Waveform Analysis

Manual Part No. 09845-12601
Cartridge Part No. 09845-12604
Template No. 7120-6735

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Printing History

New editions of this manual will incorporate all material updated since the previous edition. Update packages may be issued between editions and contain replacement and additional pages to be merged into the manual by the user. Each updated page will be indicated by a revision date at the bottom of the page. A vertical bar in the margin indicates the changes on each page. Note that pages which are rearranged due to changes on a previous page are not considered revised.

The manual printing date and part number indicate its current edition. The printing date changes when a new edition is printed. (Minor corrections and updates which are incorporated at reprint do not cause the date to change.) The manual part number changes when extensive technical changes are incorporated.

| August 1982...Updated page 6 and title page.

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INTRODUCTION

The Waveform Analysis Pack is a collection of routines for the entering, analyzing, and then displaying of waveform data. The major routine consists of a Fourier Transform. In short, this routine allows you to perform a transformation on the data from the time domain to the frequency domain. Given this routine, and several others, the user can do a complete and thorough job of characterizing the time waveform.

Information generated by Fourier Analysis can be used to simulate analog systems, enhance predominate characteristics of a signal, and produce signal transformations impossible to realize with analog hardware (e.g., a signal buried in noise from an oscilloscope may be separated and identified.)

The Waveform Analysis Pack utilizes a special form of the Discrete Fourier Transform called the Fast Fourier Transform (FFT) and is simply an efficient method for computing the Discrete Fourier Transform. Although signal analysis may be performed using a Discrete Fourier Transform, the FFT's computational speed warrant use whenever possible.

We hope this pack proves useful to you and welcome your comments.

General Information

The following table shows the amount of memory available for data points for single data blocks.

Memory Size	Full Precision		Short Precision		Integer Precision	
	Time Data	Frequency Data	Time Data	Frequency Data	Time Data	Frequency Data
Standard 56426 Bytes	4096	2048	8192	4096	16384	8192
Option 204 187306 Bytes	16384	8192	32768	16384	32768*	16384*
Option 205 318186 Bytes	32768	16384	32768*	16384*	32768*	16384*
Option 206 449 066 Bytes	32768*	16384*	32768*	16384*	32768*	16384*

The entries in the above table give the maximum of time and frequency domain data points possible for various memory sizes.

For operation with two data blocks, the number of points given in the above table is reduced by a factor of two (for each block).

Calculation Speeds (using full-precision data)

# points	FFT Model 1xx	IFT Model 1xx	FFT Model 2xx	FFT Model 2xx
256	17 sec	15.5 sec	2 sec	2 sec
512	35 sec	32.5 sec	4.5 sec	4 sec
1024	73 sec	69 sec	10 sec	9 sec
2048	155 sec	147 sec	21 sec	19.5 sec
4096	330 sec	314 sec	45 sec	42 sec

*Maximum number of data points limited by data structure not read/write memory.

Required Hardware Configuration

9845B or 9845C (Opt. 001) Desktop Computer

Opt. 311	Graphics ROM	Enables the 9845B to drive the CRT and the 9872
Opt. 700	Graphics package	Adds graphics capability to the 45B CRT
Opt. 560/ 561	Internal thermal printer	Prints data and provides hard copy for CRT plots

- Optional Hardware

  Opt. 204 187306 bytes R/W memory

  Opt. 205 318186 bytes R/W memory

  Opt. 600 Second tape cartridge

  9872 Four Color Plotter [1]

  Other Mass Storage device

  9885M floppy diskette drive

  Opt. 313 Mass Storage ROM

1 The 9872 is not supported as a digitizing device on Options 2XX of the 9845.

START-UP INSTRUCTIONS

1. Insert the Waveform Analysis cartridge into the primary tape transport (i.e., the transport above the special function keys).

2. Load the driver program and run it:
   a. Type: LOAD "AUTOST:T15",10
   b. Press: EXECUTE

   NOTE: If the 9845 is powered down (i.e., first thing in the morning), the program may be loaded by depressing the AUTO ST key on the 9845 so that it is latched in its down position prior to turning the power on. If the AUTO ST key is activated when the 9845 is turned on, the "AUTOST" file is automatically loaded and started.

3. The system configuration is printed on the CRT. When "Do you want instructions on how to start the program?" appears in the display area:
   a. If you want an explanation as to which keys are defined:
      1) Press: YES

or

   a. If you do not want an explanation as to which keys are defined:
      2) Press: NO

4. Press one of the valid keys:

Data input	-- Key Ø	--	Instructions on page 39
Dbl. data in	-- Key 8	--	Instructions on page 64
F(s) equal	-- Key 31	--	Instructions on page 83
F(s) unequal	-- Key 15	--	Instructions on page 103
Demo	-- Key 7	--	Instructions on page 118

5. Refer to the user instructions for the program corresponding to the key you pressed in step 4.

Theory of Fourier Transforms

In order to describe the Fourier transform we first need to define parameters utilized in the frequency and time domains.

Since we are concerned with the discrete form of the Fourier transform, we will define the parameters by examining an analog waveform. Through a sampling process (some A/D) we acquire enough information about the input waveform to mathematically recreate it, thus allowing mathematical processing of the signal. The following parameters that we deal with are shown in Fig. 1, along with their relationships. We may now process the data obtained by our sampling, in a fast efficient method due to its digital form.

For the time domain, the parameters are as follows:

- Δt - the time between samples, called the "time interval"
- N - the number of samples taken; this is the data block size
- T - the total time of the sample record, also called "time window". From Fig. 1 it can be seen that: time window = (no. of samples) x (time interval)

$$T = N \times \Delta t$$

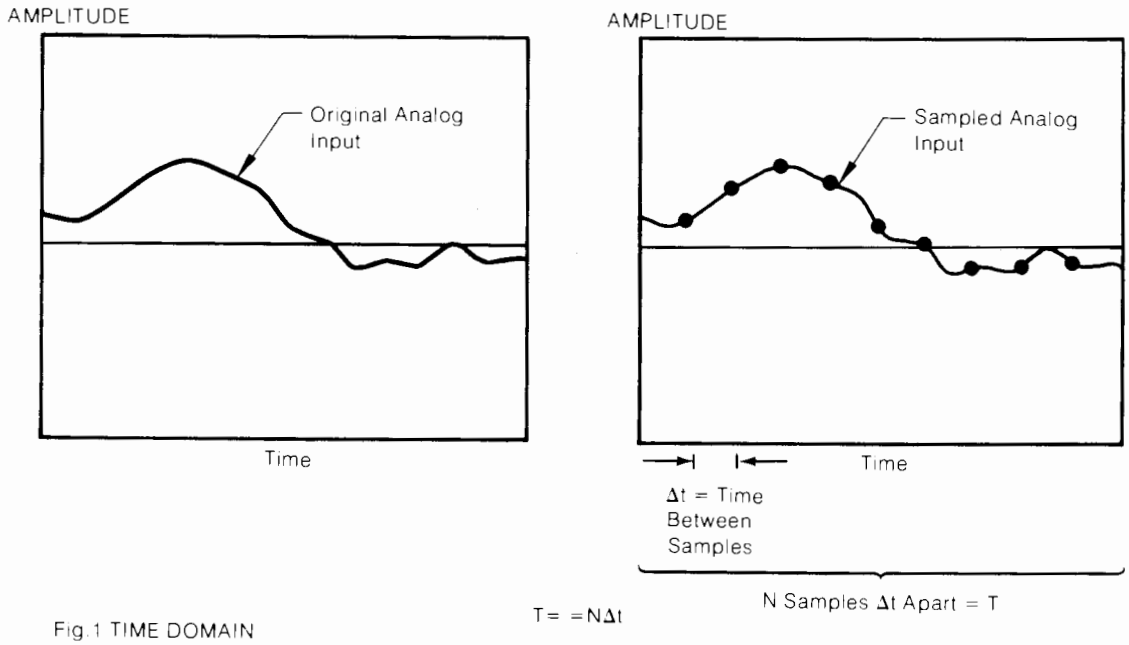


Fig.1 TIME DOMAIN

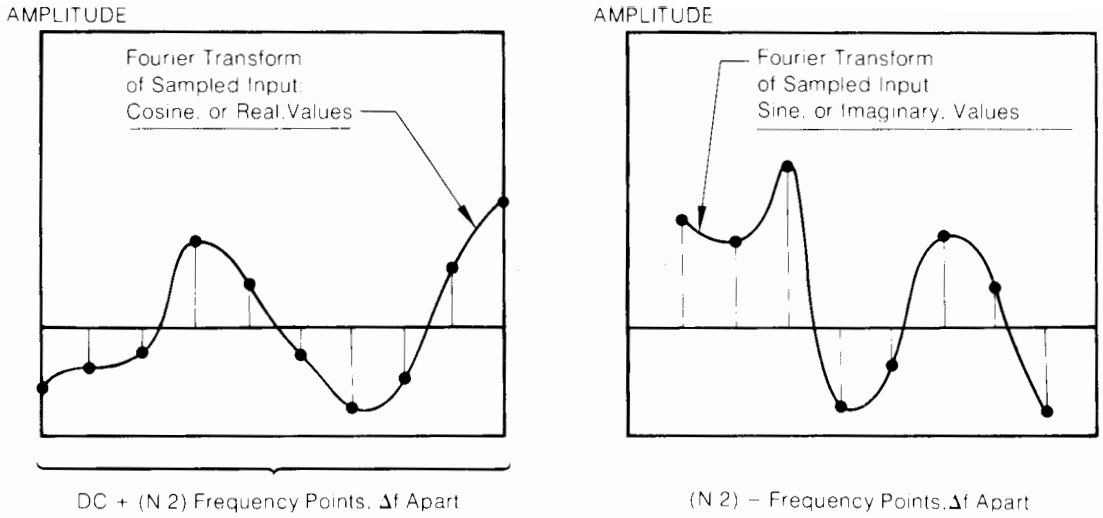


Fig. 2 FREQUENCY DOMAIN

FREQUENCY DOMAIN

Once we perform a Fourier transform upon the inputted data, we define a set of parameters for the frequency domain, as shown in Figure 2.

Δf - the number of Hz between frequency points, or, as more familiarly known, the frequency resolution. Origin of display is $0\Delta f$ (DC component, on real (cosine) displays only); next point is $1\Delta f$ (fundamental frequency); next point is $2\Delta f$ (first harmonic); next $3\Delta f$ (second harmonic), etc. Frequencies between the harmonics will not show. To make them show, a smaller Δf must be used (but there are limits to this, as explained on page 20). Δf is called frequency interval.

N/2 - the number of frequency points: this is one half of the original data block size N, with each frequency component broken down into two parts; the real and the imaginary.

F_{max} - the maximum frequency shown in the display. From Figure 2, it can be seen that:

$F_{max} = N/2 \times \Delta f$ the number of frequency points multiplied by the frequency resolution

FIG 3 shows the relationship of the time and frequency domains. The relationship of the time and frequency domain parameters are as follows:

time interval = reciprocal of 2 times the maximum frequency

$$\Delta t = \frac{1}{2Fmax}$$

the frequency resolution = the reciprocal of the time record.

$$\Delta f = \frac{1}{T}$$

This shows the dependence of one parameter to the others in the two domains.

Table 1 summarizes the equations above so that the user can obtain the best trade-off on the parameters he is interested in.
For example, suppose the user needs 1 Hz frequency resolution (Δf) and at the same time wants a 5 kHz maximum frequency (F_{max}). Using Table 1 at line 3, we substitute the desired values for Δf and F_{max} in the equation found in the last column.

$$\Delta f = 1$$

$$F_{max} = (N/2)\,\Delta f$$

giving the result

$$5000 = (N/2)x1$$

$$N = 10,000$$

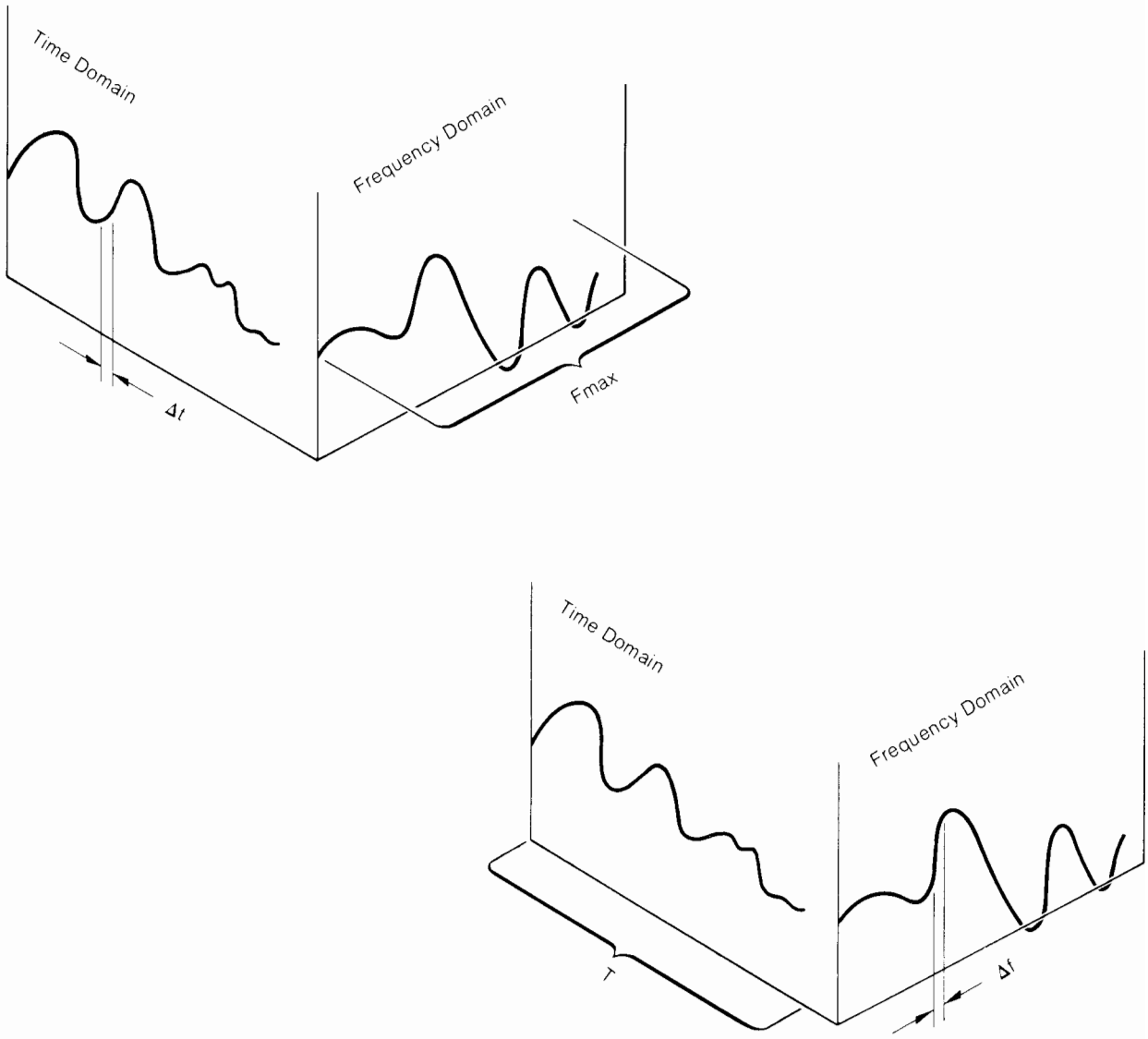


Fig. 3 HOW TIME AND FREQUENCY DOMAINS ARE RELATED

Table 1: Selecting Values for Data Sampling Parameters

Choose convenient round number for parameter shown.	Chosen parameter automatically fixes the value of parameter below, because of relationship in parentheses.	Then make either of the remaining two parameters (cannot be both) as close as possible to the desired value by choosing N* in the relationships shown.
1. Δt	F_{max} ($F_{max} = \frac{1}{2\Delta t}$)	T ($T = N\Delta t$) Δf ($\Delta f = \frac{1}{N\Delta t}$
2. F_{max}	Δt ($\Delta t = \frac{1}{2F_{max}}$)	T ($T = N\Delta$) Δf ($\Delta f = \frac{1}{N\Delta t}$)
3. Δf	T ($T = \frac{1}{\Delta f}$)	Δt ($\Delta t = \frac{T}{N}$) F_{max} ($F_{max} = \frac{N}{2} . \Delta f$)
4. T	Δf ($\Delta f = \frac{1}{T}$)	Δt ($\Delta t = \frac{T}{N}$) F_{max} ($F_{max} = \frac{N}{2} . \Delta f$)

*N, the data block size, is always a power of 2.

FURTHER DETAILS ON THE N/2 FREQUENCY DOMAIN POINTS

When data in a data block represents the values associated with a spectrum or other function of frequency, they are stored differently than when they represent a time series. A time series of N independent points results in a frequency spectrum of N/2 independent frequencies.

In the Waveform Analysis Library, N/2 positive frequencies (including dc and F_{max} terms) are computed, stored, and displayed, from an N-point real time series. Each frequency has two independent values--a "real" (cosine) value, and an "imaginary" (sine) value; the imaginary values for dc and F_{max} are zero, and are not stored. The actual arithmetic is as follows: There are N/2+1 real points. There are (N/2)-1 imaginary frequency values, since there are no imaginary values for dc or F_{max}. Adding the number of real and imaginary points together, we get:

$$(N/2)+1 \quad + \quad (N/2)-1 = N$$

points in the frequency domain from N points in the time domain. We store frequency domain data in an N-element data block as follows: the real value of dc is stored in the first location, the real value of F_{max} is stored in the second location, and the remaining locations are assigned in pairs to the data for the remaining frequencies.

FOURIER SERIES

We know that time functions are often conveniently interpreted by the analysis of their frequency content. This approach is derived from the work of French mathematician Jean Baptiste Fourier. Fourier discovered that <u>periodic</u> time functions can be broken down into an infinite sum of properly-weighted sine and cosine functions

of the proper frequencies. The mathematical statement of this discovery is:

$$x(t) = a_o + \sum_{n=1}^{\infty} a_n \cos\left(\frac{2\pi nt}{T}\right) + b_n \sin\left(\frac{2\pi nt}{T}\right) \qquad (1)$$

where T is the period of x(t), that is, $x(t) = x(t + T)$

When the coefficients a_n and b_n are calculated using the equations derived by Fourier, the amplitude of each sine and cosine wave in the series is known. Equivalently, when the coefficients a_n and b_n are known, the magnitude and phase at each frequency in x(t) is determined, where $\sqrt{a_n^2 + b_n^2}$ is the amplitude at the frequency $f_n = (n/T)$, and $\tan^{-1}(b_n/a_n)$ is the corresponding phase.

THE FOURIER TRANSFORM

The Fourier series is a useful tool for determining the frequency content of a time-varying signal. However, the Fourier series always requires a periodic time function. To overcome this shortcoming, Fourier evaluated his series as he let the period of the waveform approach infinity. The function which resulted is known as the Fourier transform. The Fourier transform pair is defined as:

$$S_x(f) = \int_{\infty}^{\infty} x(t)\, e^{-i2\pi ft}\, dt \quad \text{(Forward Fourier transform)} \qquad (2)$$

$$x(t) = \int_{\infty}^{\infty} S_x(f)\, e^{i2\pi ft}\, df \quad \text{(Inverse Fourier transform)} \qquad (3)$$

Where $e^{\pm 2\pi ft} = \cos(2\pi ft) \pm i \sin(2\pi ft)$, is known as the kernel of the Fourier transform.

$S_x(f)$ is called the Fourier Transform of $x(t)$. $S_x(f)$ contains the amplitude and phase information at every frequency present in $x(t)$ without demanding that $x(t)$ be periodic.

From the foregoing discussion of Fourier Series and Transform analysis, one sees that both of these techniques may be viewed as mathematical filtering operations.

THE DISCRETE FINITE TRANSFORM

The Waveform Analysis Library utilizes the 9845A desktop computer to calculate Fourier transforms of time-varying signals. We will examine the results of computing the Fourier transform digitally, considering the forward transform.

$$S_x(f) = \int_{-\infty}^{\infty} x(t)\, e^{-i2\pi ft}\, dt \qquad (4)$$

In order to implement the Fourier transform digitally, one must convert the continuous input signal into a series of discrete data samples. This is accomplished by sampling (measuring) the input waveform, $x(t)$, at certain intervals of time. We will assume that the samples are spaced uniformly in time, separated by an interval Δt. In order to perform the integral (4), the samples must be separated by an infinitesimal amount of time (i.e., $\Delta t \rightarrow dt$). Due to physical constraints of the analog-to-digital converter, this is not possible. As a result we must calculate

$$S_x''(f) = \Delta t \sum_{n=-\infty}^{n=+\infty} x(n\Delta t)\, e^{-i2\pi fn\Delta t} \qquad (5)$$

Where $x(n\Delta t)$ are the measured values of the input function.

Equation (5) states that, even though we are dealing with a sampled version of $x(t)$, we can still calculate a valid Fourier transform. However, the Fourier transform as calculated by (5) no longer con-

tains accurate magnitude and phase information at all of the frequencies contained in $S_x(f)$. Rather $S_x''(f)$ accurately describes the spectrum of x(t) up to some maximum frequency (F_{max}) which is dependent upon the sample spacing, Δt. The determination of F_{max} will be discussed later in paragraphs to follow.

In order to calculate $S_x''(f)$, we must take an infinite number of samples of the input waveform. As each sample must be separated by a finite amount of time, one would have to wait forever for the calculation of $S_x''(f)$ to be completed. Clearly then, we must limit our observation time in order to calculate a useful Fourier transform. Let us assume that the input signal is 'observed' (sampled) from some zero time reference to time T seconds. Then we have

$$T/\Delta t = N \tag{6}$$

where N is the number of samples, and T is the "time window".

We see that restricting the observation time to T seconds is equivalent to truncating equation (5). As we no longer have an infinite number of time points, we cannot expect to calculate magnitude and phase values at an infinite number of frequencies between zero Hz and F_{max}. Equivalently, the truncated version of equation (5) does not produce a continuous spectrum. This discrete finite transform (DFT) is given below.

$$S_x'(m\Delta f) = \Delta t \sum_{n=0}^{N-1} x(n\Delta t)\, e^{-i2\pi m\Delta f n\Delta t} \tag{7}$$

Only <u>periodic</u> functions have such a 'discrete' frequency spectra. Therefore, equation (7) requires that our input function be periodic with period T. Conversely, equation (7) assumes that the function observed between zero and T seconds repeats itself with period T for all time. This assumption is made whether or not x(t) is actually periodic. It is apparent that the discrete finite transform, as calculated by (7), is actually a sampled Fourier series.

Note that there are N points in the time series and that, for our purposes, the time series always represents a real-valued function. However, to fully describe a frequency in the spectrum two values must be calculated (i.e., the magnitude and the phase, or the real and imaginary part at the given frequency). As a result, N points in the time domain allow us to define N/2 complex quantities in the frequency domain.

If F_{max} is the maximum frequency present in the spectrum, then

$$F_{max}/(N/2) = \Delta f \tag{8}$$

where Δf is the separation of frequencies (referred to as resolution) in the frequency domain.

SHANNON'S SAMPLING THEOREM

Shannon states that it requires slightly more than two samples per period to uniquely define a sinusoid. In sampling a time function, this implies that we must sample slightly more than twice per period of the highest frequency we wish to resolve. Translating Shannon's theorem into an equation:

$$F_{max} < \frac{1}{2\Delta t} \tag{9}$$

For convenience, equation (9) will be written:

$$F_{max} = \frac{1}{2\Delta t} \tag{10}$$

When using equation (10) one should remember that the maximum frequency which can be accurately resolved is $F_{max} - \Delta f$.

Substituting (10) into (6) and employing (8) gives:

$$\Delta f = F_{max}/(N/2) = (1/2\Delta t)/(N/2) = 1/N\Delta t = 1/T$$

or

$$\Delta f = \frac{1}{T} \qquad (11)$$

Equation (11), as a direct result of Shannon's Sampling Theorem, is a physical law.

USEFUL RELATIONS BETWEEN THE TIME AND FREQUENCY DOMAIN

It is appropriate to discuss certain relations between the two domains before we consider the more complex functions.

CONVOLUTION THEOREM

given that $$S_x(f) = \int_{\infty}^{\infty} x(t)\, e^{-i2\pi ft}\, dt$$

and $$S_y(f) = \int_{\infty}^{\infty} y(t)\, e^{-i2\pi ft}\, dt$$

and $$x(t) * y(t) = \int_{\infty}^{\infty} x(t)\, y(\psi - t)\, dt$$

where * denotes convolution, the Convolution Theorem states that

$$\int_{\infty}^{\infty} [x(t) * y(t)]\, e^{-i2\pi ft}\, dt = S_x(f) \cdot S_y(f)$$

and conversely

$$\int_{\infty}^{\infty} [S_x(f) * S_y(f)]\, e^{+i2\pi ft}\, dt = x(t) \cdot y(t)$$

Simply stated: convolution in one domain corresponds to multiplication in the other domain.

* The 9845 Waveform Analysis program's convolution is defined as the time domain convolution.

  In other words, we convert the time domain data to the frequency domain, perform a multiplication, and calculate the IFT.

THE AUTO POWER SPECTRUM

The auto-power spectrum of a function x(t) is defined as:

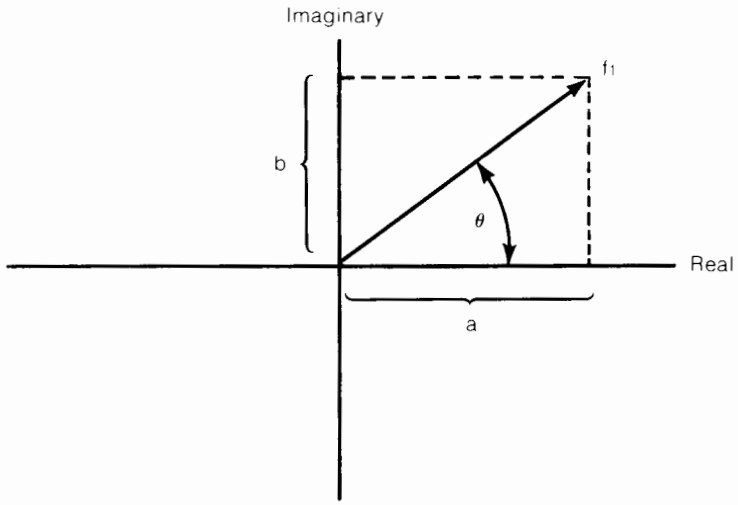
$$G_{xx} = S_x(f) \quad S_x^*(f)$$

All of the frequency components of G_{xx} are purely real and positive.

CONJUGATE MULTIPLICATION

We can describe a frequency point in the Fourier transform as a+ib. In conjugate multiplication, the a+ib of each frequency point is multiplied by the a-ib of the same point.

The result is $a^2 + b^2$. These $a^2 + b^2$ values for all frequency points make up the power spectrum. The conjugate multiply causes the loss of all phase information because the power spectrum is composed solely of real values (no "i" in a^2+b^2). See Fig. 5.



MULT *(conjugate multiplication):
$(a + ib)(a - ib) = a^2 + b^2$

Fig. 5 A POINT IN THE POWER SPECTRUM

HANNING FUNCTION

One particularly good truncation function is the Hanning [1] function illustrated in Fig. 6 and given by

$$x(t) = \frac{1}{2} - \frac{1}{2}\cos\frac{2\pi t}{T_c} \quad 0 \leq t \leq T$$

where T_c is the truncation interval. The magnitude of the Fourier transform of the Hanning function is given by

$$|X(f)| = \frac{1}{2}Q(f) + \frac{1}{4}[Q(f+\frac{1}{T_c}) + Q(f-\frac{1}{T})] \qquad (9\text{-}7)$$

where

$$Q(f) = \frac{\sin(\pi T_c f)}{\pi f} \qquad (9\text{-}8)$$

As shown in Fig. 7, this frequency function has very small side-lobes. Other truncation functions have similar properties [1]; however, we chose the Hanning function for its simplicity.

Because of the low side-lobe characteristics of the Hanning function, we expect that its utilization will significantly reduce the leakage which results from time domain truncation.

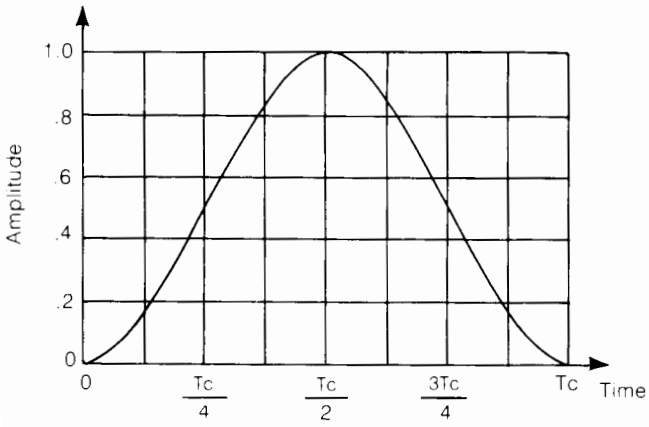


Fig. 6

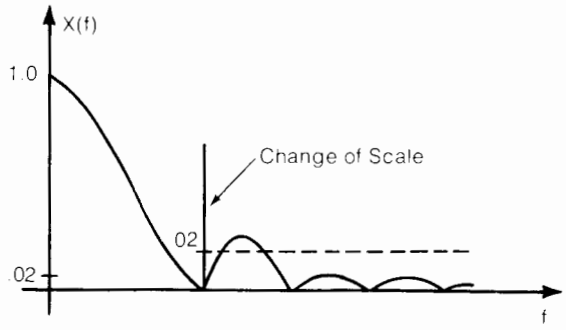


Fig. 7 HANNING FUNCTION FOURIER TRANSFORM PAIR

VOLTAGE SPECTRUM

The "voltage spectrum" is defined as $|S_x(f)|$. The voltage spectrum is the positive square root of the Auto Power Spectrum. The leakage problems we have discussed with respect to Auto Spectrum also exist in Voltage Spectrum and are dealt with in exactly the same manner as in the auto spectral case.

AUTO-CORRELATION (AUTO-COVARIANCE) FUNCTIONS

Auto-Correlation R_{xx} is defined as the inverse Fourier transform of the Auto Power Spectrum:

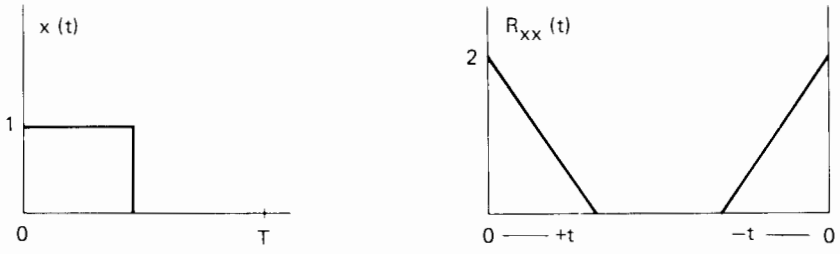
$$R_{xx}(t) = \int_{\infty}^{\infty} |S_x(f)|^2 \, e^{i2\pi ft} \, df = \int_{-\infty}^{\infty} S_x(f) \, S_x^*(f) \, e^{i2\pi ft} \, df$$

Since we are only considering real input functions

$$R_{xx}(t) = \int_{\infty}^{\infty} x(\psi) \, x(\psi - t) \, d\psi$$

Some authors refer to $R_{xx}(t)$, defined above, as the Auto-Covariance function of x(t). They define the Auto Correlation function as $\rho_{xx} = R_{xx}(t)/R_{xx}(0)$.

The correlation integral is much like the convolution integral, only the function $x(\psi)$ is not 'flipped' before it is shifted past itself as is the case in convolution. As a result, the auto-correlation of a pulse is displayed as shown below:



THE CROSS-POWER SPECTRUM

The cross-power spectrum of two signals is defined as

$$G_{yx}(f) = S_y(f) \cdot S_x^*(f)$$

Note that G_{yx} in general assumes <u>both</u> positive and negative values. The <u>relative</u> phase between the signals is preserved in cross-spectral analysis. The implied periodicity of the DFT gives rise to leakage effects similar to those we have seen in auto-spectral analysis. The leakage is diminished and the amplitude information is enhanced by Hanning just as was done in the auto-spectral case.

A zero value of cross-spectrum indicates that one or both of the individual spectra are zero at that frequency. A relatively large value for the cross-spectrum likewise indicates that both of the individual spectra have large values at that frequency. The cross-spectrum indicates the <u>relationship</u> between two signals.

If x(t) represent the input to a system, and y(t) represents the system output, cross-spectral analysis can be used to determine the system transfer function (as shown below).

$$S_x(f) \qquad H(f) \qquad S_y(f)$$

$$S_y(f) = S_x(f)\, H(f) \Rightarrow G_{yx}(f) = [S_x(f)\, h(f)]S_x^*(f)$$

or

$$H(f) = G_{yx}(f)/G_{xx}(f)$$

Thus, using cross-spectral analysis we are able to describe both the magnitude and the phase of the transfer function.

When we are doing cross-spectrum of system outputs and inputs (as is usually the case), the <u>relationship</u> between input and output is not sufficient information to determine an accurate transfer func-

tion. In addition to relationship (i.e., relative magnitude and phase of the two signals) we must know whether or not the system output was totally caused by the system input.

THE CROSS CORRELATION (CROSS-COVARIANCE) FUNCTION

Cross-correlation is defined as the inverse Fourier transform of the cross-power spectrum.

$$R_{yx}(t) = \int_{-\infty}^{+\infty} x(\psi)\, y(\psi - t)\, d\psi$$

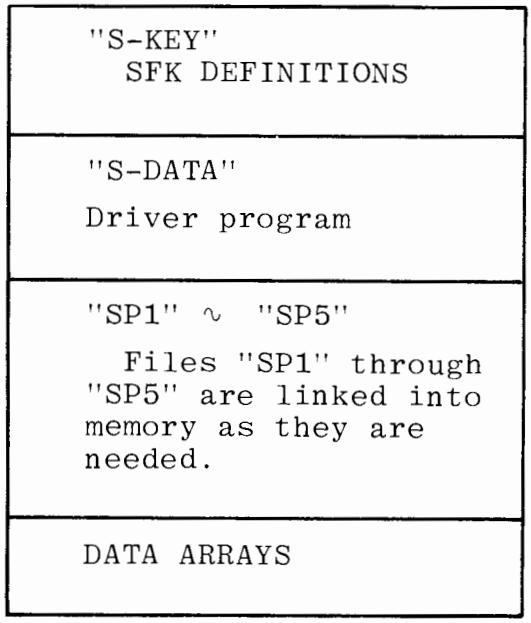
Even though the correlation function and the power spectrum theoretically have equal information content, more samples per period may be required to effectively interpret the time domain (correlation) function.

Program Operation - Single Data Block Analysis Program

The single data block analysis program uses the following files and subprograms.

File name	Subprograms(s)	Function
S-KEY		Special function keys
S-DATA		Contains the driver program which directs the linking of the needed subprogram files
SP1	Sdatain	Data input
	Smodul	Modulation
SP2	Fftandift	Calculate FFT and IFT
	Power	Calculate power
	Autocorre	Calculate autocorrelation
	Hanning	provide Hanning-function
SP3-1, SP3-2, SP3-3	Splot1	plot data
	Splot2	
SP4	Sprint	print data
SP5	Ssave	save data
	Sedit	edit data

Memory structure



VARIABLES USED FOR SUBPROGRAM PARAMETERS

Pmax - The maximum number of data points available in the frequency domain (this number includes both the DC term and the maximum frequency term). Pmax is also equivalent to half the maximum number of time domain points.

Npair - The actual number of data points being used in the frequency domain (also half the actual number of time domain points being used).

Lpower - Log_2 (Npair)

Tdelta - Sampling interval in seconds

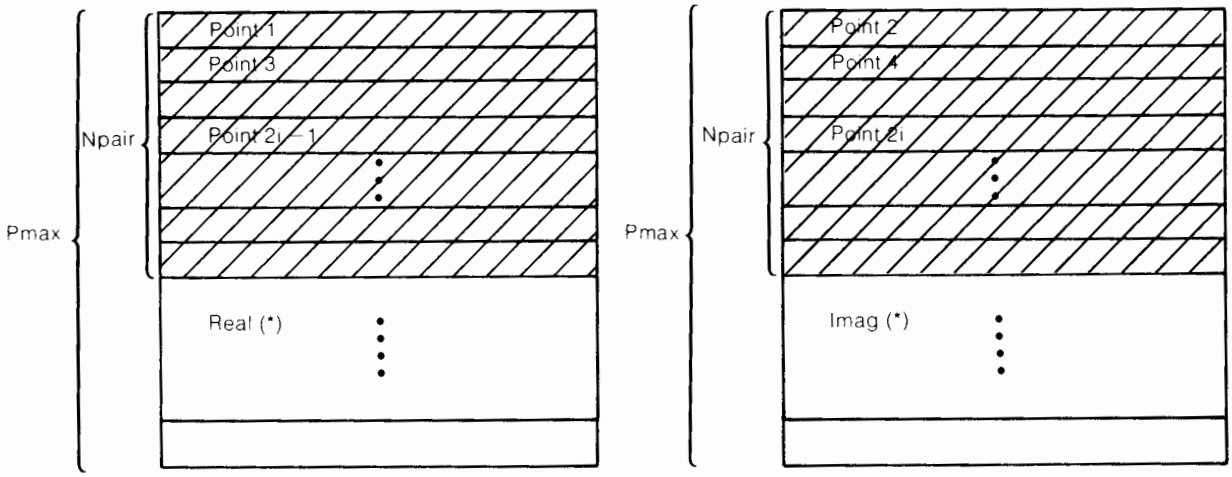
Ctype - Ctype=1 implies an FFT may be performed on the data.
Ctype=-1 implies an IFT may be performed on the data.

Dtype - Tells what type of data is contained in the arrays
Dtype=1 implies time domain data
Dtype=2 implies frequency domain data
Dtype=3 implies power data
Dtype=4 implies auto correlation data

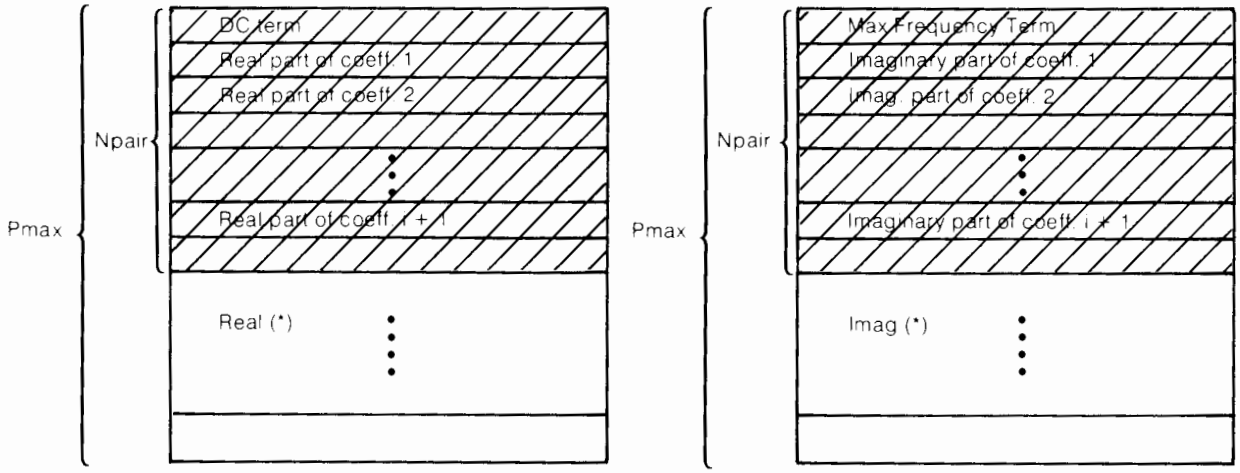
File$ - Tells which subprogram file ("SP1" through "SP5") is currently resident in memory.

Real(*),Imag(*) - Data arrays
When the data is in the time domain, Real(*) and Imag(*) have

the following structure:



When the data is in the frequency domain, Real(*) and Imag(*) have the following structure:



If the user desires to generate data from a different source (i.e., a measuring instrument or another program), the data can be put on a mass storage medium for use with the program. The data arrays are stored sequentially; Real (*) is stored first, followed by Imag (*). It should be noted that each array should be dimensioned to whatever value Pmax is set to in the program (see page 32), even if all of the elements are not used.

Mass storage device code

This program is written so that the standard mass storage device is the primary tape transport (:T15--the transport above the special function keys).
To change the standard mass storage device, change line 40 in the file "START" to read:

40 MASS STORAGE IS ":T15" (change T15 to your own device code)

Additional R/W memory

1. If you have any memory options and wish to allocate more memory for data, change the following lines in the file "S-DATA":

   40 Pmax=2048
   50 DIM Real (2048), Imag (2048)

   Change the three occurrences of 2048 given above to a value suitable for the amount of memory you have. See table on page 5.
   Example: For option 204, 2048 should be changed to 8192.
   Note: The above examples assume full precision.

2. If you change the data array size, you should also make the following changes in the data storage routine:
   Change lines 200 and 230 in file "SP5":

   200 CREATE A$&B$,128
   230 CREATE A$,128

   The value 128 in both lines should be changed to a larger value to accommodate the larger arrays. The new value should be:

   ((Pmax*2)*8)/256

   Example: For option 204, the number of records to be created should be 512.

Note: This example assumes full precision.

Short/Integer Precision

If you do not require full precision accuracy for the data arrays, short or integer arrays are available, thus following more data points to be stored in the same amount of memory.

1. Lines 40 and 50 in file "S-DATA" should be changed:

```
40  Pmax=2048
50  DIM Real (2048), Imag(2048)
```

a. All three occurrences of 2048 (or whatever the value of Pmax happens to be for the particular memory option being used) may be doubled for SHORT precision or quadrupled for INTEGER Precision.

b. Change DIM to SHORT or INTEGER, depending upon which type is desired.

Examples: For standard memory:

```
40  Pmax=4096
50  SHORT Real (4096),Imag(4096)
40  Pmax=8192
50  INTEGER Real (8192),Imag(8192)
```

Note: Although changing the precision of the data arrays will allow a higher number of elements to be stored, computational speeds will drop due to the necessity of converting the data elements before computation can be performed.

2. Lines 200 and 230 in file "SP5" should be changed:

```
200  CREATE A$&B$,128
230  CREATE A$,128
```

Change both occurrences of 128, depending upon the size of the data arrays. The new value should be:

((Pmax*2)*4)/256 for SHORT arrays and INTEGER arrays.

Example: For standard memory using SHORT precision:

```
140  CREATE A$&B$,128
170  CREATE A$,128
```

For standard memory using INTEGER precision:

```
140  CREATE A$&B$,256
170  CREATE A$,256
```

3. The following lines must be changed so that the subprograms which are linked into memory by the main program will accept the new data array precision type:

File "SP1", line 20
File "SP1", line 1390
File "SP2", line 20
File "SP2", line 840
File "SP2", line 1150
File "SP2", line 1220
File "SP3-1", line 20
File "SP3-2", line 20
File "SP4", line 20
File "SP5", line 20
File "SP5", line 550

The above lines are SUB statements which define subprogram parameter lists. They have the following general format:

SUB <Subprogram Name> (pass parameters,... , Real(*),Imag(*))

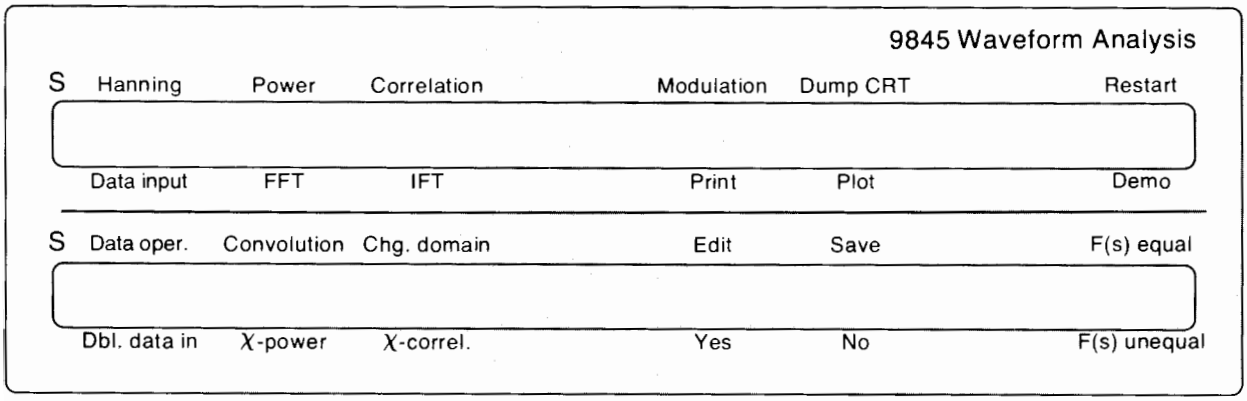
a. Insert "SHORT" or "INTEGER" before "Real(*)" in all of the lines listed above. For example, if you wanted to set the data arrays to SHORT precision, line 20 in file "SP4" should be changed to read as follows:

```
20  SUB Sprint(Npair,Tdelta,Dtype,SHORT Real(*),Imag(*))
```

Note: If you change the precision of the data arrays, but fail to make the required changes in the lines listed above, ERROR 8 (improper parameter matching) will occur whenever the main program tries to call any of the affected subprograms.

SPECIAL FUNCTION KEY INFORMATION

For single data analysis, the following special function keys are available:



Several of the keys require no interaction from the user. These keys are marked with a "*" in the discussion below. Instructions for those keys which do require user intervention immediately follow this section.

Data Input (Key Ø)

The first time that Key Ø is pressed, file "S-DATA", a bootstrap program, will be loaded. This program will in turn load the key file "S-KEY", which redefines the special function keys. Then the file "SP1", which will do the actual entering of data, is linked into memory. Subsequent use of Key Ø will result in linking file "SP1" into memory (if it is not already resident in memory).

File "SP1" allows for five ways to input data. They are:

1) Enter time domain data from the keyboard
2) Enter frequency domain data from the keyboard
3) Enter time domain data from a mass storage file
4) Enter frequency domain data from a mass storage file
5) Digitize time domain data from the 9872A plotter

FFT (Key 1)*

This key converts time domain data to frequency domain data. This key is not available if the data is already in the frequency domain.

IFT (Key 2)*

This key converts frequency domain data to time domain data. This key is not available if the data is already in the time domain.

Hanning (Key 16)*

This key provides the Hanning function for frequency domain data, and it is only available when the data is in the frequency domain. The Hanning function causes the original data to be destroyed, so care should be taken to save any critical

data prior to using this key.

Power (Key 17)*

This key causes the power function to be calculated. This causes the original data arrays to be destroyed, so care should be taken to save any critical data prior to using this key.

Correlation (Key 18)*

This key calculates the correlation. This function destroys the original data array, so care should be taken to save any critical data prior to using this key.

Modulation (Key 2Ø)

This key allows the user to modulate time domain data.

Dump CRT (Key 21)*

This key dumps CRT graphics to the internal thermal printer.

Print (Key 4)*

This key has the data printed to the internal thermal printer. The data will be printed according to its current type (i.e., time domain, frequency domain, power, correlation).

Plot (Key 5)

This key plots the data (on either the CRT or the 9872A). The data can be plotted according to its current type (i.e., time domain, frequency domain, power, correlation). When plotting frequency domain data, both phase and magnitude plots are available. LOG plots are available for magnitude or power data. In addition, three type of plots are available for the data: line, dot and bar.

Edit (Key 28)

This key is used to edit the data, whether it is time domain or frequency domain.

Save (Key 29)

This key is used to store the data on a mass storage file.

YES/NO (Keys 12 and 13)*

These keys are used for answering program questions that call for a YES/NO answer.

Restart (Key 23)*

This key loads the START file and runs it.

USER INSTRUCTIONS FOR DATA INPUT (KEY Ø)

1. When "Which entry mode do you wish to use?" appears in the display area:
   a. Enter: The entry mode you wish to use (1 to 5).
   b. Press: CONT
   Note: The entry modes will be explained on the CRT.
   c. If you entered 1, 3, or 5 in step 1a, go to step 2.
   d. If you entered 2 or 4 in step 1a, go to step 8.

2. When "NUMBER OF SAMPLES?" appears in the display area:
   a. Enter: The number of data samples.
   b. Press: CONT
   Note: The value should be a power of 2 (e.g., 8, 16, 32, etc.) and must be at least 8.

3. When "TIME INTERVAL (IN SECONDS)?" appears in the display area:
   a. Enter: The time interval (in seconds).
   b. Press: CONT
   c. If you entered 1 as the entry mode in step 1a, go to step 4.
   d. If you entered 3 as the entry mode in step 1a, go to step 5.
   e. If you entered 5 as the entry mode in step 1a, go to step 13.

4. When "DATA POINT i?" appears in the display area:
   a. Enter: The value of the ith data point.
   b. Press: CONT
   c. Repeat step 4 as often as necessary.
   d. When all the data has been entered, go to step 16.

5. When "DATA FILE NAME?" appears in the display area:
   a. Type: The name of the data file you wish to use.
   b. Press: CONT

6. When "IS YOUR MASS STORAGE DEVICE STANDARIZED (YES/NO)?" appears in the display area:
   a. If the mass storage device you are using for the data is

standardized:

1) Press: YES

2) Go to step 16.

or

a. If the mass storage device you are using for the data is not standardized:

1) Press: NO

2) Go to step 7.

Note: For more detail, refer to the 9845 Operating and Programming manual. Consult the section explaining the MASS STORAGE IS command.

7. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:

a. Type: A mass storage unit specifier.

b. Press: CONT

Note: A mass storage unit specifier has the following format: First a colon, followed by a letter indicating what type of device is being used (i.e.,T for tape cartridge,F for floppy diskette, Y for 7905 removeable platter, etc.), followed in turn by the proper select code. Examples - :T15, :T14, :F8, :Y12

c. Go to step 16.

8. When "NUMBER OF VALUES ([COEFF. PAIRS]*2+2)?" appears in the display" area:

a. Enter: The number of values in the frequency domain data.

b. Press: CONT

Note: This value should be a power of 2 ($\geq$=8 values. This value is the same as the number of data points which result from performing an IFT (conversion to time domain).

9. When "FREQUENCY INTERVAL [Hz]?" appears in the display area:

a. Enter: The frequency interval (in Hz).

b. Press: CONT

c. If you entered 2 as the entry mode in step 1a, go to step 1Ø.

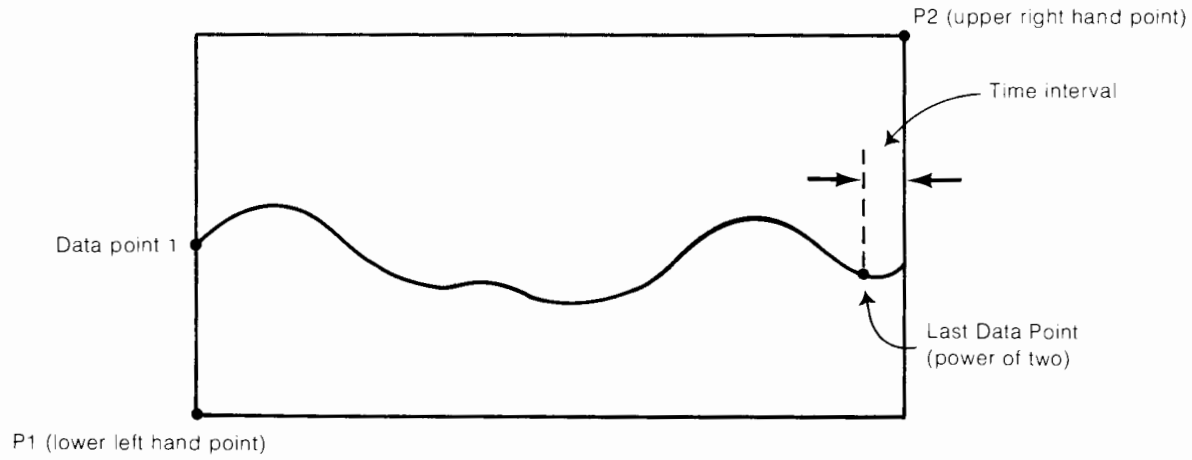
d. If you entered 4 as the entry mode in step 1a, go to step 5.

10. When "DC TERM?" appears in the display area:
    a. Enter: The DC term
    b. Press: CONT

11. When "MAX FREQUENCY TERM?" appears in the display area:
    a. Enter: The maximum frequency term
    b. Press: CONT

12. When "COEFF. (Coeff.#) REAL,IMAG?" appears in the display area:
    a. Enter: The real and imaginary components of the indicated data element separated by a comma (i.e., 4, 6).
    b. Press: CONT
    c. Repeat step 12 until all the data has been entered.
    d. Go to step 16.

13. When "DEFINE THE DIGITIZING AREA ON THE 9872A (SET P1 and P2) AND PRESS CONT" appears in the display area:
    a. Set the digitizing area on the 9872A using the front panel control buttons.
    b. Press: CONT



c. If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
   1) Enter: The plotter select code
   2) Press: CONT

d. If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
   1) Enter: The HPIB address of the plotter
   2) Press: CONT

14. When "Ymin, Ymax?" appears in the display area:
   a. Enter: The minimum Y scale value and the maximum Y scale value for digitizing, separated by a comma (i.e., 4,6).
   b. Press: CONT

15. When "DATA POINT (Data Point #)?" appears in the display area:
   a. Adjust the plotter pen to the point to be digitized using the ↑ and ↓ buttons (the X position is given automatically).
   b. Press: The ENTER button on the 9872A
   c. Repeat step 15 until all the data points have been digitized.

16. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR MODULATION KEY (KEY 2Ø)

1. When "H*COS(2*PI*F)*** H=?" appears in the display area:
   a. Enter: The value of H in the displayed equation (H is the amplitude of the carrier wave).
   b. Press: CONT

2. When "H*COS(2*PI*F)*** F [Hz]=?" appears in the display area:
   a. Enter: The value of F in the displayed equation (F is the frequency of the carrier wave).
   b. Press: CONT

3. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR PLOT KEY (KEY 5)

1. When "1---CRT PLOT 2---9872A PLOT *** SELECT NUMBER" appears in the display area:
   a. Enter: 1 or 2, depending upon which plotting device you wish to use.
   b. Press: CONT

2. If you entered 1 in step 1a, go to step 2c.
   a. If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
      1) Enter: The plotter select code
      2) Press: CONT
   b. If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
      1) Enter: The HPIB address
      2) Press: CONT
   c. If the data is in the time domain, or if the data has had the power or auto correlation functions performed on it, go to step 4.
   d. If the data is in the frequency domain, go to step 3.

3. When "1---MAG 2---PHASE *** SELECT NUMBER" appears in the display area:
   a. Enter: 1 or 2, depending upon whether you want a magnitude or a phase plot.
   b. Press: CONT

4. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:
   a. Enter: 1, 2, or 3, depending upon which of the three types of plots you want.
   b. Press: CONT
   c. If the data is magnitude or power, then go to step 5.
   d. If the data is not magnitude or power, then go to step 6.

5. When "LOG PLOT (YES/NO)?" appears in the display area:

   a. If you want a LOG plot:

      1) Press: YES

      2) Go to step 6.

   or

   a. If you do not want a LOG plot:

      1) Press: NO

      2) Go to step 6.

6. The data is plotted, a beep sounds, and the program pauses. After you press CONT, the message "SELECT KEY" will appear in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR THE EDIT KEY (KEY 28)

1. a. If the data is in the time domain, go to step 2.
   b. If the data is in the frequency domain, go to step 4.

2. When "WHICH DATA POINT DO YOU WISH TO CHANGE?" appears in the display area:
   a. Enter: The subscript of the data point you wish to change.
   b. Press: CONT

3. When "PLEASE ENTER THE NEW VALUE" appears in the display area:
   a. Enter: The new data value
   b. Press: CONT
   c. Go to step 8.

4. When "WHICH COEFFICIENT DO YOU WISH TO CHANGE?" appears in the display area:
   a. Enter: The subscript of the coefficient you wish to change
   b. Press: CONT
   c. If the value entered in part 4a is greater than Ø and less than the maximum frequency coefficient, go to step 5.
   d. If the value entered in part 4a is Ø (DC term), go to step 6.
   e. If the value entered in part 4a is the maximum frequency coefficient, then go to step 7.

5. When "PLEASE ENTER THE NEW COEFFICIENT (REAL, IMAGINARY)" appears in the display area:
   a. Enter: The real and imaginary parts of the new coefficient separated by a comma (i.e., 4, 6)
   b. Press: CONT
   c. Go to step 8.

6. When "PLEASE ENTER THE NEW DC TERM" appears in the display area:
   a. Enter: The new DC term
   b. Press: CONT
   c. Go to step 8.

7. When "PLEASE ENTER THE NEW MAX FREQUENCY TERM" appears in the display area:
   a. Enter: The new max frequency value
   b. Press: CONT

8. When "Do you wish to edit more points (YES/NO)?" appears in the display area:
   a. If you wish to edit more points:
      1) Press: YES
      2) Go to step 1.

   or

   a. If you do not wish to edit more points:
      1) Press: NO
      2) Go to step 9.

9. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR SAVE KEY (KEY 29)

1. When "Do you wish to use a new file (YES/NO)?" appears in the display area:
   a. If you want to set up a new file for storing data:
      1) Press: YES
      2) Go to step 2.

   or

   a. If you do not want to set up a new file, but would rather use an old one:
      1) Press: NO
      2) Go to step 3.

2. When "Please enter the new file name" appears in the display area:
   a. Type: The new file name
   b. Press: CONT
   c. Go to step 4.

3. When "Please enter the old file name" appears in the display area:
   a. Type: The old file name
   b. Press: CONT

4. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:
   a. If the mass storage device which you wish to use is standardized (that is, it is the system's default mass storage device -- specified by the MASS STORAGE IS command, or by power-on conditions of the 9845):
      1) Press: YES
      2) Go to step 6.

   or

   a. If the mass storage device you wish to use is not standardized:
      1) Press: NO
      2) Go to step 5.

5. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:

   a. Type: A mass storage unit specifier

   b. Press: CONT

   Note: A mass storage unit specifier has the following format: First a colon, followed by a letter indicating what type of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code.

   Examples - :T15, :T14, :F8, :Y12

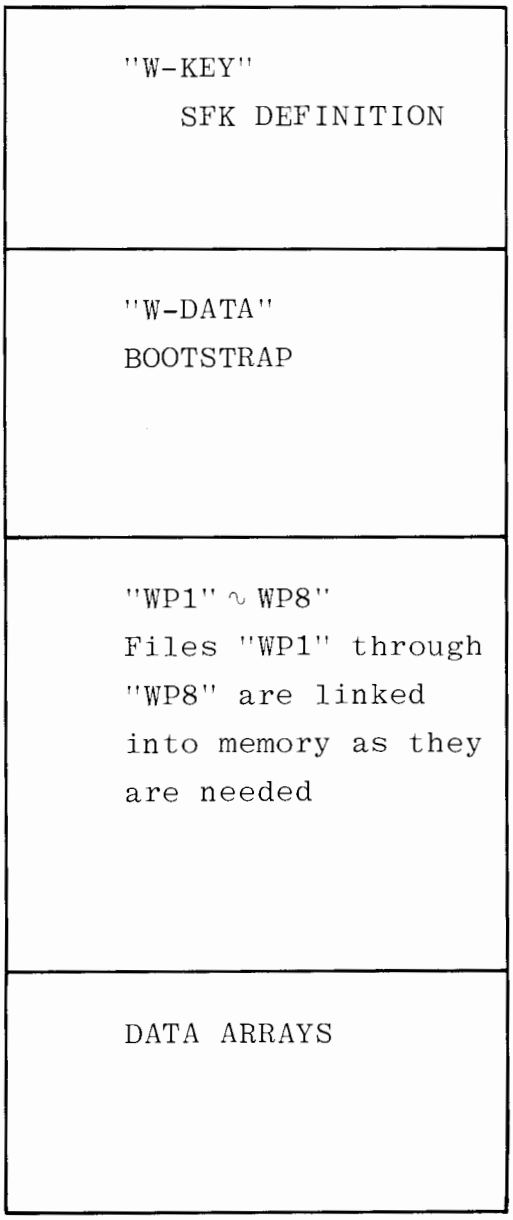
6. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

Program Operation - Double Data Block Analysis

The double data block analysis program uses the following files and subprograms.

File name	Subprogram	Function
W-KEY		Special Function Keys
W-DATA		Contains the driver program which directs the linking of the needed subprogram files
WP1	Wdatain	data input
WP2	FftandIft	Calculate FFT and IFT
	Cpower	Calculate cross power
	Ccorre	Calculate cross correlation
WP3 WP3-1 WP3-2	Wplot	plot data
WP4	Wprint	print data
WP5	Wsave	save data
	Wedit	edit data
WP6	Fft and ift	Calculate FFT and IFT
	Convol	Calculate convolution
	Cdomain	Change domain for both data
WP7 wp7	Datahand	provide data operation will be linked from "WP7"
WP8	Wmodul	provide modulation

Memory Structure



VARIABLES USED FOR SUBPROGRAM PARAMETERS

Pmax - The maximum number of data points available in the frequency domain (this number includes both the DC term and the maximum frequency term). Pmax is also equivalent to half the maximum number of time domain points in either data block.

Npair - The actual number of data points being used in the frequency domain (also half the actual number of time domain points being used).

Lpower - Log_2 (Npair)

Tdelta - Sampling interval in seconds

Ctype - Ctype = 1 implies an FFT may be performed on the data
Ctype = -1 implies an IFT may be performed on the data

Dtype 1 - Tells what type of data is contained in the block 1 arrays.

Dtype 2 - Tells what type of data is contained in the block 2 arrays.
The following values of Dtype 1 and Dtype 2 have the following meanings:

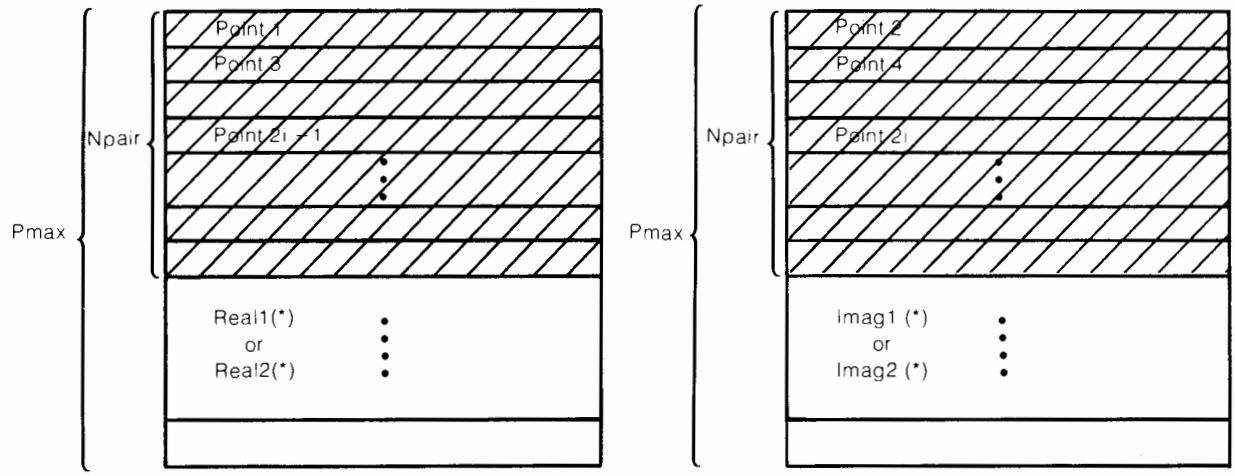
1 = time domain data
2 = frequency domain data
3 = cross power data
4 = cross correlation data
5 = convolution data
6 = power data

File$ - Tells which subprogram file ("WP1" through "WP8") is currently resident in memory.

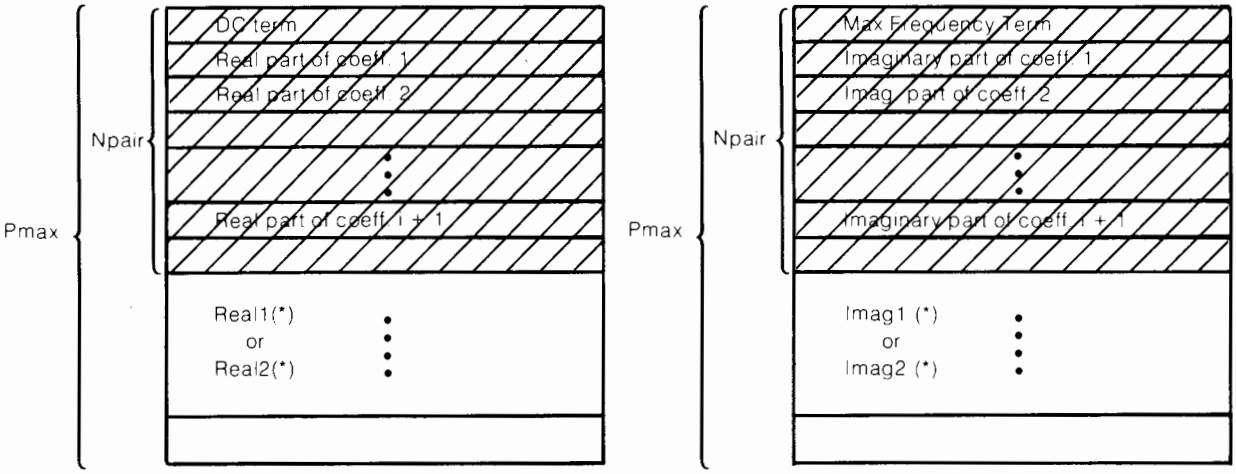
Real1(*),Imag1(*) - Data arrays for block 1

Real2(*),Imag2(*) - Data arrays for block 2

When the data is in the time domain, the data arrays have the following structure:



When the data is in the frequency domain, the data arrays have the following structure.



If the user desires to generate data from a different souce (i.e., a measuring instrument or another program), the data can be put on a mass storage medium for use with the program. Note that a different file must be used for each waveform (or block of data). Each waveform (which consists of a real and an imaginary array) is structured as shown above. On the mass storage medium, the two arrays are stored sequentially, with the real array falling first, then the imaginary one. It should be noted that each array should be dimensioned to whatever value Pmax is set to in the program (see page 57), even if all of the elements are not used.

Mass storage device code

This program is written so that the standard mass storage device is the primary tape transport (:T15 -- the transport above the special function keys).
To change the standard mass storage device, change line 40 in the file "START" to read"

```
40  MASS STORAGE IS ":T15" (change T15 to your own device
    code)
```

Additional R/W memory

1. If you have any memory options and you wish to allocate more memory for data, change the following lines in file "W-DATA":

```
60  Pmax=1024
70  DIM Real1(1024),Imag1(1024),Real2(1024),Imag2(1024)
```

   Change the five occurrences of 1024 given above to a value suitable for the amount of memory you have. See table on page 5.
   Note: Full precision is assumed here.

2. If you change the data array sizes, you must also make the following changes in the data storage routine:
   Change lines 250 and 280 in file "WP5":

```
250  CREATE A$&B$,64
280  CREATE A$,64
```

   The value 64 in both lines should be changed to a larger value to accommodate the larger arrays. The new value should be ((Pmax*2)*8)/256

Short/Integer Precision

If you do not require full precision accuracy for the data arrays, short or integer arrays are available, thus allowing more data points to be stored in the same amount of memory.

1. Lines 60 and 70 in file "W-DATA" should be changed:

```
60  Pmax=1024
70  DIM Real1(1024),Imag1(1024),Real2(1024),Imag2(1024)
```

a. All five occurrences of 1024 (or whatever the value of Pmax happens to be for the particular memory option being used) may be doubled for SHORT precision or quadrupled for INTEGER precision.

b. Change DIM to SHORT or INTEGER, depending upon which type is desired.

Example: For standard memory:

```
60  Pmax=2048
70  SHORT Real1(2048),Imag1(2048),Real2(2048),
    Imag2(2048)
60  Pmax=4096
70  INTEGER Real1(4096),Imag1(4096),Real2(4096),
    Imag2(4096)
```

Note: Although changing the precision of the data arrays will allow a higher number of elements to be stored, computational speeds will drop due to the necessity of converting the data elements before computation can be performed.

2. Lines 250 and 280 in file "WP5" must be changed:

```
250  CREATE A$&B$,64
280  CREATE A$,64
```

Change both occurrences of 64, depending upon the size of the data arrays. The new value should be:

((Pmax*2)*4)/256

The above value holds for both SHORT and INTEGER arrays, since they both require the same amount of storage on a mass storage device.

Example: For standard memory using SHORT precision:

```
250  CREATE A$&B$,64
280  CREATE A$,64
```

For standard memory using INTEGER precision:

```
250  CREATE A$&B$,128
280  CREATE A$,128
```

3. The following lines must be changed so that the subprograms which are linked into memory by the main program will accept the new data array precision type:

```
File "WP1", line 20
File "WP2", line 20
File "WP2", line 810
File "WP2", line 1290
File "WP3", line 20
File "WP4", line 20
File "WP5", line 20
File "WP5", line 700
File "WP6", line 20
File "WP6", line 810
File "WP6", line 1160
File "WP7", line 20
File "WP8", line 20
```

The above lines are SUB statements which define subprogram parameter lists.

They have the following general format:

```
SUB <Subprogram Name> (pass parameters,...,Real1(*),
      Imag1(*)" [,Real2(*),Imag2(*)])
```

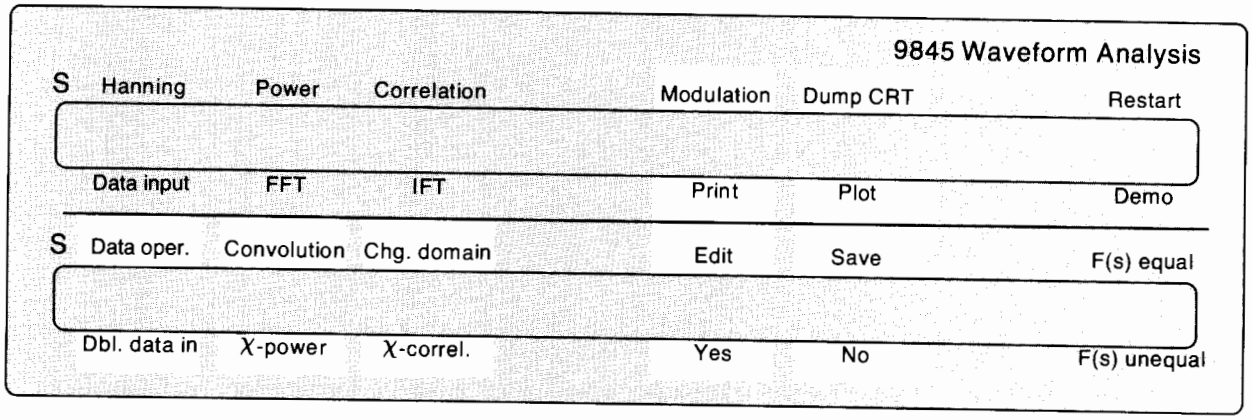
a. Insert "SHORT or "INTEGER" before "Real1(*)" (or "Real2(*)", as the case may be) in all of the lines listed above. For example, if you wanted to set the data arrays to SHORT precision, line 20 in file "WP4" should be changed to read as follows:

```
SUB Wprint(Npair,Tdelta,Dtype1,Dtype2,SHORT Real1(*),
     Imag1(*), Real2(*),Imag2(*))
```

Note: If you change the precision of the data arrays, but fail to make the required changes in the lines listed above, ERROR 8 (improper parameter matching) will occur whenever the main program tries to call any of the affected subprograms.

SPECIAL FUNCTION KEY INFORMATION

For double data handling, the following special function keys are available:



Several of the keys require no interaction from the user. These keys are marked with a "*" in the discussion below. Instructions for those keys which do require user intervention immediately follow this section.

Data Input for Both Data Blocks (Key 8)

The first time that Key 8 is pressed, file "W-DATA", a bootstrap program, will be loaded. This program will in turn load the key file "W-KEY", which redefines the special function keys. Then the file "WP1", which will do the actual entering of data, is linked into memory. Subsequent use of Key 8 will result in linking file "WP1" into memory" (if it is not already resident in memory).

File "WP1" allows for five ways to input each data block. They are:

1) Enter time domain data from the keyboard
2) Enter frequency domain data from the keyboard
3) Enter time domain data from a mass storage file
4) Enter frequency domain data from a mass storage file
5) Digitize time domain data from the 9872A plotter

X-power (Key 9)*

This key is used to calculate the cross power of data blocks 1 and 2. The data in block 1 may be in the time domain, the frequency domain, or it may be cross correlation data. The data in block 2 should be in the time domain or the frequency domain. Upon completion of this operation, the cross power data will reside in block 1 or block 2 will be cleared.

X-correl (key 10)*

This key is used to calculate the cross correlation of data blocks 1 and 2. Data block 1 should contain time domain data, frequency domain data, or cross power data. Block 2 should contain time domain or frequency domain data. Upon completion

of this operation, the cross correlation data will reside in block 1, while block 2 will be cleared.

Data oper. (Key 24)

This key is used for data handling between block 1 and block 2. Available operations are limited depending upon the data types of each block.

Convolution (Key 25)*

This key calculates the time convolution between data blocks 1 and 2. Both data blocks should be in the same domain, either the time domain or the frequency domain.

Chg. domain (Key 28)*

This key is used for changing from the time domain to the frequency domain or vice versa for both data blocks. Both blocks should be in the same domain (either the time domain or the frequency domain).

Modulation (Key 20)

This key is used to modulate time domain data. The user is given his choice as to which data block to modulate.

Dump CRT (Key 21)*

This key dumps CRT graphics to the internal thermal printer.

Print (Key 4)

This key is used for printing the data to the internal thermal printer. The data will be formatted according to its type. If the data is in the time domain or the frequency domain, the user may select which block to print. If the data is cross power, cross correlation, convolution, or power data, it must be in block 1 (to move data from one block to another, use the Data operation key).

Plot (Key 5)

This key plots the data (on either the CRT or the 9872A). The data will be plotted according to its current type. If the data is in the time domain or the frequency domain, the user may select which block gets plotted. If the data is cross power, cross correlation, convolution, or power data, it must reside in block 1. When plotting frequency domain data, both magnitude and phase plots are available. LOG plots are available for magnitude plots or cross power data. In addition, each plot may be done in any one of three ways: line, dot, and bar.

Edit (Key 28)

This key is used to edit time domain or frequency domain data in both blocks.

Save (Key 29)

This key is used for storing both data blocks. The blocks must both be saved on the same mass storage device.

YES/NO(Keys 12 and 13)*

These keys are used for answering program questions that call for a YES/NO answer.

Restart (Key 23)*

This key loads the START file and runs it.

USER INSTRUCTIONS FOR DOUBLE DATA INPUT (KEY 8)

1. When "FOR BOTH DATA BLOCKS: PLEASE ENTER THE NUMBER OF SAMPLES" appears in the display area:
   a. Enter: The number of samples:
   b. Press: CONT
   Note: The value entered in part 1a should be a power of 2.

2. When "FOR BOTH DATA BLOCKS: PLEASE ENTER THE TIME INTERVAL (IN SECONDS)" appears in the display area:
   a. Enter: The time interval
   b. Press: CONT

3. The data for both blocks is entered separately. Printed on the screen will be the message "FOR DATA BLOCK X:" followed by the available entry modes. When "Which entry mode do you wish to use?" appears in the display area:
   a. Enter: The entry mode you wish to use (1 to 5)
   b. Press: CONT
   Note: The entry modes will be explained on the CRT.
   c. If you entered 1 in step 3a, go to step 4.
   d. If you entered 2 in step 3a, go to step 5.
   e. If you entered 3 or 4 in step 3a, go to step 8.
   f. If you entered 5 in step 3a, go to step 11.

4. When "DATA POINT (data point #)?" appears in the display area:
   a. Enter: The value of the given data point
   b. Press: CONT
   c. Repeat step 4 until all the data has been entered.
   d. When all the data has been entered go to step 14.

5. When "DC TERM?" appears in the display area:
   a. Enter: The DC term
   b. Press: CONT

6. When "MAX FREQUENCY TERM?" appears in the display area:

a. Enter: The maximum frequency term
b. Press: CONT

7. When "COEFF (coeff.#) REAL, IMAG?" appears in the display area:
   a. Enter: The real and imaginary parts of the given coefficient, separated by a comma (i.e., 4, 3)
   b. Press: CONT
   c. Repeat step 7 until all the coefficients have been entered.
   d. When all the coefficients have been entered, go to step 14.

8. When "DATA FILE NAME?" appears in the display area:
   a. Type: The name of the data file from which you want to enter the data
   b. Press: CONT

9. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:
   a. If the mass storage device you are using for the data is standardized:
      1) Press: YES
      2) Go to step 14.

   or

   a. If the mass storage device you are using for the data is not standardized:
      1) Press: NO
      2) Go to step 10.

   Note: For more detail, refer to the 9845 Operating and Programming Manual. Consult the section explaining the MASS STORAGE IS command.

10. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:
    a. Type: A mass storage unit specifier
    b. Press: CONT

    Note: A mass storage unit specifier has the following format: First a colon, followed by a letter indicating what type

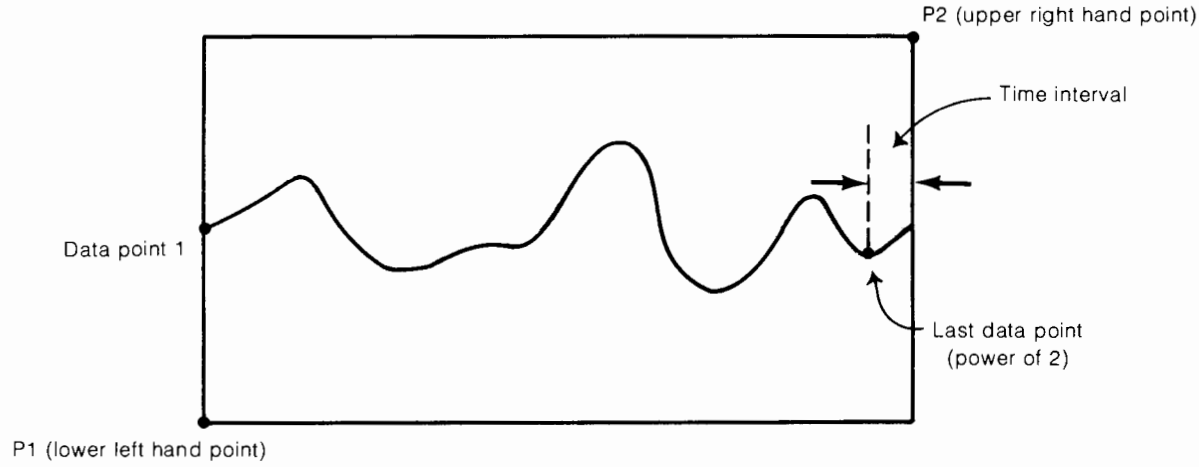
of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code. Examples - :T15, :T14, :F8, :Y12

c. Go to step 14.

11. When "DEFINE THE DIGITIZING AREA ON THE 9872A (SET P1 AND P2) AND PRESS CONT" appears in the display area:

a. Set the digitizing area on the 9872A using the front panel control buttons.

b. Press: CONT



c. If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:

1) Enter: The plotter select code

2) Press: CONT

d. If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:

1) Enter: The HPIB address of the plotter

2) Press: CONT

12. When "Ymin, Ymax?" appears in the display area:

a. Enter: The minimum and maximum Y scale values, separated by a comma.

b. Press: CONT

13. When "DATA POINT (data point #)?" appears in the display area:
    a. Adjust the plotter pen to the point to be digitized using the ↑ and ↓ buttons (the X position is given automatically).
    b. Press: The ENTER button on the 9872A
    c. Repeat step 13 until all the data points have been digitized.

14. If only the data for the first data block has been entered, go back to step 3 to enter the data for the second block. Otherwise, the program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR DATA OPERATION KEY (KEY 24)

1. When "SELECT OPERATION" appears in the display area:
   a. Enter: The operation number you wish to use (1 to 4)
   b. Press: CONT
   c. If the value you entered in part 1a is between 1 and 10, go to step 3.
   d. If the value you entered in part 1a is between 11 and 14, go to step 2.

2. When "PLEASE ENTER THE CONSTANT VALUE" appears in the display area:
   a. Enter: The constant value
   b. Press: CONT

3. The program stops, the message "SELECT KEY" will appear in the display area, and the available keys will be printed on the screen.

USER INSTRUCTIONS FOR MODULATION KEY (KEY 20)

1. When "DO YOU WANT TO MODULATE DATA BLOCK 1 (YES/NO)?" appears in the display area:
   a. If you want to modulate data block 1:
      1) Press: YES
      2) Go to step 3.

   or

   a. If you do not want to modulate data block 1:
      1) Press: NO
      2) Go to step 2.

2. When "DO YOU WANT TO MODULATE DATA BLOCK 2 (YES/NO)?" appears in the display area:
   a. If you want to modulate data block 2:
      1) Press: YES
      2) Go to step 3.

   or

   a. If you do not want to modulate data block 2:
      1) Press: NO
      2) Go to step 5.

3. When "H*COS(2*PI*F)***H=?" appears in the display area:
   a. Enter: The value of H in the displayed equation (H is the amplitude of the carrier wave).
   b. Press: CONT

4. When "H*COS(2*PI*F)***F=?" appears in the display area:
   a. Enter: The value of F in the displayed equation (F is the frequency of the carrier wave).
   b. Press: CONT

5. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR PRINT KEY (KEY 5)

1. a. If the data in block 1 is cross power, cross correlation, convolution, or power, the data will be printed automatically.
   b. Go to step 3.

   or

   a. If the data in block 1 is in either the time or frequency domain, the user may select which data block gets printed.
   b. Go to step 2.

2. When "WHICH BLOCK DO YOU WANT TO PRINT (1 or 2)?" appears in the display area:
   a. Enter: 1 or 2
   b. Press: CONT

3. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR PLOT KEY (KEY 5)

1. When "1---CRT PLOT 2---9872A PLOT***SELECT NUMBER" appears in the display area:
   a. If you want the plot to come up on the CRT:
      1) Enter: 1
      2) Press: CONT
      3) Go to step 1c.

   or

   a. If you want the plot to be on the 9872A plotter:
      1) Enter: 2
      2) Press: CONT
   b. If the plotter select code has been entered at some other time, then go to step 1c. Otherwise:
      1) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
         a) Enter: The plotter select code
         b) Press: CONT
      2) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
         a) Enter: The HPIB address of the plotter
         b) Press: CONT
   c. If the data in block 1 is cross power, cross correlation, convolution, or power, go to step 4.
   d. If the data in block 1 is in either the time domain or the frequency domain, go to step 2.

2. When "WHICH DATA BLOCK DO YOU WANT TO PLOT (1 or 2)?" appears in the display area:
   a. Enter: 1 or 2
   b. Press: CONT
   c. If the data in the chosen data block is in the frequency domain, go to step 3.
   d. If the data in the chosen data block is not in the frequency domain, go to step 4.

3. When "1---MAG 2---PHASE *** SELECT NUMBER" appears in the display area:
   a. If you want to plot the magnitude:
      1) Enter: 1
      2) Press: CONT

   or

   a. If you want to plot the phase:
      1) Enter: 2
      2) Press: CONT

4. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:
   a. Enter: 1, 2, or 3, depending upon which type of plot you desire.
   b. Press: CONT
   c. If the data is magnitude, power, or cross power, go to step 5
   d. If the data is not magnitude, power, or cross power, go to step 6.

5. When "LOG PLOT (YES/NO)?" appears in the display area:
   a. If you want a log plot:
      1) Press: YES

   or

   a. If you do not want a log plot:

6. The plot will be drawn and labelled and the program will pause. After you press CONT, two beeps will sound, the message "SELECT KEY" appears in the display area, and the available keys will be printed.

USER INSTRUCTIONS FOR EDIT KEY (KEY 28)

1. When "WHICH DATA BLOCK DO YOU WANT TO EDIT (1 or 2)?" appears in the display area:
   a. Enter: 1 or 2, depending upon which block you wish to edit.
   b. Press: CONT
   c. If the data is in the time domain, go to step 2.
   d. If the data is in the frequency domain, go to step 4.

2. When "WHICH DATA POINT DO YOU WITH TO EDIT?" appears in the display area:
   a. Enter: The subscript of the point you wish to edit
   b. Press: CONT

3. When "NEW VALUE?" appears in the display area:
   a. Enter: The new value of the given data point
   b. Press: CONT
   c. Go to step 8.

4. When "WHICH COEFFICIENT DO YOU WISH TO CHANGE?" appears in the display area:
   a. Enter: The subscript of the coefficient you wish to change
   b. Press: CONT
   c. If the subscript you entered in part 4a is greater than Ø and less than the maximum frequency term, go to step 5.
   d. If the subscript you entered in part 4a was Ø (DC term), go to step 6.
   e. If the subscript you entered in part 4a is the maximum frequency coefficient, go to step 7.

5. When "NEW REAL, IMAG?" appears in the display area:
   a. Enter: The real and imaginary parts of the new coefficient, separated by a comma. (Example: 4,5)
   b. Press: CONT
   c. Go to step 8.

6. When "NEW DC TERM?" appears in the display area:
   a. Enter: The new DC term
   b. Press: CONT
   c. Go to step 8.

7. When "NEW MAX FREQUENCY TERM [REAL]?" appears in the display area:
   a. Enter: The new maximum frequency value
   b. Press: CONT

8. When "EDIT MORE (YES/NO)?" appears in the display area:
   a. If you want to edit more data:
      1) Press: YES
      2) If you are editing time domain data, go to step 2.
      3) If you are editing frequency domain data, go to step 4.

   or

   a. If you do not want to edit more data:
      1) Press: NO
      2) Go to step 9.

9. The program stops, the message "SELECT KEY" appears in the display area, and the available keys are printed on the screen.

USER INSTRUCTIONS FOR THE SAVE KEY (KEY 29)

1. When "WHICH DATA BLOCK DO YOU WANT TO SAVE (1 or 2)?" appears in the display area:
   a. Enter: 1 or 2, depending upon which block you wish to save.
   b. Press: CONT

2. When "Do you wish to use a new file (YES/NO)?" appears in the display area:
   a. If you wish to use a new file:
      1) Press: YES
      2) Go to step 3.

   or

   a. If you do not wish to use a new file, but would rather use an old file:
      1) Press: NO
      2) Go to step 4.

3. When "Please enter the new file name" appears in the display area:
   a. Type: The name of the new file
   b. Press: CONT
   c. Go to step 5.

4. When "Please enter the old file name" appears in the display area:
   a. Type: The name of the old file
   b. Press: CONT

5. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:
   a. If your mass storage device is standardized (that is, it is the system's default mass storage device -- specified by the MASS STORAGE IS command, or by the power--on conditions of the 9845):
      1) Press:

2) Go to step 7.

or

a. If your mass storage device is not standardized:

1) Press: NO

2) Go to step 6.

6. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:

a. Type: A mass storage unit specifier

b. Press: CONT

Note: A mass storage unit specifier has the following format: First a colon, followed by a letter indicating what type of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code.

Examples - :T15, :T14, :F8, :Y12

7. The program will store the data on the specified mass storage file. Then the program stops, the message "SELECT KEY" appears in the display area, and the available keys printed.

Fourier Series Coefficients for Equally-Spaced Data

Given a set of equally - spaced data points (X_i, Y_i) $(i=1,..,n)$ where Δx is the spacing between points, it is possible to compute a set of coefficients a_i and b_i of the Fourier series which approximates the behavior of the data points.

The finite Fourier series is given by the formula:

$$\frac{a_0}{2} + \sum_{i=1}^{N} \left(a_i \cos\left(\frac{2\pi i x}{T}\right) + b_i \sin\left(\frac{2\pi i x}{T}\right)\right)$$

where T is the period of the function, given by $X_n - X_1$

and N is the number of coefficients to be computed

now, let

$$g(x_j) = y_j \cos\left(\frac{2\pi i x}{T}\right)$$

and

$$h(x_i) = y_j \sin\left(\frac{2\pi i x}{T}\right)$$

then $$a_i \approx \frac{2\Delta x}{3T} \{g(x_1) + 4g(x_2) + 2g(x_3) + 4g(x_4) + \ldots + 4g(x_{n-1}) + g(x_n)\}$$

$$b_i \approx \frac{2\Delta x}{3T} \{h(x_1) + 4h(x_2) + 2h(x_3) + 4h(x_4) + \ldots + 4h(x_{n-1}) + h(x_n)\}$$

Sine and cosine functional values are computed recursively with the following formula:

$$\sin\left(\frac{2\pi x_i}{\Delta x}(J+1)\right) = \sin\left(\frac{2\pi x_i}{\Delta x}\right)\cos\left(\frac{2\pi x_i}{\Delta x}J\right) + \cos\left(\frac{2\pi x_i}{\Delta x}\right)\sin\left(\frac{2\pi x_i}{\Delta x}J\right)$$

$$\cos\left(\frac{2\pi x_i}{\Delta x}(J+1)\right) = \cos\left(\frac{2\pi x_i}{\Delta x}\right)\cos\left(\frac{2\pi x_i}{\Delta x}J\right) - \sin\left(\frac{2\pi x_i}{\Delta x}\right)\sin\left(\frac{2\pi x_i}{\Delta x}J\right)$$

REFERENCES:

1. Hamming, R.W., Numerical Methods for Scientists and Engineers (McGraw-Hill, 1962), pp. 67 - 80.

2. Acton, Forman S., Numerical Methods that Work (Harper and Row, 1970), pp. 221 - 257.

PROGRAM OPERATION - FOURIER COEFFICIENTS
FOR EQUALLY - SPACED DATA

Program File Description

File Name	Function
EQ - KEY	Special Function Keys
FSC - EQ	Enter data, edit data, print data, save data, plot data, link on "fsc-eq"
fsc-eq	Compute coefficients plot magnitude and phase

Variables Used for Subprogram Parameters

N - The number of Fourier series coefficients to be computed

Npts - The number of data points (must be odd)

Init - Initial domain value (x(1))

Incre - Increment between domain values (Δx)

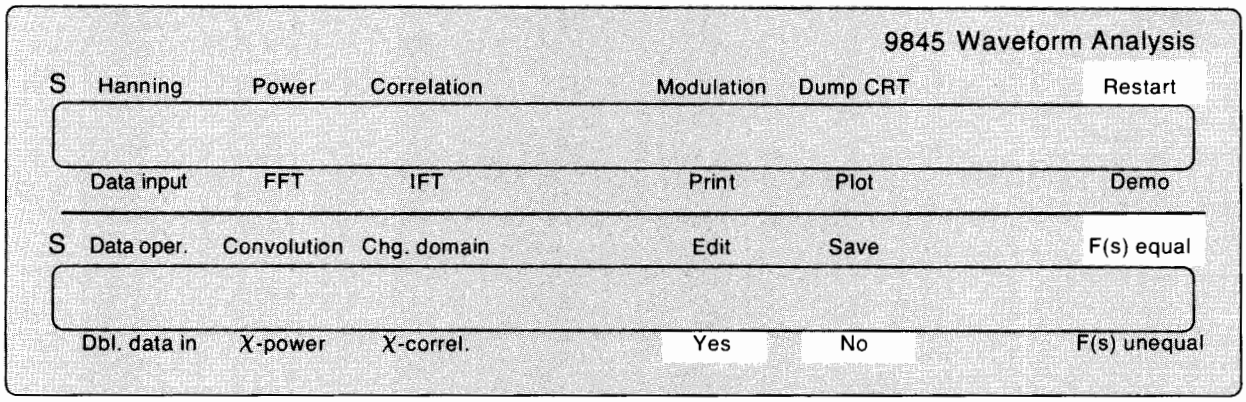
Y(*) - Array containing the range values of the data points subscripted from 1 to Npts)

A(*) - Vector containing the a_i Fourier series coefficients (subscripted from $\emptyset$ to N)

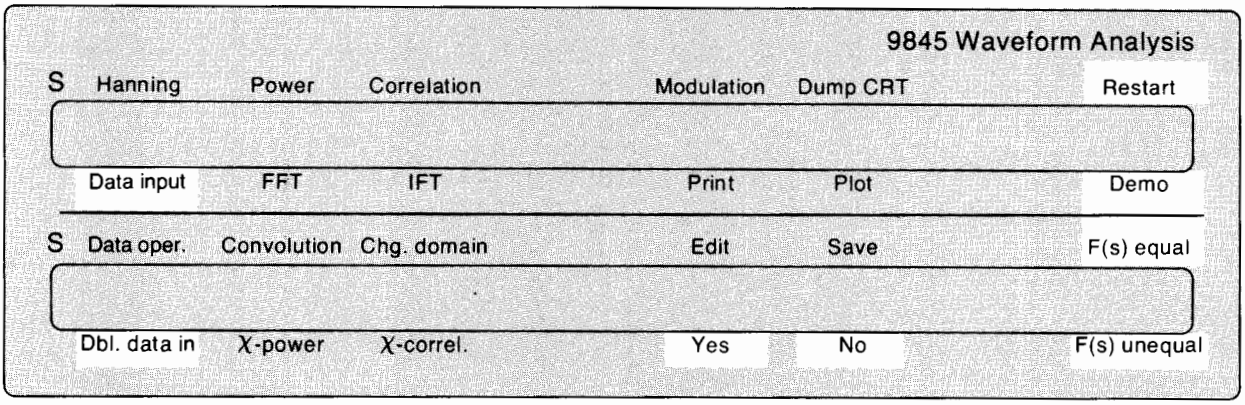
B(*) - Vector containing the b_i Fourier series coefficients (subscripted from 1 to N)

SPECIAL FUNCTION KEY INFORMATION

There are two program files used to find the Fourier Series coefficients for equally-spaced points. They are "FSC-EQ" and "fsc-eq". "fsc-eq" is linked into memory from the program in "FSC-EQ". When the "F(s) equal" key is pressed, "FSC-EQ" is loaded, and the key file "EQ-KEY" is loaded. The following keys are then active:



Upon completion of the program, the key file "KEY" is loaded, which leaves the following keys active:



USER INSTRUCTIONS (FOURIER SERIES COEFFICIENTS FOR EQUALLY-SPACED POINTS)

1. Wait for the program file "FSC-EQ" and the key file "EQ-KEY" to be loaded.

2. When "Please enter the number of data points you have" appears in the display area:
   a. Enter: The number of data points you have
   b. Press: CONT
   Note: Due to the algorithm used, it is necessary to enter an odd number of data points.

3. When "Please enter the number of Fourier series coefficients you want" appears in the display area:
   a. Enter: The number of coefficients you want the program to compute
   b. Press: CONT
   Note: The number of coefficients may be no greater than the number of data points.

4. When "Please enter the type of entry mode you wish to use (1, 2, or 3)" appears in the display area:
   a. Enter: 1, 2, or 3, depending upon whether you wish to enter the data manually from the keyboard, from a mass storage file, or from a 9872A plotter by digitizing, respectively.
   b. Press: CONT

5. When "Please enter the initial time domain value (in seconds)" appears in the display area:
   a. Enter: The initial time domain value
   b. Press: CONT

6. When "Please enter the time increment (in seconds)" appears in the display area:
   a. Enter: The time increment (i.e., the spacing in the X

direction between data points).

b. Press: CONT

c. If you entered a 1 in part 4a, then go to step 7.

d. If you entered a 2 in part 4a, then go to step 8.

e. If you entered a 3 in part 4a, then go to step 11.

7. Perform step 7 for each data point.
When "Y(i)?" appears in the display area:

a. Enter: The Y value of the ith data point

b. Press: CONT

c. Repeat step 7 until all the data points have been entered. When all the data has been entered, go to step 14.

8. When "PLEASE ENTER THE DATA FILE NAME" appears in the display area:

a. Type: The name of the data file

b. Press: CONT

9. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:

a. If your mass storage device is standardized, that is, if it is the system's default mass storage device, set by the MASS STORAGE IS command, or by the power-on conditions of the 9845:

1) Press: YES

2) Go to step 14.

or

a. If your mass storage device is not standardized:

1) Press: NO

2) Go to step 10.

10. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:

a. Type: A mass storage unit specifier

b. Press: CONT

Note: A mass storage unit specifier has the following format:

First a colon, followed by a letter indicating what type of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code.

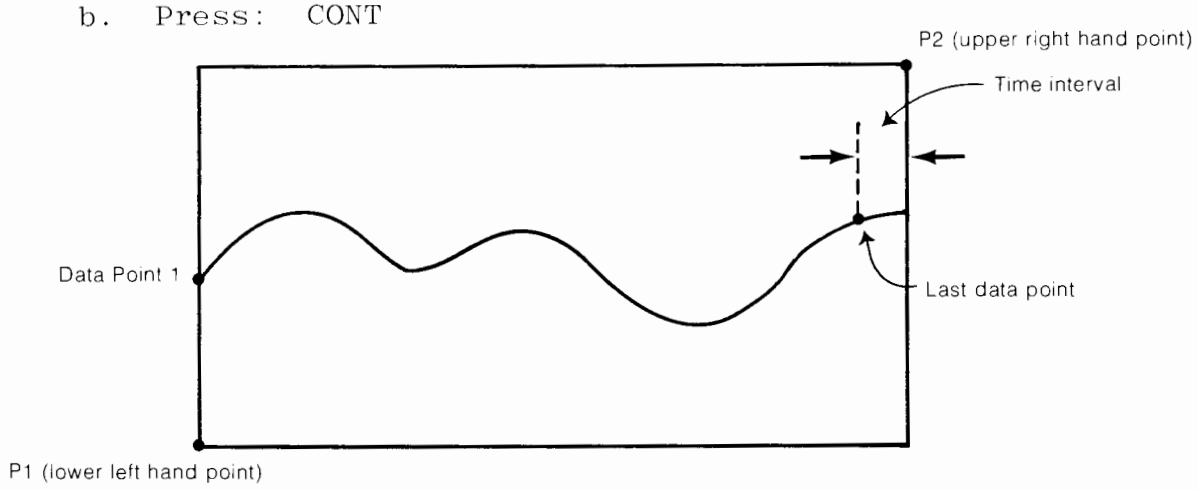
Examples - :T15, :T14, :F8, :Y12

c. Go to step 14.

11. When "DEFINE THE DIGITIZING AREA ON THE 9872A (SET P1 AND P2) AND PRESS CONT" appears in the display area:

a. Define the digitizing area on the 9872A using the front panel control buttons.

b. Press: CONT



c. If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:

a. Enter: The plotter select code

b. Press: CONT

d. If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:

a. Enter: The HPIB address of the plotter

b. Press: CONT

12. When "Please enter the values for Ymin,Ymax?" appears in the display area:

a. Enter: The values of Ymin and Ymax, separated by a comma

b. Press: CONT

13. When "Y(i)?" appears in the display area:
    a. Adjust the pen on the plotter so that it is directly above the ith data point using the ↑ and ↓ buttons on the front panel of the 9872A (the horizontal pen position will be supplied automatically).
    b. Press: The ENTER button on the front panel of the 9872A
    c. Repeat step 13 until all the points have been digitized.

14. When "Do you wish to make any changes in the data (YES/NO)?" appears in the display area:
    a. If you wish to make any changes in the data:
        1) Press: YES
        2) Go to step 15.

    or

    a. If you do not wish to make any changes in the data:
        1) Press: NO
        2) Go to step 17.

15. When "WHICH DATA POINT DO YOU WISH TO CHANGE?" appears in the display area:
    a. Enter: The subscript of the point you wish to change.
    b. Press: CONT

16. When "Y(i)?" appears in the display area:
    a. Enter: The Y value of the ith data point
    b. Press: CONT
    c. Go to step 14.

17. When "Do you wish to print the data (YES/NO)?" appears in the display area:
    a. If you wish to print the data:
        1) Press: YES
        2) Go to step 18.

    or

a. If you do not wish to print the data:
    1) Press: NO
    2) Go to step 18.

18. When "Do you wish to save the data (YES/NO)?" appears in the display area:
    a. If you wish to save the data:
        1) Press: YES
        2) Go to step 19.
    or
    a. If you do not wish to save the data:
        1) Press: NO
        2) Go to step 24.

19. When "DO YOU WISH TO USE A NEW FILE (YES/NO)?" appears in the display area:
    a. If you wish to use a new file:
        1) Press: YES
        2) Go to step 20.
    or
    a. If you do not wish to use a new file, but would rather use an old one:
        1) Press: NO
        2) Go to step 21.

20. When "PLEASE ENTER THE NEW FILE NAME" appears in the display area:
    a. Type: The name of the new file
    b. Press: CONT
    c. Go to step 22.

21. When "PLEASE ENTER THE OLD FILE NAME" appears in the display area:
    a. Type: The name of the old file
    b. Press: CONT

22. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:

    a. If your mass storage device is standardized (that is, if it is the system's default mass storage device, specified by the MASS STORAGE IS command or by the power-on conditions of the 9845):

        1) Press: YES

        2) Go to step 24.

    or

    a. If your mass storage device is not standardized:

        1) Press: NO

        2) Go to step 23.

23. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:

    a. Type: A mass storage unit specifier

    b. Press: CONT

    Note: A mass storage unit specifier is given in the following format:
    First a colon, followed by a letter indicating what kind of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code.
    Examples - :T15, :T14, :F8, :Y12

24. When "Do you wish to plot the data (YES/NO)?" appears in the display area:

    a. If you wish to plot the data:

        1) Press: YES

        2) Go to step 25.

    or

    a. If you do not wish to plot the data:

        1) Press: NO

        2) Go to step 27.

25. When "1---CRT 2-9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:

a. If you want to plot on the CRT:

1) Enter: 1

2) Press: CONT

3) Go to step 26.

or

a. If you want to plot on the 9872A:

1) Enter: 2

2) Press: CONT

3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:

a) Enter: The plotter select code

b) Press: CONT

4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:

a) Enter: The HPIB address of the plotter

b) Press: CONT

5) Go to step 26.

or

a. If you change your mind and do not want a plot after all:

1) Enter: 3

2) Press: CONT

3) Go to step 27.

26. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:

a. Enter: 1, 2, or 3, depending upon which type of plot you want

b. Press: CONT

c. If you had the plot drawn on the CRT, the following message will appear in the display area: "Do you want hard copy of the plot (YES/NO)?"

1) If you want the plot to be dumped to the internal thermal printer:

a) Press: YES

b) Go to step 27.

27. At this point, the file "fsc-un" will be linked into memory, then Fourier series coefficients will be calculated, and the coefficients will be printed on the internal thermal printer.

28. When "PLOT MAGNITUDE (YES/NO)?" appears in the display area:
    a. If you want a plot of the magnitudes of the coefficients:
        1) Press: YES
        2) Go to step 29.

    or

    a. If you do not want a plot of the magnitudes:
        1) Press: NO
        2) Go to step 31.

29. When "1---CRT 2---9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:
    a. If you want the plot to be on the CRT:
        1) Enter: 1
        2) Press: CONT
        3) Go to step 30.

    or

    a. If you want the plot to be on the 9872A:
        1) Enter: 2
        2) Press: CONT
        3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
            a) Enter: The plotter select code
            b) Press: CONT
        4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
            a) Enter: The HPIB address of the plotter
            b) Press: CONT
        5) Go to step 30.

    or

a. If you changed your mind, and you do not want a plot:
    1) Enter: 3
    2) Press: CONT
    3) Go to step 31.

30. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:
    a. Enter: 1, 2, or 3, depending upon which type of a plot you want
    b. Press: CONT
    c. If you put the plot on the CRT the following message will appear in the display area: "Do you want hard copy of the plot (YES/NO)?":
        1) If you want the plot to be dumped to the internal thermal printer:
            a) Press: YES
            b) Go to step 31.

    or

        1) If you do not want a hard copy of the plot:
            a) Press: NO
            b) Go to step 31.

31. When "PLOT PHASE (YES/NO)?" appears in the display area:
    a. If you want to plot the phases of the coefficients:
        1) Press: YES
        2) Go to step 32.

    or

    a. If you do not want to plot the phases:
        1) Press: NO
        2) Go to step 34.

32. When "1---CRT 2---9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:
    a. If you want the plot to be on the CRT:
        1) Enter: 1

2) Press: CONT

3) Go to step 33.

or

a. If you want the plot to be on the 9872A:

1) Enter: 2

2) Press: CONT

3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:

a) Enter: The plotter select code

b) Press: CONT

4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:

a) Enter: The HPIB address of the plotter

b) Press: CONT

5) Go to step 33.

or

a. If you changed your mind and you do not want to plot the phases after all:

1) Enter: 3

2) Press: CONT

3) Go to step 34.

33. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:

a. Enter: 1, 2, or 3, depending upon what type of plot you want

b. Press: CONT

c. If the plot was drawn on the CRT, then the following message will appear in the display area upon completion of the plot: "Do you want hard copy of the plot (YES/NO)?":

1) If you want the plot to be dumped to the internal thermal printer:

a) Press: YES

b) Go to step 34.

or

2) If you do not want a hard copy of the plot:
   a) Press: NO
   b) Go to step 34.

34. The program will load the key file "KEY", a beep will sound, and the message "DONE" will appear in the display area. At this point the program is finished.

    Note: To re-run the program, the user should press the special function key labelled "F(s) equal" (key 31). Pressing RUN will not suffice as the file "fsc-eq" has been linked into memory, wiping out the data entry, editing, printing, and plotting routines. Key 31 re-loads the program file "FSC-EQ".

Fourier Series Coefficients for Unequally-Spaced Data

This program calculates the Fourier series coefficients a_i and b_i of the Fourier series corresponding to a function F(x) which is approximated by n discrete data points (x,y) j=1,n.

The finite Fourier series is given by the formula:

$$\frac{a_0}{2} + \sum_{i=1}^{N} \left(a_i \cos\left(\frac{2\pi i x}{T}\right) + b_i \sin\left(\frac{2\pi i x}{T}\right)\right)$$ where the

Fourier coefficients a_i and b_i are:

$$a_i = \frac{2}{T} \int_{x_1}^{x_1+T} F(x) \cos\left(\frac{2\pi i x}{T}\right) dx \quad \text{for } i = \emptyset, N$$

$$b_i = \frac{2}{T} \int_{x_1}^{x_1+T} F(x) \sin\left(\frac{2\pi i x}{T}\right) dx \quad \text{for } i = 1, N.$$

T specifies the period, given by $(x_n - x_1)$, and N indicates the number of coefficients desired. The coefficients are evaluated by numerically integrating a parabola passing through three successive points. Execution time depends on the number of coefficients calculated.

The coefficients A_j and B_j are computed using the following formulae:

$$A_j = \sum_{i=2}^{k-1} S_i \qquad \text{for } j = 1, n$$

$$B_j = \sum_{i=2}^{k-1} T_i \qquad \text{for } j = 1, n$$

where:

$$S_i = \frac{(2Ax_{i+1}+B)\cos\left[2\pi\left(\frac{x_{i+1}J}{x_k-x_1}\right)\right] - (2Ax_i+B)\cos\left[2\pi\left(\frac{x_iJ}{x_k-x_1}\right)\right]}{\left(\frac{J}{x_k-x_1}\right)^2} +$$

$$\frac{y_{i+1}\left(\frac{J}{x_k-x_1}\right)^2 - 2A}{\left(\frac{2\pi J}{x_k-x_1}\right)^3} \sin\left[2\pi\left(\frac{x_{i+1}J}{x_k-x_1}\right)\right] -$$

$$\frac{y_i\left(\frac{J}{x_k-x_1}\right)^2 - 2A}{\left(\frac{2\pi J}{x_k-x_1}\right)^3} \sin\left[2\pi\left(\frac{x_iJ}{x_k-x_1}\right)\right]$$

$$T_i = \frac{(2Ax_{i+1}+B)\sin\left[2\pi\,\mathrm{frc}\left(\frac{x_{i+1}J}{x_k-x_1}\right)\right] - (2Ax_i+B)\sin\left[2\pi\,\mathrm{frc}\left(\frac{x_iJ}{x_k-x_1}\right)\right]}{\left(\frac{J}{x_k-x_1}\right)^2} -$$

$$\frac{y_{i+1}\left(\frac{J}{x_k-x_1}\right)^2 - 2A}{\left(\frac{2\pi J}{x_k-x_1}\right)^3} \cos\left[2\pi\left(\frac{x_{i+1}J}{x_k-x_1}\right)\right] +$$

$$\frac{y_i\left(\frac{J}{x_k-x_1}\right)^2 - 2A}{\frac{2\pi J}{x_k-x_1}^3} \cos\left[2\pi\left(\frac{x_i J}{x_k-x_1}\right)\right]$$

and

$$Q_i = \frac{(x_{i+1}-x_{i+2})\ y_i-(x_i-x_{i+2})\ y_{i+1}+(x_i-x_{i+1})\ y_{i+2}}{(x_{i+1}-x_{i+2})\ (x_i-x_{i+2})\ (x_i-x_{i+1})}$$

$$A = \frac{1}{2}\ (Q_i+Q_{i-1})$$

$$R_i = \frac{-(x_{i+1}^2-x_{i+2})^2\ y_i-(x_i^2-x_{i+2}^2)\ y_{i+1}+(x_i^2-x_{i+1}^2)\ y_{i+2}}{(x_{i+1}-x_{i+2})\ (x_i-x_{i+2})\ (x_i-x_{i+1})}$$

$$B = \frac{1}{2}\ (R_i+R_{i-1})$$

where J is the number of coefficients being computed and frc ( ) indicates fractional part, and

$$A_o = \sum_{i=2}^{k=1} U_i$$

$$U_i = \frac{A(x_{i+1}^3-x_i^3)}{3} + \frac{B(x_{i+1}^2-x_i^2)}{2} + C(x_{i+1}-x_i)$$

where A and B are defined above, and

$$C = \frac{1}{2} (P_i + P_{i-1})$$

$$P_i = \frac{(x_{i+1}-x_{i+2})x_{i+1}x_{i+2}y_i - (x_i-x_{i+2})x_i x_{i+2}y_{i+1} + (x_i-x_{i+1})x_i x_{i+1}y_{i+2}}{(x_{i+1}-x_{i+2})(x_i-x_{i+2})(x_i-x_{i+1})}$$

Sine and cosine functional values are computed recursively with the following formulae:

$$\sin\left(\frac{2\pi x_i}{x_k-x_1}(J+1)\right) = \sin\left(\frac{2\pi x_i}{x_k-x_1}\right)\cos\left(\frac{2\pi x_i}{x_k-x_1}J\right) + \cos\left(\frac{2\pi x_i}{x_k-x_1}\right)\sin\left(\frac{2\pi x_i}{x_k-x_i}J\right)$$

$$\cos\left(\frac{2\pi x_i}{x_k-x_1}(J+1)\right) = \cos\left(\frac{2\pi x_i}{x_k-x_1}\right)\cos\left(\frac{2\pi x_i}{x_k-x_1}J\right) - \sin\left(\frac{2\pi x_i}{x_k-x_1}\right)\sin\left(\frac{2\pi x_i}{x_k-x_1}J\right)$$

Where I is the data point number and J is the coefficient number

REFERENCES:

1. Hewlett-Packard 9820A Math Pac, pp. 43 - 50.
2. Hamming, R.W. Numerical Methods for Scientists and Engineers (McGraw-Hill, 1962), pp. 67 - 80.
3. Acton, Forman S., Numerical Methods that Work (Harper and Row, 1970), pp. 221 - 257.

PROGRAM OPERATION - FOURIER COEFFICIENTS
FOR UNEQUALLY-SPACED DATA

Program File Description

File Name	Function
UN-KEY	Special Function Keys
FSC - UN	Enter data, edit data, print data, save data, plot data, link on "fsc-un"
fsc-un	compute coefficients, plot magnitude and phase

Variabes Used for Subprogram Parameters

N - The number of Fourier series coefficients to be computed

Npts - The number of data points

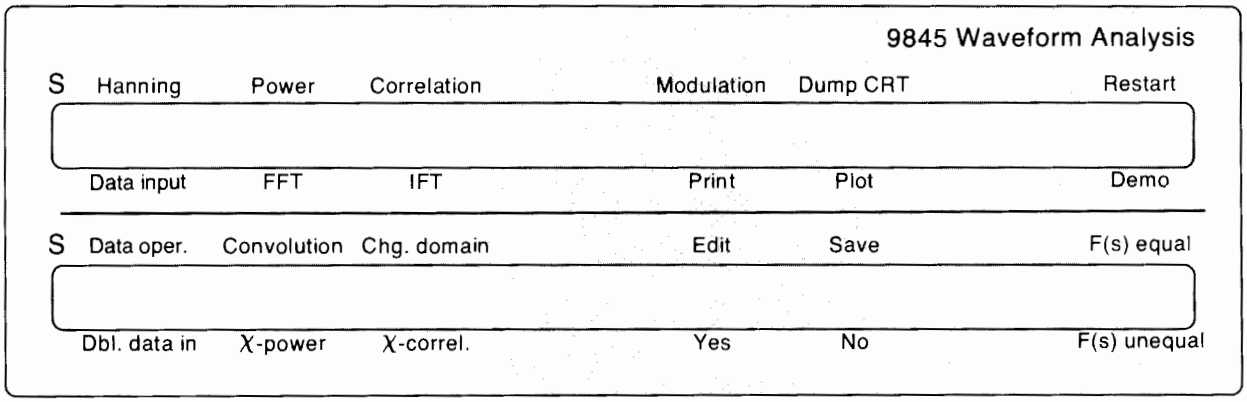
X(*) - The array holding the domain values for the data points (subscripted from 1 to Npts)

Y(*) - The array holding the range values for the data points (subscripted from 1 to Npts)

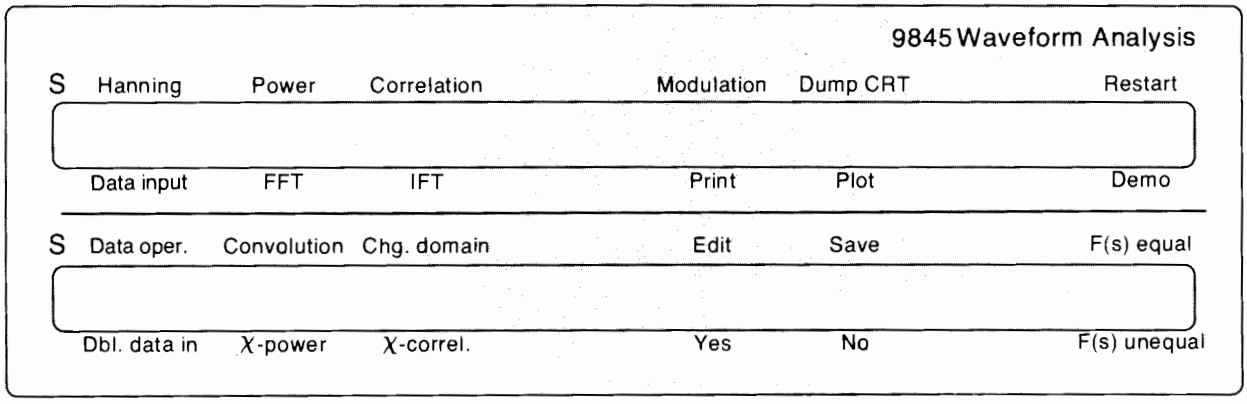
A(*) - Vector containing the a_i Fourier series coefficients (subscripted from Ø to N)

B(*) - Vector containing the b_i Fourier series coefficients (subscripted from 1 to N)

There are two program files used to find the Fourier series coefficients for unequally spaced points. They are "FSC-UN" and "fsc-un". "fsc-un" is linked into memory from the program in "FSC-UN". When the "F(s) unequal" key is pressed, "FSC-UN" is leaded, and the key file "UN-KEY" is loaded. The following keys are then active:



Upon completion of the program, the key file "KEY" is loaded, which leaves the following keys active:



USER INSTRUCTIONS (FOURIER SERIES COEFFICIENTS FOR UNEQUALLY-SPACED POINTS)

1. Wait for the program file "FSC-UN" and the key file "UN-KEY" to be loaded.

2. When "Please enter the number of data points you have" appears in the display area:
   a. Enter: The number of data points you have
   b. Press: CONT

3. When "Please enter the number of Fourier series coefficients you want" appears in the display area:
   a. Enter: The number of coefficients you want the program to compute
   b. Press: CONT
   Note: The number of coefficients may be no greater than the number of data points.

4. When "Please enter the type of entry mode you wish to use (1, 2, or 3)" appears in the display area:
   a. Enter: 1, 2, or 3, depending upon whether you wish to enter the data manually from the keyboard, from a mass storage file, or from a 9872A plotter by digitizing, respectively
   b. Press: CONT
   c. If you entered 1 in part 4a, go to step 5.
   d. If you entered 2 in part 4a, go to step 7.
   e. If you entered 3 in part 4a, go to step 10.

5. Perform steps 5 and 6 for each data point.
   When "X(i)?" appears in the display area:
   a. Enter: The X value of the ith data point.
   b. Press: CONT
   Note: The X values should be discrete, and they should occur in increasing order.

6. When "Y(i)?" appears in the display area:
   a. Enter: The Y value of the ith data point
   b. Press: CONT
   c. Repeat steps 5 and 6 until all the data points have been entered. When all the data has been entered, go to step 13.

7. When "PLEASE ENTER THE DATA FILE NAME" appears in the display area:
   a. Type: The name of the data file.
   b. Press: CONT

8. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:
   a. If your mass storage device is standardized, that is, if it is the system's default mass storage device, set by the MASS STORAGE IS command, or by the power-on conditions of the 9845:
      1) Press: YES
      2) Go to step 13.

   or

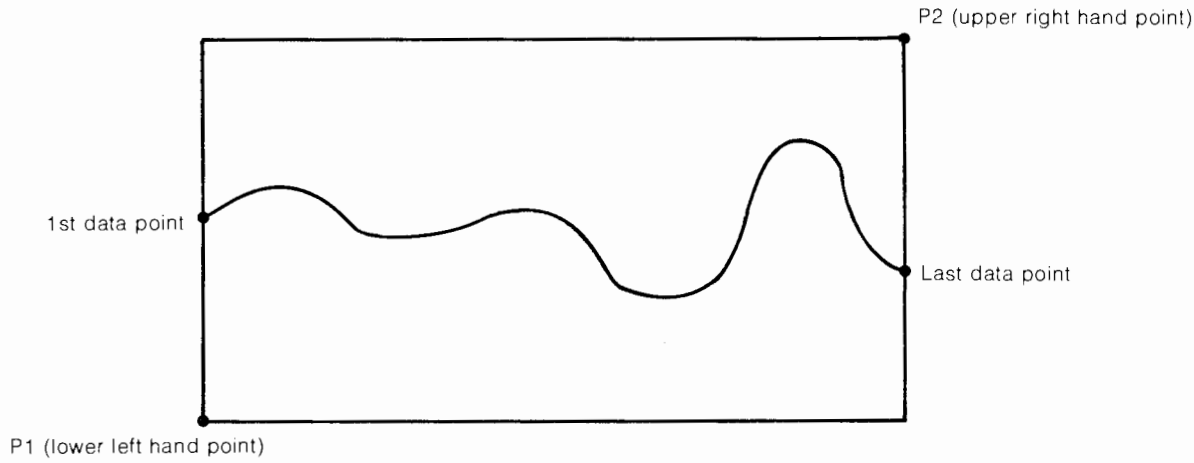
   a. If your mass storage device is not standardized:
      1) Press: NO
      2) Go to step 9.

9. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:
   a. Type: A mass storage unit specifier
   b. Press: CONT

   Note: A mass storage unit specifier has the following format: First a colon, followed by a letter indicating what type of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code. Examples - :T15, :T14, :F8, :Y12

   c. Go to step 13.

10. When "DEFINE THE DIGITIZING AREA ON THE 9872A (SET P1 and P2) AND PRESS CONT" appears in the display area:
    a. Define the digitizing area on the 9872A using the front panel control buttons.
    b. Press: CONT



    c. If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
        a. Enter: The plotter select code
        b. Press: CONT
    d. If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
        a. Enter: The HPIB address of the plotter
        b. Press: CONT

12. When "X(i),Y(i)?" appears in the display area:
    a. Adjust the pen on the plotter so that it is directly above the ith data point using the ↑, ↓, →, and ← buttons on the front panel of the 9872A.
    b. Press: The ENTER button on the front panel of the 9872A
    c. Repeat step 12 until all the points have been digitized.

13. When "Do you wish to make any changes in the data (YES/NO)?" appears in the display area:
    a. If you wish to make any changes in the data:
        1) Press: YES
        2) Go to step 14.

or

a. If you do not wish to make any changes in the data:

1) Press: NO

2) Go to step 17.

Note: Once you indicate that you have no further changes to make, the program will check to make sure that the X values are in increasing order (that is, X(i)< X(i+1) for i = 1, 2,...,N-1, where N is the number of data points. If the X points are not in increasing order, then an error message will be issued, and the user will be forced to repeat step 13 until the situation is corrected.

14. When "WHICH DATA POINT DO YOU WISH TO CHANGE?" appears in the display area:

a. Enter: The subscript of the point you wish to change.

b. Press: CONT

15. When "X(i)?" appears in the display area:

a. Enter: The X value of the ith data point

b. Press: CONT

16. When "Y(i)?" appears in the display area:

a. Enter: The Y value of the ith data point

b. Press: CONT

c. Go to step 13.

17. When "Do you wish to print the data (YES/NO)?" appears in the display area:

a. If you wish to print the data:

1) Press: YES

2) Go to step 18.

or

a. If you do not wish to print the data:

1) Press: NO

2) Go to step 18.

18. When "Do you wish to save the data (YES/NO)?" appears in the display area:
    a. If you wish to save the data:
        1) Press: YES
        2) Go to step 19.

    or

    a. If you do not wish to save the data:
        1) Press: NO
        2) Go to step 24.

19. When "DO YOU WISH TO USE A NEW FILE (YES/NO)? appears in the display area:
    a. If you wish to use a new file:
        1) Press: YES
        2) Go to step 20.

    or

    a. If you do not wish to use a new file, but would rather use an old one:
        1) Press: NO
        2) Go to step 21.

20. When "PLEASE ENTER THE NEW FILE NAME" appears in the display area:
    a. Type: The name of the new file
    b. Press: CONT
    c. Go to step 22.

21. When "PLEASE ENTER THE OLD FILE NAME" appears in the display area:
    a. Type: The name of the old file
    b. Press: CONT

22. When "IS YOUR MASS STORAGE DEVICE STANDARDIZED (YES/NO)?" appears in the display area:
    a. If your mass storage device is standardized (that is, if it is the system's default mass storage device, specified

by the MASS STORAGE IS command or by the power-on conditions of the 9845):

1) Press: YES
2) Go to step 24.

or

a. If your mass storage device is not standardized:
   1) Press: NO
   2) Go to step 23.

23. When "WHAT IS YOUR MASS STORAGE DEVICE?" appears in the display area:
    a. Type: A mass storage unit specifier
    b. Press: CONT
    Note: A mass storage unit specifier is given in the following format:
    First a colon, followed by a letter indicating what kind of device is being used (i.e., T for tape cartridge, F for floppy diskette, Y for 7905 removable platter, etc.), followed in turn by the proper select code.
    Examples - :T15, :T14, :F8, :Y12

24. When "Do you wish to plot the data (YES/NO)?" appears in the display area:
    a. If you wish to plot the data:
       1) Press: YES
       2) Go to step 25.

    or

    a. If you do not wish to plot the data:
       1) Press: NO
       2) Go to step 27.

25. When "1---CRT 2-9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:

a. If you want to plot on the CRT:
    1) Enter: 1
    2) Press: CONT
    3) Go to step 26.

or

a. If you want to plot on the 9872A:
    1) Enter: 2
    2) Press: CONT
    3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
        a) Enter: The plotter select code
        b) Press: CONT
    4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
        a) Enter: The HPIB address of the plotter
        b) Press: CONT
    5) Go to step 26.

or

a. If you change your mind and do not want a plot after all:
    1) Enter: 3
    2) Press: CONT
    3) Go to step 27.

26. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:
    a. Enter: 1, 2, or 3, depending upon which type of plot you want.
    b. Press: CONT
    c. If you had the plot drawn on the CRT, the following message will appear in the display area: "Do you want hard copy of the plot (YES/NO)?":
        1) If you want the plot to be dumped to the internal thermal printer:
            a) Press: YES
            b) Go to step 27.

or

1) If you do not want a hard copy of the plot:
   a) Press: NO
   b) Go to step 27.

27. At this point, the file "fsc-un" will be linked into memory, the Fourier series coefficients will be calculated, and the coefficients will be printed on the internal thermal printer.

28. When "PLOT MAGNITUDE (YES/NO)?" appears in the display area:
a. If you want a plot of the magnitudes of the coefficients:
   1) Press: The YES special function key (key 12).
   2) Go to step 29.

or

a. If you do not want a plot of the magnitudes:
   1) Press: NO
   2) Go to step 31.

29. When "1---CRT 2---9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:
a. If you want the plot to be on the CRT:
   1) Enter: 1
   2) Press: CONT
   3) Go to step 30.

or

a. If you want the plot to be on the 9872A:
   1) Enter: 2
   2) Press: CONT
   3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
      a) Enter: The plotter select code
      b) Press: CONT
   4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
      a. Enter: The HPIB address of the plotter
      b. Press: CONT

5) Go to step 30.

or

a. If you changed your mind, and you do not want a plot:

1) Enter: 3

2) Press: CONT

3) Go to step 31.

30. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:

a. Enter: 1, 2, or 3, depending upon which type of a plot you want.

b. Press: CONT

c. If you put the plot on the CRT the following message will appear in the display area: "Do you want hard copy of the plot (YES/NO)?":

1) If you want the plot to be dumped to the internal thermal printer:

a) Press: YES

b) Go to step 31.

or

1) If you do not want a hard copy of the plot:

a) Press: NO

b) Go to step 31.

31. When "PLOT PHASE (YES/NO)?" appears in the display area:

a. If you want to plot the phases of the coefficients:

1) Press: YES

2) Go to step 32.

or

a. If you do not want to plot the phases:

1) Press: NO

2) Go to step 34.

32. When "1---CRT 2---9872A 3---NO PLOT *** SELECT NUMBER" appears in the display area:

a. If you want the plot to be on the CRT:

1) Enter: 1
2) Press: CONT
3) Go to step 33.

or

a. If you want the plot to be on the 9872A:
1) Enter: 2
2) Press: CONT
3) If "PLEASE ENTER THE SELECT CODE OF THE PLOTTER" appears in the display area:
a) Enter: The plotter select code
b) Press: CONT
4) If "PLEASE ENTER THE HPIB ADDRESS OF THE PLOTTER" appears in the display area:
a) Enter: The HPIB address of the plotter
b) Press: CONT
5) Go to step 33.

or

a. If you changed your mind and you do not want to plot the phases after all:
1) Enter: 3
2) Press: CONT
3) Go to step 34.

33. When "1---LINE 2---POINT 3---BAR *** SELECT NUMBER" appears in the display area:
a. Enter: 1, 2, or 3, depending upon what type of plot you want.
b. Press: CONT
c. If the plot was drawn on the CRT, then the following message will appear in the display area upon completion of the plot: "Do you want hard copy of the plot (YES/NO)?":
1) If you want the plot to be dumped to the internal thermal printer:
a) Press: YES
b) Go to step 34.

or

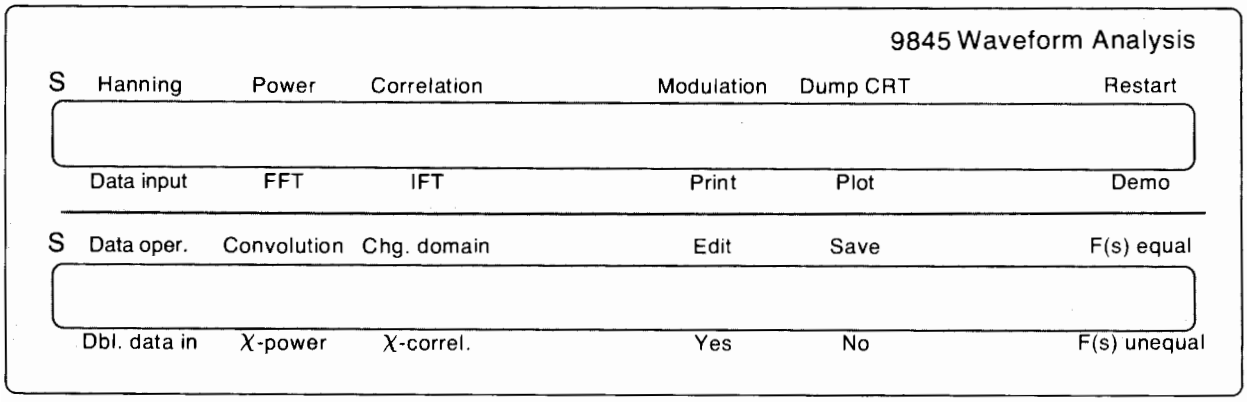
2) If you do not want a hard copy of the plot:
   a) Press: NO
   b) Go to step 34.

34. The program will load the key file "KEY", a beep will sound, and the message "DONE" will appear in the display area. At this point the program is finished.

Note: To rerun the program, the user should press the special function key labelled "F(s) unequal" (key 15). Pressing RUN will not suffice as the file "fsc-un" has been linked into memory, wiping out the data entry, editing, printing, and plotting routines. Key 15 reloads the program file "FSC-UN".

Demonstration Program

There are three program files needed for this program to run, as well as one data file. The three program files are "DEMO", "DEMO1", and "DEMO2". The data file is called "DEMO-D". In addition, a key file, "DE-KEY", is loaded. The key file leaves the special function keys defined in the following manner:



USER INSTRUCTIONS FOR DEMO

1. After pressing the Demo key (key 7), wait for the program file "DEMO" and the key file "DE-KEY" to be loaded into memory.

2. When "TO START THE DEMO, PRESS THE CONTINUE KEY (CONT)" appears in the display area:
   a. Press: CONT

3. For all of the questions asked by the program, answer by pressing the YES and NO special function keys (keys 12 and 13, respectively).

4. The program will display messages indicating when it is computing FFT's, IFT's, power, auto correlation, etc. When the program is done, the message "DONE" will appear in the display. Key 23 (Restart) will load the file "START" into memory and run it.

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