1 up

CR-128984

20817-H010-R0-00

# SPECTRAL ANALYSIS PROGRAM, VOLUME I - USER'S GUIDE

NAS 9-11977

12 June 1972

(NASA-CR-128984) SPECTRAL ANALYSIS PROGRAM. VOLUME 1: USER'S GUIDE (TRW Systems Group) ~~68~~ 69 p HC $5.50 CSCL 20N

N73-26145

Unclas

G3/07 07299

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS



TRW
SYSTEMS GROUP

20817-H010-R0-00

# SPECTRAL ANALYSIS PROGRAM, VOLUME I - USER'S GUIDE

NAS 9-11977

12 June 1972

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Prepared by

W. L. Hayden

Approved by: W. B. Warren
Project Manager

TRW
SYSTEMS GROUP

## ABSTRACT

The Spectral Analysis Program (SAP) was developed to provide the Manned Spacecraft Center with the capability of computing the power spectrum of a phase or frequency modulated high frequency carrier wave. Previous power spectrum computational techniques have been restricted to relatively simple modulating signals because of excessive computational time, even on a high speed digital computer. The present technique uses the recently developed extended fast Fourier transform and represents a generalized approach for simple and complex modulating signals. The present technique is especially convenient for implementation of a variety of low-pass filters for the modulating signal and bandpass filters for the modulated signal.

The Spectral Analysis Program was written in Fortran IV for the UNIVAC 1230 digital computer.

TABLE OF CONTENTS

Page

# 1. INTRODUCTION

The purpose of this guide is to provide the user with the necessary information to 1) understand the general computational approach used in the Spectral Analysis Program (SAP), 2) set-up the input parameters in the appropriate tape or card format, and 3) execute the program. The detailed mathematical formulation is presented in Reference 1 (Final Project Report). A programmer's manual, containing the software flow diagrams and listings, is presented in Reference 2 (Spectral Analysis Program, Volume II - Programmer's Manual).

This guide has been written in two basic sections - the Program Description section and the User's Information section. The Program Description section summarizes the mathematical model and presents the basic software structure in terms of a simplified block diagram. A discussion of limiting cases, accuracy, and operational constraints is also given in this section. The User's Information section describes 1) the magnetic tape and card input required to successfully set-up and execute the program and 2) the output power spectrum print and/or plot. A sample case and timing data are included.

This guide also includes a description of the Plot Generation Program (PLTGEN), used in conjunction with SAP, which generates an input tape for the EAI Dataplotter.

# 2. PROGRAM DESCRIPTION

## 2.1 PROGRAM DEFINITION

The Spectral Analysis Program (SAP) computes the power spectrum of an angle modulated high frequency carrier wave. The program is designed to 1) provide capability for performing spectral analyses of a wide variety of angle modulated signals likely to be encountered in the testing and evaluation of angle modulated communication systems, 2) be operationally compatible with the Electronic Systems Test Laboratory (ESTL) UNIVAC 1230 digital computer, and 3) generate a power spectrum data tape compatible with the Plot Generation Program (PLTGEN). PLTGEN generates the appropriate commands to drive the EAI 3440 Dataplotter and create the power spectrum plot. PLTGEN and the associated operating instructions are presented in Section 4.

A simplified block diagram of SAP is presented in Figure 2.1. SAP either accepts an externally supplied modulating signal existing on magnetic tape or internally generates a user specified modulating test signal. The user specified signal may be selected from 1) a sum of sinusoids containing up to 25 frequency components (the amplitude, phase, and frequency of each component are user specified), 2) a periodic four level signal in which the incremental amplitude levels and switching times are specified, and 3) a periodic square wave in which the amplitude and period are specified. After acceptance or generation, the input modulating signal may be low-pass filtered using either a Butterworth, Chebyshev, or user defined filter. For the Butterworth and Chebyshev filters, the user selects the filter order, cut-off frequency, and the amount of ripple (Chebyshev filter only). For the user defined filter, the filter transfer function is defined by the linear interpolation of the magnitude and phase for up to 50 frequency break-points supplied by the user. After low-pass filtering, the modulating signal is multiplied by the modulation parameter and then exponentiated to simulate the exponential modulation process. Next, the modulated signal may be band-pass filtered, using the same filters mentioned above. In addition, the bandpass center frequency may be specified. Finally, the power spectrum is computed, two output tapes are generated, and the output spectrum is printed.

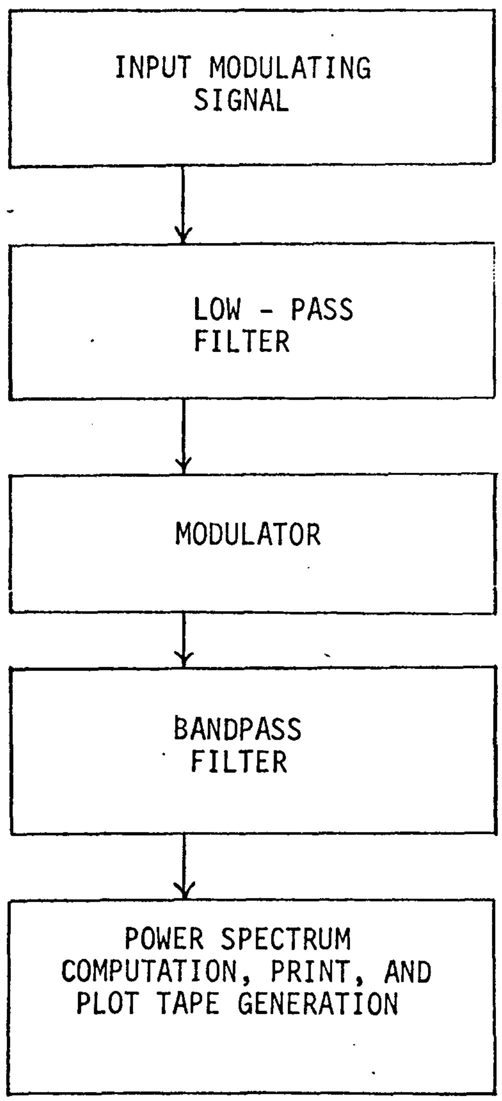



Figure 2-1. SAP Simplified Block Diagram

As stated above, two output tapes are available at the conclusion of a SAP execution. The first tape is called the SAP plot tape and is used as input to PLTGEN. PLTGEN, in turn, generates another tape which is mounted on the EAI plotter unit and drives the plotting pen. The second tape is called the SAP spectrum tape and contains the Fourier transform of the modulated signal. This tape is re-input to SAP after the first SAP execution when displays of additional spectral regions are desired, as discussed below.

The computed power spectrum may contain up to 16,384 spectral lines at a frequency resolution $\Delta f = \frac{1}{16,384\ \Delta t}$, where $\Delta t$ is the sampling interval in seconds. If desired, a specified number of adjacent spectral lines of the computed spectrum may be averaged to provide a power spectrum of lower resolution.

SAP is implemented based on the modular software design concept. The modules closely resemble the physical process being simulated. The input signal for a given module resides on one of two magnetic tapes; the output signal is computed and stored on the second tape. The second tape then contains the input signal for the next module. As a result of this signal processing technique, SAP may be restarted at an entry point corresponding to the last completely executed module.

Several power spectrum print and plot display options are available to provide maximum display utility to the user. Each point or plot may contain up to 480 spectral lines (corresponding to a maximum plot resolution of 20 lines per inch). In the carrier centered display, the carrier is centered along the frequency axis and the spectral region associated with 240 lines to the left of the carrier and 240 lines to the right of the carrier is displayed. In other displays, the starting frequency is user specified and the spectral region associated with the starting frequency plus the next 479 lines is displayed. Spectral regions larger than 480 lines may be displayed by additional plots in which the starting frequency is the last frequency of the previous plot. The entire SAP program need not be re-executed in this case; only the last part of the program (from entry point number 10) is re-executed. Thirty-five plots are required to display the maximum size computed spectrum of 16,384 lines.

All parameters describing the plot are input to SAP; PLTGEN does not require any user controlled input parameters.

## 2.2 METHOD

### 2.2.1 Mathematical Formulation

The modulated signal e(t) generated by the process of angle modulation may be written

$$e(t) = \cos[\omega_c t + \beta\phi(t)] \qquad (1)$$

where $\phi(t)$ represents a time varying phase function g(t) normalized to unit peak amplitude, i.e.,

$$\phi(t) = \frac{g(t)}{|g(t)|_{max}} , \quad |\phi(t)| \leq 1.$$

The constant $\beta$ is termed the modulation parameter and corresponds to the maximum phase deviation of the carrier. $\omega_c$ is the carrier angular frequency and $\omega_c t + \beta\phi(t)$ is the angle of the modulated signal.

For phase modulation (PM), $\phi(t)$ is the normalized modulating signal and the peak phase deviation is represented by the modulation index $\beta$. For, frequency modulation (FM), $\phi(t)$ is the integral of the normalized modulating signal. The instantaneous frequency deviation from the carrier frequency is

$$f_i - f_c = \frac{\beta}{2\pi} \phi'(t) = \Delta f \phi'(t)$$

where $\phi'(t)$ is the time derivative of $\phi(t)$ and $|\phi'(t)| \leq 1$. Thus, for FM, $\beta$ is the peak angular frequency deviation of the carrier.

By writing e(t) in exponential form as

$$e(t) = \frac{1}{2}\left[e^{j\omega_c t} e^{j\beta\phi(t)} + e^{-j\omega_c t} e^{-j\beta\phi(t)}\right], \tag{2}$$

the components of e(t) identified with positive and negative frequencies can be associated with the positive and negative exponential terms. The spectrum of e(t) is obtained by taking its Fourier transform.

$$E(\omega) = E_+(\omega) + E_-(\omega) = F[e(t)] \tag{3}$$

$$= \frac{1}{2}\left|F[e^{j\omega_c t} e^{j\beta\phi(t)}] + F[e^{-j\omega_c t} e^{-j\beta\phi(t)}]\right| .$$

But,

$$F\left[e^{j\omega_c t} e^{j\beta\phi(t)}\right] = \delta(\omega - \omega_c) * F[e^{j\beta\phi(t)}] , \tag{4}$$

where * indicates convolution. Consequently,

$$E(\omega) = \frac{1}{2} \delta(\omega - \omega_c) * F[e^{j\beta\phi(t)}]$$

$$+ \frac{1}{2} \delta(\omega + \omega_c) * F[e^{-j\beta\phi(t)}] . \tag{5}$$

For a typical situation encountered in a communications system, the carrier frequency, $\omega_c$, is large with respect to the spectral extent of $F[e^{j\beta\phi(t)}]$. In such a situation, the spectra associated with the two exponential terms do not overlap. The sketch of Figure 2-2 illustrates a typical situation.

Since the two spectra are identical except for frequency location, computation of the spectrum for only the positive exponential term in Equation (2) is sufficient. In addition, the multiplicative term, $e^{j\omega_c t}$, serves only to position the spectrum of $F[e^{j\beta\phi(t)}]$ in region around $\omega_c$. Consequently, the basic analytical problem to be resolved is the computation of the quantity

$$V_+(\omega) = F[e^{j\beta\phi(t)}]. \tag{6}$$

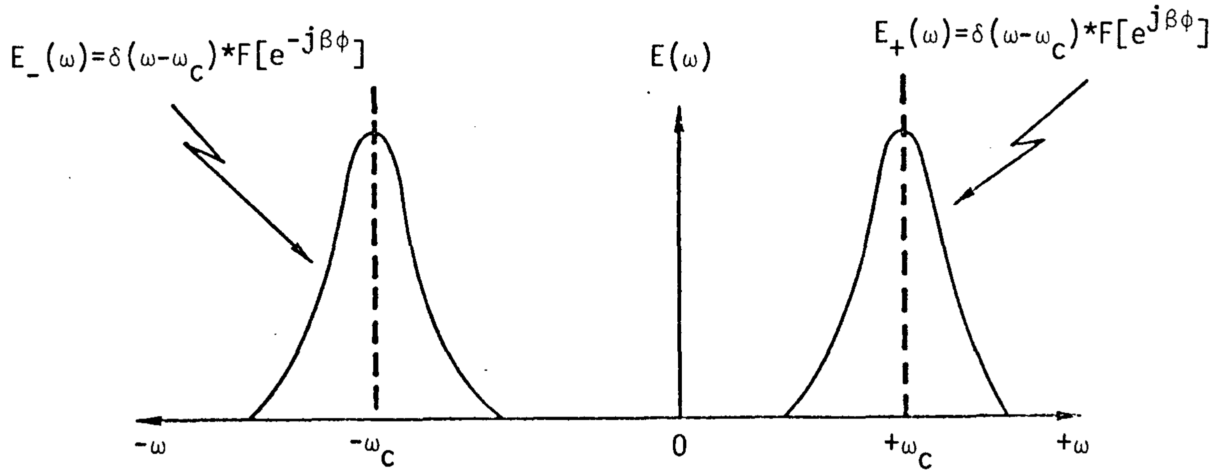



Figure 2-2. Typical Spectrum of an Angle Modulated Signal

The desired output spectrum, $E(\omega)$, is then

$$E(\omega) = \frac{1}{2} V_+(\omega - \omega_c) + \frac{1}{2} V_+(\omega + \omega_c) \quad . \tag{7}$$

For those instances where the separation of the positive negative frequency terms of $E(\omega)$ is not distinct, the two separate spectral terms can be combined by computing

$$E(\omega) = \frac{1}{2} V_+(\omega - \omega_c) + \frac{1}{2} V_-(\omega + \omega_c) \quad , \tag{8}$$

where $V_-(\omega) = F[e^{-j\beta\phi(t)}]$.

The previous discussion presented the overall mathematical description of SAP. The specific mathematical description for each module or subroutine is discussed below.

a) TSGEN - Computes the internally generated modulating signal $\phi(t)$. These signals are:

i) Sum of sinusoids

$$\phi(k\Delta t) = \sum_{j=1}^{M} A_j \sin(2\pi f_j k\Delta t + \Theta_j)$$

where

$\phi(k\Delta t)$ = $k^{th}$ sample of signal

$\Delta t$ = sampling interval

$M$ = number of sinusoids

$A_j$ = amplitude of $j^{th}$ sinusoid

$f_j$ = frequency of $j^{th}$ sinusoid

$\Theta_j$ = phase of $j^{th}$ sinusoid

ii) Periodic four level modulating signal (illustrated on Figure 2-3)

$$\phi(k\Delta t) = \sum_{j=1}^{\ell} A_j$$

where

$A_j$ = change in signal at $t_j$ time point

$t_j$ = time point of $j^{th}$ change in the signal

$\ell$ = index defined by k, $\Delta t$, and the $t_j$'s such that $t_{\ell-1} \leq k\Delta t - mt_5 \leq T$ where $t_5$ = period of signal, m = 1, 2, ..., T = record length, and $t_o \equiv 0$.

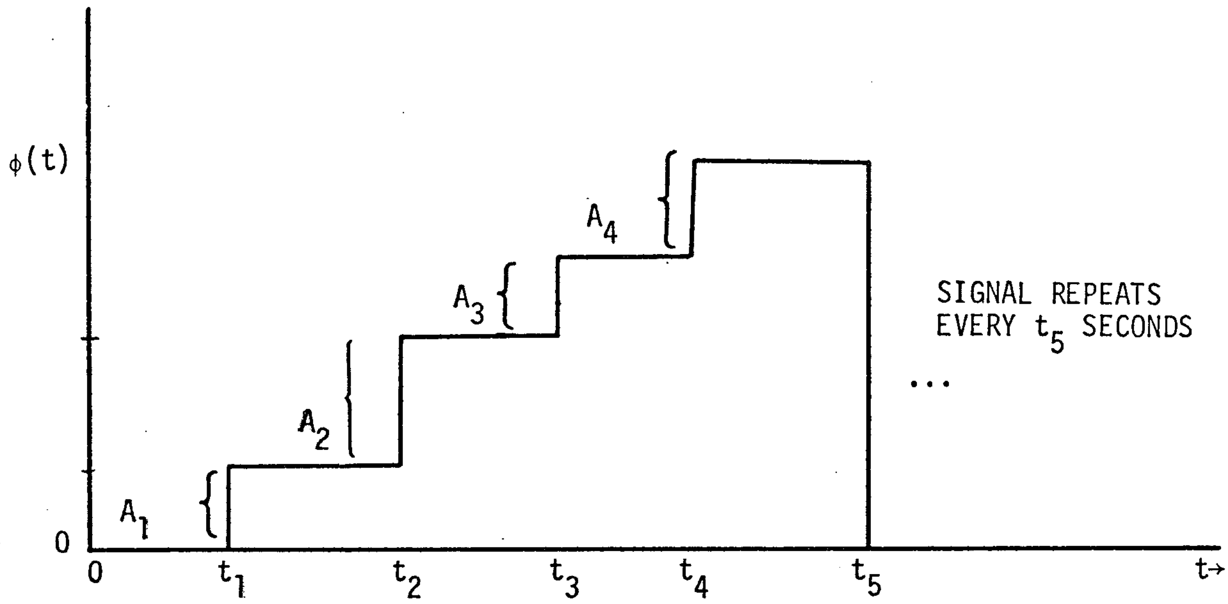



Figure 2-3. Periodic Four Level Test Signal

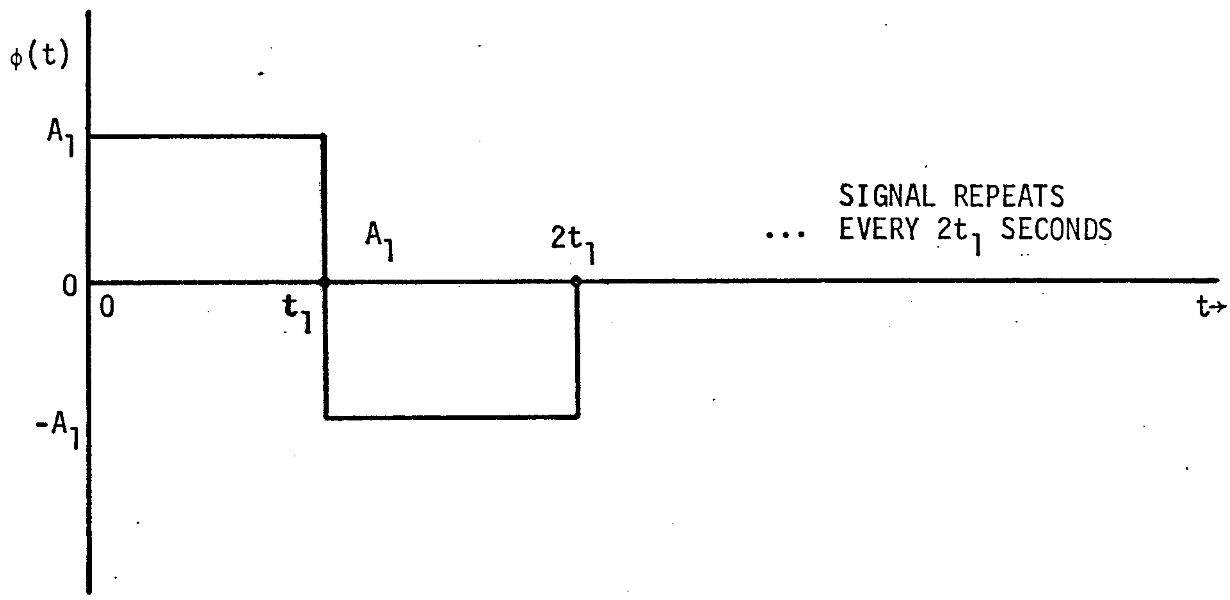



Figure 2-4. Periodic Square Wave

iii) Periodic square wave modulating signal (illustrated on Figure 2-4)

$\phi(k\Delta t) = \pm A_1$

where the + and - signs are interchanged every $t_1$ seconds, i.e., period of square wave is $2*t_1$.

b) ISAR - resamples (using linear interpolation) user supplied modulating signal and generates a signal compatible with the program

$$\phi_{out}(k\Delta t) = \phi_{in}(K\Delta T) + (\phi_{in}(K\Delta T + \Delta T) - \phi_{in}(K\Delta T))*(k\Delta t - K\Delta T)/\Delta T$$

where $\phi_{in}(K\Delta T)$ = the $K^{th}$ sample of the input signal

$\Delta T$ = sampling interval for the input signal

$\phi_{out}(k\Delta t)$ = the $k^{th}$ sample of the output signal

$\Delta t$ = sampling interval for the output signal

$(=\Delta T/KSR)$

and the relation between k and K is

$$K\Delta T \leq k\Delta t \leq (K+1)\Delta T$$

c) EFFT - computes the discrete Fourier Transform or inverse of a signal. The transform and inverse are defined by the pair:

$$X(j) = \frac{1}{N} \sum_{k=0}^{N-1} x(k) W_N^{-jk}$$

$$x(k) = \sum_{j=0}^{N-1} X(j) W_N^{jk}$$

for $j = 0, 1, \ldots, N - 1$ and $k = 0, 1, \ldots, N - 1$. $W_N$ is defined by:

$$W_N = \exp(2\pi i/N)$$

where $i = \sqrt{-1}$ .

The details of this calculation are given in Appendix A.

d) FILTER - filters the modulating and/or modulated signal by multiplying the transform of the signal by the transfer function of the appropriate filter. The equation is

$$S_{out}(f) = H(f)\ S_{in}(f)$$

where

$S_{in}(f)$ = Fourier Transform of input signal

$H(f)$ = Fourier Transform of the impulse response of the filter (i.e., the transfer function)

$S_{out}(f)$ = Fourier Transform of the output signal

$f$ = frequency

e) TRFN - routine which evaluates the transfer function H(f) in the FILTER module. Three possible transfer functions are available - a user defined filter, a Butterworth filter, or a Chebychev filter. A detailed description of TRFN is given in Appendix B.

f) MOD - computes the modulated signal e(t)

$$e(t) = \exp[-j\beta\phi(t)]$$

exp = exponential

$j = \sqrt{-1}$

$\beta$ = modulation parameter

$\phi(t)$ = modulating signal for phase modulation or integral of modulating signal for frequency modulation

g) PLOT - generates power spectrum data for display by:

$$P'(k\Delta f) = \alpha \sum_{i=1}^{NAVE} P(k\Delta f + i\Delta f - \Delta f)$$

where

$\Delta f$ = frequency increment

$\alpha$ = scale factor computed by [NAVE*MAX(P(k$\Delta$f))]

$P(k\Delta f)$ = power in signal at frequency ($k\Delta f$)

$P'(k\Delta f)$ = average of P over NAVE frequency increments beginning at frequency $k\Delta f$

NAVE = number of frequency increments over which output data is averaged

### 2.2.2 Software Implementation

The Spectral Analysis Program (SAP) software is implemented using the modular design concept. Each module performs a specific operation on the input signal to yield an output signal. These operations correspond closely to the physical process being simulated.

The overall program structure is presented by Figure 2.5. All modules and subroutines are shown. These routines and the associated functions were defined previously.

SAP uses two tape units alternately for the input and output of the software modules. Each module accepts the signal stored on the input tape (termed the data tape), processes the signal, and stores the output signal on the output tape (termed the spare tape). The output tape then functions as the input tape for the next module, i.e., the program switches the tape unit labels for both tapes.

Key to Subroutine Names and Functions

SAP - Driver for the Spectral Analysis Program

TSGEN - Test Signal Generation

ISAR - Input Signal and Resampling

TRANS - Transpose

EFFT - Extended Fast Fourier Transform

FILTER - Filtering

TRFN - Transfer Function Calculation

MOD - Modulation Operation

PLOT - Plot and Output Generation

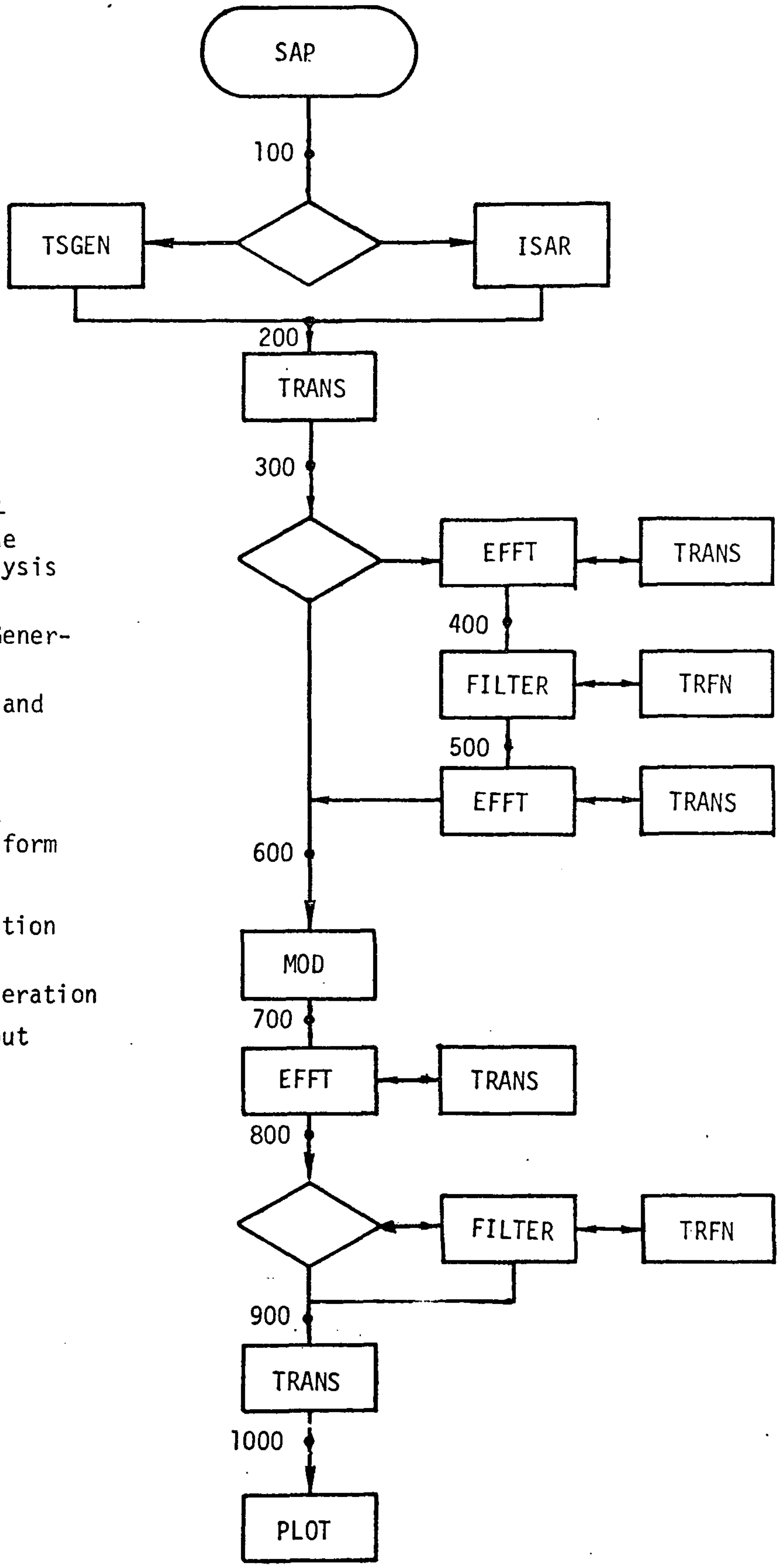



Figure 2-5. Spectral Analysis Program Functional Block Diagram

The points in the driver program at which tape unit label switching occurs are called entry points. Ten entry points exist and the program locations are shown in Figure 2.5. The entry points are labeled 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 on the output listing. As each entry point is passed during program execution, the following messages are printed:

PROGRAM HAS PASSED ENTRY POINT XXXX.

DATA IS CURRENTLY ON UNIT XI.

SPARE TAPE IS CURRENTLY ON UNIT X2.

THERE ARE X ROWS AND Y COLUMNS OF DATA.

EXECUTION TIME = X MINUTES, Y SECONDS.

The modular software design provides a convenient recovery capability should a machine or other failure occur. To recover after a failure, the user specifies the last entry point passed, the data unit number, and spare tape unit number as provided by the last set of entry point messages. The driver program then jumps to the specified entry point and execution of SAP continues. (Note: the entry points are labeled 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 on the output listing; to re-execute SAP, the input entry points are 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, respectively.)

## 2.3 LIMITATIONS

This section lists SAP operational constraints and discusses some special considerations relative to the analytical formulation of a problem.

### 2.3.1 Operational Constraints

SAP operational constraints are listed below.

- The total number of data samples N = NCIDT*NRIDT must not exceed 16,384. NCIDT is the number of columns of data and NRIDT is the number of rows of data.

- The total number of data samples N = NCIDT*NRIDT must be an integral power of two; i.e., $N = 2^n$, where n = 1, 2, 3, ..., 13, 14.

- The maximum value of NCIDT or NRIDT is 256. (For example, if N = 16,384, the following factors are acceptable: N = NCIDT*NRIDT = 256*64, 128*128, and 64*256. If N = 4096, N = 256*16, 128*32, 64*64, 32*128, and 16*256.)

- The sum of sinusoids modulating signal generated internally must contain 25 or fewer sine wave components; i.e., $M \leq 25$.

- Use of the Butterworth filter is restricted to filter orders one through six; i.e., NORD1 or NORD2 = 1, 2, 3, 4, 5 and 6. NORD1 and NORD2 are the filter orders of the low-pass and bandpass filters, respectively.

- Use of the Chebyshev filter is restricted to filter orders one, three, and five; i.e., NORD1 or NORD2 = 1, 3, and 5. Even order Chebyshev filters are generally physically unrealizable for equal source and load impedances.

- Use of the user filter is restricted to 50 break-points; i.e., NF1 or NF2 $\leq$ 50. NF1 and NF2 are the number of frequency break-points for the low-pass and bandpass filters, respectively.

### 2.3.2 Special Considerations

Experience indicates that the user should be familiar with the leakage effect, aliasing, and the Gibbs phenomenon. These considerations are briefly summarized below. Refer to the Final Project Report (Reference 1) for additional discussion and references.

Leakage Effect. SAP is based on the use of the discrete approximation to the continuous Fourier transform. The discrete Fourier transform (DFT) approximation is exact only when the input signal is periodic and the frequency components are harmonically related. Otherwise, a leakage effect exists. This leakage effect exists because a finite record is formed containing only T seconds of the actual signal x(t). Forming a finite record may be viewed as multiplying the signal by a rectangular window function g(t) with unit amplitude during the T second interval and zero magnitude at other times. Thus,

$$x'(t) = g(t)\ x(t)$$

and

$$x'(t) = x(t) \qquad \text{if } \frac{-T}{2} \leq t \leq \frac{T}{2}$$

$$= 0 \qquad \text{if } |t| > \frac{T}{2}$$

Multiplication in the time domain corresponds to convolution in the transform domain; i.e.,

$$X'(\omega) = G(\omega) * X(\omega).$$

Since $G(\omega)$ is the Fourier transform of $g(t)$ and has the form $(\sin \omega)/\omega$, the convolution results in a blurring of frequency components. For example, if $x(t)$ is an infinitely long cosine waveform of frequency $\omega_0$, the Fourier transform yields two impulses that are symmetric about zero frequency (Figure 2-6a). If, however, a finite length record is transformed, these two impulses will be convolved with $G(\omega) = (\sin \omega)/\omega$, yielding the results presented in Figure 2-6c. Thus, some of the energy of the impulse "leaks" through the sidelobes into adjacent frequencies.

Aliasing. The term "aliasing" refers to the fact that high-frequency components of a time function will appear as low frequencies if the sampling rate is too slow. If the sampling frequency is $f_s = 1/\Delta t$ (where $\Delta t$ is the sampling interval in seconds), a "folding frequency" exists defined by $f_f = f_s/2$. An input signal $x(t)$ will be represented correctly if the highest frequency component is less than the folding frequency. A frequency component 5 Hz higher than the folding frequency will appear as a frequency 5 Hz lower than the folding frequency. Aliasing may be avoided by sampling the signal at a rate at least twice as high as the highest frequency present; i.e., at the Nyquist rate.

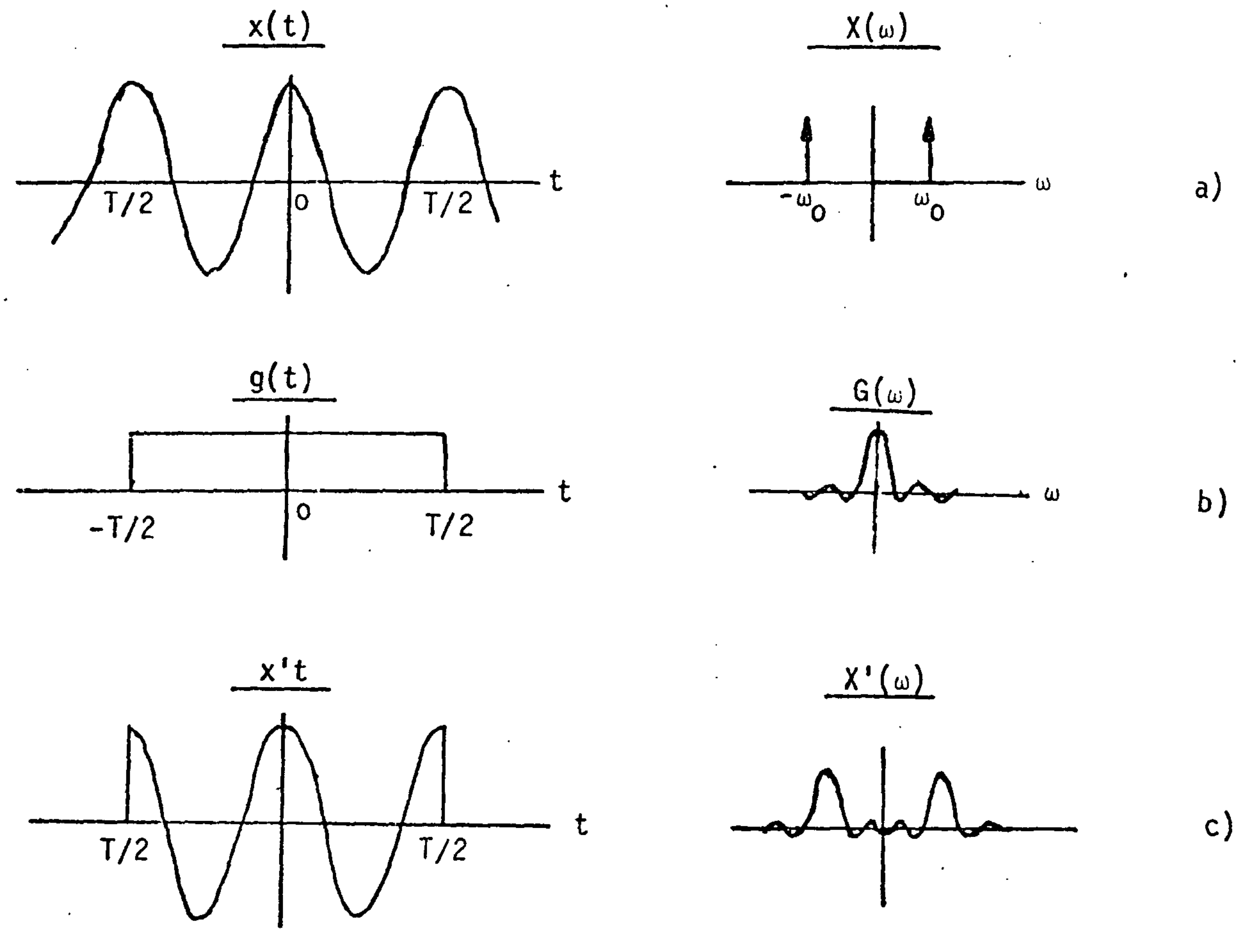



Figure 2-6. Leakage Effect

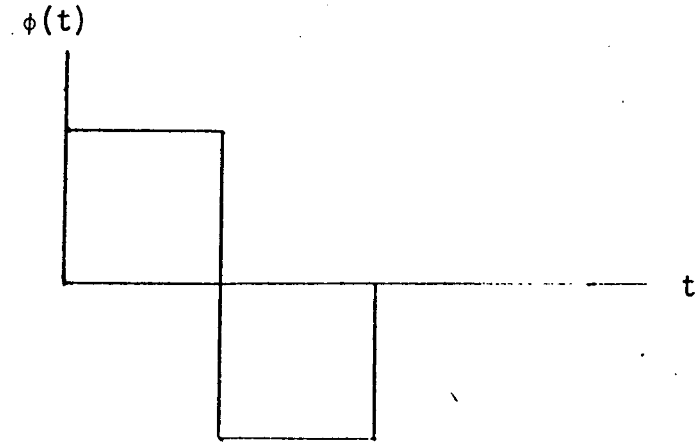
Aliasing is of particular significance when the input signal is not band limited. For example, a square wave contains an infinite number of frequency components and can not be sampled at the Nyquist rate. The amplitudes of the components, however, decrease with increasing frequency. Thus, the number of components with significant (in terms of user requirements) magnitudes is limited to a finite number. Aliasing is always present when sampling a square wave, but may be reduced in significance by increasing the sampling rate. The sampling rate, however, may not be made arbitrarily large because the SAP capability is limited to 16,384 data samples.

Gibbs Phenomenon. The Gibbs phenomenon exists when a Fourier series is used to represent a function which has a finite number of discontinuities. This phenomenon has been experienced during SAP executions when the modulating signal was a square wave. In this case, the square wave shown in Figure 2-7a is approximated by the wave shown in Figure 2-7b and the power spectrum is computed accordingly.

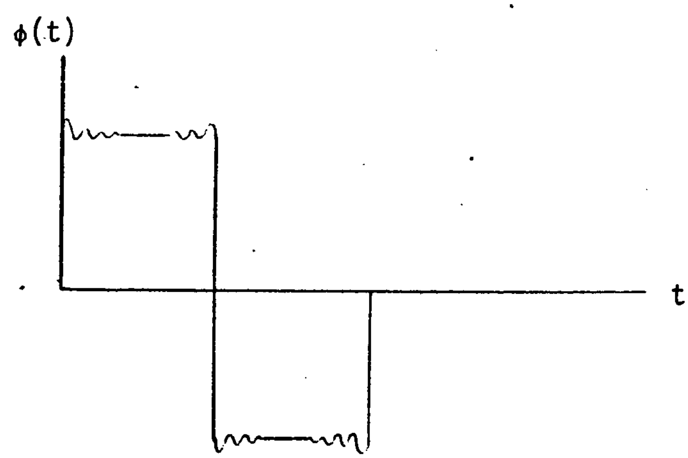
As shown by the latter figure, ripples exists in the vicinity of the discontinuities. According to Fourier theory, the trigonometric series approximation of the square wave improves in a mean square error sense as the number of terms n in the series increases. The theory, however, also indicates that the ripples exists even for very large values of n. As n is increased further, the ripples show a proportionately increased rate of oscillation, but the ripple amplitudes relative to the magnitude of the discontinuity remains the same. As $n \to \infty$, the ripples are compressed into a single vertical line at the point of discontinuity. The square wave can never be approximated in the vicinity of the discontinuity with an error less than 18 percent.

## 2.4 ACCURACY

The Spectral Analysis Program was verified at the individual module level and at the overall software package level. Verification was accomplished using test cases with known theoretical results. For example,




(a) True Square Wave Modulating Signal




(b) Approximate Square Wave Modulating Signal

Figure 2-7. Gibbs Phenomenon

at the overall software package level, the computed power spectrum was compared with theoretical results for phase and frequency modulating signals consisting of sine waves and periodic square waves. Results indicated a minimum of six significant figures accuracy for the power spectrum expressed in decibels.

This high degree of accuracy is a direct result of using the extended fast Fourier transform (EFFT) technique to compute Fourier transforms. Use of the EFFT for complex modulating signals is advantageous because 1) the number of multiply-add operations is reduced very significantly compared to non-FFT power spectrum computational techniques and 2) the EFFT accumulates a long series of floating point numbers optimally. The optimal accumulation method is to add pairs of numbers, then pairs of the resulting sums, etc. The error generated by the EFFT was investigated experimentally by performing the EFFT of a unit impulse, performing the inverse EFFT, and then examining the difference between the original and reconstructed sets of data. At least seven significant figures of agreement, depending on the array size, was obtained.

# 3. USER'S INFORMATION

## 3.1 INPUT DESCRIPTION

The subsections below define the input parameters for the Spectral Analysis Program, the formats for the inputs, the overall card deck setup, and the necessary detailed machine operating procedures.

### 3.1.1 Input Parameters

For convenience, the inputs for the SAP are divided into a number of categories. The categories are general inputs, inputs to define the test signal or the input signal, inputs to define filtering for both the modulating and modulated signals, and inputs to define the plot parameters. The input symbols and definitions are given by Table 3-1.

### 3.1.2 Formats for Inputs

Input to SAP consists of a set of data cards and a magnetic tape (if ISOPT = 0) containing an externally generated modulating signal. The card input parameters, card group description, and format are described in Table 3-2. (A card group is a set of one or more cards that relate to a given computational function. For example, if the modulated signal is to be filtered with the user filter, the bandpass user filter group of cards must be included. If not, this group of cards is omitted.)

Each SAP execution must contain the first three card groups in Table 3-2; i.e., each execution must contain a title card (which may be blank), two integer data cards, and a fixed point data card. If 1) an externally generated modulating signal is to be used and 2) neither the modulating signal nor the modulated signal is to be filtered, additional card input is not included; otherwise, one or more card groups are required. Card group requirements are presented in Table 3-3.

The number of cards required for a group is given by the number of formats given for that group in Table 3-2. For example, two formats are given for the integer data card group. Thus, two integer data cards are required. The first card contains 16 parameters, each occupying five card

Table 3-1. Inputs for Spectral Analysis Program

General

IEP - defines entry point to the driver by

= { 1 - nominal run
K - restart entry point (as shown in Figure 2-1) }

IDT, IST - defines data tape and spare tape units. For normal cases, IDT = 1 and IST = 2. For restart capability (IEP ≠ 1), signal data resides on IDT.

NCIDT, NRIDT - defines the number of points, N, in the test signal by N = NCIDT*NRIDT. Each must be a power of 2. For efficiency, NCIDT and NRIDT should be approximately equal (for example NCIDT = 64 and NRIDT = 128). For restarting (IEP ≠ 1), NCIDT and NRIDT define the number of columns and rows, respectively, of the arrays on tape IDT.

ISOPT - defines signal option by

= { 0, user input signal on tape IDT
1, sinusoidal test signal
2, periodic four level gray test signal
3, periodic square wave test signal }

IFM - defines modulation type by

= { 1, FM modulation
2, phase modulation }

IFOPT - defines filtering options

= { 0, no filtering
1, filter modulating signal only
2, filter modulated signal only
3, filter modulating and modulated signal }

Table 3-1. Inputs for Spectral Analysis Program (Continued)

BETA - defines modulation index by

$$= \begin{cases} \text{if IFM = 1, BETA = maximum frequency deviation (Hertz)} \\ \text{if IFM = 2, BETA = maximum phase deviation (radians)} \end{cases}$$

DELT = time separation (in seconds) between points in test signal or between user input signal prior to resampling

FC = carrier frequency (in Hertz)

IZPRT(I) - special print control

= 0, no special print

1, special print at indicated entry point

| I | ENTRY POINT |
|---|---|
| 1 | 2 |
| 2 | 4 |
| 3 | 5 |
| 4 | 6 |
| 5 | 8 |
| 6 | 9 |

Test Signals

a) Sinusoids (ISOPT = 1)

M - number of sinusoids ($\leq$ 25)

A(I) - amplitude of $I^{th}$ sinusoid

F(I) - frequency (in Hertz) of $I^{th}$ sinusoid

THETA(I) - phase angle (in degrees) of $I^{th}$ sinusoid

For IFM = 1, A(I) is the peak frequency deviation associated with each sinusoid

For IFM = 2, A(I) is the peak phase deviation associated with each sinusoid

Note: If ISOPT = 1, the input specification for BETA must be omitted

Table 3-1. Inputs for Spectral Analysis Program (Continued)

b) Periodic four level gray (ISOPT =2)

TP(I) - I = 1, 2, 3, 4 - defines the time points (in seconds) of the breaks or changes in the signal

A(I) - I = 1, 2, 3, 4 - defines the corresponding changes in the amplitude of the signal

TP(5) - defines period of signal

c) Periodic Square Wave (ISOPT = 3)

TP(1) - period (in seconds) of the square wave

A(1) - amplitude of square wave

<u>Input Signal</u>

NR1 - number of words per record on input data tape

NC1 - number of records on input data tape

KSR - defines sampling rate for resampled signal by DELT/KSR

<u>Filtering</u> (depending on IFOPT - zero, one or two filters need to be specified)

a) for the modulating signal

IFTYP1 - defines filter type by

$$=\begin{cases} 1, \text{ Butterworth} \\ 2, \text{ Chebychev} \\ 3, \text{ Input filter} \end{cases}$$

NORD1 - defines order of Butterworth of Chebychev filter ($\leq 5$)

FCUT1 - defines cutoff frequency of Butterworth or Chebychev filter (in Hertz)

RIP1 - defines ripple for Chebychev filter (refer to Appendix B)

Table 3-1. Inputs for Spectral Analysis Program (Continued)

| | |
|---|---|
| NF1 | - for IFTYP1 = 3, defines number of points specified for input filter ($\leq$ 50) |
| TMAG1(I) | - for IFTYP1 = 3, defines magnitude of input filter transfer function at $I^{th}$ frequency |
| TPH1(I) | - for IFTYP1 = 3, defines corresponding phase (in radians) at $I^{th}$ frequency |
| F1(I) | - for IFTYP1 = 3, defines frequency (in Hertz) at which magnitude and phase is specified |
| | - intermediate values of the magnitude and phase are generated by using linear interpolation over the input values |

b) for the modulated signal

| | |
|---|---|
| IFTYP2<br>NORD2<br>FCEN2<br>FCUT2<br>RIP2<br>NF2<br>TMAG2(I)<br>TPH2(I)<br>F2(I) | identical in definition as corresponding variables for modulating or test signal filter - but apply to filtering the modulated signal. The additional parameter FCEN2 defines the center frequency for the bandpass filter. |

Plot

| | |
|---|---|
| FSTRT | - frequency (in Hertz) at which plot display begins; if < 0, then display with centered FC is generated. |
| AMAX | - scaling factor in output plot, if set to zero the plot module computes AMAX as maximum power component in total signal and scales data to be plotted by this value, if set positive then the input value is used to scale data for plotting. |
| NAVE | - number of points to be averaged for each output display point, each output point represents a bandwidth of NAVE*$\Delta$f where $\Delta$f = 1/(NRIDT*NCIDT*DELT) |

Table 3-1. Inputs for Spectral Analysis Program (Continued)

IPMODE - controls printing and plotting by

$$= \begin{cases} 0, \text{ print and plot} \\ 1, \text{ plot only} \\ 2, \text{ print only} \end{cases}$$

IPLPOS - controls plot position on page by

$$= \begin{cases} 0, \text{ top half} \\ 1, \text{ bottom half} \end{cases}$$

ITITLE - 30 characters for title on run and title on plot

Table 3-2. Card Input

| Card Group Description | Parameters on Card | Format |
|---|---|---|
| Title | (Up to 30 alpha-numeric characters) | (30A1) |
| Integer Data | IDT, IEP, IFM, IFOPT, IFTYP1, IFTYP2, IPLPOS, IPMODE, ISOPT, IST, KSR, NCIDT, NC1, NF1, NF2, NRIDT | (16I5) |
| | NR1, NAVE, IZPRT(1), ..., IZPRT(6) | (8I5) |
| Fixed Point Data | AMAX, BETA, DELT, FC, FSTRT | (5F10.0) |
| Low Pass User Filter | F1(1), F1(2), F1(3), ..., F1(8),<br>F1(9), F1(10), F1(11), ..., F1(16),<br>F1(17), ..., F1(NF1) | (8F10.0)<br>"<br>" |
| | TMAG1(1), TMAG1(2), TMAG1(3), ..., TMAG1(8)<br>TMAG1(9), TMAG1(10), TMAG1(11), ..., TMAG1(16),<br>TMAG1(17), ..., TMAG1(NF1) | (8F10.0)<br>"<br>" |
| | TPH1(1), TPH1(2), TPH1(3), ..., TPH1(8),<br>TPH1(9), TPH1(10), TPH1(11), ..., TPH1(16),<br>TPH1(17), ..., TPH1(NF1) | (8F10.0)<br>"<br>" |
| Low Pass Built-in Filter | NORD1, FCUT1, RIP1 | (I5,2F10.0) |
| Bandpass User Filter | F2(1), F2(2), F2(3), ..., F2(8),<br>F2(9), F2(10), F2(11), ..., F2(16),<br>F2(17), ..., F2(NF2) | (8F10.0)<br>"<br>" |
| | TMAG2(1), TMAG2(2), TMAG2(3), ..., TMAG2(8),<br>TMAG2(9), TMAG2(10), TMAG2(11), ..., TMAG2(16),<br>TMAG2(17), ..., TMAG2(NF2) | (8F10.0)<br>"<br>" |
| | TPH2(1), TPH2(2), TPH2(3), ..., TPH2(8),<br>TPH2(9), TPH2(10), TPH2(11), ..., TPH2(16),<br>TPH2(17), ..., TPH2(NF2) | (8F10.0)<br>"<br>" |
| Bandpass Built-in Filter | NORD2, FCEN2, FCUT2, RIP2 | (I5,3F10.0) |

Table 3-2. Card Input (Continued)

| Card Group Description | Parameter on Card | Format |
|---|---|---|
| Test Signal-Sinusoids | M | (I2) |
| | A(1), A(2), A(3), ..., A(8), | (8F10.0) |
| | A(9), A(10), A(11), ..., A(16), | " |
| | A(17), ..., A(M) | " |
| | F(1), F(2), F(3), ..., F(8), | (8F10.0) |
| | F(9), F(10), F(11), ..., F(16), | " |
| | F(17), ..., F(M) | " |
| | THETA(1), THETA(2), THETA(3), ..., THETA(8), | (8F10.0) |
| | THETA(9), THETA(10), THETA(11), ..., THETA(16), | " |
| | THETA(17), ..., THETA(M) | " |
| Test Signal-Multilevel | TP(1), TP(2), TP(3), TP(4), TP(5) | (8F10.0) |
| | A(1), A(2), A(3), A(4) | (8F10.0) |
| Test Signal-Square | TP, A | (2F10.0) |

Table 3-3. Card Group Requirements

| Card Group | Requirement |
|---|---|
| Title | Always required |
| Integer Data | Always required |
| Fixed Point Data | Always Required |
| Low Pass User Filter | IFOPT = 1 or 3, IFTYP1 = 3 |
| Low Pass Built-in Filter | IFOPT = 1 or 3, IFTYP1 = 1 or 2 |
| Bandpass User Filter | IFOPT = 2 or 3, IFTYP2 = 3 |
| Bandpass Built-in Filter | IFOPT = 2 or 3, IFTYP2 = 1 or 2 |
| Test Signal-Sinusoids | ISOPT = 1 |
| Test Signal-Multilevel | ISOPT = 2 |
| Test Signal-Square | ISOPT = 3 |

columns (i.e., each parameter card field corresponds to five card columns). The second card contains eight parameters, each occupying five card columns. In this case, the first eight card fields must be used. The parameter must be key-punched on the card in the order shown by the table.

The low pass user filter, bandpass user filter, and the test signal-sinusoids card groups use a variable number of cards, as indicated by the " marks. For example, if the low pass user filter is to be used and NF1 = 8, then one card containing eight F1 values, a second card containing eight TMAG1 values, and a third card containing eight TPH1 values are required. If NF1 = 50 (corresponding to the maximum allowable break-points), then the following cards inputs are required: six cards containing eight F1 values plus one card containing two F1 values, six cards containing eight TMAG1 values plus one card containing two TMAG1 values, and six cards containing eight TPH1 values plus one card containing two TPH1 values.

A magnetic tape containing an externally generated modulating signal is required if ISOPT = 0. This tape contains NC1 number of records and NR1 number of words per record. Words are written at 556 bpi in unformatted binary.

3.1.3 Overall Deck Setup

The overall deck setup and control cards required to execute SAP on the UNIVAC 1230 computer are shown in Figure 3-1.

The UNIVAC 1230 control cards are described below:

- FORTN

  This card specifies to the Compiler Executive that a FORTRAN program follows and that the program is to be compiled. FORTN starts in column one.

- CONTROL,T,BASE 646

  This card specifies that the desired mode of output to be used by the Compiling System is tape. A base of 646 is used for the main program. The base for subroutines is optional. CONTROL starts in column seven.

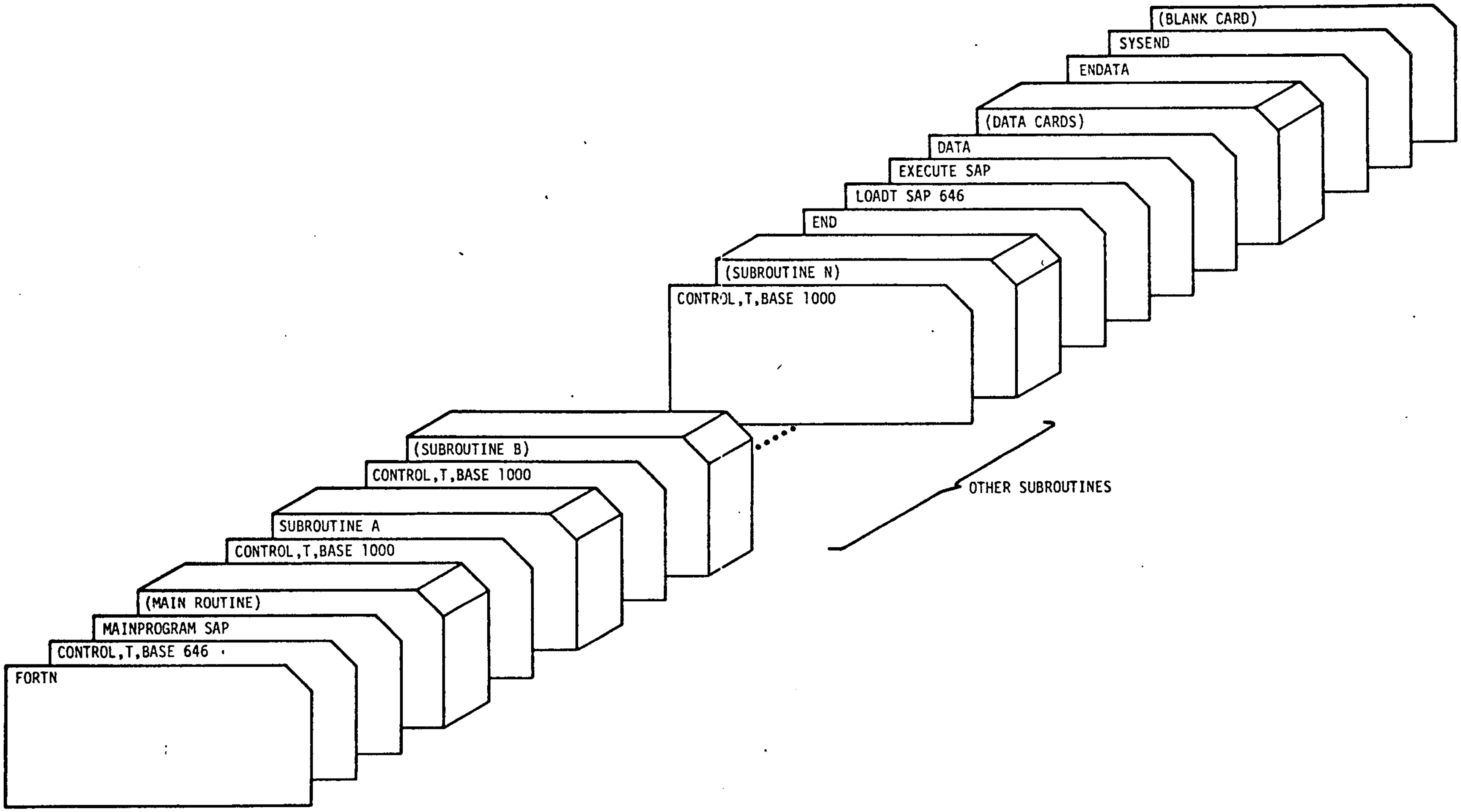



Figure 3-1. Overall Deck Setup

- MAIN PROGRAM NAME

  This card designates the main routine. MAINPROGRAM begins in column seven.

- END

  This card specifies the end of the compilation. END begins in column one.

- LOADT NAME 646

  This card specifies to the Compiler Executive that a previously compiled program, which has been output onto magnetic tape, is to be loaded into the computer starting at location 646. LOADT begins in column one. NAME begins in column eleven. "646" begins in column twenty-one.

- EXECUTE NAME ACCEPT

  This card indicates by name which program is to have control. The word EXECUTE begins in column one. The name of the program (NAME) begins in column eleven. The word ACCEPT is unnecessary unless it is desirable to operate the program under non-fatal error circumstances. ACCEPT starts in column twenty-one.

- DATA

  This card specifies to the Compiler Executive that input data may follow, and that the program is to be executed. This card is necessary to cause the execution of the program even if there are no data cards present. DATA begins in column one.

- ENDATA

  This card signifies the end of the data stream. END begins in column one.

- SYSEND

  This card signals the end of the FORTRAN job and causes control to be transfered back to the Compiler Executive. SYSEND begins in column one.

## 3.2 OUTPUT DESCRIPTION

### 3.2.1 Printed Output

The print output is a listing which includes 1) case title, 2) all input parameters, 3) tape unit residence for input and output tapes, module execution times, and entry point passage, 4) frequency and power (in decibels) for 480 points of the computed spectrum. An example of the printed output is presented in Section 3.4.

### 3.2.2 Plotted Output

The plotted output is a plot of 480 points of the computed power spectrum. The plot ordinate is relative power expressed in decibels in the range 0 to -70 dB; the abscissa is frequency expressed in Hertz, Kilohertz, or Megahertz. Each power component is represented by a vertical line extending from -70 dB to the component value. The case title, carrier frequency, and plot starting frequency are printed in the upper right-hand corner of the plot. An example of power spectrum plot is presented in Section 3.4.

### 3.2.3 Tape Output

SAP generates the SAP plot tape and the SAP spectrum tape. The SAP plot tape contains one data file consisting of two records. Record #1 contains 1) the upper/lower plotting surface designation, 2) case title, 3) plot frequency spacing, 4) carrier frequency, 5) plot starting frequency, 6) number of spectral points to be plotted, and 7) a SAP internally generated parameter (IFC) related to a centered spectrum plot. Record #2 contains up to 480 spectral values (in decibels). The SAP spectrum tape contains one data file consisting of the signal processed through entry point 10. This file contains NCIDT record pairs with NRIDT words per record. A record pair consists of two records - the first containing the real part of the signal and the second containing the imaginary part.

The above two tapes are generated by a normally terminated SAP execution. At intermediate stages of signal processing, the output from a given module is stored on tape as a single file consisting of NCIDT record pairs and NRIDT words per record. As each entry point is passed during execution, a message is printed indicating the number of columns of output data (NCIDT) and the number of rows of output data (NRIDT).

## 3.3 OPERATING PROCEDURE

The operating requirements and procedure for executing SAP is presented below.

I. REQUIREMENTS

A. Program Deck
B. Input signal data tape mounted on tape unit IDT. If signal is to be generated by TSGEN a spare tape is mounted on tape unit IDT.
C. A spare tape is mounted on tape unit IST.
D. CS-1 subroutines MAGTAP and CLØCK on paper tape.

II. OPERATING INSTRUCTIONS

A. Load program deck
B. Set sense switch 6 up
C. Compile program
D. Check load map for starting core storage locations of MAGTAP and CLØCK
E. Load CS-1 routine MAGTAP (paper tape) into correct core location
F. Load CS-1 routine CLØCK (paper tape) into correct core location
G. Reset sense switch 6
H. Execute program

III. OUTPUTS

A. Computer printout
B. SAP plot tape
C. SAP spectrum tape

IV. RESTARTS

A. Check printout for restart information. This information will include:

(1) Last successful entry point completed
(2) Data tape unit
(3) Spare tape unit
(4) Number of rows of data on data tape
(5) Number of columns of data on data tape

B. Reload data cards with the above changes, also load ENDATA, SYSEND, and blank cards.
C. Continue operation starting with Operating Instruction II-H.

V. ADDITIONAL RUNS WITHOUT RECOMPILING

Additional runs may be made by 1) loading data cards, SYSEND and ENDATA control cards, and 2) starting with Operating Instruction II-H.

## 3.4 SAMPLE CASE

A sample case is presented to demonstrate the program capabilities and options. The sample case includes specification of the problem, sample coding form, sample listing of the program input and output, and the associated power spectrum plot.

Example. Compute the power spectrum of a 1 MHz carrier (FC = $1 \times 10^6$) frequency modulated (IFM = 1) by a square wave of frequency 1.5625 Hz (TP = 0.639990) and amplitude unity (A = 1.0). Exactly one period of the square wave will be generated internally (ISOPT = 3). A peak frequency deviation of 200 Hz (BETA = 200.0) is desired. No filtering is to be performed. The output power spectrum, centered about the carrier (FSTART = -1.0), is to be both printed and plotted using the maximum available frequency resolution (NAVE = 1). The spectral region of interest is $1 \times 10^6 \pm 375$ Hz. Based on analytical considerations, the amount of aliasing is estimated to be small in the region of interest if the number of samples is selected to be 1024 (NRIDT = 32 and NCIDT = 32) and the sampling time interval is selected to be $0.625 \times 10^{-3}$ seconds (DT = 0.000625). (The validity of this estimation may be experimentally verified by comparing with a second power spectrum computation in which the number of samples is doubled and the sampling interval is halved. The estimate is valid when the agreement between the first and second computations is within an acceptable tolerance in the region of interest.)

## 3.5 TIMING DATA

Typical timing data for SAP is presented in Table 3-4.

TRW SYSTEMS
HOUSTON COMPUTING CENTER
**SYMBOLIC AND FORTRAN CODING FORM**

DATE ______ NAME ______ EXT ______ NO. OF CARDS ______
PRIORITY ______ PROBLEM NO. ______ SPECIAL CHARACTERS:
CARD STOCK: ☐ PLAIN ______ ☐ FORTRAN SOURCE ☐ 7094 SYMBOLIC
PAGE ____ OF ____ KEYPUNCHED BY ______ VERIFIED BY ______

SYMBOL / C NUMBER | OPERATION / FORTRAN STATEMENT | ADDRESS, TAG, DECREMENT | COMMENTS | SEQUENCE

```
 EXAMPLE 2     MAY 24, 1972
    11   1    1    0    0    0    0    0    3    2    0   32    0    0    0   32
    0    1    0
                200.   .000625 1000000.        -1.
0.6399999       1.0
```

SYSTEMS 7030-H *FORTRAN STATEMENT CONTINUATION

```
********************************************************************************************************************
*                                             * EXAMPLE 2     MAY 31,1972     *                                    *
********************************************************************************************************************

                   IDT IEP IFM IFOPT IFTYP1 IFTYP2 IPLPOS IPMODE ISOPT IST KSR NCIDT NC1 NF1 NF2 NRIDT NR1 NAVE IZPRT
                     1   1   1   0     0      0      0      0      3    2   0   32   0   0   0   32   0    1   0 0 0 0 0 0
AMAX =                0E00,    BETA =   0.20000000E03,    DELT =  0.62500000E-03,    FSTART =          0E00,    FC =   0.10000000E07
********************************************************************************************************************
                                                                   TP               A
                                                            0.63999990E00   1.00000000E00
********************************************************************************************************************

                                   *****************************************************
                                   **                                                 **
                                   **      PROGRAM HAS PASSED ENTRY POINT  100.       **
                                   **            DATA IS CURRENTLY ON UNIT 1.         **
                                   **         SPARE TAPE IS CURRENTLY ON UNIT 2.      **
                                   **  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
                                   ** EXECUTION TIME =  0 MINUTES,    2.968 SECONDS   **
                                   **                                                 **
                                   *****************************************************

                                   *****************************************************
                                   **                                                 **
                                   **      PROGRAM HAS PASSED ENTRY POINT  200.       **
                                   **            DATA IS CURRENTLY ON UNIT 1.         **
                                   **         SPARE TAPE IS CURRENTLY ON UNIT 2.      **
                                   **  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
                                   ** EXECUTION TIME =  0 MINUTES,    4.538 SECONDS   **
                                   **                                                 **
                                   *****************************************************

                                   *****************************************************
                                   **                                                 **
                                   **      PROGRAM HAS PASSED ENTRY POINT  300.       **
                                   **            DATA IS CURRENTLY ON UNIT 1.         **
                                   **         SPARE TAPE IS CURRENTLY ON UNIT 2.      **
                                   **  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
                                   ** EXECUTION TIME =  0 MINUTES,  16.516 SECONDS    **
                                   **                                                 **
                                   *****************************************************

                                   *****************************************************
                                   **                                                 **
                                   **      PROGRAM HAS PASSED ENTRY POINT  400.       **
                                   **            DATA IS CURRENTLY ON UNIT 2.         **
                                   **         SPARE TAPE IS CURRENTLY ON UNIT 1.      **
                                   **  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
                                   ** EXECUTION TIME =  1 MINUTES,    3.427 SECONDS   **
                                   **                                                 **
                                   *****************************************************

                                   *****************************************************
                                   **                                                 **
                                   **      PROGRAM HAS PASSED ENTRY POINT  500.       **
                                   **            DATA IS CURRENTLY ON UNIT 1.         **
                                   **         SPARE TAPE IS CURRENTLY ON UNIT 2.      **
                                   **  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
                                   ** EXECUTION TIME =  0 MINUTES,    9.347 SECONDS   **
                                   **                                                 **
                                   *****************************************************
```

```
*****************************************************
**                                                 **
**     PROGRAM HAS PASSED ENTRY POINT  600.        **
**         DATA IS CURRENTLY ON UNIT 2.            **
**       SPARE TAPE IS CURRENTLY ON UNIT 1.        **
**  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
** EXECUTION TIME =  1 MINUTES,   1.521 SECONDS    **
**                                                 **
*****************************************************

*****************************************************
**                                                 **
**     PROGRAM HAS PASSED ENTRY POINT  700.        **
**         DATA IS CURRENTLY ON UNIT 1.            **
**       SPARE TAPE IS CURRENTLY ON UNIT 2.        **
**  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
** EXECUTION TIME =  0 MINUTES,  26.222 SECONDS    **
**                                                 **
*****************************************************

*****************************************************
**                                                 **
**     PROGRAM HAS PASSED ENTRY POINT  800.        **
**         DATA IS CURRENTLY ON UNIT 2.            **
**       SPARE TAPE IS CURRENTLY ON UNIT 1.        **
**  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
** EXECUTION TIME =  1 MINUTES,   8.054 SECONDS    **
**                                                 **
*****************************************************

*****************************************************
**                                                 **
**     PROGRAM HAS PASSED ENTRY POINT  900.        **
**         DATA IS CURRENTLY ON UNIT 2.            **
**       SPARE TAPE IS CURRENTLY ON UNIT 1.        **
**  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
** EXECUTION TIME =  0 MINUTES,   0.816 SECONDS    **
**                                                 **
*****************************************************

*****************************************************
**                                                 **
**     PROGRAM HAS PASSED ENTRY POINT 1000.        **
**         DATA IS CURRENTLY ON UNIT 1.            **
**       SPARE TAPE IS CURRENTLY ON UNIT 2.        **
**  THERE ARE  32 ROWS AND  32 COLUMNS OF DATA.    **
** EXECUTION TIME =  0 MINUTES,   6.806 SECONDS    **
**                                                 **
*****************************************************
**************************************************************************************************************************************
```

| F(K) | P(K) | F(K) | P(K) | F(K) | P(K) | F(K) | P(K) |
|---|---|---|---|---|---|---|---|
| 0.99962500E06 | -0.70000000E02 | 0.99981250E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10001875E07 | -0.70000000E02 |
| 0.99962656E06 | -0.47334565E02 | 0.99981406E06 | -0.22731644E02 | 0.10000000E07 | -0.40305256E02 | 0.10001891E07 | -0.20611214E02 |
| 0.99962812E06 | -0.70000000E02 | 0.99981562E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10001906E07 | -0.70000000E02 |
| 0.99962969E06 | -0.47143814E02 | 0.99981719E06 | -0.24411345E02 | 0.10000000E07 | -0.40300892E02 | 0.10001922E07 | -0.17750607E02 |
| 0.99963125E06 | -0.70000000E02 | 0.99981875E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10001937E07 | -0.70000000E02 |
| 0.99963281E06 | -0.46950013E02 | 0.99982031E06 | -0.25798450E02 | 0.10000000E07 | -0.40292145E02 | 0.10001953E07 | -0.13374833E02 |
| 0.99963437E06 | -0.70000000E02 | 0.99982187E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10001969E07 | -0.70000000E02 |
| 0.99963594E06 | -0.46752597E02 | 0.99982344E06 | -0.26976664E02 | 0.10000000E07 | -0.40279013E02 | 0.10001984E07 | -0.38930183E01 |
| 0.99963750E06 | -0.70000000E02 | 0.99982500E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002000E07 | 0E00 |
| 0.99963906E06 | -0.46551933E02 | 0.99982656E06 | -0.27998678E02 | 0.10000000E07 | -0.40261462E02 | 0.10002016E07 | -0.39529613E01 |
| 0.99964062E06 | -0.70000000E02 | 0.99982812E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002031E07 | -0.70000000E02 |
| 0.99964219E06 | -0.46347263E02 | 0.99982969E06 | -0.28898589E02 | 0.10000000E07 | -0.40239490E02 | 0.10002047E07 | -0.13554742E02 |
| 0.99964375E06 | -0.70000000E02 | 0.99983125E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002062E07 | -0.70000000E02 |
| 0.99964531E06 | -0.46136926E02 | 0.99983281E06 | -0.29701113E02 | 0.10000000E07 | -0.40213045E02 | 0.10002078E07 | -0.18050403E02 |
| 0.99964687E06 | -0.70000000E02 | 0.99983437E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002094E07 | -0.70000000E02 |
| 0.99964844E06 | -0.45926177E02 | 0.99983594E06 | -0.30423668E02 | 0.10000000E07 | -0.40182116E02 | 0.10002109E07 | -0.21031140E02 |
| 0.99965000E06 | -0.70000000E02 | 0.99983750E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002125E07 | -0.70000000E02 |
| 0.99965156E06 | -0.45710618E02 | 0.99983906E06 | -0.31079678E02 | 0.10000000E07 | -0.40146590E02 | 0.10002141E07 | -0.23271413E02 |
| 0.99965312E06 | -0.70000000E02 | 0.99984062E06 | -0.70000000E02 | 0.10000000E07 | -0.70000000E02 | 0.10002156E07 | -0.70000000E02 |
| 0.99965469E06 | -0.45489481E02 | 0.99984219E06 | -0.31679007E02 | 0.10000000E07 | -0.40106512E02 | 0.10002172E07 | -0.25071382E02 |
| 0.99965625E06 | -0.70000000E02 | 0.99984375E06 | -0.70000000E02 | 0.10000312E07 | -0.70000000E02 | 0.10002187E07 | -0.70000000E02 |
| 0.99965781E06 | -0.45264350E02 | 0.99984531E06 | -0.32229831E02 | 0.10000328E07 | -0.40061752E02 | 0.10002203E07 | -0.26578663E02 |
| 0.99965937E06 | -0.70000000E02 | 0.99984687E06 | -0.70000000E02 | 0.10000344E07 | -0.70000000E02 | 0.10002219E07 | -0.70000000E02 |
| 0.99966094E06 | -0.45034448E02 | 0.99984844E06 | -0.32738255E02 | 0.10000359E07 | -0.40012281E02 | 0.10002234E07 | -0.27877466E02 |
| 0.99966250E06 | -0.70000000E02 | 0.99985000E06 | -0.70000000E02 | 0.10000375E07 | -0.70000000E02 | 0.10002250E07 | -0.70000000E02 |
| 0.99966406E06 | -0.44800024E02 | 0.99985156E06 | -0.33210198E02 | 0.10000391E07 | -0.39957974E02 | 0.10002266E07 | -0.29019463E02 |
| 0.99966562E06 | -0.70000000E02 | 0.99985312E06 | -0.70000000E02 | 0.10000406E07 | -0.70000000E02 | 0.10002281E07 | -0.70000000E02 |
| 0.99966719E06 | -0.44560283E02 | 0.99985469E06 | -0.33648802E02 | 0.10000422E07 | -0.39898813E02 | 0.10002297E07 | -0.30040235E02 |
| 0.99966875E06 | -0.70000000E02 | 0.99985625E06 | -0.70000000E02 | 0.10000437E07 | -0.70000000E02 | 0.10002312E07 | -0.70000000E02 |
| 0.99967031E06 | -0.44315454E02 | 0.99985781E06 | -0.34058354E02 | 0.10000453E07 | -0.39834654E02 | 0.10002328E07 | -0.30963480E02 |
| 0.99967187E06 | -0.70000000E02 | 0.99985937E06 | -0.70000000E02 | 0.10000469E07 | -0.70000000E02 | 0.10002344E07 | -0.70000000E02 |
| 0.99967344E06 | -0.44064894E02 | 0.99986094E06 | -0.34441582E02 | 0.10000484E07 | -0.39765477E02 | 0.10002359E07 | -0.31807125E02 |
| 0.99967500E06 | -0.70000000E02 | 0.99986250E06 | -0.70000000E02 | 0.10000500E07 | -0.70000000E02 | 0.10002375E07 | -0.70000000E02 |
| 0.99967656E06 | -0.43809191E02 | 0.99986406E06 | -0.34801197E02 | 0.10000516E07 | -0.39690912E02 | 0.10002391E07 | -0.32584071E02 |
| 0.99967812E06 | -0.70000000E02 | 0.99986562E06 | -0.70000000E02 | 0.10000531E07 | -0.70000000E02 | 0.10002406E07 | -0.70000000E02 |
| 0.99967969E06 | -0.43546879E02 | 0.99986719E06 | -0.35139125E02 | 0.10000547E07 | -0.39611222E02 | 0.10002422E07 | -0.33304903E02 |
| 0.99968125E06 | -0.70000000E02 | 0.99986875E06 | -0.70000000E02 | 0.10000562E07 | -0.70000000E02 | 0.10002437E07 | -0.70000000E02 |
| 0.99968281E06 | -0.43278501E02 | 0.99987031E06 | -0.35457416E02 | 0.10000578E07 | -0.39526010E02 | 0.10002453E07 | -0.33977286E02 |
| 0.99968437E06 | -0.70000000E02 | 0.99987187E06 | -0.70000000E02 | 0.10000594E07 | -0.70000000E02 | 0.10002469E07 | -0.70000000E02 |
| 0.99968594E06 | -0.43003344E02 | 0.99987344E06 | -0.35757532E02 | 0.10000609E07 | -0.39435226E02 | 0.10002484E07 | -0.34608035E02 |
| 0.99968750E06 | -0.70000000E02 | 0.99987500E06 | -0.70000000E02 | 0.10000625E07 | -0.70000000E02 | 0.10002500E07 | -0.70000000E02 |
| 0.99968906E06 | -0.42721460E02 | 0.99987656E06 | -0.36041213E02 | 0.10000641E07 | -0.39338624E02 | 0.10002516E07 | -0.35201071E02 |
| 0.99969062E06 | -0.70000000E02 | 0.99987812E06 | -0.70000000E02 | 0.10000656E07 | -0.70000000E02 | 0.10002531E07 | -0.70000000E02 |
| 0.99969219E06 | -0.42431985E02 | 0.99987969E06 | -0.36309248E02 | 0.10000672E07 | -0.39236144E02 | 0.10002547E07 | -0.35762550E02 |
| 0.99969375E06 | -0.70000000E02 | 0.99988125E06 | -0.70000000E02 | 0.10000687E07 | -0.70000000E02 | 0.10002562E07 | -0.70000000E02 |
| 0.99969531E06 | -0.42134645E02 | 0.99988281E06 | -0.36563057E02 | 0.10000703E07 | -0.39127507E02 | 0.10002578E07 | -0.36294761E02 |
| 0.99969687E06 | -0.70000000E02 | 0.99988437E06 | -0.70000000E02 | 0.10000719E07 | -0.70000000E02 | 0.10002594E07 | -0.70000000E02 |
| 0.99969844E06 | -0.41828767E02 | 0.99988594E06 | -0.36803465E02 | 0.10000734E07 | -0.39012593E02 | 0.10002609E07 | -0.36801145E02 |
| 0.99970000E06 | -0.70000000E02 | 0.99988750E06 | -0.70000000E02 | 0.10000750E07 | -0.70000000E02 | 0.10002625E07 | -0.70000000E02 |
| 0.99970156E06 | -0.41516286E02 | 0.99988906E06 | -0.37031491E02 | 0.10000766E07 | -0.38890980E02 | 0.10002641E07 | -0.37283902E02 |
| 0.99970312E06 | -0.70000000E02 | 0.99989062E06 | -0.70000000E02 | 0.10000781E07 | -0.70000000E02 | 0.10002656E07 | -0.70000000E02 |
| 0.99970469E06 | -0.41192304E02 | 0.99989219E06 | -0.37247715E02 | 0.10000797E07 | -0.38762703E02 | 0.10002672E07 | -0.37745679E02 |
| 0.99970625E06 | -0.70000000E02 | 0.99989375E06 | -0.70000000E02 | 0.10000812E07 | -0.70000000E02 | 0.10002687E07 | -0.70000000E02 |
| 0.99970781E06 | -0.40859211E02 | 0.99989531E06 | -0.37452973E02 | 0.10000828E07 | -0.38627293E02 | 0.10002703E07 | -0.38188007E02 |
| 0.99970937E06 | -0.70000000E02 | 0.99989687E06 | -0.70000000E02 | 0.10000844E07 | -0.70000000E02 | 0.10002719E07 | -0.70000000E02 |
| 0.99971094E06 | -0.40515546E02 | 0.99989844E06 | -0.37647613E02 | 0.10000859E07 | -0.38484558E02 | 0.10002734E07 | -0.38612859E02 |
| 0.99971250E06 | -0.70000000E02 | 0.99990000E06 | -0.70000000E02 | 0.10000875E07 | -0.70000000E02 | 0.10002750E07 | -0.70000000E02 |
| 0.99971406E06 | -0.40160954E02 | 0.99990156E06 | -0.37833180E02 | 0.10000891E07 | -0.38334061E02 | 0.10002766E07 | -0.39020959E02 |
| 0.99971562E06 | -0.70000000E02 | 0.99990312E06 | -0.70000000E02 | 0.10000906E07 | -0.70000000E02 | 0.10002781E07 | -0.70000000E02 |
| 0.99971719E06 | -0.39794136E02 | 0.99990469E06 | -0.38008698E02 | 0.10000922E07 | -0.38175607E02 | 0.10002797E07 | -0.39414584E02 |
| 0.99971875E06 | -0.70000000E02 | 0.99990625E06 | -0.70000000E02 | 0.10000937E07 | -0.70000000E02 | 0.10002812E07 | -0.70000000E02 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.99972031E06 | -0.39414563E02 | 0.99990781E06 | -0.38175606E02 | 0.10000953E07 | -0.38008700E02 | 0.10002828E07 | -0.39794136E02 |
| 0.99972187E06 | -0.70000000E02 | 0.99990937E06 | -0.70000000E02 | 0.10000969E07 | -0.70000000E02 | 0.10002844E07 | -0.70000000E02 |
| 0.99972344E06 | -0.39020960E02 | 0.99991094E06 | -0.38334061E02 | 0.10000984E07 | -0.37833188E02 | 0.10002859E07 | -0.40160956E02 |
| 0.99972500E06 | -0.70000000E02 | 0.99991250E06 | -0.70000000E02 | 0.10001000E07 | -0.70000000E02 | 0.10002875E07 | -0.70000000E02 |
| 0.99972656E06 | -0.38612857E02 | 0.99991406E06 | -0.38484557E02 | 0.10001016E07 | -0.37647604E02 | 0.10002891E07 | -0.40515546E02 |
| 0.99972812E06 | -0.70000000E02 | 0.99991562E06 | -0.70000000E02 | 0.10001031E07 | -0.70000000E02 | 0.10002906E07 | -0.70000000E02 |
| 0.99972969E06 | -0.38188006E02 | 0.99991719E06 | -0.38627293E02 | 0.10001047E07 | -0.37452971E02 | 0.10002922E07 | -0.40859212E02 |
| 0.99973125E06 | -0.70000000E02 | 0.99991875E06 | -0.70000000E02 | 0.10001062E07 | -0.70000000E02 | 0.10002937E07 | -0.70000000E02 |
| 0.99973281E06 | -0.37745678E02 | 0.99992031E06 | -0.38762703E02 | 0.10001078E07 | -0.37247714E02 | 0.10002953E07 | -0.41192306E02 |
| 0.99973437E06 | -0.70000000E02 | 0.99992187E06 | -0.70000000E02 | 0.10001094E07 | -0.70000000E02 | 0.10002969E07 | -0.70000000E02 |
| 0.99973594E06 | -0.37283902E02 | 0.99992344E06 | -0.38890981E02 | 0.10001109E07 | -0.37031491E02 | 0.10002984E07 | -0.41516298E02 |
| 0.99973750E06 | -0.70000000E02 | 0.99992500E06 | -0.70000000E02 | 0.10001125E07 | -0.70000000E02 | 0.10003000E07 | -0.70000000E02 |
| 0.99973906E06 | -0.36801144E02 | 0.99992656E06 | -0.39012591E02 | 0.10001141E07 | -0.36803463E02 | 0.10003016E07 | -0.41828780E02 |
| 0.99974062E06 | -0.70000000E02 | 0.99992812E06 | -0.70000000E02 | 0.10001156E07 | -0.70000000E02 | 0.10003031E07 | -0.70000000E02 |
| 0.99974219E06 | -0.36294762E02 | 0.99992969E06 | -0.39127507E02 | 0.10001172E07 | -0.36563056E02 | 0.10003047E07 | -0.42134844E02 |
| 0.99974375E06 | -0.70000000E02 | 0.99993125E06 | -0.70000000E02 | 0.10001187E07 | -0.70000000E02 | 0.10003062E07 | -0.70000000E02 |
| 0.99974531E06 | -0.35762550E02 | 0.99993281E06 | -0.39236144E02 | 0.10001203E07 | -0.36309248E02 | 0.10003078E07 | -0.42431984E02 |
| 0.99974687E06 | -0.70000000E02 | 0.99993437E06 | -0.70000000E02 | 0.10001219E07 | -0.70000000E02 | 0.10003094E07 | -0.70000000E02 |
| 0.99974844E06 | -0.35201074E02 | 0.99993594E06 | -0.39338625E02 | 0.10001234E07 | -0.36041214E02 | 0.10003109E07 | -0.42721480E02 |
| 0.99975000E06 | -0.70000000E02 | 0.99993750E06 | -0.70000000E02 | 0.10001250E07 | -0.70000000E02 | 0.10003125E07 | -0.70000000E02 |
| 0.99975156E06 | -0.34608031E02 | 0.99993906E06 | -0.39435225E02 | 0.10001266E07 | -0.35757530E02 | 0.10003141E07 | -0.43003343E02 |
| 0.99975312E06 | -0.70000000E02 | 0.99994062E06 | -0.70000000E02 | 0.10001281E07 | -0.70000000E02 | 0.10003156E07 | -0.70000000E02 |
| 0.99975469E06 | -0.33977284E02 | 0.99994219E06 | -0.39526011E02 | 0.10001297E07 | -0.35457415E02 | 0.10003172E07 | -0.43278501E02 |
| 0.99975625E06 | -0.70000000E02 | 0.99994375E06 | -0.70000000E02 | 0.10001312E07 | -0.70000000E02 | 0.10003187E07 | -0.70000000E02 |
| 0.99975781E06 | -0.33304901E02 | 0.99994531E06 | -0.39611223E02 | 0.10001328E07 | -0.35139125E02 | 0.10003203E07 | -0.43546880E02 |
| 0.99975937E06 | -0.70000000E02 | 0.99994687E06 | -0.70000000E02 | 0.10001344E07 | -0.70000000E02 | 0.10003219E07 | -0.70000000E02 |
| 0.99976094E06 | -0.32584071E02 | 0.99994844E06 | -0.39690916E02 | 0.10001359E07 | -0.34801197E02 | 0.10003234E07 | -0.43809192E02 |
| 0.99976250E06 | -0.70000000E02 | 0.99995000E06 | -0.70000000E02 | 0.10001375E07 | -0.70000000E02 | 0.10003250E07 | -0.70000000E02 |
| 0.99976406E06 | -0.31807123E02 | 0.99995156E06 | -0.39765474E02 | 0.10001391E07 | -0.34441581E02 | 0.10003266E07 | -0.44064893E02 |
| 0.99976562E06 | -0.70000000E02 | 0.99995312E06 | -0.70000000E02 | 0.10001406E07 | -0.70000000E02 | 0.10003281E07 | -0.70000000E02 |
| 0.99976719E06 | -0.30963480E02 | 0.99995469E06 | -0.39834654E02 | 0.10001422E07 | -0.34058354E02 | 0.10003297E07 | -0.44315454E02 |
| 0.99976875E06 | -0.70000000E02 | 0.99995625E06 | -0.70000000E02 | 0.10001437E07 | -0.70000000E02 | 0.10003312E07 | -0.70000000E02 |
| 0.99977031E06 | -0.30040235E02 | 0.99995781E06 | -0.39898813E02 | 0.10001453E07 | -0.33648802E02 | 0.10003328E07 | -0.44560283E02 |
| 0.99977187E06 | -0.70000000E02 | 0.99995937E06 | -0.70000000E02 | 0.10001469E07 | -0.70000000E02 | 0.10003344E07 | -0.70000000E02 |
| 0.99977344E06 | -0.29019464E02 | 0.99996094E06 | -0.39957974E02 | 0.10001484E07 | -0.33210202E02 | 0.10003359E07 | -0.44800025E02 |
| 0.99977500E06 | -0.70000000E02 | 0.99996250E06 | -0.70000000E02 | 0.10001500E07 | -0.70000000E02 | 0.10003375E07 | -0.70000000E02 |
| 0.99977656E06 | -0.27877464E02 | 0.99996406E06 | -0.40012281E02 | 0.10001516E07 | -0.32738251E02 | 0.10003391E07 | -0.45034448E02 |
| 0.99977812E06 | -0.70000000E02 | 0.99996562E06 | -0.70000000E02 | 0.10001531E07 | -0.70000000E02 | 0.10003406E07 | -0.70000000E02 |
| 0.99977969E06 | -0.26578662E02 | 0.99996719E06 | -0.40061753E02 | 0.10001547E07 | -0.32229830E02 | 0.10003422E07 | -0.45264351E02 |
| 0.99978125E06 | -0.70000000E02 | 0.99996875E06 | -0.70000000E02 | 0.10001562E07 | -0.70000000E02 | 0.10003437E07 | -0.70000000E02 |
| 0.99978281E06 | -0.25071382E02 | 0.99997031E06 | -0.40106513E02 | 0.10001578E07 | -0.31679006E02 | 0.10003453E07 | -0.45489482E02 |
| 0.99978437E06 | -0.70000000E02 | 0.99997187E06 | -0.70000000E02 | 0.10001594E07 | -0.70000000E02 | 0.10003469E07 | -0.70000000E02 |
| 0.99978594E06 | -0.23271413E02 | 0.99997344E06 | -0.40146592E02 | 0.10001609E07 | -0.31079678E02 | 0.10003484E07 | -0.45710622E02 |
| 0.99978750E06 | -0.70000000E02 | 0.99997500E06 | -0.70000000E02 | 0.10001625E07 | -0.70000000E02 | 0.10003500E07 | -0.70000000E02 |
| 0.99978906E06 | -0.21031139E02 | 0.99997656E06 | -0.40182115E02 | 0.10001641E07 | -0.30423667E02 | 0.10003516E07 | -0.45926174E02 |
| 0.99979062E06 | -0.70000000E02 | 0.99997812E06 | -0.70000000E02 | 0.10001656E07 | -0.70000000E02 | 0.10003531E07 | -0.70000000E02 |
| 0.99979219E06 | -0.18050402E02 | 0.99997969E06 | -0.40213046E02 | 0.10001672E07 | -0.29701113E02 | 0.10003547E07 | -0.46138927E02 |
| 0.99979375E06 | -0.70000000E02 | 0.99998125E06 | -0.70000000E02 | 0.10001687E07 | -0.70000000E02 | 0.10003562E07 | -0.70000000E02 |
| 0.99979531E06 | -0.13554741E02 | 0.99998281E06 | -0.40239491E02 | 0.10001703E07 | -0.28898589E02 | 0.10003578E07 | -0.46347262E02 |
| 0.99979687E06 | -0.70000000E02 | 0.99998437E06 | -0.70000000E02 | 0.10001719E07 | -0.70000000E02 | 0.10003594E07 | -0.70000000E02 |
| 0.99979844E06 | -0.39529608E01 | 0.99998594E06 | -0.40261464E02 | 0.10001734E07 | -0.27998680E02 | 0.10003609E07 | -0.46551933E02 |
| 0.99980000E06 | -0.14263706E-06 | 0.99998750E06 | -0.70000000E02 | 0.10001750E07 | -0.70000000E02 | 0.10003625E07 | -0.70000000E02 |
| 0.99980156E06 | -0.38930186E01 | 0.99998906E06 | -0.40279015E02 | 0.10001766E07 | -0.26976662E02 | 0.10003641E07 | -0.46752597E02 |
| 0.99980312E06 | -0.70000000E02 | 0.99999062E06 | -0.70000000E02 | 0.10001781E07 | -0.70000000E02 | 0.10003656E07 | -0.70000000E02 |
| 0.99980469E06 | -0.13374833E02 | 0.99999219E06 | -0.40292148E02 | 0.10001797E07 | -0.25798450E02 | 0.10003672E07 | -0.46950014E02 |
| 0.99980625E06 | -0.70000000E02 | 0.99999375E06 | -0.70000000E02 | 0.10001812E07 | -0.70000000E02 | 0.10003687E07 | -0.70000000E02 |
| 0.99980781E06 | -0.17750607E02 | 0.99999531E06 | -0.40300897E02 | 0.10001828E07 | -0.24411345E02 | 0.10003703E07 | -0.47143815E02 |
| 0.99980937E06 | -0.70000000E02 | 0.99999687E06 | -0.70000000E02 | 0.10001844E07 | -0.70000000E02 | 0.10003719E07 | -0.70000000E02 |
| 0.99981094E06 | -0.20611215E02 | 0.99999644E06 | -0.40305273E02 | 0.10001859E07 | -0.22731645E02 | 0.10003734E07 | -0.47334567E02 |

**************************************************************************************************************
**************************************************************************************************************

AMAX = 0.25003932E00

```
*************************************************************************************************************************
                                   RUN TERMINATED. PLOT DATA TAPE GENERATED ON UNIT 2
*************************************************************************************************************************
                                      ** EXECUTION TIME =  5 MINUTES,  37.985 SECONDS **
                                      **                                              **
                                      **************************************************
```

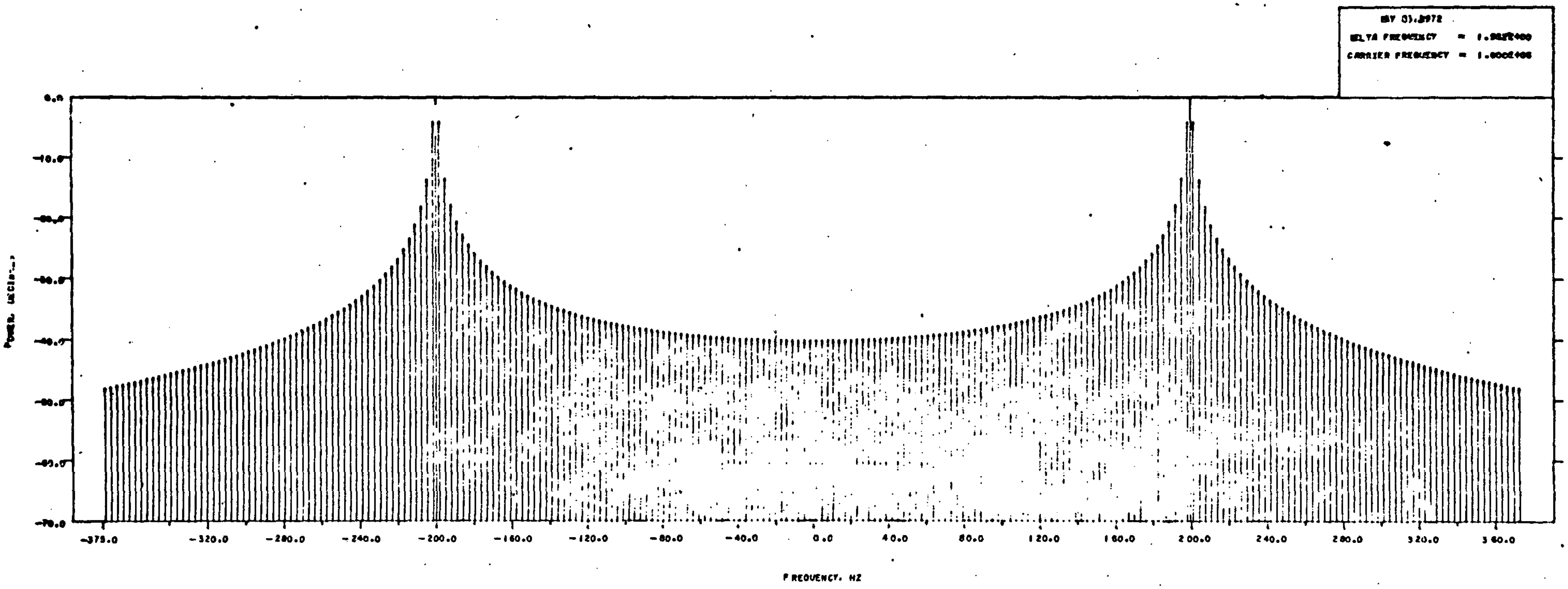

-375.0
-320.0
-280.0
-240.0
-200.0
-160.0
-120.0
-80.0
-40.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
360.0
FREQUENCY, HZ

TABLE 3-4

TIMING DATA FOR UNIVAC 1230 SPECTRAL ANALYSIS PROGRAM

| NUMBER OF SAMPLES | NCIDT X NRIDT | EXECUTION TIME | COMMENTS |
|---|---|---|---|
| 1,024 | 32 x 32 | 5 min, 38 sec | No filtering performed |
| 4,096 | 64 x 64 | 20 min, 19 sec | No filtering performed |
| 4,096 | 64 x 64 | 32 min, 13 sec | Bandpass filtered |
| 16,384 | 128 x 128 | 80 min, 41 sec | No filtering performed |

# 4. PLOT GENERATION PROGRAM

## 4.1 DESCRIPTION

The PLTGEN Program is a stand alone FORTRAN program, designed to read a data tape generated by the SAP program, convert the data into plot commands for the EAI 3440 DATAPLOTTER, and write these commands on a magnetic tape.

The plot subroutines may be divided into two categories: the basic plot routines and the routines designed specifically for the construction of the spectral analysis plot.

The basic plot routines provide the general functions of a plot package. These subroutines initialize the scale factors, raise and lower the pen, move the pen from one position to another, write formatted numbers, print character strings, and write these formatted plot commands on a magnetic tape.

The special plot routines utilize the basic routines in forming the grid, annotating the axes, and plotting the spectrum. The main program PLTGEN, is the driver, which calls the special subroutines in the proper sequence to complete the desired plot. There are nine subroutines in addition to the main program. The basic subroutines are: COMAND, INITIAL, NUMBER, PEN, PLOTPT, and PRINT. The specific routines are ANNOTE, PLOTER, and GRID. These subroutines are each briefly described below.

COMAND - Subroutine COMAND is called each time a plot command is written on the output plot tape. An X and Y command code, which specifies the command function, and corresponding X and Y numerical value is received through the calling arguments, formatted into an eight word record, and written on the output plot tape.

INITAL - This routine is used to initialize the EAI 3440 Dataplotter by constructing the scale factor, data offset, and board offset commands. These three commands must be the first three written on the output plot tape.

NUMBER - Subroutine NUMBER converts a floating point number into a formatted Hollerith string. The Hollerith string is contained in an array having one Hollerith character stored left adjusted in each word. The two formats available are the F7.1 and the scientific notation E10.3. The formatted string is then passed to subroutine PRINT for further processing.

PEN - This subroutine is used to select the plot pen or the printer. After the plot pen has been selected, subroutine PEN is used to place the pen in the up or down position.

PLOTPT - The purpose of subroutine PLOTPT is to construct a command to move the plot pen from its present position to a new (X,Y) position. The plot pen may be in either the up or down position when the PLOTPT command is given.

PRINT - Subroutine PRINT converts a string of Hollerith characters into the EAI 3440 DATAPLOTTER character set. The Hollerith string of characters must be contained in an array having one Hollerith character left adjusted in each word. The Hollerith string will be printed with the first character at a specified (X,Y) position. The orientation of the characters and the distance between characters must also be specified through the calling arguments.

ANNOTE - Subroutine ANNOTE calculates a scale appropriate for the amplitude and frequency bandwidth of the spectrum being plotted. The carrier frequency is used as a bias frequency and each frequency label is biased by that amount. The placement of the tic marks along the x axis is determined so that the corresponding labels are in even increments of frequency. The Y axis is labeled from 0.0 to -70.0 dB using increments of -10.0 dB. A plot title and other pertinent spectral frequency information is printed in a title box in the upper right corner of the plot.

PLOTER - This subroutine is used to draw the spectral lines on the plot. The input data array is received through Labeled Common /A/. A straight line is drawn from the x axis to each amplitude value in the data array.

GRID - The purpose of this routine is to draw a rectangular box 25 inches by 7 inches with tic marks 1 inch apart along the two 7 inch sides. A small title box is drawn in the upper right corner of the rectangular box.

## 4.2 OPERATING INSTRUCTIONS

The PLTGEN Program can be loaded into the UNIVAC 1230 computer by reading the card deck or the magnetic tape containing the compiled program. Execution of the program requires a small deck consisting of five cards (see Figure 4-1). These cards must be read for each data case. These cards will be described in more detail below. The PLTGEN Program requires approximately five minutes to load from the card deck and about one minute to read from the compiled tape. The execution time required for one data case is approximately one minute.

In executing the program, the UNIVAC 1230 operator should be instructed to load the PLTGEN Program from the desired input source. He should also be instructed to mount the SAP output spectrum data tape on Unit 2 and a blank plot tape on Unit 1. The five cards required for executing the program should be available for the operator at this time. Multiple cases may be stored on one plot tape by mounting different spectrum data tapes on Unit 2 and re-executing the program. The PLTGEN output plot tape on Unit 1 should not be rewound until all desired cases have been run. The plot tape may be plotted at this time or stored by the operator for plotting at a later time.

Before plotting the PLTGEN output tape, the operator should be instructed to make the proper switch settings on the EAI 3440 plotter control panel. The switch functions and proper settings on this panel are discussed on the following pages. If multiple cases have been written on the tape, the operator should be informed how many plot files are on the tape.

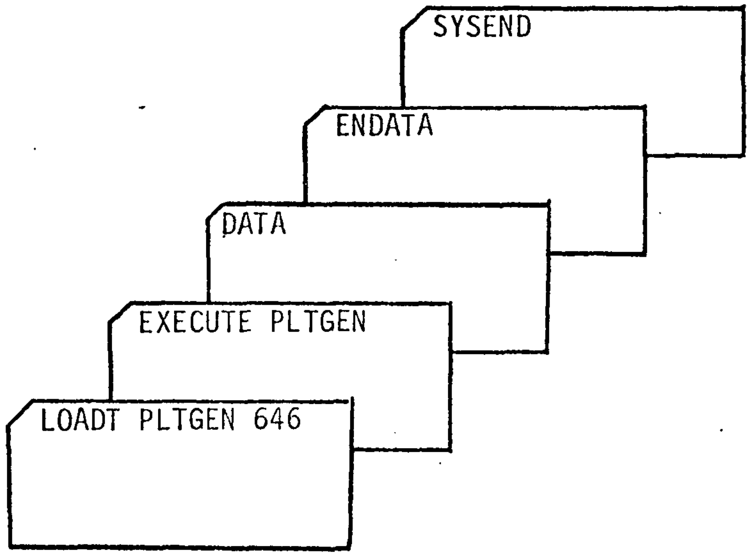



Figure 4-1. Execution Card Deck

## 4.3 OPERATING CONTROLS AND INDICATORS

a. Control Panel 20.700

| CONTROL | FUNCTION | REQUIRED SWITCH POSITION |
|---|---|---|
| X AND Y CHARACTER SELECT | | |
| SIGN | This rotary selector switch allows the operator to select any of the twelve characters in a word as the sign character. With this switch in the zero position the system reads all input data as positive. | 11 |
| COMMAND | The setting of this switch determines which character in the word functions as the X or Y command. If either switch (X or Y) is rotated to zero, both controls are considered to be zero, the command codes from the tape are ignored, and all data is plotted. | 1 |
| THOUSANDS, HUNDREDS, TENS, AND UNITS | These 13-position selector switches provide the operator with a means of selecting any of the twelve characters in a word as the X or Y thousands, hundreds, tens, and units value. | X Y<br>Thousands 2 2<br>Hundreds 3 3<br>Tens 4 4<br>Units 5 5 |
| X AND Y WORD SELECT | | |
| TENS AND UNITS | The X and Y word selectors allow the operator to select any of the first 159 words in a record as the X and Y word for processing. The TENS switch functions as a X10 multiplier and the units selector setting adds to the TENS switch setting. These switches select the word according to the setting of the WORD SIZE switch. Therefore, if the words selectors are set to 150 and the WORD SIZE switch is on 10, the first character in the selected word would be the 149st character in the record. | X Y<br>Tens 0 0<br>Units 1 6 |

| CONTROL | FUNCTION | REQUIRED SWITCH POSITION |
|---|---|---|
| WORD SIZE | This 11-position rotary selector is used to set the number of characters in a data word. The word size is variable from 2 to 12 characters. | 12 |
| TAPE MODE | This switch determines the speed at which information from the tape is read and plotted and also controls the tape transport. In the AUTO position, the tape is momentarily stopped at the end of each record and the command codes cause the appropriate action to occur. In FREE RUN, the tape moves at 75 inches per second and the tape does not stop unless a command other than 0, 0 (skip) or 1, 1(plot) is detected. The tape is stopped for all other commands to allow the machine sufficient time to process the data. When using this position, the accuracy of the plotted graph is dependent upon the distance between points. The MAX POINT DISPLACEMENT switch usually will be rotated to the FREE RUN position when the FREE RUN setting of the TAPE MODE switch is used. | Auto |
| PLOT MODE | The setting of this switch determines whether the system functions to cause the pen to point-plot or line-plot. The POINT position of this switch automatically selects the free run filters for high speed pen and arm movement. | Line |
| MAX POINT DISPLACEMENT | This control consists of two concentrically mounted rotary selector switches. The outer switch is set to the length which will accommodate the maximum distance between two successive points on the graph. The inner switch is used in conjunction with the outer switch to set the time or speed of the plotted points. The inner switch can be placed to a lower setting than necessary if speed rather than maximum accuracy is required. | Outer Switch 5.0 Inch<br>Inner Switch Maximum Clockwise position |

| CONTROL | FUNCTION | REQUIRED SWITCH POSITION |
|---|---|---|
| PARITY ACTION | This switch determines the action taken by the magnetic tape DATAPLOTTER circuitry in the event of a parity error. In the STOP position, a parity error switches the system to a hold status, the BAD PARITY indicator lights, and the fault alarm sounds. If a parity error occurs with this switch in the REJECT position, the accumulators are automatically reset and the tape is started forward. Therefore, in REJECT, data with parity errors is ignored. | Reject |
| SCALING UNITS | The unit of measure used in plotting is set by this switch. The selected position, 1/2 INCH or CM (for centimeter) also determines the distance obtained for each unit of board offset. If the plot is setup in units of half-inches, the same values can be used for plotting in centimeters by simply changing the setting of this switch. No additional changes are necessary since all data conversion is done in the magnetic tape DATAPLOTTER. | 1/2 inch |

APPENDIX A

## 1.1 THE EXTENDED FAST FOURIER TRANSFORM

THE DISCRETE FOURIER TRANSFORM

Both the Fast Fourier Transform (FFT) and the Extended Fast Fourier Transform (EFFT) algorithms compute the discrete Fourier transform or its inverse for a given signal. The discrete Fourier transform pair is defined by

$$X(j) = \frac{1}{N} \sum_{k=0}^{N-1} x(k)\, W_N^{-jk} \qquad \text{(A-1)}$$

$$x(k) = \sum_{j=0}^{N-1} X(j) W_N^{jk} \qquad \text{(A-2)}$$

for j=0, 1, ..., N-1 and k=0, 1, ..., N-1. $W_N$ is defined by

$$W_N = \exp(2\pi i/N) \qquad \text{(A-3)}$$

where $i = \sqrt{-1}$ .

In the above x(k) represents the time-domain function and X(j) represents the frequency-domain function.

Consider the expression

$$\hat{x}(j) = \sum_{k=0}^{N-1} A(k) W_N^{jk} \qquad \text{(A-4)}$$

By comparison with Equations (A-1) and (A-2)

$$\text{if } A(k) = \frac{x^*(k)}{N} \qquad \text{then } \hat{x}(j) = \hat{X}^*(j)$$

and if

$$A(k) = X(j) \qquad \text{then } \hat{x}(j) = x(k)$$

where the * superscript denotes the complex conjugate. Thus, only Equation (A-4) needs to be considered in computing Equations (A-1) and (A-2).

ALGEBRA OF THE EFFT

Suppose N, in Equation (A-4), may be written as

$$N = LM$$

where both M and L are powers of 2.

The indices j and k in Equation (A-4) may be expressed as

$$k = l + mL$$

$$j = m' + l'M$$

where $l = 0, 1, \ldots, L - 1$; $m = 0, 1, \ldots, M - 1$; $m' = 0, 1, \ldots, M - 1$; and $l' = 0, 1, \ldots, L - 1$.

In terms of the new indices Equation (A-4) becomes

$$x(m' + l'M) = \sum_{l=0}^{L-1} \sum_{m=0}^{M-1} A(l + mL)\, W_N^{(m'+l'M)(l+mL)} \tag{A-5}$$

Now

$$W_N^{(m'+l'M)(l+mL)} = \exp\left[\frac{2\pi i}{N}\,(m'+l'M)(l+mL)\right]$$

$$= \exp\left[2\pi i\left(\frac{m'l}{N} + \frac{l'l}{L} + \frac{m'm}{M} + l'm\right)\right]$$

$$= W_N^{m'l}\; W_L^{l'l}\; W_M^{m'm}\; W_1^{l'm}$$

the term $W_1^{l'm} = 1$.

So Equation (A-5) becomes

$$x(m'+l'M) = \sum_{l=0}^{L-1} \sum_{m=0}^{M-1} A(l+mL)\, W_N^{m'l}\, W_L^{l'l}\, W_M^{m'm} \qquad \text{(A-6)}$$

Rewriting Equation (A-6) as

$$\hat{x}(m'+l'M) = \sum_{l=0}^{L-1} W_N^{m'l}\, W_L^{l'l} \sum_{m=0}^{M-1} A(l+mL)\, W_M^{m'm} \qquad \text{(A-7)}$$

In Equation (A-7) define $A_l(m',l)$ by

$$A_l(m',l) = \sum_{m=0}^{M-1} A(l + mL)\, W_M^{m'm} \qquad \text{(A-8)}$$

Comparing Equations (A-8) and (A-4), then $A_l(m',l)$ is the discrete Fourier transform evaluated at index or frequency m' of the series produced by taking every $L^{th}$ sample from A. These samples are produced by beginning from the $l^{th}$ sample of A. There are L of the sequences $A_l(m',l)$, each has M terms.

Defining

$\hat{A}(m',l)$ by

$$\hat{A}(m',l) = W_N^{m'l}\, A_l(m',l) \qquad \text{(A-9)}$$

and substituting into Equation (A-7) yields

$$\hat{x}(m'+l'M) = \sum_{l=0}^{L-1} A(m',l)\, W_L^{l'l} \qquad \text{(A-10)}$$

Comparing Equations (A-10) and (A-4) indicates that $\hat{x}$ is produced by taking the discrete Fourier transform of the M sequences defined by Equation (A-9).

All FFT transform algorithms are based upon factoring N into products and then going through algebra steps as above. The algorithm used as a subroutine in the EFFT routine is based upon factoring N into products of 2.

MATRIX INTERPRETATION

The algebra of the EFFT has a simple interpretation in terms of matrices. Consider the original signal term A(l + mL) in Equation (A-5). The l,m indexing is such that A may be stored as a complex matrix with M rows and L columns. Thus, m is the row index and l is the column index. The discrete Fourier transforms defined by Equation (A-8) represent the separate transforms of each column of the matrix. There are L such columns and each is of length M. After transforming, the complex array represented by $A_1(m',l)$ is stored as a matrix with m' representing the row index and l the column index.

The operation defined by Equation (A-9) represents multiplying each term of the resulting transforms by an appropriate cos + i sin terms. This complex sinusoidal term is called the "twiddle factor."

The discrete Fourier transform defined by Equation (A-10) is produced by transforming separately each row of the complex matrix A. There are M rows and each row has L terms. The row index is m' and the column index is l'.

DETAILS OF THE EFFT ALGORITHM

In order to transform extremely long data sequences, the EFFT routine that has been implemented uses tapes for storage of the input and output signals. Two tapes are required.

The matrix interpretation of the previous section indicates that the general flow of the algorithm must be

1. The data is input, properly stored as a complex matrix on tape 1.
2. Transform each column of the matrix on tape 1 and multiply by the twiddle factor and store on tape 2.

3. Transpose complex matrix on tape 2 and store on tape 1.

4. Transform each column of the matrix on 1 and store final result on tape 2.

The transpose is required as the algebra indicates than in the first set of transforms the <u>columns</u> are operated on while in the second set of transforms the <u>rows</u> are operated on.

The format of the data on the tapes at input or output is as follows: Let AR(I,J) and AI(I,J) denote the real and imaginary components of the complex matrix respectively. The index I corresponds to the row index where I=1, ..., NR. The index J corresponds to the column index where J=1, ..., NC. Then the matrices AR and AI are stored on the tape as

| | | |
|---|---|---|
| Record 1 | AR(I,1) | I = 1, ..., NR |
| Record 2 | AI(I,1) | I = 1, ..., NR |
| Record 3 | AR(I,2) | I = 1, ..., NR |
| Record 4 | AI(I,2) | I = 1, ..., NR |
| . | | |
| . | | |
| . | | |
| Record 2*NC-1 | AR(I,NC) | I = 1, ..., NR |
| Record 2*NC | AI(I,NC) | I = 1, ..., NR |

If at input the row and column dimensions are NR = NR1 and NC = NC1, then at output the row and column dimensions are NR = NC1 and NC = NR1. This interchange of the dimensions of the AR and AI arrays is due to the transpose operation.

The correspondence between the (I,J) indices and the time or frequency variables at either input or output is as follows:

A. If AR and AI represent the real and imaginary parts of a time function, then the value of the time variable t is

$$t = [(j-1) + NC*(I-1)]*\Delta t$$

for J = 1, ..., NC and I = 1, ..., NR and where $\Delta t$ is the time separation between points.

B. If AR and AI represent the real and imaginary parts of a frequency function, then the value of the frequency variable f is

1. For I = 1, NR/2

$$f = [(J-1) + (I-1)*NC]*\Delta f$$

for J = 1, ..., NC and where $\Delta f$ is the frequency separation between points, i.e.,

$$\Delta f = \frac{1}{NR*NC*\Delta t}$$

2. For I = (NR/2) + 1, NR

$$f = -[(NR*NC-(J-1)-(I-1)*NC]*\Delta f$$

for J = 1, ..., NC.

## APPENDIX B
## FILTER TRANSFER FUNCTION IMPLEMENTATION

Subroutine TRFN computes the filter transfer functions for the Butterworth, Chebyshev, and the user specified filters. A detailed discussion and derivation of the Butterworth and Chebyshev transfer functions are available in Reference 1.

Butterworth Filter. The transfer function H(s) for the Butterworth filter is implemented in the form

$$H(s) = \frac{1}{1+a_1 s+a_2 s^2+ \;.\;.\;. \;+a_n s^n}, \qquad \text{(B-1)}$$

where the $a_i$'s are constant coefficients built into the software program and are given in Table A-1, n is the filter order, and $s = j\omega_p$ (defined below).

The Butterworth filter is defined by the maximally flat response function

$$|H(j\omega_p)| = \frac{1}{\sqrt{1 + \omega_p^{2n}}} \quad , \qquad \text{(B-2)}$$

which has poles given by

$$s_k = \exp[j(\frac{2k + n - 1}{n})(\frac{\pi}{2})] \text{ , } k=1, 2, \ldots, 2n. \qquad \text{(B-3)}$$

The coefficients $a_i$ are derived by writing Equation (B-1) as

$$H(s) = \frac{1}{(s-s_1)\ (s-s_2)\ (s-s_3)\ \ldots.\ (s-s_n)} \quad , \qquad \text{(B-4)}$$

Table B-1 Butterworth Filter Coefficients

| n | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ |
|---|---|---|---|---|---|---|
| 1 | 1.0 | | | | | |
| 2 | 1.414213562 | 2.0 | | | | |
| 3 | 2.0 | 2.0 | 1.0 | | | |
| 4 | 2.613125929 | 3.414213562 | 2.613125929 | 1.0 | | |
| 5 | 3.236067977 | 5.236067977 | 5.236067977 | 3.236067977 | 1.0 | |
| 6 | 3.863703305 | 7.464101615 | 9.141620172 | 7.464101615 | 3.863703305 | 1.0 |

substituting the poles $s_1, s_2, s_3, \ldots s_n$, performing the indicated multiplications in (B-4) to obtain the form of (B-1), and normalizing the results such that $H(o) = 1$.

Equation B-1 is in a frequency normalized form such that $|H(j\omega_p)| = 0.707$ when $\omega_p = 1$. Thus, for any order Butterworth filter, $|H(jo)| = 1$ and $|H(j1)| = 0.707$. The normalized form may be applied as a low pass filter by normalizing the frequency $\omega$ to the cut-off frequency $\omega_c$; i.e., $\omega_p = \omega/\omega_c$. Thus, $|H(j\omega)| = 1.0$ when $\omega = 0$ and $|H(j\omega)| = 0.707$ when $\omega = \omega_c$. The normalized form may be applied as a bandpass filter by defining the bandpass center frequency $\omega_o$ and normalizing $\omega$ such that $\omega_p = (\omega-\omega_o)/(\omega_c-\omega_o)$ for $\omega > \omega_o$ and $\omega_p = (\omega_o-\omega)/(\omega_c-\omega_o)$ for $\omega \le \omega_o$. The upper and lower cut-off frequencies are assumed to be symmetrically positioned about $\omega_o$.

Summarizing, Butterworth filtering may be obtained by user specification of (1) the filter order, (2) upper cut-off frequency, and (3) center frequency of bandpass filter. The center frequency is assumed to be zero for a low pass filter.

Chebyshev Filter. The transfer function $H(s)$ for the Chebyshev filter is implemented in the form

$$H(s) = \frac{1}{1 + b_1 s + b_2 s^2 + \ldots + b_n s^n}, \qquad \text{(B-5)}$$

where the $b_i$'s are coefficients computed by the software program, n is the filter order, and $s = j\omega_p$ (defined below).

The Chebyshev filter is defined by the equal ripple response function

$$|H(j\omega_p)| = \frac{1}{\sqrt{1 + \varepsilon^2 C_n^2(\omega_p)}}, \qquad \text{(B-6)}$$

where $\varepsilon$ is the ripple width and $C_n$ is the nth order Chebyshev polynomial. The pole locations ($s_k = \sigma_k + j\omega_k$) of Equation (B-6) are given by

$$\sigma_k = \pm \tanh a \sin\left[\left(\frac{2k-1}{n}\right)\left(\frac{\pi}{2}\right)\right] \tag{B-7}$$

$$\omega_k = \cos\left[\left(\frac{2k-1}{n}\right)\left(\frac{\pi}{2}\right)\right] \tag{B-8}$$

for k = 1, 2, 3, ..., 2n. The parameter a is defined by

$$a = \frac{1}{n} \sinh^{-1} \frac{1}{\varepsilon} . \tag{B-9}$$

Implementation of the Chebyshev filter is somewhat more involved than than the Butterworth filter because the pole locations (for a given filter order) are a function of the input specification $\varepsilon$. Thus, note that the expression for $\sigma_k$ contains the parameter a. Consequently, the coefficients $b_i$ must be computed for each problem-oriented application of the filter. The equations for this computation are presented in Table B-2. Only odd orders are given since only odd order Chebyshev filters are physically realizable for equal source and load impedance.

Equation (B-5) is in a frequency normalized form such that $|H(j\omega_p)| \approx 0.707$ when $\omega_p = 1$. The normalized frequency, $\omega_p$, is defined

$$\omega_p = \omega/(\omega_c \cosh a).$$

The normalized form may be applied as a low pass or bandpass filter using the frequency normalizing relations (divided by the factor cosh a) described in the discussion of the Butterworth filter.

Summarizing Chebyshev filtering may be obtained by user specification of the (1) filter order, (2) upper cut-off frequency, (3) center frequency of bandpass filter, and (4) ripple width $\varepsilon$.

User Filter. The user may simulate an arbitrary filter by specifying selected complex data values of the transfer function and the corresponding frequencies. The software program computes the transfer function at desired frequencies by linearly interpolating the specified data values. For example, if the approximation of a transfer function by m straight-line segments is desired, the user inputs are m break-point frequencies and the associated m complex values of the transfer function.

$$k = \tanh a = \tanh\left[\frac{1}{n} \sinh^{-1} \frac{1}{\varepsilon}\right]$$

| Filter Order n | Equation |
|---|---|
| 1 | $a_1 = 1/k$ |
| 3 | $a_1 = \dfrac{a^2+b^2+2a}{(a^2+b^2)}$ |
| | $a_2 = \dfrac{2a + 1}{(a^2+b^2)}$ |
| | $a_3 = \dfrac{1}{(a^2+b^2)}$ |
| | where $a = k/2$, $b = \sqrt{3}/2$ |
| 5 | $a_1 = 1 + \dfrac{2a}{a^2+b^2} + \dfrac{2c}{c^2+d^2}$ |
| | $a_2 = \dfrac{2a}{a^2+b^2} + \dfrac{2c}{c^2+d^2} + \dfrac{a^2+b^2+c^2+d^2+4ac}{(a^2+b^2)(c^2+d^2)}$ |
| | $a_3 = \dfrac{1}{a^2+b^2} + \dfrac{1}{c^2+d^2} + \dfrac{2a+2c+4ac}{(a^2+b^2)(c^2+d^2}$ |

Table B-2. Chebyshev Filter Coefficients

| Filter Order n | Equation |
|---|---|
| 5 | $a_4 = \frac{1+2a+2c}{(a^2+b^2)(c^2+d^2)}$ |
| | $a_5 = \frac{1}{(a^2+b^2)(c^2+d^2)}$ |
| | where $a = k \cos 36°$, $b = \sin 36°$ |
| | $c = k \cos 72°$, $d = \sin 72°$ |

Table B-2. Chebyshev Filter Coefficients (Continued)

## REFERENCES

1. Final Project Report, Development of Spectral Analysis Math Models and Software Program and Spectral Analyzer - Digital Converter Interface Equipment Design, TRW Technical Report No. 20817-H012-R0-00.

2. Spectral Analysis Program, Volume II - Programmer's Manual, TRW Technical Report No. 20817-H011-R0-00.