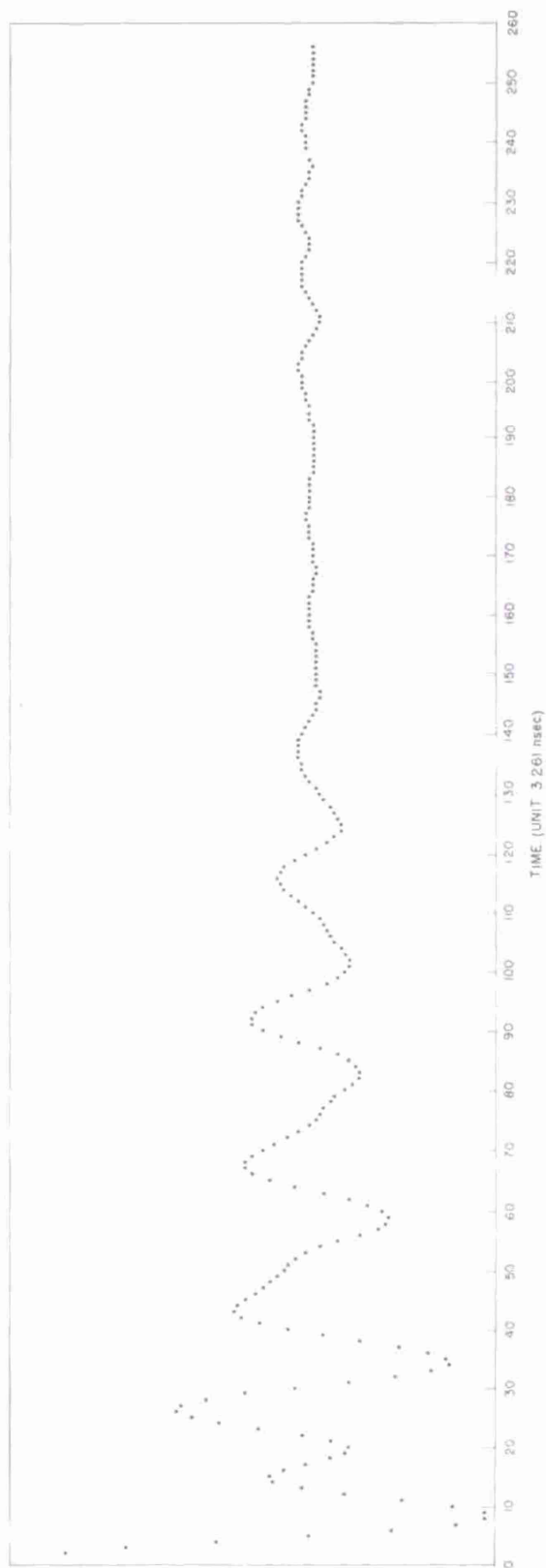


Figure 17. Plot of mean lagged products,  $C_r$ ,  $r=1, \dots, 256$ . The log interval,  $\Delta\tau$ , is given by  $\Delta\tau = \hbar \cdot \Delta\tau_c = 3.61$  nsec.

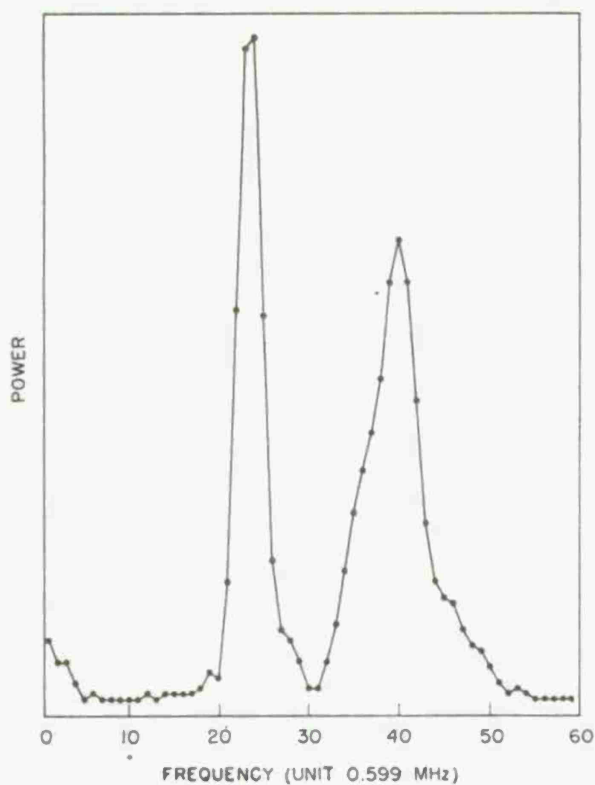
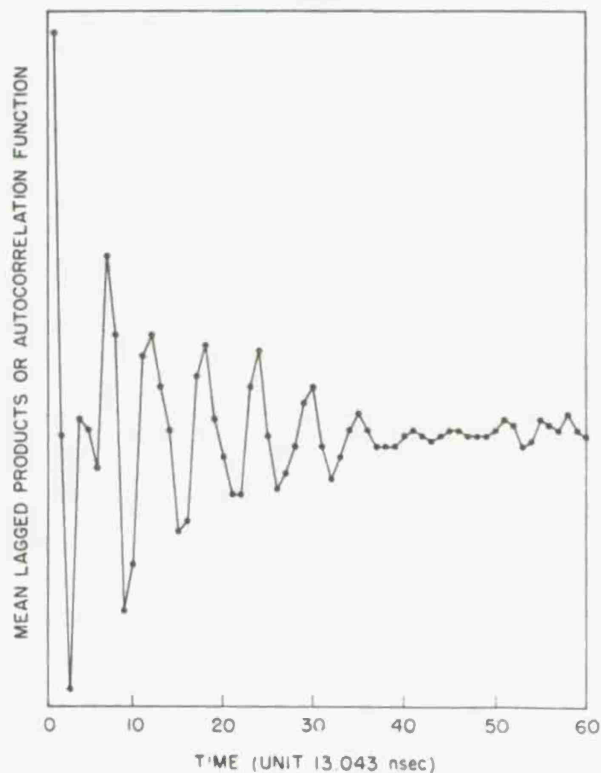


Figure 18. Refined spectral density estimates for the autocorrelation function of figure 17.

Figure 19. Plot of mean lagged products  $C_r$ ,  $r=1, \dots, 64$ .



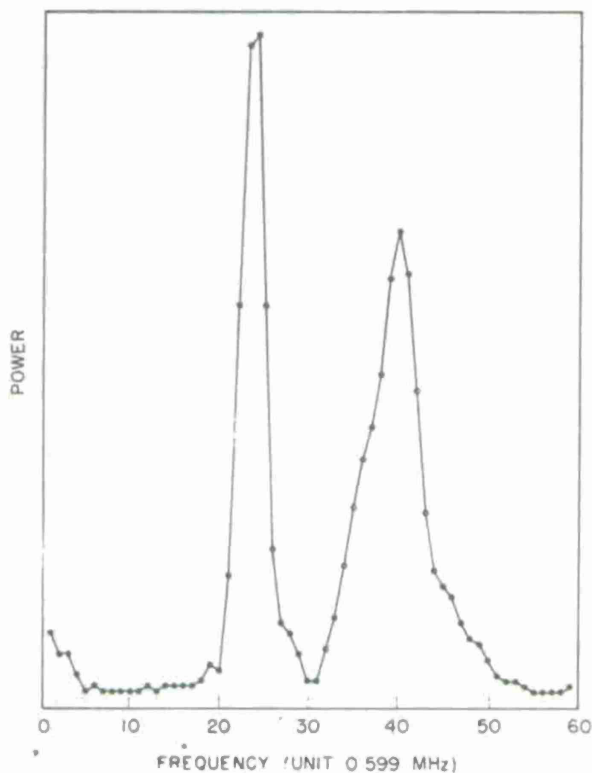
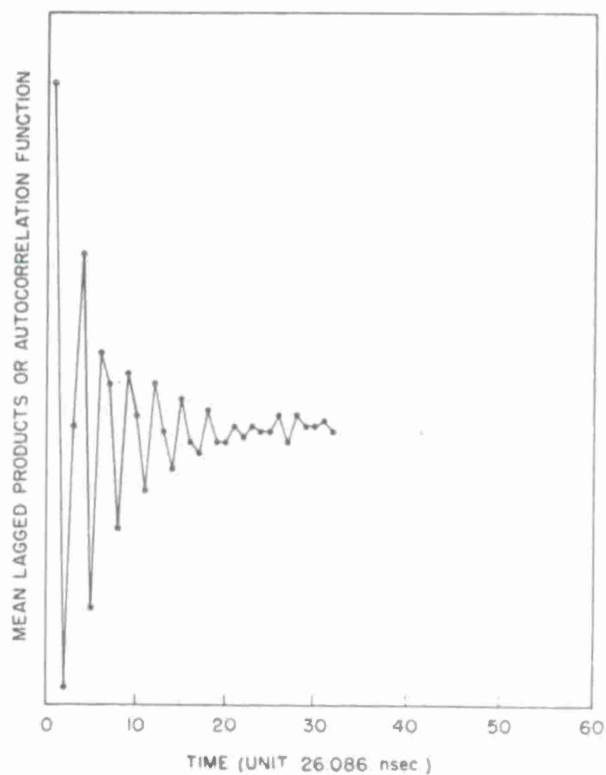


Figure 20. Refined spectral density estimates for the autocorrelation function of figure 19.

Figure 21. Plot of mean lagged products,  $C_r$ ,  $r=1 \dots, 32$ .



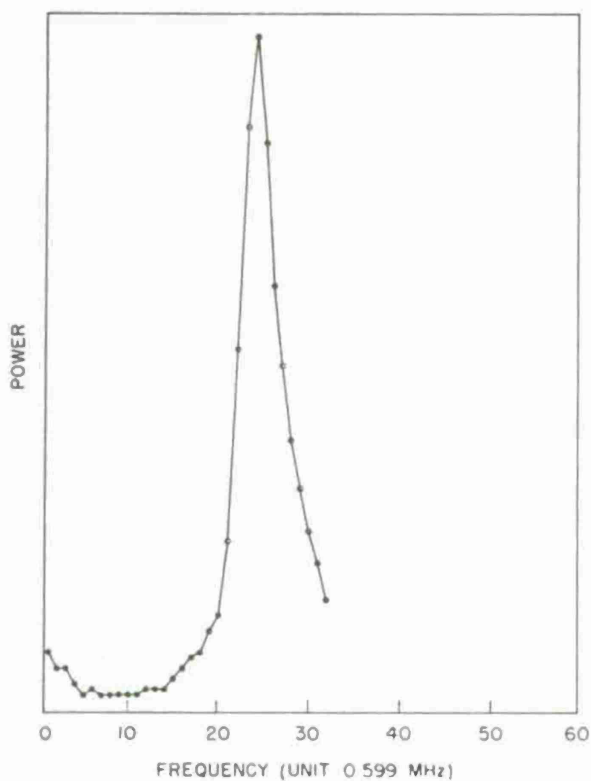
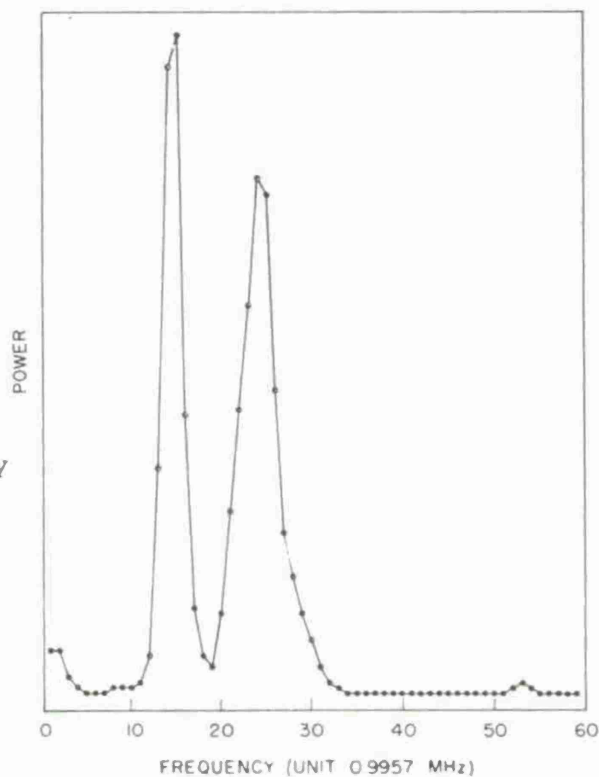


Figure 22. Refined spectral density estimates for the autocorrelation function of figure 21.

Figure 23. Refined spectral density estimated, obtained after truncation of the autocorrelation function of figure 6 at 0.1502  $\mu$ sec.



### 3. PROGRAM DESCRIPTION AND INPUT FORMATS

A flow chart of the main program is presented in figure 24. Each subroutine performs a definite signal analysis function. As indicated, the user is privileged to employ the technique of his choice by setting the control parameters on the input cards. The subroutines and their functions are listed.

#### 3.1 Subroutine Descriptions

- MAIN: This routine directly or indirectly calls the rest of the subroutines and thus controls the passage of the program through all the signal analysis options.
- READIN: This routine reads in all input parameters and data.
- SCARTP: This routine calculates the rotation angle, the sine and cosine of the rotation angle, the origin (center) of the scope graticule, and the scale factors (tablet units/div) along both the time and voltage axes.
- ROT: This routine rotates and scales the input time and amplitude arrays given in digitization-tablet units into units of time and volts.
- CSTOUT: This routine checks the time ordering of the digital time series. It discards those points from the array whose time values,  $t_i$ ,  $i = 1, \dots, N$ , do not satisfy  $t_{i+1} \geq t_i$ . On those points that have the same time values, the program averages the amplitude values.
- LNYQ: This routine interpolates at the Nyquist sampling intervals with a linear interpolator. If the time value,  $X$ , satisfies  $XF(I-1) < X < XF(I)$ , where  $XF$  is the time array, then the interpolated amplitude is  $Y = C1 * X + C2$  where
- $$C1 = (YF(I) - YF(I-1)) / (XF(I) - XF(I-1))$$
- $$C2 = (YF(I-1) * XF(I) - YF(I) * XF(I-1)) / (XF(I) - XF(I-1))$$
- NYQST: This routine interpolates at the Nyquist sampling intervals by using a least-squares interpolator. If the time value,  $X$ , satisfies  $XF(I-1) < X < XF(I)$  where  $XF$  is the time array, then a least-squares fit of the function  $\phi = a_1 X(I) + a_2$  is made to the set of points  $(XF(J), YF(J))$ ,  $J = I-2, I-1, I, I+1$ . Thus, this routine is also a linear interpolator. Program modifications can be made to increase the number of points and/or the degree of the polynomial used in the fitting procedures.

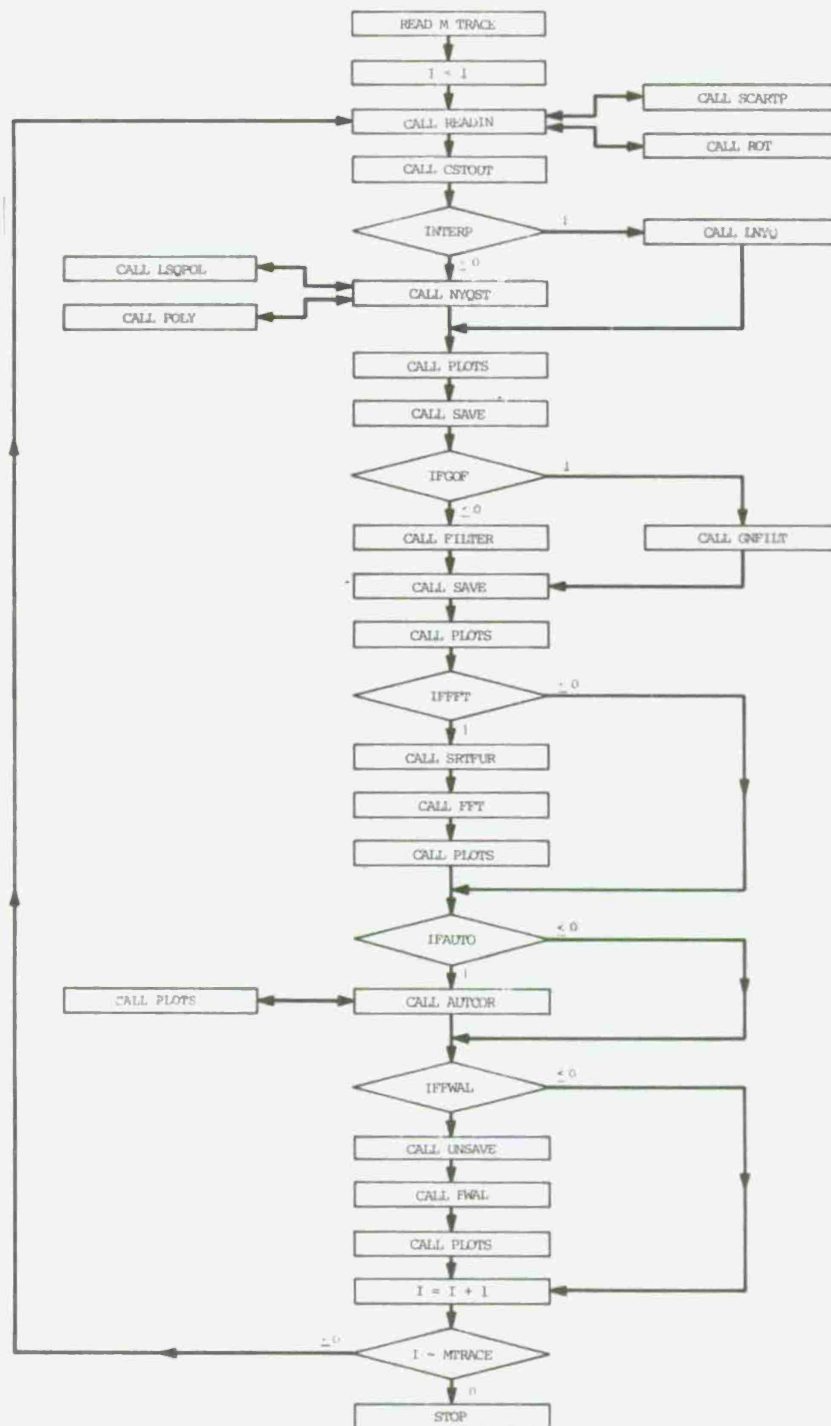


Figure 24. Flow chart for signal analysis program.

GNFILT: This routine will calculate the coefficients A(J) and B(J) for a Butterworth linear recursive low-pass digital filter. If Y(K) and U(K) are the output and input arrays to the filter, then

$$Y(K) = - \sum_{J=1}^N A(J) * Y(K-J) + \sum_{J=1}^{N+1} B(J) * U(K-J+1) \quad .$$

After calculating the coefficients, the routine filters the data.

FILTER: This routine filters the data through a Butterworth linear low-pass digital filter when the coefficients are known.

SRTFUR: This routine performs a *bit reversal* of the original Nyquist array. If I is the element of the array, then  $I = \sum_{n=0}^m a(n) * (2^{**n})$ ,  $a(n) = 0$  or  $1$ . The element specified by I is exchanged with the element specified by J, where  $J = \sum_{n=0}^m a(m-n) * (2^{**n})$ .

FFT: This routine calculates the Fourier transform of a Nyquist sampled array that has its elements in bit-reversed order. The technique is generally known as the "fast Fourier transform."

FWAL: This routine calculates Walsh transforms of a Nyquist sampled array. The technique is generally known as the "fast Walsh transform."

AUTCOR: This routine calculates the autocorrelation function for a Nyquist sampled array. From the autocorrelation function, the power spectrum is calculated by the method of refined spectral densities.

PLOTS: This routine plots an equispaced array.

SAVE: Utility subroutine for saving arrays.

UNSAVE: Utility subroutine for retrieving saved arrays.

### 3.2 Input Data Descriptions

Listed below are the input cards and their format.

CARD 1: READ MTRACE

FORMAT (I5)

MTRACE: The total number of the sets of data to be processed by the program.

CARD 2: READ FMT

FORMAT (20A4)

FMT: An array that contains the format of the input data arrays (X(I), Y(I)).

CARD 3: READ TITLE

FORMAT (20A4)

TITLE: An array that contains 80 characters of alpha-numeric information describing the data.

CARD 4: READ NROT, NSTAR, NPOW, ND, JD.

FORMAT (5I5)

NROT: If 0, then the input array must be rotated.

NSTAR: The number of points in the equispaced Nyquist array. It must be an interger power of two.

NPOW:  $NSTAR = 2^{**} NPOW$ .

ND: Used for plotting power spectra, every  $ND^{th}$  point will be plotted.

JD: Used for plotting time series, every  $JD^{th}$  point will be plotted.

CARD 5: READ INTERP, IFFFT, IFFWAL, IFAUTO, IFGOF

FORMAT (6I5)

INTERP = 0 Main calls NYQST

= 1 Main calls LNYQ

IFFFT = 0 Main skips FFT

= 1 Main calls FFT

IFFWAL = 0 Main skips FWAL

= 1 Main calls FWAL

IFAUTO = 0 Main skips AUTCOR

= 1 Main calls AUTCOR

IFGOF = 0 Main calls FILTER

= 1 Main calls GNFILT.

CARD 6: READ YSCAL, XSCAL

FORMAT (2(2X, E13.7))

YSCAL: A scale factor that multiplies the input amplitude array.

XSCAL: A scale factor that multiplies the input time values.

Note: The program assumes the time array is in nanoseconds after it is scaled.

CARD 7: READ JF

FORMAT (2X, I4)

JF: The number of points in the input time and amplitude arrays.

CARD 8: READ (XF(I), YF(I), I=1, JF)

FORMAT (FMT)

XF: An array which contains the initial time array.

YF: An array which contains the initial amplitude array.

CARD 9: READ XZ YZ FORMAT (2(1X, E11.4))

XZ,YZ: Are the tablet coordinates of the zero point of the trace.

CARD 10: READ X1, X2, Y1, Y2

FORMAT (4F510)

X1, X2: Coordinate labels for digitization points on the X axis of the grid.

Y1, Y2: Coordinate labels for digitization points on the Y axis of the grid.

CARD 11: READ (XT(I), YT(I), I=1,4)

FORMAT (2(1X, E11.4))

XT,YT: Tablet coordinates for the four grid measurements defined by X1, X2, Y1, and Y2.

CARD 12: READ T, V

FORMAT (2(1X, E11.4))

T: A time-scale factor nanoseconds/division.

V: A voltage scale factor volts/division.

Note: Cards 9, 10, 11, and 12 only appear if NROT = 1.

CARD 13: READ F1, F2, GW2

FORMAT (3E13.7)

F1: Half-power point for the low-pass digital filter given in megahertz.

F2: <F1 is another frequency at which we specify the gain, GW2, and thus determine the number of poles for the filter. F2 is in megahertz and  $0 < 0.5$ .

Note: Card 13 only appears if IFGOF=1. If IFGOF=0 then

CARD 13: READ NP

FORMAT(IS)

CARD 14: READ(A(D), K=1, NP)

FORMAT (5(2X, E13.7))

READ (B(K), K=1, NP+1)

FORMAT (5(2X,E13.7))

If further analysis is desired repeat cards 2 through 12. The program will continue analyzing data until all input data are exhausted. If much similar data are to be processed, it would be convenient to define all the parameters internal to the program and then delete a great many input cards.

A computer printout of the signal analysis program is included as appendix A.

#### 4. REPRESENTATION OF EMP WAVEFORMS BY PARAMETRIZED FUNCTIONS

As previously reported, it is very convenient to characterize an EMP-induced waveform by a finite set of parametrized functions. This allows an analyst to conveniently handle the thousands of waveforms generated in any given experiment. At present, most analysts deal with the data as a digital record consisting of  $\sim 10^3$  digital values per waveform and an equivalent number of digital values in the Fourier power spectrum. Although this is a valid approach, it is difficult and tedious to make comparisons between large sets of data and to discover trends in the data.

A large fraction of the data that is generated in EMP experiments consists of waveforms that can be described as a product of a growth factor, an exponential damping factor, and a sinusoidal function. In many of these records there is more than one dominant frequency. Most data are then fitted to a judicious mix of the functions  $\phi_n$ , where

$$\phi_n = t^{n-1} \exp(-\xi_n t) \sin \omega_n t. \quad (76)$$

A linear combination of the  $\phi_n$  generally suffices, thus a function  $\phi$  is fit to the digital data, where

$$\phi = \sum_{n=0}^N a_n \phi_n ; \quad (77)$$

or

$$\phi = \sum_{n=0}^N a_n \phi_n + \sum_{n'=0}^{N'} b_{n'} \phi_{n'} \quad (78)$$

There is no general rule that allows a blind selection of such functions; thus, at some point the data must be examined and a "guess" made for a good set of functions to characterize the data.

Following is a description of the method used to fit an N parameter nonlinear function to a set of data. Also, some examples of data are included, which were processed by using the computer codes especially developed for this problem. A listing of the computer program with detailed annotations is given in appendix B.

#### 4.1 Method of Nonlinear Least Squares

For simplicity, consider the problem of fitting an N-parameter function with one independent variable  $X_i$ ,  $\phi(X_i, P_1, \dots, P_N)$ , to the measured quantities  $Y(X_i)$  where the subscript  $i$  refers to the  $i^{\text{th}}$  data point. Thus, we find the parameters that minimize

$$S^2 = \sum_{i=1}^M \left[ Y(X_i) - \phi(X_i, P_1, \dots, P_N) \right]^2 W_i , \quad (79)$$

where  $M$  is the number of data points, and  $W_i$  is the statistical weight of the  $i^{\text{th}}$  data point.

Let us assume now that an iterative procedure has been defined for determining the parameter  $P_j$ ; that is,  $P_j^k$  = the  $k^{\text{th}}$  iteration of the  $j^{\text{th}}$  parameter. Expand the function  $\phi$  in a Taylor series about  $P_j$  and truncate all but the linear terms. Then use the  $k^{\text{th}}$  iteration to determine the parameters for the  $(k+1)^{\text{th}}$  iteration. Let

$$\phi = \phi^k + \sum_{j=1}^N \left[ \frac{\partial \phi}{\partial P_j} \right]^k \Delta P_j^k, \quad (80)$$

where

$$\Delta P_j^k = P_j^{k+1} - P_j^k,$$

and

$$\phi^k = \phi(X_1, P_1^k, \dots, P_N^k).$$

Note that given  $P_j^k$ , we must now determine  $P_j^{k+1}$ . Substituting equation (80) into equation (79) yields in the linear approximation

$$S^2 \approx S_k^2 = \sum_{i=1}^M \left( Y(X_i) - \phi^k - \sum_{j=1}^N \left[ \frac{\partial \phi}{\partial P_j} \right]^k \Delta P_j^k \right)^2 w_i. \quad (81)$$

To minimize  $S_k^2$ , form

$$\frac{\partial S_k^2}{\partial P_\ell} = 0, \quad \ell=1, \dots, N, \quad (82)$$

which yields

$$\sum_{i=1}^M \left[ Y(X_i) - \phi^k \right] \left[ \frac{\partial \phi}{\partial P_\ell} \right]^k w_i = \sum_{i=1}^M \left[ \sum_{j=1}^N \left[ \frac{\partial \phi}{\partial P_j} \right]^k \Delta P_j^k \right] \left[ \frac{\partial \phi}{\partial P_\ell} \right]^k w_i, \quad \ell=1, \dots, N. \quad (83)$$

Defining  $\psi_i^k = Y(X_i) - \phi^k$ ,

$$Z_{\ell i}^k = \left[ \frac{\partial \phi}{\partial P_{\ell}} \right]^k ,$$

$$C_{\ell}^k = \sum_{i=1}^M \psi_i^k Z_{\ell i}^k W_i ; \quad (84)$$

then from equations (81) and (82),

$$\begin{bmatrix} \sum_{i=1}^M (Z_{1i}^k Z_{1i}^k) W_i, \dots, \sum_{i=1}^M (Z_{1i}^k Z_{Ni}^k) W_i \\ \cdot \\ \cdot \\ \cdot \\ \sum_{i=1}^M (Z_{Ni}^k Z_{1i}^k) W_i, \dots, \sum_{i=1}^M (Z_{Ni}^k Z_{Ni}^k) W_i \end{bmatrix} \begin{bmatrix} \Delta P_1^k \\ \Delta P_2^k \\ \cdot \\ \cdot \\ \Delta P_N^k \end{bmatrix} = \begin{bmatrix} C_1^k \\ C_2^k \\ \cdot \\ \cdot \\ C_N^k \end{bmatrix} \quad (85)$$

Or, more concisely,

$$A \cdot \Delta \vec{P} = \vec{C} . \quad (86)$$

Equation (83) can now be inverted to solve for the  $\Delta P_j^k$  and, hence, the  $P_j^{k+1}$ . If now our iterative procedure is converging, the  $P_j^{k+1}$  should be closer to the values  $P_j^*$  which minimizes  $S^2$  and can then be used for the next iteration. This iterative procedure is continued until the use of  $P_j^{k+1}$  produces a chi-squared which differs from that using  $P_j^k$  by less than some preset value,  $V$  usually  $V = 10^{-6}$ ; that is,

$$|S_{k+1}^2 - S_k^2| < V . \quad (87)$$

To insure that the step  $\Delta P_j^k$  is converging, first note that in the linear approximation the quantity

$$D_T^k = \sum_{\ell=1}^N C_{\ell}^k \Delta P_{\ell}^k = \sum_{i=1}^M \sum_{j=1}^N \sum_{\ell=1}^N z_{ji}^k \Delta P_j^k z_{\ell i}^k w_i \Delta P_{\ell}^k, \quad (88)$$

$$= \sum_{i=1}^M w_i \left[ \sum_{j=1}^N z_{ji}^k \Delta P_j^k \right]^2 \geq 0,$$

which implies the  $D_T^k$  must always be positive semidefinite. Thus, if at the  $k^{\text{th}}$  iteration  $D_T^k < 0$ , then change the sign of all the  $\Delta P_{\ell}^k$ . Another approach that shows this is to expand  $S^2$  in a Taylor series and to keep only the first derivatives of  $\Phi$ ; that is,

$$S^2 = S_k^2 \Big|_k + \sum_{\ell} \frac{\partial S^2}{\partial P_{\ell}} \Big|_k \Delta P_{\ell}^k + \frac{1}{2} \sum_{\ell j} \frac{\partial^2 S^2}{\partial P_{\ell} \partial P_j} \Big|_k \Delta P_{\ell}^k \Delta P_j^k + \dots,$$

$$= \sum_{i=1}^M w_i \left[ \left( \psi_i^k \right)^2 - 2 \psi_i^k \sum_{\ell} z_{\ell i}^k \Delta P_{\ell}^k + \sum_{j\ell} z_{ji}^k z_{\ell i}^k \Delta P_j^k \Delta P_{\ell}^k \right]. \quad (89)$$

If  $\Delta P^k$  is considered as defining a vector, construct  $S^2$  to be a function of one variable  $\alpha$ , for example, by letting  $\Delta P_{\ell}^k \rightarrow \alpha \Delta P_{\ell}^k$ ; then we have

$$S^2(\alpha) = S_k^2 - 2\alpha D_T^k + \alpha^2 D_T^k. \quad (90)$$

Now the slope of  $S^2(\alpha)$  evaluated at  $\alpha=0$  is

$$\frac{dS^2(\alpha)}{d\alpha} \Big|_{\alpha=0} \approx -2D_T^k; \quad (91)$$

and to reach a minimum this slope must be negative, that is,  $D_T^k > 0$ , as in equation (86).

Although the condition  $D_T^k > 0$  insures convergence, barring roundoff errors, the procedure can take divergent steps, thus oscillating and giving slow convergence. The following test has been used to overcome this problem and found to work satisfactorily on most data. It is first necessary to check  $D_T^k$  and, if it is negative, to change the sign of all the  $\Delta P_\ell^k$ . Then test to determine if the value  $S_{k+1}^2(\alpha=1) < S_k^2$ ; if it is, perform the test described by equation (85). If  $S_{k+1}^2[(\alpha) = 1] > S_k^2$ ,  $S_{k+1}^2(\alpha)$  must be calculated for the following four values of  $\alpha$ . Thus,

$$\alpha = 1/2 ,$$

$$\alpha = D_T^k / (S_{k+1}^2(\alpha=1) - S_k^2 + 2D_T^k)$$

[determined by the parabola with slope  $-D_T^k$  at  $\alpha=0$  and passing through the points  $S_k^2$  and  $S_{k+1}^2(\alpha=1)$ ],

$$\alpha = 1/D_T^k$$

(determined from the parabola given in equation (90)),

$$\alpha = \left[ S_{k+1}^2(\alpha=1) + 3S_k^2 - 4S_{k+1}^2(\alpha=1/2) \right] / 4 \left[ S_k^2 + S_{k+1}^2(\alpha=1) - 2S_{k+1}^2(\alpha=1/2) \right]$$

[determined by the parabola passing through the points  $S_k^2$ ,  $S_{k+1}^2(\alpha=1/2)$ , and  $S_{k+1}^2(\alpha=1)$ ] with the restriction that any value of  $\alpha < 10^{-2}$  is ignored. From these four (or less) values of  $S_{k+1}^2(\alpha)$ , find the minimum, compare it with  $S_k^2$ , and perform the termination test equation (85) if  $S_k^2$  is improved. If, however,  $S_k^2$  is still not improved, then either bad data points remain or the initial starting parameters are too far from the ones that minimize  $S^2$ .

After achieving a minimum as determined by equation (87), an error analysis is performed to give an indication of how well the parameters can be determined from the data. The method used is that described by Cohen, Crowe, and Dumond.<sup>3</sup> Their discussion deals only with linear least squares fitting and we have not made a detailed study for the nonlinear case. However, in the neighborhood of the minimum in  $S^2$  the linearization given by equation (81) should be a good approximation. With the above warning the error ( $\sigma_\ell$ ) on the  $\ell^{\text{th}}$  parameter is given by,

$$\sigma_\ell = \sqrt{(A^{-1})_{\ell\ell} \chi^2}, \quad (92)$$

where

$$\chi^2 = S^2/(M-N), \quad (93)$$

which is the chi-squared normalized with the number of degrees of freedom. To be conservative in our error estimate  $\chi^2$  is set equal to one if the fit gives a smaller value.

The other important quantities in the error analysis are the correlation coefficients defined by

$$\rho_{ij} = (A^{-1})_{ij} / \sqrt{(A^{-1})_{ii} (A^{-1})_{jj}} \quad (94)$$

The correlation coefficients are necessary for computing effects of error propagation when using the "best" parameters. Consider a function  $f$  which depends on  $L$  fitted parameters, then the error on  $f$  is given by

$$\sigma_f = \sum_{\ell=1}^L \left( \frac{\partial f}{\partial p_\ell} \right)^2 \sigma_\ell^2 + 2 \sum_{i < j} \rho_{ij} \frac{\partial f}{\partial p_i} \frac{\partial f}{\partial p_j} \sigma_i \sigma_j \quad (95)$$

<sup>3</sup>E. R. Cohen, K. M. Crowe, and J. W. M. Dumond, *Fundamental Constants of Physics*, Interscience Publishers, Inc., New York (1957), Ch. 7.

#### 4.2 Parametrization of an EMP Waveform and its Autocorrelation Function

As simple examples of the use of the program the data of figure 4 has been analyzed in several different ways. The power spectrum of the time series data is shown in figure 5. It is seen that there are two predominant frequencies in the time waveform, 13.2 and 24 MHz. To isolate one of the frequencies (and obtain a less complicated time series), the data of figure 4 were digitally filtered, using a 6-pole low-pass digital filter with a half-power point at 17.5 MHz and a gain at 25 MHz of 0.05. The resulting time series is shown in figure 25. Its power spectrum is shown in figure 26. It is seen from figures 25. and 26 that the time series consists primarily of a sinusoid with frequency of 13.2 MHz. To the time series of figure 25 is fit the following function

$$\phi(t, \vec{P}) = P(1) t \exp(-P(2)t) \sin[P(3)t + P(4)] \quad (96)$$

It took the program five iterations to converge to a solution. The initial estimates and the final fitted parameters are given in table II. A combined plot of the experimental data and the fitted function is shown in figure 27. Generally, the fit is good only in the central portion of the trace and it fails badly at the beginning and end of the trace. This clearly means that equation (96) is not the best representation of this trace.

From the filtered time series of figure 25, the autocorrelation (lagged products) function was formed as displayed in figure 28. The following function was fit to these data.

$$\phi(t, \vec{P}) = P(1) \exp[-P(2)t] \cos[P(3)t] \quad (97)$$

It took the program two iterations to converge to a solution. The initial estimates and the final fitted parameters are given in table III. A combined plot of the data and the fitted functions is shown in figure 29. As can be seen the fit is quite good over the entire trace.

As our third example, the autocorrelation function for the data of figure 4 was calculated and is plotted in figure 30 (no filtering of any kind was done); it was fit by the following function,

$$\phi(t, \vec{P}) = P(1) \exp[-P(2)t] \cos[P(3)t] + P(4) \exp[-P(5)t] \cos[P(6)t] \quad (98)$$

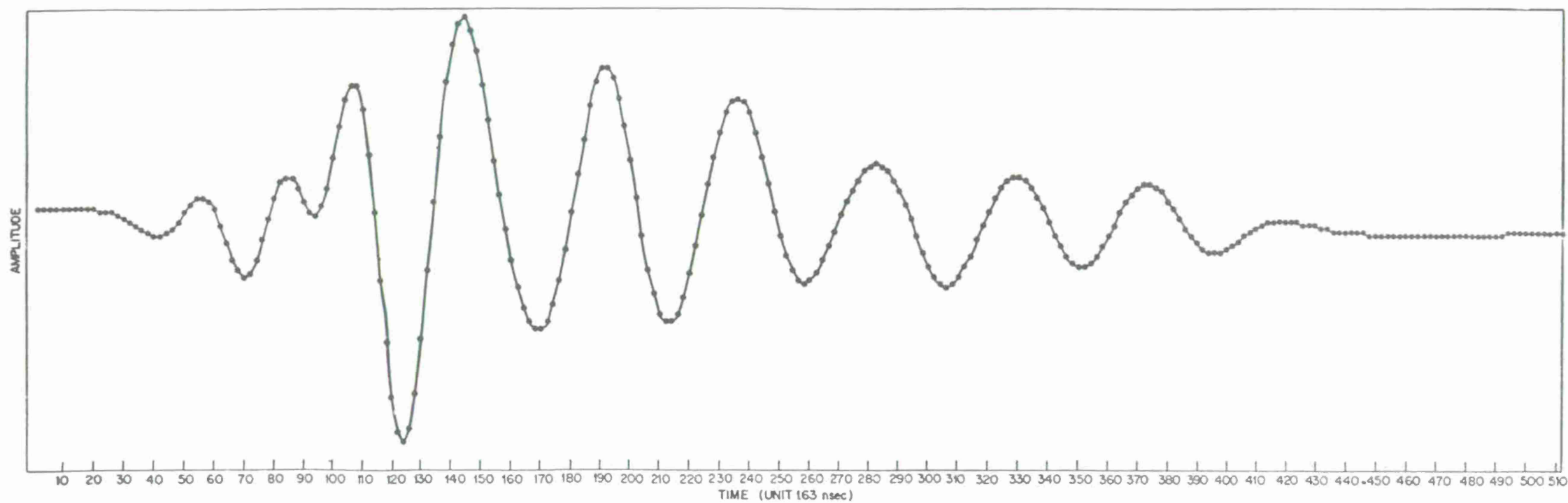


Figure 25. Time series of figure 4 after digital filtering.



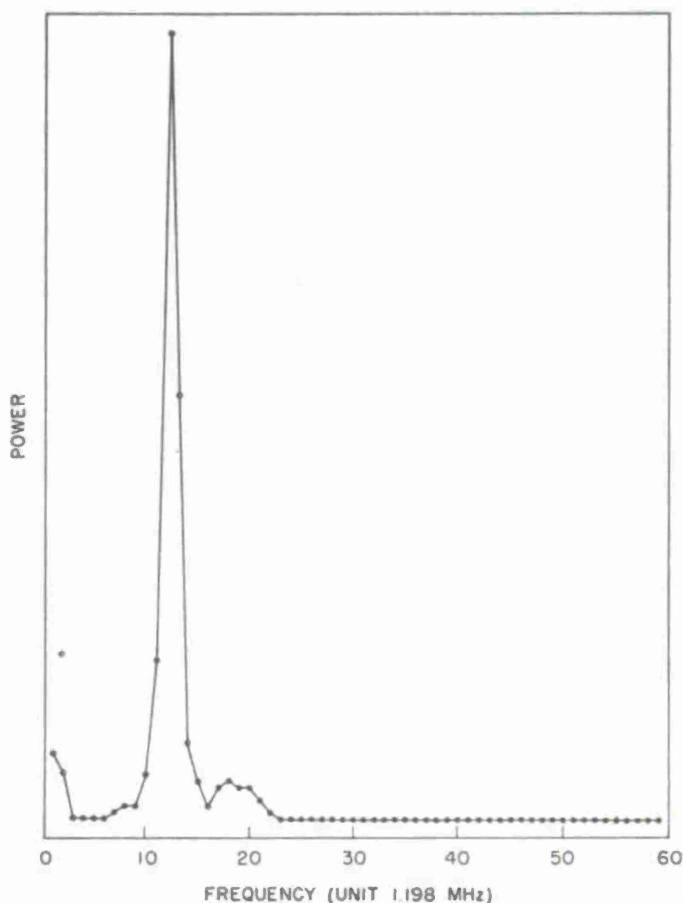


Figure 26. Power spectrum for the time series of figure 6.

It took the program three iterations to converge to a solution. The initial estimate and the final fitted parameters are given in table IV. A combined plot of the experimental data and the fitted function is shown in figure 31. The fit is quite excellent throughout the length of the trace.

Several attempts were made to fit the data of figure 4 with various forms of the functions listed in equation (76). Whenever  $n$  was greater than 2, the fitting procedure either diverged or produced a bad fit.

TABLE II. INITIAL ESTIMATES AND FINAL FITTED PARAMETERS FOR EQUATION (96)  
AND DATA OF FIGURE 25

| Parameter | Initial estimates | Final fitted values |
|-----------|-------------------|---------------------|
| P(1)      | 1.08              | +0.742              |
| P(2)      | 4.27              | +4.958              |
| P(3)      | 90.43             | +84.433             |
| P(4)      | -19.59            | -18.207             |

TABLE III. INITIAL ESTIMATES AND FINAL FITTED PARAMETERS FOR EQUATION (97)  
AND DATA OF FIGURE 28

| Parameter | Initial estimates | Final fitted values |
|-----------|-------------------|---------------------|
| P(1)      | +0.001            | +0.00102            |
| P(2)      | +4.27             | +3.921              |
| P(3)      | +86.35            | +84.196             |

TABLE IV. INITIAL ESTIMATES AND FINAL FITTED PARAMETERS FOR EQUATION (98)  
AND DATA OF FIGURE 30

| Parameter | Initial estimates | Final fitted values |
|-----------|-------------------|---------------------|
| P(1)      | 0.0014            | 0.00108             |
| P(2)      | 3.92              | 4.0289              |
| P(3)      | 84.20             | 84.7402             |
| P(4)      | 0.001             | 0.00148             |
| P(5)      | 3.92              | 9.8083              |
| P(6)      | 147.58            | 146.0411            |

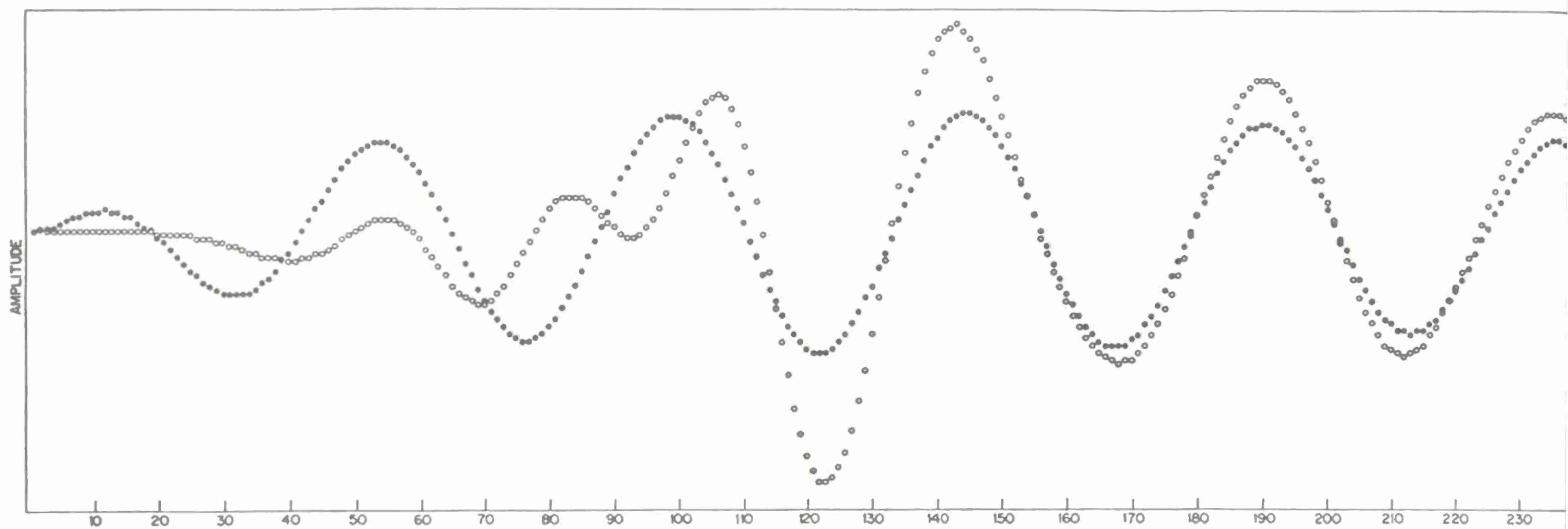
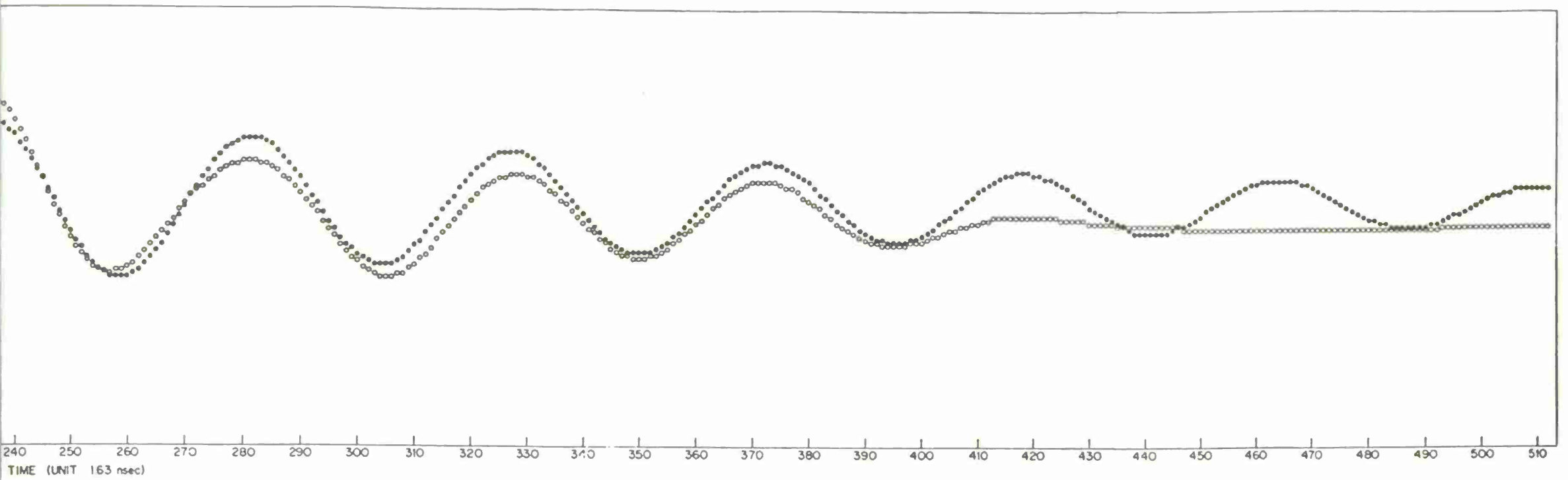


Figure 27. Plot of a least-squares fit of equation (96) to the time series of figure 6.



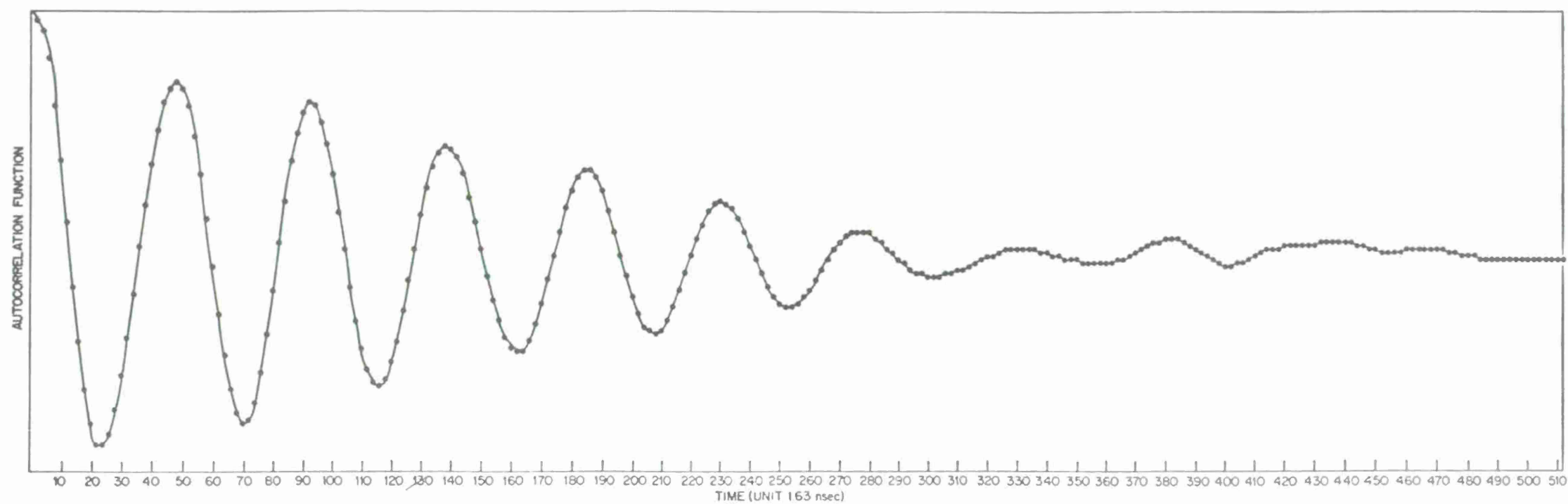


Figure 28. Autocorrelation function for the time series of figure 6.



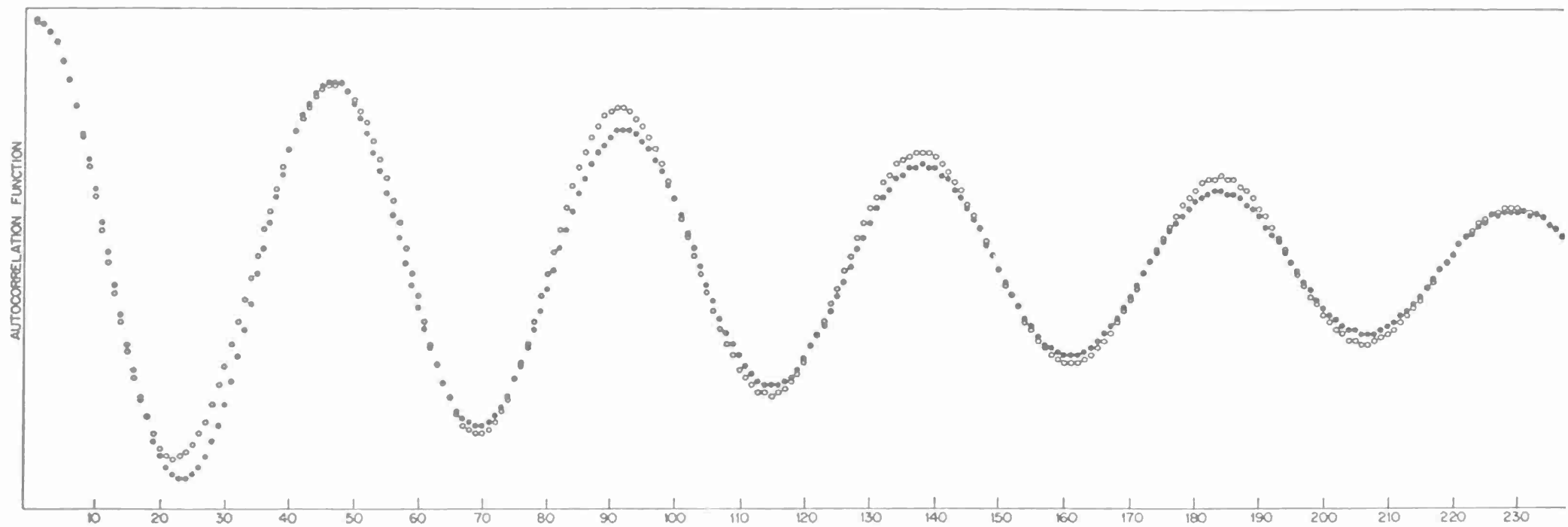
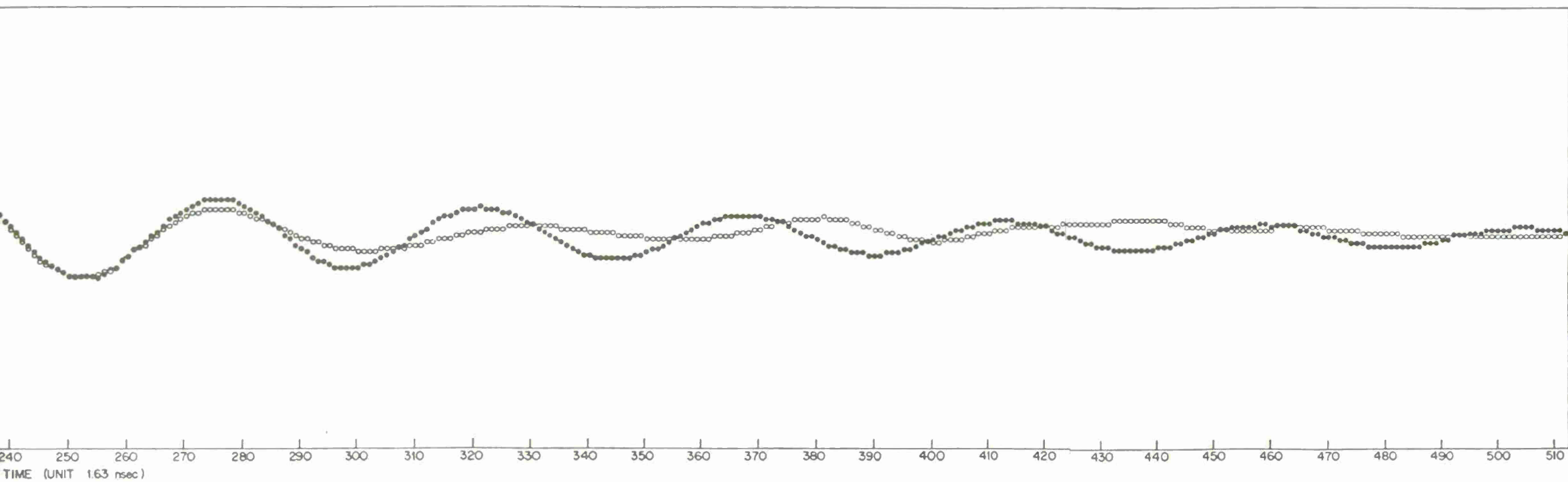


Figure 29. Plot of a least-squares fit of equation (97) to the autocorrelation function of figure 21.



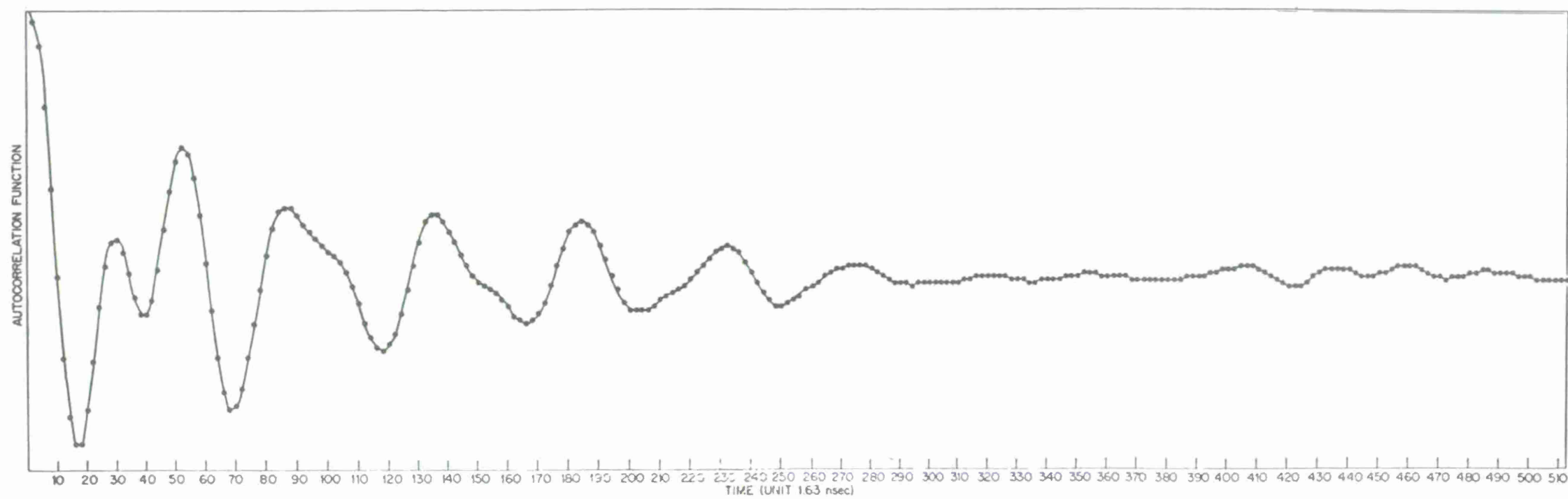


Figure 30. Autocorrelation function for the time series of figure 1.



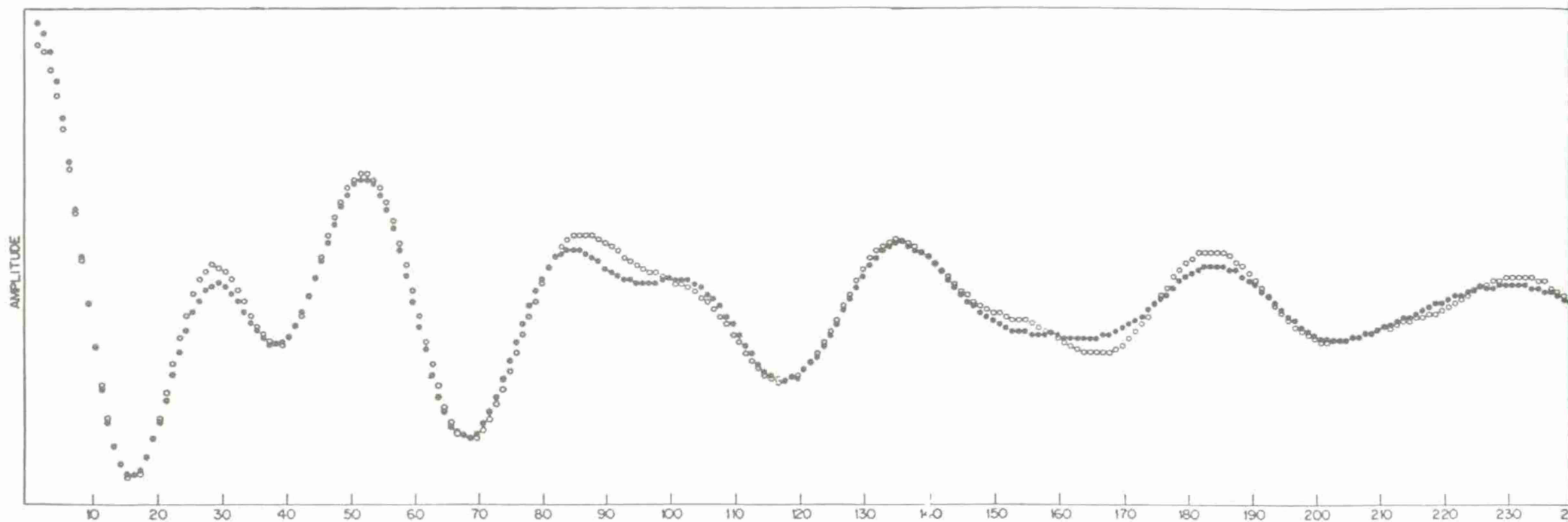
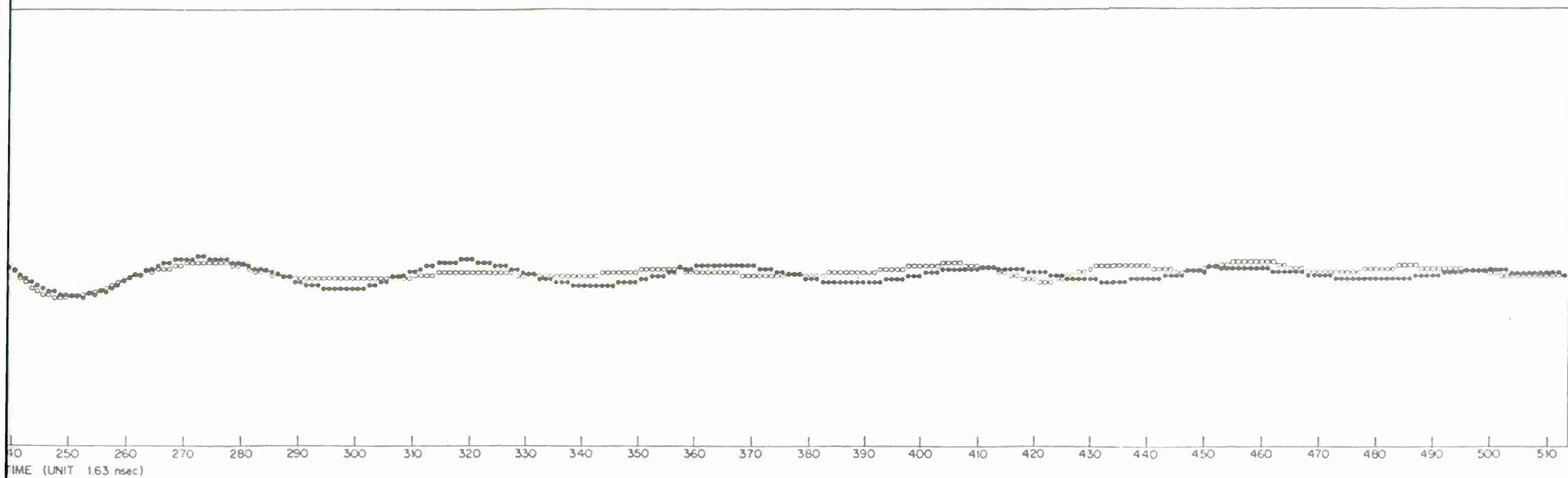


Figure 31. Plot of least-squares fit of equation (98) to the auto-correlation function of figure 11.



It seems clear that before fitting a function to the data (to obtain parametrization) a process such as digital filtering or formation of the autocorrelation function is necessary to isolate the functional dependence (at least the oscillatory part).

Following are parameters to the power spectrum of the record. Since the power spectrum,  $P(\omega)$ , is given by the cosine transform of the autocorrelation function, we have

$$P(\omega) = 2 \int_0^{\infty} \cos \omega t [P(1) \exp\{-P(2)t\} \cos\{P(3)t\} + P(4) \exp\{-P(5)t\} \cos\{P(6)t\}] dt . \quad (99)$$

Thus, after some algebraic manipulation, a power spectrum is given by

$$P(\omega) = \frac{P(1) P(2)}{[\omega - P(3)]^2 + P(2)^2} + \frac{P(4) P(5)}{[\omega - P(6)]^2 + P(5)^2} . \quad (100)$$

It would have been just as easy to fit equation (100) to the power spectrum displayed in figure 5 and thus obtain a parametrization of the data. However, we have used a plot of equation (100) superimposed on the power spectrum of figure 5 as shown in figure 32.

Considering the storage of data, it is concluded that only six numbers must be stored to characterize the pulse instead of thousands. Thus, long-term storage costs are minimized and a high degree of analytical ease is realized in handling large blocks of data.

#### 4.3 Program Listing and Description

The program is written in FORTRAN and consists of eleven subroutines and two user supplied functions; the program names with a description of each are listed below.

- MAIN This routine directly or indirectly calls the rest of the subroutines and thus controls the passage of the program through all the calculations used in the fit.
- READIN This routine reads in all the input parameters and data as well as setting up all the internal control parameters.
- LSQPHI This routine calculates the theoretical function, residuals, and chi square. The user must supply the function PHIFNC(I) for LSQPHI to use.

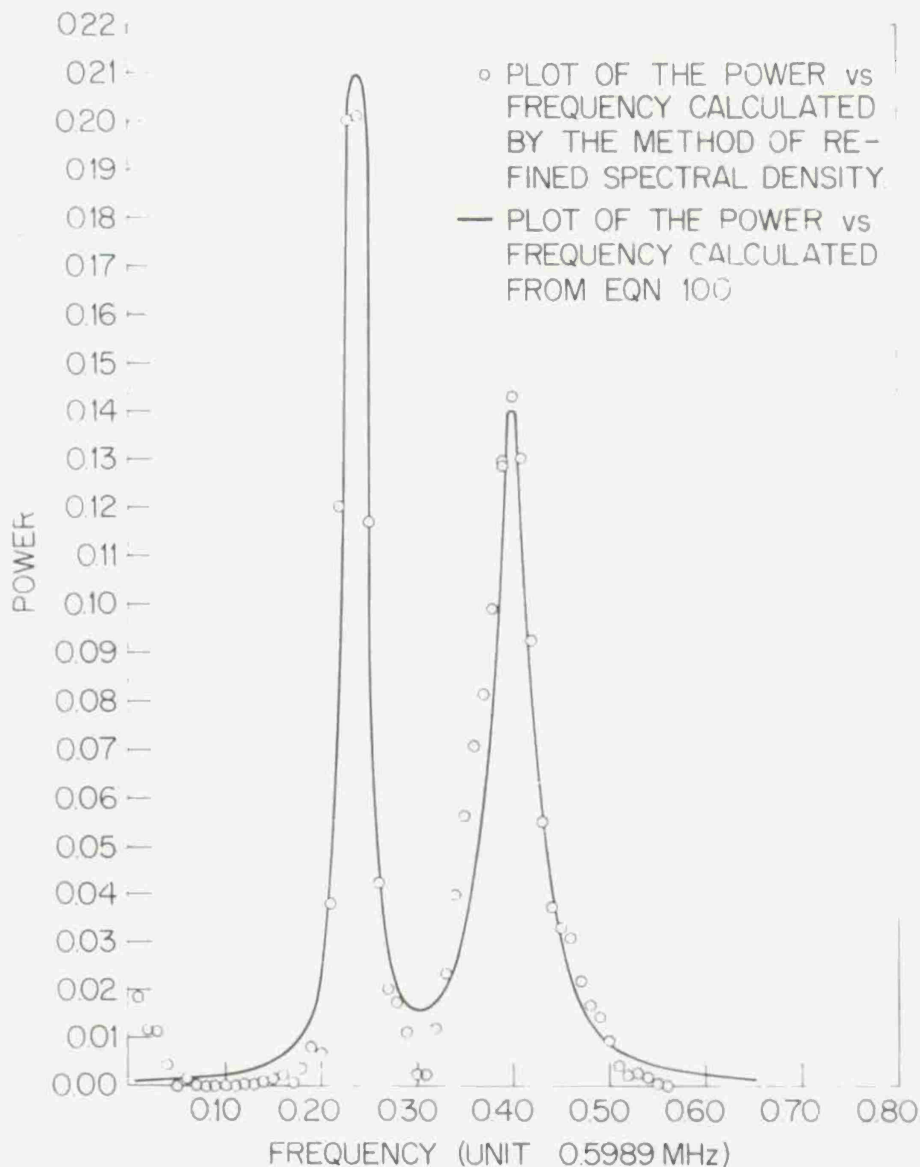


Figure 32. Plot of power spectrum obtained from equation (100) and that obtained from a numerical algorithm.

ELTS(I) This routine calculates all the derivatives of the theoretical function at the  $I^{\text{th}}$  data point. The user must supply the function (DPHI(I)J) for ELTS to call.

GRIND This routine sets up the matrix of derivatives, the constants in the normal equations, then calls the matrix inverter.

TESTS This routine does the necessary testing of the changes in the parameters and performs the necessary changes.

ERRMAT This routine does all the calculations for a full error analysis on the fitted parameters.

CALS2 This routine is called by TESTS repeatedly for the purpose of swapping arrays and computing chi.

INVMAT Inverts a symmetric  $N \times N$  matrix.

SCRIBE This routine writes out all the results of the program fit.

PLOTS Gives a plot of the experimental data and theoretical function on the same graph so that the goodness of the fit can be clearly seen

PHIFNC(I)  $PHIFNC = \phi(X(I), P(1), P(2), \dots, P(N))$

DPHI(I,J)  $DPHI = \frac{d\phi}{dP(J)} (X(I), P(1), P(2), \dots, P(N))$

The flow chart of figure 33 shows the logical connection of the subroutines and functions.

Listed below are the input parameters, their meaning, and their format.

CARD 1 READ JSTOP, FMT FORMAT (I5, 5A4)

JSTOP Maximum number of iterations allowed for each fit. This is used to prevent excessive iterations in case there are errors in the experimental data or control parameters. Usually  $JSTOP \sim 100$ .

FMT The format with which the experimental data are to be read in, e.g., (6E13.7).

NOTE: Card 1 appears once independent of the number of sets of data to be fit.

CARD 2 READ TITLE FORMAT (20A4)

TITLE Any combination of alphanumeric data may appear in columns 1 through 80 to identify the fit.

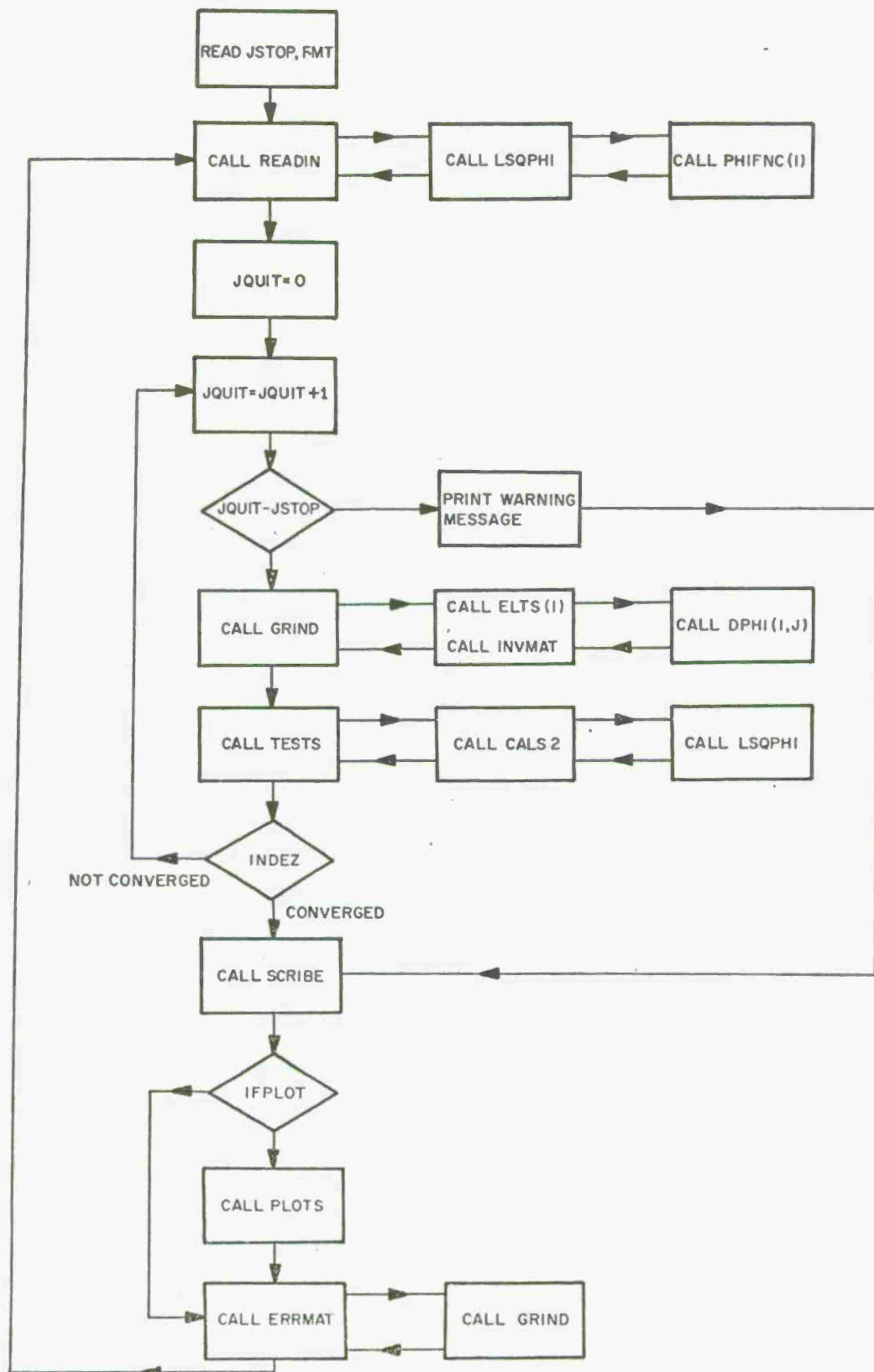


Figure 33. Flow chart of nonlinear least-squares fitting program.

CARD 3 READ NCHAN, NBADPT, NRUNS, NRP, NPSTEP, IFPLOT, IFCOR  
FORMAT (7I5)

NCHAN The number of experimental data points.

NBADPT The number of bad points in the data.

NRUNS The number of sets of experimental data to be added together.

NRP The number of independent parameters.

NPSTEP  $\geq 0$ , used for plotting; that is, every NPSTEP<sup>th</sup> data point is plotted starting with the first (0 is internally set to 1).

IFPLOT = 0 no plot of data and fit  
= 1 gives plot

IFCOR = -1 This prints and punches the correlation coefficients  
= 0 Does not print or punch  
= 1 Only prints

CARD 4 READ (P(I), I=1, NP)

P the array containing the fitted parameters.

CARDS 5 READ (Y(I), I=1, NCHAN) FORMAT (FMT)

Y the array containing the experimental data, one run following another for NRUNS worth of data.

CARDS 6 READ (X(I), I=1, NCHAN) FORMAT (FMT)

X the array containing values of the dependent variable for  $\phi$  and Y; for example,  $\phi(X(I), \vec{P})$ .

CARDS 7 READ (W(I), I=1, NCHAN) FORMAT (FMT)

W the array containing values of the statistical weights for the I<sup>th</sup> data point.

CARDS 8 READ (NBAD(I), I=J, NBADPT)

NBAD Index number of the bad data points in any order.  
These cards do not appear in the data deck if  
NBADPT = 0.

If multiple fits are desired, repeat cards 2 through 8. The program will continue doing fits until it has exhausted all of the input data.

# APPENDIX A. SIGNAL ANALYSIS PROGRAM

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

```

C *****
C
C MAIN PROGRAM FOR THE ANALYSIS OF DIGITAL TIME SERIES
C PROGRAMMER DR. THOMAS A TUMOLILLO
C USAMC HARRY DIAMOND LABORATORIES
C WASHINGTON8D.C. 20438
C
C COMMON VARIABLES DEFINITION
C
C      YVYQA    COMPLEX ARRAY USED TO STORE THE DIGITAL TIME SERIES AT VARIOUS
C               STAGES OF THE ANALYSIS.
C
C      NW      SYMBOLIC DESIGNATOR FOR THE OUTPUT LINE PRINTER
C      NR      SYMBOLIC DESIGNATOR FOR THE INPUT CARD READER
C      NT      SYMBOLIC DESIGNATOR FOR THE OUTPUT CARD PUNCH
C      XF      ARRAY WHICH INITIALLY CONTAINS THE TIME VALUES
C      YF      ARRAY WHICH INITIALLY CONTAINS THE AMPLITUDE VALUES
C      NSTAR   THE NUMBER OF INTERPOLATED POINTS9IT MUST BE A POWER OF TWO
C      NPOW    NSTAR=2**NPOW
C      ND      USED FOR PLOTTING POWER SPECTRA3EVERY ND-TH POINT WILL BE PLOTTED
C      JF      THE NUMBER OF POINTS IN THE INPUT DIGITAL TIME SERIES
C      CT      THE COSINE OF THE ROTATION ANGLE
C      ST      THE SINE OF THE ROTATION ANGLE
C      XJ      X-COORDINATE OF THE GRATICULE ORIGIN
C      YJ      Y-COORDINATE OF THE GRATICULE ORIGIN
C      XS      SCALE FACTOR TABLET INTEGERS/SCALE DIVISION ALONG X AXIS
C      YS      SCALE FACTOR TABLET INTEGERS/SCALE DIVISION ALONG Y AXIS
C      T       SCALE FACTOR NANOSECONDS/SCALE DIVISION
C      V       SCALE FACTOR VOLTS/SCALE DIVISION
C      XVYQ    THE NYQUIST SAMPLING INTERVAL OR THE TIME INTERVAL BETWEEN

```

```

C          BETWEEN DIGITAL VALUES
C      XZ      THE X-COORD OF THE ZERO POINT OF THE TRACE
C      YZ      THE Y-COORD OF THE ZERO POINT OF THE TRACE
C      JD      USED FOR PLOTTING TIME SERIES, EVERY JD-TH POINT WILL BE PLOTTED
C      INTERP  INTERP=0 CALL NYQST,=1 CALL LNYQ
C      IFFFT   IFFFT=0 NO FFT,=1 CALL FFT
C      IFFWAL  IFFWAL=0 NO WALSH TRANSFORM,=1 CALL FWAL
C      IFAUTO  IFAUTO=0 NO FT VIA AUTOCORRELATION,=1 CALL AUTCOR
C      IFGOF   IFGOF=0 CALL FILTER,=1 CALL GNFILT
C      IFPUNF  IFPUNF=1 PUNCH OUT FREQUENCY AND POWER SPECTRA VALUES,=0 DONT
C      IFPUNW  IFPUNW=1 PUNCH OUT SEQUENCY AND WALSH POWER VALUES,=0 DONT
C      FPUNA   IFPUNA=1 PUNCH OUT TIME AND AUTOCORRELATION VALUES,=0 DONT
C      IFPUND  IFPUND=1 PUNCH OUT TIME AND AMPLITUDE VALUES OF INPUT DATA,=0 DON
C      IFPUNI  IFPUNI=1 PUNCH OUT TIME AND INTERPOLATED VALUES,=0 DONT
C      IFPUNR  IFPUNR=1 PUNCH OUT FREQUENCY AND REFINED SPECTRAL DENSITIES,=0DON
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,
1  XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA
NW=6
NR=5
NT=7
READ (NR,1)MTRACE
1  FORMAT(I5)
DO 120 I=1,MTRACE
CALL READIN
CALL CSTOUT
IF (INTERP) 10,10,20
10  CALL NYQST
GO TO 30
20  CALL LNYQ

```

```

30  CALL PLOTS(1)
    CALL SAVE(0)
    NPOWS=NPOW
    NKEEP=NSTAR
    IF(IFGOF) 40,40,50
40  CALL FILTER
    CALL SAVE(1)
    GO TO 60
50  CALL GNFILT
    CALL SAVE(1)
60  CALL PLOTS(4)
    IF(IFFFT) 80,80,70
70  CALL SRTFUR
    CALL FFT
    CALL PLOTS(2)
80  IF(IFAUTO) 100,100,90
90  CALL AUTCOR(1,NKEEP,NPOWS)
100 IF(IFFWAL) 120,120,110
110 CALL UNSAVE(1)
    CALL FWAL
    CALL PLOTS(2)
120 CONTINUE
    STOP
    END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

```
SUBROUTINE READIN
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,
1 XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA
DIMENSION FMT(20),TITLE(20)
READ(NR,1)FMT
1 FORMAT(20A4)
READ(NR,1) TITLE
WRITE(NW,2) TITLE
2 FORMAT(1H1,20X,20A4)
READ(NR,3) NROT,NSTAR,NPOW,ND,JD
3 FORMAT(5I5)
WRITE (NW,13)
13 FORMAT (1X,'NROT NSTAR NPOW ND JD')
WRITE(NW,14) NROT,NSTAR,NPOW,ND,JD
14 FORMAT(14,4I5,/)
READ(NR,3) INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF
WRITE(NW,11)
11 FORMAT(1X,'INTERP IFFFT IFFWAL IFAUTO IFGOF')
WRITE(NW,12)INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF
12 FORMAT(1X,2I6,2I7,16,6I7,/)
READ(NR,8) YSCAL,XSCAL
8 FORMAT(2(2X,E13.7))
WRITE (NW,15)
15 FORMAT(1X,' Y SCALE FACTOR X SCALE FACTOR ')
WRITE (NW,16) YSCAL,XSCAL
16 FORMAT(2(2X,E13.7),/)
WRITE(NW,5)
```

```

5      FORMAT(' IMAGE OF INPUT DATA')
      READ(NR,7) JF
7      FFORMAT(2X,I4)
      READ(NR,FMT) (XF(I),YF(I),I=1,JF)
      DO 100 I=1,JF
      YF(I)=YSCAL*YF(I)
100    XF(I)=XSCAL*XF(I)
      XNYQ=XF(JF)/NSTAR
      WRITE(NW,4) (XF(I),YF(I),I=1,JF)
4      FFORMAT(8(1X,E11.4))
      IF(NROT-1)60,50,50
50     CALL SCARTP
      CALL ROT
      WRITE(NW,5)
6      FFORMAT(/,' SCALED AND ROTATED DATA')
      WRITE(NW,4) (XF(I),YF(I),I=1,JF)
60     RETURN
      END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

```
SUBROUTINE GNFILT
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,X0,Y0,
1 XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNK
COMPLEX YNYQA,U,R,S,ROOT,BETA,UNIT
EQUIVALENCE (ARRAY(1),YNYQA(1))
DIMENSION ARRAY(4096)
DIMENSION STH(40),CTH(40),INOM(40)
DIMENSION U(40),R(20),S(20),ROOT(20),P(20),
1Q(20),PQ(20),A(20),B(20)
```

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

C  
C THIS ROUTINE WILL CALCULATE THE COEFFICIENTS A(J) AND B(J)  
C FOR A BUTTERWORTH LINEAR RECURSIVE FILTER. IF Y(K) AND U(K)  
C ARE THE OUTPUT AND INPUT ARRAYS FOR THE FILTER THEN,

C  
C  $Y(K) = -\text{SUM}(1 \text{ TO } N)(A(J)*Y(K-J)) + \text{SUM}(1 \text{ TO } N+1)(B(J)*U(K-J+1))$

C  
C THE GAIN FACTOR FOR THE BUTTERWORTH FILTER IS GIVEN BY

C  
C  $\text{GAIN} = H(W) / **2 = 1 / (1 + (\text{TAN}(W*T/2) / \text{TAN}(W1*T/2)) ** (2*N))$

C  
C HERE T IS THE SAMPLING INTERVAL, N IS COMPUTED BY SPECIFYING  
C THE HALF POWER POINT W1 AND THE RELATIVE GAIN AT THE POINT  
C  $W=W2>W1$ , AND THE TRANSFER FUNCTION H(Z) IS GIVEN BY THE TWO FORMULAS

C  
C  $H(Z) = \text{SUM}(1 \text{ TO } N+1)(B(J)*Z**(-J+1)) / (1 + \text{SUM}(1 \text{ TO } N)(A(J)*Z**(-J))$

C  
C  $H(Z) = \text{BETA} * (1+Z)**N / (Z-P(1)) * (Z-P(2)) * ... * (Z-P(N)).$

```

C
C HERE THE POLES OF THE FILTER, P(I), ARE GIVEN BY
C
C   P(I)=(1-TAN(ARG)**2+(-1)**95*2*TAN(ARG)*SIN(TH(I)))/
C       (1-2*TAN(ARG)*COS(TH(I))+TAN(ARG)**2)
C WHERE ARG=W1*T/2, TH(I)=(I-1)*PI/N FOR N ODD, =(2*I-1)*PI/2*N
C FOR N EVEN, AND ONLY THOSE N P(I) ARE CHOSEN THAT SATISFY
C /P(I)<1.. THE NORMALIZING FACTOR BETA IS GIVEN BY
C
C   BETA=(1-P(1))*(1-P(2))$...*(1-P(N))/2**N
C
C BY COMPARISON OF THE TWO EXPRESSIONS FOR THE TRANSFER FUNCTION
C THE FILTER COEFFICIENTS A(J) AND B(J) ARE DEDUCED
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PI=3.1415927
C
C READ IN OR COMPUTE THE FREQUENCIES F1 AND F2, THE GAIN AT F2,GW28 AND
C THE SAMPLING INTERVAL
C
      TIME=0.001*XNYQ
      READ(NR,1) F1,F2,GW2
      FORMAT(3E13.7)
      WRITE(NW,2) F1,F2,GW2,TIME
      FORMAT(1H1,' THE HALF POWER POINT IS ',E13.7,'MHZ',/,
1' THE GAIN AT ',E13.7,'MHZ IS',E13.7,/,
2' THE SAMPLING INTERVAL IS ',E13.7,'MICROSECONDS',/)
C
C COMPUTE AND PRINT OUT THE NUMBER OF POLES FOR THIS FILTER
C
      NMAX=10
      ARG1=F1*TIME*PI
      TAG1=TAN(ARG1)

```

```

      ARG2=F2*TIME*PI
      RT=(TAN(ARG2)/TAG1)**2
      TVAL=(1.0-GW2)/GW2
      N=1
      NOE=-1
10    IF(RT**N.GE.TVAL) GO TO 20
      N=N+1
      NOE=-NOE
      IF(N.GT.NMAX) GO TO 25
      GO TO 10
25    WRITE(NW,3) NMAX
3     FORMAT(1X,' THE NUMBER OF POLES FOR THE FILTER EXCEEDED ',/,
1     ' THE ALLOWED LIMIT OF ',I5)
      STOP

C
C COMPUTE ALL THE 2*N POLES WHICH ARE EITHER INSIDE OR OUTSIDE THE
C UNIT CIRCLE
C
20    TWON=2*N
      ITWON=TWON
      EN=N
      WRITE(NW,4)
      WRITE(NW,5)
      DO 40 I=1,ITWON
      IF(NOE.EQ.1) GO TO 30
      TH=(I-1)*PI/EN
      GO TO 35
30    TH=(2*I-1)*PI/TWON
35    CTH(I)=COS(TH)
      STH(I)=SIN(TH)
40    CONTINUE
      R1=1-TAG1**2
      R2=2*TAG1
      D1=1+TAG1**2

```

```

      K=0
      DO 50 I=1,ITWON
      DENOM=D1-R2*CTH(I)
      P(I)=R1/DENOM
      Q(I)=R2*STH(I)/DENOM
      PQ(I)=P(I)**2+Q(I)**2
      WRITE(NW,6) I,P(I),Q(I),PQ(I)
C
C SELECT ONLY THOSE POLES WHICH ARE INSIDE THE UNIT CIRCLE
C
      IF(PQ(I).GT.1.0) GO TO 50
      K=K+1
      ROOT(K)=CMPLX(P(I),Q(I))
50    CONTINUE
      5    FORMAT(1H/,'INDEX',5X,'REAL PART',5X,'IMAG PART',8X,'SQUARE')
      4    FORMAT(1H/,20X,'FILTER POLE LOCATIONS')
      6    FORMAT(1X,I5,3(1X,E13.7))
      IF(K.EQ.N) GO TO 60
      WRITE(NW,7) K,ITWON
      7    FORMAT(1H/,' ONLY',I3,' POLES OUT OF',I3,' ARE INSIDE UNIT CIRCLE'
1,/,1X,' PROGRAM EXECUTION HALTED')
      STOP
C
C COMPUTE BETA
C
60    BETA=CMPLX(1.0,0.0)
      UNIT=BETA
      DO 70 I=1,N
      70    BETA=BETA*(UNIT-ROOT(I))/2.0
C
C COMPUTE THE BINOMIAL COEFFICIENTS
C
      INOM(1)=1
      NP1=N+1

```

```

      DO 75 I=2,NP1
75    INOM(I)=((N-I+2)*INOM(I-1))/(I-1)
      WRITE(NW,14) N
14    FORMAT(' BINOMIAL COEFFICIENTS FOR (1+Z)**',I2,/,
1' INDEX COEFFICIENT')
      WRITE(NW,15) (I,INOM(I),I=1,NP1)
15    FORMAT(4X,I2,7X,I4)
      C
      C COMPUTE THE DIGITAL FILTER COEFFICIENTS
      C
      IF(N-2)80,90,100
80    U(1)=-ROOT(1)
      GO TO 125
90    U(3)=CMPLX(1.0,0.0)
      U(2)=-ROOT(1)-ROOT(2)
      U(1)=ROOT(1)*ROOT(2)
      GO TO 125
100   U(1)=ROOT(1)*ROOT(2)
      U(2)=-ROOT(1)-ROOT(2)
      U(3)=CMPLX(1.0,0.0)
      L=3
      R(2)=CMPLX(1.0,0.0)
      DO 120 K=3,N
      R(1)=-ROOT(K)
      DO 110 I=1,L
110   S(I)=U(I)
      CALL POLMLT(2,R,L,S,LR,U)
      L=LR
120   CONTINUE
125   WRITE(NW,8)
      8    FORMAT(1H/, ' INDEX',5X,'REAL A(I)',5X,'IMAG A(I)')
      DO 130 I=1,N
      IS=N+1-I
      RA=REAL(U(IS))

```

```

      A(I)=RA
      AA=AIMAG(U(I))
130  WRITE(NW,9) I,RA,AA
9    FORMAT(1X,I6,2(1X,E13.7))
      NP1=N+1
      WRITE(NW,11)
11   FORMAT(1H/, ' INDEX',5X,'REAL B(I)',5X,'IMAG B(I)')
      NP2=N+2
      DO 140 I=1,NP1
      NR=NP2-I
      SHIT=INOM(NR)
      S(I)=CMPLX(SHIT,0.0)*BETA
      RB=REAL(S(I))
      B(I)=RB
      BB=AIMAG(S(I))
140  WRITE(NW,9) I,RB,BB
C
C  DIGITALLY FILTER THE INPUT TIME SERIES
C
      DO 170 K=1,NSTAR
      Z=0.0
      DO 150 J=1,NP1
      IND=K-J+1
      IF(IND.LE.0) GO TO 155
      Z=Z+B(J)*AIMAG(YNYQA(IND))
150  CONTINUE
155  DO 160 J=1,N
      IND=K-J
      IF(IND.LE.0) GO TO 165
      Z=Z-A(J)*REAL(YNYQA(IND))
160  CONTINUE
165  X=AIMAG(YNYQA(K))
      YNYQA(K)=CMPLX(Z,X)
170  CONTINUE

```

```
      DO 180 K=1,NSTAR
      X=REAL(YNYQA(K))
180    YNYQA(K)=CMPLX(X,0.0)
      NS2=2*NSTAR
C
C PRINT OUT AND PLOT THE FILTERED TIME SERIES
C
      WRITE(NW,12)
      WRITE(NW,13) (ARRAY(I),I=1,NS2,2)
12    FORMAT(' FILTERED TIME SERIES')
13    FORMAT(9(1X,E13.7))
      RETURN
      END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

SUBROUTINE FILTER

C THIS IS A RECURSIVE FILTER ROUTINE WHERE NP IS THE NUMBER OF POLES, A  
C AND B ARE THE FILTER COEFFICIENTS,  
C AIMAG(YNYQA) IS THE INPUT ARRAY,  
C REAL(YNYQA) IS THE OUTPUT ARRAY  
C REAL(YNYQA(I))=SUMB(J)\*AIMAG(YNYQA(I-J+1)) - SUMA(J)\*REAL(YNYQA(I-J)).  
C FOR NO FILTERING SET B(1)=1,B(K)=0,K.NE.1;A(K)=0 ALL K.  
COMMON YNYQA(2048)  
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,  
1 XS,YS,T,V,XNYQ  
2,NT,XZ,YZ,JD  
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
1IFPUND,IFPUNI,IFPUNR  
COMPLEX YNYQA  
DIMENSION ARRAY(4096)  
DIMENSION A(10),B(10)  
EQUIVALENCE (ARRAY(1),YNYQA(1))  
READ(NR,3) NP  
3 FORMAT(I5)  
READ(NR,4) (A(K),K=1,NP)  
NP1=NP+1  
READ(NR,4) (B(K),K=1,NP1)  
4 FORMAT(5(2X,E13.7))  
WRITE(NW,101)  
101 FORMAT(1H1,' FILTER COEFFICIENTS')  
WRITE(NW,102) (K,A(K),K,B(K),K=1,NP)  
102 FORMAT(1X,'A(',I2,')=',E13.7,'B(',I2,')=',E13.7)  
WRITE(NW,103) NP1,B(NP1)  
103 FORMAT(21X,'B(',I2,')=',E13.7)  
C DIGITALLY FILTER THE INPUT TIMESERIES  
C  
DO 170 K=1,NSTAR

APPENDIX A

```

      Z=0.0
      DO 150 J=1,NP1
        IND=K-J+1
        IF(IND.LE.0) GO TO 155
        Z=Z+B(J)*AIMAG(YNYQA(IND))
150    CONTINUE
155    DO 160 J=1,NP
        IND=K-J
        IF(IND.LE.0) GO TO 165
        Z=Z-A(J)*REAL(YNYQA(IND))
160    CONTINUE
165    X=AIMAG(YNYQA(K))
        YNYQA(K)=CMPLX(Z,X)
170    CONTINUE
        DO 180 K=1,NSTAR
          X=REAL(YNYQA(K))
180    YNYQA(K)=CMPLX(X,0.0)
      C
      C PRINT OUT THE FILTERED TIME SERIES
      C
        NS2=2*NSTAR
        WRITE(NW,12)
        WRITE(NW,13) (ARRAY(I),I=1,NS2,2)
12    FORMAT(30X,' FILTERED TIME SERIES',/)
13    FORMAT(8(1X,E13.7))
        RETURN
      END

```

' ( JAN 73 )

OS/360 FORTRAN H

```

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF
      SUBROUTINE LNYQ
      COMMON YNYQA(2048)
      COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,X0,Y0,
1     XS,YS,T,V,XNYQ
2     NT,XZ,YZ,JD
      COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
      LIEPUND,IFPUNI,IFPUNR
      COMPLEX YNYQA
      DIMENSION XOUT(4),YOUT(4)
C THIS ROUTINE INTERPOLATES AT THE NYQUIST INTERVALS
C USING A STRAIGHT LINE AS THE INTERPOLATING POLYNOMIAL
C IF XF(I-1)<X<XF(I) THEN THE INTERPOLATED VALUE
C IS Y WHERE Y=C1*X+C2 WITH
C C1=(YF(I)-YF(I-1))/(XF(I)-XF(I-1))
C C2=(YF(I-1)*XF(I)-YF(I)*XF(I-1))/(XF(I)-XF(I-1))
      IFLAG=-1
      L=1
      I=1
20     IF(XF(I).GE.0)GO TO 30
      I=I+1
      IF(I-JF)20,150,150
30     JST=I
      YNYQA(L)=CMPLX(0.0,YF(I))
40     X=XF(JST)+L*XNYQ
90     IF(X-XF(I))100,130,140
100    IFLAG=IFLAG+1
110    DENOM=XF(I)-XF(I-1)
      C1=(YF(I)-YF(I-1))/DENOM
      C2=(YF(I-1)*XF(I)-YF(I)*XF(I-1))/DENOM
115    Y=C1*X+C2
116    L=L+1
      IF(L-NSTAR)120,120,150

```

APPENDIX A

```

120  YNYQA(L)=CMPLX(0.0,Y)
      GO TO 40
130  Y=YF(I)
      GO TO 116
140  IFLAG=-1
      I=I+1
      IF(I-JF)90,90,145
145  I=JF
      GO TO 110
150  WRITE(NW,3)
      WRITE(NW,1)
      DO 160 K=1,NSTAR,4
      DO 155 J=1,4
      JP=J+K-1
      XOUT(J)=XF(JST)+(JP-1)*XNYQ
155  YOUT(J)=AIMAG(YNYQA(JP))
      WRITE(NW,2)((XOUT(L),YOUT(L)),L=1,4)
160  CONTINUE
2    FORMAT(8(2X,E13.7))
1    FORMAT(4(11X,'TIME',6X,'INTERP. Y'))
3    FORMAT(11H,20X,'LISTING OF THE LINEARLY INTERPOLATED TIME SERIES')
      RETURN
      END

```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINENR=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

SUBROUTINE NYQST

C NYQST TAKES NON-EQUI SPACED ARRAY YF,XF AND PRODUCES AN EQUISPACED COMPLEX  
C ARRAY YNYQA. INITIALLY RE(YNYQA) =0 AND IM(YNYQA)=INTERPOLATED VALUES  
C EQUISPACED ARRAY.  
C YF(I), I=1,JF GIVEN AS V/DIV  
C XF(I), I=1,JF GIVEN AS NS/DIV  
C XNYQ IS THE NYQUIST TIME INTERVAL IN NS/DIV  
C NSTAR = 2\*\*NPOW IS GIVEN  
C  
C INITIALIZE VALUES  
C  
    DIMENSION XOUT(4),YOUT(4)  
    COMMON YNYQA(2048)  
    COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,C1,ST,X0,Y0,  
1    XS,YS,T,V,XNYQ  
2    NT,XZ,YZ,JD  
    COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
11FPUND,IFPUNV,IFPUNR  
    COMPLEX YNYQA  
    DIMENSION A(4,4),B(4)  
    LTSAV=0  
    LBSAV=0  
    ISAV=0  
    L=1  
    IST=1  
  
C  
C SEARCH FOR FIRST XF > 0  
C  
20 IF(XF(IST).GE.0)GO TO 30  
    IST=IST+1  
    IF(IST - JF) 20,150,150  
30 JSTRT=IST

```

YNYQA(L)=CMPLX(0.0,YF(JSTRT))
I=JSTRT
70 XVAL=XF(JSTRT) + L*XNYQ
75 IF(XF(I).GT.XVAL)GO TO 80
    I=I+1
    IF(I - JF) 75,115,75
80 LT=I+1
    LB=I-2
    IF(LB .LE. JSTRT)GO TO 110
    I=I-1
85 L=L+1
C
C CHECK IF BOUNDS ARE SAME AS LAST TIME
C
    IF(LT.EQ.LTSAV .AND. LB.EQ.LBSAV .AND. I.EQ.ISAV)GO TO 100
C
C NEW BOUNDS
C
    LTSAV=LT
    LBSAV=LB
    ISAV=I
    IF(L - NSTAR) 95,95,120
C
C FIT THE FOUR POINTS TO A CUBIC
C
95 CALL LSQPOL(A,B,2,LB,LT)
    DENOM=A(1,1)*A(2,2)-A(1,2)**2
    T1=A(2,2)*B(1)-A(1,2)*B(2)
    T2=A(1,2)*B(1)-A(1,1)*B(2)
    B(1)=T1/DENOM
    B(2)=-T2/DENOM
100 YVYQA(L)=CMPLX(0.0,POLY(B,2,XVAL))
    IF(L-NSTAR)70,120,120

```

```

C      NEAR BEGINNING OF TRACE
C
110    LB=JSTRT
        LT=LB+3
        I=LB
        GO TO 85

C
C      NEAR END OF TRACE
C
115    LB=JF-3
        LT=JF
        I=I-1
        GO TO 85

150    WRITE(NW,1)
1      FORMAT(1X,' ALL TIMES ARE NEGATIVE')
        STOP

120    WRITE(NW,3)
        WRITE(NW,4)
        DO 200 K=1,NSTAR,4
        DO 190 J=1,4
            IND=K+J-1
            XOUT(J)=XF(JSTRT)+(IND-1)*XNYQ
190    YOUT(J)=AIMAG(YNYQA(IND))
        WRITE(NW,2)((XOUT(L),YOUT(L)),L=1,4)

200    CONTINUE
2      FORMAT(8(2X,E13.7))
3      FORMAT(1H1,'LISTING OF LEAST SQUARES INTERPOLATED TIME SERIES')
4      FORMAT(4(11X,'TIME',6X,'INTERP. Y'))
        RETURN
        END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF
SUBROUTINE AUTCOR(K,NSAVE,NPSAV)
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,
1  XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA
DIMENSION FREQ(2048),POWER(2048),ZF(2048),OUT(8)
DIMENSION ARRAY(4096)
EQUIVALENCE (ARRAY(1),YNYQA(1))
EQUIVALENCE (FREQ(1),ZF(1)),(POWER(1),XF(1))
WRITE(NW,1)
1  FORMAT('1 LISTING OF THE AUTOCORRELATION FUNCTION')
PI=3.1415927
C
C COMPUTE AND PRINT OUT THE VALUES OF NSAVE,M,AND IH
C
      KML=K-1
      IH=1
      M=NSAVE-NSAVE*KML/10
      NSTAR=M
      WRITE(NW,1001) NSAVE,IH,M
C
C COMPUTE DTAU=IH*XNYQ
C
      DTAU=IH*XNYQ
1001  FORMAT(' THERE ARE',I3,' VALUES IN THE DIGITAL TIME SERIES',/,
1' THE LAG INTERVAL IS DTAU=IH*DT WHERE IH=',I3,/, 'THERE ARE',I3,'
2VALUES IN THE DIGITAL AUTOCORRELATION FUNCTION',/)
C
C COMPUTE THE AUTOCORRELATION FUNCTION AND STORE IT IN THE ARRAY XF
```

```

C
      DO 30 IR=1,M
      SUM=0.0
      INMHR=NSAVE-IH*(IR-1)
      DO 20 IQ=1,INMHR
      IMESS=IQ+IH*(IR-1)
20    SUM=SUM+YF(IQ)*YF(IMESS)
      SUM=SUM/INMHR
      XF(IR)=SUM
30    CONTINUE
C
C PRINT OUT AND PLOT THE AUTOCORRELATION FUNCTION
C
      WRITE(NW,5)
5     FORMAT(1X,4(10X,'TIME',7X,'AUTOCOR'))
      DO 35 I=1,M
35    YNYQA(I)=CMPLX(XF(I),0.0)
      XNYSV=XNYQ
      XNYQ=DTAU
      DO 37 I=1,M,4
      DO 36 J=1,4
      OUT(2*J-1)=XNYQ*(I-I+J-1)
36    OUT(2*J)=XF(I+J-1)
      WRITE(NW,4) (OUT(L),L=1,8)
69    FORMAT(4(7X,E13.7))
4     FORMAT(1X,8(1X,E13.7))
37    CONTINUE
      CALL PLOTS(4)
      XNYQ=XNYSV
C
C COMPUTE THE RAW SPECTRAL DENSITY ESTIMATES AND STORE THEM
C IN THE ARRAY ZF.
C
      DO 50 IR=1,M

```

```

      IPO=IR-1
      SUM=XF(1)+XF(M)*(-1.)**IPO
      MM1=M-1
      DO 40 IQ=2,MM1
40      SUM=SUM+2.0*XF(IQ)*COS(PI*((IQ-1)*(IR-1)/M)
      ZF(IR)=DTAU*SUM
50      CONTINUE
C
C COMPUTE THE REFINED SPECTRAL DENSITIES AND STORE THEM IN THE
C ARRAY XF
C
      XF(1)=0.54*ZF(1)+0.23*ZF(2)
      XF(M)=0.23*ZF(M-1)+0.54*ZF(M)
      DO 60 I=2,MM1
60      XF(I)=0.23*ZF(I-1)+0.54*ZF(I)+0.23*ZF(I+1)
      DO 70 I=1,M
70      ZF(I)=(I-1)/(2*M*DTAU)
C
C PRINT OUT AND PLOT THE REFINED SPECTRAL DENSITIES
C
      WRITE(NW,7)
7      FORMAT('1REFINED SPECTRAL DENSITY ESTIMATES FOR THE AUTOCORRELATIO
IN FUNCTION')
      WRITE(NW,3)
3      FORMAT(1H/,4(5X,'FREQUENCY',9X,'POWER'),/)
      DO 80 I=1,M,4
80      WRITE(NW,4) (FREQ(I+J-1),POWER(I+J-1),J=1,4)
      NSTAR=2*M
      XNYSV=XNYQ
      XNYQ=DTAU
      DO 90 I=1,M
90      YNYQA(I)=CMPLX(POWER(I),0.0)
      CALL PLOTS(2)
      XNYQ=XNYSV
      NSTAR=NSAVE
      RETURN
      END

```

' ( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

SUBROUTINE FFT

C  
C THIS ROUTINE CALCULATES THE FOURIER TRANSFORM OF A NYQUIST SAMPLED ARRAY  
C THAT HAS ITS ELEMENTS IN BIT REVERSED ORDER. THE TECHNIQUE IS GENERALLY  
C KNOWN AS THE FAST FOURIER TRANSFORM.

C

COMMON YNYQA(2048)

COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,

1 XS,YS,T,V,XNYQ

2,VT,XZ,YZ,JD

COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,

1IFPUND,IFPUNI,IFPUNR

COMPLEX YNYQA,W,WE,FACTOR,SWAP,ZIP,S

TP1=6.2831854

DO 40 I=1,NPOW

TI=2\*\*I

ARG=TP1/TI

S=CMPLX(COS(ARG),SIN(ARG))

IM1=I-1

I1=2\*\*IM1

KSTOP=I1+1

K=1

W=CMPLX(1.0,0.0)

20 SWAP=YNYQA(K)

KP11=K+I1

FACTOR=YNYQA(KP11)\*W

YNYQA(K)=SWAP+FACTOR

YNYQA(KP11)=SWAP-FACTOR

K=K+1

W=W\*S

IF (K-KSTOP)20,30,20

30 K=KP11+1

101

APPENDIX A

```

      KSTOP=K+11
      W=CMPLX(1.0,0.0)
      IF(KSTOP.LE.NSTAR) GO TO 20
40    CONTINUE
      DELF=1./(NSTAR*XNYQ)
      WRITE(NW,1)
      XSQ=XNYQ**2
      DO 50 I=1,NSTAR,ND
      ZIP=YNYQA(I)
      RZIP=REAL(ZIP)
      AIZIP=AIMAG(ZIP)
      FREQ=(I-1)*DELF
      PWR=(RZIP**2+AIZIP**2)*XSQ
      PHS=ATAN(AIZIP/RZIP)
      WRITE(NW,2)FREQ,RZIP,AIZIP,PWR,PHS
      YNYQA(I)=CMPLX(PWR,PHS)
50    CONTINUE
1    FORMAT(1H1,'      FREQUENCY      REAL F(W)      IMAG F(W)      POW
1ER      PHASE')
2    FORMAT(5(1X,E13.7))
      RETURN
      END

```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE FWAL

C  
C THIS ROUTINE CALCULATES WALSH TRANSFORMS OF A NYQUIST  
C SAMPLED ARRAY. THE TECHNIQUE IS GENERALLY KNOWN AS THE FAST WALSH TRANSFORM.  
C

```
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,
1  XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA
DO 10 I=1,NSTAR
XF(I)=REAL(YNYQA(I))
10 YF(I)=0.0
DO 40 I=1,NPOW
IM1=I-1
I1=2**IM1
KSTOP=I1+1
L=1
K=1
J=0
W=1.0
20 S1=XF(K)
KPI1=K+I1
S2=XF(KPI1)
SW2=S2*W
INDEX=J/2
SIG=(-1)**INDEX
YF(L)=(S1+SW2)*SIG
YF(L+1)=(-S1+SW2)*SIG
K=K+1
```

```

J=J+1
L=L+2
W=-W
IF(K-KSTOP)20,30,20
30 K=KPI1+1
KSTOP=K+11
J=0
W=1
IF(KSTOP.LE.NSTAR) GO TO 20
DO 35 IZX=1,NSSTAR
XF(IZX)=YF(IZX)
35 YF(IZX)=0.0
40 CONTINUE
DELF=1./(NSTAR*XNYQ)
WRITE(NW,1)
WRITE(NW,2)
NSM1=NSTAR-1
G=XF(1)**2
L=0
YNYQA(L+1)=CMPLX(G,0.0)
WRITE(NW,3) L,XF(1),G
DO 50 I=2,NSM1,2
L=L+1
AS=XF(I)
AC=XF(I+1)
G=AS**2+AC**2
YNYQA(L+1)=CMPLX(G,0.0)
50 WRITE(NW,4) L,AS,AC,G
L=L+1
G=XF(NSTAR)**2
YNYQA(L+1)=CMPLX(G,0.0)
WRITE(NW,5) L,XF(NSTAR),G
1 FORMAT(1H1,' OUTPUT OF THE WALSH TRANSFORM')
2 FORMAT('      I',9X,'AS(I)',9X,'AC(I)',10X,'G(I)')

```

```
3  FORMAT(1X,I5,14X,2(1X,E13.7))
4  FORMAT(1X,I5,3(1X,E13.7))
5  FORMAT(1X,I5,1X,E13.7,15X,E13.7)
   RETURN
   END
```

```

COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=57,SIZE=0000K,
                     SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF
SUBROUTINE INVMAT(A,B,N,PIVOT,INV)
DIMENSION A(4,4),B(4),INDEX(4,2),IPIVOT(4)
EQUIVALENCE (JROW,IROW),(JCOLUMN,ICOLUMN),(AMAX,SWAP,T)

```

```
C
C      MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
C      INITIALIZATION
C
C      DO 10 I=1,N
C          IPIVOT(I)=0
C      CONTINUE
C
C      DO 100 I=1,N
C
C          SEARCH FOR PIVOT ELEMENT
C
C              AMAX=0.0
C              DO 40 J=1,N
C                  IF(IPIVOT(J).EQ.1) GO TO 40
C                  DO 30 K=1,N
C                      IF(IPIVOT(K)-1)20,30,130
C                      IF(ABS(AMAX).GT.ABS(A(J,K))) GO TO 30
C                      IROW=J
C                      ICOLUM=K
C                      AMAX=A(J,K)
C                  CONTINUE
C              CONTINUE
C              IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C          INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
```

```

        IF(IROW.EQ.ICOLUMN) GO TO 60
        DO 50 J=1,N
            SWAP=A(IROW,J)
            A(IROW,J)=A(ICOLUMN,J)
            A(ICOLUMN,J)=SWAP
50      CONTINUE
        SWAP=B(IROW)
        B(IROW)=B(ICOLUMN)
        B(ICOLUMN)=SWAP
        PIVOT=A(ICOLUMN,ICOLUMN)
        INDEX(I,2)=ICOLUMN
60      INDEX(I,1)=IROW
        IF(PIVOT.EQ.0.0) GO TO 130
C
C      DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
        A(ICOLUMN,ICOLUMN)=1.0
        DO 70 J=1,N
            A(ICOLUMN,J)=A(ICOLUMN,J)/PIVOT
70      CONTINUE
        B(ICOLUMN)=B(ICOLUMN)/PIVOT
C
C      REDUCE NON-PIVOT ROWS
C
        DO 90 J=1,N
            IF(J.EQ.ICOLUMN) GO TO 90
            T=A(J,ICOLUMN)
            A(J,ICOLUMN)=0.0
            DO 80 K=1,N
                A(J,K)=A(J,K)-A(ICOLUMN,K)*T
80      CONTINUE
            B(J)=B(J)-B(ICOLUMN)*T
90      CONTINUE
100     CONTINUE

```

```
C
C   INTERCHANGE COLUMNS
C
DO 120 I=1,N
    J=N+1-I
    IF(INDEX(J,1).EQ.INDEX(J,2)) GO TO 120
    JROW=INDEX(J,1)
    JCOLUMN=INDEX(J,2)
    DO 110 K=1,N
        SWAP=A(K,JROW)
        A(K,JROW)=A(K,JCOLUMN)
        A(K,JCOLUMN)=SWAP
110    CONTINUE
120    CONTINUE
130    RETURN
      END
```

' ( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,LD,NOXREF  
SUBROUTINE LSQPOL(A,B,N,LB,LT)

C  
C THIS ROUTINE CALCULATES THE MATRIX A AND VECTOR B WHICH ARE USED TO SOLVE FOR  
C THE VECTOR X IN THE EQUATION  $A \cdot X = B$ . THE VECTOR X HAS ELEMENTS WHICH CORRESPOND  
C TO THE POLYNOMIAL COEFFICIENTS IN  $SUMCOEFF(I) \cdot Z^{**I}$ . THE COEFFICIENTS ARE  
C DETERMINED IN A LEAST SQUARES SOLUTION OF THE POLYNOMIAL TO SOME DATA.  
C

COMMON YNYQA(2048)  
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,  
1 XS,YS,T,V,XNYQ  
2,NT,XZ,YZ,JD  
COMPLEX YNYQA  
DIMENSION A(4,4),B(4),C(10)  
LQ=2\*N-1  
NPTS=LT-LB+1  
DO 10 I=1,N  
B(I)=0.0  
DO 10 J=1,N  
10 A(I,J)=0.0  
DO 5 L=1,LQ  
5 C(L)=0.0  
C(1)=NPTS  
DO 15 I=LB,LT  
DO 13 K=1,N  
KML=K-1  
IF(XF(I).EQ.0.0.AND.KML.EQ.0) GO TO 113  
B(K)=B(K)+YF(I)\*(XF(I)\*\*KML)  
GO TO 13  
113 B(K)=B(K)+YF(I)  
13 CONTINUE  
DO 14 L=2,LQ  
LML=L-1

```
14 C(L)=C(L)+XF(I)**LM1
15 CONTINUE
   DO 20 K=1,N
     KM1=K-1
     DO 20 KP=K,N
       A(K,KP)=C(KP+KM1)
20  A(KP,K)=A(K,KP)
   RETURN
   END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

SUBROUTINE PLCTS(N)

C\*\*\* PLOT ONLY THE LOG OF THE POWER FOR THE MOMENT

COMMON YNYQA(2048)

COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,X0,Y0,

1 XS,YS,T,V,XNYQ

2,VT,XZ,YZ,JD

COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,

1IFPUND,IFPUNI,IFPUNR

COMPLEX YNYQA

DIMENSION ARR(126),PHI(1024),Y(1024)

DATA BLANK,STAR,ZERO,PLUS,BAD/1H ,1H\*,1H0,1H+,1HB/

NCHAN=0

GO TO (100,200,300,400),N

100 DO 110 I=1,NSTAR,JD

NCHAN=NCHAN+1

PHI(NCHAN)=AMAG(YNMQ(I))

110 Y(NCHAN)=PHI(NCHAN)

GO TO 500

200 N1=NSTAR/2

DO 210 I=1,N1,ND

NCHAN=NCHAN+1

PHI(NCHAN)=REAL(YNMQ(I))

210 Y(NCHAN)=PHI(NCHAN)

GO TO 500

300 DO 310 I=1,NSTAR,ND

NCHAN=NCHAN+1

PHI(NCHAN)=AMAG(YNMQ(I))

310 Y(NCHAN)=PHI(NCHAN)

GO TO 500

400 DO 410 I=1,NSTAR,JD

NCHAN=NCHAN+1

PHI(NCHAN)=REAL(YNMQ(I))

APPENDIX

```

410  Y(NCHAN)=PHI(NCHAN)
500  NPSTEP=1
C***  THIS ROUTINE DOES THE PLOTTING OF THE DATA AND THEORETICAL FIT.
      WRITE(NW,1)
C***  INITIALIZE FOR FINDING MAXIMUM AND MINIMUM.
      AMAX=PHI(1)
      AMIN=AMAX
C***  INITIALIZE THE PLOTTING ARRAY TO BLANKS.
      DO 10 I=1,126
          ARR(I)=BLANK
10      CONTINUE
C***  FIND MAXIMUM AND MINIMUM OF EITHER THE DATA OR THE FIT.
      DO 30 I=1,NCHAN,NPSTEP
          IF(Y(I).GT.AMAX)  AMAX=Y(I)
          IF(Y(I).LT.AMIN)  AMIN=Y(I)
20      IF(PHI(I).GT.AMAX)  AMAX=PHI(I)
          IF(PHI(I).LT.AMIN)  AMIN=PHI(I)
30      CONTINUE
C***  FIND THE BIN SIZE.
      DBIN=(AMAX-AMIN)/124.0
C***  FIND WHERE TO PUT THE CURVES.
      DO 80 I=1,NCHAN,NPSTEP
          II=IFIX((PHI(I)-AMIN)/DBIN)+2
          JJ=IFIX((Y(I)-AMIN)/DBIN)+2
40      IF(II.NE.JJ) GO TO 50
          ARR(II)=PLUS
          GO TO 605
50      ARR(JJ)=ZERO
60      ARR(II)=STAR
605  GO TO (61,62,62,61),N
61      K=(I-1)*JD
          GO TO 70
62      K=(I-1)*ND
70      WRITE(NW,2) K,(ARR(K),K=1,126)

```

```

      ARR(II)=BLANK
      ARR(JJ)=BLANK
80      CONTINUE
      DELF=1./(NSTAR*XNYQ)
      GO TO (81,82,83,84),N
81      WRITE(NW,4)
4      FORMAT(' PLOT OF AMPLITUDE VS TIME  AFTER INTERPOLATION')
      WRITE(NW,5) XNYQ
5      FORMAT(' TO OBTAIN TIME VALUES MULTIPLY XCOORD BY',E13.7)
      RETURN
84      WRITE(NW,6)
6      FORMAT(' PLOT OF THE FILTERED TIME SERIES')
      WRITE(NW,5) XNYQ
      RETURN
82      WRITE(NW,7)
7      FORMAT(' PLOT OF THE POWER VS. FREQUENCY')
      WRITE(NW,3) DELF
      RETURN
83      WRITE(NW,8)
8      FORMAT(' PLOT OF THE PHASE VS. FREQUENCY')
      WRITE(NW,3) DELF
      RETURN
3      FORMAT(' TO OBTAIN FREQUENCY VALUES MULTIPLY X VALUE BY',E13.7)
1      FORMAT (1H1)
2      FORMAT (1X,14,2X,126A1)
      END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,ERCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE CSTOUT  
C CHECK TIME ORDERING OF THE POINTS AND CAST OUT THOSE POINTS NOT IN THE  
C PROPER TIME ORDER  
C IT ALSO AVERAGES THOSE POINTS WHICH HAVE THE SAME X VALUES  
COMMON YNYQA(2048)  
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,  
1 XS,YS,T,V,XNYQ  
2,NT,XZ,YZ,JD  
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
1IFPUNJ,IFPUNL,IFPUNR  
COMPLEX YNYQA  
LSUM=1  
J=1  
JBAD=0  
K=2  
YSUM=YF(1)  
XSAV=XF(1)  
80 IF(XF(K)-XSAV)90,100,110  
90 K=K+1  
JBAD=JBAD + 1  
IF(K-JF)80,80,110  
100 LSUM=LSUM+1  
YSUM=YSUM+YF(K)  
K=K+1  
IF(K-JF)80,80,30  
110 YF(J)=YSUM/LSUM  
XF(J)=XSAV  
IF(K-JF)120,130,30  
120 XSAV=XF(K)  
YSUM=YF(K)  
LSUM=1  
K=K+1
```

```

      J=J+1
      GO TO 80
130   J=J+1
      YF(J)=YF(K)
      XF(J)=XF(K)
30    WRITE(NW,1) JBAD,JF,J
1     FORMAT(/,1X,I5,' POINTS OUT OF A TOTAL OF ',I5,
1     ' DID NOT SATISFY THE TIME ORDER CRITERION',
2     /,I5,' POINTS WILL BE USED')
      JF=J
      RETURN
      END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE SAVE (N)  
COMMON YNYQA(2048)  
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,  
1 XS,YS,T,V,XNYQ  
2,NT,XZ,YZ,JD  
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
1IFPUND,IFPUNI,IFPUNR  
COMPLEX YNYQA  
IF(N) 10,10,20  
10 DO 15 I=1,NSTAR  
15 YF(I)=AIMAG (YNYQA(I))  
RETURN  
20 DO 25 I=1,NSTAR  
25 YF(I)=REAL (YNYQA(I))  
RETURN  
END
```

' ( JAN 73 )

OS/360 FORTRAN H

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
                   SUBROUTINE UNSAVE(N)  
                   COMMON YNYQA(2048)  
                   COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,  
1  XS,YS,T,V,XNYQ  
2,NT,XZ,YZ,JD  
   COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
1IFPUND,IFPUNI,IFPUNR  
   COMPLEX YNYQA  
   IF (N) 10,10,20  
10  DO 15 I=1,NSTAR  
15  YNYQA(I)=CMPLX(0.0,YF(I))  
   RETURN  
20  DO 25 I=1,NSTAR  
25  YNYQA(I)=CMPLX(YF(I),0.0)  
   RETURN  
   END
```

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APPENDIX A

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NDEDIT,IO,NOXREF  
      SUBROUTINE ROT  
C      ROTATE ZERO POINT OF THE TRACE  
      COMMON YNYQA(2048)  
      COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,X0,Y0,  
1      XS,YS,T,V,XNYQ  
2,VT,XZ,YZ,JD  
      COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,  
1IFPUND,IFPUNI,IFPUNR  
      COMPLEX YNYQA  
      XZS=XZ-X0  
      YZS=YZ-Y0  
      XZ= CT*XZS + ST*YZS  
      YZ= -ST*XZS + CT*YZS  
C      ROTATE AND SCALE INPUT ARRAY  
      DO 10 I=1,JF  
      SWX=XF(I) - X0  
      SWY=YF(I) - Y0  
      YF(I)= ( -ST*SWX+CT*SWY - YZ)*V  
10     XF(I)=(CT*SWX+ST*SWY-XZ)*T  
      RETURN  
      END
```

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```

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF
SUBROUTINE SCARTP
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,XO,YO,
1  XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA
DIMENSION XT(4),YT(4)
READ(NR,2)XZ,YZ
READ(NR,1) X1,X2,Y1,Y2
1  FORMAT(4I5)
READ(NR,2) (XT(I),YT(I),I=1,4)
2  FORMAT(2(1X,E11.4))
READ(NR,2)T,V
3  FORMAT(1X,'THETA=',E13.7/1X,'COS(THETA)=',E13.7/
X 1X,'SIN(THETA)=',E13.7/1X,'COORDINATE ORIGIN S=',E13.7/
X 1X,'COORDINATE ORIGIN Y = ',E13.7,1X,'SCALE FACTOR X = ',E13.7/
X 1X,'SCALE FACTOR Y = ',E13.7/)
4  FORMAT(1X,'XAXIS PTS      X,Y COORDINATES',/,
X 3(1X,E13.7),/,3(1X,E13.7))
5  FORMAT(1X,'YAXIS PTS      X,Y COORDINATES',/,
X 3(1X,E13.7),/,3(1X,E13.7))
XO=ABS (X2*XT(1)-X1*XT(2))/ABS(Y1-X2)
YO=ABS (Y2*YT(3)-Y1*YT(4))/ABS(Y1-Y2)
XS=SQRT((XT(2)-XT(1))**2+(YT(2)-YT(1))**2)/ABS (X2-X1)
YS=SQRT((XT(4)-XT(3))**2+(YT(4)-YT(3))**2)/ABS (Y2-Y1)
IF(YT(2).EQ.YT(1)) GO TO 20
TANT=((YT(2)-YT(1))/(XT(2)-XT(1))-(XT(4)-XT(3))/(YT(4)-YT(3)))/2.0
CT=1.0/SQRT(1.0+TANT**2)
ST=TANT*CT
THETA=ATAN(TANT)

```

```
GO TO 30
20 THETA=0.0
   ST=0.0
   CT=1.0
30  T=T/XS
   V=V/YS
   WRITE(NW,3) THETA,CT,ST,X0,Y0,XS,YS
   WRITE(NW,4) X1,XT(1),YT(2),X2,XT(2),YT(2)
   WRITE(NW,5) Y1,XT(3),YT(3),Y2,XT(4),YT(4)
   RETURN
END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE SRTFUR

```
C
C   THIS ROUTINE PERFORMS A BIT REVERSAL OF THE ORIGINAL NYQUIST ARRAY.
C   IF I IS THE INDEX OF AN ELEMENT OF THE ARRAY THEN I=SUM(A(N)*2**N)
C   WHERE THE LIMITS OF THE SUM ARE 0 AND M AND A(N) IS 0 OR 1.
C   THE ELEMENT SPECIFIED BY I IS EXCHANGED WITH THE ELEMENT SPECIFIED
C   BY J, WHERE J=SUM(A(M-N)*2**N.
C   EXAMPLE: SUPPOSE I=0110101, THEN J=1010110.
C   NSTAR=2**NPOW
COMMON YNYQA(2048)
COMMON NW,NR,XF(2048),YF(2048),NSTAR,NPOW,ND,JF,CT,ST,X0,Y0,
1  XS,YS,T,V,XNYQ
2,NT,XZ,YZ,JD
COMMON INTERP,IFFFT,IFFWAL,IFAUTO,IFGOF,IFPUNF,IFPUNW,IFPUNA,
1IFPUND,IFPUNI,IFPUNR
COMPLEX YNYQA,SWAP
DIMENSION INT(15)
DO 10 I=1,NPOW
10  INT(I)=2** (NPOW-I)
DO 30 I=1,NSTAR
J=I-1
ISUM=0
DO 20 K=1,NPOW
ISUM=ISUM + MOD(J,2)*INT(K)
20  J=J/2
ISUM=ISUM+1
IF (ISUM-1) 30,30,25
25  SWAP=YNYQA(I)
YNYQA(I)=YNYQA(ISUM)
YNYQA(ISUM)=SWAP
30  CONTINUE
RETURN
END
```

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APPENDIX A

( JAN 73 )

OS/360 FORTRAN H

APPENDIX A

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
FUNCTION POLY(B,N,XVAL)

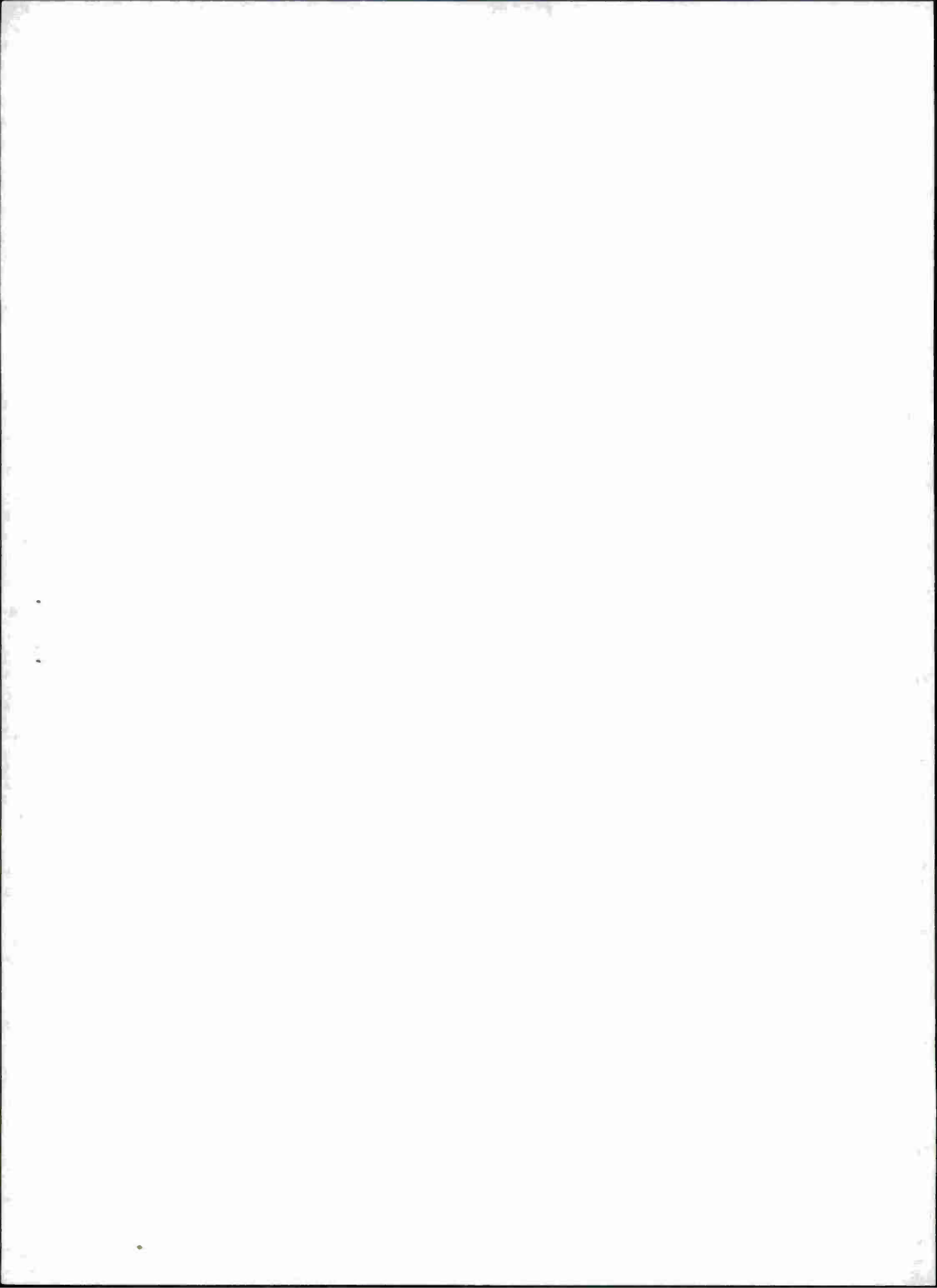
C  
C EVALUATES A POLYNOMIAL FUNCTION  
C

        DIMENSION B(4)  
        POLY=0.0  
        XP=1.0  
        DO 10 I=1,N  
        POLY=POLY + B(I)\*XP  
10      XP=XP\*XVAL  
        RETURN  
        END

( JAN 73 )

OS/360 FORTRAN H

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
                   SUBROUTINE POLMLT(M,A,N,B,L,C)  
                   COMPLEX C(40),B(20),A(20)  
                   L=M+N-1  
                   DO 10 I=1,L  
10      C(I)=CMPLX(0.0,0.0)  
                   DO 20 J=1,M  
                   DO 20 K=1,N  
                   I=J+K-1  
20      C(I)=C(I)+A(J)*B(K)  
                   RETURN  
                   END
```



# APPENDIX B. SIGNAL PROGRAM

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

```

C
C MAIN PROGRAM FOR A GENERAL NON-LINEAR LEAST SQUARES FIT OF A
C PARAMETRIZED FUNCTION TO A SET OF DATA Y
C
C
C
C NON LINEAR LEAST SQUARES FITTING PROGRAM
C
C
C
C
C *****COMMON INFORMATION*****
C      A      MATRIX OF EQN. 8 AND INVERSE AFTER INVERSION
C      C      VECTOR IN EQN.8
C      DPR     CHANGES IN THE RESTRICTED PARAMETERS
C      FMT     FORMAT FOR THE EXPERIMENTAL DATA
C      PR      RESTRICTED PARAMETERS
C      PSAVR   ARRAY FOR TEMPORARY SAVING OF PR
C      Z       ARRAY OF DERIVATIVES
C      PHI     VALUE OF THEORETICAL FUNCTION
C      RESID   RESIDUALS
C      X      ARRAY OF INDEPENDENT VARIABLES SUCH AS TIME
C      Y       THE EXPERIMENTAL DATA
C      W       THE STATISTICAL WEIGHTS
C      IFCOR   DETERMINES DISPOSITION OF CORRELATION COEFFICIENTS
C      IFPLOT  DETERMINES IF THE PLOTTING PROGRAM IS CALLED
C      INDEZ   INTERNAL PARAMETER COMMUNICATING BETWEEN MAIN AND TESTS
C              THE INFORMATION THAT THE PROGRAM HAS OR HAS NOT
C              CONVERGED

```

```

C      N3      THE NUMBER OF THE BEGINNING PARAMETER IN A GIVEN
C              REGION OF PARAMETER SPACE
C      N3ADPT  THE NUMBER OF BAD DATA POINTS
C      NCHAN   THE NUMBER OF CHANNELS
C      NE      THE NUMBER OF THE LAST PARAMETER IN A GIVEN REGION OF
C              PARAMETER SPACE
C      NP      NUMBER OF PARAMETERS TO BE FIT IN A GIVEN REGION OF
C              PARAMETER SPACE
C      NPSTEP  USED FOR PLOTTING
C      NP      THE NUMBER OF PARAMETERS TO BE FIT IN A GIVEN REGION
C              OF PARAMETER SPACE
C      NRP     THE NUMBER OF RESTRICTED PARAMETERS
C      AA      ALPHA IN EQN. 12
C      CHI     CHI-SQUARED
C      CHIB    CHI-SQUARED BEFORE EACH ITERATION
C      CHIA    CHI-SQUARED AFTER EACH ITERATION
C      DEGF    THE NUMBER OF DEGREES OF FREEDOM
C *****
C
C
C *** I/O INFORMATION
C *** NREAD IS THE SYMBOLIC DESIGNATION FOR THE CARD READER
C *** NWRITE IS THE SYMBOLIC DESIGNATION FOR THE LINE PRINTER
C *** NPUNCH IS THE SYMBOLIC DESIGNATION FOR THE CARD PUNCH
C *** THE I/O CHANNELS ARE DEFINED IN THE NEXT THREE STATEMENTS
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
1      NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
NREAD=5
NWRITE=6
NPUNCH=7

```

```
C
C GET THE MAXIMUM # OF ITERATIONS AND THE INPUT DATA FORMAT
C
C     READ(INREAD,1) JSTOP,FMT
C
C GET THE INPUT DATA FOR THE N-TH FIT
C
10  CALL READIN
C
C INITIALIZE ITERATION COUNTER
C
C     JQUIT=0
C     WRITE(NWRITE,2)
C
C INCREMENT ITERATION COUNTER
C
20  JQUIT=JQUIT+1
C
C TEST # OF ITERATIONS
C
C     IF(JQUIT.LE.JSTOP)GO TO 30
C     WRITE(NWRITE,3)
C     GO TO 40
C
C SET UP MATRIX OF DERIVATES AND SOLVE FOR DELTA PARAMETERS
C
30  CALL GRIND(0)
C
C TEST AND MAKE CHANGES IN THE PARAMETERS
C
C     CALL TESTS
C
C INDEZ=0 IF THE FIT HAS CONVERGED
```

```
C
      IF(INDEZ)20,40,40
C
C  WRITE OUT THE PARAMETERS AND THE THEORETICAL FIT
C
40    CALL SCRIBE
C
C  TEST IF A PLOT IS DESIRED
C
      IF(IFPLOT)60,70,60
C
C  DO THE PLOTTING
C
60    CALL PLOTS
C
C  DO THE ERROR ANALYSIS
C
70    CALL ERRMAT
C
C  GO GET THE DATA FOR THE NEXT FIT
C
      IF(1)80,80,10
1      FORMAT(15,5A4)
2      FORMAT(1H-,'CHANGES IN PARAMETERS')
3      FORMAT(1H-,' THE NUMBER OF ITERATIONS EXCEEDED JSTOP. THE',/,
1          ' PROGRAM WILL AUTOMATICALLY GO TO THE PLOTTING AND ',/,
2          ' ERROR ANALYSIS ROUTINES IN WHICH CAEE THE ANSWERS DO',/,
3          ' NOT REPRESENT THE TRUE CHI-SQUARE SOLUTUON')
80    STOP
      END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE LSQPHI

C  
C THIS ROUTINE CALCULATES THE THEORETICAL FUNCTION, RESIDUALS,  
C AND CHI-SQUARE. THE USER MUST SUPPLY THE FUNCTION PHIFNC  
C

COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)  
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)  
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,  
1 VREAD,NWRITE,NPUNCH  
COMMON AA,CHI,CHIB,CHIA,DEGF

C  
C CALCULATE CHI,PHI,AND RESID  
C

CHI=0.0  
DO 10 I=1,NCHAN  
PHI(I)=PHIFNC(I)  
RESID(I)=(Y(I)-PHI(I))\*W(I)  
CHI=CHI+RESID(I)\*\*2

10 CONTINUE

C  
C DIVIDE CHI BY THE # OF DEGREES OF FREEDOM  
C

CHI=CHI/DEGF  
RETURN  
END

APPENDIX B

/ ( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
 SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
 SJBROUTINE ELTS(1)

C

C THIS ROUTINE CALCULATES THE DERIVATIVES OF PHI(1).

C THE USER MUST SUPPLY THE FUNCTION DPHI(1,J)

C

COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)

COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)

COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,

1 VREAD,NWRITE,NPUNCH

COMMON AA,CHI,CHIB,CHIA,DEGF

DO 10 J=NB,NE

Z(J)=DPHI(1,J)

10 CONTINUE

RETURN

END

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE READIN

```
C
C*** THIS ROUTINE READS IN ALL THE INPUT PARAMETERS, DATA, AND SETS UP
C*** INTERNAL CONTROL PARAMETERS.
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
1 NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION NBAD(1024),YRUN(1024),TITLE(20)
EQUIVALENCE (X(1),YRUN(1),NBAD(1)),(W(1),TITLE(1))
WRITE(NWRITE,1001)
READ(NREAD,1)TITLE
WRITE(NWRITE,2) TITLE
C
C*** READ AND WRITE THE CONTROL PARAMETERS.
C
READ(NREAD,3) NCHAN,NBADPT,NRUNS,NRP,NPSTEP,IFPLOT,IFCOR
WRITE(NWRITE,1002)
WRITE(NWRITE,4) NCHAN,NBADPT,NRUNS,NRP,NPSTEP,IFPLOT,IFCOR
C
C*** CALCULATE THE INTERNAL CONTROL PARAMETERS.
C
IF(NPSTEP.EQ.0) NPSTEP=1
NPARAM=NRP
NP=NRP
NB=1
NE=NRP
```

```

C
C*** READ AND WRITE THE PARAMETERS FOR THE FUNCTION.
C
    READ(NREAD,5)(PR(I),I=1,NRP)
    WRITE(NWRITE,1003)
    WRITE(NWRITE,6)(I,PR(I),I=1,NRP)
    DO 40 I=1,NRP
    P(I)=PR(I)
40  CONTINUE
C
C*** INITIALIZE FOR SUMMING NRUNS OF DATA.
C
    DO 130 I=1,NCHAN
        Y(I)=0.0
130  CONTINUE
C*** GET DATA AND SUM IT.
    DO 150 K=1,NRUNS
        READ(NREAD,FMT)(YRUN(I),I=1,NCHAN)
        DO 140 I=1,NCHAN
            Y(I)=Y(I)+YRUN(I)
140  CONTINUE
150  CONTINUE
C
C*** GET THE X AND W VALUES FOR EACH DATA POINT
C
    READ(NREAD,FMT)(X(I),I=1,NSTAR)
    READ(NREAD,FMT)(W(I),I=1,NSTAR)
C
C*** TEST FOR BAD DATA POINTS.
C
180  IF(NBADPT)210,210,190
190  WRITE(NWRITE,1006)

```

```

C*** READ AND WRITE CHANNEL # OF BAD POINTS.
      READ(NREAD,9)(NBAD(I),I=1,NBADPT)
      WRITE(NWRITE,9)(NBAD(I),I=1,NBADPT)
C*** DISCARD BAD DATA POINTS.
      DO 200 I=1,NBADPT
          J=NBAD(I)
          Y(J)=0.0
          W(J)=0.0
200      CONTINUE
C*** WRITE DATA.
210      WRITE(NWRITE,1007)
          WRITE(NWRITE,12)(Y(I),I=1,NCHAN)
          WRITE(NWRITE,1008)
          WRITE(NWRITE,12)(X(I),I=1,NCHAN)
          WRITE(NWRITE,1009)
          WRITE(NWRITE,12)(W(I),I=1,NCHAN)
          WRITE(NWRITE,1001)

C
C*** CALCULATE THE # OF DEGREES OF FREEDOM FOR THE FIT.
C
      DEGF=NCHAN-NBADPT-NRP

C
C*** CALCULATE THE INITIAL THEORETICAL FUNCTION AND CHI-SQUARED.
C
      CALL LSQPHI
      CHIB=CHI

C
C*** SET CHI AFTER AN ITERATION TO 100.0 IN CASE PROGRAM CAN MAKE NO
C*** SUCCESSFUL ITERATIONS.
C
      CHIA=100.0
1001      FORMAT (1H1,/,1H-)
1          FORMAT (20A4)

```

```
2      FORMAT (20X,20A4)
3      FORMAT(7I5)
1002   FORMAT(1H-'      NCHAN  NBADPT  NRUNS      NRP  NPSTEP  IFPLOT  ',
1      1'IFCOR')
4      FORMAT(1X,7I8)
5      FORMAT(8F10.4)
1003   FORMAT (1H-'PARAMETER NUMBER',5X,'PARAMETER')
6      FORMAT (14X,I3,4X,F10.2)
7      FORMAT(4(I5,F10.5))
9      FORMAT(14I5)
1006   FORMAT ('-CHANNEL NUMBER OF THE BAD DATA POINTS')
1007   FORMAT (1H1,/,1H-,30X,'EXPERIMENTAL DATA',/)
1008   FORMAT(1H1,30X,'X VALUES FO THE EXPERIMENTAL DATA')
1009   FORMAT(1H1,30X,' W VALUES FO THE EXPERIMENTAL DATA')
12     FORMAT(10(1X,E12.6))
      RETURN
      END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF

SUBROUTINE TESTS

```
C
C*** THIS ROUTINE DOES THE TESTING OF THE CHANGES IN THE PARAMETERS
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
      NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION WED(4),ZED(4)
C*** AND PERFORMS THE NECESSARY CHANGES.
C*** INITIALIZE FOR SUMMING.
      DT=0.0
C*** SUM AND SAVE THE PARAMETERS.
      DO 10 I=NB,NE
          DT=DT+DPR(I)*C(I)
          PSAVR(I)=PR(I)
      10      CONTINUE
C*** TEST FOR DT < ZERO.
      IF(DT)20,40,40
C*** CHANGE THE SIGN OF THE DELTA P'S IF DT< ZERO.
      20      DO 30 I=NB,NE
          DPR(I)=-DPR(I)
      30      CONTINUE
      DT=-DT
C*** USE THE FULL LENGTH OF THE CHANGES VECTOR TO FIND A NEW CHI.
      40      AA=1.0
C*** FIND THE NEW CHI.
      CALL CALS2
C*** TEST FOR NEW CHI SMALLER THAN OLD, IF NOT GO TO STATEMENT 90.
      IF(CHIB.LE.CHI) GO TO 90
C*** TEST FOR THE CHANGE IN CHI LESS THAN TERMINATION VALUE.
```

```

50   IF((CHIB-CHI).GT.0.1E-08) GO TO 80
C*** REACHES HERE IF TERMINATED.
      INDEZ=0
C*** SET CHI AFTER ITERATION EQUAL TO CHI.
60   CHIA=CHI
C*** WRITE OUT CHANGES IN PARAMETERS, LENGTH OF VECTOR, CHI BEFORE,
C*** AND CHI AFTER.
      WRITE(NWRITE,1)(I,DPR(I),I=NB,NE)
      WRITE(NWRITE,2)AA,CHIB,CHIA
C*** SET CHI BEFORE TO CHI AFTER.
70   CHIB=CHIA
      RETURN
C*** REACHES HERE IF NOT CONVERGED YET AND GOES BACK TO WRITE OUT.
80   INDEZ=-1
      GO TO 60
C*** REACHES HERE IF FULL LENGTH OF VECTOR WILL NOT LOWER CHI AND
C*** TRIES THE PARABOLAS DESCRIBED IN WRITE UP.
90   S=CHI
      AA=0.5
      CALL CALS2
      ZED(1)=CHI
      WED(1)=AA
      N=1
      K=0
      AA=DT/(S-CHIB+2.0*DT)
100  K=K+1
C*** IF THE FACTOR MULTIPLYING THE CHANGES VECTOR IS TOO SMALL SKIP IT
C*** FOR THE CHI AFTER CALCULATION.
      IF(AA.LT.0.1E-01) GO TO 110
      CALL CALS2
      N=N+1

```

```

      ZED(N)=CHI
      WED(N)=AA
110    IF(K-2)120,130,150
120    AA=1.0/DT
      GO TO 100
130    ZED1=CHIB+S-2.0*ZED(1)
      IF(ZED1)140,150,140
140    AA=(S+3.0*CHIB-4.0*ZED(1))/(4.0*ZED1)
      GO TO 100
150    AA=0.5
      CHI=ZED(1)
      DO 160 I=1,N
          IF(CHI.GT.ZED(I)) GO TO 160
          CHI=ZED(I)
          AA=WED(I)
160          CONTINUE
C***  TEST THE SMALLEST VALUE GIVEN BY THE PARABOLAS TO SEE IF IT IS
C***  SMALLER THAN CHI BEFORE, IF NOT RESET PARAMETERS AND GO TO NEXT
C***  SUBSPACE.
      IF(CHIB.LE.CHI) GO TO 170
      CALL CALS2
      GO TO 50
C***  RESET PARAMETERS.
170    DO 180 I=NB,NE
          PR(I)=PSAVR(I)
180          CONTINUE
      AA=0.0
      CALL CALS2
      INDEZ=0
190    WRITE(NWRITE,1001)
      WRITE(NWRITE,1)(I,DPR(I),I=NB,NE)

```

```
1      FORMAT (6(4H DP(,I2,2H)=,E12.5,2X))
2      FORMAT (4H AA=,F14.7,5X,5HCHIB=,E14.7,3X,5HCHIA=,E14.7,/)
1001   FORMAT ('-THE FOLLOWING DPR(I) PRODUCED A DIVERGENT STEP WHICH ',
1       'COULD NOT BE FIXED')
      RETURN
      END
```

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
 SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
 SUBROUTINE GRIND(INV)

```

C
C*** THIS ROUTINE SETS UP THE MATRIX OF DERIVATIVES, THE CONSTANTS IN
C*** THE NORMAL EQUATIONS, THEN CALLS THE MATRIX INVERTER, AND FINALLY
C*** SHIFTS THE CONSTANTS AND THE SOLUTION TO MATCH THE PARAMETERS.
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
1  NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION B(50)
EQUIVALENCE (DPR(1),B(1))
C*** INITIALIZE FOR SUMMING.
DO 20 I=1,NP
    DO 10 J=1,NP
        A(I,J)=0.0
10        CONTINUE
        B(I)=0.0
20        CONTINUE
C*** SET UP MATRIX AND CONSTANTS.
DO 70 I=1,NCHAN
C*** TEST FOR BAD DATA POINTS.
    IF(Y(I))40,70,40
40    CALL ELTS(I)
    DO 60 J=1,NP
        DO 50 K=J,NP
            A(J,K)=A(J,K)+Z(J)*Z(K)
50            CONTINUE
            B(J)=B(J)+Z(J)*RESID(I)
60            CONTINUE
70        CONTINUE

```

```
C*** GET LOWER HALF OF MATRIX (THE MATRIX IS SYMETERIC).  
DO 90 J=1,NP  
    DO 80 K=J,NP  
        A(K,J)=A(J,K)  
80      CONTINUE  
C      SAVE THE CONSTANTS.  
        C(J)=B(J)  
90      CONTINUE  
C*** CALL THE MATRIX INVERTER.  
        CALL INVMAT (NP,INV,ZZZ)  
120    .RETURN  
        END
```

( JAN 73 )

OS/360 FORTRAN H

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,
                   SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF
                   SUBROUTINE INVMAT (N,INV,PIVOT)
                   COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
                   COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
                   COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
1                   VREAD,NWRITE,NPUNCH
                   COMMON AA,CHI,CHIB,CHIA,DEGF
                   DIMENSION B(50),INDC(50),INDR(50),IPIVOT(50)
                   EQUIVALENCE (JROW,IROW),(JCOLUMN,ICOLUMN),(AMAX,SWAP,T)
                   EQUIVALENCE (DPR(1),B(1))
C*** MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS.
C*****NOTE. PIVOT IS RETURNED AS ZERO IF MATRIX IS SINGULAR.
C*****NOTE. INV=1 IF THE INVERSE IS DESIRED.
C*** INITIALIZATION
      DO 10 I=1,N
          IPIVOT(I)=0
10      CONTINUE
      DO 100 I=1,N
C*** SEARCH FOR PIVOT ELEMENT.
          AMAX=0.0
          DO 40 J=1,N
              IF(IPIVOT(J).EQ.1) GO TO 40
              DO 30 K=1,N
                  IF(IPIVOT(K)-1)20,30,130
20                  IF(ABS(AMAX).GT.ABS(A(J,K))) GO TO 30
                  IROW=J
                  ICOLUMN=K
                  AMAX=A(J,K)
30                  CONTINUE
40                  CONTINUE
          IPIVOT(ICOLUMN)=IPIVOT(ICOLUMN)+1
C*** INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL.
          IF(IROW.EQ.ICOLUMN) GO TO 60
```

```

DO 50 J=1,N
    SWAP=A(IROW,J)
    A(IROW,J)=A(ICOLUMN,J)
    A(ICOLUMN,J)=SWAP
50    CONTINUE
    SWAP=B(IROW)
    B(IROW)=B(ICOLUMN)
    B(ICOLUMN)=SWAP
60    PIVOT=A(ICOLUMN,ICOLUMN)
C***    TEST FOR SINGULAR MATRIX.
    IF(PIVOT.EQ.0.0) GO TO 130
C***    DIVIDE PIVOT ROW BY PIVOT ELEMENT.
    DPIVOT=1.0/PIVOT
    A(ICOLUMN,ICOLUMN)=1.0
    DO 70 J=1,N
        A(ICOLUMN,J)=A(ICOLUMN,J)*DPIVOT
70    CONTINUE
    B(ICOLUMN)=B(ICOLUMN)*DPIVOT
C***    REDUCE NON-PIVOT ROWS.
    DO 90 J=1,N
        IF(J.EQ.ICOLUMN) GO TO 90
        T=A(J,ICOLUMN)
        A(J,ICOLUMN)=0.0
        DO 80 K=1,N
            A(J,K)=A(J,K)-A(ICOLUMN,K)*T
80        CONTINUE
        B(J)=B(J)-B(ICOLUMN)*T
90    CONTINUE
C***    SET INDEX IF INVERSE IS DESIRED.
    IF(INV.NE.1) GO TO 100
    INDR(I)=IROW
    INDC(I)=ICOLUMN

```

```

100          CONTINUE
C*** INTERCHANGE COLUMNS IF INVERSE IS DESIRED.
      IF(INV.NE.1) GO TO 130
      DO 120 I=1,N
          J=N+1-I
          IF(INDR(J).EQ.INDC(J)) GO TO 120
          JROW=INDR(J)
          JCOLUMN=INDC(J)
          DO 110 K=1,N
              SWAP=A(K,JROW)
              A(K,JROW)=A(K,JCOLUMN)
              A(K,JCOLUMN)=SWAP
          CONTINUE
110      CONTINUE
120      RETURN
130      END

```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX B

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE CALS2

```
C
C*** THIS ROUTINE IS CALLED BY TESTS TO SET UP THE PARAMETERS
C*** AFTER THE PERAMETERS HAVE BEEN CHANGED, AND CALCULATE CHI BY
C*** BY CALLING LSQPHI
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
I      VREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
C*** FIND THE CHANGED RESTRICTED PARAMETERS.
DO 10 I=NB,NE
      PR(I)=PSAVR(I)+AA*DPR(I)
      P(I)=PR(I)
10    CONTINUE
C
C*** FIND THE CHI.
C
60    CALL LSQPHI
      RETURN
      END
```

( JAN 73 )

OS/360 FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE SCRIBE

```
C
C*** THIS ROUTINE DOES THE WRITING OUT.
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
1      NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION PHIN(512),YN(512),XVEL(512)
WRITE(NWRITE,1)
WRITE(NWRITE,2)(I,PR(I),I=1,NRP)
20  WRITE(NWRITE,3)
WRITE(NWRITE,4)(PHI(I),I=1,NCHAN)
1   FORMAT ('-PARAMETER NUMBER',10X,'PARAMETER')
2   FORMAT (14X,I3,5X,E14.7)
3   FORMAT (1H1,/ ,1H-,30X,'THEORETICAL FIT',//)
4   FORMAT(8(2X,E13.7))
30  RETURN
END
```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX B

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE ERRMAT

```
C
C*** THIS ROUTINE DOES THE ERROR ANALYSIS.
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
      NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION ACSRS(50),AMS(50),FINT(50),SIGI(50)
C*** TEST FOR NO SUCCESSFUL ITERATIONS.
      IF(CHIA.EQ.100.0) GO TO 160
      PIE=3.1415927
C*** INITIALIZE FOR FINDING THE DATA POINT WITH MAXIMUM WEIGHTED
C*** RESIDUAL.
      TAX=0.0
C*** FIND CHANNEL # OF MAXIMUM WEIGHTED RESIDUAL AND WRITE IT OUT.
      DO 10 I=1,NCHAN
          Q=ABS(RESID(I))
          IF(Q.LT.TAX) GO TO 10
          ITRACK=I
          TAX=Q
10      CONTINUE
      WRITE(NWRITE,1)ITRACK
C*** FIND THE PROBABILITY FOR THE FITTED CHI.
      AR=SQRT(2.0*CHIA*DEGF)-SQRT(2.0*DEGF-1.0)
      PROB=ERFC(AR)/2.0
      NCH=NCHAN-NBADPT
C*** WRITE OUT STATISTICAL INFORMATION.
      WRITE(NWRITE,2)NCH,NRP,CHIA,PROB
C*** TEST CHI FOR LESS THAN 1.0 AND SET TO ONE IS SATISFIED.
      IF(CHIA.LT.1.0) CHIA=1.0
```

```

C*** CALL GRIND TO FIND THE ERROR MATRIX.
20 CALL GRIND(1)
C*** FIND THE STANDARD DEVIATIONS ON THE FITTED PARAMETERS.
DO 30 I=1,NRP
    ACSRS(I)=SQRT(A(I,I)*CHIA)
30 CONTINUE
C*** FIND THE CORRELATION COEFFICIENTS.
II=NRP-1
DO 50 I=1,II
    JJ=I+1
    SIG=ACRS(I)
    DO 40 J=JJ,NRP
        A(I,J)=A(I,J)*CHIA/(SIG*ACRS(J))
40 CONTINUE
50 CONTINUE
C*** WRITE OUT THE PARAMETERS AND THEIR STANDARD DEVIATIONS.
WRITE(NWRITE,3)
WRITE(NWRITE,4)(I,PR(I),ACRS(I),I=1,NRP)
C*** TEST FOR CORRELATION COEFFICIENTS DESIRED.
100 IF(IFCOR)110,150,120
C*** IF IFCOR < ZERO PUNCH OUT PARAMETERS.
110 WRITE(NPUNCH,11)(PR(I),ACRS(I),I=1,NRP)
120 WRITE(NWRITE,12)
C*** WRITE OUT CORRELATION COEFFICIENTS.
II=NRP-1
DO 140 I=1,II
    JJ=I+1
    WRITE(NWRITE,13)(I,J,A(I,J),J=JJ,NRP)
C*** TEST FOR PUNCHING.
IF(IFCOR)130,140,140
130 WRITE(NPUNCH,14)(A(I,J),J=JJ,NRP)

```

```
140          CONTINUE
150      RETURN
160      WRITE(NWRITE,15)
1          FORMAT ('-CHANNEL NUMBER OF THE WORST DATA POINT IS ',I5)
2          FORMAT ('-CHI-SQUARED FOR',I5,' CHANNELS AND',I5,' PARAMETERS IS',
1              F11.7,/, ' THE PROBABILITY FOR WHICH IS',E16.7)
3          FORMAT (1H1,/, '-PARAMETER NUMBER',10X,'PARAMETER',10X,'STANDARD ',
1              'DEVIATION')
4          FORMAT (14X,I3,5X,E14.7,14X,E14.7)
5          FORMAT (1X,E14.7,15X,E14.7)
11         FORMAT (5E16.7)
12         FORMAT (1H1,/,1H-,30X,'CORRELATION COEFFICENTS')
13         FORMAT (1H-,6(3H A(,I2,1H,,I2,2H)=,F10.7))
14         FORMAT (8F10.5)
15         FORMAT (' PROGRAM COULD MAKE NO SUCCESSFUL ITERATIONS')
          RETURN
          END
```

( JAN 73 )

OS/360 FORTRAN H

APPENDIX B

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
SUBROUTINE PLOTS

```
C
C*** THIS ROUTINE DOES THE PLOTTING OF THE DATA AND THEORETICAL FIT.
C
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,
      NREAD,NWRITE,NPUNCH
COMMON AA,CHI,CHIB,CHIA,DEGF
DIMENSION ARR(126)
WRITE(NWRITE,1)
DATA BLANK,STAR,ZERO,PLUS,BAD/LH ,1H*,1H0,1H+,1HB/
C*** INITIALIZE FOR FINDING MAXIMUM AND MINIMUM.
      AMAX=PHI(1)
      AMIN=AMAX
C*** INITIALIZE THE PLOTTING ARRAY TO BLANKS.
      DO 10 I=1,126
            ARR(I)=BLANK
10      CONTINUE
C*** FIND MAXIMUM AND MINIMUM OF EITHER THE DATA OR THE FIT.
      DO 30 I=1,NCHAN,NPSTEP
            IF(Y(I).EQ.0.0) GO TO 20
            IF(Y(I).GT.AMAX)      AMAX=Y(I)
            IF(Y(I).LT.AMIN)      AMIN=Y(I)
20      IF(PHI(I).GT.AMAX)      AMAX=PHI(I)
            IF(PHI(I).LT.AMIN)      AMIN=PHI(I)
30      CONTINUE
C*** FIND THE BIN SIZE.
      DBIN=(AMAX-AMIN)/124.0
C*** FIND WHERE TO PUT THE CURVES.
      DO 80 I=1,NCHAN,NPSTEP
            II=IFIX((PHI(I)-AMIN)/DBIN)+2
```

```

        IF(Y(1).NE.0.0) GO TO 40
        JJ=1
        ARR(1)=BAD
        GO TO 60
40      JJ=IFIX((Y(1)-AMIN)/DBIN)+2
        IF(II.NE.JJ) GO TO 50
        ARR(II)=PLUS
        GO TO 70
50      ARR(JJ)=ZERO
60      ARR(II)=STAR
70      WRITE(NWRITE,2) I, (ARR(K), K=1, 126)
        ARR(II)=BLANK
        ARR(JJ)=BLANK
80      CONTINUE
        WRITE(NWRITE,3)
1        FORMAT (1H1)
2        FORMAT (1X, I4, 2X, 126A1)
3        FORMAT ('-0=EXPERIMENTAL POINT, *=FITTED POINT, +=COINCIDENT ',
1          'EXPERIMENTAL AND FITTED POINTS, B=BAD EXPERIMENTAL ',
2          'POINT')
        RETURN
        END

```

( JAN 73 )

OS/360 FORTRAN H

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
FUNCTION PHIFNC(I)  
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)  
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)  
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,  
1 NREAD,NWRITE,NPUNCH  
COMMON AA,CHI,CHIB,CHIA,DEGF  
DIMENSION PSX(50)  
  
C  
C THIS SUBROUTINE CALCULATES THE THEORETICAL FUNCTION FOR THE FITTING  
C PROCESS . SPECIFICALLY PHI =SUM(P(K)*EXP(-P(K+1)*X(I))*COS(P(K+2)*X(I))  
C WHERE THE SUM IS OVER THE TOTAL NUMBER OF FUNCTIONS  
C  
    XI=X(I)  
    DO 10 K=1,NP  
    PSX(K)=P(K)*XI  
10  CONTINUE  
    PHIFNC=0.0  
    DO 20 J=1,NP,3  
20  PHIFNC=PHIFNC+P(J)*EXP(-PSX(J+1))*COS(PSX(J+2))  
    RETURN  
END
```

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APPENDIX B

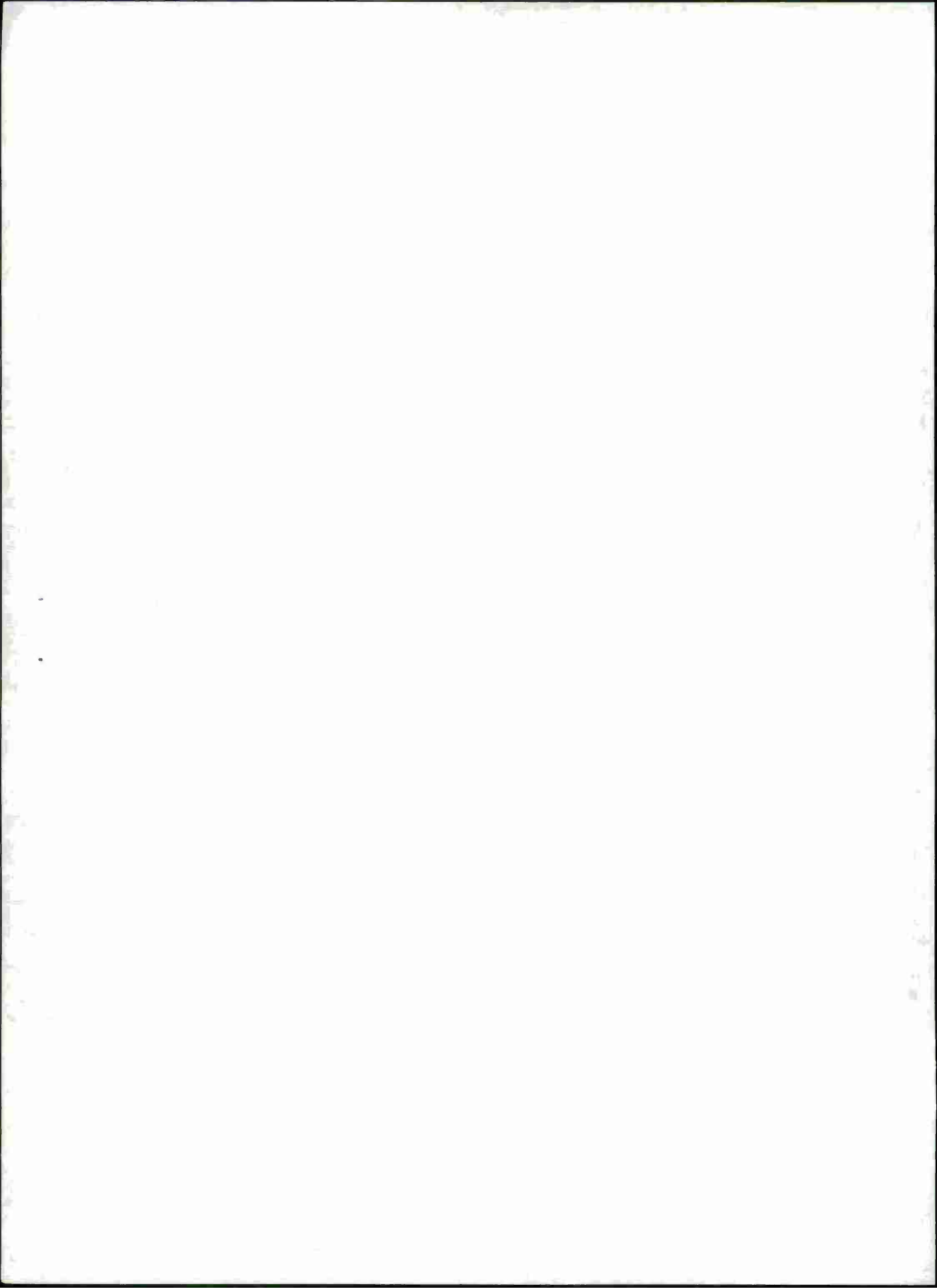
( JAN 73 )

OS/360 FORTRAN H

APPENDIX B

```
COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=57,SIZE=0000K,  
SOURCE,EBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,ID,NOXREF  
FUNCTION DPHI(I,J)  
COMMON A(50,50),C(50),DPR(50),FMT(5),PR(50),PSAVR(50),Z(50),P(50)  
COMMON PHI(1024),RESID(1024),X(1024),Y(1024),W(1024)  
COMMON IFCOR,IFPLOT,INDEZ,NB,NBADPT,NCHAN,NE,NP,NPSTEP,NRP,  
1 NREAD,NWRITE,NPUNCH  
COMMON AA,CHI,CHIB,CHIA,DEGF  
DIMENSION PSX(50)  
DIMENSION SAVS(50),SAVC(50)  
  
C  
C THIS ROUTINE CALCULATES THE DERIVATIVES OF THE THEORETICAL FUNCTION  
C WHERE THE FUNCTION IS GIVEN BY  
C  $\text{PHI} = \sum (\text{P}(K) * \exp(-\text{P}(K+1) * X(I)) * \cos(\text{P}(K+2) * X(I)))$  WHERE THE  
C SUM IS OVER ALL FUNCTIONS  
C  
IF(J.NE.1) GO TO 20  
XI=X(I)  
DO 10 K=1,NP  
PSX(K)=P(K)*XI  
10 CONTINUE  
K=0  
DO 15 L=1,NP,3  
K=K+1  
CON=P(L)*EXP(-PSX(L+1))  
SAVC(K)=CON*COS(PSX(L+2))  
SAVS(K)=CON*SIN(PSX(L+2))  
15 CONTINUE  
20 ITE=J-1  
K=MOD(ITE,3)+1  
L=(J-1)/3+1  
GO TO (1,2,3),K  
1 DPHI=SAVC(L)/P(J)  
RETURN
```

```
2      DPHI=-XI*SAVC(L)  
      RETURN  
3      DPHI=-XI*SAVS(L)  
      RETURN  
      END
```



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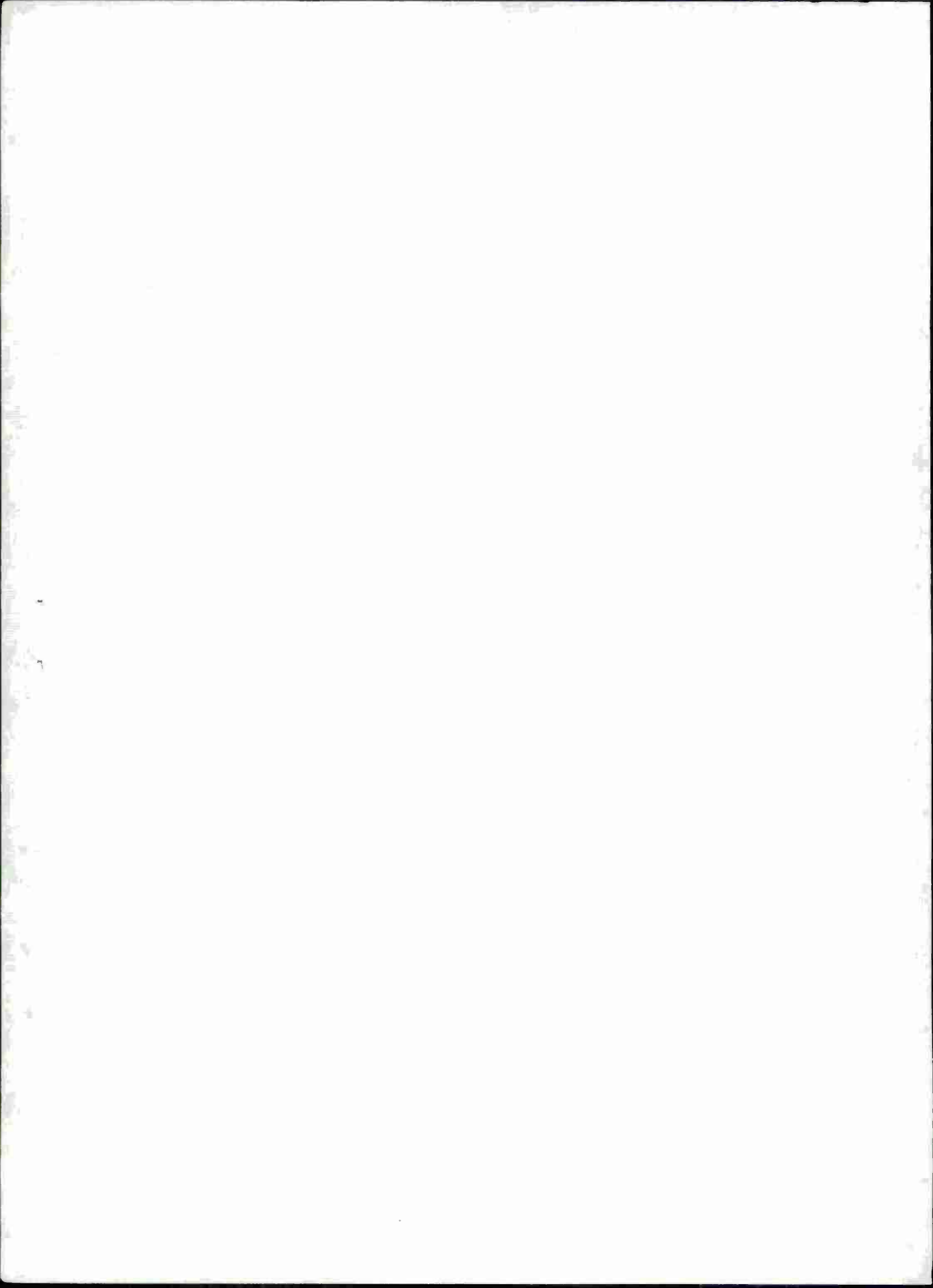
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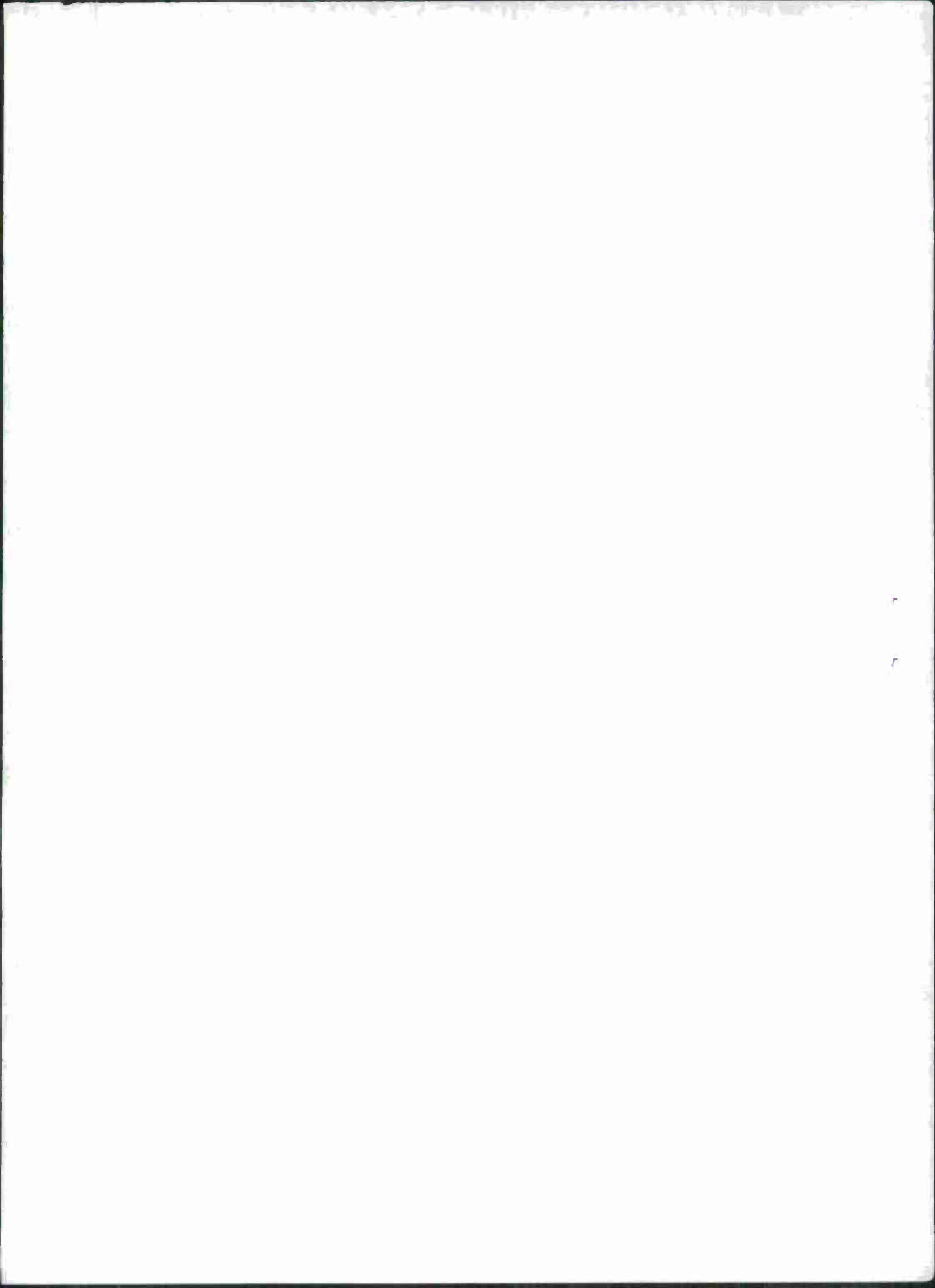
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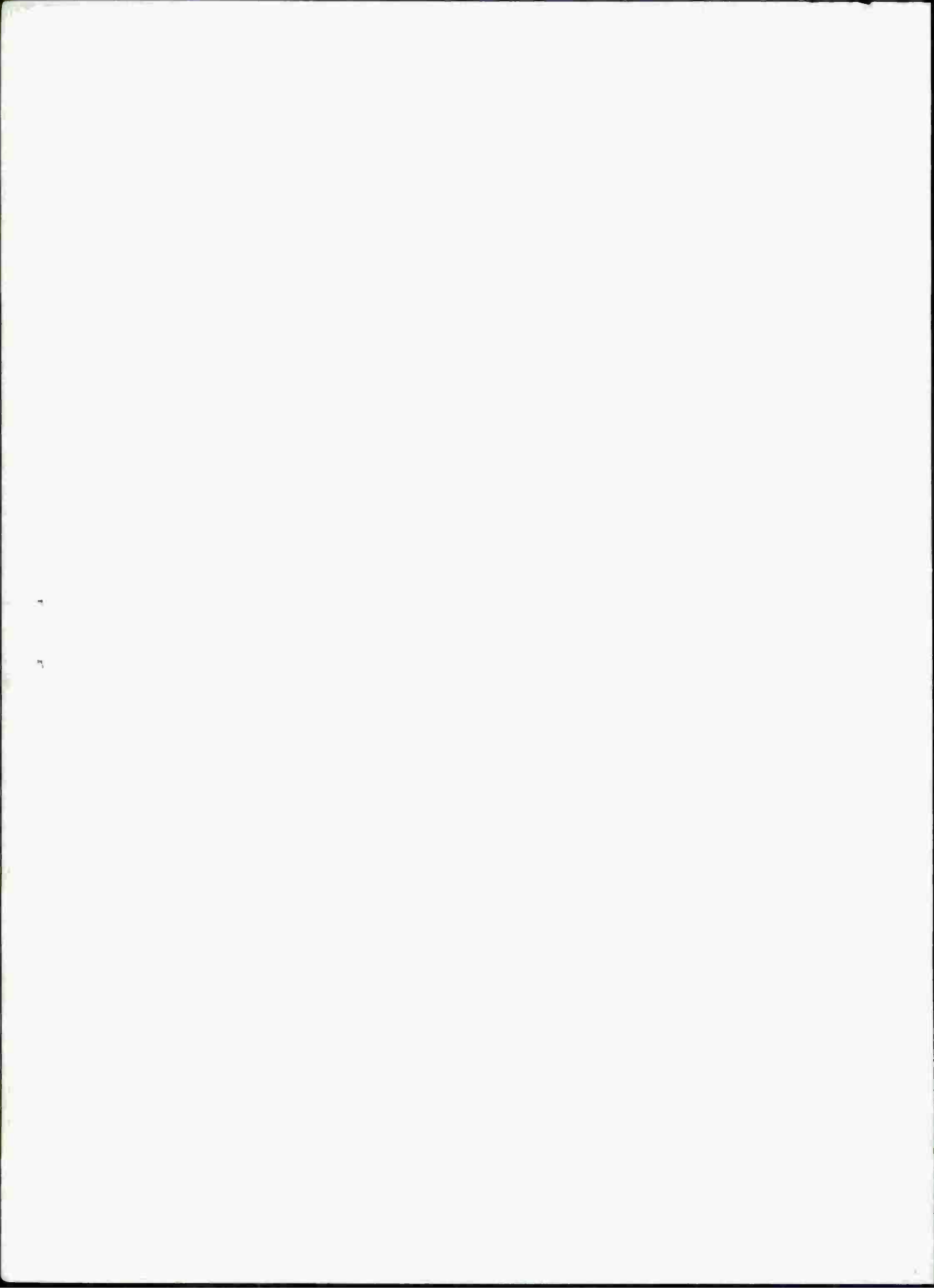
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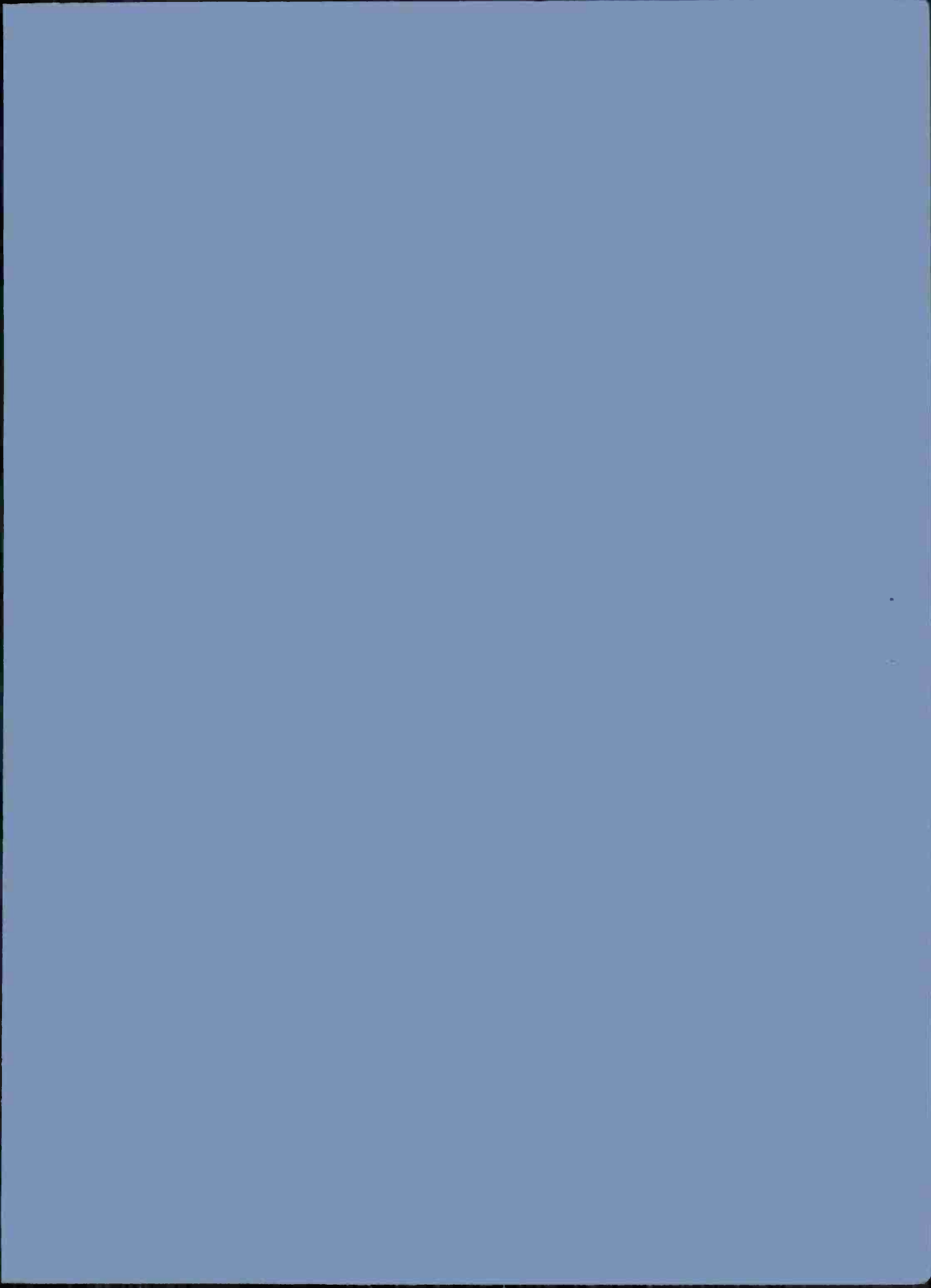
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