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EMPFIT: A COMPUTER CODE FOR FITTING EMP WAVEFORMS THAT FACILITA--ETC(U)
APR 77 J M CLODFELTER
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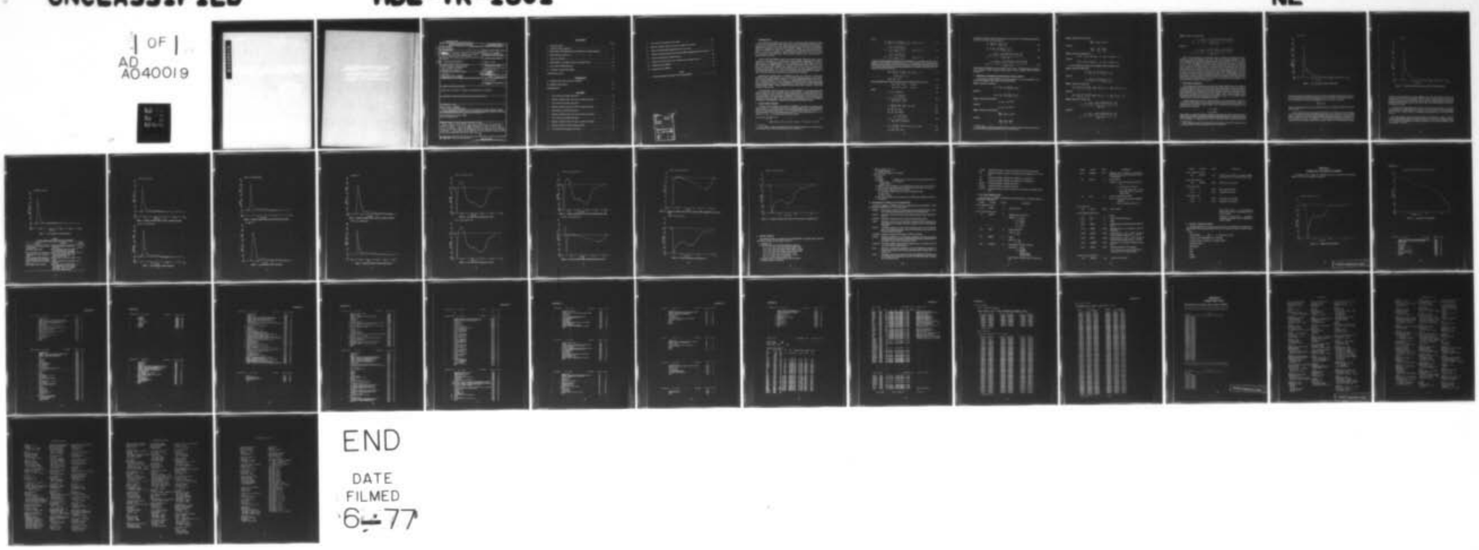

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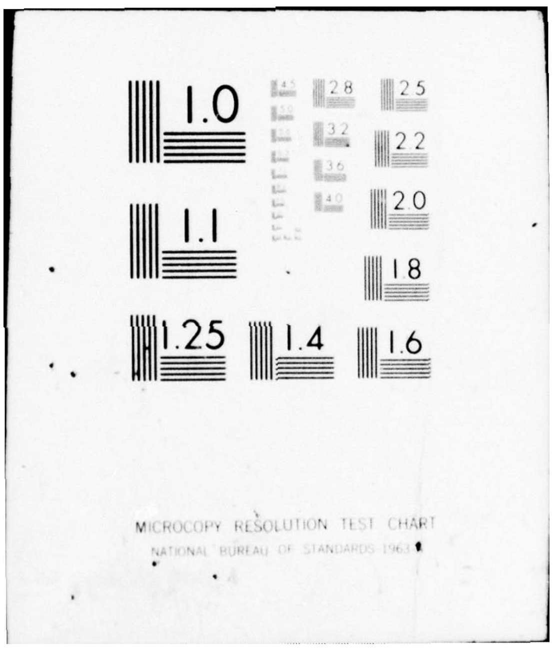
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The computer code EMPFIT provides a method to fit an electromagnetic pulse, as well as other waveforms, with as little as 15 to 30 points. The code EMPFIT allows the user to fit a smooth curve to the data under consideration and to calculate the Fourier transform. An examination of EMPFIT's capabilities is given along with the procedures for using the code.

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CONTENTS

APPENDICES

FIGURES

TABLE

1. INTRODUCTION

The computer code EMPFIT was written to give a method for approximating the output waveform of an electromagnetic (EMP) pulse with a relatively simple function that smooths out small numerical variations, but is easily differentiated and Fourier transformed. In development, EMPFIT was coded from the theoretical work of Daniel F. Higgins.[1] Also, the Fourier transform code used in EMPFIT was written by W. Talmadge Wyatt of the Harry Diamond Laboratories (HDL). As can be seen in appendix A, EMPFIT produces excellent results, but some care must be exercised when choosing particular input parameters needed to run the code. This aspect is dealt with fully in section 4.

A quite useful code, EMPFIT requires only a minimal number of input data points to find a smooth fit to a waveform over several decades in time. Normally, digitization of a waveform requires from 60 to 500 digitized points or more, depending on the wanted degree of accuracy and refinement, but EMPFIT allows one to describe the waveform with as little as 15 to 30 points. This aspect makes EMPFIT most attractive where the user desires a smooth curve through data points and a "nice" Fourier transform (that is, low noise, smoothness). Thus, this advantage makes EMPFIT a very useful tool in analyzing and describing EMP waveforms, as well as other data that require smooth curves and nice Fourier transforms.

Regarding the operational aspects of EMPFIT, the code was written for a Control Data Corporation (CDC) 6600 computer system at the Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, VA, using standard FORTRAN IV. The code is run by using the SCOPE 3.4.3 control language. A Houston Instruments Complot Plotter along with the appropriate software is used in EMPFIT to obtain plots at the HDL Woodbridge Research Facility (WRF). Listings of EMPFIT and the control cards necessary to run the code are given in later sections.

In the following sections, the general theory behind EMPFIT is summarized along with some problems and errors encountered while coding EMPFIT. A detailed discussion of the results is included, as well as numerous examples of common problems and solutions to the most recurrent problems. The output options of EMPFIT are numerated, a brief description of the subroutines of the code is given, and a detailed section on preparing data cards to run EMPFIT is presented. In the appendices, a sample run and examples of input data are given.

2. CURVE FITTING THEORY

A general, short description of the theory[1] for EMPFIT is now given. Let the input data points (t_i, f_i) for $1 \le i \le N$ be given that describe the general shape of any waveform $f(t)$ that we wish to fit. We can approximate $f(t)$ for $t \le t_1$ by an exponential that varies as $e^{\alpha t}$, and for $t \ge t_N$ we can approximate $f(t)$ by an exponential that varies as $e^{-\beta t}$. For any time interval $t_i \le t \le t_i+1$ where $1 \le i \le N - 1$, we fit the data points with the function

$$f(t) = \frac{f_{i+1}\cdot(t - t_i) + f_i\cdot(t_{i+1} - t)}{t_{i+1} - t_i} + \tfrac{1}{2}(B_i + B_{i+1})(t - t_i)(t - t_{i+1}) + C_i(t - t_i)(t_{i+1} - t)^3 + D_{i+1}(t_{i+1} - t)(t - t_i)^3, \quad (1)$$

[1] Daniel F. Higgins, A Method for Fitting EMP Waveforms that Facilitates Calculation of the Time Derivative and Fourier Transform, Defense Nuclear Agency Report DNA 3231T (November 1973).

where

$$B_i = \left(\frac{f_{i+1} - f_i}{t_{i+1} - t_i} - \frac{f_i - f_{i-1}}{t_i - t_{i-1}}\right)\left(\frac{1}{t_{i+1} - t_i}\right), \qquad \text{for } 2 \le i \le N - 1, \tag{2}$$

$$C_i = \frac{-\Delta f_i^{[1]} + \Delta f_i^{[2]}\left(\frac{t_i - t_{i-1}}{6}\right)}{(t_{i+1} - t_i)^2(t_{i+1} - t_{i-1})}, \qquad \text{for } 2 \le i \le N - 1, \tag{3}$$

$$D_i = \frac{-\Delta f_i^{[1]} - \Delta f_i^{[2]}\left(\frac{t_i - t_{i-1}}{6}\right)}{(t_i - t_{i-1})^2(t_{i+1} - t_{i-1})}, \qquad \text{for } 2 \le i \le N - 1. \tag{4}$$

A brief, general description concerning the fit of equation (1) is as follows: the first term in equation (1) is just a linear fit between the ith and $(i + 1)$st data points; the second term is the quadratic correction based on an average curvature (B_i); the third and fourth terms of equation (1) are used to insure that the first and second derivatives are continuous at the data points. The values $\Delta f_i^{[1]}$ and $\Delta f_i^{[2]}$ are given by

$$\Delta f_i^{[1]} = \frac{f_{i+1} - f_i}{t_{i+1} - t_i} - \frac{f_i - f_{i-1}}{t_i - t_{i-1}} + \tfrac{1}{2}(B_i + B_{i+1})(t_{i+1} - t_i) \tag{5}$$

$$- \tfrac{1}{2}(B_i + B_{i-1})(t_i - t_{i-1}),$$

$$\Delta f_i^{[2]} = B_{i+1} - B_{i-1}. \tag{6}$$

The exponential functions fitted to the front and rear of the data points (t_i, f_i) are

$$f(t) = A_1 e^{\alpha t} + A_3 e^{2\alpha t}, \qquad \text{for } t \le t_1, \tag{7}$$

$$f(t) = A_2 e^{-\beta t} + A_4 e^{-2\beta t}, \qquad \text{for } t \ge t_N, \tag{8}$$

where

$$A_1 = (f_1 - A_3 e^{2\alpha t_1})e^{-\alpha t_1}, \tag{9}$$

$$A_3 = \frac{k_1 + k_2\left(\frac{t_2 - t_1}{6}\right)}{\left[\alpha^2\left(\frac{t_2 - t_1}{2}\right) + \alpha\right]e^{2\alpha t_1}}, \tag{10}$$

$$k_1 = \frac{f_2 - f_1}{t_2 - t_1} + \tfrac{1}{2}(B_1 + B_2)(t_1 - t_2) - \alpha f_1, \tag{11}$$

$$k_2 = B_1 + B_2 - \alpha^2 f_1, \tag{12}$$

$$A_2 = [f_N - A_4 e^{-2\beta t_N}]e^{\beta t_N}, \tag{13}$$

$$A_4 = \frac{k_3 - k_4\left(\frac{t_N - t_{N-1}}{6}\right)}{\left[\beta + \beta^2\left(\frac{t_N - t_{N-1}}{2}\right)\right]e^{-2\beta t_N}}, \tag{14}$$

$$k_3 = -\frac{f_N - f_{N-1}}{t_N - t_{N-1}} - \tfrac{1}{2}(B_N + B_{N-1})(t_N - t_{N-1}) - \beta f_N, \tag{15}$$

$$k_4 = \beta^2 f_N - (B_N + B_{N-1}). \tag{16}$$

The special parametric values for α and β are discussed in section 4. The following special values for B_1, B_N, C_1, and D_N can now be given as

$$B_1 = \left(\frac{f_2 - f_1}{t_2 - t_1} - \alpha f_1\right)\left(\frac{1}{t_2 - t_1}\right), \tag{17}$$

$$B_N = \left(-\beta f_N - \frac{f_N - f_{N-1}}{t_N - t_{N-1}}\right)\left(\frac{1}{t_N - t_{N-1}}\right), \tag{18}$$

$$C_1 = \frac{k_2 - 3\alpha^2\left[k_1 + k_2\left(\frac{t_2 - t_1}{6}\right)\Big/\left(\alpha^2\left(\frac{t_2 - t_1}{2}\right) + \alpha\right)\right]}{6(t_2 - t_1)^2}, \tag{19}$$

$$D_N = \frac{-k_4 - 3\beta^2\left[k_3 - k_4\left(\frac{t_N - t_{N-1}}{6}\right)\Big/\left(\beta + \beta^2\left(\frac{t_N - t_{N-1}}{2}\right)\right)\right]}{6(t_N - t_{N-1})^2}. \tag{20}$$

Using the above coefficients, we can evaluate $f(t)$ at any time t. The function given in equation (1) is continuous, passes through the data points, and has continuous first and second derivatives.

3. PROBLEMS AND ERRORS ENCOUNTERED IN CODING EMPFIT

In the process of coding EMPFIT from the theoretical work, several typographical errors were found in Higgins' report,[1] which are enumerated below.

Higgins' equation (4) should read

$$B_N = \left(-\beta f_N - \frac{f_N - f_{N-1}}{t_N - t_{N-1}}\right)\left(\frac{1}{t_N - t_{N-1}}\right)$$

instead of

$$B_N = \left(-\beta f_N - \frac{f_n - f_{N-1}}{t_N - t_{N-1}}\right)\left(\frac{1}{t_N - t_{N-1}}\right).$$

Higgins' equation (20) should read

$$A_2 = (f_N - A_4 e^{-2\beta t_N})e^{\beta t_N}$$

instead of

$$A_3 = (f_N - A_4 e^{-2\beta t_N})e^{\beta t_N}.$$

Higgins' equation (21a) should read

$$\frac{df(t)}{dt} = \alpha[f(t) + A_3 e^{2\alpha t}]$$

instead of

$$\frac{df(t)}{dt} = \frac{f(t)}{\alpha} + \frac{A_3 e^{2\alpha t}}{\alpha}.$$

[1] Daniel F. Higgins, A Method for Fitting EMP Waveforms that Facilitates Calculation of the Time Derivative and Fourier Transform, Defense Nuclear Agency Report DNA 3231T (November 1973).

Higgins' equation (21c) should read

$$\frac{df(t)}{dt} = -\beta[f(t) + A_4 e^{-2\beta t}]$$

instead of

$$\frac{df(t)}{dt} = -\frac{f(t)}{\beta} - \frac{A_4 e^{-2\beta t}}{\beta}.$$

Higgins' equation (34) should read

$$\Delta f_n^{[3]} = -(18C_n + 6D_{n+1})(t_{n+1} - t_n) - (6C_{n-1} + 18D_n)(t_n - t_{n-1})$$

instead of

$$\Delta f_n^{[3]} = -(18C_n + 6D_{n+1})(t_{n+1} - t_n) - (6C_{n-1} + 18D_n)(t_n - t_{n+1}).$$

Also, the following corrections were supplied by Mission Research Corp.

Higgins' equation (2) should read

$$B_n = \left(\frac{f_{n+1} - f_n}{t_{n+1} - t_n} - \frac{f_n - f_{n-1}}{t_n - t_{n-1}}\right)\left(\frac{1}{t_{n+1} - t_{n-1}}\right)$$

instead of

$$B_n = \left(\frac{f_{n+1} - f_n}{t_{n+1} - t_n} - \frac{f_n - f_{n-1}}{t_n - t_{n-1}}\right)\left(\frac{1}{t_{n+1} - t_n}\right).$$

Higgins' equation (7) should read

$$\Delta f_n^{[1]} = \frac{f_{n+1} - f_n}{t_{n+1} - t_n} - \frac{f_n - f_{n-1}}{t_n - t_{n-1}} - \tfrac{1}{2}(B_n + B_{n+1})(t_{n+1} - t_n) - \tfrac{1}{2}(B_n + B_{n-1})(t_n - t_{n-1})$$

instead of

$$\Delta f_n^{[1]} = \frac{f_{n+1} - f_n}{t_{n+1} - t_n} - \frac{f_n - f_{n-1}}{t_n - t_{n-1}} + \tfrac{1}{2}(B_n + B_{n+1})(t_{n+1} - t_n) - \tfrac{1}{2}(B_n + B_{n-1})(t_n - t_{n-1}).$$

Higgins' equation (12) should read

$$C_1 = \frac{k_2 - 3\alpha^2\left[k_1 + k_2\left(\frac{t_2 - t_1}{6}\right)\Big/\left(\alpha^2\left(\frac{t_2 - t_1}{2}\right) + \alpha\right)\right]}{6(t_2 - t_1)^2}$$

instead of

$$C_1 = \frac{k_2 + 3\alpha^2\left[k_1 + k_2\left(\frac{t_2 - t_1}{6}\right)\Big/\left(\alpha^2\left(\frac{t_2 - t_1}{2}\right) + \alpha\right)\right]}{6(t_2 - t_1)^2}.$$

Higgins' equation (16) should read

$$D_N = \frac{-k_4 - 3\beta^2\left[k_3 - k_4\left(\frac{t_N - t_{N-1}}{6}\right)\Big/\left(\beta + \beta^2\left(\frac{t_N - t_{N-1}}{2}\right)\right)\right]}{6(t_N - t_{N-1})^2}$$

instead of

$$D_N = \frac{k_4 + 3\beta^2\left[k_3 - k_4\left(\frac{t_N - t_{N-1}}{6}\right)\Big/\left(\beta + \beta^2\left(\frac{t_N - t_{N-1}}{2}\right)\right)\right]}{6(t_N - t_{N-1})^2}.$$

There was also encountered a considerable amount of difficulty in employing the Fourier transform as calculated by Higgins.[1] This trouble, which was mentioned by Higgins,[1] occurred when computing some complex exponential terms in the Fourier transform. As it turns out, there was encountered some high-order cancellation, which involved the exponentials $e^{i\omega t_n}$ written as ($\cos \omega t_n + i \sin \omega t_n$) in Higgins' equation (36). This round-off problem occurs since the CDC 6600 series computer has only 14-digit accuracy in single precision, and information in the sixth and higher-order terms is lost when the cosine and sine are evaluated, and it is just these terms that are required to find the Fourier transform. Even when carrying 28-digit accuracy in double-precision calculations, the high-order cancellation is still evident. Although Higgins[1] dealt with this problem, his report did not provide adequate information to solve this difficulty. Instead of generating the necessary coding to handle the problem, the employment of an existing Fourier transform routine was decided upon. As can be seen by the various plots in appendix A, this Fourier transform code gives very nice results.

4. DISCUSSION OF RESULTS

Several troublesome difficulties encountered when running EMPFIT must be overcome to run the code effectively. First, care must be taken when choosing the data points to describe the waveform of interest. It has been noticed that the spacing of the points is somewhat arbitrary, with the guideline that the density of the data points should be greatest where the function being fitted varies most rapidly. This result can be seen in figures 1 and 2. Notice how figure 2 shows data points being taken where the slope varies the greatest. Figure 1 is an example of poorly chosen data pairs, in that not enough points were taken.

Another important aspect to note is that the values of α and β in equations (7) and (8) are very critical in the goodness of fit to the data points at the front and rear of the waveform. For waveforms that start at about 1 shake (1 shake = $1 \cdot 10^{-8}$ s) and end at about 1000 shakes, some good values for α and β are

$$\alpha = 1.2 \cdot 10^8,$$

$$\beta = 5.0 \cdot 10^4.$$

These values are variable and change according to the particular data points of interest, but these figures have been found to be the best in fitting the exponential functions (7) and (8) to the ends of the waveform. It is important that the last few data points used to describe the end of a

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[1] Daniel F. Higgins, A Method for Fitting EMP Waveforms that Facilitates Calculation of the Time Derivative and Fourier Transform, Defense Nuclear Agency Report DNA 3231T (November 1973).

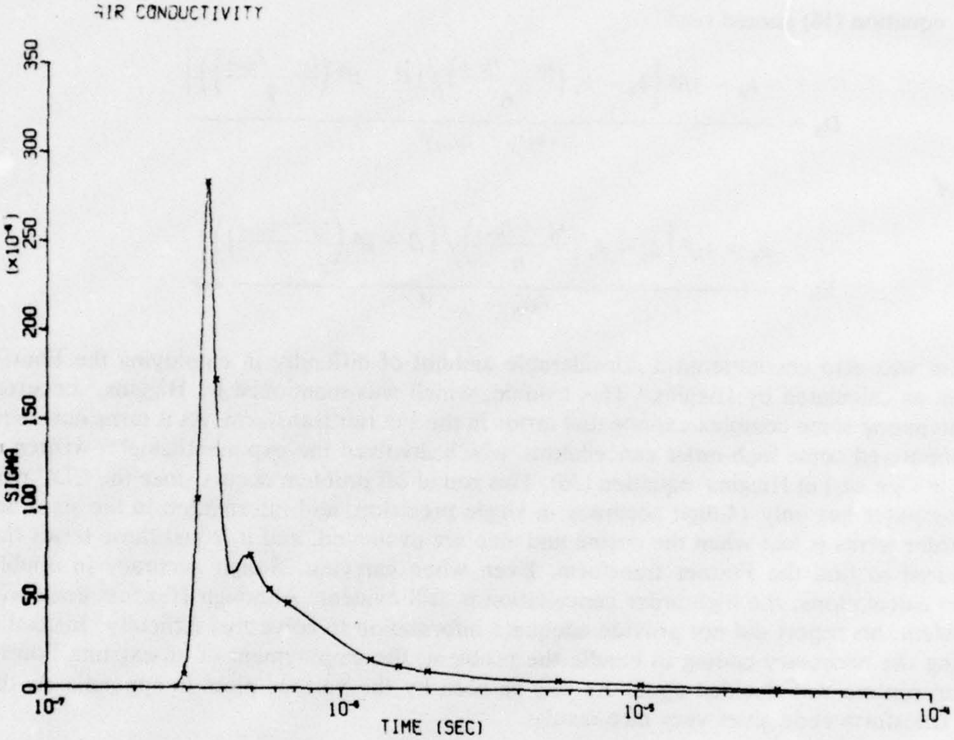

Figure 1. Curve that does not follow data points.

waveform should be decreasing toward zero so that the exponential function (8) fits a curve to the last data point that asymptotically approaches zero. If a value for α is desired other than the one recommended above, then a good guideline to follow is to choose α such that

$$\frac{f_2 - f_1}{t_2 - t_1} \approx \alpha f_1.$$

This has been found generally to give reasonable values of α and facilitate a good fit to the front of the waveform.

A third troublesome point that happens occasionally is the fitting of the peak amplitude value. It sometimes occurs that the peak amplitude data point is overshot by the curve being fitted to the data pairs. Then it has been found that the peak amplitude point is matched only if the data points are chosen very judiciously. A rule of thumb to alleviate this problem is to choose the closest two points on both sides of the peak value to have corresponding time-change

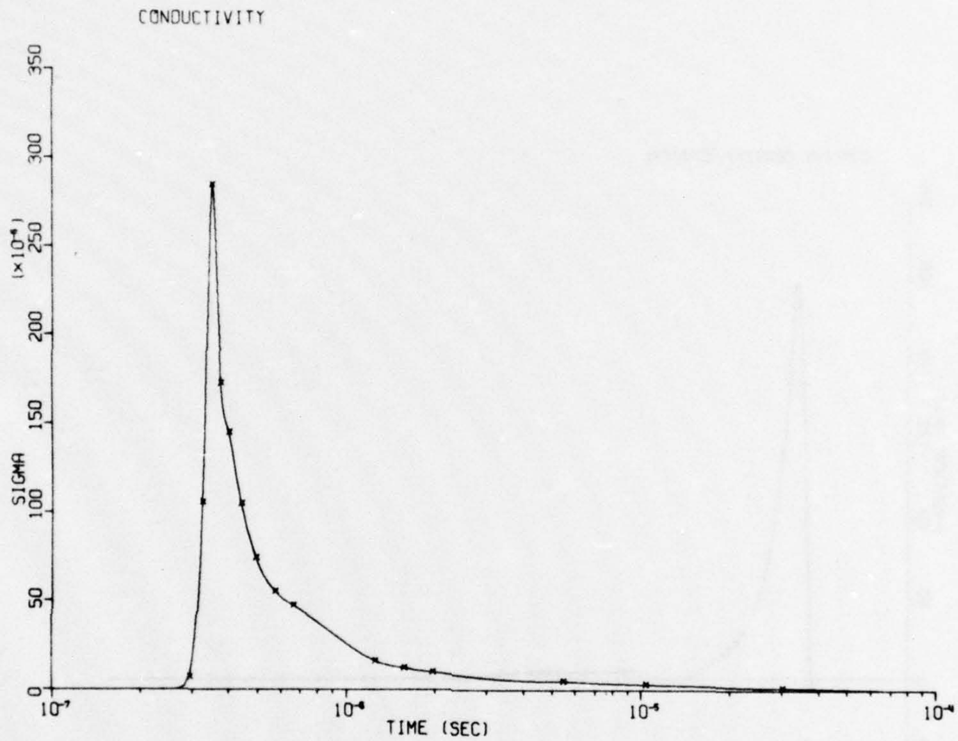

Figure 2. Solution to problem where curve does not follow data points.

separations and approximately the same amplitude value. This correspondence matches the average-curvature term B_i on the opposite sides of the peak amplitude value, except that the slopes are the same but have opposite signs. Hence, the curve going through these points goes through the peak amplitude value, and the slopes on either side of the peak value are the same, but are opposite in sign.

One final remark about fitting various types of waveforms concerns fitting a very steeply rising waveform. A useful procedure is to choose as the first data point the peak amplitude value. Then with a suitable choice of α, the fitting is done appropriately, as can be seen in figure 9 (p. 15).

These four problems and other frequent problems are summarized in table I. This table outlines specific problems and gives corresponding solutions. It also refers specifically to figures 1 to 16, which show the problems and solutions. Examples of correct plots from EMPFIT can be seen in figures A-1 and A-2.

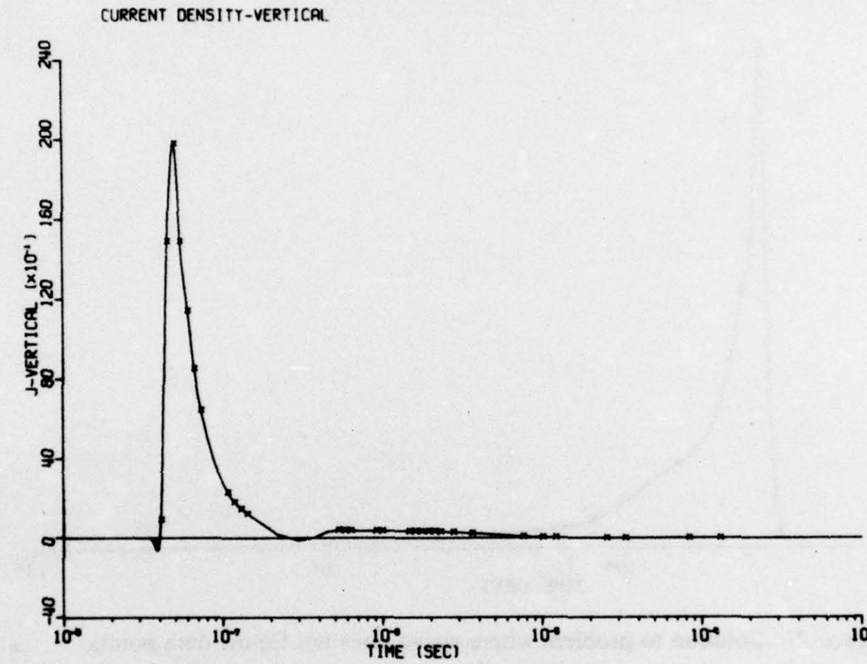

Figure 3. Curve that does not follow data points.

TABLE I.
Common Problems and Solutions When Running EMPFIT

Problem	Solution	Figure
Curve does not follow general outline of data points	Add more data points to describe trace more fully	1, 2, 3, 4, 5, 6, 7, 8
Waveform is steeply rising	Pick peak amplitude value as first data point and then choose α accordingly	9
End of waveform is not smooth and approaches zero with too great a slope	Decrease value of β one order of magnitude and add more points to describe trace more fully	10, 11, 12
Front of waveform differs markedly in sign and form from rest of waveform	Decrease value of α one order of magnitude	13, 14
End of waveform does not approach zero	Increase maximum time to be plotted (TMAX)	15, 16
Peak amplitude value is overshot	Pick closest points on either side of peak amplitude value to have equal time-change steps and approximately same amplitude values	—

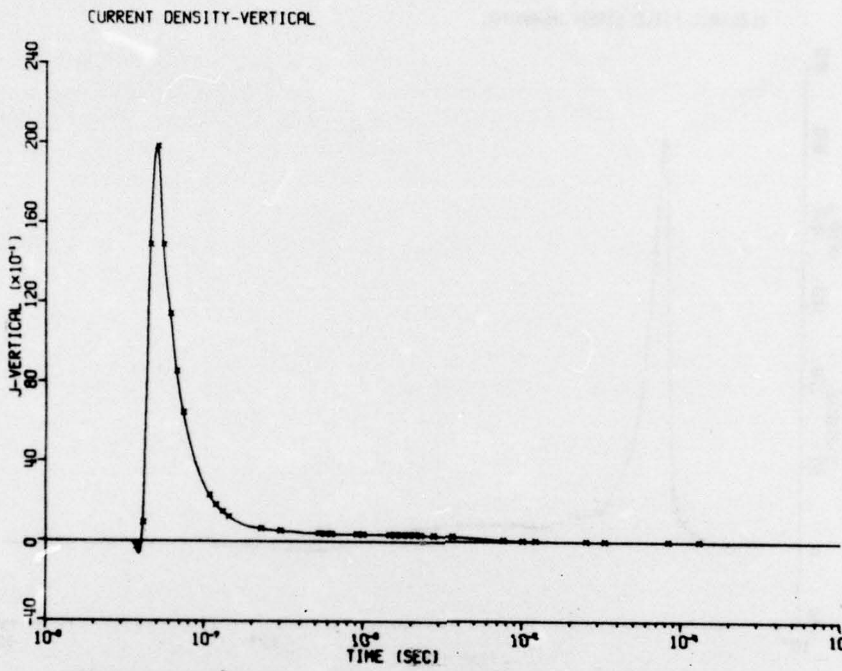

Figure 4. Solution to problem where curve does not follow data points.

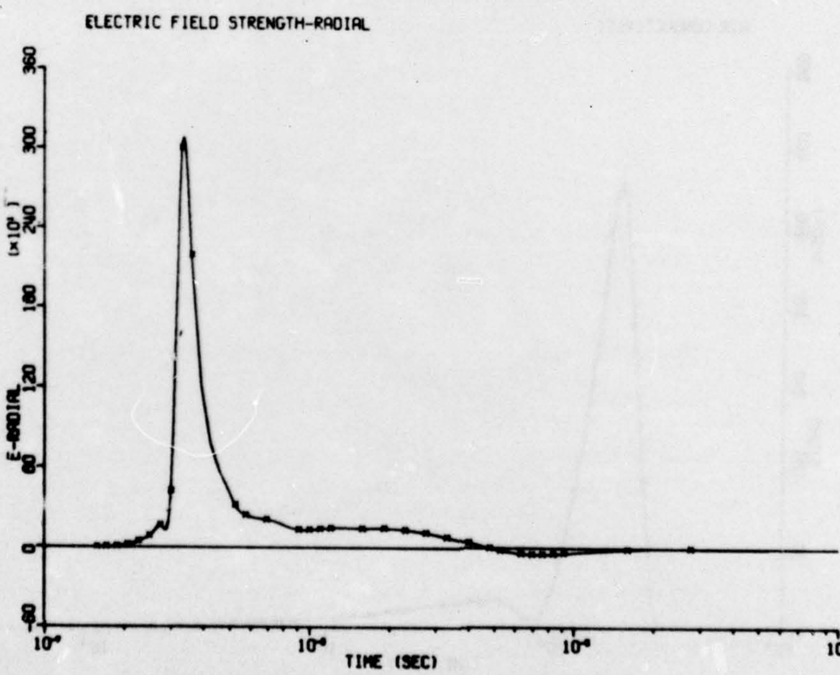

Figure 5. Curve that does not follow data points.

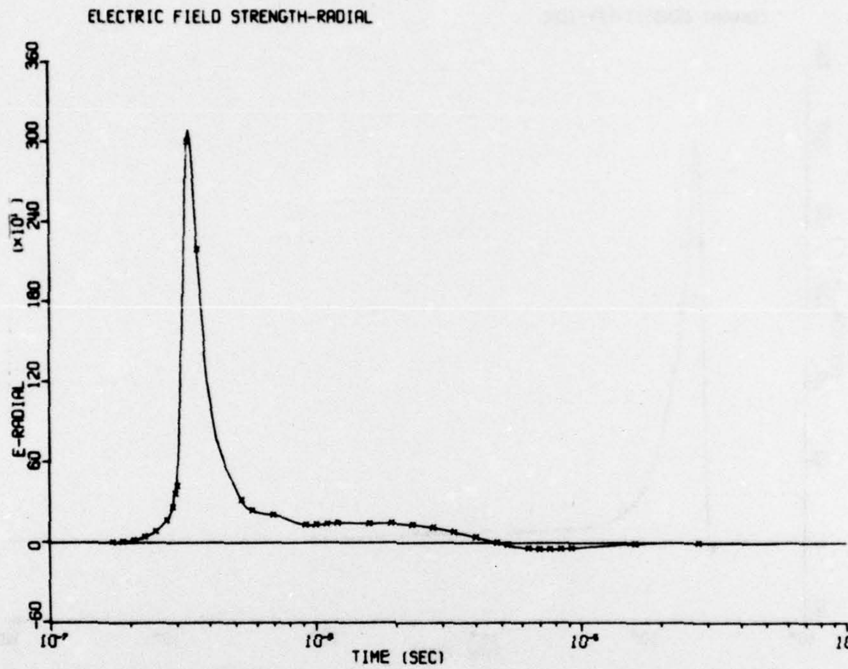

Figure 6. **Solution to problem where curve does not follow data points.**

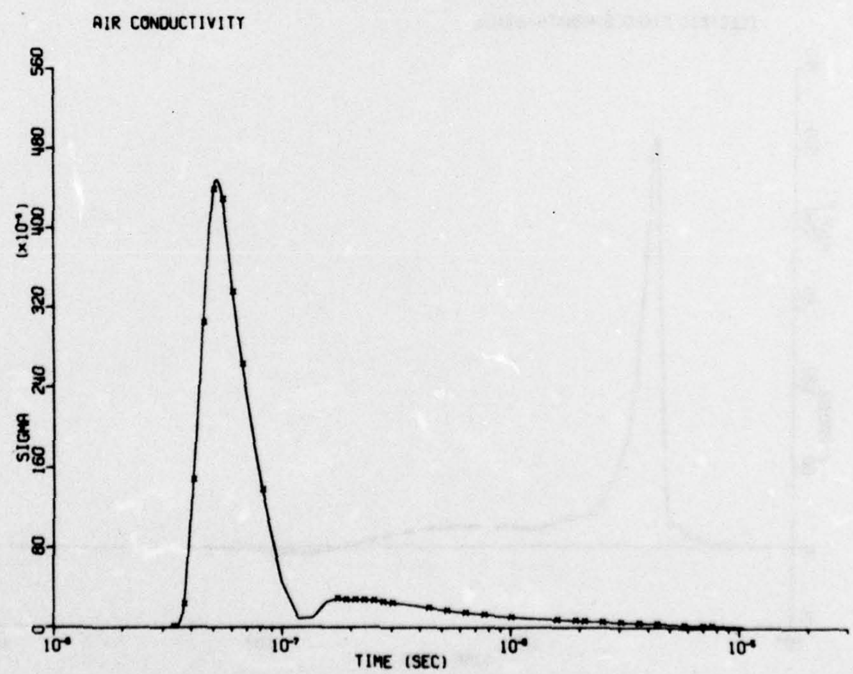

Figure 7. **Curve that does not follow data points.**

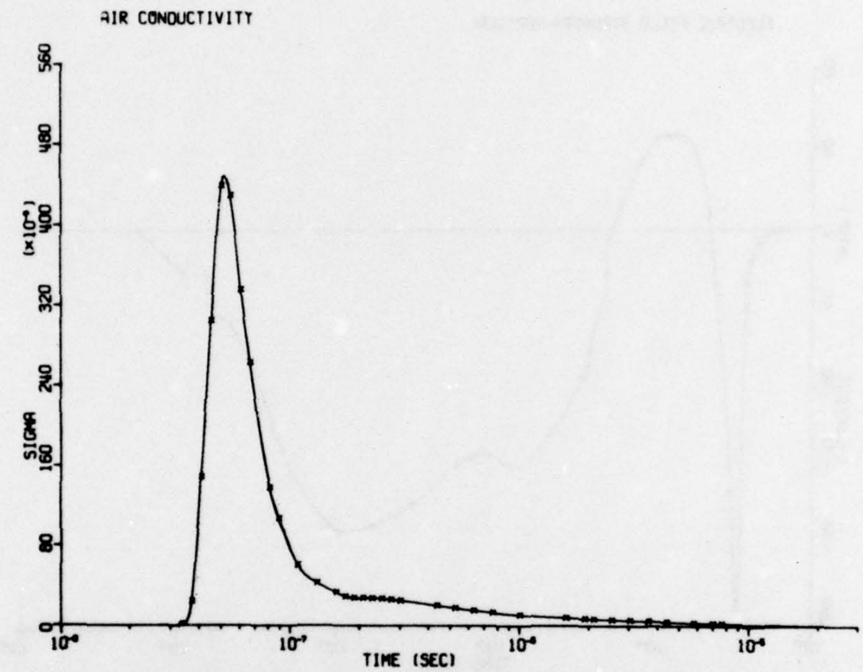

Figure 8. Solution to problem where curve does not follow data points.

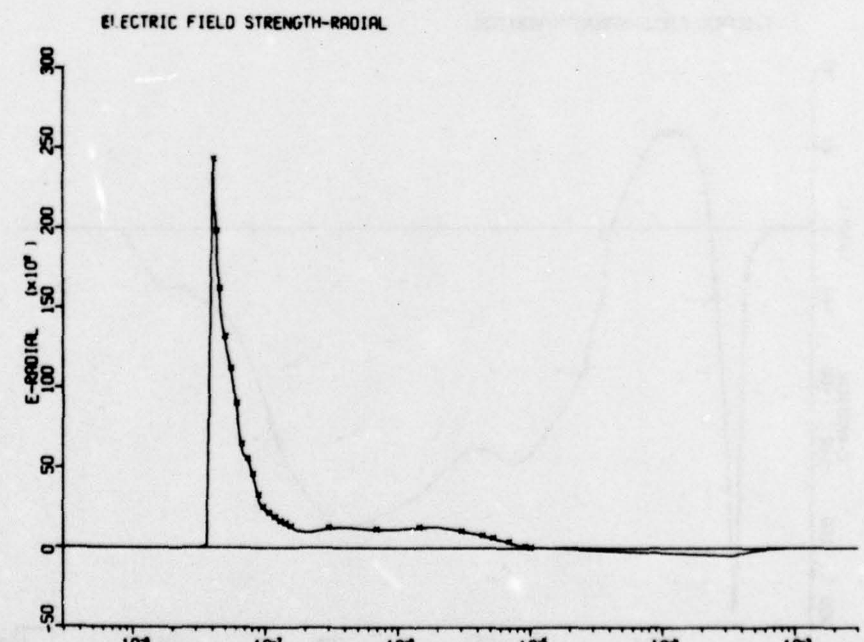

Figure 9. Solution to problem of steeply rising waveform.

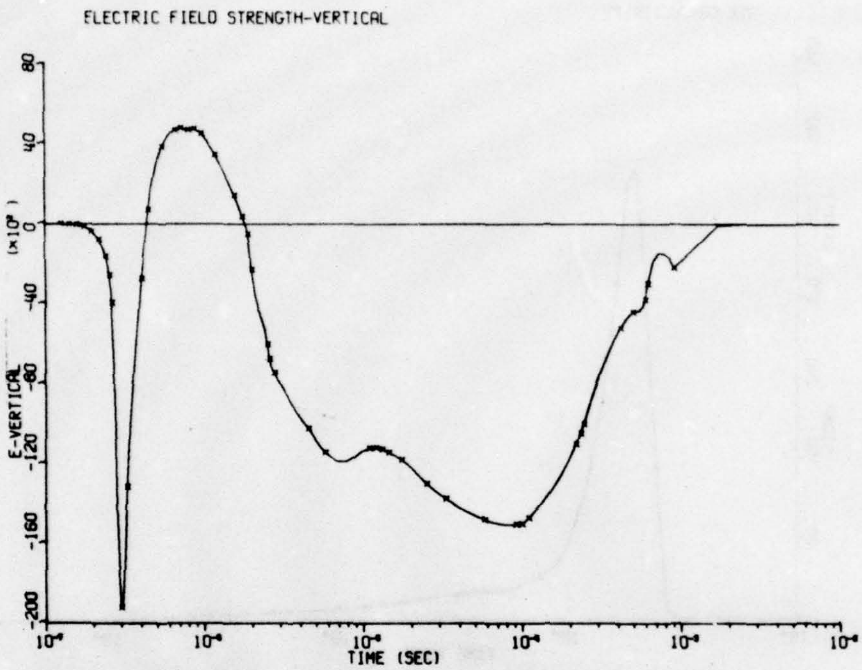

Figure 10. Curve that does not approach zero nicely.

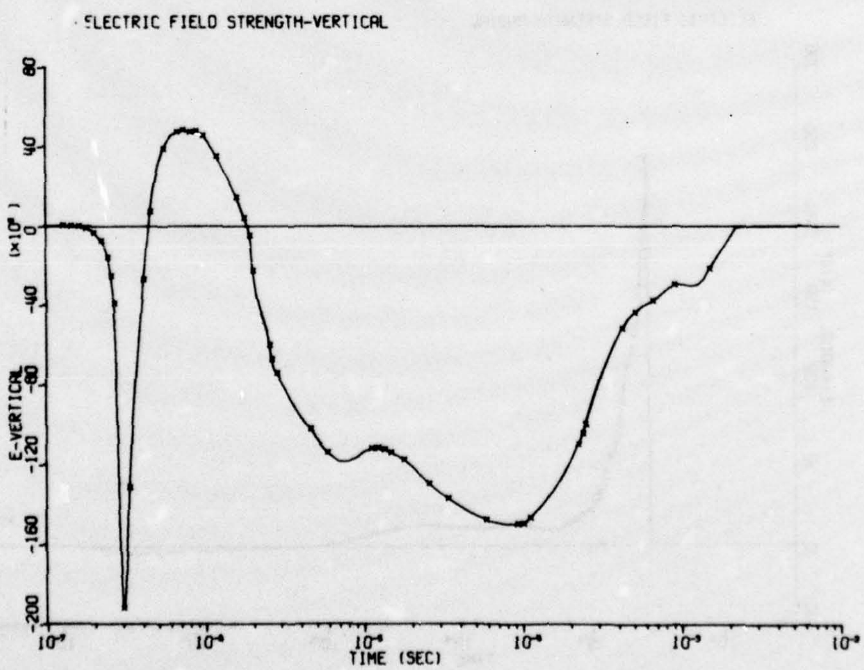

Figure 11. Curve that does not approach zero nicely.

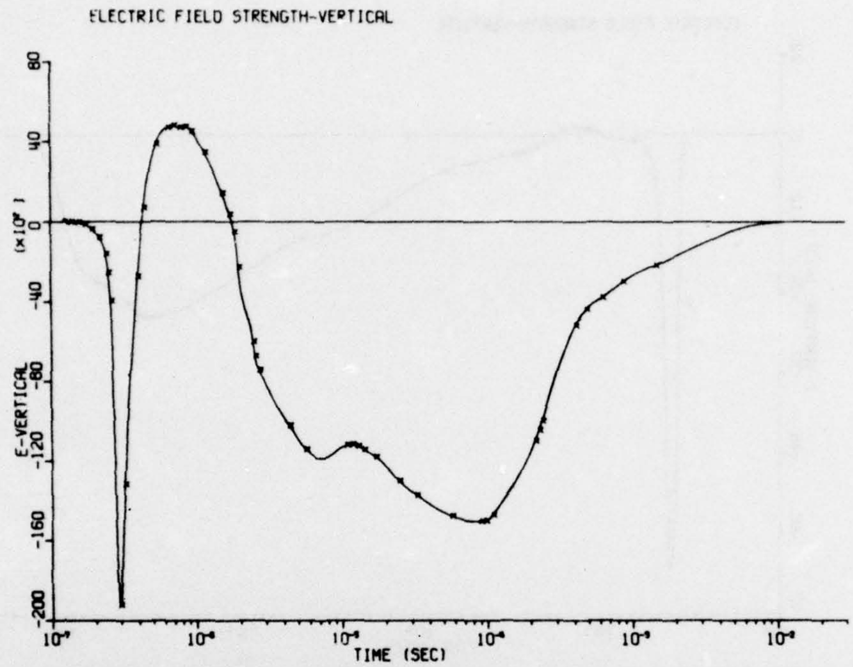

Figure 12. Solution to problem where curve does not approach zero nicely.

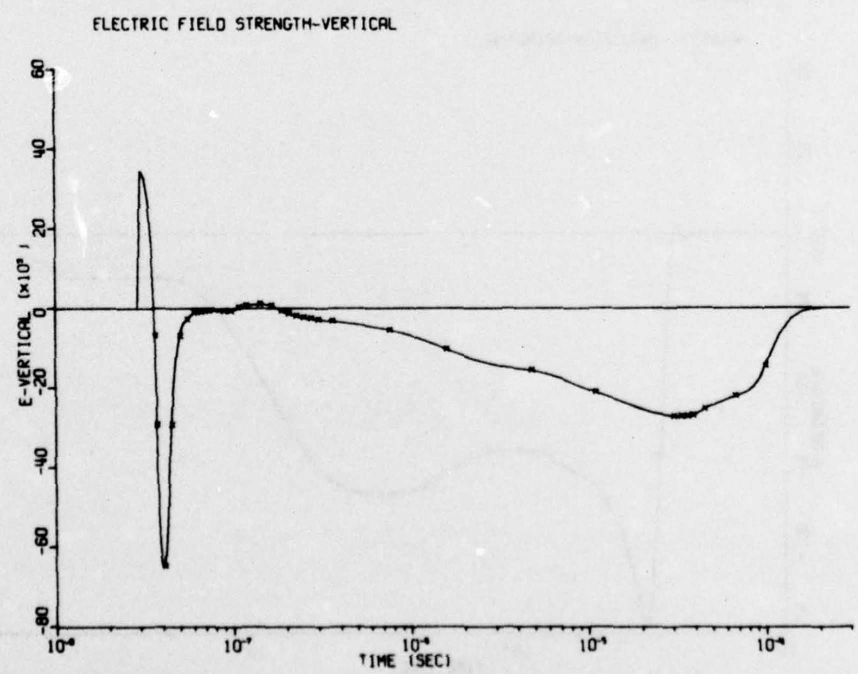

Figure 13. Front of waveform differs significantly from rest of curve.

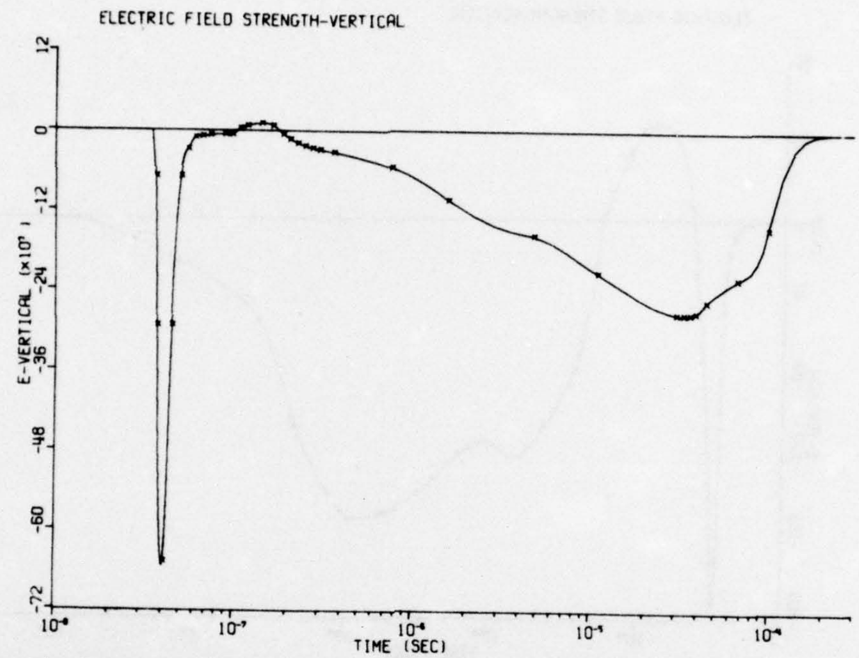

Figure 14. Solution to problem where front of waveform differs significantly from rest of curve.

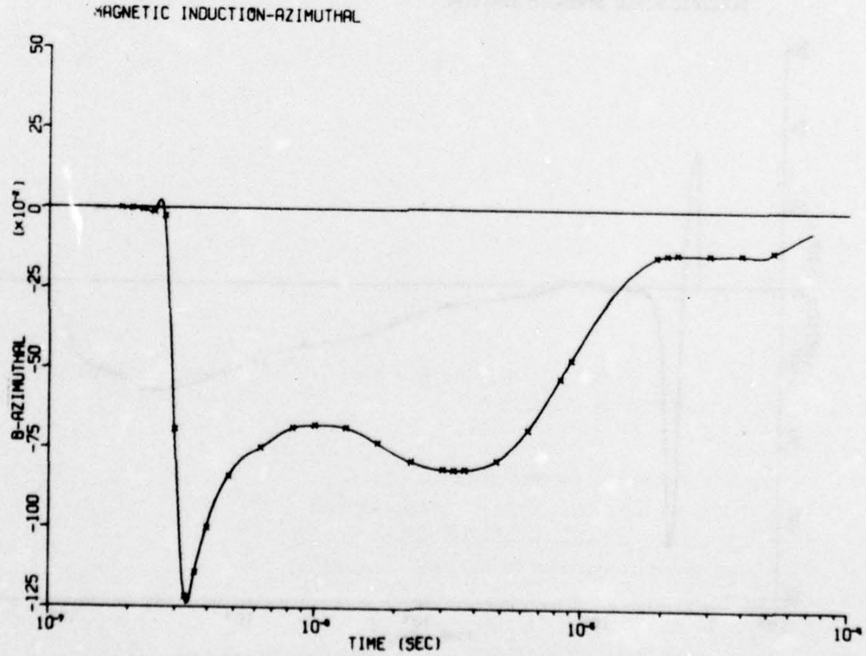

Figure 15. End of waveform does not approach zero.

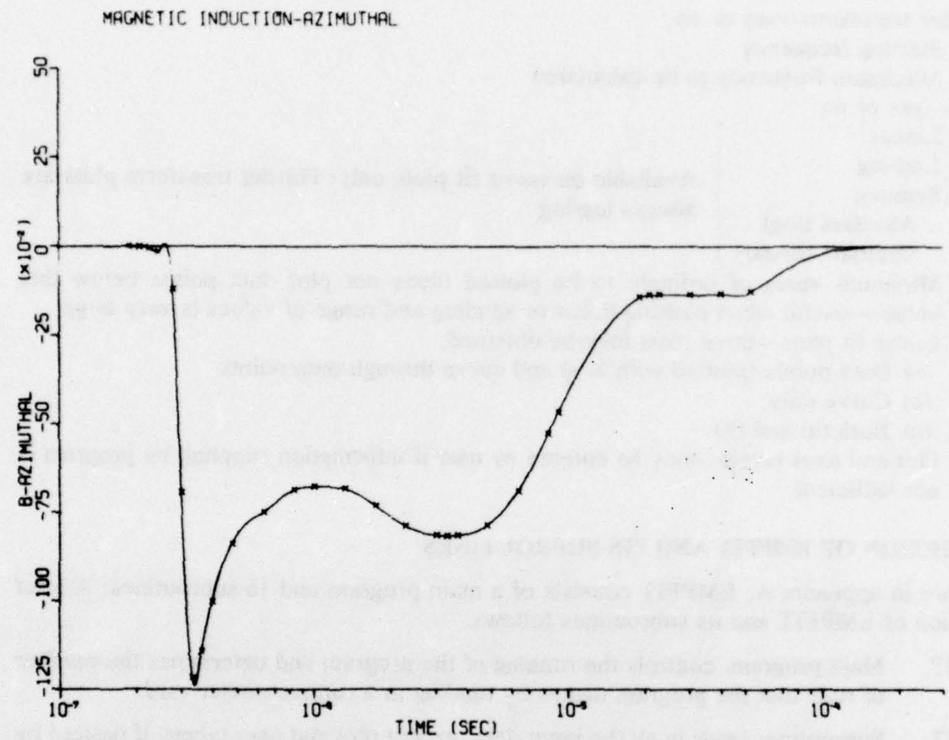

Figure 16. Solution to problem where end of waveform does not approach zero.

5. OUTPUT OPTIONS

The following options are available when running EMPFIT. The specific places where the card entries are made are documented in section 7.

a. Multiple runs

b. Plot titles and axes information (supplied in program)

- **(1) T vs E_R—time versus electric field strength—radial**
- **(2) T vs E_V—time versus electric field strength—vertical**
- **(3) T vs B_ϕ—time versus magnetic induction—azimuthal**
- **(4) T vs J_R—time versus current density—radial**
- **(5) T vs J_V—time versus current density—vertical**
- **(6) T vs σ—time versus air conductivity**

c. Number of points calculated between input data points

d. Maximum time to be calculated

e. Fourier transform—yes or no
    (1) Starting frequency
    (2) Maximum frequency to be calculated

f. Plots—yes or no
    (1) Linear
    (2) Log-log
    (3) Semilog
        Abscissa (log)
        Ordinate (linear)

    (1)–(3): Available on curve fit plots only; Fourier transform plots are always log-log

    (4) Minimum value of ordinate to be plotted (does not plot data points below this value)—useful when plotting linear or semilog and range of values is very large
    (5) Curve fit plots—three plots may be obtained:
        (a) Data points (plotted with X's) and curve through data points
        (b) Curve only
        (c) Both (a) and (b)
    (6) Plot and axes labels—may be entered by user if information supplied by program is not sufficient

6. DESCRIPTION OF EMPFIT AND ITS SUBROUTINES

As shown in appendix A, EMPFIT consists of a main program and 16 subroutines. A brief documentation of EMPFIT and its subroutines follows.

EMPFIT — Main program: controls the running of the program and determines the number of runs that the program makes by reading in a run parameter card.

INPUTT — Subroutine: reads in all the input data, except plot and axes labels, if desired by the user.

CURFIT — Subroutine: calculates the curve fit between the input data points.

FORT — Subroutine: calls the Fourier transform subroutine FLINE, determines the delta frequency, and separates the Fourier transform into its real and imaginary components.

OTPUT — Subroutine: performs all of the output operations and also calls COLMNS; prints out the input data points, the curve fit data pairs and, if wanted, the Fourier transform data points.

COLMNS — Subroutine: outputs the information of OTPUT in columns.

PLOTT — Subroutine: performs all of the plotting calculations and calls the plotting package ANAPAC for plotting on the Houston Instruments Complot Plotter on the Mohawk Data Systems remote batch terminal.

ANOTAT — Subroutine: contains all the plot labels and titles (sect. 5) necessary to get the curve fit and Fourier transform plots.

A1A3 — Subroutine: calculates the constants A1 and A3 of equation (7) necessary in fitting the exponential to the front of the input data points, calculates also C_1 of equation (19).

A2A4 — Subroutine: calculates the constants A2 and A4 of equation (8), which are used in the fitting of the exponential to the end of the input data points; calculates also D_N of equation (20).

FLINE	Subroutine: calculates the Fourier transform of the curve fit data points.
BN	Function subroutine: calculates the coefficients B_i of equations (2), (17), and (18).
CN	Function subroutine: calculates the coefficients C_i of equation (3).
DN	Function subroutine: calculates the coefficients D_i of equation (4).
DELFI	Function subroutine: calculates equation (5).
DELF2	Function subroutine: calculates equation (6).
ENTITL	Subroutine: reads in the plot label and axes information if requested by the user.

7. DATA INPUT PREPARATION

Input data cards for EMPFIT are prepared in the following manner. Examples of input card decks appear in appendix B.

Column	*Variable*	*Format*	*Explanation*
Card 1: Multiple run card			
8–10	NRUN	I3	Number of runs
Card 2: Plot parameter card			
10	IDENT	I1	Identifies data to be read in IDENT = 1 T vs E_R = 2 T vs E_V = 3 T vs B_ϕ = 4 T vs J_R = 5 T vs J_V = 6 T vs σ
20	IFFT	I1	Fourier transform? IFFT = 0 Yes = 1 No
30	IPLOT	I1	Plots? IPLOT = 0 Yes = 1 No
40	ILNLOG	I1	Plots in linear, log-log, or semilog? ILNLOG = 1 Linear = 2 Log-log = 3 Semilog Abscissa (log) Ordinate (linear) Note: Fourier transform plots are always log-log.

Column	*Variable*	*Format*	*Explanation*
41–50	ORDMIN	E10.3	Minimum value of ordinate to be plotted (all points below this value are not plotted on linear or semilog plots)
60	ICURV	I1	Curve fit plots ICURV = 0 One plot of data points and curve fit = 1 One plot of curve fit only = 2 Two plots—one plot of data points and curve fit, one plot of curve fit only
70	IOT	I1	Enter own plot and axes labels? IOT = 0 Use plot and axes labels supplied in program = 1 Enter own labels on cards 5, 6, 7
Card 3: Title card			
1–80	TITLE	8A10	Title or subtitle
Card 4: Fitting parameter card			
1–7	—	—	Blank
8–10	IPTS	I3	Number of data points read in
11–17	—	—	Blank
18–20	MPTS	I3	Number of points calculated between input data points
21–30	TMAX	E10.3	Maximum time to be calculated in curve fit calculations
31–40	ALPHA	E10.3	Used to fit $f(t) = A_1e^{\alpha t} + A_3e^{2\alpha t}$ to front of waveform (good starting value: α = 1.2E+8)
41–50	BETA	E10.3	Used to fit $f(t) = A_2e^{-\beta t} + A_4e^{-2\beta t}$ to end of waveform (good starting value: β = 5.0E+4)
51–60	OSTART	E10.3	Frequency to start Fourier transform calculations
61–70	OMAX	E10.3	Maximum frequency to be calculated Note: Cards 5, 6, and 7 are used only if IOT = 1 on card 2. If IOT = 0, skip to card 8.
Card 5: Abscissa label card			
1–10	XTITLE	A10	X label; start in column 1

Column	*Variable*	*Format*	*Explanation*
Card 6: Ordinate label card			
1–20	YTITLE	2A10	Y label; start in column 1; on output, ordinate label is only in A10, A2 format instead of 2A10.
Card 7: Plot label card			
1–40	ATITLE	4A10	Plot label; start in column 1
Card 8: Data card			
1–10	T	E10.3	Time value of first point
11–20	F	E10.3	Amplitude of first point
Card 9: Data card			
1–10	T	E10.3	Time value of second point
11–20	F	E10.3	Amplitude of second point

Note: Card 8, card 9, . . . are repeated with respect to the number of input points indicated on card 4, IPTS.

Note: Card 2 to card 8, card 9, . . . are repeated according to the number of times identified on CARD 1, NRUN.

8. CONTROL CARDS FOR EMPFIT

The following SCOPE 3.4.3 control cards are necessary to run EMPFIT on the CDC 6600 at MERADCOM. All the underlined entries in the list are variable and must be entered for each user.

EM_ _ _.

TASK (TNEM_ _ _ _ _ _, PW_ _ _ _ _ _, TRTS) [User's name]

ATTACH, AGO, BINEMPFIT, ID = EM71602.

ATTACH, LIBA, ANAPAC, ID = EM71605, MR = 1.

LIBRARY (LIBA)

MAP (PART)

AGO.

7/8/9

[Data]

0/6/7/8/9

APPENDIX A

SAMPLE RUN AND LISTING OF EMPFIT

This appendix shows a sample run of EMPFIT and lists its main program and subroutines. Figures A-1 and A-2 are samples of correct plots.

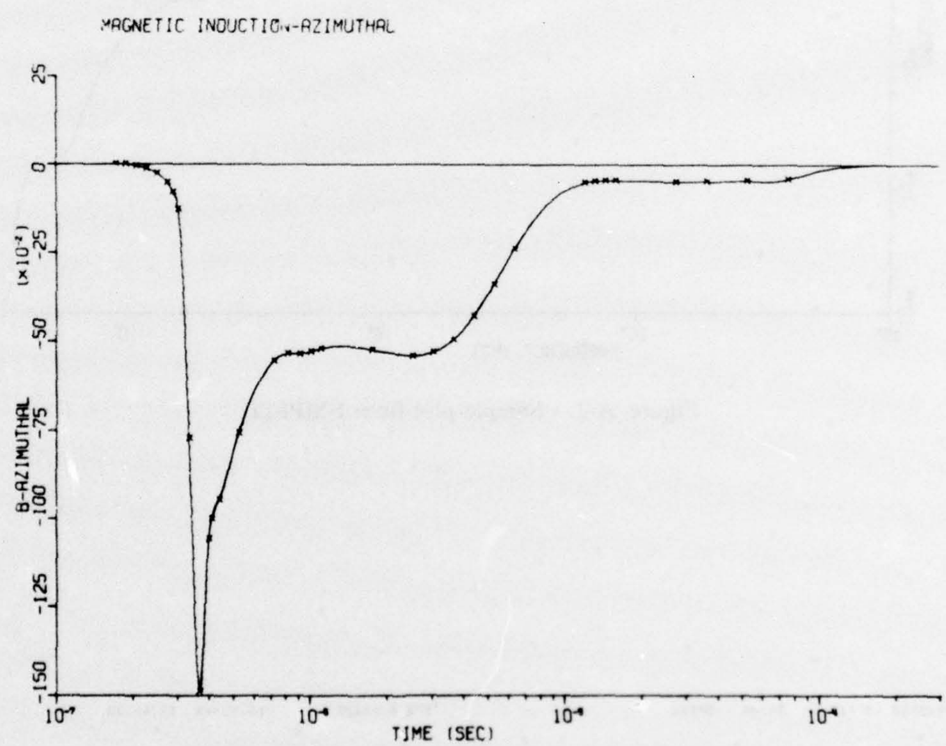

Figure A-1. Sample plot from EMPFIT.

APPENDIX A

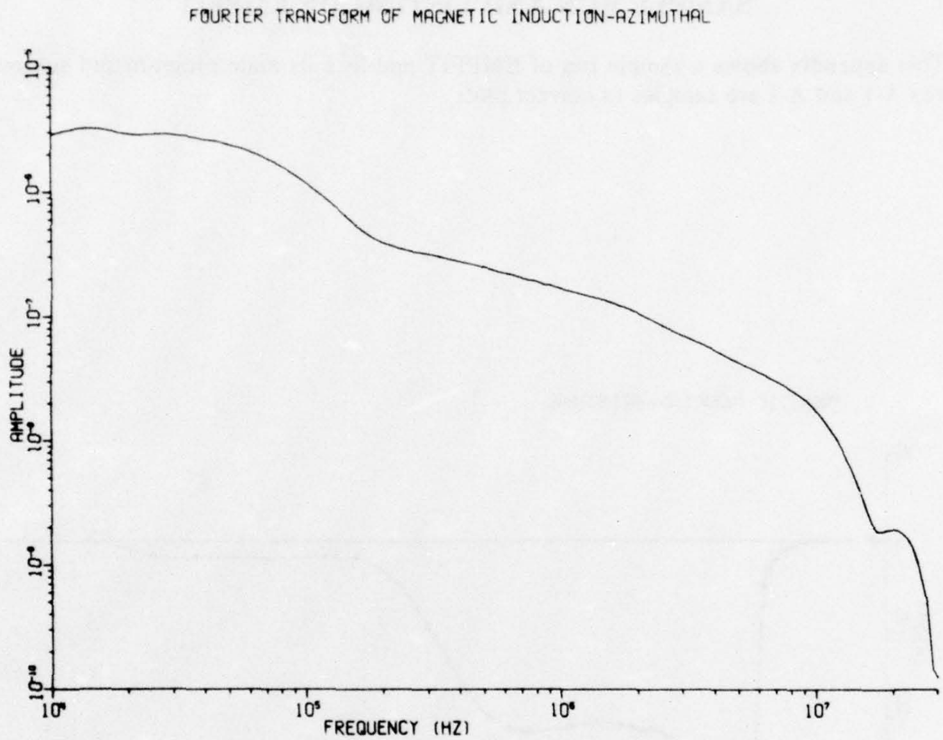

Figure A-2. Sample plot from EMPFIT.

```
PROGRAM EMPFIT      74/74    OPT=1                       FTN 4.6+420        12/16/76  13.45.20

          PROGRAM EMPFIT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)         EMPFIT     2
          COMMON/A/ IDENT,IFFT,TITLE(10),IPLOT,ILNLOG,ORDMIN                  EMPFIT     3
          READ(5,10) NRUN                                                     EMPFIT     4
     10   FORMAT(7X,I3)                                                       EMPFIT     5
          J=0                                                                 EMPFIT     6
          DO 30 L=1,NRUN                                                      EMPFIT     7
          CALL INPUTT                                                         EMPFIT     8
          CALL CURFIT                                                         EMPFIT     9
          IF(IFFT.EQ.1)  GO TO 20                                             EMPFIT    10
          CALL FORT                                                           EMPFIT    11
     20   CALL OTPUT                                                          EMPFIT    12
          IF(IPLOT.EQ.1)  GO TO 30                                            EMPFIT    13
          J=J+1                                                               EMPFIT    14
          IF(J.EQ.1)  WRITE(6,25)                                             EMPFIT    15
     25   FORMAT(17HPH THIS JOB PLOTS)                                        EMPFIT    16
          CALL PLOTT                                                          EMPFIT    17
     30   CONTINUE                                                            EMPFIT    18
          END                                                                 EMPFIT    19
```

APPENDIX A

```
SUBROUTINE INPUTT      74/74    OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      SUBROUTINE INPUTT
      COMPLEX FT
      COMMON/A/ IDENT,IFFT,TITLE(10),IPLOT,ILNLOG,ORDMIN
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      COMMON/D/ DELF,OSTART,OMAX,OMEGA(1000),FT(1000)
      COMMON/G/ ICURV
      COMMON/H/ IOT
      DIMENSION XTITLE(10),YTITLE(10),ATITLE(10)
      DATA TITLE/10*1H /
      READ(5,10) IDENT,IFFT,IPLOT,ILNLOG,ORDMIN,ICURV,IOT
   10 FORMAT(4(9X,I1),E10.3,2(9X,I1))
      READ(5,20) (TITLE(I),I=1,8)
   20 FORMAT(8A10)
      READ(5,30) IPTS,MPTS,TMAX,ALPHA,BETA,OSTART,OMAX
   30 FORMAT(7X,I3,7X,I3,5E10.3)
      NPTS=IPTS+1
      IF(IOT.EQ.0) GO TO 35
      CALL ENTITL(1,XTITLE,YTITLE,ATITLE)
   35 DO 50 I=2,NPTS
      READ(5,40) T(I),F(I)
   40 FORMAT(2E10.3)
   50 CONTINUE
      RETURN
      END
```

```
SUBROUTINE CURFIT      74/74    OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      SUBROUTINE CURFIT
      INTEGER OPTS
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      COMMON/E/ A1,A2,A3,A4,C1,CNM1,D2,DNN
      I=2
      J=2
      T(1)=.8*T(2)
      F(1)=0.
      TT(1)=T(1)
      FF(1)=0.
      T(NPTS+1)=TMAX
      CALL A1A3(A1,A3,C1)
      CALL A2A4(A2,A4,DNN)
   10 H=T(J)-T(J-1)
      DEL=H/(MPTS+1)
   20 TT(I)=TT(I-1)+DEL
      IF(TT(I).LT.(T(J)-DEL/100.))  GO TO 30
      IF(TT(I).GT.T(NPTS))  GO TO 50
      TT(I)=T(J)
      FF(I)=F(J)
      I=I+1
   40 J=J+1
      GO TO 10
   30 CONTINUE
      IF(TT(I).GT.T(2))  GO TO 50
      ARG1=ALPHA*TT(I)
      ARG2=2.*ARG1
      FF(I)=A1*EXP(ARG1)+A3*EXP(ARG2)
      I=I+1
      GO TO 20
   50 IF(TT(I).LT.T(NPTS))  GO TO 60
      ARG3=-BETA*TT(I)
      ARG4=2.*ARG3
      FF(I)=A2*EXP(ARG3)+A4*EXP(ARG4)
      IF(TT(I).GE.TMAX)  GO TO 90
      I=I+1
      GO TO 20
   60 CONTINUE
      DT=TT(I)-T(J-1)
      DTN=T(J)-TT(I)
      DTNN=T(J)-T(J-1)
      DTP1=TT(I)-T(J)
      IF(J.NE.NPTS)  GO TO 70
      CALL A2A4(U,V,D)
      GO TO 80
   70 D=DN(J)
   80 P1=(F(J)*DT+F(J-1)*DTN)/DTNN
      P2=.5*(BN(J-1)+BN(J))*DT*DTP1
      P3=CN(J-1)*DT*(DTN**3)
      P4=D*DTN*(DT**3)
      FF(I)=P1+P2+P3+P4
      I=I+1
```

APPENDIX A

```
SUBROUTINE CURFIT      74/74    OPT=1                          FTN 4.6+420        12/16/76  13.45.20

                   GO TO 20
               90  CONTINUE
                   MAXPTS=I
                   OPTS=MAXPTS
                   L=0
                   DO 100 I=2,NPTS
                   L=L+1
                   T(L)=T(I)
                   F(L)=F(I)
              100  CONTINUE
                   RETURN
                   END
```

```
SUBROUTINE FORT        74/74    OPT=1                          FTN 4.6+420        12/16/76  13.45.20

                   SUBROUTINE FORT
                   REAL IPFT
                   INTEGER OPTS
                   COMPLEX FT
                   COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
                   COMMON/C/ TMAX,NPTS,NPTS,IPTS,MAXPTS,OPTS
                   COMMON/D/ DELF,OSTART,OMAX,OMEGA(1000),FT(1000)
                   COMMON/E/ A1,A2,A3,A4,C1,CMM1,D2,DMM
                   COMMON/F/ RPFT(1000),IPFT(1000),ZABS(1000)
                   DATA TOPI/6.2831853/
                   OMEGA(1)=OSTART
                   DELF=(OMAX/OSTART)**(1./(OPTS-1))
                   DO 10 J=1,OPTS
                   CALL FLINE(FT(J),OMEGA(J)*TOPI,TT,FF,OPTS)
                   OMEGA(J+1)=OMEGA(J)*DELF
               10  CONTINUE
                   DO 20 J=1,OPTS
                   RPFT(J)=REAL(FT(J))
                   IPFT(J)=AIMAG(FT(J))
                   ARG=RPFT(J)**2+IPFT(J)**2
                   ZABS(J)=SQRT(ARG)
               20  CONTINUE
                   RETURN
                   END
```

APPENDIX A

```
SUBROUTINE OTPUT        74/74   OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      SUBROUTINE OTPUT
      INTEGER OPTS
      COMPLEX FT
      COMMON/A/ IDENT,IFFT,TITLE(10),IPLOT,ILNLOG,ORDMIN
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      COMMON/D/ DELF,OSTART,OMAX,OMEGA(1000),FT(1000)
      COMMON/H/ IOT
      DIMENSION ATITLE(10),FTITLE(10),XTITLE(10),YTITLE(10)
      DATA ATITLE/10*1H /,FTITLE/10*1H /,XTITLE/10*1H /,YTITLE/10*1H /
      IF(IOT.EQ.1)  GO TO 5
      CALL ANOTAT(XTITLE,YTITLE,ATITLE,0)
      GO TO 7
    5 CALL ENTITL(0,XTITLE,YTITLE,ATITLE)
    7 WRITE(6,10)
   10 FORMAT(1H1)
      WRITE(6,20) (TITLE(I),I=1,8)
   20 FORMAT(1X,8A10)
      WRITE(6,30) (ATITLE(I),I=1,5)
   30 FORMAT(/,/,6X,13HINPUT DATA - ,5A10)
      WRITE(6,40) ALPHA,BETA,TMAX,IPTS,MPTS
   40 FORMAT(/,/,9X,7HALPHA= ,1PE11.3,5X,6HBETA= ,1PE11.3,5X,
     131HMAXIMUM TIME TO BE CALCULATED= ,1PE11.3,/,9X,
     229HNUMBER OF INPUT DATA POINTS= ,I3,5X,
     355HNUMBER OF POINTS CALCULATED BETWEEN INPUT DATA POINTS= ,I3)
      WRITE(6,50) XTITLE(1),YTITLE(1),YTITLE(2),XTITLE(1),YTITLE(1),
     1YTITLE(2),XTITLE(1),YTITLE(1),YTITLE(2)
   50 FORMAT(/,/,11X,A10,4X,A10,A2,2(10X,A10,4X,A10,A2))
      WRITE(6,60)
   60 FORMAT(3(11X,25(1H-)))
      CALL COLMNS(3,IPTS,T,F)
      WRITE(6,80) IPTS
   80 FORMAT(/,15X,19HNUMBER OF POINTS = ,I3)
      WRITE(6,90)
   90 FORMAT(/,/,6X,22HCURVE FIT CALCULATIONS)
      WRITE(6,95) ORDMIN
   95 FORMAT(/,/,9X,41HMINIMUM VALUE OF ORDINATE TO BE PLOTTED= ,
     11PE11.3)
      WRITE(6,50) XTITLE(1),YTITLE(1),YTITLE(2),XTITLE(1),YTITLE(1),
     1YTITLE(2),XTITLE(1),YTITLE(1),YTITLE(2)
      WRITE(6,60)
      CALL COLMNS(3,MAXPTS,TT,FF)
      WRITE(6,80) MAXPTS
      IF(IFFT.EQ.1)  RETURN
      CALL ANOTAT(XTITLE,YTITLE,ATITLE,1)
      WRITE(6,100)
  100 FORMAT(/,/,6X,30HFOURIER TRANSFORM CALCULATIONS)
      WRITE(6,110) OSTART,DELF,OMAX
  110 FORMAT(/,/,9X,27HSTARTING FREQUENCY(HERTZ)= ,1PE11.3,5X,
     117HDELTA FREQUENCY= ,1PE11.3,/,9X,
     236HMAXIMUM FREQUENCY TO BE CALCULATED= ,1PE11.3)
      WRITE(6,120) XTITLE(1),YTITLE(1),XTITLE(1),YTITLE(1)
  120 FORMAT(/,/,2(12X,A10,11X,A10,7X),/,2(20X,4HREAL,7X,9HIMAGINARY,

SUBROUTINE OTPUT        74/74   OPT=1                    FTN 4.6+420        12/16/76  13.45.20

     11X))
      WRITE(6,130)
  130 FORMAT(2(11X,30(1H-)))
      CALL COLMNS(2,OPTS,OMEGA,FT)
      WRITE(6,80) OPTS
      RETURN
      END
```

APPENDIX A

```
SUBROUTINE COLMNS      74/74    OPT=1                     FTN 4.6+420          12/16/76  13.45.20

      SUBROUTINE COLMNS(L,KPTS,X,Y)
      COMPLEX FT
      DIMENSION X(1),Y(1)
      COMMON/D/ DELF,OSTART,OMAX,OMEGA(1000),FT(1000)
      IF(L.EQ.3)  GO TO 40
      INC=KPTS/2
      IK=MOD(KPTS,2)
      ICOL=INC+1
      IF(IK.EQ.0)  GO TO 10
      IF(IK.EQ.1)  GO TO 30
   10 WRITE(6,20) (OMEGA(I),FT(I),OMEGA(I+INC),FT(I+INC),I=1,INC)
   20 FORMAT(2(11X,1PE11.3,3X,1PE11.3,2X,1PE11.3))
      GO TO 90
   30 WRITE(6,20) (OMEGA(I),FT(I),OMEGA(I+ICOL),FT(I+ICOL),I=1,INC)
      WRITE(6,20) OMEGA(ICOL),FT(ICOL)
      GO TO 90
   40 INC=KPTS/3
      IK=MOD(KPTS,3)
      ICOL=INC+1
      IF(IK.EQ.0)  GO TO 50
      IF(IK.EQ.1)  GO TO 70
      IF(IK.EQ.2)  GO TO 80
   50 WRITE(6,60) (X(I),Y(I),X(I+INC),Y(I+INC),X(I+2*INC),Y(I+2*INC),
     1I=1,INC)
   60 FORMAT(3(11X,1PE11.3,3X,1PE11.3))
      GO TO 90
   70 WRITE(6,60) (X(I),Y(I),X(I+ICOL),Y(I+ICOL),X(I+2*ICOL-1),
     1Y(I+2*ICOL-1),I=1,INC)
      WRITE(6,60) X(ICOL),Y(ICOL)
      GO TO 90
   80 WRITE(6,60) (X(I),Y(I),X(I+ICOL),Y(I+ICOL),X(I+2*ICOL),
     1Y(I+2*ICOL),I=1,INC)
      WRITE(6,60) X(ICOL),Y(ICOL),X(2*ICOL),Y(2*ICOL)
   90 CONTINUE
      RETURN
      END
```

```
SUBROUTINE PLOTT       74/74    OPT=1                     FTN 4.6+420          12/16/76  13.45.20

      SUBROUTINE PLOTT
      REAL IPFT
      INTEGER OPTS
      COMPLEX FT
      COMMON/A/ IDENT,IFFT,TITLE(10),IPLOT,ILNLOG,ORDMIN
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      COMMON/D/ DELF,OSTART,OMAX,OMEGA(1000),FT(1000)
      COMMON/E/ A1,A2,A3,A4,C1,CNM1,D2,DNN
      COMMON/F/ RPFT(1000),IPFT(1000),ZABS(1000)
      COMMON/G/ ICURV
      COMMON/H/ IOT
      DIMENSION FTITLE(10),ATITLE(10),XTITLE(10),YTITLE(10)
      DATA FTITLE/10*1H /,ATITLE/10*1H /,XTITLE/10*1H /,YTITLE/10*1H /
      IF(ILNLOG.EQ.2)  GO TO 2
      L=0
      DO 1 I=1,MAXPTS
      IF(FF(I).LT.ORDMIN)  GO TO 1
      L=L+1
      TT(L)=TT(I)
      FF(L)=FF(I)
    1 CONTINUE
      MAXPTS=L
      GO TO 4
    2 CONTINUE
      DO 3 I=1,MAXPTS
      IF(FF(I).LT.ORDMIN)  TT(I)=0.
    3 CONTINUE
    4 CONTINUE
      IF(IOT.EQ.1)  GO TO 5
      CALL ANOTAT(XTITLE,YTITLE,ATITLE,0)
      GO TO 7
    5 CALL ENTITL(0,XTITLE,YTITLE,ATITLE)
    7 IF(ICURVE.EQ.1)  GO TO 8
      CALL DRAW4(1,7,1,2,4,8,XTITLE,YTITLE,ATITLE,TITLE)
      CALL DRAW4(2,7,ILNLOG,IPTS,-2,10,T,F,0.,0.)
      CALL DRAW4(2,7,ILNLOG,MAXPTS,0,10,TT,FF,0.,0.)
      CALL DRAW4(3,7,ILNLOG,0,0,MAXPTS,TT,FF,2.,0.)
      IF(ICURV.EQ.0)  GO TO 9
    8 CONTINUE
      CALL DRAW4(1,7,1,2,4,8,XTITLE,YTITLE,ATITLE,TITLE)
      CALL DRAW4(2,7,ILNLOG,MAXPTS,0,10,TT,FF,0.,0.)
      CALL DRAW4(3,7,ILNLOG,0,0,MAXPTS,TT,FF,2.,0.)
    9 CONTINUE
      IF(IFFT.EQ.1)  RETURN
      CALL ANOTAT(XTITLE,YTITLE,FTITLE,1)
      DO 10 J=4,7
      K=J-3
   10 FTITLE(J)=ATITLE(K)
      CALL DRAW4(1,7,2,1,8,0,XTITLE,YTITLE,FTITLE,TITLE)
      CALL DRAW4(2,7,2,OPTS,0,10,OMEGA,ZABS,0.,0.)
      CALL DRAW4(3,7,2,0,0,OPTS,OMEGA,ZABS,2.,0.)
      RETURN
```

APPENDIX A

```
SUBROUTINE PLOTT       74/74    OPT=1                          FTN 4.6+420        12/16/76  13.45.20

          END                                                         PLOTT     55


SUBROUTINE ANOTAT      74/74    OPT=1                          FTN 4.6+420        12/16/76  13.45.20

          SUBROUTINE ANOTAT(XTITLE,YTITLE,ATITLE,IZ)                  ANOTAT     2
          COMMON/A/ IDENT,IFFT,TITLE(10),IPLOT,ILNLOG,ORDMIN          ANOTAT     3
          DIMENSION ATITLE(10),XTITLE(10),YTITLE(10)                  ANOTAT     4
          DO 5 I=1,8                                                  ANOTAT     5
          ATITLE(I)=10H                                               ANOTAT     6
          XTITLE(I)=10H                                               ANOTAT     7
          YTITLE(I)=10H                                               ANOTAT     8
        5 CONTINUE                                                    ANOTAT     9
          IF(IZ.EQ.1)  GO TO 70                                       ANOTAT    10
          XTITLE(1)=10HTIME (SEC)                                     ANOTAT    11
          GO TO (10,20,30,40,50,60),IDENT                             ANOTAT    12
       10 ATITLE(1)=10HELECTRIC F                                     ANOTAT    13
          ATITLE(2)=10HIELD STREN                                     ANOTAT    14
          ATITLE(3)=10HGTH-RADIAL                                     ANOTAT    15
          YTITLE(1)=8HE-RADIAL                                        ANOTAT    16
          RETURN                                                      ANOTAT    17
       20 ATITLE(1)=10HELECTRIC F                                     ANOTAT    18
          ATITLE(2)=10HIELD STREN                                     ANOTAT    19
          ATITLE(3)=10HGTH-VERTIC                                     ANOTAT    20
          ATITLE(4)=2HAL                                              ANOTAT    21
          YTITLE(1)=10HE-VERTICAL                                     ANOTAT    22
          RETURN                                                      ANOTAT    23
       30 ATITLE(1)=10HMAGNETIC I                                     ANOTAT    24
          ATITLE(2)=10HNDUCTION-A                                     ANOTAT    25
          ATITLE(3)=8HZIMUTHAL                                        ANOTAT    26
          YTITLE(1)=10HB-AZIMUTHA                                     ANOTAT    27
          YTITLE(2)=1HL                                               ANOTAT    28
          RETURN                                                      ANOTAT    29
       40 ATITLE(1)=10HCURRENT DE                                     ANOTAT    30
          ATITLE(2)=10HNSITY-RADI                                     ANOTAT    31
          ATITLE(3)=2HAL                                              ANOTAT    32
          YTITLE(1)=10HJ-RADIAL                                       ANOTAT    33
          RETURN                                                      ANOTAT    34
       50 ATITLE(1)=10HCURRENT DE                                     ANOTAT    35
          ATITLE(2)=10HNSITY-VERT                                     ANOTAT    36
          ATITLE(3)=4HICAL                                            ANOTAT    37
          YTITLE(1)=10HJ-VERTICAL                                     ANOTAT    38
          RETURN                                                      ANOTAT    39
       60 ATITLE(1)=10HAIR CONDUC                                     ANOTAT    40
          ATITLE(2)=6HTIVITY                                          ANOTAT    41
          YTITLE(1)=5HSIGMA                                           ANOTAT    42
          RETURN                                                      ANOTAT    43
       70 CONTINUE                                                    ANOTAT    44
          ATITLE(1)=10H         F                                     ANOTAT    45
          ATITLE(2)=10HOURIER TRA                                     ANOTAT    46
          ATITLE(3)=10HNSFORM OF                                      ANOTAT    47
          XTITLE(1)=10HFREQUENCY                                      ANOTAT    48
          XTITLE(2)=10H(HZ)                                           ANOTAT    49
          YTITLE(1)=10HAMPLITUDE                                      ANOTAT    50
          RETURN                                                      ANOTAT    51
          END                                                         ANOTAT    52


SUBROUTINE FLINE       74/74    OPT=1                          FTN 4.6+420        12/16/76  13.45.20

          SUBROUTINE FLINE(SUM,W,T,V,NT)                              FLINE      2
          DIMENSION T(1),V(1)                                         FLINE      3
          COMPLEX AA,AB,AC,F3,F4,SUM                                  FLINE      4
          SUM=(0.0,0.0)                                               FLINE      5
          IF(W.EQ.0.0) GO TO 101                                      FLINE      6
          AA=CMPLX(COS(W*T(1)),-SIN(W*T(1)))                          FLINE      7
          DO 100 I=2,NT                                               FLINE      8
          DT=T(I)-T(I-1)                                              FLINE      9
          AB=CMPLX(COS(W*T(I)),-SIN(W*T(I)))                          FLINE     10
          WDT=W*DT                                                    FLINE     11
C   THE BREAKPOINT BETWEEN LARGE- AND SMALL-ARGUMENTS SHOULE BE 1.0E-N,  FLINE  12
C   WHERE N=(D-4)/8, WHERE D = NUMBER OF DIGITS CARRIED BY THE COMPUTER.  FLINE 13
C   THE AMPLITUDE ACCURACY OF THE LARGE ARGUMENT PROCEDURE IS D-2N DIGITS FLINE 14
C   AND OF THE SMALL-ARGUMENT PROCEDURE IS 6N+4 DIGITS.               FLINE     15
          IF(ABS(WDT).GT.5.0E-2) GO TO 50                             FLINE     16
          G=WDT**2                                                    FLINE     17
          AC= G    *(CMPLX(0.5,-(1.0/3.0)*WDT)+G*(CMPLX(-0.125,(1.0/30.0)*WDT FLINE 18
         *)+G*CMPLX((1.0/144.0),-(1.0/840.0)*WDT)))                   FLINE     19
          F3=CONJG(AC)*AB                                             FLINE     20
          F4=AC*AA                                                    FLINE     21
          GO TO 60                                                    FLINE     22
   50     AC=CMPLX(1.0,WDT)                                           FLINE     23
          F4=AC*AB-AA                                                 FLINE     24
          F3=CONJG(AC)*AA-AB                                          FLINE     25
   60     SUM=SUM+(F3*V(I-1)+F4*V(I))/(WDT*W)                         FLINE     26
  100     AA=AB                                                       FLINE     27
          RETURN                                                      FLINE     28
  101     DO 102 J=2,NT                                               FLINE     29
  102     SUM=SUM+0.5*(V(J-1)+V(J))*(T(J)-T(J-1))                     FLINE     30
          RETURN                                                      FLINE     31
          END                                                         FLINE     32
```

APPENDIX A

```
SUBROUTINE A1A3        74/74    OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      SUBROUTINE A1A3(A1,A3,C1)
      REAL K1,K2
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      DF2=F(3)-F(2)
      DT2=T(3)-T(2)
      DT1=T(2)-T(3)
      K1=DF2/DT2+.5*(BN(2)+BN(3))*DT1-ALPHA*F(2)
      K2=BN(2)+BN(3)-(ALPHA**2)*F(2)
      ARG1=2.*ALPHA*T(2)
      ARG2=-ALPHA*T(2)
      EXA2=EXP(ARG1)
      EXA=EXP(ARG2)
      A3=(K1+K2*DT2/6.)/(((ALPHA**2)*DT2/2.+ALPHA)*EXA2)
      A1=(F(2)-A3*EXA2)*EXA
      RNUM=K1+K2*DT2/6.
      RDENOM=((ALPHA**2)*DT2/2.)+ALPHA
      C1=(K2-3.*(ALPHA**2)*(RNUM/RDENOM))/(6.*(DT2**2))
      RETURN
      END
```

```
SUBROUTINE A2A4        74/74    OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      SUBROUTINE A2A4(A2,A4,DNN)
      REAL K3,K4
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      DFN=F(NPTS)-F(NPTS-1)
      DTN=T(NPTS)-T(NPTS-1)
      K3=-DFN/DTN-.5*(BN(NPTS)+BN(NPTS-1))*DTN-BETA*F(NPTS)
      K4=(BETA**2)*F(NPTS)-(BN(NPTS)+BN(NPTS-1))
      ARG1=-2.*BETA*T(NPTS)
      ARG2=BETA*T(NPTS)
      EXB2=EXP(ARG1)
      EXB=EXP(ARG2)
      A4=(K3-K4*DTN/6.)/((BETA+(BETA**2)*DTN/2.)*EXB2)
      A2=(F(NPTS)-A4*EXB2)*EXB
      RNUM=K3-K4*DTN/6.
      RDENOM=BETA+(BETA**2)*DTN/2.
      DNN=(-K4-3.*(BETA**2)*(RNUM/RDENOM))/(6.*(DTN**2))
      RETURN
      END
```

```
FUNCTION BN            74/74    OPT=1                    FTN 4.6+420        12/16/76  13.45.20

      FUNCTION BN(I)
      COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)
      COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS
      IF(I.NE.2)  GO TO 10
      DF2=F(3)-F(2)
      DT2=T(3)-T(2)
      D1=DF2/DT2
      BN=(D1-ALPHA*F(2))*(1./DT2)
      RETURN
   10 IF(I.NE.NPTS)  GO TO 20
      DFN=F(NPTS)-F(NPTS-1)
      DTN=T(NPTS)-T(NPTS-1)
      D2=DFN/DTN
      BN=(-BETA*F(NPTS)-D2)*(1./DTN)
      RETURN
   20 DFP=F(I+1)-F(I)
      DF=F(I)-F(I-1)
      DTP=T(I+1)-T(I)
      DT=T(I)-T(I-1)
      BN=(DFP/DTP-DF/DT)*(1./(T(I+1)-T(I-1)))
      RETURN
      END
```

APPENDIX A

```
FUNCTION CN         74/74    OPT=1                        FTN 4.6+420        12/16/76  13.45.20

                 FUNCTION CN(J)                                                CN        2
                 COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)          CN        3
                 COMMON/C/ TMAX,NPTS,MPTS,IPTS,MAXPTS,OPTS                     CN        4
                 COMMON/E/ A1,A2,A3,A4,C1,CNM1,D2,DNN                          CN        5
                 IF(J.EQ.2)  GO TO 10                                          CN        6
                 DTN=T(J)-T(J-1)                                               CN        7
                 DTP1=T(J+1)-T(J)                                              CN        8
                 DTP2=T(J+1)-T(J-1)                                            CN        9
                 CN=(-DELF1(J)+DELF2(J)*DTN/6.)/((DTP1**2)*DTP2)               CN       10
                 IF(J.NE.NPTS-1)  RETURN                                       CN       11
                 CNM1=CN                                                       CN       12
                 RETURN                                                        CN       13
              10 CN=C1                                                         CN       14
                 RETURN                                                        CN       15
                 END                                                           CN       16
```

```
FUNCTION DN         74/74    OPT=1                        FTN 4.6+420        12/16/76  13.45.20

                 FUNCTION DN(J)                                                DN        2
                 COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)          DN        3
                 COMMON/E/ A1,A2,A3,A4,C1,CNM1,D2,DNN                          DN        4
                 DTN=T(J)-T(J-1)                                               DN        5
                 DTP2=T(J+1)-T(J-1)                                            DN        6
                 DN=(-DELF1(J)-DELF2(J)*DTN/6.)/((DTN**2)*DTP2)                DN        7
                 IF(J.NE.3)  RETURN                                            DN        8
                 D2=DN                                                         DN        9
                 RETURN                                                        DN       10
                 END                                                           DN       11
```

```
FUNCTION DELF1      74/74    OPT=1                        FTN 4.6+420        12/16/76  13.45.20

                 FUNCTION DELF1(J)                                             DELF1     2
                 COMMON/B/ T(100),F(100),ALPHA,BETA,TT(1000),FF(1000)          DELF1     3
                 DFP1=F(J+1)-F(J)                                              DELF1     4
                 DFN=F(J)-F(J-1)                                               DELF1     5
                 DTP1=T(J+1)-T(J)                                              DELF1     6
                 DTN=T(J)-T(J-1)                                               DELF1     7
                 R1=.5*(BN(J)+BN(J+1))*DTP1                                    DELF1     8
                 R2=.5*(BN(J)+BN(J-1))*DTN                                     DELF1     9
                 DELF1=DFP1/DTP1-DFN/DTN-R1-R2                                 DELF1    10
                 RETURN                                                        DELF1    11
                 END                                                           DELF1    12
```

```
FUNCTION DELF2      74/74    OPT=1                        FTN 4.6+420        12/16/76  13.45.20

                 FUNCTION DELF2(J)                                             DELF2     2
                 DELF2=BN(J+1)-BN(J-1)                                         DELF2     3
                 RETURN                                                        DELF2     4
                 END                                                           DELF2     5
```

APPENDIX A

```
SUBROUTINE ENTITL       74/74    OPT=1                       FTN 4.6+420          12/16/76  13.45.20

                 SUBROUTINE ENTITL(IZ,XLAB,YLAB,PLAB)                         ENTITL     2
                 COMMON/I/ XTITLE(10),YTITLE(10),ATITLE(10)                   ENTITL     3
                 DIMENSION XLAB(10),YLAB(10),PLAB(10)                         ENTITL     4
                 IF(IZ.EQ.0)  GO TO 40                                        ENTITL     5
                 READ(5,10) XTITLE(1)                                         ENTITL     6
           10    FORMAT(A10)                                                  ENTITL     7
                 READ(5,20) (YTITLE(I),I=1,2)                                 ENTITL     8
           20    FORMAT(2A10)                                                 ENTITL     9
                 READ(5,30) (ATITLE(I),I=1,4)                                 ENTITL    10
           30    FORMAT(4A10)                                                 ENTITL    11
                 RETURN                                                       ENTITL    12
           40    XLAB(1)=XTITLE(1)                                            ENTITL    13
                 DO 50 I=1,2                                                  ENTITL    14
           50    YLAB(I)=YTITLE(I)                                            ENTITL    15
                 DO 60 I=1,4                                                  ENTITL    16
           60    PLAB(I)=ATITLE(I)                                            ENTITL    17
                 RETURN                                                       ENTITL    18
                 END                                                          ENTITL    19
```

```
LOAD MAP - EMPFIT                                  CYBER LOADER 1.1-420       12/16/76  13.30.26.

FWA OF THE LOAD                111
LWA+1 OF THE LOAD            55061

TRANSFER ADDRESS -- EMPFIT            6310
```

PROGRAM AND BLOCK ASSIGNMENTS.

BLOCK	ADDRESS	LENGTH	FILE	DATE	PROCSSR	VER	LEVEL	HARDWARE	COMMENTS
/A/	111	17							
EMPFIT	130	6226	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
/R/	6356	4232							
/C/	12610	6							
/D/	12616	5673							
/G/	20511	1							
/H/	20512	1							
INPUTT	20513	150	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
/E/	20663	10							
CURFIT	20673	234	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
/F/	21127	5670							
FORT	27017	52	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
OTPUT	27071	451	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
COLMNS	27542	401	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
PLOTT	30143	332	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
ANOTAT	30475	156	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
FLINE	30653	221	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
A1A3	31074	111	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
A2A4	31205	115	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
BN	31322	63	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
CN	31405	46	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
DN	31453	40	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
DELF1	31513	66	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
DELF2	31601	30	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
/I/	31631	36							
ENTITL	31667	64	LGO	12/16/76	FTN	4.6	420	666X I	OPT=1
PLOT	31753	762	UL-LIBA	10/31/75	FTN	4.3	P393	666X I	OPT=1
WRDSK	32735	17	UL-LIBA	05/27/75	FTN	4.2	74365	666X I	OPT=1
DROP	32754	23	UL-LIBA	05/27/75	FTN	4.2	74365	666X I	OPT=1
MARKER	32777	65	UL-LIBA	05/29/75	FTN	4.2	74365	666X I	OPT=1
LOGXIS	33064	724	UL-LIBA	07/01/75	FTN	4.3	P393	666X I	OPT=1
LNAXIS	34010	515	UL-LIBA	08/18/75	FJN	4.3	P393	666X I	OPT=1
NORM	34525	331	UL-LIBA	09/18/75	FTN	4.3	P393	666X I	OPT=1
MINMAX	35056	65	UL-LIBA	02/03/76	FTN	4.3	P393	666X I	OPT=1
DRAW	35143	150	UL-LIBA	03/31/76	FTN	4.3	P393	666X I	OPT=1
COMPRES	35313	6	UL-LIBA	11/03/75	FTN	4.3	P393	666X I	OPT=1
RDDSK	35321	20	UL-LIBA	05/27/75	FTN	4.2	74365	666X I	OPT=1
LGNORM	35341	155	UL-LIBA	09/04/75	FTN	4.3	?393	666X I	OPT=1
LINE	35516	140	UL-LIBA	02/03/76	FTN	4.3	P393	666X I	OPT=1
DRAWG	35656	1777	UL-LIBA	02/05/76	FTN	4.3	P393	666X I	OPT=1
NUMBER	37655	353	UL-LIBA	03/31/76	FTN	4.3	P393	666X I	OPT=1
SYMBOL	40230	341	UL-LIBA	08/03/76	FTN	4.6	420	666X I	OPT=1
/STP.END/	40571	1							
/PCL.C./	40572	23							
/Q8.IO./	40615	133							

APPENDIX A

LOAD MAP - ENMFIT CYBER LOADER 1.1-420 12/16/76 13.30.26.

BLOCK	ADDRESS	LENGTH	FILE	DATE	PROCSSR	VER	LEVEL	HARDWARE	COMMENTS
Q8NTRY=	40750	0	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FCL INITIALIZATION ROUTINE.
CORIO=	40750	64	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMMON CODED I/O ROUTINES AND CONSTANTS.
ENCODE=	41034	123	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FORMATTED WRITE INTO CORE.
FECMSK=	41157	41	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		INITIALIZE CONSTANTS.
FLTOUT=	41220	311	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMMON FLOATING OUTPUT CODE
FORSYS=	41531	602	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FORTRAN OBJECT LIBRARY UTILITIES.
INCOM=	42333	276	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMMON INPUT FORMATTING CODE
INPC=	42631	160	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FORMATTED READ FORTRAN RECORD.
KODER=	43011	456	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		OUTPUT FORMAT INTERPRETER.
OUTC=	43467	172	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FORMATTED WRITE FORTRAN RECORD.
SQRT	43661	43	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMPUTE THE SQUARE ROOT OF X. OPT=ALL.
SYS=1ST	43724	62	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		MATH LIBRARY LINK TO ERROR MESSAGE PROCESSO
XTOI=	44006	10	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		REAL TO INTEGER EXPONENTIATION.
XTOY=	44016	7	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		REAL TO REAL EXPONENTIATION.
FLTIN=	44025	154	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMMON FLOATING INPUT CONVERTER.
FMTAP=	44201	352	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		CRACK APLIST AND FORMAT FOR KCDER/KRAKER.
FORUTL=	44553	16	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		FCL MISC. UTILITIES.
GETFIT=	44571	42	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		LOCATE AN FIT GIVEN A FILE NAME.
/IO.BUF./	44633	227							
INPB=	45062	314	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		BINARY READ FORTRAN RECORD.
KRAKER=	45376	406	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		PROCESS FORMATTED FORTRAN INPUT.
OUTB=	46004	203	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		BINARY WRITE FORTRAN RECORD.
OUTCOM=	46207	154	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMMON OUTPUT CODE
REWIND=	46363	37	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		POSITION FILE AT BEGINNING-OF-INFORMATION.
CLOCK=	46422	31	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		ACCESS SYSTEM CLOCKS FOR FORTRAN.
GOTOER=	46453	14	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMPUTED GO TO ERRL' PROCESSOR.
ALOG	46467	73	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		COMPUTE COMMON AND NATURAL LOGARITHMS. OPT=
EXP	46562	75	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		EXPONENTIAL FUNCTION. E TO POWER X. OPT=ALL
SINCOS=	46657	66	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		TRIGONOMETRIC SINE OR COSINE OF X. OPT=ALL.
SYSAID=	46745	1	SL-FORTRAN	06/22/76	COMPASS	3.	3-420		LINK BETWEEN SYS=AID AND INITIALIZATION COD
/COM.RM/	46746	6							
CIO.RM	46754	40	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/AOB.RM/	47014	10							
MOVE.RM	47024	64	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
RCT.RM	47110	233	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/JMPS.RM/	47343	11							
/MEMC.RM/	47354	3							
/OPES.FO/	47357	1							
/OPEN.FO/	47360	7							
OPEN.RM	47367	235	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/TERM.RM/	47624	1							
/PUT.FO/	47625	7							
PUT.SQ	47634	1362	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
WAR.SQ	51216	260	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/CLSF.FO/	51476	7							
CLSF.RM	51505	23	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/GET.BT/	51530	5							
BTRT.SQ	51535	114	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
WEOX.SQ	51651	142	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/SKFL.FO/	52013	7							
SKFL.SQ	52022	47	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
ERR.RM	52071	404	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
CMWR.SQ	52475	7	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
JSUB.RM	52504	65	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
OPEN.SQ	52571	262	SL-SYSIO	06/22/76	COMPASS	3.	3-420		

LOAD MAP - ENMFIT CYBER LOADER 1.1-420 12/16/76 13.30.26.

OPEX.SQ	53053	14	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/PUT.RT/	53067	11							
RLEQ.RM	53100	42	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
CLSF.SQ	53142	132	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/CLSV.FO/	53274	7							
CLSV.SQ	53303	123	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/REW.FO/	53426	7							
REW.SQ	53435	31	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
/GET.FO/	53466	7							
/GET.RT/	53475	11							
GET.SQ	53506	1035	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
Z.SQ	54543	101	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
W.SQ	54644	50	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
FSU.SQ	54714	106	SL-SYSIO	06/22/76	COMPASS	3.	3-420		
SYS.RM	55022	37	SL-NUCLEUS	10/12/76	COMPASS	3.	3-420		PROCESS SYSTEM REQUEST.

1.202 CP SECONDS 710008 CM STORAGE USED 95 TABLE MOVES

APPENDIX A

BLAST RELATED ENVIRONMENT

INPUT DATA - MAGNETIC INDUCTION-AZIMUTHAL

ALPHA= 1.200E+08 BETA= 5.000E+04 MAXIMUM TIME TO BE CALCULATED= 2.000E-04
NUMBER OF INPUT DATA POINTS= 34 NUMBER OF POINTS CALCULATED BETWEEN INPUT DATA POINTS= 4

TIME (SEC)	B-AZIMUTHAL	TIME (SEC)	B-AZIMUTHAL	TIME (SEC)	B-AZIMUTHAL
1.718E-07	-5.681E-04	4.380E-07	-9.453E-01	4.399E-06	-4.300E-01
1.886E-07	-1.644E-04	5.239E-07	-7.567E-01	5.287E-06	-3.405E-01
2.072E-07	-4.846E-03	7.167E-07	-5.543E-01	6.358E-06	-2.398E-01
2.276E-07	-1.241E-02	8.132E-07	-5.338E-01	1.211E-05	-5.038E-02
2.498E-07	-2.587E-02	9.096E-07	-5.344E-01	1.328E-05	-4.605E-02
2.745E-07	-5.296E-02	1.006E-06	-5.273E-01	1.456E-05	-4.458E-02
2.883E-07	-7.937E-02	1.104E-06	-5.196E-01	1.596E-05	-4.482E-02
3.021E-07	-1.279E-01	1.751E-06	-5.235E-01	2.773E-05	-4.887E-02
3.319E-07	-7.715E-01	2.529E-06	-5.411E-01	3.656E-05	-4.766E-02
3.653E-07	-1.488E+00	3.041E-06	-5.299E-01	5.284E-05	-4.497E-02
3.987E-07	-1.057E+00	3.656E-06	-4.948E-01	7.638E-05	-4.105E-02
4.100E-07	-1.000E+00				

NUMBER OF POINTS = 34

CURVE FIT CALCULATIONS

MINIMUM VALUE OF ORDINATE TO BE PLOTTED= -1.000E+05

TIME (SEC)	B-AZIMUTHAL	TIME (SEC)	B-AZIMUTHAL	TIME (SEC)	B-AZIMUTHAL
1.374E-07	0.	4.077E-07	-1.009E+00	4.102E-06	-4.579E-01
1.443E-07	-3.988E-05	4.100E-07	-1.000E+00	4.250E-06	-4.442E-01
1.512E-07	-8.885E-05	4.156E-07	-9.825E-01	4.399E-06	-4.300E-01
1.581E-07	-1.916E-04	4.212E-07	-9.698E-01	4.577E-06	-4.126E-01
1.649E-07	-3.798E-04	4.268E-07	-9.603E-01	4.754E-06	-3.947E-01
1.718E-07	-5.681E-04	4.324E-07	-9.526E-01	4.932E-06	-3.767E-01
1.752E-07	-5.085E-04	4.380E-07	-9.453E-01	5.109E-06	-3.585E-01
1.785E-07	-3.431E-04	4.552E-07	-9.133E-01	5.287E-06	-3.405E-01
1.819E-07	-1.551E-04	4.724E-07	-8.735E-01	5.501E-06	-3.192E-01
1.852E-07	-5.179E-05	4.895E-07	-8.319E-01	5.715E-06	-2.984E-01
1.886E-07	-1.644E-04	5.067E-07	-7.924E-01	5.930E-06	-2.781E-01
1.923E-07	-6.732E-04	5.239E-07	-7.567E-01	6.144E-06	-2.585E-01
1.960E-07	-1.502E-03	5.625E-07	-6.912E-01	6.358E-06	-2.398E-01
1.998E-07	-2.532E-03	6.010E-07	-6.415E-01	7.508E-06	-1.595E-01
2.035E-07	-3.671E-03	6.396E-07	-6.038E-01	8.659E-06	-1.084E-01
2.072E-07	-4.846E-03	6.781E-07	-5.754E-01	9.809E-06	-7.876E-02
2.113E-07	-6.141E-03	7.167E-07	-5.543E-01	1.096E-05	-6.234E-02
2.154E-07	-7.502E-03	7.360E-07	-5.470E-01	1.211E-05	-5.038E-02
2.194E-07	-8.985E-03	7.553E-07	-5.415E-01	1.234E-05	-4.903E-02
2.235E-07	-1.062E-02	7.746E-07	-5.377E-01	1.258E-05	-4.790E-02
2.276E-07	-1.241E-02	7.939E-07	-5.352E-01	1.281E-05	-4.706E-02
2.320E-07	-1.454E-02	8.132E-07	-5.338E-01	1.305E-05	-4.647E-02
2.365E-07	-1.691E-02	8.325E-07	-5.332E-01	1.328E-05	-4.605E-02
2.409E-07	-1.958E-02	8.518E-07	-5.333E-01	1.354E-05	-4.561E-02
2.454E-07	-2.257E-02	8.710E-07	-5.337E-01	1.379E-05	-4.521E-02
2.498E-07	-2.587E-02	8.903E-07	-5.343E-01	1.405E-05	-4.490E-02
2.547E-07	-2.992E-02	9.096E-07	-5.344E-01	1.430E-05	-4.469E-02
2.597E-07	[illegible]	9.288E-07	-5.337E-01	1.456E-05	-4.458E-02
2.646E-07	-3.977E-02	9.482E-07	-5.323E-01	1.484E-05	-4.453E-02
2.696E-07	-4.589E-02	9.674E-07	-5.307E-01	1.512E-05	-4.455E-02
2.745E-07	-5.296E-02	9.867E-07	-5.290E-01	1.540E-05	-4.460E-02
2.773E-07	-5.725E-02	1.006E-06	-5.279E-01	1.568E-05	-4.470E-02
2.800E-07	-6.219E-02	1.026E-06	-5.257E-01	1.596E-05	-4.482E-02
2.828E-07	-6.783E-02	1.065E-06	-5.241E-01	1.831E-05	-4.576E-02
2.855E-07	-7.381E-02	1.065E-06	-5.225E-01	2.067E-05	-4.670E-02
2.883E-07	-7.937E-02	1.084E-06	-5.210E-01	2.302E-05	-4.762E-02
2.911E-07	-8.303E-02	1.104E-06	-5.196E-01	2.538E-05	-4.841E-02
2.938E-07	-8.840E-02	1.233E-06	-5.140E-01	2.773E-05	-4.887E-02
2.966E-07	-9.529E-02	1.363E-06	-5.133E-01	2.950E-05	-4.889E-02
2.993E-07	-1.073E-01	1.492E-06	-5.156E-01	3.126E-05	-4.869E-02
3.021E-07	-1.279E-01	1.622E-06	-5.193E-01	3.303E-05	-4.838E-02
3.081E-07	-2.091E-01	1.751E-06	-5.235E-01	3.479E-05	-4.802E-02
3.140E-07	-3.271E-01	1.907E-06	-5.282E-01	3.656E-05	-4.766E-02
3.200E-07	-4.660E-01	2.062E-06	-5.326E-01	3.982E-05	-4.706E-02
3.259E-07	-6.156E-01	2.218E-06	-5.367E-01	4.307E-05	-4.638E-02
3.319E-07	-7.715E-01	2.373E-06	-5.399E-01	4.633E-05	-4.564E-02
3.386E-07	-9.504E-01	2.529E-06	-5.411E-01	4.958E-05	-4.503E-02
3.453E-07	-1.129E+00	2.631E-06	-5.405E-01	5.284E-05	-4.497E-02
3.519E-07	-1.293E+00	2.734E-06	-5.389E-01	5.755E-05	-4.606E-02
3.586E-07	-1.423E+00	2.836E-06	-5.366E-01	6.226E-05	-4.724E-02
3.653E-07	-1.488E+00	2.939E-06	-5.336E-01	6.696E-05	-4.712E-02
3.720E-07	-1.466E+00	3.041E-06	-5.299E-01	7.167E-05	-4.504E-02
3.787E-07	-1.377E+00	3.164E-06	-5.246E-01	7.638E-05	-4.105E-02
3.853E-07	-1.255E+00	3.287E-06	-5.184E-01	1.011E-04	-1.623E-02
3.920E-07	-1.136E+00	3.410E-06	-5.113E-01	1.258E-04	-5.078E-03
3.987E-07	-1.057E+00	3.533E-06	-5.034E-01	1.506E-04	-1.506E-03
4.010E-07	-1.040E+00	3.656E-06	-4.948E-01	1.753E-04	-4.400E-04
4.032E-07	-1.028E+00	3.805E-06	-4.834E-01	2.000E-04	-1.280E-04
4.055E-07	-1.018E+00	3.953E-06	-4.710E-01	2.247E-04	-3.721E-05

NUMBER OF POINTS = 177

APPENDIX A

FOURIER TRANSFORM CALCULATIONS

STARTING FREQUENCY(HERTZ)= 1.000E+04 DELTA FREQUENCY= 1.047E+00
MAXIMUM FREQUENCY TO BE CALCULATED= 3.000E+07

FREQUENCY	AMPLITUDE REAL	AMPLITUDE IMAGINARY
1.000E+04	-2.673E-06	1.076E-06
1.047E+04	-2.752E-06	1.070E-06
1.095E+04	-2.822E-06	1.088E-06
1.146E+04	-2.879E-06	1.125E-06
1.200E+04	-2.920E-06	1.178E-06
1.255E+04	-2.942E-06	1.243E-06
1.314E+04	-2.944E-06	1.313E-06
1.375E+04	-2.925E-06	1.384E-06
1.439E+04	-2.888E-06	1.450E-06
1.506E+04	-2.835E-06	1.507E-06
1.576E+04	-2.771E-06	1.552E-06
1.649E+04	-2.701E-06	1.582E-06
1.726E+04	-2.631E-06	1.597E-06
1.806E+04	-2.565E-06	1.599E-06
1.891E+04	-2.509E-06	1.591E-06
1.979E+04	-2.465E-06	1.580E-06
2.071E+04	-2.434E-06	1.568E-06
2.167E+04	-2.415E-06	1.564E-06
2.268E+04	-2.406E-06	1.572E-06
2.373E+04	-2.399E-06	1.597E-06
2.484E+04	-2.387E-06	1.639E-06
2.599E+04	-2.363E-06	1.694E-06
2.720E+04	-2.322E-06	1.758E-06
2.847E+04	-2.262E-06	1.821E-06
2.980E+04	-2.187E-06	1.874E-06
3.118E+04	-2.107E-06	1.915E-06
3.263E+04	-2.029E-06	1.950E-06
3.415E+04	-1.951E-06	1.986E-06
3.574E+04	-1.864E-06	2.025E-06
3.741E+04	-1.762E-06	2.056E-06
3.915E+04	-1.659E-06	2.064E-06
4.097E+04	-1.577E-06	2.066E-06
4.287E+04	-1.500E-06	2.091E-06
4.487E+04	-1.396E-06	2.124E-06
4.696E+04	-1.272E-06	2.135E-06
4.914E+04	-1.156E-06	2.124E-06
5.143E+04	-1.048E-06	2.111E-06
5.383E+04	-9.378E-07	2.098E-06
5.633E+04	-8.217E-07	2.075E-06
5.895E+04	-7.080E-07	2.039E-06
6.170E+04	-6.009E-07	1.996E-06
6.457E+04	-4.982E-07	1.949E-06
6.757E+04	-3.942E-07	1.897E-06
7.072E+04	-2.929E-07	1.832E-06
7.401E+04	-2.043E-07	1.761E-06
7.745E+04	-1.153E-07	1.689E-06
8.106E+04	-3.845E-08	1.598E-06
8.483E+04	2.588E-08	1.518E-06
8.878E+04	8.849E-08	1.426E-06
9.291E+04	1.342E-07	1.336E-06
9.723E+04	1.758E-07	1.247E-06
1.018E+05	2.055E-07	1.156E-06
1.065E+05	2.277E-07	1.072E-06
1.115E+05	2.433E-07	9.869E-07
1.166E+05	2.509E-07	9.100E-07
1.221E+05	2.517E-07	8.316E-07
1.277E+05	2.498E-07	7.629E-07
1.337E+05	2.397E-07	6.978E-07
1.399E+05	2.268E-07	6.371E-07
1.464E+05	2.096E-07	5.843E-07
1.532E+05	1.892E-07	5.363E-07
1.604E+05	1.682E-07	4.947E-07
1.678E+05	1.460E-07	4.626E-07
1.757E+05	1.241E-07	4.352E-07
1.838E+05	1.043E-07	4.155E-07
1.924E+05	8.779E-08	3.972E-07
2.013E+05	7.620E-08	3.846E-07
2.107E+05	6.567E-08	3.733E-07
2.205E+05	5.945E-08	3.616E-07
2.308E+05	5.459E-08	3.515E-07
2.415E+05	4.900E-08	3.424E-07
2.528E+05	4.485E-08	3.342E-07
2.645E+05	4.292E-08	3.279E-07
2.768E+05	4.279E-08	3.234E-07
2.897E+05	4.521E-08	3.183E-07
3.032E+05	5.062E-08	3.127E-07
3.173E+05	5.649E-08	3.050E-07
3.321E+05	6.117E-08	2.962E-07
3.475E+05	6.547E-08	2.877E-07
3.637E+05	7.044E-08	2.812E-07
3.806E+05	7.721E-08	2.739E-07
3.984E+05	8.462E-08	2.649E-07
4.169E+05	9.080E-08	2.554E-07
4.363E+05	9.685E-08	2.472E-07
4.566E+05	1.046E-07	2.388E-07
4.778E+05	1.131E-07	2.287E-07
5.001E+05	1.206E-07	2.167E-07
5.234E+05	1.267E-07	2.050E-07
5.477E+05	1.324E-07	1.934E-07
5.732E+05	1.381E-07	1.816E-07
5.999E+05	1.432E-07	1.703E-07
6.278E+05	1.495E-07	1.584E-07
6.570E+05	1.554E-07	1.447E-07
6.876E+05	1.592E-07	1.301E-07
7.196E+05	1.613E-07	1.163E-07
7.531E+05	1.637E-07	1.050E-07
7.882E+05	1.699E-07	9.151E-08
8.248E+05	1.718E-07	7.264E-08
8.632E+05	1.689E-07	5.920E-08
9.034E+05	1.727E-07	4.617E-08
9.454E+05	1.721E-07	2.648E-08
9.894E+05	1.677E-07	1.109E-08
1.035E+06	1.649E-07	-4.721E-09
1.084E+06	1.594E-07	-2.186E-08
1.134E+06	1.520E-07	-3.770E-08
1.187E+06	1.432E-07	-5.333E-08
1.242E+06	1.327E-07	-6.845E-08
1.300E+06	1.201E-07	-8.263E-08
1.360E+06	1.052E-07	-9.578E-08
1.424E+06	8.840E-08	-1.069E-07
1.490E+06	6.943E-08	-1.159E-07
1.559E+06	4.876E-08	-1.214E-07
1.632E+06	2.751E-08	-1.244E-07
1.708E+06	5.703E-09	-1.220E-07
1.787E+06	-1.653E-08	-1.176E-07
1.871E+06	-3.608E-08	-1.083E-07
1.958E+06	-5.441E-08	-9.496E-08
2.049E+06	-6.930E-08	-7.869E-08
2.144E+06	-8.042E-08	-5.972E-08
2.244E+06	-8.722E-08	-3.910E-08
2.348E+06	-8.936E-08	-1.769E-08
2.458E+06	-8.673E-08	3.084E-09
2.572E+06	-7.947E-08	2.227E-08
2.692E+06	-6.809E-08	3.932E-08
2.817E+06	-5.307E-08	5.316E-08
2.948E+06	-3.526E-08	6.266E-08
3.085E+06	-1.558E-08	6.713E-08
3.229E+06	4.781E-09	6.592E-08
3.379E+06	2.397E-08	5.863E-08
3.536E+06	4.006E-08	4.581E-08
3.701E+06	5.115E-08	2.796E-08
3.873E+06	5.515E-08	7.403E-09
4.054E+06	5.140E-08	-1.309E-08
4.242E+06	4.024E-08	-3.042E-08
4.440E+06	2.329E-08	-4.204E-08
4.646E+06	3.333E-09	-4.569E-08
4.863E+06	-1.626E-08	-4.065E-08
5.089E+06	-3.177E-08	-2.743E-08
5.326E+06	-3.928E-08	-8.291E-09
5.574E+06	-3.648E-08	1.219E-08
5.833E+06	-2.350E-08	2.826E-08
6.104E+06	-3.856E-09	3.496E-08
6.389E+06	1.611E-08	2.949E-08
6.686E+06	2.915E-08	1.323E-08
6.997E+06	2.953E-08	-7.463E-09
7.323E+06	1.669E-08	-2.370E-08
7.664E+06	-3.680E-09	-2.712E-08
8.020E+06	-2.033E-08	-1.573E-08
8.393E+06	-2.388E-08	3.801E-09
8.784E+06	-1.180E-08	1.923E-08
9.193E+06	7.216E-09	1.959E-08
9.621E+06	1.846E-08	5.061E-09
1.007E+07	1.298E-08	-1.154E-08
1.054E+07	-3.101E-09	-1.528E-08
1.103E+07	-1.331E-08	-3.717E-09
1.154E+07	-7.689E-09	9.315E-09
1.208E+07	5.182E-09	9.007E-09
1.264E+07	8.549E-09	-1.989E-09
1.323E+07	-2.379E-11	-7.270E-09
1.384E+07	-5.819E-09	-8.791E-10
1.449E+07	-9.756E-10	6.567E-09
1.516E+07	3.569E-09	5.993E-10
1.587E+07	-6.430E-11	-2.751E-09
1.661E+07	-2.020E-09	7.794E-10
1.738E+07	1.423E-09	1.233E-09
1.819E+07	3.107E-10	-1.850E-09
1.904E+07	-1.021E-09	6.752E-10
1.992E+07	1.486E-09	1.294E-09
2.085E+07	3.349E-10	-1.905E-09
2.182E+07	-1.651E-09	7.577E-10
2.283E+07	1.485E-09	7.436E-10
2.390E+07	-4.779E-10	-1.368E-09
2.501E+07	-3.789E-10	1.004E-09
2.617E+07	6.631E-10	-3.135E-10
2.739E+07	-4.762E-10	-5.464E-11
2.867E+07	1.110E-10	9.470E-11
3.000E+07	1.205E-10	-3.560E-11

NUMBER OF POINTS = 177

APPENDIX B
SAMPLE INPUT DATA

This appendix shows examples of input card decks of EMPFIT.

```
.................................................................................
         1         2         3         4         5         6         7         8
.................................................................................


         1
         2                              3-1.000E+05         2
ENVIRONMENT III
        48         4 1.000E-02 1.200E+09 5.000E+02 1.000E+04 3.000E+07
 1.263E-07-6.363E+00
 1.418E-07-1.724E+01
 1.588E-07-4.985E+01
 1.772E-07-1.469E+02
 1.976E-07-3.774E+02
 2.198E-07-7.875E+02
 2.445E-07-1.626E+03
 2.550E-07-2.554E+03
 2.650E-07-3.957E+03
 3.019E-07-2.468E+04
 3.317E-07-1.316E+04
 4.080E-07-2.742E+03
 4.493E-07 7.050E+02
 5.478E-07 3.863E+03
 6.643E-07 4.692E+03
 7.307E-07 4.809E+03
 8.068E-07 4.708E+03
 8.878E-07 4.747E+03
 9.760E-07 4.524E+03
 1.181E-06 3.462E+03
 1.565E-06 1.445E+03
 1.751E-06 3.743E+02
 1.890E-06-4.929E+02
 2.000E-06-2.270E+03
 2.529E-06-6.020E+03
 2.600E-06-6.736E+03
 2.800E-06-7.447E+03
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