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DESIGN AND IMPLEMENTATION OF A MICROPROCESSOR FLIGHT DAMAGE MON--ETC(U)
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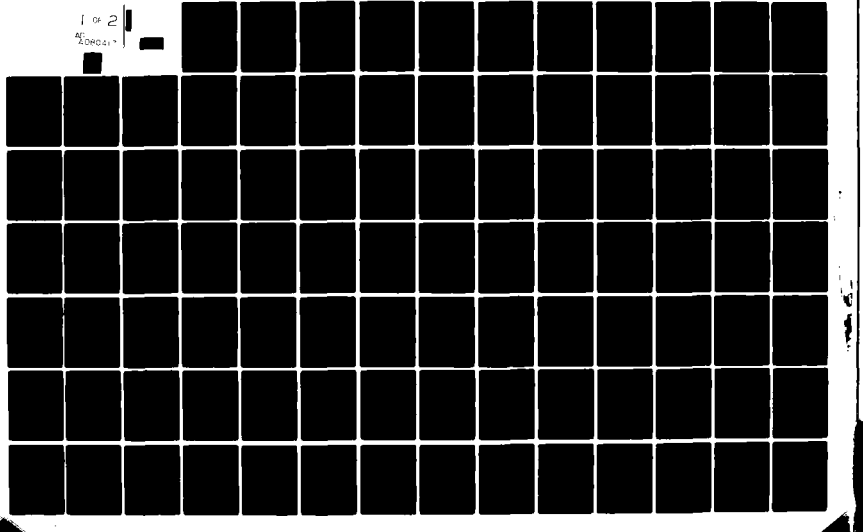

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DESIGN AND IMPLEMENTATION OF A MICROPROCESSOR FLIGHT DAMAGE MONITOR

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
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by

Brian C. Johnson
Capt USAF

Graduate Computer Systems

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Preface

This thesis describes the design and implementation of a microprocessor based data acquisition and processing system for the Air Force Flight Dynamics Laboratory. Wright-Patterson Air Force Base Ohio. A structured design of the system was performed, and a bench model system was implemented. The bench model demonstrated that real-time data acquisition and computation of a cumulative damage matrix can be performed.

I wish to thank my advisor, Dr. Gary B. Lamont for his help during the design and implementation of this system, and for help in preparing this report I also would like to thank the members of my thesis committee, Dr. Thomas C. Hartrum and Dr. John M. Borky, for their help with this thesis. For their assistance and support. I would like to thank my sponsors Dr. Lynn C. Rogers and Mr. Robert W. Gordon, of the Air Force Flight Dynamics Laboratory; and for his help with the software development. I would like to thank Mr. Frank Beitel of the Air Force Materials Laboratory Computer Activities Division, Wright-Patterson Air Force Base, Ohio.

Last but not least, I would like to express my indebtedness to my wife Cynthia, for her love, patience, and help in preparing this thesis.

Brian C Johnson

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Abstract

In order to design a constrained layer damping treatment for aircraft components the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base Ohio requires a knowledge of vibration and temperature variations which a component encounters during its life This report discusses the design and implementation of a microprocessor based system to acquire vibration and temperature information, and computes the cumulative damage factor versus frequency and temperature in real time. The cumulative damage factor is computed for one of eight user selectable frequency ranges and for a temperature range of -50 to +225 degrees Fahrenheit and is stored in a non-volatile memory.

The designed system uses an LSI 11 microcomputer system consisting of an LSI-11 processor, an analog-to-digital converter, a real-time clock, PROM, a non-volatile memory, and a serial interface. The software developed for this system controls the data acquisition, the computation of a fast Fourier transform (FFT), the power spectrum of vibration data, and the subsequent computation of the cumulative damage factor. The data acquisition and FFT modules were coded in assembly language, and the other modules were coded in FORTRAN. The output of the system consists of a table containing the cumulative damage as a function of frequency and temperature. A bench model system was constructed and tested, and a proposal for a flight-worthy system is made

DESIGN AND IMPLEMENTATION OF A MICROPROCESSOR FLIGHT DAMAGE MONITOR

I. Introduction

Aircraft and avionics hardware operate in an environment of varying temperature and vibration. The resonant fatigue damage caused by this environment is a major factor in airframe and avionics hardware structural failure. In order to reduce the resonant fatigue damage, design engineers must know what temperatures and vibration frequencies an object will encounter during its life. With this information, a constrained layer damping treatment which reduces the resonant fatigue damage can be applied to the object (Ref 10).

The Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base Ohio, has the technology to produce a constrained layer damping treatment, although the current flight data acquisition and analysis systems are very large and hard to use, and require undue time and resources (Ref 10). In order to simplify the data acquisition, a microprocessor based data acquisition and processing system to acquire the necessary data, and process it in real-time, was designed (Ref 7). This investigation, sponsored by AFFDL, is a continuation of that effort and will focus on an expanded design, bench model construction, testing, and recommendations for a flight-worthy system.

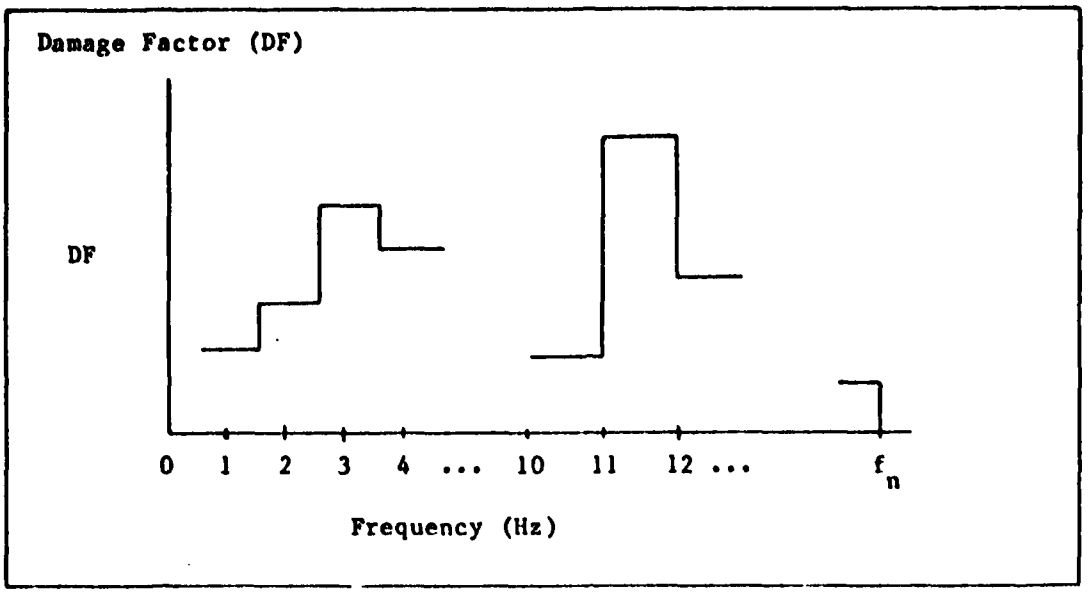


Fig 1. Damage Factor versus Frequency

Background

Research has determined that the resonant vibrations which cause structural damage occur at frequencies under 6,000 Hz and in a temperature range between -50 degrees Fahrenheit and +225 degrees Fahrenheit (Ref 10). The damage factor (DF) at a given frequency (f) and temperature (T) can be approximated with the following equation (Ref 10):

$$DFT(f) = K(\overline{A})^{B}/(f)^{2B-1} , \qquad (1)$$

where k is a constant, $\overline{A}$ is the root mean square (RMS) value of the acceleration at the specified frequency (f), and B is approximately 3.3. Figure 1 is a graph of damage factor vs. frequency computed by using Eq 1. This damage factor, when computed for a given frequency

and temperature, and summed for a predetermined period of time (t), forms the cumulative damage factor (CDF) as shown in Eq 2:

$$CDF(f,T) = \sum_{t} DF_{t}(f,T) \quad , \tag{2}$$

The cumulative damage factor for a given frequency and temperature forms one damage coefficient in the "three dimensional" cumulative damage matrix, as shown in Figure 2 (Ref 10).

Current in-flight data acquisition techniques use analog signal conditioners and multi-channel analog tape recorders to record the frequency and temperature data necessary to compute the CDF. After the data has been acquired, the CDF is computed and plotted. This technique requires skilled personnel to operate the equipment, and due to the time required to compute the cumulative damage factor, there can be a long delay between the ending of the test and obtaining the cumulative damage matrix output (Ref 10).

In order to simplify this process, it was decided to design a Microprocessor Flight Damage Monitor (MFDM) which would acquire and process the data in real-time. Such a system appeared attractive, as it would be easy to install and remove, would not require skilled personnel to operate, and the cumulative damage data would be available immediately after the test (Ref 10).

System Concept

The MFDM system concept consists of a self-contained configuration which would compute, in real time, the cumulative damage factor CDF from analog temperature and frequency data, and store the cumulative

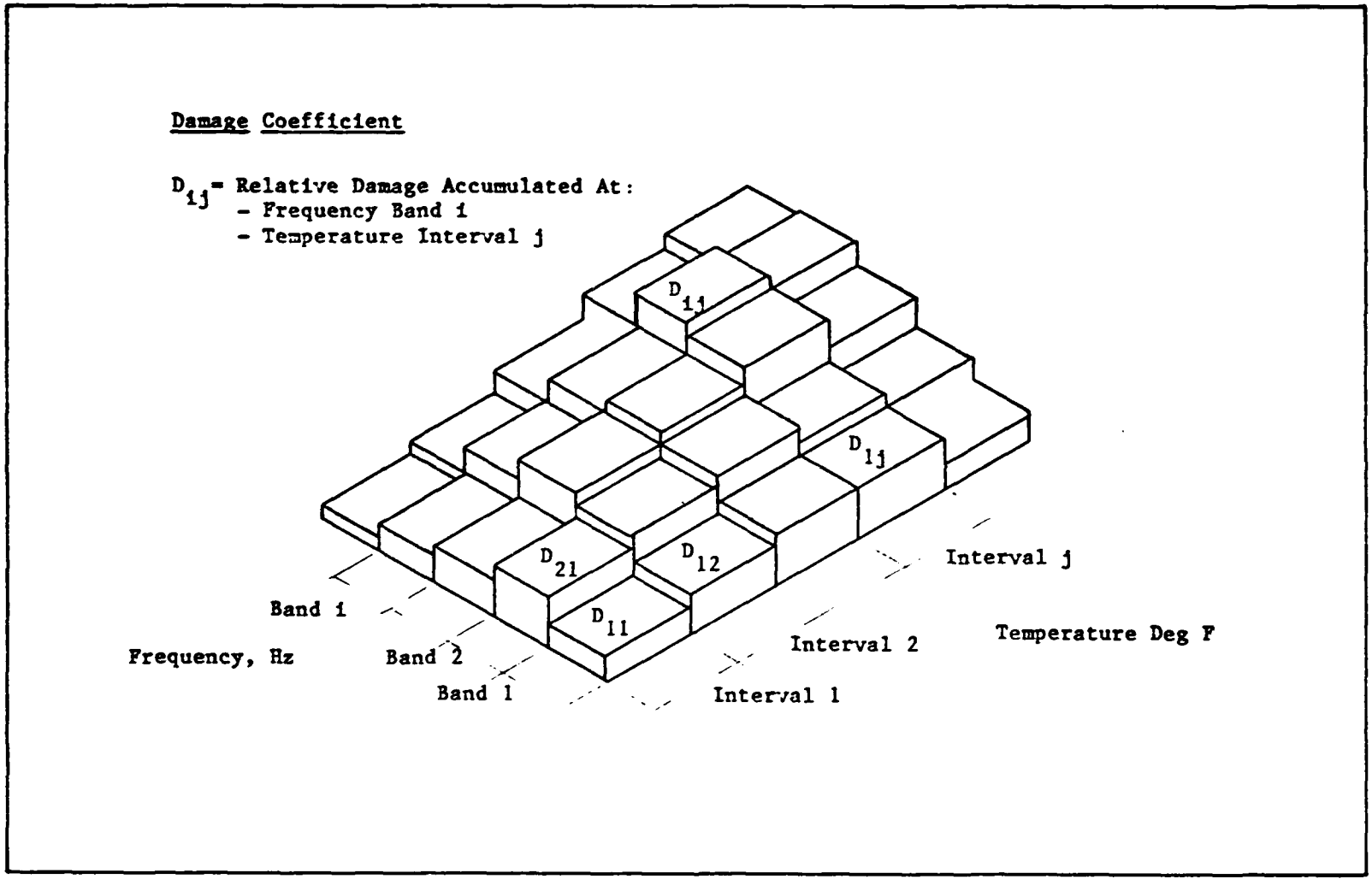


Fig 2. Cumulative Damage Matrix

damage factor in non-volatile memory. This concept was expanded to include an interactive capability where the user can select the frequency range and resolution for which the CDF is to be computed, select the duration of the test, and have the cumulative damage matrix printed (Ref 10). In addition to the interactive requirements, two start-up modes were required. The first mode would start processing data upon system power initiation and the second mode would start processing data when given a start command. Figure 3 shows an activity diagram (Ref 7 11) which summarizes the system.

Approach

The MFDM (also referred to as the "system") was developed in four phases bassed upon execpted top down structured approach. The four phases were: the conceptual phase the design phase. the implementation phase, and the testing phase. The conceptual phase uses structured analysis and design to define the detailed requirements placed on the system. The design phase included the algorithm design and selection of the system hardware. During the implementation phase, the system is coded, assembled, and given a functional check Then the testing phase verifies the operation of the system.

Development Environment

An LSI-11 microcomputer, manufactured by Digital Equipment Corporation (DEC), was used as the system processor because of its powerful instruction set, processing speed, data structure and availability of support hardware and software. The support hardware used in the MFDM is listed in Table I. In addition to the LSI-11 microcomputer and support hardware, the development system had a

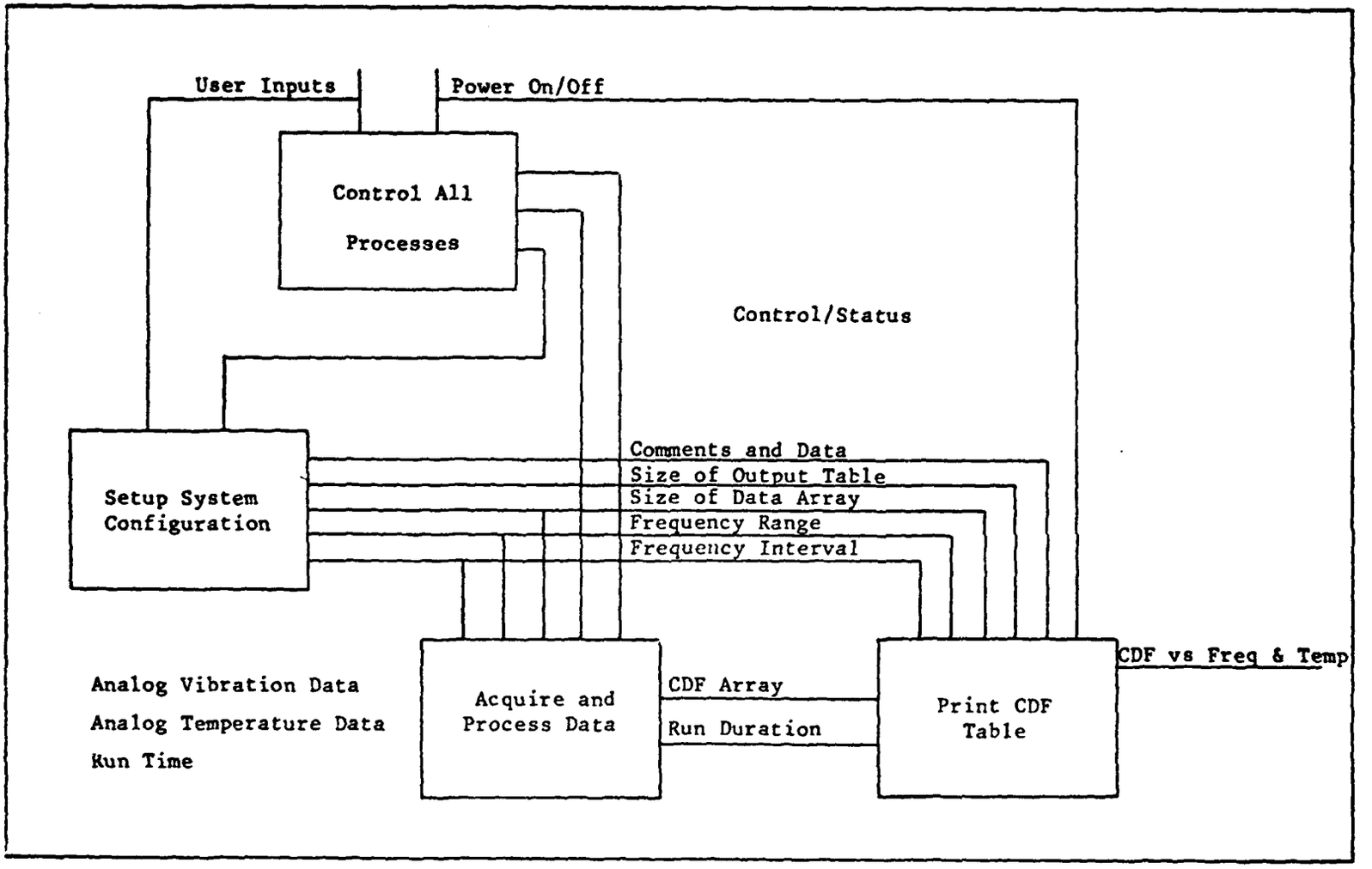


Fig 3. Activity Diagram for the MFDM

TABLE I

LSI-11 Support Hardware

Module	Description
1. KD11-J	LSI-11 Processor
2. MMV11-A	4 K by 16 bit Core Memory
3. DLV11-J	4 Channel Asynchronous Serial Line Interface
4. KWV11-A	Programmable Real-Time Clock
5. ADV11-A	16 Channel 12 bit Analog-to-Digital Converter
6. MSV11-DB	8 K by 16 bit Semiconductor Memory (Used Two Modules)
7. BCV1B	Backplane Expansion Cables
8. H9270	Backplanes (two)
9. TEV11	120 OHM Bus Terminator
10. H780-H	Powersupply

Heathkit H27 dual floppy disk drive, a Heathkit H14 line printer, and a Lear Siegler ADM-3 terminal. The software was developed using DEC's RT-11 version 03-B operating system, version 2.1-11 FORTRAN IV compiler, and version 03.01 macroassembler (Ref 8:643-647). This development system was located atthe Air Force Institute of Technology Wright-Patterson AFB, Ohio.

Scope of Thesis

First the system requirements and design constraints are defined (Chap II), and then a structured analysis and design of the system is performed, producing a structure chart for the entire system (Chap III). Following this, the hardware selections (Ref 7 25-36) are reviewed with respect to the new system design (Chap IV). After the hardware considerations the required software modules are developed by modifying existing modules (Ref 7:75-95) where possible, and creating new modules for functions which had not yet been implemented (Chap V). The hardware

and the software were then integrated into a bench model of the MFDM which was functionally tested (Chap VI). A proposed flight-worthy system is then discussed (Chap VII). Recommendations for the flight-worthy system and investigative conclusions about this effort are presented in Chap VIII.

II. Requirements Definition

Introduction

Before any system can be designed and implemented, the system requirements must be defined. These requirements form a base line from which a system can be designed, and must include the purpose of the system, its input parameters, output parameters, any time constraints, and any hardware constraints. The purpose of this chapter is to accurately define the system in terms of the requirements established by the AFFDL (Ref 10) and the design constraints of the system.

System Requirements

The purpose of the MFDM is the real-time computation of the CDF as a function of frequency and temperature from analog frequency and temperature signals. The output of this system will be a cumulative damage table which contains the CDF as a function of frequency and temperature. This gives a general definition of the system, the specific requirements of which are as follows (Ref 7:6-22):

- The input to the system will be an analog frequency signal and an analog temperature signal. Signal amplifiers will amplify the signals so as to make the signals compatible with an analog-to-digital converter.
- The temperature range for which resonant fatigue damage usually occurs is between -50 degrees and +225 degrees Fahrenheit. In order to produce a damping layer, the cumulative damage factor must be known at 25 degree intervals for this temperature range.
- The frequency range over which damage occurs depends upon the object being tested as well as its environment. For these reasons, the frequency range and interval for which the DCF will be computed must be user selectable. Table II gives the frequency ranges/intervals for which the CDF must be computed in order to provide the user with the

capability of selecting the combination which best meets his needs.

- This system must be capable of operating for the duration of a transport aircraft's mission. The duration of these missions can be as long as 20 hours, so the MFDM must be capable of operating for 20 hours. Because the length of test missions vary the user must be able to set the desired run time before the mission.

- The user must be able to interactively, from a computer terminal, configure the system as desired. The interactive aspects of the system must be very easy to understand since they may be used by people without a computer background. Thus, the user should be prompted for responses and must be able to respond with simple responses such as one letter or one numeral. If a wrong input is entered by the user an appropriate error message will be written at the terminal, and the prompt line repeated.

- The user must be able to enter a test date and a line of comments into the computer. This date and comment is to be printed in the heading of the CDF output table along with the total time the system processed data. This will provide the information needed for correlating the output tables with the test mission.

- There must be two modes of operation: one, an automatic mode where, upon application of system power, data processing starts automatically for the last, user set, system configuration; and a second manual mode by which the user can start data processing by giving a start command from a terminal. This will allow the system to be used automatically when on a plane, and manually when used in a laboratory.

- When data processing has been performed for the desired length of time, data processing will automatically stop. Program control will return to the user if operating in the manual mode and will halt if operating in the automatic mode. This will prevent the system from processing data after a mission is over, and will allow the user to control the length of time for which data is processed.

- When processing data, the CDF matrix must be updated as fast as possible. CDF update rate of once every 6 seconds is desired as this will provide at least five updates during a plane's 30-second take-off roll.

TABLE II

The Required Frequency Ranges and Intervals

Frequency Range (0 - MAXFREQ) (K Hz)	Interval (Hz)
0 - 6.0	100
0 - 3 0	100
0 - 3.0	50
0 - 3.0	25
0 - 1.5	100
0 - 1.5	50
0 - 1.5	25

- The dynamic range of the CDF matrix must be at least 360 db, which allows any two elements of the matrix to differ by 10^{18}. The reason for the large dynamic range is that if there is a large cumulative damage factor at one frequency its large magnitude will not cause smaller cumulative damage factors to be lost due to the finite word size of the computer.

- The system program and CDF matrix must be stored in a non-volatile memory so program execution can start automatically upon power-up, and system power can be turned off after the processing is complete, without the loss of the CDF matrix.

- When an automatic power-up occurs the CDF matrix will be cleared only if it is the first power-up since a manual power-up. This allows data to be acquired from multiple flights if a manual power-up is not performed between flights.

This completes the list of system requirements defined for this project. Two other system requirements exist but are not requirements for this phase of the project (Ref 10). They are: the system must be battery-powered, and it must be as small as possible. This will allow the system to be used in a small space where no power is available such as in the wing of an airplane. Engineers at AFFDL will design the case for the system as well as the battery pack required to power the

system when an operational bench model system has been produced and tested.

Summary

This chapter has defined the general system requirements. These requirements will now be used to design algorithms which will be used to implement the system. The design and implementation of the algorithm is the subject of the following chapters

III. Algorithm Design

Introduction

This chapter explains the design of the algorithms which were used to implement the system according to the requirements defined in Chapter II. These algorithms were developed using a combination of structured design techniques (Ref 9), resulting in a structure chart which describes the system. The structure chart and associated module interface table developed in this chapter, along with the discussion of the function of each module which make up the structure chart define the algorithm.

Algorithm Development

The algorithm for this system was developed in three steps. First, an algorithm was developed for the "data processing" function. Then one was developed for the interactive user "configuration" function, and finally the two algorithms were integrated into one "system" algorithm.

Data Processing Algorithm

The basic steps which must be performed to compute the cumulative damage factor are as follows (Ref 10):

> Obtain analog vibration and temperature signals from the item being tested and digitize the signals (subroutine EXECUTIVE).
>
> Compute the Fourier transform of the vibrational data for the frequency range and interval of interest (subroutine FFT).
>
> Compute the average power in each frequency interval (subroutine POWERSPECTRUM).

Compute the damage factor for each frequency interval (subroutine DAMAGEFACTOR).

Repeat these steps as long as desired, summing the damage factor into a cumulative damage matrix which contains the cumulative damage versus frequency and temperature.

These five steps are illustrated in Figure 4. The linear amplifiers shown in the figure are used to amplify the voltage signal of the sensors to a level required by the analog-to-digital converter.

In order to show the relationship between the modules discussed in the following paragraphs, a dataflow diagram and structure chart for the process just described is shown in Figures 5 and 6 respectively These two figures are constructed from data obtained from Ref 7 55-65 which discusses a basic system to compute the cumulative damage factor. The next step is to define the functions of each of the modules shown in Figure 6. The Fourier transform module (Ref 7 80-85), will be discussed first, followed by the power spectrum and damage factor modules. After completing this, the module interfaces will be discussed.

FFT. This module is responsible for the computation of the fast Fourier transform (FFT) of the digitized vibration data. It converts the data from a function of time to a function of frequency. Since the input data is a sampled version of a continuous time domain signal, a discrete Fourier transform method has to be used. Eq 3 gives an expression for the transform of N sampled points from the time domain to the frequency domain.

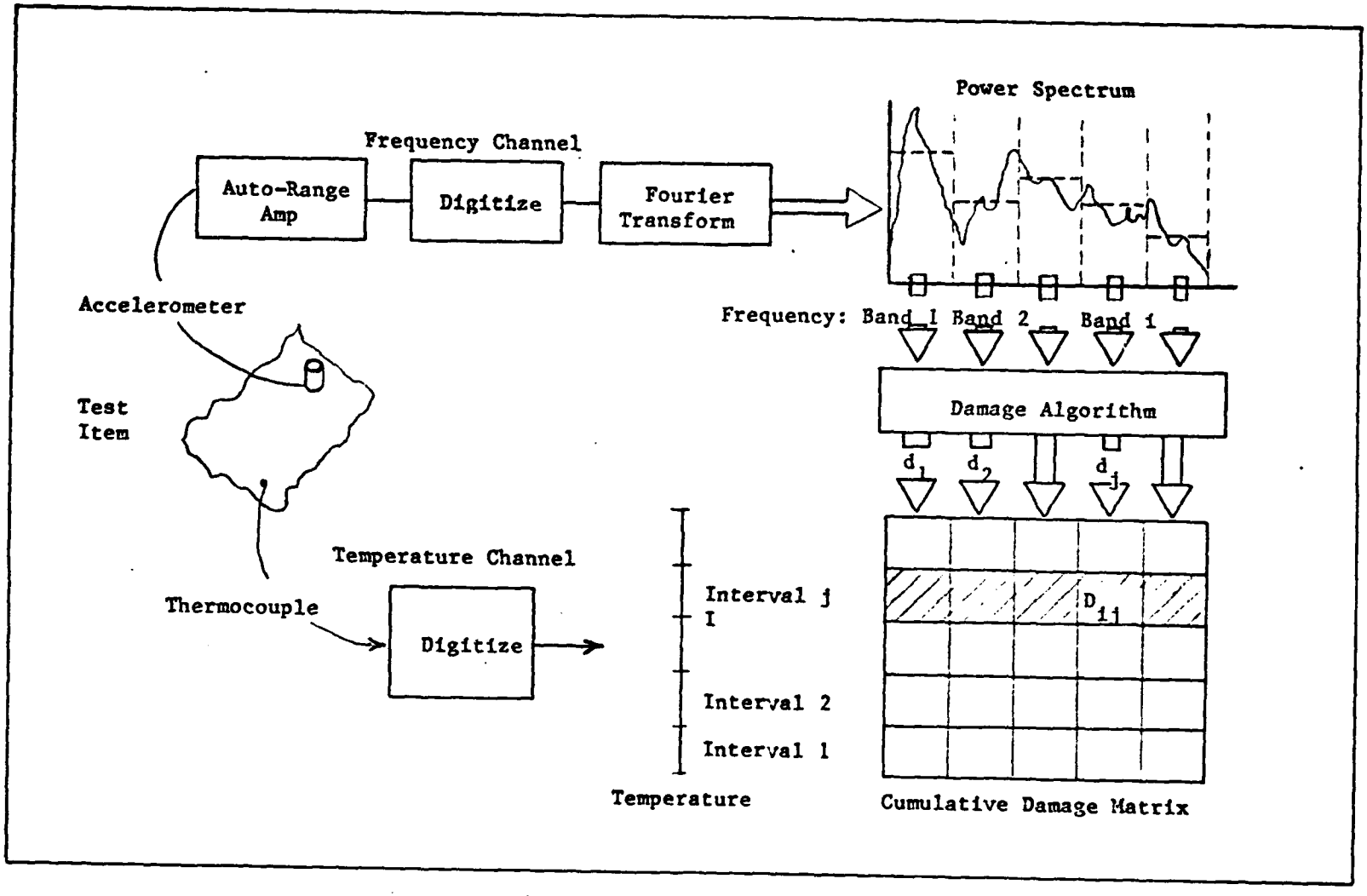


Fig 4. Steps In Computing The CDF

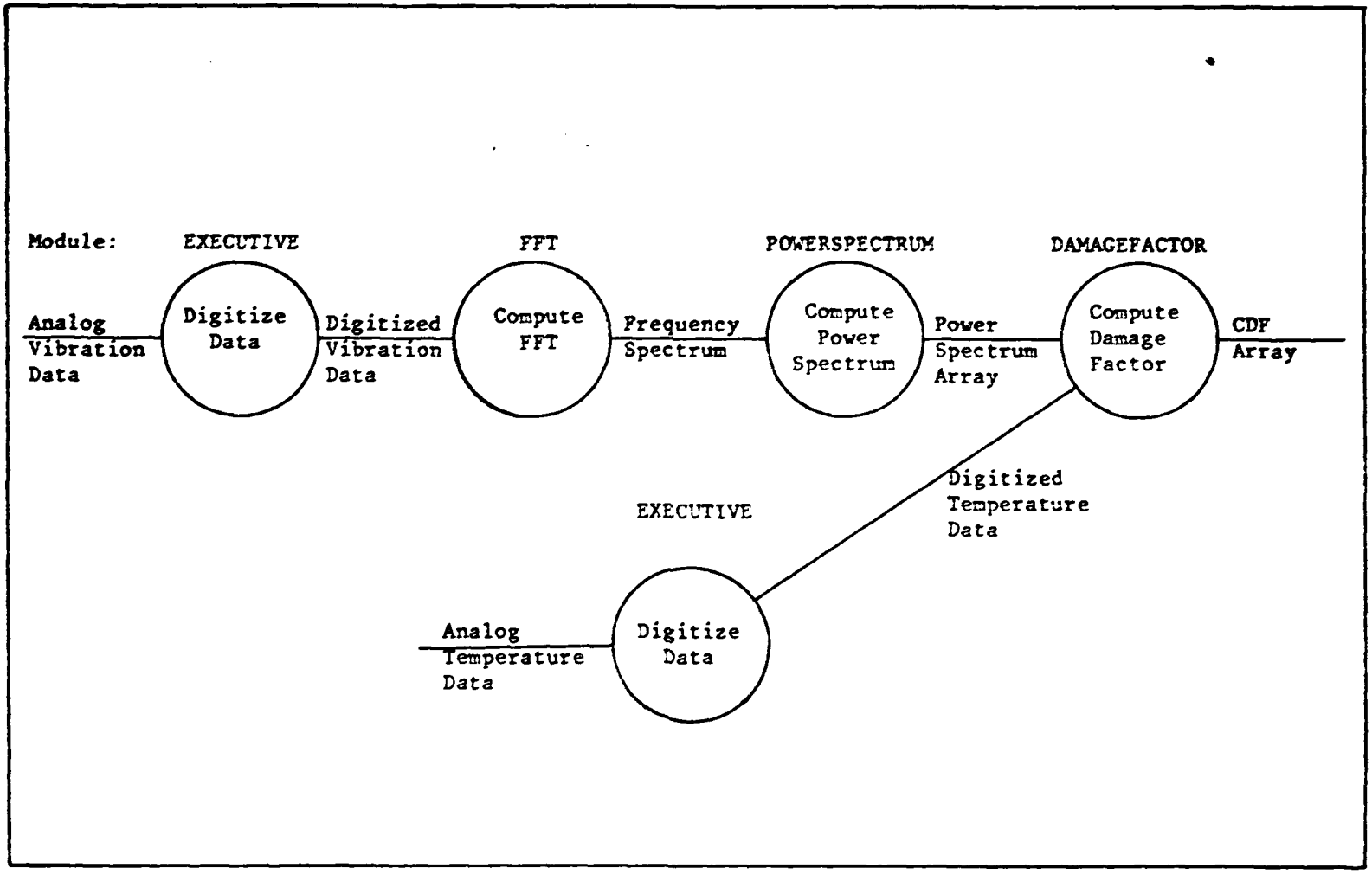


Fig 5. Data Flow Diagram for Data Processing

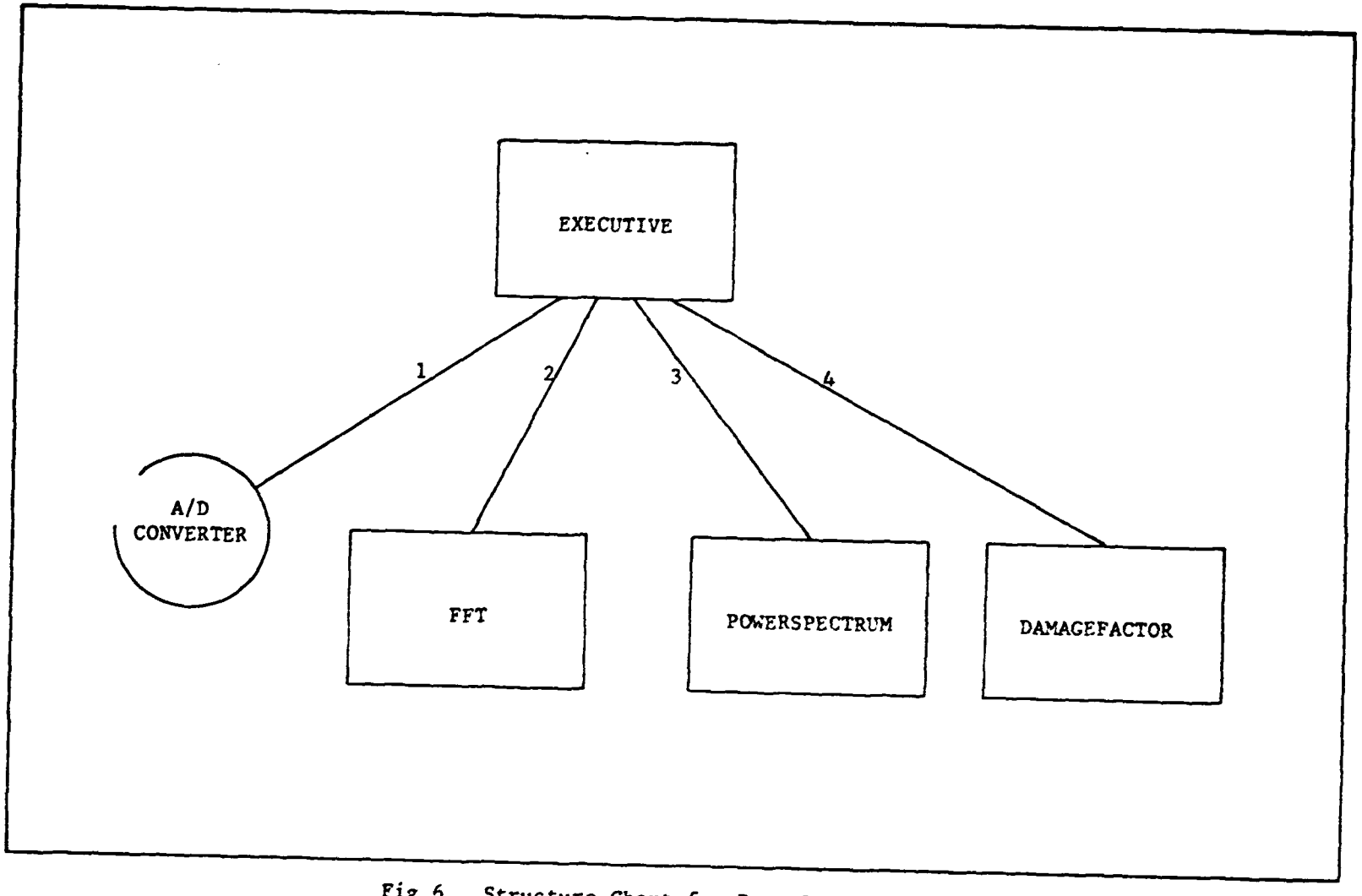


Fig 6. Structure Chart for Data Processing

Equation 3 is:

$$F(n) = \sum_{k=0}^{k=N-1} X(k)W^{nk} \quad , \qquad n = 0\ 1, 2, \quad N-1 \qquad (3)$$

where

$$W = \exp(-2\ i/N) \qquad (4)$$

F(n) is the nth point in the frequency domain, and X(k) is the kth point in the time domain. X(k) may be real or complex, but F(n) is always complex (Ref 7:70). Constraints on Eq 3 require that the frequency function be band limited at some frequency f_c, and in order to insure that no aliasing will occur in the frequency domain, the time domain function must be sampled at a rate at least twice f_c. The frequency $2f_c = 1/T$ is known as the Nyquist sampling rate, where T is the sampling interval (Ref 3:85). The number of sampled points (N) can be determined using Eq 5:

$$N\Delta f = 1/T = 2f_c \qquad (5)$$

where Δf is the desired frequency interval in the frequency domain and 1/T is the Nyquist sampling frequency (Ref 3:85-96).

Solving Eq 3 with a computer is a slow and time-consuming process as it requires on the order of N^2 complex multiplications and additions (Ref 4:316). To speed up this calculation, Cooley and Tukey developed a fast Fourier transform for N being an integer power of two. This reduced the order to Nx complex multiplications and

additions where x is the integer power of two, satisfying $N=2^x$ (Ref 3:174). Since X(k) in Eq 3 can be real or complex, it is possible to solve Eq 3 with N complex data points and have the N complex data points consist of a 2N point real data sequence (Ref 3:167). This reduces the order of complexity to Nx/2. Thus Eq 3 can be efficiently implemented on a computer for $N=2^x$ where x is an integer and the number of real data points is 2N. A complete explanation of this procedure can be found in Ref 3 148-238 and Ref 7 141-156. Table III shows the values of 2N and 1/T which satisfy these equations, using the requirements for the frequency range and interval defined in Chapter II. After completing the Fourier transform of the input data, the power within each frequency interval must be calculated.

POWERSPECTRUM. This module computes the power in each of the frequency intervals which make up the frequency spectrum. The frequency component F(n) resulting from the Fourier transform is a complex number which can be represented as given in Eq 6:

$$F(n) = X_n^2 + iY_n^2 \qquad ,n = 0,1,2,\ldots N-1 \qquad (6)$$

and the power within a frequency interval can be computed using Eq 7:

$$A(n) = (X_n^2) + (Y_n^2) \quad , \qquad n = 0,1,2. \cdot N-1 \qquad (7)$$

Because the input signal is random, Eq 7 represents an instantaneous power, and that which is needed is the average

Table III

Nyquist Sampling Rate for the Required Frequency Ranges

Frequency Range (0 - MAXFREQ K Hz)	Interval (Hz)	2N	Sampling Rate (1/T K Hz)
0 - 6.0	100	128	12.8
0 - 3.0	100	64	6.4
0 - 3.0	50	128	6.4
0 - 3.0	25	256	6.4
0 - 1.5	100	32	3.2
0 - 1.5	50	64	3.2
0 - 1.5	25	128	3.2

power (Ref 10). The average power ($\bar{A}$) can be approximated by taking the average of a set of P instantaneous power calculations (Ref 7:73). Mathematically, this can be expressed as:

$$\bar{A}(n) = 1/P \sum_{k=1}^{P-1} A_k(n) \quad , \qquad n = 0,1,2\ldots,N-1 \tag{8}$$

where the subscript k represents a unique set of N instantaneous power calculations. The average power computed using Eq 8 can be interpreted as the average (RMS) value of the acceleration at the center of the frequency interval, which is the frequency of F(n). After completing the power calculation, the damage factor can be calculated.

DAMAGEFACTOR. The damage factor (DF) can be computed using Eq 1, which is repeated here:

$$DF(f(n)) = K(\bar{A}(n))^{3.3}/f(n)^{5.4} \quad , \qquad n = 1,2,3,\ldots,N-1 \tag{1}$$

where k is a constant for all frequency f(n) and B in Eq 1 was replaced with its value of 3.3. Since the damage factor is a relative

quantity (Ref 10), and the K factor is in all n damage factor computations it can be factored out as in Eq 9.

$$DF(n) \propto \bar{A}^{3.3}/f(n)^{5.4} \qquad n = 1\ 2,3,\ldots.N-1 \qquad (9)$$

The cumulative damage factor (CDF) is then the sum of the damage factors calculated using Eq 9, for a period of time T. This is expressed mathematically as:

$$CDF(f(n)\ T) = \sum_{t} DF_{t}(f(n)) \quad , \qquad n = 1.2,3,\ldots.N-1 \qquad (10)$$

where t is the rate at which the DF (f) is to be calculated, and T is the temperature interval at which the damage occurred.

This completes the discussion of the data processing modules. The remaining module, EXECUTIVE is the module which controls the data processing.

EXECUTIVE. The function of this module is to acquire the 2N vibration data points and the temperature data, and coordinate the computation of the cumulative damage factor. The first time this module is called, it must clear the cumulative damage matrix before the data processing can begin. In addition, it must monitor the system time, and stop data processing when the users set run time has expired.

Modules' Interfaces. The next step in developing the algorithm is to establish the interfaces between the modules. Table IV lists the

Table IV

Interfaces for Data Processing Modules

INPUT	OUTPUT
----	ADDATA, TEMP
ADDATA	FFTDATA
FFTDATA	PWRDATA
PWRDATA, TEMP	CDFMATRIX

input and output interfaces corresponding to the numbered lines in Figure 6. The executive module must acquire the 2N data points (ADDATA) and pass them to the FFT module which returns the transformed data points as N complex frequency points (FFTDATA). These complex frequency points are then passed to the power spectrum module which computes the power in each interval of the frequency spectrum. The N real power values are then returned in the array PWRDATA. The damage factor module uses PWRDATA to compute the damage factor which is then summed into the cumulative damage factor matrix (CDFMATRIX). The cumulative damage matrix is the final product and it has a maximum size of 12 N elements, where the 12 is the number of temperature intervals required (Ref Chap II).

This completes the design of the data processing algorithm required to satisfy the requirements defined in Chapter II. The next section will discuss the design of the "configuration" algorithm which satisfies the interactive requirements defined in Chapter II.

Configuration Algorithm

A "configuration" algorithm was developed which meets the interactive requirements defined in Chapter II. This initializes the

number of data points (N) which the data processing algorithm requires and also initializes the rate at which the analog vibration signal is to be sampled. The requirements defined in Chapter II specify that the user be able to interactively do the following: configure the system to process data for a specified frequency range interval, and time period; initiate data processing; and have the CDF matrix printed. The requirements for an "interactive system" also specify that the system be easy to operate by someone without any computer experience, that the the user be prompted for a response, and that the user's response consist of a single letter or numeral.

Because of these requirements, it was decided to design an interactive system similar to that used in the UCSD Pascal operating system (Ref 12). This interactive system was chosen because the author felt it was the best systm he had used and it meets the requirements of the system. The user is prompted with the allowable responses in the following form: the first letter of the response, a left parenthesis, and the remainder of the word. If one of the possible functions was to setup the system for a new configuration, one of the prompts would be "S(ETUP". If this was the desired function, the user would enter an "S" followed by a carriage return ("<CR>"). Thus, by reading the prompt lines and entering the first letter of his choice, the user can control which function is executed. If an illegal response is made, an error message is printed at the user's terminal and the prompt line is repeated, allowing the user to enter a legal response. A structure chart of the algorithm designed to meet these requirements is shown in Figure 7, and a discussion of the functions of each of the modules which make up the structure chart follows.

MFDM. The Microprocessor Flight Damage Monitor controlling module is the MFDM. This is the module which is executed first when the system is started in the "manual" mode. This module will prompt the user to input the function which he desires to be executed. The user will respond by entering the first letter of the desired function - either S(ETUP, E(XECUTE, O(UTPUT, or Q(UIT. Depending on the input value, one of the subordinate modules SETUP, XECUTE, or CDFOUTPUT will be called, unless the input is a "Q" which will stop program execution.

If an illegal entry is made, the error module will be called to print out an error message and then return control to the beginning of the module. After the called subordinate module completes execution, program control will pass back to MFDM.

SETUP. The functions which the SETUP module must perform are defined by the system requirements. The user must be able to select a specific frequency range and frequency interval, enter the run time for which data is to be processor, and enter a date and a line of comments which are to be printed in the header of the CDF table. In order to make this algorithm easier to modify should future requirements warrant it, this module was designed to be an interactive module. It first prints the last used system configuration and then prompts the user to enter the name of the function he desires to change. Then program control passes to that module. If an illegal entry is made, the error module will be called to print out an error message and then return control to the beginning of the module. By using this method of design, future modifications should only require the adding, deleting, or changing of small special purpose modules to make changes to the

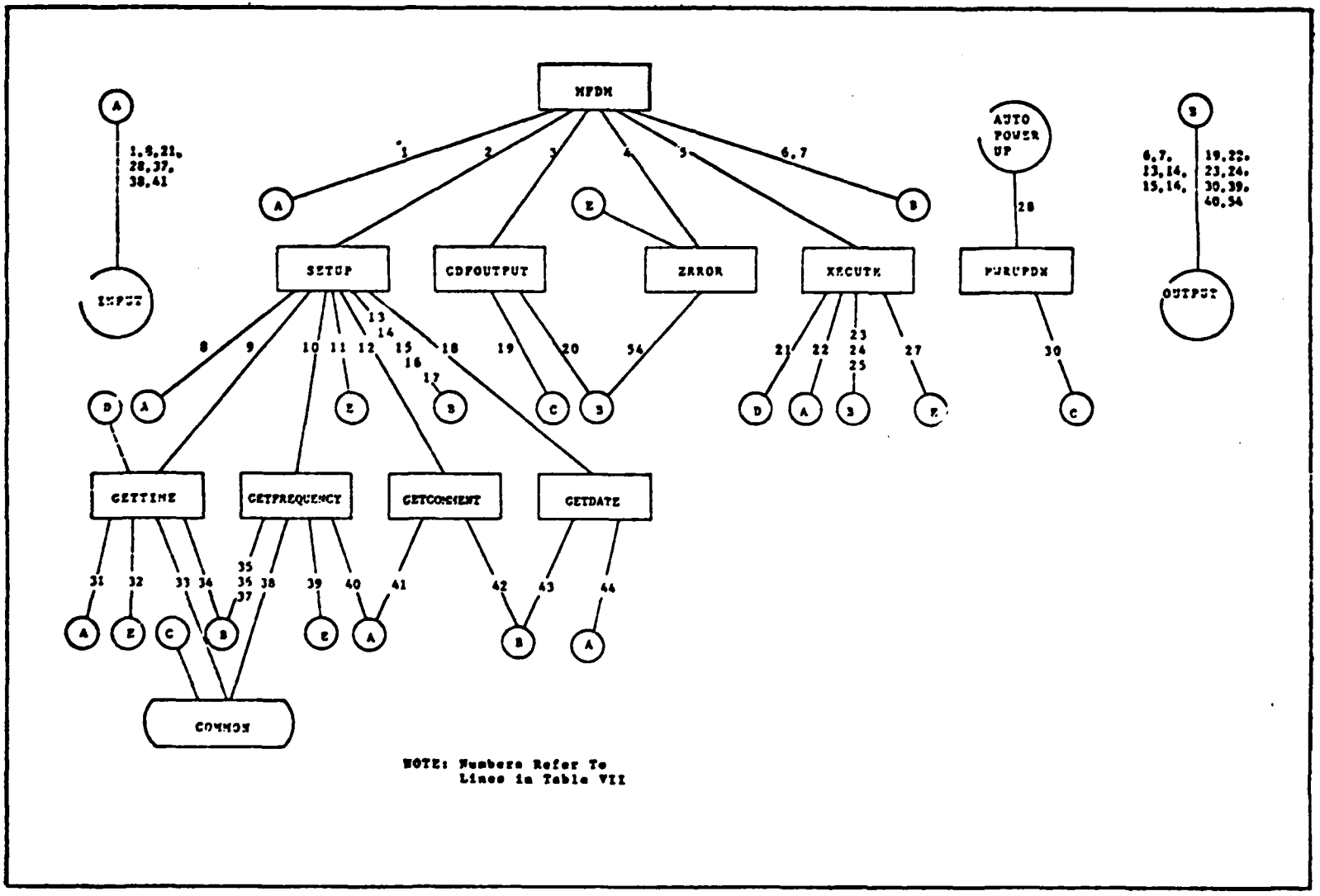


Fig 7. Structure Chart for Configuration Modules

functions performed by SETUP.

GETDATE and GETCOMMENT. These two modules read the data/comment from the terminal as the user inputs it. The date can be up to 13 characters long, and the comments up to 40 characters long. No error checking is performed since whatever is input will be printed in the CDF output table heading in the same format as it was input. If the input is longer than the 13 or 40 characters allowed, the input string will be truncated to the first 13 or 40 characters.

GETFREQUENCY. If the frequency range/interval is to be changed, this module is called. It will first print a list of possible frequency range/interval combinations as shown in Table II. Then it will prompt the user to enter the combination which is desired. As in previous modules, if an illegal response is made the ERROR module will be called with an error message. After control returns from the error module, the list of possible combinations will be printed at the terminal followed by a repeat of the prompt for the user's response.

When a valid response is received, this module will initialize the global variables used in other routines, according to the selected configuration. The variables which must be initialized are: the number of data points to be sampled (N), the frequency interval (INTERVAL), the number of frequency intervals (NFREQ), and the data sampling rate (CLKRATE). After initializing these variables control is returned to the SETUP module where other changes can be requested by the user.

GETTIME. This module procedure will be used if the duration of the test is to be changed. It will accept as input the planned length of the test, in hours, and check that the time is greater than zero. If an illegal input is received, procedure ERROR will be called with an

appropriate error message followed by a request to enter a new time. After receiving a valid time, the variable "DURATION" will contain the run time in hours. This completes the discussion of the modules called by SETUP except for the error module which will be discussed next

ERROR. This module will be called by any module which receives an invalid input from the user. The error message to be printed will be passed, as an argument, to this module. The word "ERROR" will be concatenated to the beginning of the error message, and the message will be printed at the user's terminal. After printing the message, program control returns to the calling module.

XECUTE. This module is called when the user wants to start program execution from the terminal. This module will check the run time, and if it is positive, a message indicating the start of data processing will be printed at the user's terminal. Program control will then pass to the EXECUTIVE module in the "process data" algorithm. If the run time is less than or equal to zero, the TIME module will be called so that the user can enter the desired run time. After completion of data processing, program control will return to this module. A message indicating termination of data processing will then be printed at the user's terminal, and program control will return to MFDM.

The last module which can be called by MFDM is the CDFOUTPUT module which prints out the CDF matrix.

CDFOUTPUT. This module prints the CDF matrix at a printer connected to the system. The CDF will be printed in tabular form as a function of frequency and temperature. Each page of the table will

contain a heading which will include the user-supplied date and comments in addition to the time in which data was actually processed. After printing the CDF matrix, program control will return to MFDM.

This completes the development of the "configuration" algorithm, except for the definition of the interfaces which will be done when the two algorithms are combined into one system algorithm.

System Algorithm

The system algorithm is the combination of the two algorithms just developed. A structure chart for the system algorithm is shown in Figure 8. The module interfaces are given in Table VII, which is shown in Chapter V. The only requirement that the two separate algorithms do not satisfy is that of the "automatic start-up" mode. The PWRUPDN module fulfills this requirement.

PWRUPDN. This mode of operation requires a non-volatile memory for both the data and the program. When system power is applied, program control will then pass to the beginning of the EXECUTIVE module where the CDF array is cleared. If the power is removed and then reapplied, the power-up sequence will have to check the run time to see if it is still less than the pre-set run time. If so, program control will have to pass to the EXECUTIVE module at a point after the CDF array has been cleared so data processing can continue. If the run time has expired, the program execution will halt.

Having an automatic power-up module implies that something should be done in case of a power loss. This module is designed so that all the power-down module has to do is execute a halt command. Data processing will automatically restart when power is restored.

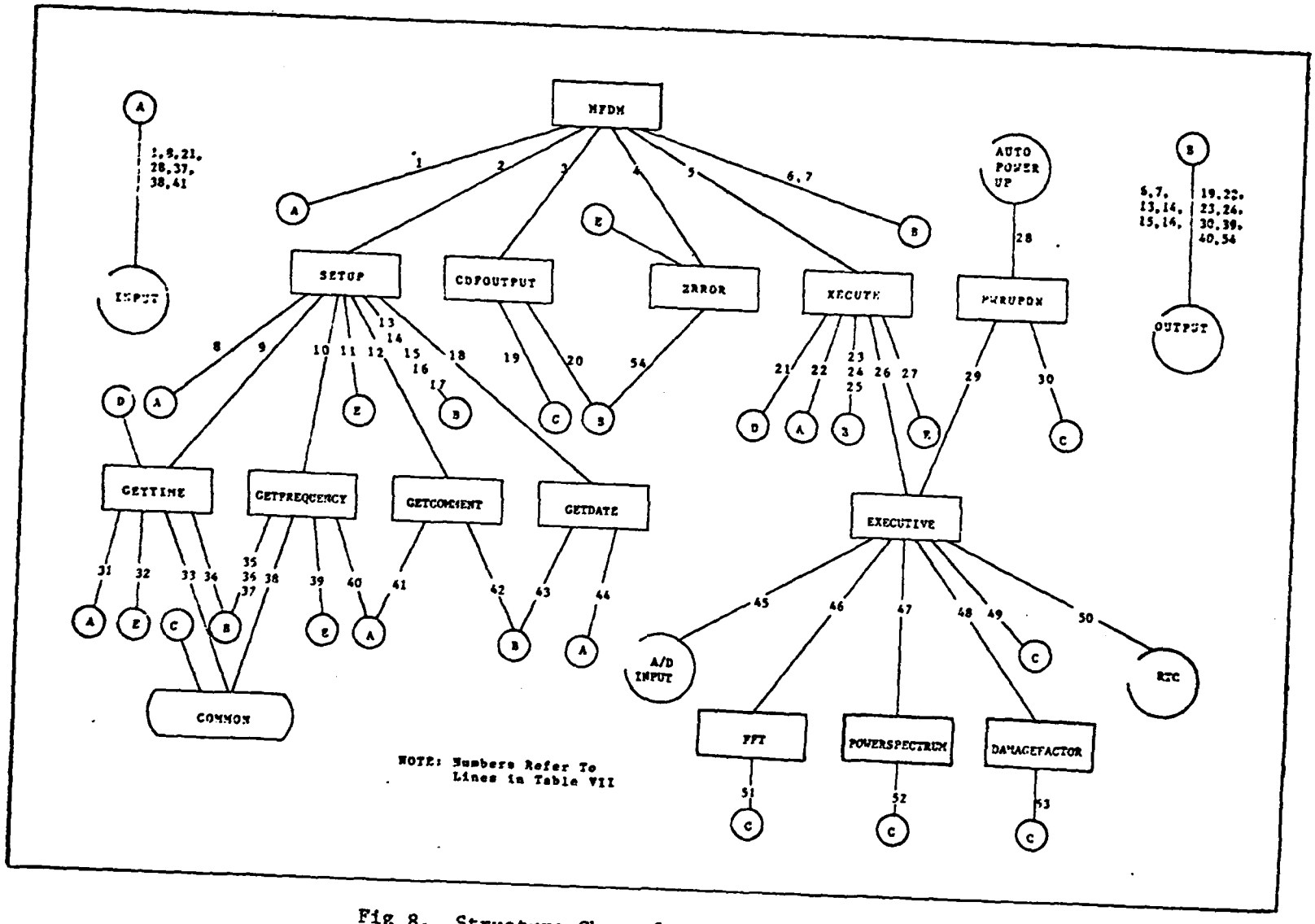


Fig 8. Structure Chart for the MFDM System

Summary

This chapter discussed the design of the algorithm which when implemented, will fulfill the requirements established in Chapter II. The algorithm was designed with specalized modules, each having one function. This design method allows future modifications to be made to a module without having to modify the entire system. The interactive aspect was designed to prompt the user for single letter or numeral responses thus making it easier to operate by someone inexperienced in its operation. The LSI-11 which was previously selected as the "best" computer to use for this effort (Ref 7:25) will be presented, with this algorithm in mind, in the next chapter.

IV. Hardware Considerations

Introduction

The algorithm discussed in Chapter III describes the system in detail, but does not discuss its implementation. This chapter presents the decisions that were made concerning the implementation of the system. The decisions made previous to this investigation (Ref 7:23-35) are discussed in the light of the new system requirements.

LSI-11 Microcomputer System

The LSI-11M Microcomputer manufactured by Norden Systems, Inc. was previously selected as the best computer for this system because of its word size I/O capability, instruction set, memory capability, and availability of software development tools (Ref 7:24).

Norden's LSI-11M is identical, in its functions to the LSI-11 produced by Digital Electronics Corporation (DEC), but uses a different backplane, thus making it incompatible with standard DEC systems. Therefore, a special backplane and card cage would have to be constructed in order to use the Norden LSI-11M with DEC's analog converter and real-time clock that were selected for the MFDM (Ref 7:29-34). Although the Norden LSI- 11 is a more durable module (Ref 7:25), DEC's modules are designed to operate in "Minimally Controlled Environmental Conditions" (Ref 6 20) such as the environment in which the MFDM will be operating. Therefore, the LSI-11 was acquired and used for the development of this system. The LSI-11 Microcomputer is capable of handling the additional requirements by using different options than initially determined (Ref 7·25-35).

KD11-J Processor Module. The KD11-F processor module was originally selected for the system, but is not adequate for the real-time processing of data at the higher frequency range of interest (6 K Hz). This is because the KD11-F processor module has a 4 K by 16 bit semiconductor RAM within the module. This memory requires the on-board memory refresh to be enabled which results in an execution stoppage for up to 130 micro-seconds during a memory refresh cycle (Ref 8·76). This delay time, when combined with a 40 micro-second data acquisition service routine, results in an execution delay of up to 170 micro-seconds. This is then the minimum interval between real-time events for which it can be insured that no real-time event will be lost. Thus, the maximum sampling frequency would be 5.8 KHz (1/170 micro-seconds).

The KD11-J processor module does not have the on-board memory, so the 130 micro-second delay does not exist because the on-board memory refresh capability is disabled. This reduces the e minimun interval for real-time events to the time required by the data acquisition service routine or the time required for the analog-to-digital converter to digitize a data point, whichever is greater.

The KD11 series processors can all satisfy the power-up auto-start and the manual start as specified by the system requirements (Ref Chap II). These processors have three power-up modes (Ref 8:237). Mode 0, which will be used for this system, allows program execution to start at the address contained in location 24 if the RUN/HALT switch is in the RUN position when power is applied. Otherwise, when power is applied the system is in the halt mode and the user can manually enter the required starting address to start program execution.

Thus, the KD11-J processor module meets the requirements defined in Chapter II, although the system must include a separate memory for the program and data.

MRV11 UV-PROM. The requirement that the system be able to start processing data upon application of system power means that the program must be stored in a non-volatile memory such as core memory or programmable read-only memory (PROM). The contents of core memory can accidentally be changed, thus the use of core memory to store the program would not be the best solution. A UV-PROM memory is a read-only memory which makes it difficult to change the program accidentally. The program can be executed directly from a PROM module even though data cannot be stored in the PROM memory. Therefore, the best memory configuration to use is PROM to hold the program, and core memory to hold the data arrays.

A DEC MRV-11 module, which contains up to 4 K words of UV-PROM and 256 words of RAM is available for the LSI-11 (Ref 8:254). Three of these modules (10 K words) will be required to store the complete program. An advantage of UV-PROM is that if modifications to the system are required, the PROM can be re-programmed with the modifications. With the program in PROM, the data arrays and system variables have to be contained in a non-volatile read/write memory such as the MMV-11 Core Memory.

MMV11-A Core Memory. A non-volatile memory is required to store the data array so that it is available to the user after the test run has been performed. The MMV-11 4 K by 16 bit core memory meets the requirements of the system (Ref 7:29). The number of core memory

modules required is determined by the size of the CDF array. The maximum size of the CDF array is 1440 elements ((60000 Hz/50Hz)x12 temperature intervals), and the requirement that any two elements in the array can differ by as much as 10 (Ref Chap II) requires that two words (floating point numbers) be used to hold each element in the array (Ref 8:560). This requires 2880 words of core memoy to hold the CDF array. Thus, one 4 K core memory module is adequate.

ADV11-A Analog-to-Digital Converter. The A-to-D converter must be capable of processing analog data at a rate equal to or greater than the Nyquist sampling frequency. For a frequency range of 0-6 K Hz the analog signal must be sampled at a rate of at least 12 K Hz, which is the minimum sampling rate for the analog-to-digital converter.

In order to obtain data at a specific frequency interval, the sampling rate must be controllable so as to satisfy equation 5. The ADV11-A (Analog-to-Digital Converter) and KWV11-A (Programmable Real-Time Clock) are the only modules made for the LSI-11 computer which allow the sampling rate to be controlled so as to obtain the required frequency intervals.

The ADV11-A is capable of a 21.5 K Hz sampling rate (Ref 2:23) which exceeds the 12 K Hz sampling rate required for this system. The ADV11-A converter can be controlled by the program or by an external event. In order to control the real-time data acquisition, the conversions can be controlled by the KWV11-A programmable real-time clock.

KWV11-A Programmable Real-Time Clock. This option is available for the LSI-11 and can be used to control the analog-to-digital conversions. It can be operated in any one of four programmable modes: single interval, repeated interval, external event timing, and external event timing from zero base (Ref 2:3-1).

This application requires that it be used in mode 1 - repeated interval with the interval being set by the program. The analog-to-digital converter with the programmable real-time clock will handle the data acquisition under program control. The remaining system hardware that is required is the hardware to interface the system to the user.

DLV11-J Serial Line Interface. The DLV11-J is the interface for serial line devices such as the terminal and printer, and the LSI-11 bus. There are four independent serial interfaces on the module, and each channel can independently be configured for the following: baud rate (150-38400), number of data bits - 7 or 8, number of stop bits - 1 or 2, and parity - even or odd. Therefore, this module is capable of interfacing with the user's terminal and printer.

DDV11-B Backplane. The DDV11-B is used to hold and electrically connect the different modules. It is used with the H0341 card cage which supports the modules. The backplane will accept the KD11-J processor, core memory, and up to 11 option modules (Ref 8:50). This backplane/card cage combination will hold all of the required modules for the system in one cage, thus making it a portable, self-contained system. The size of the backplane with card cage is 17.1 inches long, 4.8 inches high and 8.7 inches deep (Ref 8:51).

This completes the description of the required LSI-11 hardware. Digital Equipment Corporation recently introduced two new versions of

the LSI-11 - the LSI-11/2, and LSI-11/23 (Ref 5:55) - either of which could be used for the MFDM system. These two processors are half the width of the LSI-11 but are double the thickness (Ref 5:55-56). As of December 1979, DEC is not yet making a correspondingly smaller analog-to-digital converter, real time clock, or core memory so there is no size gain by using these newer processors. However, the LSI-11/23 is four times faster (Ref 5:57) than the LSI-11 which would increase the cumulative damage matrix update rate if future requirements need a faster rate.

In addition to the microcomputer hardware required, some hardware is needed to acquire the analog signals. This hardware consists of two sensors and associated linear amplifiers which are discussed next.

IBV11-A LSI-11/Instrument Bus Interface. This module is used to allow the computer to control the auto-ranging gain of the vibration signal amplifier. It provides the means of inhibiting the auto-ranging gain, and reading the gain setting of the amplifier before the frequency signal is sampled. Due to a lack of time, this module was never integrated into the bench model system.

KPV11-B Power Fail/Line Time Clock/Terminator. This module controls the power-up and power-down sequences and has provisions for an external clock and a remote console capability (Ref 8:339). With a DC power supply, no line clock will be available. Thus, the external clock input can be used as an input for the system clock. The remote console capability provides the necessary switching controls to allow the system to start up in either the automatic mode or manual mode. Although the module is designed for an AC input, the rectifier circuit

can be bypassed to allow operation with DC power.

Analog Sensors

In order to gather the required data, two analog sensors are required - one thermocouple and one accelerometer. The AFFDL laboratory supplied the sensors and associated amplifiers for this project. The thermocouple was made from type K thermocouple wire and the accelerometer was a Vibra Metrics VM-112 integrated accelerometer (Ref 13). The accelerometer had a "built in" electronic pre-amplifier allowing its signals to be transmitted over long cables of conventional 2-wire, or coaxial construction, with no loss in sensitivity or spurious cable noise (Ref 13). The output of each sensor goes into an amplifier which amplifies the signal to a level which can be digitized by the analog-to-digital converter.

The amplifiers supplied with the sensors were Intech Model A2583 wide band data amplifiers (Ref 1:1). The gain of the amplifiers can be set either automatically or manually to any one of eight internally programmed gain ranges. The gain setting of the amplifier can be determined by either an analog voltage output or a BCD output, and the auto ranging can be inhibited under program control (Ref 1:1). The thermocouple was connected to one amplifier with the gain set to +60 db. The accelerometer was connected to another amplifier which used a 10 position thumb wheel switch to determine the gain setting. Figure 9 shows the output of the thermocouple amplifier for the temperature range of interest, and Table V shows the gain of the accelerometer amplifier for the 10 possible thumb wheel settings. Table VI shows the specifications for the Intech amplifiers (Ref 1:6).

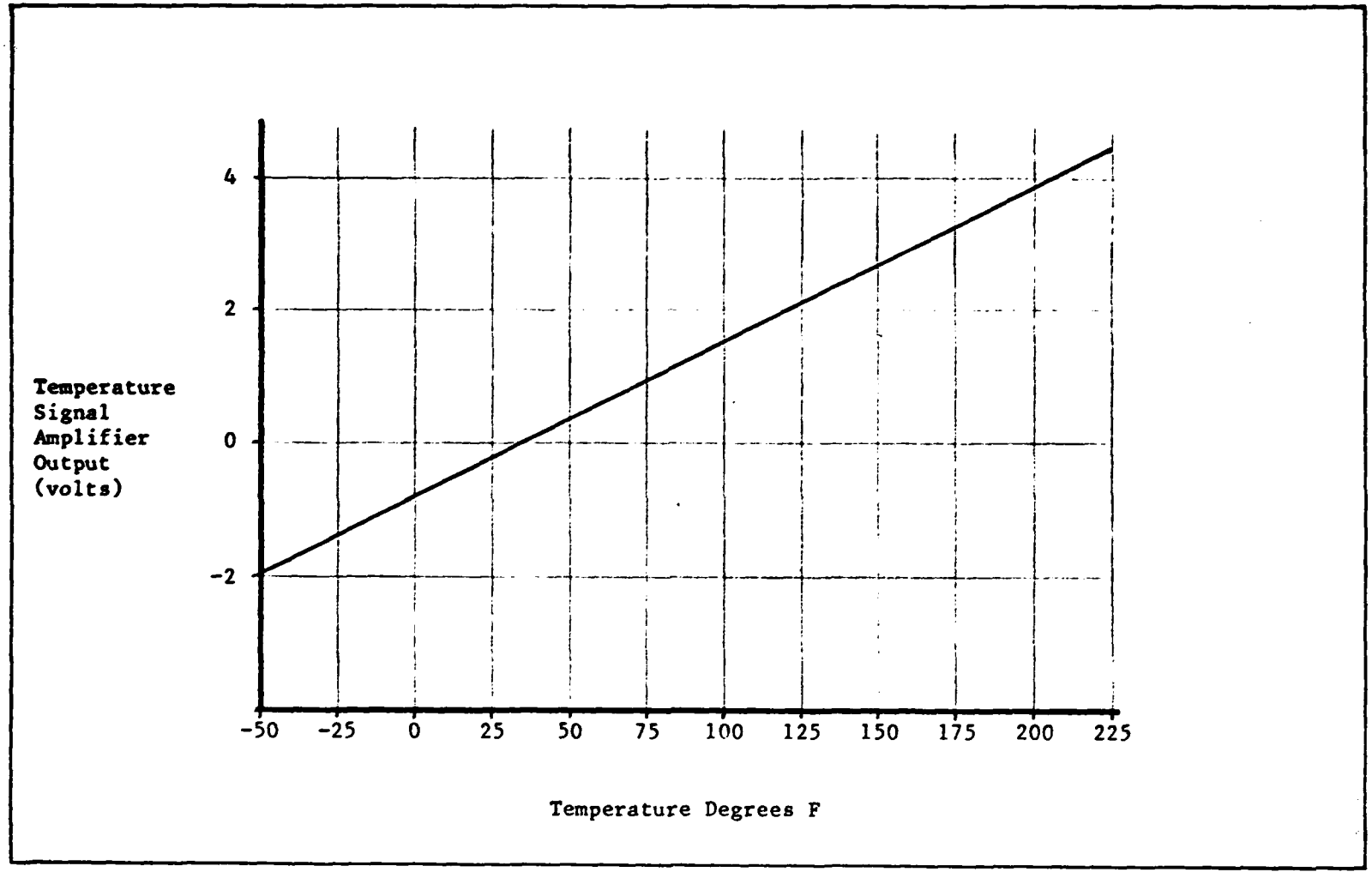


Fig 9. Temperature Signal Versus Temperature

TABLE V

Gain Settings For Frequency Amplifier

Switch Setting	Gain (db)	Digital Gain Code	Analog Gain Code
0	-10	111	-2.40
1	0	110	-1.70
2	10	101	-1.00
3	20	100	-0.35
4	30	011	0.35
5	40	010	1.00
6	50	001	1.70
7	60	000	2.40
8	Auto-		
9	Ranging		

TABLE VI

SPECIFICATIONS

A2583 Automatic Gain Ranging Amplifier

Functions	Range		Units
	Min	Max	
Gain Range (10db steps)	-10.0	+60.0	db
Vernier Gain/step	-6 5	+3.5	db/step
Gain Accuracy	0.1		db
Gain Stability	0.1		db
Gain change threshold			
Down (adjustable)	0.5	2.0	V RMS
UP (adjustable)	10 0	20.0	db below down
Temperature Range	-25 0	+85.0	C
Power Supply Voltage	14.0	16.0	VDC
Current		60.0	ma

The design also requires two hardware modules which are not commercially produced for the LSI-11 system. The modules are: a DC power supply and a system clock. The DC power supply will be designed and built by the AFFDL at Wright-Patterson AFB (Ref 11), and is not covered in this report.

System Clock

The system clock must produce a TTL level compatible square wave with a one-second period. This signal will be the external clock input to the KPV11-B module. This module will produce an external interrupt which will drive a software system clock. A clock chip such as the National Semiconductor MM5316 Digital Alarm Clock can be used to generate the 1 second pulse and will also provide a digital readout of the system time if it is desired.

Summary

This section has described the hardware available for the MFDM. The hardware previously selected (Ref 7:23-35) was re-considered in light of the new system requirements. The KD11-F and DLV11 are the only previously selected modules which do not meet the new requirements. The KD11-F processor module has an on-board memory which requires the use of on-board memory refresh and, therefore, could not acquire the data at 12 K Hz as required to obtain the desired frequency range. Thus, the KD11-J processor module was selected. It is the same as the KD11-F processor except there is no on-board memory, and therefore the on-board memory refresh is not required. The DLV11 module is a single port serial interface module. In order to use a terminal and printer, two modules would be required; thus, a DLV11-J

four-port serial interface module was selected. This module can be used for both the printer and the terminal.

Two additional modules, not previously considered, are also required. The first one is an MRV11 UV-PROM (Ref 8:137) which is used to store the program, and the second one is an IBV11 LSI-11/Instrument Bus Interface (Ref 8:180) which is used to control the auto-ranging gain of the vibration signal amplifier. These additional modules, along with the modules previously selected, establish the hardware requirements for the MFDM. The next chapter uses this information in designing the software to implement the system algorithm.

V. Software Design

Introduction

The next step in the development of the MFDM is to design an algorithm for each of the software modules. In this chapter, the possible program languages available to implement the algorithm are discussed, and a decision is made as to which programming language is the best to use. Each of the required software modules is then developed, insuring that each module will interface properly with the other modules.

Programming Languages

The language in which a module is coded affects the complexity of the program, execution speed, and the ease with which the module can be maintained. The programming languages which were available on the LSI-11 development system were RT-11 assembly language, RT-11 FORTRAN, and UCSD Pascal. The Pascal operating system required 24 K words of memory to operate (Ref 12:iii), and the development system only had 20 K words of memory which could be used without memory refresh when executing the program (Ref Chap IV). Therefore, the Pascal operating system could not be used when executing the program. In addition, no debugging routine was included in the Pascal operating system. Without such a routine, program debugging would be very difficult. Because of these two restrictions, it was decided not to use Pascal to develop the software.

Generally, a structured FORTRAN program is easier to understand than a structured assembly language program which performs the same

task. A FORTRAN program, being easier to understand, will generally be easier to maintain during its life; and therefore, it will have a lower life cycle cost. The disadvantage of a FORTRAN program as compared to an assembly language program is that the execution time is generally longer. Therefore it was decided to code the modules which require the most computational time or which require real-time data processing in assembly language, while the other modules were coded in FORTRAN. It was decided to code the EXECUTIVE and FOURIER modules in assembly language because EXECUTIVE controls the real-time data aquisition and FOURIER, which computes a fast Fourier transform, requires the greatest percentage of execution time (Ref 7:115). The remaining modules were all coded in FORTRAN for ease in future maintenance.

The system algorithm was constructed using top-down structured design, which was considered by the author to be the best design methodology available. The process started with the development of a module which controlled the entire process. This module was then expanded into subordinate modules, each of which performed one major function. These subordinate modules were then expanded into subordinate modules if the major function could be reduced to a series of independent functions. The result of this type of design was a structured system where each module accomplished a specific function, and the coupling between modules was minimized. A structure chart for the complete system is shown in Figure 10, and the module interfaces are shown in Table VII. The following paragraphs describe each of the modules which make up the system in detail, and appendices A and B contain flow charts and the source code for each of the modules.

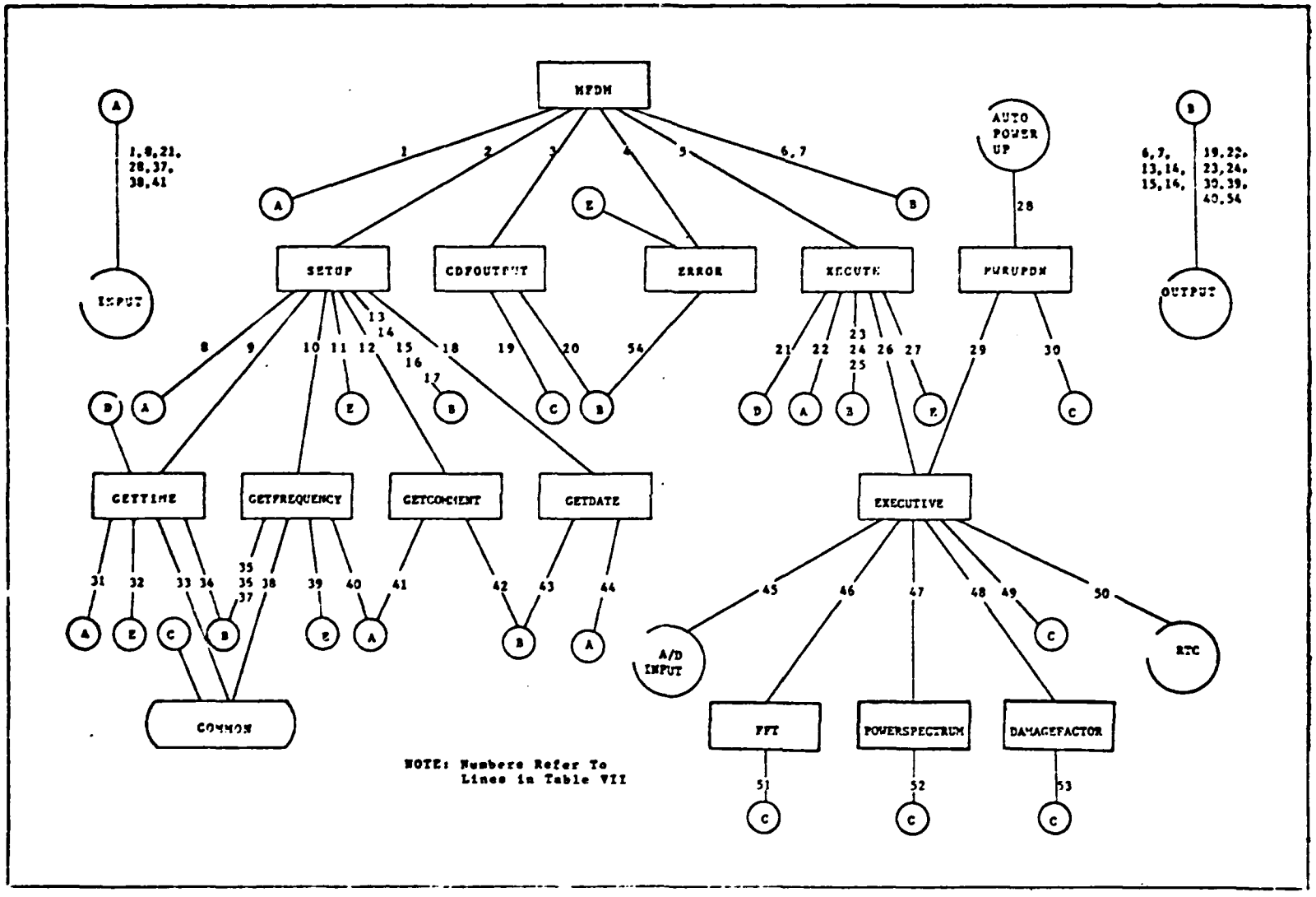


Fig 10. Structure Chart for the MFDM System

TABLE VII

Arguments of the MFDM Modules

	INPUT	OUTPUT
1.		ANSWER
2.	COMMENTS, DATE, DELTAF, DURATION	COMMENTS, DATE, DELTAF, DURATION
3.	CDF, NFREQ, DELTAF, DATE, COMMENTS	
4.	'ENTRY MUST BE AN S, E, O, OR Q REENTER LETTER <CR>'	
5.	MINUTES	MINUTES
6.	'MICROPROCESSOR FLIGHT DAMAGE MONITOR'	
7.	'ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - ?<CR>'	
8.		ANSWER
9.		DURATION
10.		DELTAF
11.	'THE INPUT MUST BE AN F, R, D, C, Q, OR V'	
12.		COMMENTS
13.	'THE DURATION WILL BE', DURATION	
14.	'THE COMMENTS ARE', COMMENTS	
15.	'THE DATE IS', DATE	
16.	'THE FREQUENCY RANGE IS -', NFREQ*DELTAF, 'Hz; DELTAF IS', DELTAF, 'Hz'	
17.	'CHANGE F(REQ, R(UN DURATION, D(ATE, C(OMMENTS, Q(UIT, OR V(ERIFY - ?<CR>'	
18.		DATE
19.		
20.	CDF OUTPUT TABLE	RTIME

TABLE VII

Arguments of the MFDM Modules (cont.)

	INPUT	OUTPUT
21.		DURATION
22.		ANSWER
23.	'THE DURATION IS', DURATION, 'HOURS'	
24.	'DATA BEING PROCESSED'	
25.	'DATA PROCESSING COMPLETE'	
26.		
27.	'INPUT MUST BE A Y OR AN N'	
28.		
29.		
30.	PWRFLG	PWRFLG, PTIME, RTIME
31.		DURATION
32.	'DURATION MUST BE IN HOURS AND > 0	
33.	MINUTES	
34.	'ENTER DURATION OF TEST (HOURS) EXAMPLE 15.25 <CR>	
35.	'FREQ RANGE (K Hz) DELTAF ENTER'	
36.	'0 - 6.0 100 1	
	0 - 6.0 50 2	
	0 - 3.0 100 3	
	0 - 3.0 50 4	
	0 - 3.0 25 5	
	0 - 1.5 100 6	
	0 - 1.5 50 7	
	0 - 1.5 25 8	

TABLE VII

Arguments of the MFDM Modules (cont.)

	INPUT	OUTPUT
37.	'ENTER THE NUMBER CORRESPONDING TO THE DESIRED COMBINATION ENTER AN INTEGER BETWEEN 1 AND 7 ?<CR>'	
38.	B, INDX, INTVL, DELTA	
39.	'INPUT MUST BE AN INTEGER BETWEEN 1 AND 7'	
40.		ENTRY
41.		COMMENTS
42.	'ENTER COMMENTS - 40 CHARACTERS MAX <CR>	
43.	'ENTER THE NEW DATE EXAMPLE - 14 - DEC - 79 <CR>	
44.		DATE
45.	7240, 22401	ADDATA
46.		
47.		
48.	ADDATA, ADGAIN, BITCOUNT, CDFDATA, COUNT, INDEX, INTCELNUM, N, N2, NINTVL, NM, PTIME, PWRSPC, RTIME	ADDATA, B, N, PTIME, RTCMODE, RTCRATE, RTIME, TFLG
49.		
50.	RTCMODE, RTCRATE	
51.	ADDATA, SFACTR	ADDATA, BITCOUNT, COUNT, INDX, ITVL, INTCELNUM, N, N2, SFACTR
52.	PWRSPC	ADDATA, ADGAIN, SFACTR
53.	CDFDATA	PWRSPC,CDFDATA
54.	'ERROR', MESSAGE	

Configuration Modules

The configuration modules are the modules which initialize the parameters used by the data processing modules. These modules are interactive modules which allow the user to configure the system for a particular test. In order to make the configuration process easy for the user to accomplish, the modules were designed to display the system's current configuration and then prompt the user to input the first letter of the function to be executed. Thus, by using prompting messages, the system instructs the user what to do to configure the system. The following sections discuss the design of the modules which are used to configure the system to process data according to the requirements of the user.

MFDM. Program MFDM is the controlling module for the entire system. It is an interactive module which is initally executed when the system is started in the manual mode. It prints the program's name at the user's terminal and then requests that the user enter the first letter of the function to be performed. The format of these two lines is as follows:

"MICROPROCESSOR FLIGHT DAMAGE MONITOR"

"ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - <CR>"

where <CR> means the user's response followed by a carriage return. If a "Q" is entered by the user, program execution halts. If an "S", "E", or "O" is entered, the appropriate subordinate module is executed. If an illegal entry is made, the system's ERROR module is called with an error message (Table VII, line 4) being passed to it. After the subordinate module completes execution, control is passed back to MFDM.

The modules which are subordinate to MFDM are discussed next.

SETUP. Subroutine SETUP is called when the user wants to configure the system before a test. The module first displays the last used system configuration and asks what is to be changed. If the last configuration was 0-3 K Hz and 25 Hz the following lines would be printed at the user's terminal:

FREQUENCY RANGE:	0-3000 Hz
FREQUENCY INTERVAL:	25 Hz
RUN DURATION:	(Last Time) Hours
COMMENTS:	(Last Comments)
DATE:	(Last Date)

CHANGE F(REQ, R(UN DUR, C(OMMENTS, D(ATE, Q(UIT, or V(ERIFY - ?<CR>

The user's input is then read and, based upon validity, the corresponding module is called. An "F" input calls the GETFREQUENCY module, an "R" calls GETTIME, a "D" calls GETDATE, and a "C" calls GETCOMMENT. The arguments passed to the subordinate modules are shown in Table VII lines 8-18. If a "Q" is entered, program control returns to MFDM; if a "V" is entered, the current system configuration is printed at the terminal. If an invalid input is made, the error module is called - passing the error message shown in Table VII line 11. After the error message is printed, the current system configuration is printed at the terminal, followed by the prompt line requesting another input.

GETFREQUENCY. Subroutine GETFREQUENCY is called by SETUP when the frequency range and/or interval is to be changed. This subroutine prints the possible configuration at the terminal and requests which configuration is desired. This is accomplished by printing the

following lines:

FREQ. RANGE (K Hz)	DELTAF (Hz)	ENTER
0 - 6.0	100	1
0 - 6.0	50	2
0 - 3.0	100	3
0 - 3.0	50	4
0 - 3.0	25	5
0 - 1.5	100	6
0 - 1.5	50	7
0 - 1.5	25	8

ENTER A NUMBER BETWEEN 1 & 8 CORRESPONDING TO THE DESIRED SETUP ?<CR>

An integer is then read from the terminal and used in an arithmetic go-to statement which passes control to an appropriate initialization section corresponding to the desired configuration. If the first character entered is not an integer between 1 and 8, program control falls through the go-to statement, and the error routine is called with the message shown in Table VII line 39. After this, the configuration table is re-printed at the terminal and the user is prompted to enter an integer. When a valid entry is read, control passes to the corresponding label where the following variables are initialized:

COMMON	LOCAL	DEFINITION
B	EXP	The power of 2 which gives the number of data (N) points to be acquired (N=2**EXP) - used in EXECUTIVE.
INDX	INDEX	An integer index used with the sine-look-up table in the subroutine FFT. It is initialized to the offset required for the look-up table.

INTVL	INTERVAL	The number of frequency intervals in the selected frequency range (INTERVAL=MAXFREQ/DELTAF + 1). It is used in the DAMAGEFACTOR and CDFOUTPUT subroutine.
	DELTAF	The frequency interval for which the CDF is to be computed. It is used in the CDFOUTPUT subroutine.
	MAXFREQ	The maximum frequency for which the CDF is to be computed. It is used in the CDFOUTPUT subroutine.
RTCMODE	CLKMODE	CLKMODE is a local variable initialized with a data statement to 11 (base 10). This value sets the real-time clock to 1 MHz (Ref x7:3-12). It is used in EXECUTIVE.
RTCRATE	CLKRATE	A variable which controls the frequency with which the A/D converter samples the vibration signal. The CLKMODE (initialized to 1 MHz with a data statement in this routine) divided by the CLKRATE determines the sampling rate.It is used in EXECUTIVE.

After initializing these variables, thus re-configuring the system, program control returns to MFDM.

GETTIME. Subroutine GETTIME is called when the user wants to change the length of time for which the system is to process data. The arguments passed to and from this routine are shown in Table VII line 9. The argument "MINUTES" is a local variable corresponding to the "PTIME" (Planned Time) common block. "PTIME" is the global assembly language variable used in the assembly language routine EXEC. Thus, when the value of "MINUTES" is changed, the global variable is also changed.

This routine first prompts the user to enter the desired run duration, in hours, by printing the following line at the terminal:

"ENTER DURATION OF TEST (HOURS) EXAMPLE 15.25 <CR>

The user then enters the desired run duration and it is stored in the variable "DURATION". This value is tested, and if it is zero or less, the error module is called, passing to it the error message shown in Table VII line 32, and a new time is requested. When a positive time is entered it is multiplied by 60 to form the number of minutes the test will run, which is stored in the global variable PTIME. Program control then goes back to the calling module, returning the new DURATION.

GETDATE. Subroutine GETDATE is called when the user desires to change the test date. The purpose of the test date is to allow the user to have the date of the test printed in the heading of the CDF table.

This subroutine prompts the user to enter the desired date with the following message:

ENTER THE NEW DATE Ex. 14-DEC-79 <CR>

The user then responds by entering the date - which can be up to 13 characters long. The date is stored in the array DATE (13) of type BYTE. No error checking is performed, and if the user enters more than 13 characters, the input is truncated after 13 characters.

GETCOMMENT. Subroutine GETCOMMENT is the same as subroutine GETDATE except that an array COMMENTS (40) is first cleared before it is loaded with the user's supplied comments. As with GETDATE, the only purpose of the COMMENTS is to allow the user to have identifying comments printed in the heading of the CDF table. The user is prompted with the following line:

ENTER COMMENTS - 40 CHARACTERS MAX <CR>

and the user then enters up to 40 characters. If more than 40 characters are entered, the input string is truncated to the first 40 characters.

ERROR. Subroutine ERROR is called by MFDM, SETUP, GETFREQUENCY, GETTIME, and XECUTE when an illegal input is entered. The argument passed to this routine consists of an error message up to 40 characters long and in single quotation marks, printed at the user's terminal. ERROR concatenates "ERROR" to the beginning of the message, prints it at the terminal, and returns program control to the calling module. If a message sent to this routine contains more than 40 characters, the message is truncated to the first 40 characters.

CDFOUTPUT. This subroutine is called when the cumulative damage matrix is to be printed. It is designed to operate with a Heathkit H14 printer, and uses its software selectable font size feature to control the size of the print. The table heading is printed at 10 characters per inch, while the table entries are printed at 12 characters per inch. The table is printed as two sections + the first for a temperature range from -50 to 100 degrees Fahrenheit, and the s second for a 75 to 225 degree Fahrenheit range. The 75 and 100 degree temperature intervals were repeated on both sections to make interpolation in this temperature range easier.

In addition, each section consists of up to six pages, depending on the frequency range and interval selected, with 41 lines per page. This allows one page of the table to be printed on an 8 1/2 by 11

inch piece of paper. The table heading is printed on the top of every page and consists of:

CUMULATIVE DAMAGE MATRIX PAGE (page)

DATE - test date
DURATION - test duration
COMMENTS - user's comments

Following the table heading, one page of the table is printed. An example of the output is shown in Table IX, and is explained in Chapter VII.

The variables used in this routine are defined as follows:

CDF (120,12)	The cumulative damage factor array
CONTENTS (40)	A string for any comments the user wants on the output
DATE (13)	A string to hold the date which will be printed on the output
DELTAF	The frequency between elements of the CDF array
FREQPAGE	The frequency range per page of output
I,J,K,L	General purpose indexes
LARGE	A three character alpha constant which, when sent to the printer, causes 80 characters per line to be printed
LOW, HIGH	Two indexing limits used to control the printing of the temperature scale. Their values are: LOW=1=50 deg F; HIGH=7=100 deg F LOW=6=75 deg F; HIGH=12=225 deg F
HIGHFREQ	Index limits to control the printing of the frequency in the table

LOWTEMP, HIGHTEMP	Index limits to control the printing of the temperature in the table
LTSYM	The symbol to the left of the first temperature in the table heading. It is either a space or a < (less than)
MAXFREQ	The maximum frequency in the CDF array
NFREQ	The number of frequency components in the CDF array
NPAGE	The number of pages required to print the table for one temperature range
RMINUTES	The actual duration of the test run
RTSYM	The symbol printed to the left of the last temperature on the table heading. It is either a space or a > (greater than)

After printing the complete table program control returns to the MFDM module, where, if the user desires another copy of the output table can be obtained by entering another "0".

This completes the discussion of the configuration modules. The next section discusses the execution modules.

Execution Modules

The requirements defined in Chapter II state that there be two methods to initiate data processing. One method required that the user be capable of starting data processing from a terminal, and the second method required that data processing commence with the application of power to the system. The XECUTE module is used to initiate data processing from a terminal. The PWRUPDN module is used to initiate data processing when power is applied if the processor's RUN/HALT

switch is in the run position (Ref Chap IV). An explanation of the two modules follows:

XECUTE. Subroutine XECUTE is an interactive module for user-controlled data processing. The variables used in this subroutine are defined below:

Global variable:

PTIME	A label common block with length of one word used to store the planned time (in minutes) for which data processing is to take place.

Local variables:

ANSWER	A variable which contains the user's response. It should contain be either a "Y" or an "N". Anything else results in an error.
MINUTES	A local variable equal to PTIME
DURATION	The planned processing time in hours.

When called by MFDM, this procedure first checks that PTIME is greater than zero. If it isn't, GETTIME is called to get a new run time. The new run time is then printed at the terminal followed by a prompt asking if it needs to be changed. The user's input is then read, and if it is an "N" (NO), then the following message is printed at the terminal:

"DATA BEING PROCESSED"

and program control passes to the EXECUTIVE module where data processing is initiated. If a "Y" (YES) is entered, then GETTIME is called so a new time can be entered. Afer the new time is entered,

program control returns to this module and the new time is printed at the terminal. The user is then asked if it needs to be changed. This second printing of the time is to provide a "last chance" recovery capability in case a wrong time is entered. When the user responds with a "Y" or an "N", the process is repeated. If anything other than a "Y" or an "N" is entered, the error module is called with the error message given in Table VII line 27. After data processing is complete, control returns to this module and a "DATA PROCESSING COMPLETE" message is printed at the terminal. Program control then returns to MFDM.

PWRUPDN. Subroutine PWRUPDN controls the start of data processing when the system starts in the "automatic mode". When the processor's RUN/HALT switch is in the "RUN" position and power is applied to the system, this routine is entered via the interrupt vector at location 24.

The global variables/labels which are used in this subroutine are defined below:

GLOBAL VARIABLES/LABELS	DEFINITION
BEGIN	The label of the second instruction in subroutine EXEC. If power fails and comes up in the middle of data processing, control returns to this point.
EXEC	The label of the first instruction in subroutine EXEC. Initial data processing starts at this location.
PTIME	A global variable containing the planned duration of the test.
PWRFLG	A global variable used to indicate if it is the first power-up or not.
PTIME	A global variable used to store the total time the system has been processing data.

This routine first sets location 24 to the address of the power-down sequence (PWRDN) in case of a power failure, and then checks to see if it is the first power-up sequence. If it is, PWRFLG is set equal to one, and program control passes to subroutine EXECUTIVE. If it is not (PWRFLG = 1), then PTIME and RTIME are compared. If RTIME is greater than or equal to PTIME, program execution halts. Otherwise, program control jumps to label "BEGIN" in EXECUTIVE.

After the first power-up sequence, location 24 contains the address of the power-down (PWRDN) sequence. When power fails, the power-down sequence loads location 35 with the address of the power-up sequence (PWRUP) and executes a halt instruction. This allows for multiple power up/down sequences during the data processing period.

Data Processing Modules

The modules discussed in this section - EXECUTIVE, FFT, POWERSPECRUM, and DAMAGEFACTOR - are the data acquisition and processing modules. The functions which these modules must perform are: acquiring and digitizing the analog vibration and temperature signals, computing the fast Fourier transform of the vibration signal producing the frequency spectrum which the test item is "seeing", computing the power in each of the frequency intervals which make up the frequency spectrum, computing the damage factor for each frequecy interval, and summing the damage factors into a cumulative damage matrix. The FFT module was taken from the previous work on this system (Ref 7:75-85) and modified to meet the additional requirements of this system (Ref Chap II). Two modules, POWERSPECTRUM and DAMAGEFACTOR, were written in FORTRAN so as to make future modifications easier - should

they be required - while EXECUTIVE was written in assembly language for speed of execution for the data acquisition. The design of the four modules will now be explained.

EXECUTIVE. The subroutine EXECUTIVE is the controlling module for the data processing. When called from XECUTE, or the first time called from PWRUPDN, a macro-setup routine (INITAL) is called to clear the power spectrum array (PWRSPEC) used in POWERSPEC, clear the CDF array (DATA) used in DAMAGEFACTOR, and to initialize the global variables used in the data processing modules. INITAL uses the global variable B to initialize the following macro-global variables:

BITCOUNT	A counter used in the FFT module's "bit inversion routine". It is initialized to half the number of binary bits required to write the value of N.
COUNT	A counter used in FFT and initialized to half the number of "complex" data points.
INTCELNUM	An initial value for the local variable "CELNUM" which is used in FFT's "2nd PASS AND ONWARD" routine.
N	The number of real data points to be processed. It is used in EXECUTIVE and FFT and is equal to the value 2N discussed in Chapter III. (A macro variable cannot begin with a number).
N2	The number of "complex" data points. It is equal to N/2 and is used in FFT, POWERSPECTRUM, DAMAGEFACTOR.
NM	An index used in FFT's "POST PROCESSING" routine. It is initialized to the relative location of the N-1st "complex" data point.
PWRFLG	A flag set by PWRUPDN upon the first system power up in the auto-start mode. It is initialized to zero.
RTIME	A variable used in EXECUTIVE to hold the actual time data has been processed. It is initialized to zero.

TIME	A variable used in the EXECUTIVE's time interrupt routine. It is used as a "60's" counter to count 60 seconds. It is initialized to zero.
TSUM	A variable used in EXECUTIVE to hold the sum of ten temperature values, which is used to set the global variable TFLG. It is initialized to zero.

In addition to initializing these variables, INITAL also loads the time and power interrupt vectors with their proper values. The next function of EXECUTIVE is to control the acquisition of the temperature data.

The temperature data is acquired using channel 05 of the analog-to-digital converter. This is accomplished by writing 2401 (octal) into the analog-to-digital (A/D) command-status register (ADCSR). This selects channel 05 as the temperature channel and starts the A/D conversion. After the conversion is completed, the 4000 (octal) bias is subtracted, and the converted data is summed into the variable TSUM, which is used to determine the temperature interval in which to store the damage factor. After acquiring the temperature data, EXECUTIVE must control the acquisition of the vibration data. The amplifier used to amplify the vibration signal has an auto-ranging feature which adjusts the gain of the amplifier depending on the magnitude of the vibration signal. Before any vibration data can be digitized, the auto-ranging feature must be disabled - freezing it at one gain for the sampling period - and then enabling it after the sampling period.

This ability to inhibit the auto-ranging gain has not yet been implemented, due to a lack of time. It will require the use of the IBV11-A LSI-11 Instrument Bus Interface module. First, a logical "0" will have to be written to a bit in the instrument bus data register,

which is connected to the inhibit line of the vibration signal amplifier. This will inhibit the auto-ranging feature of the amplifier, allowing one set of data points to be acquired at the same gain setting.

After inhibiting the auto-ranging gain, the BCD gain setting can be read from the instrument bus data register and converted into an integer gain multiplication factor. The multiplication factor is stored as the variable "ADGAIN" which is used in the POWERSPECTRUM module. After acquiring one set of data points, the auto-ranging feature must be released by writing a logical "1" to the inhibit line. This will allow the gain of the amplifier to vary with the intensity of the input signal until the next data set is required.

Since this function has not yet been implemented in EXECUTIVE, the ADGAIN has been set to 1 in EXECUTIVE. After obtaining the multiplication factor, EXECUTIVE loads the ADCSR with 7040 (octal), which selects channel 16 as the channel to be used for the vibration signal, and disables A/D interrupts. The real-time clock (RTC) is then initialized as required by the GETFREQUENCY module and "N" vibration data samples are acquired and stored in the array (ADDATA) under program wait. The reason for using program wait rather than interrupt-driven data acquisition is that there is a 44 micro-second delay after an interrupt is requested before the first interrupt service routine instruction is executed (Ref 8:B-5), during which time nothing is done. This, combined with a 40 micro-second service routine (the length of the routine used in EXECUTIVE), would mean the fastest sampling rate would be 11.9 K Hz which is not fast enough (Ref Chap

III). With program wait, the maximum sampling rate (22.2 K Hz) is determined by the execution time of the service routine (approximately 45 micro-seconds), or the analog-to-digital conversion time (37 micro-seconds), whichever is longer. After the sampling of "N" data points, the real-time clock is stopped and the damage factor is computed.

EXECUTIVE then calls FFT followed by POWERSPECTRUM. The sequence - sample data, call FFT, call POWERSPECTRUM - is repeated ten times in order to compute an average power spectrum (Ref Chap III). After this, the value in TSUM is compared to a series of pre-set values which correspond to the temperature intervals. These values, located at label TINTVL, are obtained by taking ten times the theoretical digitized temperature signal for the temperature intervals of interest. After each comparison where TSUM was greater than the value in TINTVL, TFLG is incremented by one. Thus, TFLG will take on a value between 1 and 12 corresponding to the average temperature of the test item. The DAMAGE module is then called to compute the cumulative damage factor and update the CDF array. After this, the variables TFLG, TSUM, and the power spectrum array PWRSPC are cleared, the run time is checked and if RTIME (actual run-time) does not equal PTIME (planned run-time) the procedure is repeated. When RTIME equals PTIME, program control is passed back to the module which called EXECUTIVE - either XECUTE or PWRUPDN.

FFT. This module was taken from the previous work performed on a cumulative damage acquisition system (Ref 7:75-85) and modified to allow for different values of "N" as defined in the EXECUTIVE section just discussed. Reference 7 should be consulted to obtain the theory and the actual equations implemented in this routine. This section

will cover the modifications that were made to the module to meet the requirements defined in Chapter II.

Originally, the module was designed to compute a fast Fourier transform (FFT) of 32 data points. In the present system, an FFT of 32,64,128, or 256 data points may be required. To accomplish this, constants which were originally initialization constants were changed to variables initialized by GETFREQUENCY and by INITAL in EXECUTIVE. These global variables are: INDX - initialized by GETFREQUENCY; and BITCOUNT, COUNT, INTCELNUM, N, N2, and NM - initialized by INITAL in EXECUTIVE. Each of the variables is defined in the EXECUTIVE or GETFREQUENCY section of this chapter, and Table VIII shows the values to which these variables are initialized.

The largest modification necessary was the modification of the sine-cosine look-up table which is used in the "2nd pass and onward" routine and in the "post processing" routine. The "2nd pass and onward" routine requires the sine and cosine values of (2 * PHI * K)/N2 for K = 0,1,2,...,(N 2/2) - 1, and the "post processing" routine requires the sine and cosine values of (2 * PHI * K)/N for K = 0,1,2,..., (N/2) - 1. One look-up table was constructed containing the sine and cosine values of (PHI * K)/128 for K = 0,1,2,...,127 - which contains all of the required values for N = 32,64,128,256. The appropriate value can then be extracted from the table by adjusting the arguments passed to the look-up routine according to N. This adjustment is accomplished with the global constant INDX. The exact details of how this is done can be found in the source code and in Reference 7.

TABLE VIII

Initialized Constants Used in FFT

N	N2	COUNT	INTCELNUM	NM	INDX	BITCOUNT
256	128	64	32	508	2	7
128	64	32	16	236	4	6
64	32	16	8	124	8	5
32	16	8	4	60	16	4

This modification, along with the variables initialized by the other modules, allows the FFT module to function with values of N = 32,64,128, or 256. Thus, the FFT module meets the requirements defined in Chapter II in addition to allowing frequency ranges/intervals of 0-10 K Hz at 100 Hz, 0-6 K Hz at 50 Hz, and 0-3 K Hz at 25 Hz (N=256) which, if desired, can be implemented in the future. The output of FFT, the frequency spectrum of the vibrational signal, is stored as complex fixed-point values in the input array ADDATA. The binary point is located between bits 14 and 15, and the scale factor for the array is stored in "SFACTR". After completing the FFT, program control is passed back to EXECUTIVE which then calls POWERSPECTRUM to compute the power spectrum.

POWERSPECTRUM. After the FFT of the input data is calculated, the instantaneous power spectrum for each frequency interval in the FFT spectrum must be computed, except for the zero frequency interval. The power spectrum for the zero frequency interval is not computed because it is undefined (computation would involve division by zero). The computed instantaneous power spectrum is then summed into the array PWRSPEC. The FFT and instantaneous power spectrum calculations are

repeated for ten vibration data sets, thus forming ten times the average power spectrum in the global array PWRSPEC (Ref 7:73.85).

This module was coded in FORTRAN because of the ease of coding and future modification. A FORTRAN macro was used to convert the fixed point frequency spectrum values to floating point values. The macro assumes the fixed point value is an integer, converts it to a floating point number, and multiplies it by the scale factor and the amplifier's gain. The macro is encoded as follows:

$$\text{FPDATA(I)} = \text{DATA(I)} \times 2^{(\text{scale})} \times \text{GAIN} \quad , \tag{11}$$

where DATA(I) is the fixed point value (treated as an integer), SCALE is the scale factor from the FFT module, and GAIN is the gain of the amplifier ADGAIN which is determined in EXECUTIVE. The square of the instantaneous power spectrum is computed by squaring the real and complex floating point values of the frequency spectrum values and adding them together. This value is then summed into the local power spectrum array - PWRSPECTRUM (global array PWRSPC). This is represented mathematically by Eq 12:

$$\text{POWERSPECTRUM(I)} = \text{POWERSPECTRUM(I)} + (\text{FPDATA(K)})^2 + (\text{FPDATA(K+1)})^2 \quad ,$$
$$\text{I} = 1\ 2,3,\ldots\text{NFREQ}, \quad \text{K} = 3,5,7,\ldots \tag{12}$$

where FPDATA(K) and FPDATA(K+1) are the real and imaginery values of the complex frequency spectrum data, and Imax is the maximum number of frequency intervals in the desired frequency range.

The output of this module is the sum of the squares of the instantaneous power spectrums. After ten summations the array PWRSPECTRUM contains ten times the square of the power spectrum - which is the data passed to the damage module.

DAMAGEFACTOR. This module computes the damage factor for each frequency interval, of interest, in the FFT spectrum and sums the values into a cumulative damage matrix. The input arguments to this module are the power spectrum array from POWERSPECTRUM and the temperature flag TFLG from EXECUTIVE. Since the power spectrum array actually contains ten times the square of the average of the power spectrum, Eq 1 is re-written as:

$$\text{DAMAGEFACTOR}(n) = (K(\bar{A}'(n))^{3.3})/f(n)^{5.4} \qquad n = 1,2,3,\ldots \text{NFREQ} \qquad (13)$$

$$\text{where} \quad \bar{A}'(n) = (\text{POWRESPECTRUM}(n))^{0.5}/10 \quad , \qquad (14)$$

$n \neq 0$ because DAMAGEFACTOR(0) is undefined, and NFREQ is the maximum number of frequency intervals in the frequency range of interest. Since K is a constant for all n, and the damage factor is a relative value it can be left out. Re-writing Eq 14 without the "K" term and substituting for A'(n) yields:

$$DF(n) = (\text{PWRSPEC}(n)^{1.65})/f(n)^{5.4}, \quad n = 1,2,3,\ldots,\text{NFREQ} \qquad (15)$$

where the $10^{3.3}$ term was left out because it is also a constant for all n. Eq 15 was coded as a FORTRAN macro DAMAGE (n,f(n)) and was used to sum the damage factor into the CDF matrix. Using a local variable

TEMP as the global variable TFLG the equation for the CDF matrix is:

$$CDF(n,TEMP) = CDF(n,TEMP) + DF(n) \quad , \qquad n = 1,2,3,\ldots,NFREQ \qquad (16)$$

Eqs 15 and 16 were implemented, and the resulting cumulative damage matrix is an nmax by 12 array. The FFT routine is coded for a maximum nmax of 120 (6000 Hz range with a frequency interval of 50 Hz), which means the largest CDF array is 120 by 12, or 1440 elements, which requires 2880 16 bit words. In order to operate with values of N between 32 and 256, the CDF array was defined as CDF (120,12). For values of N less than 256, only part of the array is used.

Summary

A top-down structured design was used to design each of the software modules needed to implement this system. The structure chart, shown in Figure 10, and the module interface table shown in Table VII, describe the system as a whole while appendices A and B contain the flow charts and source code for each of the modules. The next step in implementing the system is the individual testing of the software modules, followed by the assembly and testing of the complete system.

VI. Testing and Experimental Results

Introduction

This chapter discusses both the individual testing of the software modules and the construction and testing of a bench model system. The experimental results obtained from the bench model testing are then discussed, and an explanation of the CDF output table is given.

Testing of Software Modules

Each of the 14 software modules was individually tested for proper operation by writing a controlling program which executed the module being tested, and simulated the other modules. After testing each module, the "configuration" modules were tested as a unit by using a dummy execution routine which simulated the processing of data. This "configuration" system was tested using the RT-11 operating system's On-Line-Debugging-Technique (ODT) (Ref 8:645) to control program execution. Using ODT, the program execution was halted before and after each subroutine call in order to verify the proper operation of the subroutines. After verifying the proper operation of each module in the system, the interactive functions were checked for proper operation and variable initialization. When an error was discovered, the module where the error occurred was checked and corrected.

After completing the tests on the "configuration" system, the "data processing" modules were tested as a unit. First, proper array indexing was verified and then the calculation of the damage factor was checked by a manual calculation. This completed the software testing of the MFDM. The next step was the integration of the hardware and the

software into a complete system.

Integration of the Hardware and the Software

After completing the software testing, the hardware and the software was configured into a complete system which was then tested for functional accuracy.

Bench Model Configuration. In order to assemble a bench model system, the KD11-J processor board had to have the 4 K of on-board memory disabled. This was accomplished by installing wire wrap posts for jumper W9 which must be installed to disable a reply from the resident memory (Ref 8:234). The processor jumpers were then configured as a KD11-J processor (Ref 8:234). The 4 K core memory was set to be the first bank of memory and 16 K of semiconductor memory was set to memory banks one through four. A DDV11-B backplane was not available, so two H9270 backplanes were used - connecting them together with a BCV1B option module (Ref 8:380). Figure 11 shows the system configuration used for the bench model.

Bench Model Testing. To test the computational accuracy of the bench model, it was taken to an AFFDL laboratory where both a shaker table and spectrum analyzing equipment were available. The lab's analog data processing system, which computes the cumulative damage factor, was not working, so a B and K Instrument's graphic spectrum equalizer was used to simulate the vibrational input signal. A Spectral Dynamics Corporation's one-third octave analyzer was connected to the input signal in order to determine the input spectrum. There was no equipment available to test the temperature signal acquisition function, so the temperature input leads were shorted together

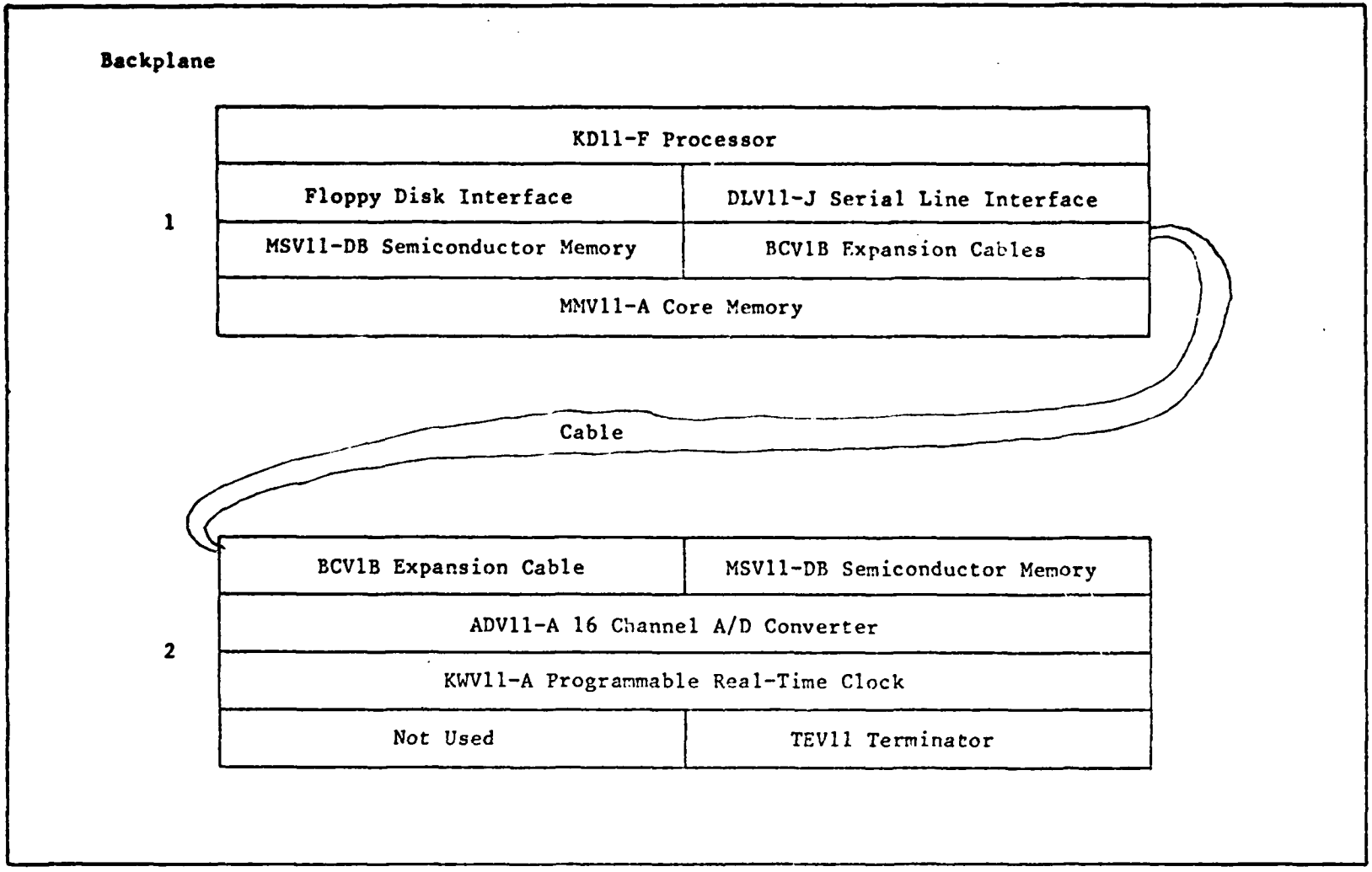


Fig 11. Bench Model Configuration

simulating a 0 voltage input. After the MFDM processed the simulated data, it was determined that the resolution of the spectrum analyzer was so much less than that of the MFDM that no estimations of the accuracy of the MFDM were possible.

The testing of the system was then continued at the Air Force Institute of Technology where the bench model was designed and constructed. The input signals were simulated by using four sine-wave generators to simulate the vibration signal, and a DC power supply was used to simulate the temperature signal. The accuracy of the temperature scale was determined by using a test routine which printed the computed temperature interval corresponding to the DC voltage being used as the simulated temperature input signal. By varying the DC voltage, the voltage at which the computed temperature interval changed was determined. From this voltage, the corresponding temperature at which the computed temperature interval changed was computed. This test determined that the temperature scale for the CDF output table is accurate within one degree.

The vibration data was checked by using four sine-wave generators as simulated input signals. Sine wave generators were used in order to have a known frequency spectrum for an input to the system. This allowed the resolution of the system to be determined by varying the frequencies of the input signals until the frequencies were so close as to make them indistinguishable. The smallest difference in frequencies for which the two signals were distinguishable was the resolution. Using this method, it was determined that the resolution of the CDF output was twice the frequency interval of the output table. The reason for this large resolution is the following: if two input

frequencies are within two frequency intervals of each other, the output table will show a peak at both frequencies. Since the two frequency peaks are next to each other, it is impossible to determine if there was one frequency input between the two intervals, or one frequency input in each interval. By using only one frequency as an input signal, it was determined that the system's accuracy is within 15 Hz when using the 25 Hz frequency interval, within 25 Hz when using the 50 Hz frequency interval, and within 50 Hz when using the 100 Hz frequency interval.

Experimental Results

Without an analog data processing system to compute the damage factor, no accurate method of checking the computational accuracy of the MFDM was available. Also, without an audio frequency spectrum analyzer, no accurate method of checking the output spectrum was available. This left only the testing that was done with the simulated input signals. Table IX shows the results of one of the tests using a system configuration of 0-3 K Hz and an interval of 25 Hz. The input vibration signal consisted of 500 Hz, 835 Hz, 875 Hz, and 2685 Hz sine waves. The amplitudes were 3,5,4, and 1 volt respectively. By varying the input frequency, it was determined that the frequency resolution, for one input signal, is +/- 20Hz up to 6000 Hz. A temperature resolution was not obtained because the thermocouple's linear amplifier did not work.

Explanation of CDF Table. The CDF Table shown in Table IX is an example of the output of the MFDM. The date and comments in the table

TABLE IX

Cumulative Damage Table Output

CUMULATIVE DAMAGE MATRIX PAGE 1

DATE 12-NOV-79
DURATION 14.72 HOURS
COMMENTS 500 HZ @3V, 835 @5V, 875 @4V, 2685 @1V

FREQ (HZ)	TEMPERATURE (DEG F)						
	<-50	-25	0	25	50	75	100
25.	0.000E+00	0.000E+00	0.000E+00	0.15EE+06	0.000E+00	0.000E+00	0.000E+00
50.	0.000E+00	0.000E+00	0.000E+00	0.370E+04	0.000E+00	0.000E+00	0.000E+00
75.	0.000E+00	0.000E+00	0.000E+00	0.424E+03	0.000E+00	0.000E+00	0.000E+00
100.	0.000E+00	0.000E+00	0.000E+00	0.934E+02	0.000E+00	0.000E+00	0.000E+00
125.	0.000E+00	0.000E+00	0.000E+00	0.290E+02	0.000E+00	0.000E+00	0.000E+00
150.	0.000E+00	0.000E+00	0.000E+00	0.113E+02	0.000E+00	0.000E+00	0.000E+00
175.	0.000E+00	0.000E+00	0.000E+00	0.527E+01	0.000E+00	0.000E+00	0.000E+00
200.	0.000E+00	0.000E+00	0.000E+00	0.272E+01	0.000E+00	0.000E+00	0.000E+00
225.	0.000E+00	0.000E+00	0.000E+00	0.156E+01	0.000E+00	0.000E+00	0.000E+00
250.	0.000E+00	0.000E+00	0.000E+00	0.963E+00	0.000E+00	0.000E+00	0.000E+00
275.	0.000E+00	0.000E+00	0.000E+00	0.644E+00	0.000E+00	0.000E+00	0.000E+00
300.	0.000E+00	0.000E+00	0.000E+00	0.451E+00	0.000E+00	0.000E+00	0.000E+00
325.	0.000E+00	0.000E+00	0.000E+00	0.334E+00	0.000E+00	0.000E+00	0.000E+00
350.	0.000E+00	0.000E+00	0.000E+00	0.257E+00	0.000E+00	0.000E+00	0.000E+00
375.	0.000E+00	0.000E+00	0.000E+00	0.214E+00	0.000E+00	0.000E+00	0.000E+00
400.	0.000E+00	0.000E+00	0.000E+00	0.185E+00	0.000E+00	0.000E+00	0.000E+00
425.	0.000E+00	0.000E+00	0.000E+00	0.175E+00	0.000E+00	0.000E+00	0.000E+00
450.	0.000E+00	0.000E+00	0.000E+00	0.204E+00	0.000E+00	0.000E+00	0.000E+00
475.	0.000E+00	0.000E+00	0.000E+00	0.431E+00	0.000E+00	0.000E+00	0.000E+00
500.	0.000E+00	0.000E+00	0.000E+00	0.409E+04	0.000E+00	0.000E+00	0.000E+00
525.	0.000E+00	0.000E+00	0.000E+00	0.257E+00	0.000E+00	0.000E+00	0.000E+00
550.	0.000E+00	0.000E+00	0.000E+00	0.105E+00	0.000E+00	0.000E+00	0.000E+00
575.	0.000E+00	0.000E+00	0.000E+00	0.948E-01	0.000E+00	0.000E+00	0.000E+00
600.	0.000E+00	0.000E+00	0.000E+00	0.983E-01	0.000E+00	0.000E+00	0.000E+00
625.	0.000E+00	0.000E+00	0.000E+00	0.111E+00	0.000E+00	0.000E+00	0.000E+00
650.	0.000E+00	0.000E+00	0.000E+00	0.135E+00	0.000E+00	0.000E+00	0.000E+00
675.	0.000E+00	0.000E+00	0.000E+00	0.177E+00	0.000E+00	0.000E+00	0.000E+00
700.	0.000E+00	0.000E+00	0.000E+00	0.253E+00	0.000E+00	0.000E+00	0.000E+00
725.	0.000E+00	0.000E+00	0.000E+00	0.412E+00	0.000E+00	0.000E+00	0.000E+00
750.	0.000E+00	0.000E+00	0.000E+00	0.804E+00	0.000E+00	0.000E+00	0.000E+00
775.	0.000E+00	0.000E+00	0.000E+00	0.215E+01	0.000E+00	0.000E+00	0.000E+00
800.	0.000E+00	0.000E+00	0.000E+00	0.109E+02	0.000E+00	0.000E+00	0.000E+00
825.	0.000E+00	0.000E+00	0.000E+00	0.671E+03	0.000E+00	0.000E+00	0.000E+00
850.	0.000E+00	0.000E+00	0.000E+00	0.105E+03	0.000E+00	0.000E+00	0.000E+00
875.	0.000E+00	0.000E+00	0.000E+00	0.508E+03	0.000E+00	0.000E+00	0.000E+00
900.	0.000E+00	0.000E+00	0.000E+00	0.701E+00	0.000E+00	0.000E+00	0.000E+00
925.	0.000E+00	0.000E+00	0.000E+00	0.209E+00	0.000E+00	0.000E+00	0.000E+00
950.	0.000E+00	0.000E+00	0.000E+00	0.814E-01	0.000E+00	0.000E+00	0.000E+00
975.	0.000E+00	0.000E+00	0.000E+00	0.374E-01	0.000E+00	0.000E+00	0.000E+00
1000.	0.000E+00	0.000E+00	0.000E+00	0.193E-01	0.000E+00	0.000E+00	0.000E+00
1025.	0.000E+00	0.000E+00	0.000E+00	0.10EE-01	0.000E+00	0.000E+00	0.000E+00
FREQ (HZ)	<-50	-25	0	25	50	75	100
			TEMPERATURE (DEG F)				

TABLE IX

Cumulative Damage Table Output (cont)

CUMULATIVE DAMAGE MATRIX PAGE 2

DATE 12-NOV-79
DURATION 14.72 HOURS
COMMENTS 500 HZ @3V, 835 @5V, 875 @4V, 2685 @1V

FREQ (HZ)	TEMPERATURE (DEG F)						
	<-50	-25	0	25	50	75	100
1025.	0.000E+00	0.000E+00	0.000E+00	0.106E-01	0.000E+00	0.000E+00	0.000E+00
1050.	0.000E+00	0.000E+00	0.000E+00	0.626E-02	0.000E+00	0.000E+00	0.000E+00
1075.	0.000E+00	0.000E+00	0.000E+00	0.389E-02	0.000E+00	0.000E+00	0.000E+00
1100.	0.000E+00	0.000E+00	0.000E+00	0.249E-02	0.000E+00	0.000E+00	0.000E+00
1125.	0.000E+00	0.000E+00	0.000E+00	0.166E-02	0.000E+00	0.000E+00	0.000E+00
1150.	0.000E+00	0.000E+00	0.000E+00	0.113E-02	0.000E+00	0.000E+00	0.000E+00
1175.	0.000E+00	0.000E+00	0.000E+00	0.793E-03	0.000E+00	0.000E+00	0.000E+00
1200.	0.000E+00	0.000E+00	0.000E+00	0.564E-03	0.000E+00	0.000E+00	0.000E+00
1225.	0.000E+00	0.000E+00	0.000E+00	0.415E-03	0.000E+00	0.000E+00	0.000E+00
1250.	0.000E+00	0.000E+00	0.000E+00	0.307E-03	0.000E+00	0.000E+00	0.000E+00
1275.	0.000E+00	0.000E+00	0.000E+00	0.231E-03	0.000E+00	0.000E+00	0.000E+00
1300.	0.000E+00	0.000E+00	0.000E+00	0.175E-03	0.000E+00	0.000E+00	0.000E+00
1325.	0.000E+00	0.000E+00	0.000E+00	0.135E-03	0.000E+00	0.000E+00	0.000E+00
1350.	0.000E+00	0.000E+00	0.000E+00	0.105E-03	0.000E+00	0.000E+00	0.000E+00
1375.	0.000E+00	0.000E+00	0.000E+00	0.831E-04	0.000E+00	0.000E+00	0.000E+00
1400.	0.000E+00	0.000E+00	0.000E+00	0.671E-04	0.000E+00	0.000E+00	0.000E+00
1425.	0.000E+00	0.000E+00	0.000E+00	0.535E-04	0.000E+00	0.000E+00	0.000E+00
1450.	0.000E+00	0.000E+00	0.000E+00	0.429E-04	0.000E+00	0.000E+00	0.000E+00
1475.	0.000E+00	0.000E+00	0.000E+00	0.346E-04	0.000E+00	0.000E+00	0.000E+00
1500.	0.000E+00	0.000E+00	0.000E+00	0.297E-04	0.000E+00	0.000E+00	0.000E+00
1525.	0.000E+00	0.000E+00	0.000E+00	0.251E-02	0.000E+00	0.000E+00	0.000E+00
1550.	0.000E+00	0.000E-00	0.000E+00	0.207E-02	0.000E+00	0.000E+00	0.000E+00
1575.	0.000E+00	0.000E+00	0.000E+00	0.171E-02	0.000E+00	0.000E+00	0.000E+00
1600.	0.000E+00	0.000E+00	0.000E+00	0.144E-02	0.000E-00	0.000E+00	0.000E+00
1625.	0.000E+00	0.000E+00	0.000E+00	0.122E-02	0.000E+00	0.000E+00	0.000E+00
1650.	0.000E+00	0.000E+00	0.000E+00	0.106E-02	0.000E+00	0.000E+00	0.000E+00
1675.	0.000E+00	0.000E+00	0.000E+00	0.101E-02	0.000E+00	0.000E+00	0.000E+00
1700.	0.000E+00	0.000E+00	0.000E+00	0.753E-03	0.000E+00	0.000E+00	0.000E+00
1725.	0.000E+00	0.000E+00	0.000E+00	0.647E-03	0.000E+00	0.000E+00	0.000E+00
1750.	0.000E+00	0.000E+00	0.000E+00	0.660E-03	0.000E+00	0.000E+00	0.000E+00
1775.	0.000E+00	0.000E+00	0.000E+00	0.482E-03	0.000E+00	0.000E+00	0.000E+00
1800.	0.000E+00	0.000E+00	0.000E+00	0.417E-03	0.000E+00	0.000E+00	0.000E+00
1825.	0.000E+00	0.000E-00	0.000E+00	0.368E-03	0.000E+00	0.000E+00	0.000E+00
1850.	0.000E+00	0.000E+00	0.000E+00	0.319E-03	0.000E+00	0.000E+00	0.000E+00
1875.	0.000E+00	0.000E+00	0.000E+00	0.284E-03	0.000E+00	0.000E+00	0.000E+00
1900.	0.000E+00	0.000E+00	0.000E+00	0.249E-03	0.000E+00	0.000E+00	0.000E+00
1925.	0.000E+00	0.000E+00	0.000E+00	0.219E-03	0.000E+00	0.000E+00	0.000E+00
1950.	0.000E+00	0.000E+00	0.000E+00	0.196E-03	0.000E+00	0.000E+00	0.000E+00
1975.	0.000E+00	0.000E+00	0.000E+00	0.176E-03	0.000E+00	0.000E+00	0.000E+00
2000.	0.000E+00	0.000E+00	0.000E+00	0.155E-03	0.000E+00	0.000E+00	0.000E+00
2025.	0.000E+00	0.000E+00	0.000E+00	0.146E-03	0.000E+00	0.000E+00	0.000E+00
2050.	0.000E+00	0.000E+00	0.000E+00	0.126E-03	0.000E+00	0.000E+00	0.000E+00
FREQ (HZ)	<-50	-25	0	25	50	75	100
			TEMPERATURE (DEG F)				

TABLE IX

Cumulative Damage Table Output (cont)

CUMULATIVE DAMAGE MATRIX PAGE 3

DATE 12-NOV-79
DURATION 14.72 HOURS
COMMENTS 500 HZ @3V, 835 @5V, 875 @4V, 2685 @1V

FREQ (HZ)	TEMPERATURE (DEG F)						
	<-50	-25	0	25	50	75	100
2050.	0.000E+00	0.000E+00	0.000E+00	0.126E-03	0.000E+00	0.000E+00	0.000E+00
2075.	0.000E+00	0.000E+00	0.000E+00	0.115E-03	0.000E+00	0.000E+00	0.000E+00
2100.	0.000E+00	0.000E+00	0.000E+00	0.104E-03	0.000E+00	0.000E+00	0.000E+00
2125.	0.000E+00	0.000E+00	0.000E+00	0.958E-04	0.000E+00	0.000E+00	0.000E+00
2150.	0.000E+00	0.000E+00	0.000E+00	0.857E-04	0.000E+00	0.000E+00	0.000E+00
2175.	0.000E+00	0.000E+00	0.000E+00	0.795E-04	0.000E+00	0.000E+00	0.000E+00
2200.	0.000E+00	0.000E+00	0.000E+00	0.737E-04	0.000E+00	0.000E+00	0.000E+00
2225.	0.000E+00	0.000E+00	0.000E+00	0.697E-04	0.000E+00	0.000E+00	0.000E+00
2250.	0.000E+00	0.000E+00	0.000E+00	0.635E-04	0.000E+00	0.000E+00	0.000E+00
2275.	0.000E+00	0.000E+00	0.000E+00	0.602E-04	0.000E+00	0.000E+00	0.000E+00
2300.	0.000E+00	0.000E+00	0.000E+00	0.564E-04	0.000E+00	0.000E+00	0.000E+00
2325.	0.000E+00	0.000E+00	0.000E+00	0.544E-04	0.000E+00	0.000E+00	0.000E+00
2350.	0.000E+00	0.000E+00	0.000E+00	0.526E-04	0.000E+00	0.000E+00	0.000E+00
2375.	0.000E+00	0.000E+00	0.000E+00	0.515E-04	0.000E+00	0.000E+00	0.000E+00
2400.	0.000E+00	0.000E+00	0.000E+00	0.514E-04	0.000E+00	0.000E+00	0.000E+00
2425.	0.000E+00	0.000E+00	0.000E+00	0.531E-04	0.000E+00	0.000E+00	0.000E+00
2450.	0.000E+00	0.000E+00	0.000E+00	0.557E-04	0.000E+00	0.000E+00	0.000E+00
2475.	0.000E+00	0.000E+00	0.000E+00	0.606E-04	0.000E+00	0.000E+00	0.000E+00
2500.	0.000E+00	0.000E+00	0.000E+00	0.729E-04	0.000E+00	0.000E+00	0.000E+00
2525.	0.000E+00	0.000E+00	0.000E+00	0.870E-04	0.000E+00	0.000E+00	0.000E+00
2550.	0.000E+00	0.000E+00	0.000E+00	0.113E-03	0.000E+00	0.000E+00	0.000E+00
2575.	0.000E+00	0.000E+00	0.000E+00	0.177E-03	0.000E+00	0.000E+00	0.000E+00
2600.	0.000E+00	0.000E+00	0.000E+00	0.328E-03	0.000E+00	0.000E+00	0.000E+00
2625.	0.000E+00	0.000E+00	0.000E+00	0.855E-03	0.000E+00	0.000E+00	0.000E+00
2650.	0.000E+00	0.000E+00	0.000E+00	0.404E-02	0.000E+00	0.000E+00	0.000E+00
2675.	0.000E+00	0.000E+00	0.000E+00	0.414E+00	0.000E+00	0.000E+00	0.000E+00
2700.	0.000E+00	0.000E+00	0.000E+00	0.441E-01	0.000E+00	0.000E+00	0.000E+00
2725.	0.000E+00	0.000E+00	0.000E+00	0.215E-02	0.000E+00	0.000E+00	0.000E+00
2750.	0.000E+00	0.000E+00	0.000E+00	0.487E-03	0.000E+00	0.000E+00	0.000E+00
2775.	0.000E+00	0.000E+00	0.000E+00	0.191E-03	0.000E+00	0.000E+00	0.000E+00
2800.	0.000E+00	0.000E+00	0.000E+00	0.955E-04	0.000E+00	0.000E+00	0.000E+00
2825.	0.000E+00	0.000E+00	0.000E+00	0.587E-04	0.000E+00	0.000E+00	0.000E+00
2850.	0.000E+00	0.000E+00	0.000E+00	0.399E-04	0.000E+00	0.000E+00	0.000E+00
2875.	0.000E+00	0.000E+00	0.000E+00	0.297E-04	0.000E+00	0.000E+00	0.000E+00
2900.	0.000E+00	0.000E+00	0.000E+00	0.245E-04	0.000E+00	0.000E+00	0.000E+00
2925.	0.000E+00	0.000E+00	0.000E+00	0.185E-04	0.000E+00	0.000E+00	0.000E+00
2950.	0.000E+00	0.000E+00	0.000E+00	0.151E-04	0.000E+00	0.000E+00	0.000E+00
2975.	0.000E+00	0.000E+00	0.000E+00	0.138E-04	0.000E+00	0.000E+00	0.000E+00
3000.	0.000E+00	0.000E+00	0.000E+00	0.120E-04	0.000E+00	0.000E+00	0.000E+00

FREQ (HZ)	TEMPERATURE (DEG F)						
	<-50	-25	0	25	50	75	100

heading are user-supplied and are printed in the same format as input by the user. The duration is the length of time the system actually processed data. If, for some reason, data processing was stopped before the expiration of the planned duration, the duration printed on the table would be the actual time - not the planned time.

Each column of the table corresponds to a 25 degree Fahrenheit temperature range, the center of the range being the temperature printed at the top of the column. If the temperature of the test item is below -37.5 degrees the cumulative damage factor will appear in the column labelled <-50. Also, if the temperature is greater than 217.5 degrees, the cumulative damage factor will appear in the column labelled >225. The temperature range of -50 to +225 is split into two ranges: -50 to +100 and +75 to +225 in order to fit the table on an 8 1/2 x 11" sheet of paper. The 75 and 100 degree columns have been reproduced in both ranges to make analysis of the data at the page boundary easier. Each row of the table contains the CDF at the frequency printed in the left-hand column. After printing 41 lines, the temperature scale is re-printed and a new page is started. Once the complete frequency spectrum is printed for the lower temperature range, the spectrum is printed for the high temperature range, thus completing the CDF Table.

Summary

As stated earlier, due to a lack of time and of the proper test equipment, it was impossible to give the MFDM system a complete testing. The testing with the simulated input signals shows that the system is working properly, although it was not possible to test the

accuracy of its output. The system still needs to be tested with an audio spectrum analyzer, and a test with an analog data processing system should be performed.

VII. Proposed Flight-Worthy System

Introduction

The previous chapters have discussed the design and development of a bench model MFDM. This chapter presents a proposed flight-worthy MFDM system. Proposed hardware will be discussed, including that required to control the auto-ranging gain function of the vibration signal amplifier, which was not implemented in the bench model. The program modifications required to execute the program from PROM are also discussed. In conclusion, the power requirements, as well as a mechanical description of the proposed MFDM system will be presented.

Hardware

The proposed MFDM system configuration, shown in Figure 12, uses a DEC DDV11-B Backplane and an H0341 card cage to hold the hardware modules. The modules are located in the card cage according to their priority - the processor being the highest priority, and the serial interface being the second highest. The position of the remaining modules does not matter since they do not require any specific priority. In addition to holding the required hardware modules, the H0341 has enough space to hold the hardware required for the signal amplifiers and for the system clock. This allows all of the required hardware to be in one chassis, making it easier to package (Ref 11).

The hardware not implemented in the bench model was the controller for the auto-ranging gain of the vibration signal amplifier. The gain must be constant during the data sampling period, and allowed to auto-

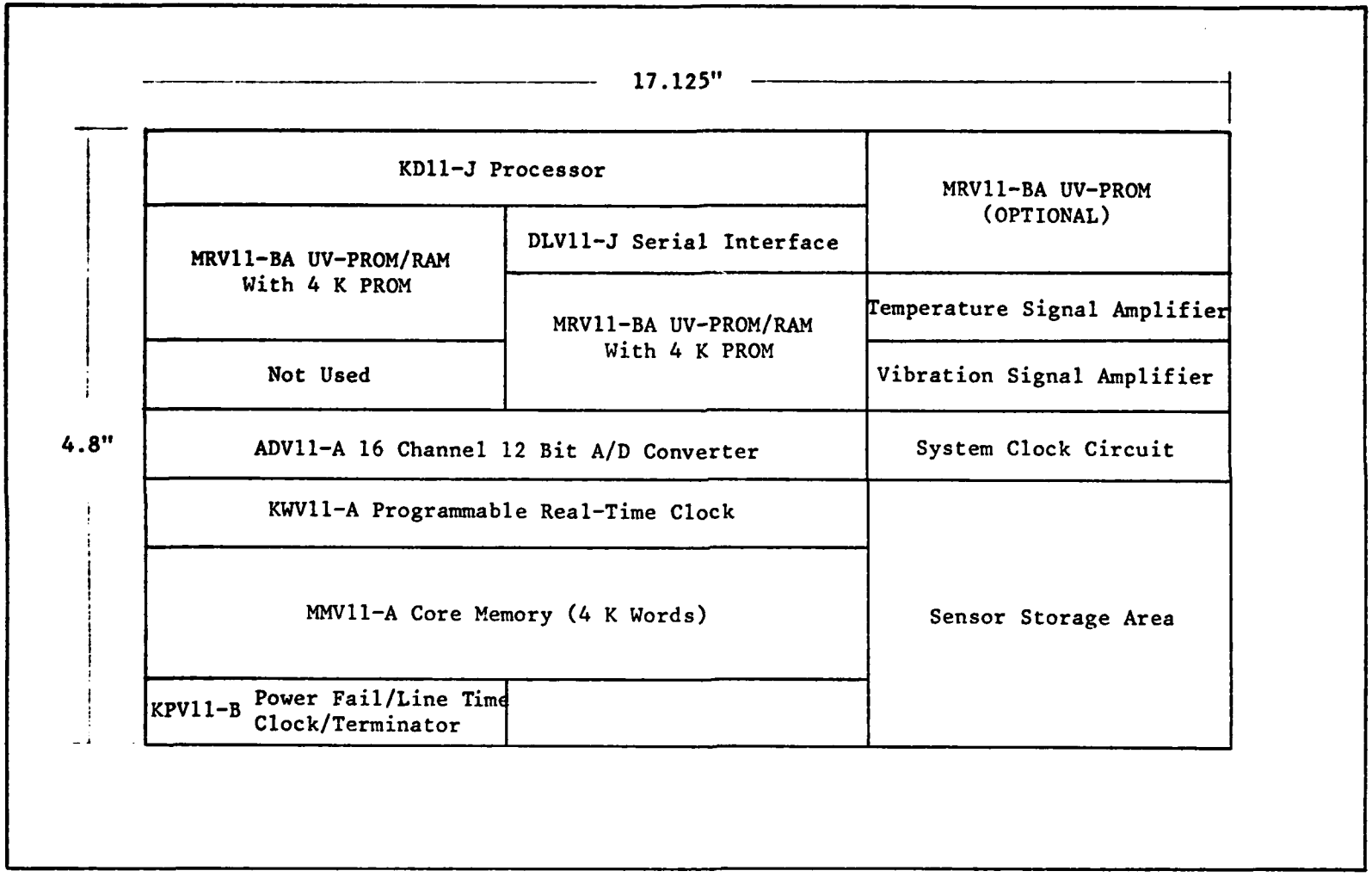


Fig 12. Proposed System Configuration

range when data is not being sampled (Ref 11). This allows the intensity of the signals to vary without a loss of data. If the gain of the amplifier is held constant for the duration of the test, then the intensity of some signals may be too small to be digitized, while the intensity of some other signals may be too large for the analog-to-digital converter.

The auto-ranging function adjusts the amplifier gain, within limits, to keep the input signal to the A/D converter less than the 5 volts maximum, thus keeping it within the allowable limits of the A/D converter (Ref 2:2-1). The IBV11-A Instrument Bus Interface Module is designed to control external devices using the "Instrument Bus" (Ref 8:314).

In this case, the module allows the program to control the vibration signal amplifier. In addition, if future uses of the system require the control of multiple signal amplifiers, this module is capable of controlling them (Ref 8:315). In order to control the vibration signal amplifier's auto-ranging gain the inhibit line of the amplifier can be controlled by one bit of the data register, and the 3 bit gain code can be read from the data register (Ref 8:318). The code necessary to use this module will be discussed in the next section.

Software

In order to control the IBV11-A Bus Interface Module, some assembly language code must be added to the EXECUTIVE module. Before the "N" data points are sampled, the auto-ranging feature must be inhibited, and the gain must be stored as the multiplication factor "ADGAIN". This value, which has been set to one in EXECUTIVE until

the actual code is implemented, is the value by which the data is multiplied in the POWERSPECTRUM module to scale the data.

The valid range for "ADGAIN" was determined by computing the damage factor for the largest and smallest possible values of the power spectrum at the highest and lowest frequency, respectively, and then determining what multiplication factor would cause data overflow or underflow. The largest value for any one element of the power spectrum array is 10^7 (Ref Chap V), which when used in Eq 15 with a frequency of 25 Hz, gives a damage factor on the order of 10^7. Since the largest floating point number the computer can store is 10^{28} (Ref 8:560), the largest multiplication factor ("ADGAIN") is 10^{21} ($10^{28}/10^7$).

The smallest "ADGAIN" was determined by using the smallest possible value (1) for an element of the power spectrum array to compute the damage factor at a frequency of 6000 Hz. The damage factor obtained, using Eq 15, was 10^{-21}, and the smallest number which can be repesented by a floating point number is on the order of 10^{-28} (Ref 8:560). Therefore, the smallest "ADGAIN" is 10^{-7} ($10^{-28}/10^{-21}$). If a smaller value is used, the resulting damage factor will be zero due to the 16 bit word size.

After the "N" data points are sampled, the gain must be released to auto-range until the next data sample is required. A flow chart showing the control of the auto-ranging gain of the signal amplifier is shown in figure 13.

In addition to the code necessary to control the amplifier, the program must be stored in MRV11-BA UV-PROM modules. Because a PROM is a read-only memory, the program must be linked so that all variables

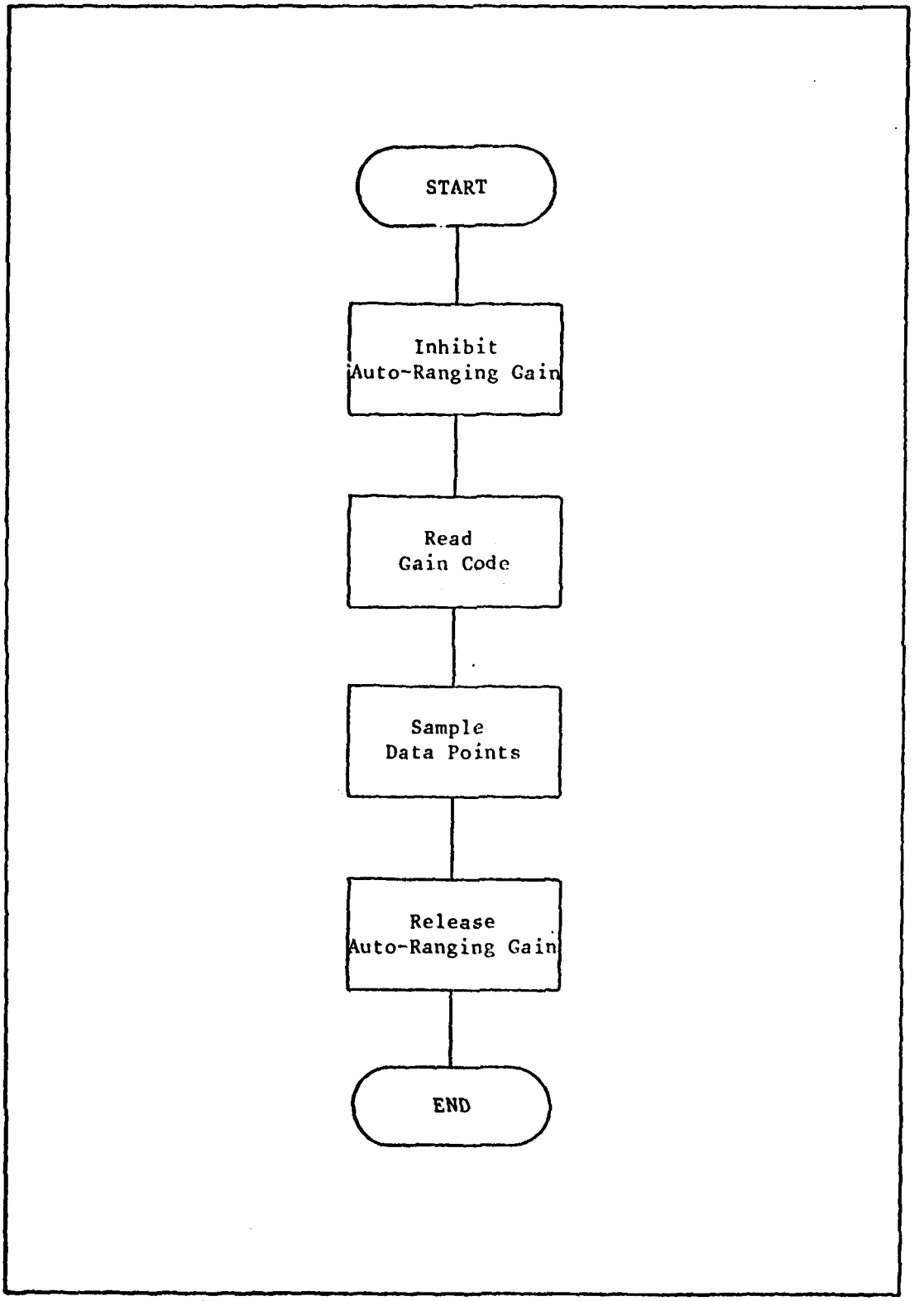


Fig 31. Flow Chart for Auto-Ranging Gain

have addresses in the core memory. Also, there are five instructions which cannot be executed with operands located in PROM. These instructions are MTPS, MUL, DIV, ASH, and ASHC (Ref 8:403). Only two modules use these instructions. EXECUTIVE uses MTPS; and FFT uses MUL, ASH, and ASHC. EXECUTIVE is coded so that it will be executable from PROM, but the FFT module must be modified to store the values for "SINE" and "COS" in the core memory. This can be accomplished by defining the "SINE" and "COS" variables in the PSECT section of the EXECUTIVE module where the CDF array is defined (Ref Appendix B). With this change, all of the modules included in the MFDM system will be executable from the PROM memory.

Figure 12 shows 3 MRV11- BA (4 K by 16 bit PROMS), although the program can be contained in 2 modules - 8 K words. The third PROM is included for future program expansion. Although not a requirement, it is desired to have the CDF matrix plotted in "3 dimensions" (Ref 10). A program to accomplish this can be stored in the third PROM.

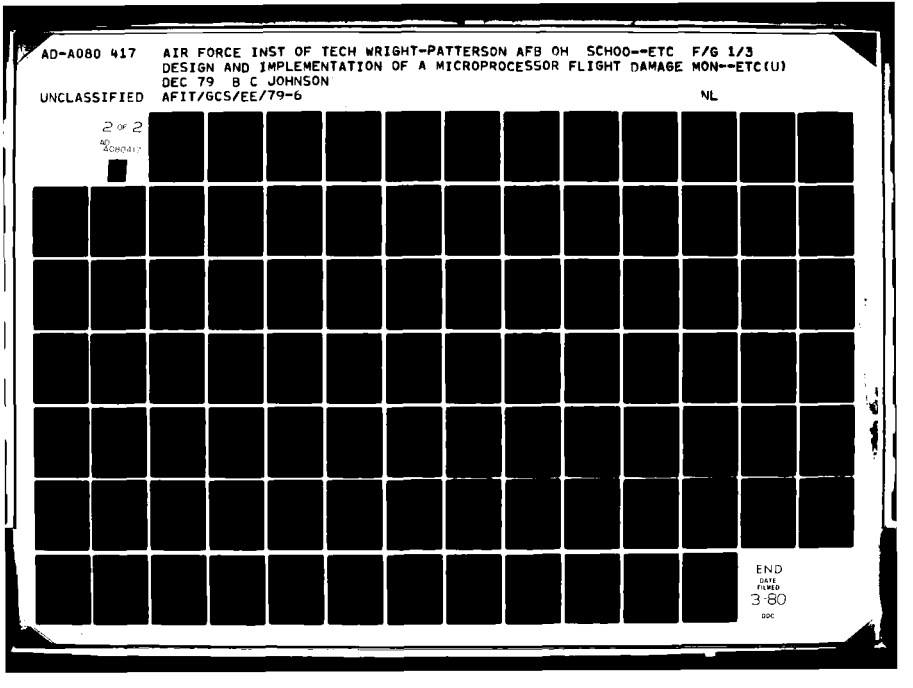
Power Requirements

The power requirements for each hardware module are given in Table X (Ref 8:43-46). The total power required is the sum of the values given in Table X plus the power required by the amplifiers and clock. The total power for the modules is 15.4 amps at 5 volts DC and 2.7 amps at 12 volts DC, while the amplifier requires .06 amps at 15 volts DC and the clock requires .003 amps between 8 and 29 volts DC. This power is to be supplied by rechargeable batteries, and they should be capable of operating the system for up to 20 hours (Ref Chap 2).

TABLE X

Proposed Module Specifications (Ref 5:43-46)

Module	Module No.	Description	Power Requirements +5V	+12V
KD11-J	M7264	LSI-11 Processor	2.0 A	0.9 A
MMV11-A	H223	4 K x 16 Core Memory	7.0 A	0.6 A
DLV11-J	M8043	4-Channel Asynchronous Serial Line Unit Interface	1.3 A	0.2 A
MRV11-BA	M8021	UV-PROM-RAM	0.7 A	0.5 A
KWV11-A	M7952	Programmable Real-Time Clock	1.8 A	0.1 A
ADV11-A	A012	16 Channel 12-bit A/D Converter	2.0 A	0.5 A
IBV11-A	M7954	Instrument Bus Interface	0.1 A	
KPV11-B	M8016YB	Power Fail/Line Time Clock/Terminator	0.6 A	
DDV11-B	H0341	Backplane Card Cage		


AD-A080 417
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 1/3
DESIGN AND IMPLEMENTATION OF A MICROPROCESSOR FLIGHT DAMAGE MON--ETC(U)
DEC 79 B C JOHNSON
UNCLASSIFIED
AFIT/GCS/EE/79-6
NL
2 OF 2
AD A080417
END
DATE FILMED
3-80
DDC

Packaging

Figure 14 shows the author's concept of the MFDM's final shape, and the layout of the subunits which make up the system is shown in figure 15. Some things which must be considered when designing the package are the cooling and damping of the card cage, the strength of the case and the method by which it will be fastened to the airplane. The two switches on the front panel are keylock switches The reason for this type of switch is that the "RUN/HALT" switch can be locked in the run position when automatic start-up is required. Then, when the DC power switch is turned on, data processing will start automatically.

The use of keylock switches, although not required, will prevent the inadvertent application or removal of the system's power, or turning the system on with the "RUN/HALT" switch in the "HALT" position when it should be in the "RUN" position. Manual start up can be accomplished by turning the DC power switch on with the "RUN/HALT" switch in the "HALT" position and then switching it to the "RUN" position, or by entering the starting address of the MFDM from a terminal. The package shown in Figures 13 and 14 does not include the power pack which may be a separate box. A seperate power supply will reduce the size and allow it to be used with a DC power pack or with an AC power converter pack. The power supply can be included in the system case but this will restrict its use in that only one power source will be available to use.

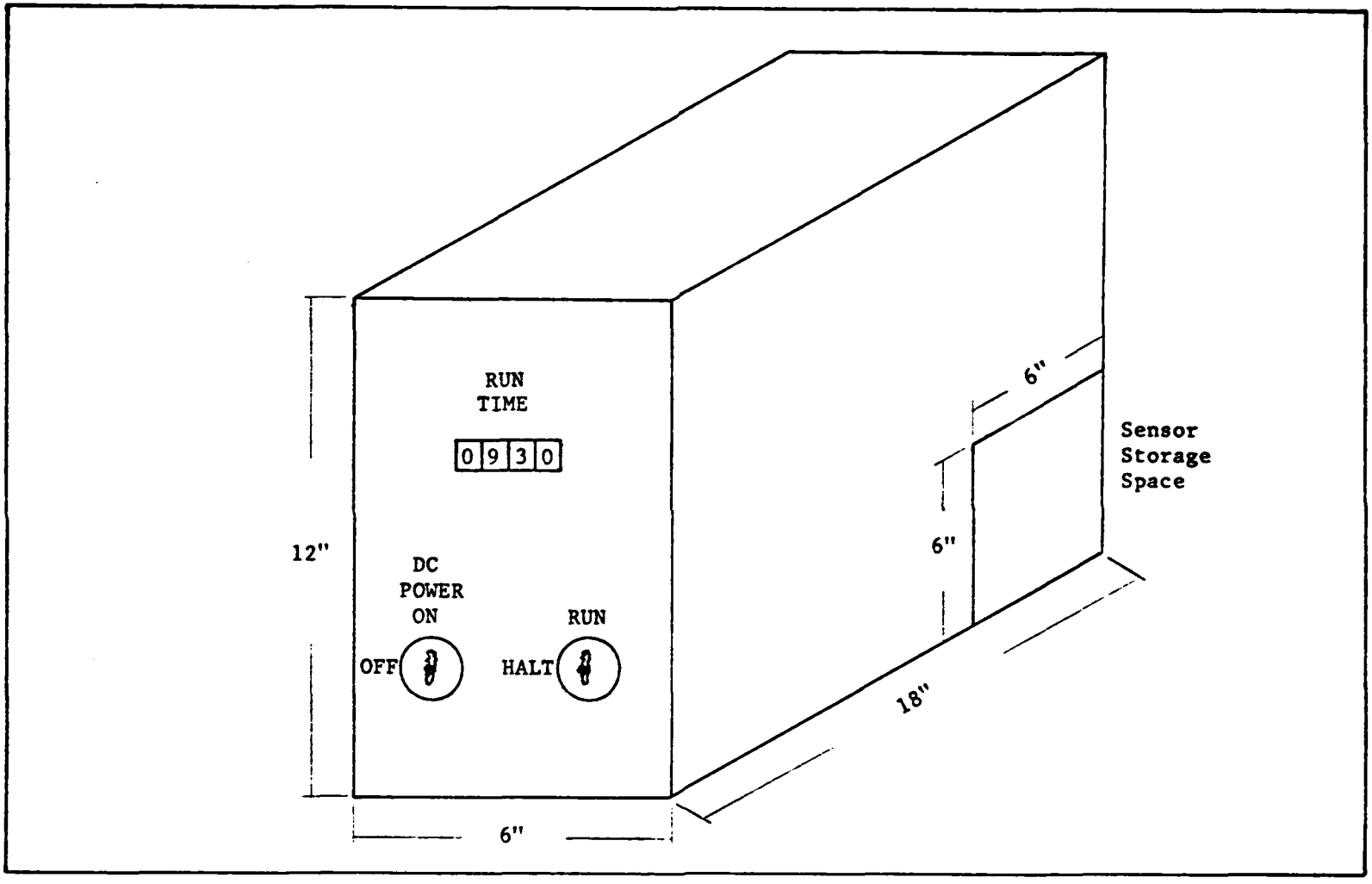


Fig 14. Proposed Concept for the MFDM

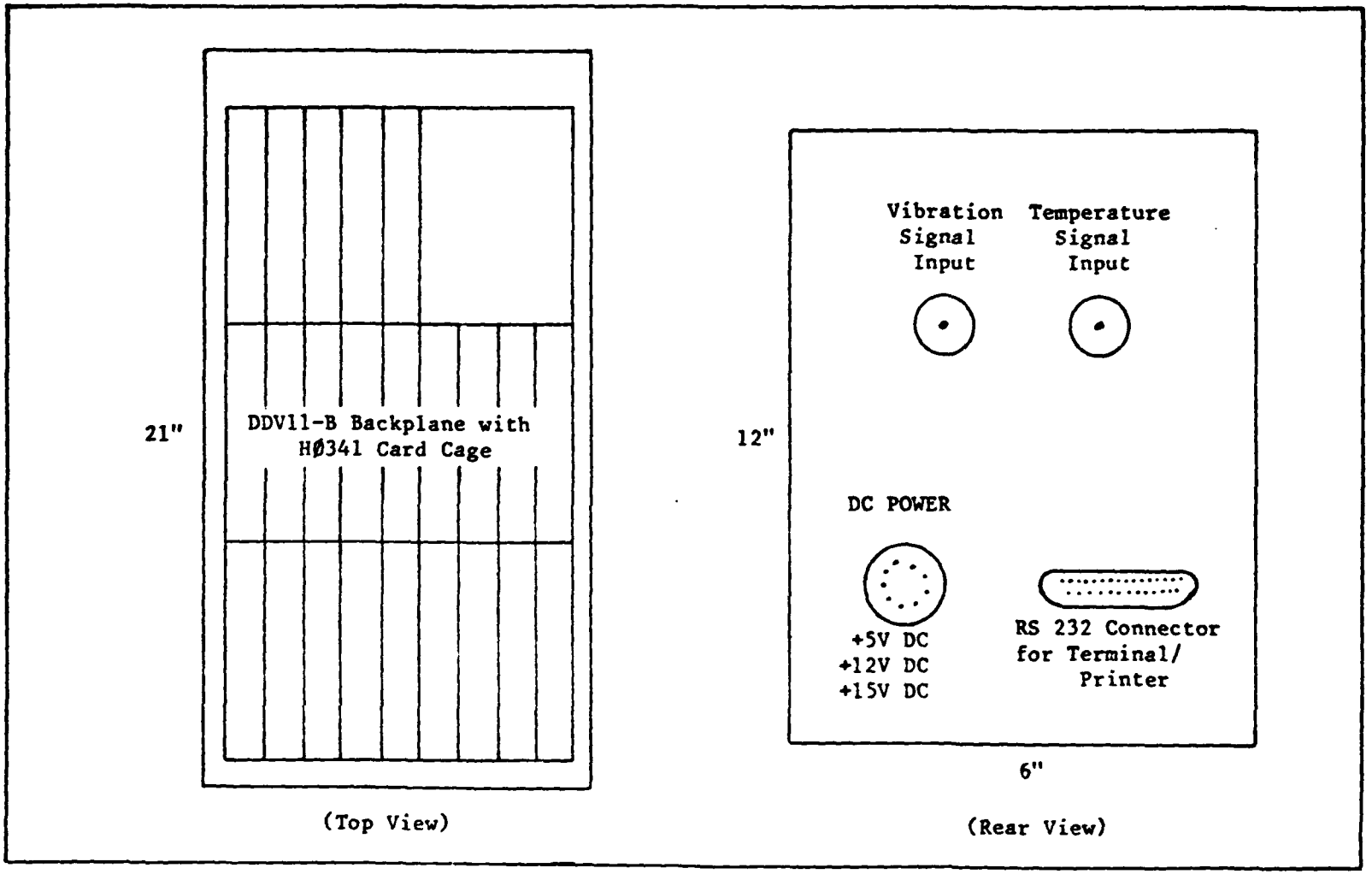


Fig 15. Subunit Layout for Proposed System

Summary

In this chapter, the implementation of the flight-worthy system was discussed. The additional hardware needed to control the auto-ranging feature of the vibration signal amplifier was discussed along with the associated additional code in the EXECUTIVE module required to control the gain of the amplifier. The modifications required to store the program in a UV-PROM were discussed, and the power requirements and packaging of the MFDM were given.

VIII. Recommendations and Conclusions

Introduction

A bench model of the MFDM currently exists. The implementation of a flight-worthy system will require additional work. This effort would include developing the auto-ranging gain controller, completing the system testing, storing the program in PROM, packaging the system, and constructing the DC power supply required. This chapter presents some recommendations for future development, and some conclusions drawn from this effort.

Recommendations

Recommendations for future work include the installation of the IBV11- A Instrument Bus Interface, and the modification to the EXECUTIVE module necessary to control the auto- ranging amplifier must be completed. The new code should read the amplifier's gain setting from the Instrument Bus Interface and store a multiplication factor equivalent to the gain in the global variable "ADGAIN". The allowable range of "ADGAIN" is from 10^{-6} to 10^{22} , and will insure proper cumulative damage factor computation (Ref Chap VII).

Further testing of the system is required. The testing should be performed using a random vibration signal as an input to the analog sensor, with the output of the sensor going to the MFDM and an audio spectrum analyzer. A vibration table is available at the AFFDL and can be used to generate the input vibration signals for the system and for an audio frequency spectrum analyzer. In addition, an analog data acquisition system can be connected to the same vibration input signals

and can be used to check the computation of the cumulative damage factor. This consists of comparing the peaks in the outputs. The relative difference between the two outputs should be the same for all peaks. The spectrum analyzer can also be used to verify that the peaks in the CDF table are at the same frequency as the input spectrum.

The system program must be stored in UV-PROM. This will allow the system to be run without the disk system that the bench model used. Some minor modifications to the code in the FFT module will be required in order for it to execute from PROM (Ref Chap VII).

The system needs to be assembled in an H0341 card cage with a DDV-11 Back Plane (Ref VII). The clock circuit and signal amplifiers can be included in this card cage, resulting in a self-contained system, except for batteries

The system casing must be constructed to protect the modules from damage in an aircraft environment, and to allow the system to be controlled with the use of two key switches (Ref Chap VII).

A DC power supply must be designed. It will have to supply +5.12, and 15 volts DC at 15.4, 2.7, and .007 amps, respectively, for a period of up to 20 hours of continuous operation (Ref Chap VII). The power supply will connect to the MFDM system via a power line which plugs into the back of the MFDM.

Conclusions

The original design for this system was reviewed with respect to a new set of requirements. The system was then re-designed to meet the new requirements, and a bench model of the MFDM was constructed. Although time did not allow testing of the complete system, each of the

modules which make up the system was tested individually and found to be accurate within the limits of a 16 bit word size. The complete computer system was tested using sine wave generators to simulate the output of the signal amplifiers. The sine wave generators produced a known input spectrum which allowed the output of the system to be compared to the input signal. The frequency resolution was determined to be half of the frequency interval selected. Due to a lack of time, a complete spectrum analysis comparing the output of the MFDM to a known frequency spectrum input signal was not accomplished.

The current system demonstrates the practicability of using state-of-the-art technology to accomplish the task of real-time data acquisition and processing. In particular, the real-time data acquisition of vibration and temperature signals and the real-time computation of the cumulative damage matrix from these signals was accomplished. This system thus computes the data required to enable the AFFDL to produce a damping layer treatment for an item being tested. Construction of a flight-worthy system can now be accomplished following the design discussed in Chapter VIII. This investigation has successfully developed a bench model system for the real-time processing of the cumulative damage matrix, and has proposed a flight-worthy design which can now be constructed.

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11. Talmadge, R. D., personal interviews June-November 1979, Aerospace Engineer, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

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Appendix A

Flow Charts and Source Code for Configuration Modules

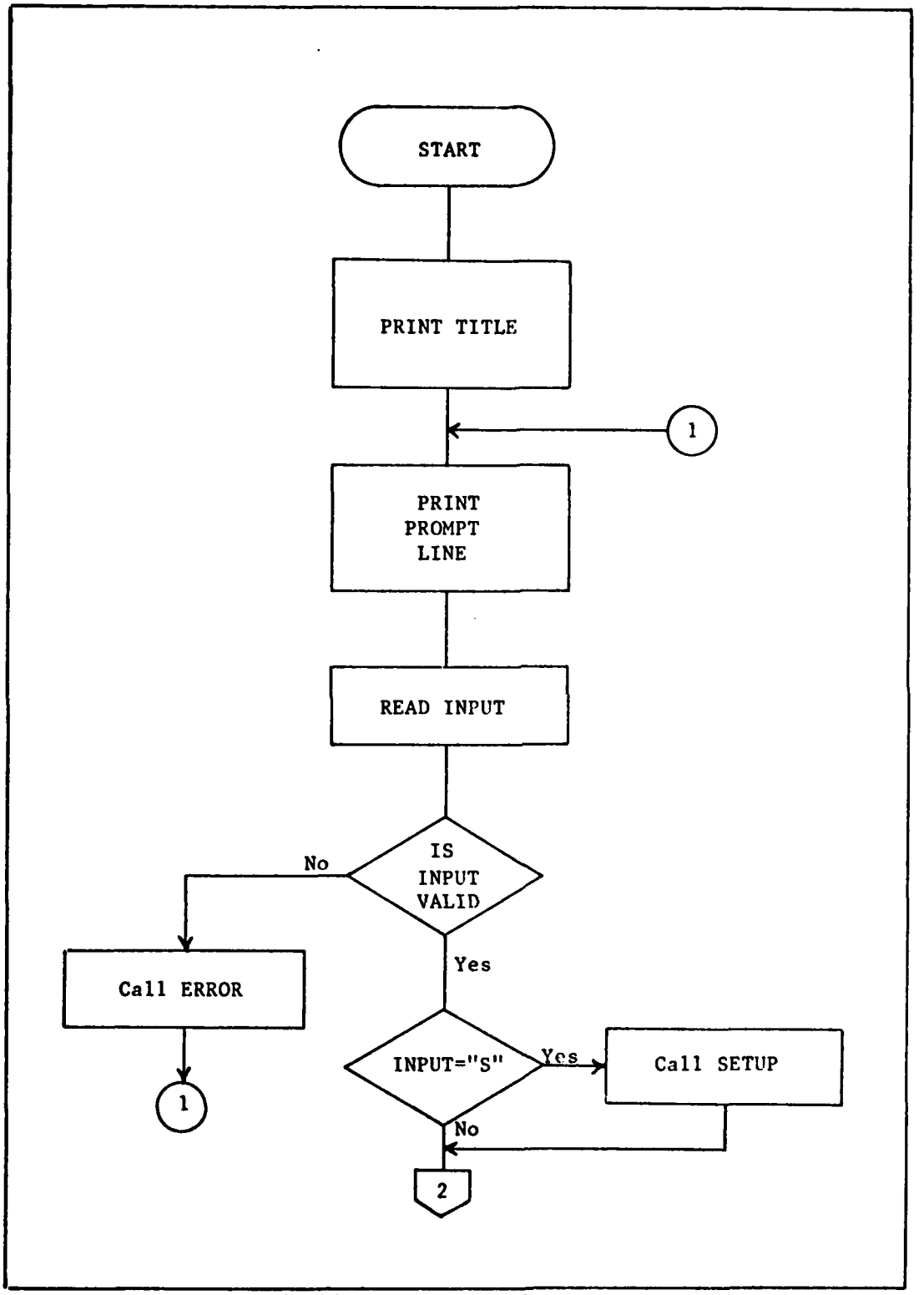

Fig 16. Flow Chart for MFDM

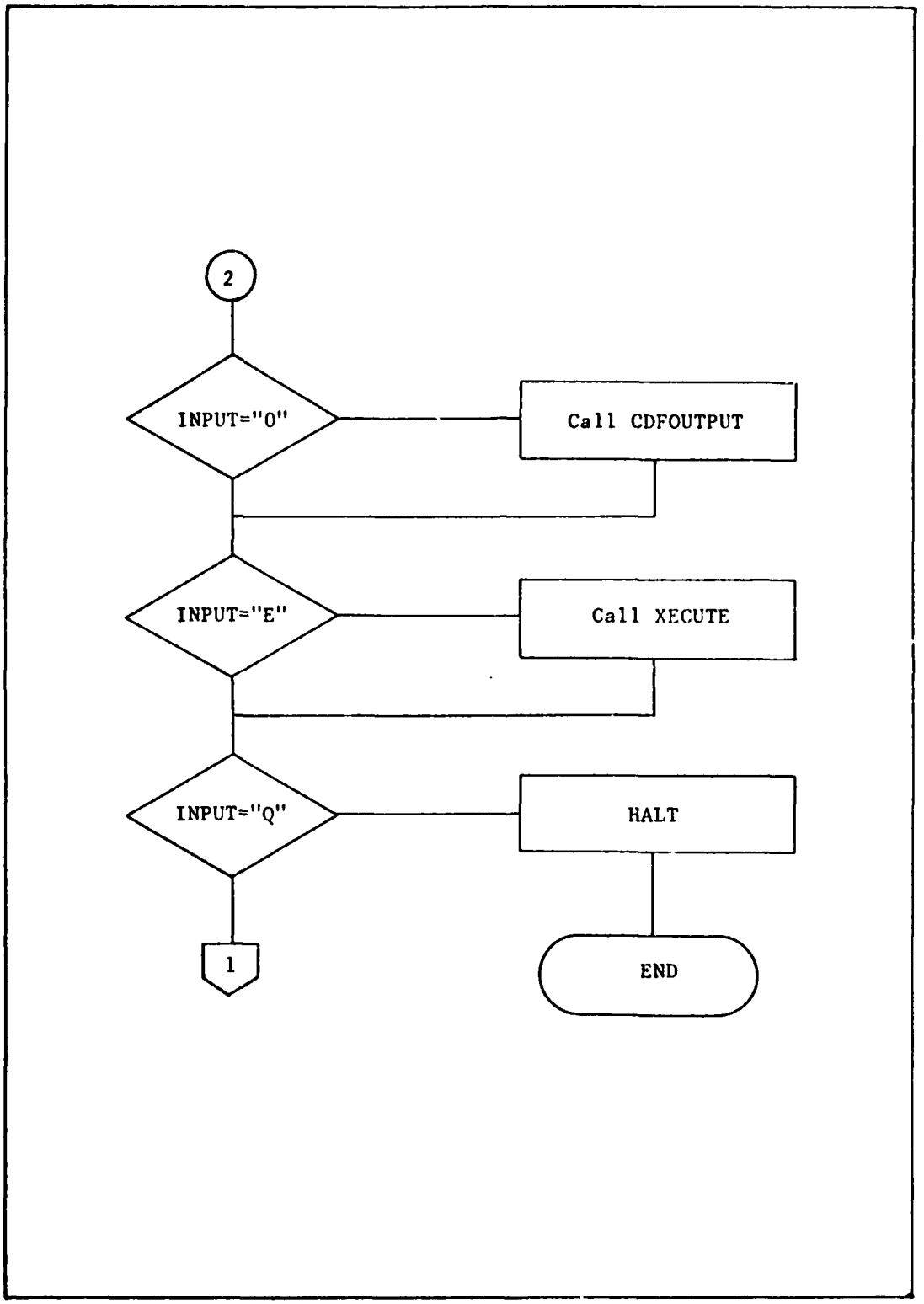

Fig 16. Flow Chart for MFDM (cont)

```
FORTRAN IV   V02.1-11   Wed 28-Nov-79 00:00 00                PAGE 001
0001          PROGRAM MFDM
      C
      C     THIS MICROPROCESSOR FLIGHT DAMAGE MONITOR (MFDM)
      C PROGRAM IS AN INTERACTIVE PROGRAM WHICH DOES THREE THINGS
      C ALLOWS THE USER TO CONFIGURE THE SYSTEM AS DESIRED,  ALLOWS
      C THE ESER TO MANUALLY CONTROL DATA PROCESSING,  ALLOWS THE USER
      C REQUEST AN OUTPUT OF THE CDF MATRIX.
      C
      C     THIS PROGRAM IS STARTED BY TYPING RU MFDM IF UNDER RT-11,
      C OR BY TYPING 1000 G IF UNDER SYSTEM ODT. DATA PROCESSING
      C CAN BE STARTED MANUALLY BY TURNING THE SYSTEM HALT/RUN TO RUN
      C AND THEN TURNING THE DC POWER SWITCH ON.
      C
      C     WHEN THE PROGRAM IS STARTED EITHER OF THE FIRST TWO WAYS,
      C THE USER WILL BE GREETED BY:
      C
      C     MICROPROCESSOR FLIGHT DAMAGE MONITOR
      C     ENTER  S(ETUP, E(XECUTE, O(UTPUT, Q(UIT    ?<CR>
      C
      C WHEN THE USER ENTERS THE FIRST LETTER OF THE SUBROUTINE DESIRED
      C FOLLOWED BY A CARRIAGE RETURN (<CR>),, THAT SUBROUTINE WILL BE
      C EXECUTED.
      C
      C     SUBROUTINE SETUP INITIALIZES THE VARIABLES USED IN THE
      C DIFFERENT SUBROUTINES TO THEIR INITIAL VALUES. THE DEFAULT
      C VALUES ARE THE LAST USED VALUES, WITH THE VALUES INITIALIZED TO
      C A FREQUENCY RANGE OF 0-3000 HZ  WITH A FREQUENCY INTERVAL OF
      C 100 HZ THE FIRST TIME THE PROGRAM IS RUN.
      C
      C     SUBROUTINE XECUTE CONTROLS THE DATA ACQUISITION IN
      C A CONTROLLED ENVIRONMENT SUCH AS A LABORATORY WHERE A TERMINAL
      C IS AVAILABLE.
      C
      C     SUBROUTINE CDFOUTPUT PRINTS OUT A CUMULATIVE DAMAGE MATRIX
      C FOR FREQUENCY VS TEMPERATURE.
      C
      C     FORTRAN COMMON BLOCKS (USED TO TRANSFER INFORMATION TO
      C AND FROM THE ASSEMBLY SUBROUTINES).
      C
      C      ANSWER          !USED TO HOLD THE ANSWER TO YES/NO QUESTIONS
      C      CDF(1452)       !THE CUMULATIVE DAMAGE FACTOR ARRAY
      C      COMMENTS(40)    !AN ARRAY OF ALPHANUMERICS WHICH IS PRINTED
      C                      !ON THE OUTPUT TABLE.
      C      DATE(13)        !AN ARRAY TO HOLD THE DATE
      C      DELTAF          !THE SIZE OF THE FREQ INTERVAL IN THE
      C                      !CDF ARRAY
      C      DURATION        !THE DURATION OF A TEST IN HOURS
      C      EXP             !THE EXPONENT FOR N=2**EXP WHERE
      C                      !EXP IS THE LOCAL VARIABLE CORRESPONDING
      C                      !TO THE GLOBAL VARIABLE B USED IN EXEC
      C                      !AND FOURIE
      C      MINUTES         !THE DURATION OF A TEST IN MINUTES
```

```
C       NFREQ          !THE NUMBER OF FREQ INTERVALS IN THE
C                      !CDF ARRAY
C       POWERFLAG      !A FLAG USED IN THE POWER-UP ROUTINE TO
C                      !INDICATE THE FIRST "AUTOMATIC" POWER-UP.
C
C  VARIABLE TYPE DEFINITION
C
0002        LOGICAL*1 ANSWER,DATE(13) COMMENTS(40) POWERFLAG
0003        INTEGER*2 EXP,NFREQ
0004        INTEGER*2 MINUTES,INDEX
0005        REAL*4 DURATION,DELTAF,CDF(120,12)
C
C  GLOBAL VARIABLES DEFINED
C
0006        COMMON /CDFDATA/CDF,/PTIME/MINUTES,/DELTA/DELTAF
0007        COMMON /B/EXP,/INDX/INDEX /NINTVL/NFREQ,/PWRFLG/POWERFLAG
C
C  SUSTEM DEFAULT ARGUMENTS INITIALIZED
C
0008        DATA EXP INDEX,NFREQ DELTAF/6,8,30,100.2/
0009        DATA DATE/'1'  4','-','D'  E','C','-','7','9',4*' '/
0010        DATA MINUTES/30/
0011        DATA POWERFLAG/0/      !POWERFLAG IS INITIALIZED TO 1
C                                  !FOR USE IN THE POWER-UP ROUTINE.
C
C  PROGRAM EXECUTION STARTS HERE.  TITLE AND A REQUEST FOR THE USERS
C  RESPONSE IS PRINTED AT THE TERMINAL FIRST.
C
0012        TYPE 100
0013   100  FORMAT (2X, MICROPROCESSOR FLIGHT DAMAGE MONITOR')
0014   200  TYPE 300
0015   300  FORMAT (/2X, ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - ?<CR>'$)
0016        ACCEPT 400,ANSWER
0017   400  FORMAT (A1)
C
C  THE USERS ANSWER IS CHECKED AND IF IT IS VALID PROGRAM CONTROL
C  PASSES TO THE REQUESTED ROUTINE.
C
0018        IF ((ANSWER.NE. S').AND.(ANSWER.NE.'E').AND.(ANSWER.NE.'O').AND.
           1(ANSWER.NE.'Q')) CALL ERROR ('INPUT MUST BE AN S E.O.OR Q')
C
0020        IF (ANSWER.EQ. S')
           1CALL SETUP(DELTAF,NFREQ,DATE,COMMENTS,MINUTES/60.)
C
0022        IF (ANSWER.EQ.'E') CALL XECUTE
C
0024        IF (ANSWER.EQ 'O')
           1CALL CDFOUTPUT(CDF NFREQ DELTAF,DATE,COMMENTS)
C
0026        IF (ANSWER.EQ.'Q') STOP ' ALL DONE'
C
0028        GO TO 200
0029        END
```

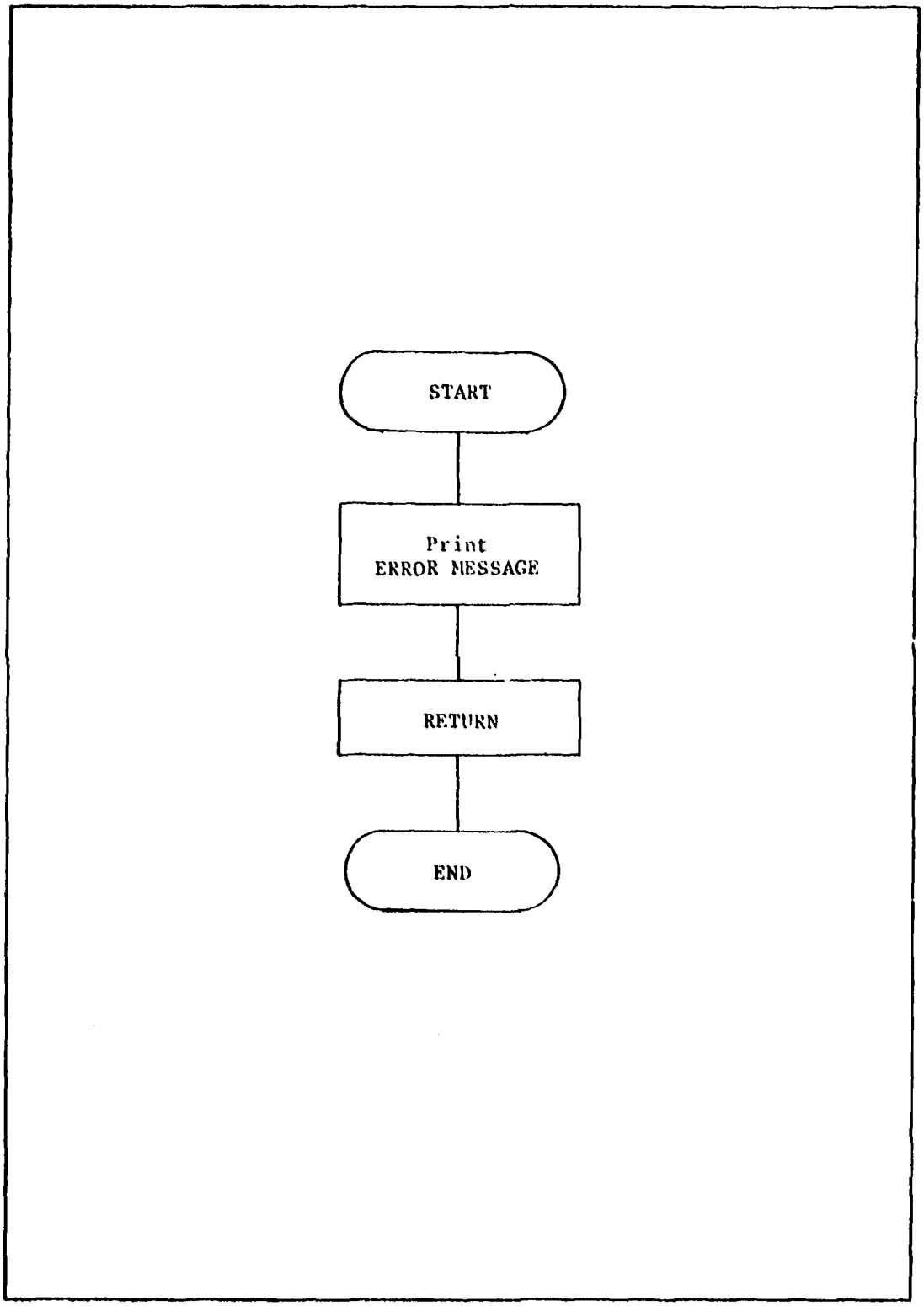

Fig 17. Flow Chart for ERROR

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 14:55:18                PAGE 001
0001          SUBROUTINE ERROR (MESSAGE)
      C
      C     ERROR ROUTINE WHICH TYPES THE ERROR MESSAGE "MESSAGE".
      C "MESSAGE" IS A STRING OF TYPE LOGICAL*1 OF LENGTH UP TO 40.
      C
0002          LOGICAL*1 MESSAGE(40)
0003          TYPE 100,MESSAGE
0004    100   FORMAT (/2X 'ERROR - ', 40A1)
0005          RETURN
0006          END
```

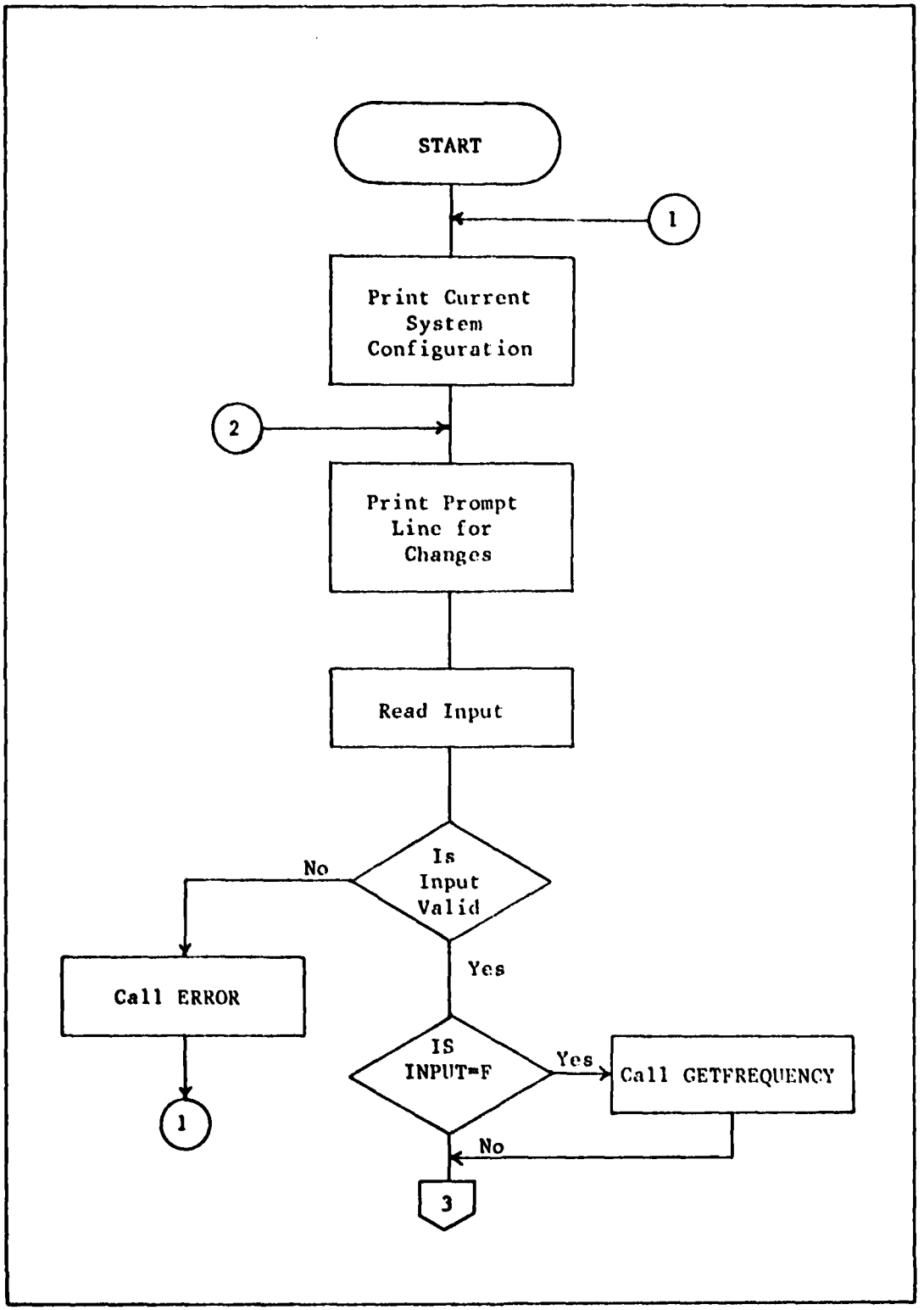

Fig 18. Flow Chart for SETUP

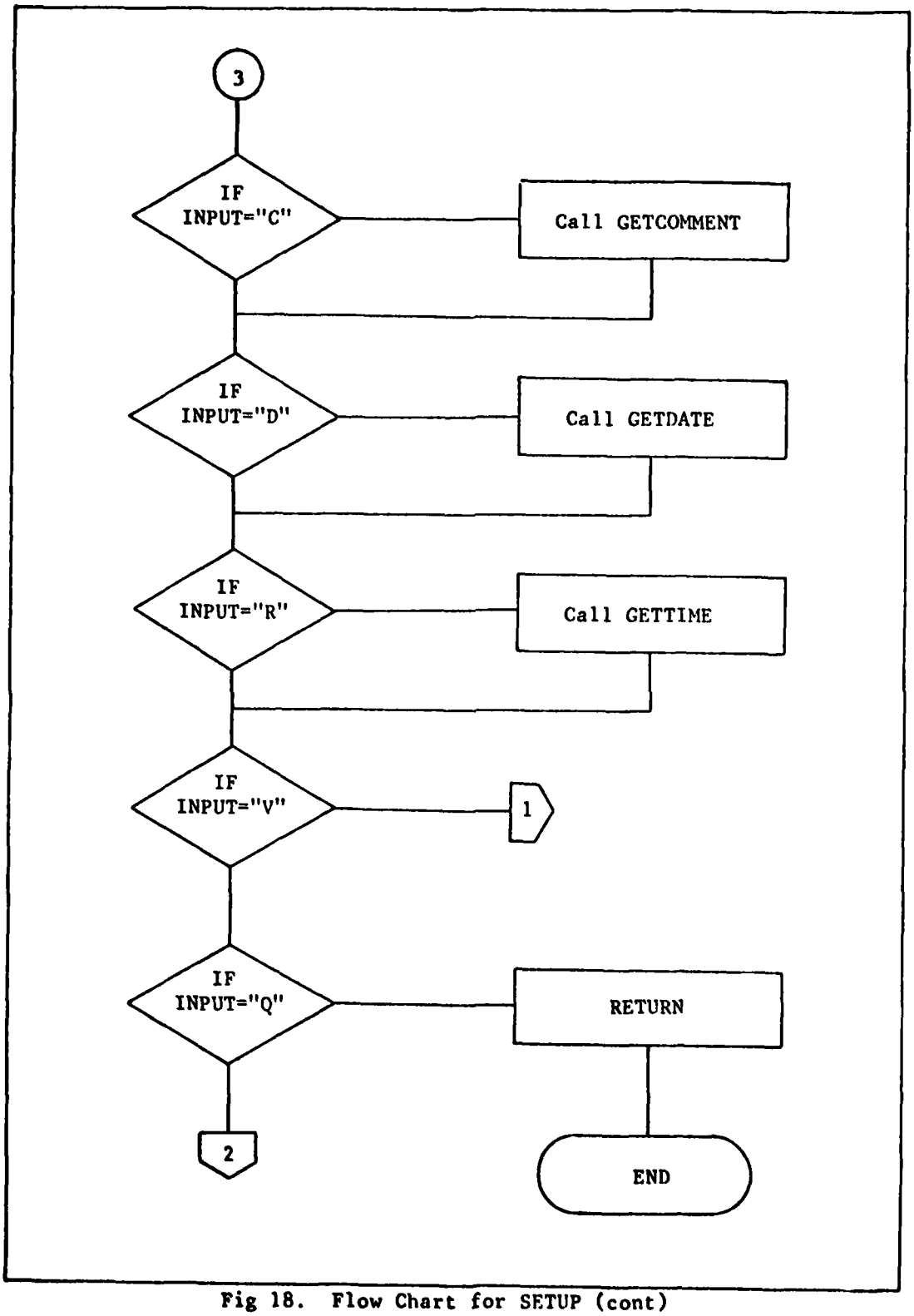

Fig 18. Flow Chart for SETUP (cont)

```
FORTRAN IV   V02.1-11   Tue 27-Nov-79 00:00:00                PAGE 001
0001          SUBROUTINE SETUP(DELTAF,NFREQ,DATE,COMMENTS,DURATION)
      C
      C     SETUP CONTROLS THE INITIALIZATION OF THE PROGRAM VARIABLES.
      C IT IS AN INTERACTIVE ROUTINE BY WHICH THE USER CAN CHANGE THE
      C FREQUENCY RANGE AND INTERVAL FOR WHICH DATA IS TO BE PROCESSED.
      C IN ADDITION THE USER CAN CHANGE THE RUN DURATION,DATE AND COMMENTS.
      C
      C
      C     THREE SUBROUTINES ARE CALLED BY THIS SUBROUTINE. THEY ARE:
      C
      C     GETFREQUENCY(DELTAF)  - A ROUTINE WHICH INITIALIZES THE
      C                             GLOBAL VARIABLES USED IN THE ASSEMBLY
      C                             LANGUAGE ROUTINE EXEC. ALSO  VARIABLES
      C                             MAXFREQ AND DELTAF ARE SET TO THE
      C                             MAXIMUM FREQUENCY IN THE CDF ARRAY,
      C                             AND DELTAF IS THE FREQUENCY INTERVAL
      C                             IN THE CDF ARRAY.
      C
      C     GETTIME(DURATION)  - A ROUTINE WHICH READS THE DESIRED RUN
      C                          TIME FROM THE TERMINAL AND STORES IT IN
      C                          DURATION (IN  HOURS) ,AND IN MINUTES (IN
      C                          MINUTES).
      C
      C
      C     VARIABLES USED IN THESE ROUTINE ARE
      C
      C     ANSWER            - LOCATION WHERE THE RESULTS OF A Y/N QUESTION
      C                         IS STORED.
      C     COMMENTS(40)      - A 40 BYTE STRING TO CONTAIN ANY MESSAGE THE
      C                         USER WANTS TO BE PUT IN THE OUTPUT TABLE.
      C     DATE(13)          - A 9 BYTE STRING TO HOLD THE DATE WHICH IS
      C                         PRINTED ON THE OUTPUT TABLE
      C     DELTAF            - THE FREQUENCY INTERVAL IN THE CDF ARRAY.
      C     DURATION          - THE PLANNED RUN TIME IN HOURS
      C     NFREQ             - THE NUMBER OF FREQUENCY INTERVALS IN THE CDF
      C                         ARRAY.
      C
0002          LOGICAL*1 ANSWER,DATE(13) COMMENTS(40)
0003          INTEGER*2 NFREQ
0004          REAL*4 DURATION,DELTAF
```

```
      C
      C     THIS ROUTINE, BEING INTERACTIVE, FIRST DISPLAYS THE CURRENT
      C VALUE OF A VARIABLE AND THEN ASKS IF IT SHOULD BE CHANGED.  THE
      C USER RESPONDS WITH A YES (Y) OR NO (N). IF IT IS TO BE CHANGED
      C THE USER IS PROMPTED TO ENTER THE NEW VALUE.
      C     FOR THE DATE AND COMMENTS NO ERROR CHECKING IS DONE SO
      C WHAT EVER IS ENTERED (PRINTABLE CHARACTERS ONLY) WILL BE PRINTED
      C ON THE OUTPUT TABLE.
      C
      C
      C
0005   10   TYPE 20,NFREQ*DELTAF,DELTAF
0006   20   FORMAT(///2X,'FREQUENCY RANGE:  0 - ' F6.1,' HZ'/
           12X 'DELTAF:                'F5.1,' HZ')
0007        TYPE 30,DURATION
0008   30   FORMAT(2X 'RUN DURATION:      ',F5.2,' HOURS')
0009        TYPE 40 COMMENTS
0010   40   FORMAT(2X,'COMMENTS:',10X,40A1)
0011        TYPE 50,DATE
0012   50   FORMAT(2X,'DATE:',14X,13A1)
0013   60   TYPE 70
0014   70   FORMAT(///2X,'CHANGE  F(REQ, R(UN DUR  C(OMMENTS',
           1' D(ATE, Q(UIT ,OR V(ERIFY - ?<CR>'$)
0015        ACCEPT 80,ANSWER
0016   80   FORMAT(A1)
      C
0017        IF ((ANSWER.NE.'F').AND.(ANSWER.NE.'R').AND.(ANSWER.NE.'C').AND.
           1(ANSWER.NE.'D').AND.(ANSWER.NE.'Q').AND.(ANSWER.NE.'V')) CALL
           2 ERROR(' INPUT MUST BE A: F,R C D Q,OR V')
      C
0019        IF (ANSWER .EQ. 'F') CALL GETFREQUENCY(DELTAF)
0021        IF (ANSWER .EQ. 'R') CALL GETTIME(DURATION)
0023        IF (ANSWER .EQ. 'C') CALL GETCOMMENT(COMMENTS)
0025        IF (ANSWER .EQ. 'D') CALL GETDATE(DATE)
0027        IF (ANSWER .EQ. 'V') GO TO 10
0029        IF (ANSWER .EQ. 'Q') RETURN
0031        GO TO 10            !CHANGED FROM 60 TO 10 AFTER THESIS WAS
      C                         PRINTED - VERIFY IS NOW AUTOMATIC.
0032        END
```

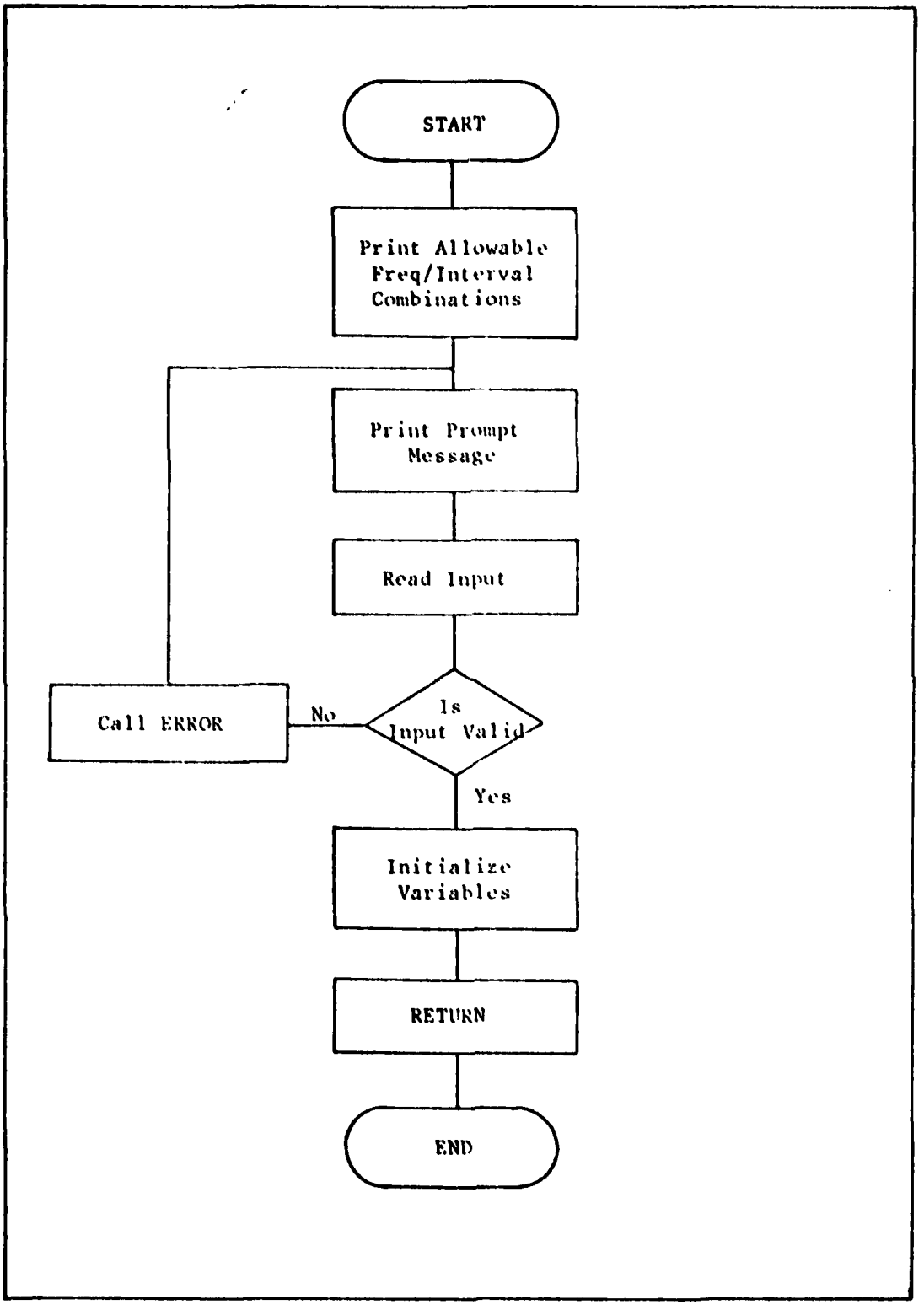

Fig 19. Flow Chart for GETFREQUENCY

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 14:54:13                PAGE 001
0001          SUBROUTINE GETFREQUENCY
      C
      C     CHANGEF IS USED TO INITIALIZE THE FOLLOWING VARIABLES
      C
      C   COMMON      LOCAL    DEFINITION
      C
      C   /B/            EXP   - THE INTEGER WHICH SATISFIES
      C                        THE EQ. N=2**EXP.  WHERE "N"
      C                        IS THE NUMBER OF  COMPLEX"
      C                        DATA POINTS PROCESSED.
      C
      C  /DELTA/      DELTAF   - THE FREQUENCY INTERVAL IN
      C                        THE CDF ARRAY.
      C
      C   /INDX/      INDEX    - AN INTEGER INDEX USED WITH
      C                        THE SINE LOOK-UP TABLE IN THE
      C                        FFT ROUTINE.
      C
      C   /NINTVL/    NFREQ    - THE NUMBER OF FREQUENCY INTERVALS
      C                        IN THE CDF ARRAY.
      C
      C   /RTCMODE/   CLKMODE  - THE MODE OF OPERATION OF THE
      C                        PROGRAMMABLE REAL TIME CLOCK,
      C                        POSSIBLE VALUES ARE:
      C
      C                         CLKMODE          FREQUENCY
      C                         (DECIMAL)
      C
      C                           11               1   MHZ
      C                           19             100   KHZ
      C                           27              10   KHZ
      C
      C
      C    /RTCRATE/ CLKRATE - THE FREQUENCY DIVISOR FOR THE CLKMODE
      C
      C
      C
      C     VARIABLE TYPE DEFINITION
      C
      C
0002          INTEGER*2 EXP,INDEX,INTERVAL,ENTRY,NFREQ
0003          INTEGER*2 CLKMODE,CLKRATE
0004          REAL*4 DELTAF
      C
      C  GLOBAL VARIABLES
      C
0005          COMMON /B/EXP,/INDX/INDEX,/NINTVL/NFREQ,/DELTA/DELTAF
0006          COMMON /RTCMODE/CLKMODE /RTCRATE/CLKRATE
      C
      C  DEFAULT REAL-TIME CLOCK SETTINGS
      C
0007          DATA CLKMODE /11/,CLKRATE /-156/
```

```
      C
      C
      C     THE POSSIBLE COMBINATIONS OF THE FREQUENCY RANGE AND FREQUENCY
      C INTERVAL ARE DISPLAYED FIRST.  THE USER IS THEN PROMPTED TO ENTER
      C THE INTEGER (1-6) CORRESPONDING TO THE COMBINATION DESIRED. THE
      C INTEGER IS USED IN A COMPUTED GO TO STATEMENT TO BRANCH TO THE
      C APPROPRIATE LOCATOIN FOR VARIABLE INITIALIZATION.
      C
      C
0008   100  TYPE 200
0009   200  FORMAT(//2X,'FREQ. RANGE (KHZ)   DELTAF (HZ)',9X,'ENTER'/)
0010        TYPE 300,6..100.2.1,6. .50.1.2,3.,100.2,3.3. 50.1.4 3..25.0.5,
           91.5.100.2,6 1.5.50.1,7.1.5,25.0,8
0011   300  FORMAT(8(8X F4.1,12X F5.1,15X.I1/))
0012        TYPE 400
0013   400  FORMAT(//1X,'ENTER A NUMBER BETWEEN 1 & 8 CORRESPONDING TO THE',
           1' DESIRED SETUP ?<CR>'$)
0014        ACCEPT 500,ENTRY
0015   500  FORMAT(I1)
0016        GO TO (1 2,3,4,5 6,7,8) ENTRY     !IF ENRTY>8 OR <1 CONTROL
      C                                       !FALLS THROUGH.
0017        CALL ERROR('INPUT MUST BE AN INTEGER BETWEEN 1 AND 8')
0018        GO TO 100
      C
      C VARIABLE INITIALIZATION STARTS HERE
      C
0019      1  EXP=7
0020         INDEX=4
0021         NFREQ=60
0022         DELTAF=100.2
0023         CLKRATE=-78
0024         GO TO 600
0025      2  EXP=8
0026         INDEX=2
0027         NFREQ=120
0028         DELTAF=50.1
0029         CLKRATE=-78
0030         GO TO 600
0031      3  EXP=6
0032         INDEX=8
0033         NFREQ=30
0034         DELTAF=100.2
0035         CLKRATE=-156
0036         GO TO 600
0037      4  EXP=7
0038         INDEX=4
0039         NFREQ=60
0040         DELTAF=50.1
0041         CLKRATE=-156
0042         GO TO 600
```

```
0043      5  EXP=8
0044         INDEX=2
0045         NFREQ=120
0046         DELTAF=25.
0047         CLKRATE=-156
0048         GO TO 600
0049      6  EXP=5
0050         INDEX=15
0051         NFREQ=15
0052         DELTAF=100.2
0053         CLKRATE=-312
0054         GO TO 600
0055      7  EXP=6
0056         INDEX=8
0057         NFREQ=30
0058         DELTAF=50.1
0059         CLKRATE=-312
0060         GO TO 600
0061      8  EXP=7
0062         INDEX=4
0063         NFREQ=60
0064         DELTAF=25.
0065         CLKRATE=-312
0066    600  RETURN
0067         END
```

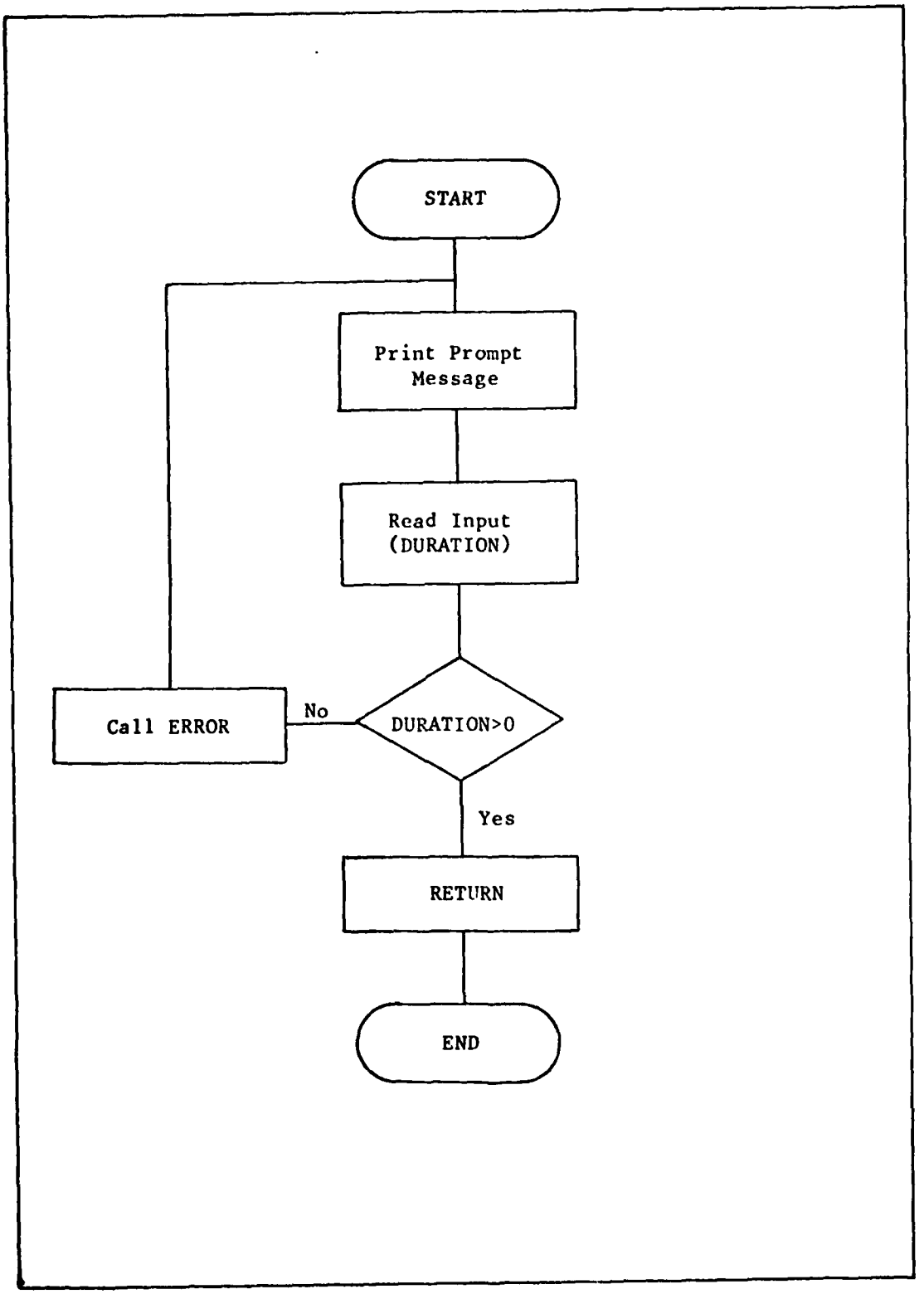

Fig 20. Flow Chart for GETTIME

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 14:56:19                PAGE 001
0001          SUBROUTINE GETTIME ( DURATION )
      C
      C     TIME GETS THE DESIRED DATA PROCESSING DURATION FROM THE USER
      C AND STORES IT IN THE GLOBAL VARIABLE RTIME (USING COMMON).
      C RTIME IS AN INTEGER (LOCAL VARIABLE MINUTES), AND DURATION IS THE
      C REAL VARIABLE EQUIVALENT TO MINUTES.
      C
      C  VARIABLES DEFINED HERE
      C
0002          INTEGER*2 MINUTES
0003          REAL*4 DURATION
0004          COMMON /PTIME/MINUTES
      C
      C  REQUEST USER TO ENTER A NEW TIME
      C
0005    100   TYPE 200
0006    200   FORMAT(/2X,'ENTER DURATION OF TEST (HOURS) EXAMPLE 15 25 <CR>'$)
0007          ACCEPT 300,DURATION
0008    300   FORMAT(F5.0)
0009          IF (DURATION.LE  0.)
             1CALL ERROR('DURATION MUST BE IN HOURS AND > .01666')
0011          IF (ERR) GO TO 100
0013          MINUTES=DURATION*60.
0014          RETURN
0015          END
```

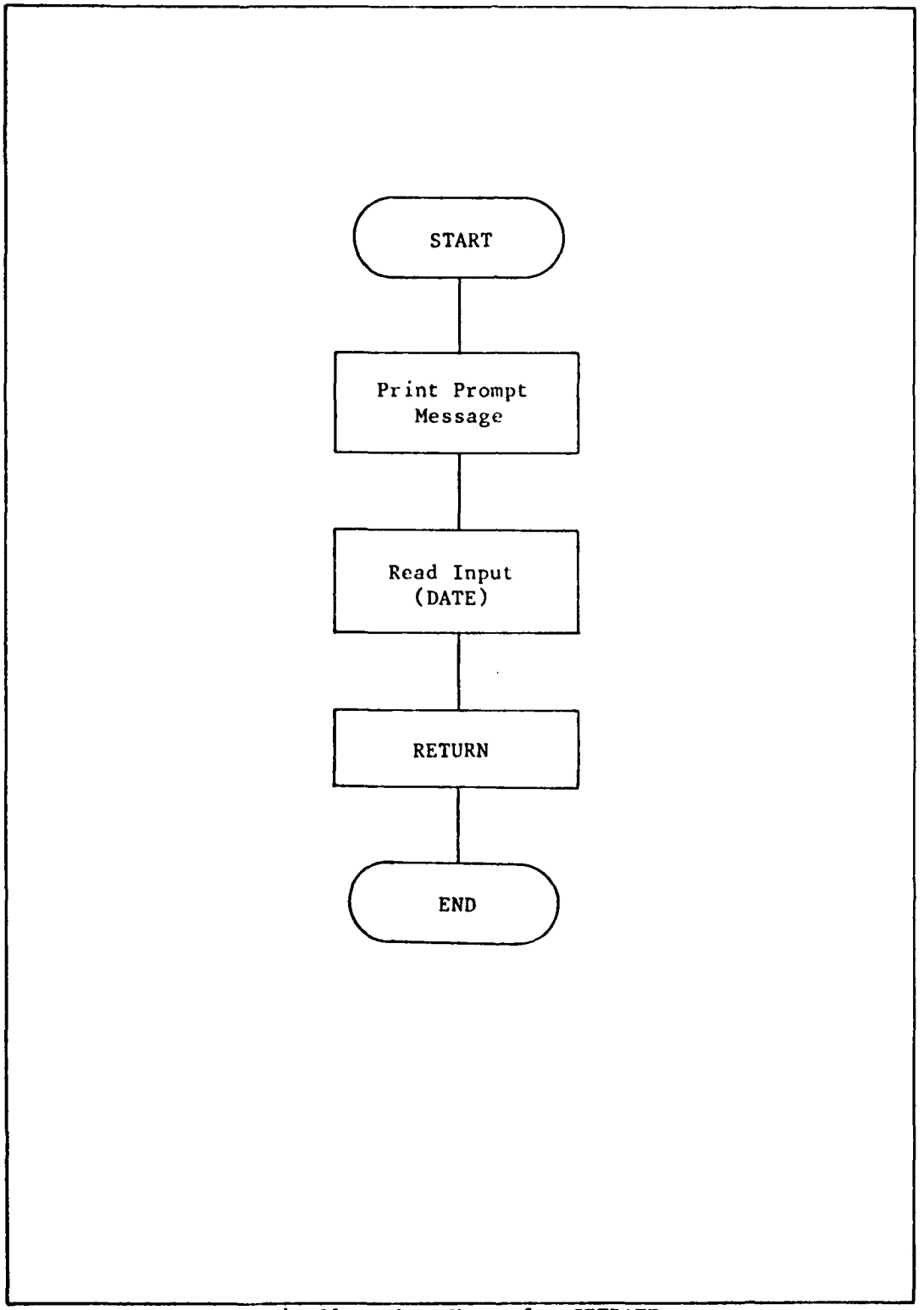

Fig 21. Flow Chart for GETDATE

```
FORTRAN IV   V02.1-11   Tue 27-Nov-79 00:00:00                PAGE 001
0001          SUBROUTINE GETDATE( DATE )
      C
      C DATE READS IN THE USER-SUPPLIED DATE AND STORES IT IN THE STRING
      C DATE.  UP TO 13 CHARACTERS ARE ALLOWED.  DATE IS ONLY USED IN
      C SUBROUTINE GRAPH TO PRINT OUT THE DATE.
      C
      C
0002          LOGICAL*1 DATE(13)
0003          INTEGER*2 I
      C
0004          TYPE 100
0005     100  FORMAT(/2X 'ENTER THE NEW DATE EX. 13-AUG-79<CR>'$)
0006          ACCEPT 200,(DATE(I),I=1.13)
0007     200  FORMAT(13A1)
0008          RETURN
0009          END
```

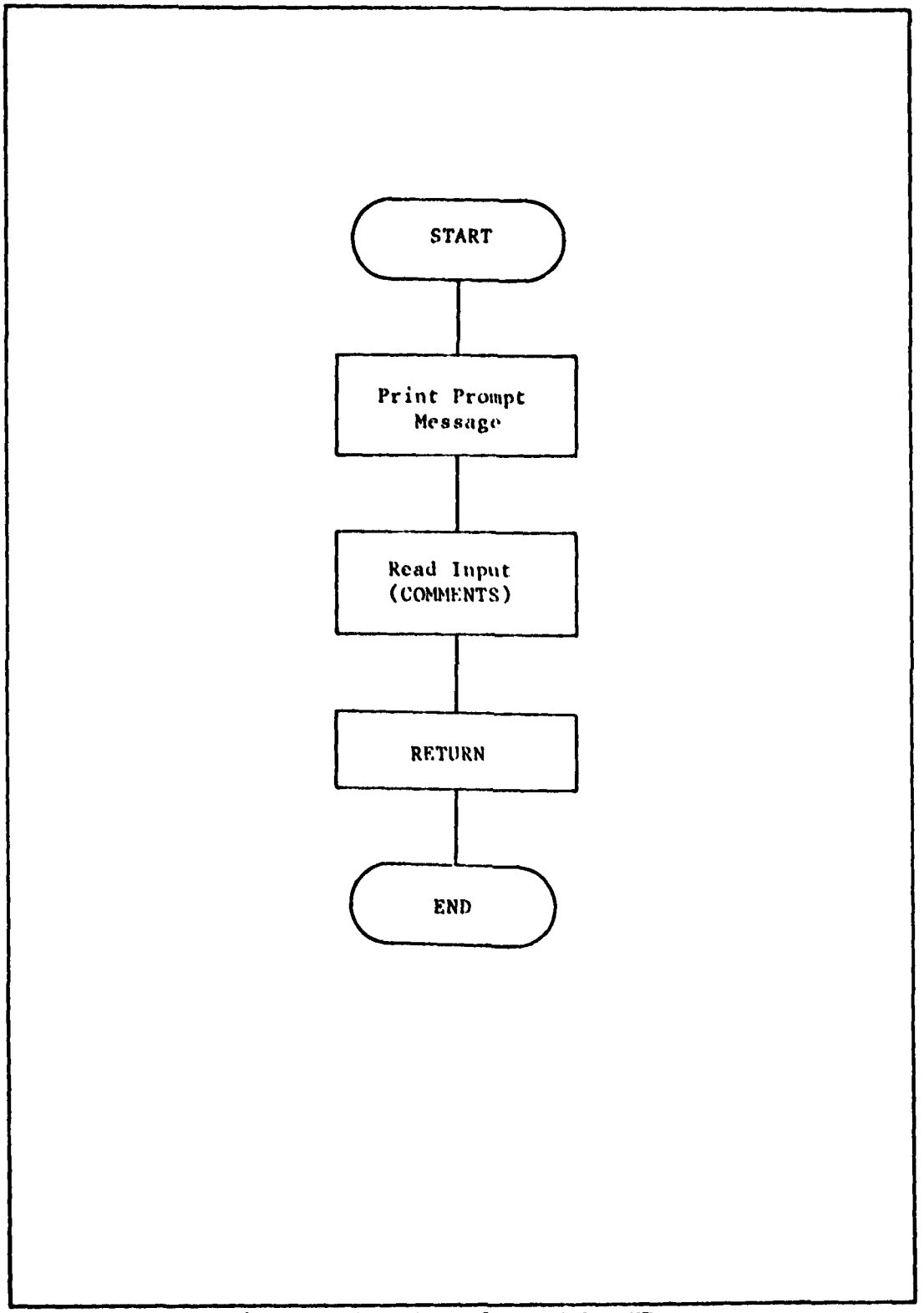

Fig 22. Flow Chart for GETCOMMENT

```
FORTRAN IV   V02.1-11   Tue 27-Nov-79 00:00 00                PAGE 001
0001          SUBROUTINE GETCOMMENT( COMMENTS )
      C
      C COMM READS IN USERS COMMENTS, UP TO 40 CHARACTERS
      C AND STORES THEM IN THE ARRAY COMMENTS. NO ERROR CHECKING
      C IS DONE.  WHAT EVER IS ENTERED WILL BE PRINTED ON THE
      C OUTPUT TABLE.
      C
0002          LOGICAL*1 COMMENTS(40)
0003          INTEGER*2 I
      C
      C
0004          DO 100,I=1,40
0005          COMMENTS(I)=' '
0006    100   CONTINUE
0007          TYPE 200
0008    200   FORMAT(/2X,'ENTER COMMENTS - 40 CHARACTERS MAX <CR>'$)
0009          ACCEPT 300,(COMMENTS(I).I=1.40)
0010    300   FORMAT(:40A1)
0011          RETURN
0012          END
```

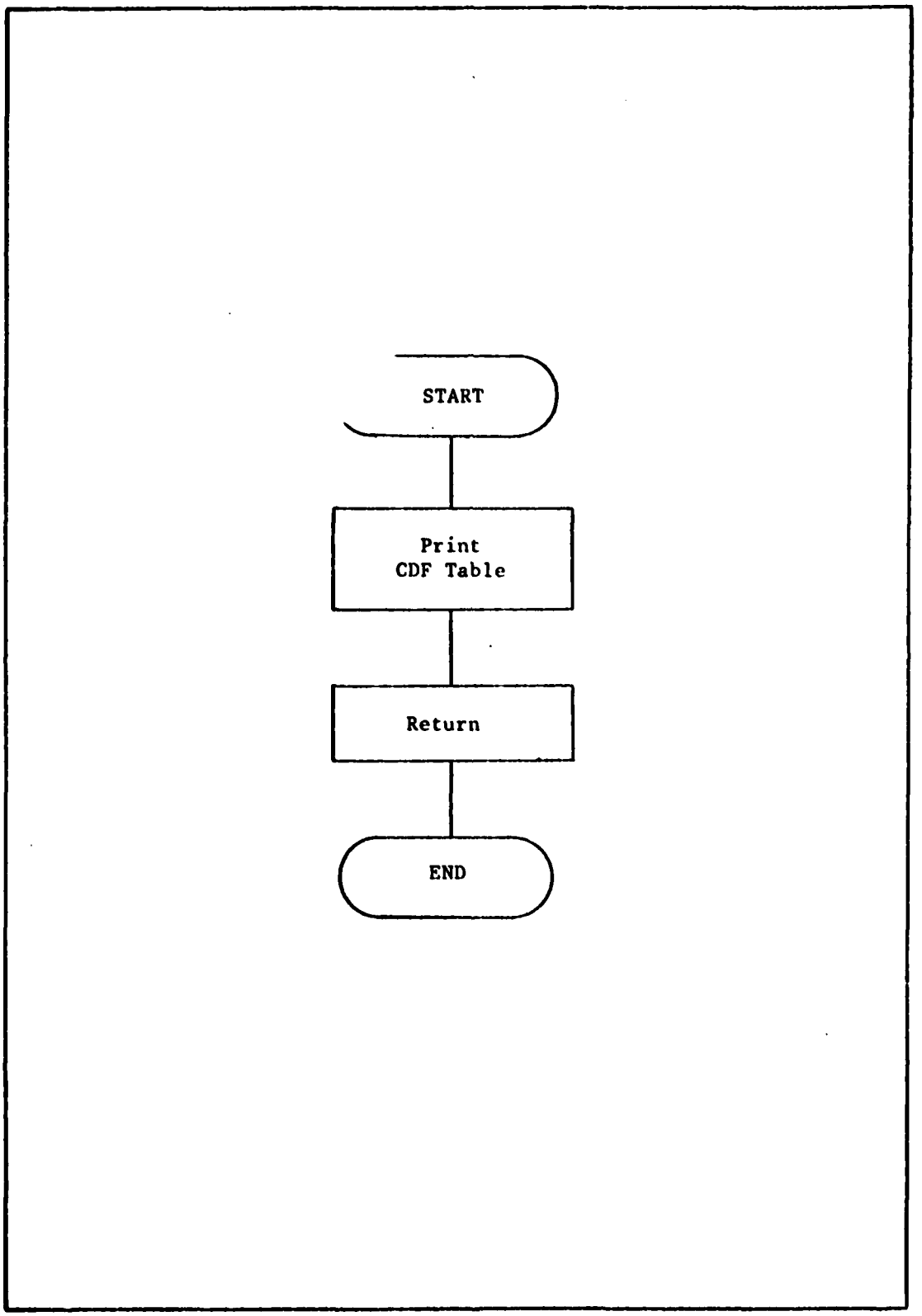

Fig 23. Flow Chart for CDFOUTPUT

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 13:28:27                PAGE 001
0001        SUBROUTINE CDFOUTPUT(CDF,NFREQ DELTAF,DATE,COMMENTS)
      C
      C
      C     OUTPUT IS USED TO PRINT OUT THE CDF ARRAY.  THE STRUCTURE OF
      C THE CDF ARRAY IS:
      C
      C     CDF(1,1)-                ;NFREQ NUMBER OF FREQUENCIES DELTAF APART
      C        .
      C        .
      C        .
      C
      C     CDF(NFREQ,1)      :(0-MAXFREQ)
      C     CDF(1,2)          ;START OF TEMP INTERVAL #2
      C     CDF(2,2)-
      C        .
      C        .
      C        .
      C
      C     CDF(NFREQ,2)
      C        .
      C        .
      C        .
      C
      C     CDF(1,12)
      C     CDF(2,12)
      C        .
      C        .
      C        .
      C
      C     CDF(120,12)
      C
      C
      C   THE VARIABLES USED IN THIS SUBROUTINE ARE:
      C
      C     CDF(120,12)              ;THE CUMULATIVE DAMAGE FACTOR ARRAY
      C     CONTENTS(40)      ;A STRING FOR USERS COMMENTS
      C                       ;THE USER WANTS ON THE OUTPUT
      C     DATE(13)          ;A STRING TO HOLD THE DATE WHICH WILL
      C                       ;BE PRINTED ON THE OUTPUT.
      C     DELTAF            ;THE FREQUENCY NFREQ BETWEEN ELEMENTS
      C                       ;OF THE CDF ARRAY
      C     FREQPAGE          ;THE FREQUENCY RANGE PER PAGE OF OUTPUT
      C     I J K,L           ;GENERAL PURPOSE INDEXES
      C     LARGE             ;A THREE CHARACTER ALPHA CONSTANT WHICH
      C                        WHEN SENT TO THE PRINTER, CAUSES 80
      C                       ;CHARACTERS PER LINE TO BE PRINTED
      C     LOW,HIGH          ;TWO INDEXING LIMITS USED TO CONTROL
      C                       ;THE TEMPERATURE SCALE PRINTING
      C                       ;LOW=1=-50 F;HIGH=7=100 F
      C                       ;LOW=6=75 F;HIGH=12=225 DEG F.
      C     HIGHFREQ          ;INDEX LIMITS TO CONTROL THE PRINTING
      C                       ;OF THE FREQUENCY IN THE TABLE
```

```
C     LOWTEMP,HIGHTEMP ;INDEX LIMITS TO CONTROL THE PRINTING
C                      ;OF THE TEMPERATURE IN THE TABLE
C     LTSYM            ;THE SYMBOL TO THE LEFT OF THE FIRST
C                      ;TEMPERATURE IN THE TABLE HEADING. IT IS
C                      ;EITHER A SPACE OR < (LESS THAN).
C     MAXFREQ          ;THE MAXIMUM FREQUENCY IN THE CDF ARRAY
C     NFREQ            ;THE NUMBER OF FREQUENCY COMPONENTS IN
C                      ;THE CDF ARRAY
C     NPAGE            ;THE NUMBER OF PAGES REQUIRED TO PRINT
C                      ;THE TABLE FOR ONE TEMPERATURE RANGE
C    /RTIME/RMINUTES   :THE ACTUAL DURATION OF THE TEST RUN
C     RTSYM            ;THE SYMBOL PRINTED TO THE LEFT OF THE
C                      ;LAST TEMPERTURE ON THE TABLE HEADING.
C                      :IT IS EITHER A SPACE OR A > (GREATER
C                      ;THAN)
C
C
C     TYPE DEFINITION
C
0002      LOGICAL*1 DATE(13),COMMENTS(40),LARGE(4),SMALL(4),LTSYM,RTSYM
0003      INTEGER*2 NFREQ,PAGE,LOWTEMP,HIGHTEMP,I,J,K,L,M,N
0004      INTEGER*2 LOW,HIGH,NPAGE,MINUTES
0005      REAL*4 DURATION,DELTAF,FREQ,CDF(120,12)
0006      REAL*4 MAXFREQ,HIGHFREQ,FREQPAGE
C
C  GLOBAL VARIABLE
C
0007      COMMON /RTIME/MINUTES
C
C  SMALL INITIALIZED FOR H14 PRINTER - 12 CHAR/INCH PRINTING.
C  LARGE - 80 CHAR/INCH.
C
0008      DATA SMALL/27,117,24,0/
0009      DATA LARGE/27,117,4,0/
C
C  PROGRAM EXECUTATION STARTS HERE.
C
0010      DURATION=MINUTES/60.
0011      NPAGE=(NFREQ/41)+1
0012      LOW = 1
0013      HIGH=7
0014      FREQPAGE=41.*DELTAF
0015      LOWTEMP=-50
0016      HIGHTEMP=100
0017      PAGE=0
0018      LTSYM='<'
0019      RTSYM=' '
0020      MAXFREQ=NFREQ*DELTAF
```

```
      C
      C  THE CDF TABLE FOR HALF OF THE TEMPERATURE RANGE IS NOW PRINTED OUT.
      C
0021        DO 150,I=1 2
0022        FREQ=DELTAF
0023        HIGHFREQ=0.
0024        K=0
0025        TYPE 80 LARGE
      C
      C  PRINTING OF EACH PAGE STARTS HERE.
      C
0026        DO 140,J=1 NPAGE
0027        HIGHFREQ=HIGHFREQ+FREQPAGE
0028        IF(HIGHFREQ.GT.MAXFREQ) HIGHFREQ=MAXFREQ
0030        TYPE 10
0031   10   FORMAT(1H1////)
0032        PAGE=PAGE+1
0033        TYPE 20,PAGE
0034   20   FORMAT(24X 'CUMULATIVE DAMAGE MATRIX'13X,'PAGE ',I2/)
0035        TYPE 30,DATE
0036   30   FORMAT(1X 'DATE' 6X 13A1)
0037        TYPE 35,DURATION
0038   35   FORMAT(1X  DURATION',2X,F5.2 ' HOURS')
0039        TYPE 40,COMMENTS
0040   40   FORMAT(1X,'COMMENTS' 2X 40A1/)
0041        TYPE 50
0042   50   FORMAT(1X, FREQ (HZ)' 18X 'TEMPERATURE  (DEG F)')
0043        TYPE 70,LTSYM,(L,L=LOWTEMP HIGHTEMP-25 25),RTSYM,HIGHTEMP
0044   70   FORMAT(9X,A1,5(I3,7X),I3,6X A1,I3)
0045        TYPE 80 SMALL
0046   80   FORMAT('+',3A1)
0047        TYPE 90
0048   90   FORMAT(7X,86('-'))
      C
      C  CDF DATA IS PRINTED BY THE FOLLOWING CODE
      C
0049   100  IF (FREQ.GT HIGHFREQ) GO TO 130
0051        K=K+1
0052        TYPE 110,FREQ,(CDF(K,N),N=LOW HIGH)
0053   110  FORMAT(1X,F5.0,1X,'|' 7(1X E10.3 1X),'|')
0054        FREQ=FREQ+DELTAF
0055        GO TO 100
0056   130  CONTINUE
      C
      C  END OF PRINTING TABLE; NOW PRINT TEMP AXIS.
      C
0057        TYPE 90
0058        TYPE 80 LARGE
0059        TYPE 70,LTSYM,(L L=LOWTEMP HIGHTEMP-25,25),RTSYM HIGHTEMP
0060        TYPE 50
0061        K=K-1
0062        FREQ=FREQ-DELTAF
0063   140  CONTINUE
```

```
C
C  SET VARIABLES TO PRINT HIGH TEMPERATURE RANGE.
C
0064        LOW=6
0065        HIGH=12
0066        LOWTEMP=75
0067        HIGHTEMP=225
0068        LTSYM=' '
0069        RTSYM='>'
0070   150  CONTINUE
0071        RETURN
0072        END
```

Appendix B

Flow Charts and Source Code for Data Processing and Execution Modules

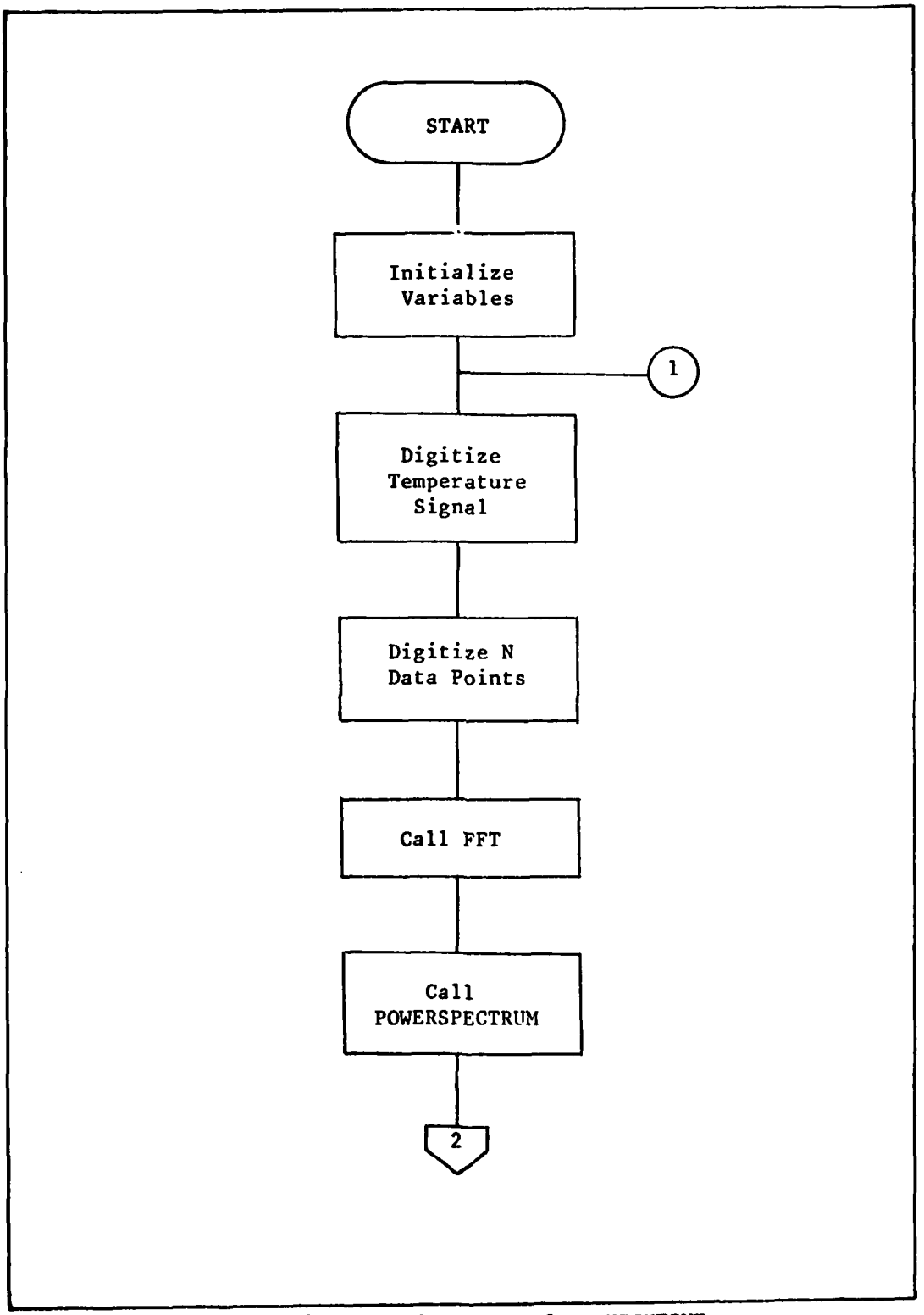

Fig 24. Flow Chart for EXECUTIVE

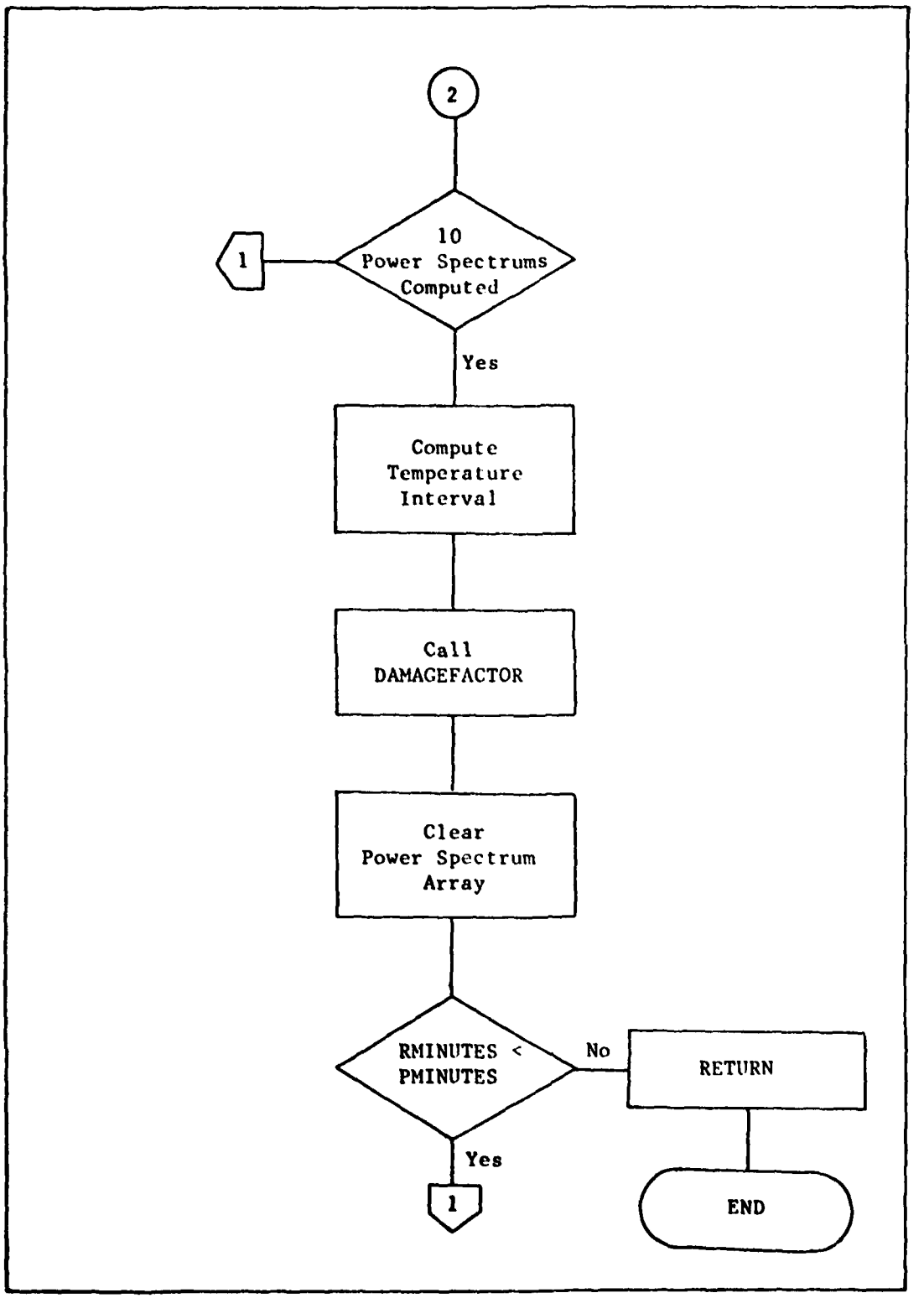

Fig 24. Flow Chart for EXECUTIVE (cont)

```
                        .TITLE EXECUTIVE
                    ;.SBTTL INTRODUCTION TO CONTROL EXECUTIVE
                    ;
                    ;

                    ;
                    ;1. INTRODUCTION TO CONTROL EXECUTIVE:
                    ;-------------------------------------
                    ;   THIS PART OF THE CONTROL EXECUTIVE GETS CONTROL OF
                    ;THE SYSTEM ONCE POWER HAS BEEN SWITCHED ON AND THE
                    ;RUN/STANDBY SWITCH HAS BEEN PLACED IN RUN POSITION. THE
                    ;EXECUTIVE WILL RELINQUISH CONTROL IF THE POWER
                    ;HAS BEEN SWITCHED OFF, THE SYSTEM HAS BEEN SWITCHED
                    ;TO STANDBY MODE. OR THE RUN TIME HAS EXPIRED.
                    ;
                    ;
                    ;NOTE: THE GLOBL DATA STORAGE AREAS ARE DEFINED BELOW
                    ;---------------------------------------------------
                    ;
                            .GLOBL B BITCOUNT,COUNT,INTCELNUM
                            .GLOBL N,N2,NM,NINTVL,TFLG
                            .GLOBL  EXEC BEGIN,RTCRATE,RTCMODE TIMEINT
                            .GLOBL  ADDATA PWRSPC,CDFDATA
                            .GLOBL INDX,RTIME PTIME,ER,ADGAIN

                    ;
                    ;NOTE: THE GLOBAL SUBROUTINES ARE DEFINED BELOW
                    ;----------------------------------------------
                    ;
                            .GLOBL  FFT POWERSPECTRUM,DAMAGEFACTOR
                    ;
                    ;
                    ;NOTE: THE REGISTERS ARE DEFINED BELOW
                    ;-------------------------------------
                    ;
                            .MCALL  .REGDEF
                                    .REGDEF
```

DEFINITION OF DEVICES

```
1       .SBTTL DEFINITION OF DEVICES
2       ;2. DEFINITION OF DEVICES:
3       ;-------------------------
4           THE DEVICES THAT ARE CALLED IN BY THE EXECUTIVE
5       ;ARE DEFINED HERE.
6       ;
7       ; ANALOG TO DIGITAL CONVERTOR (ADC)
8       ;-----------------------------------
9       ;
10      ;
11      ;
12      ADCSR=170400            ;ADC CONTROL AND STATUS
13                              ;REGISTER.
14      ADBFR=170402            ;ADC DATA BUFFER REGISTER
15
16      .PSECT ADGAIN,RW,D,GBL,REL,OVR
17      ADGAIN: 0               ;ADGAIN IS FOR FUTURE
18      .PSECT                  ;IMPLEMENTATION. IT WILL CONTAIN
19                              ;THE GAIN OF THE VIBRATION SIGNAL
20                              ;AMPLIFIER.
21      ;
22      ; REAL TIME CLOCK (RTC)
23      ;---------------------
24      ;
25      ;
26
27      RTCSR=170420            ;RTC CONTROL AND STATUS REG
28
29      RTBFR=170422            ;RTC DATA BUFFER REGISTER
30      ;
31      ;NOTE:
32      ;-----
33      ;       BEFORE THESE POINTS ARE PROCESSED, THE PROCESS
34      ;      LOOP COUNTER (PRCLOP) IS DEFINED
35      ;      AND INITIALIZED BELOW
36      ;
37      PRCLOP: .WORD 11        ;THIS COUNTER IS USED TO
38                              ;DETERMINE HOW MANY POWER
39                              ;SPECTRUM SETS HAVE TO BE
40                               ADDED TOGETHER.
41                              ;12(OCTAL) INTERVALS 0-11.
```

INTERRUPT SERVICE ROUTINE.

```
1       .SBTTL INTERRUPT SERVICE ROUTINE.
2       ;3. INTERRUPT SERVICE ROUTINE:
3       ;-----------------------------
4        TIME INTERRUPT ROUTINE
5
6       ;AN EXTERNAL INTERRUPT (A TIME SIGNAL EVERY MINUTE)
7       ;CAUSES A BRANCH TO THIS ROUTINE WHICH INCREMENTS
8       ;THE MINUTES COUNTER - RTIME.
9       ;
10      TIMEINT: INC    TIME            ;INCREMENT TIME BY ONE COUNT
11               CMP    #74.TIME        ;WHEN TIME EQUALS 60 (BASE 10)
12                                      ;INCREMENT RTIME 1.IF THE SYSTEM
13                                       CLOCK IS SET TO 60HZ RTIME
14                                       WILL BE IN HOURS.  IF IT IS
15                                       SET TO 1HZ RTIME WILL BE IN MIN.
16               BNE    TIM
17               INC    RTIME
18               CLR    TIME            ;RESET TIME TO 0.
19      TIM      RTI
20
21
22      ;
23      ;
24      ;4. REAL TIME ERROR ROUTINE.
25      ;---------------------------
26      ;
27      ;THIS ERROR ROUTINE IS DESIGNED TO HANDLE REAL-TIME ERRORS.
28      ;IF THE ANALOG DATA IS BEING SAMPLED TOO FAST, THIS ROUTINE
29      ;IS CALLED.  A LOCAL VARIABLE "ER" IS A COUNTER WHICH
30       INDICATES THE NUMBER OF TIMES THIS ROUTINE HAS BEEN CALLED.
31      ;IT IS FOR MAINTENCE PURPOSES ONLY.  "ER" CAN BE EXAMINED
32      ;USING ODT.
33      ;
34      ERROR:  MOV     #0 @#RTCSR      ;STOP RTC
35              MOV     @#ADBFR (R3)    ;CLEAR A/D DONE FLAG.
36              BIC     #100200,@#ADCSR ;CLEAR A/D ERROR FLAG.
37              INC     ER              ;INCREMENT ERROR COUNTER.
38              BR      ERRTN           ;RETURN
39      TMPERR: MOV     (R1),R3  REMOVE BAD DATA & CLEAR DONE FLAG.
40                                      ;DONE FLAG.
41              BIC     #100000,(R0)    ;CLEAR ERROR FLAG.
42              INC     (R0)            ;RESTART CONVERSION.
43              BR      LOOP
```

```
        .SBTTL FPASS --FIRST PASS THROUGH THE EXECUTIVE
              .SBTTL PROCESSING CONTROL
        ;
        ;5. PROCESSING CONTROL:
        ;----------------------
        ;   THE TEMPERATURE SIGNAL IS SAMPLED FIRST. THE DIGITIZED
        ;VALUE IS SUMMED IN A  STORAGE VARIABLE "TSUM".
        ;   THEN A SET OF N FREQUENCY DATA POINTS ARE DIGITIZED.
        ;THE FOURIE TRANSFORM, POWER SPECTRUM, ARE THEN COMPUTED. THIS
        ;PROCESS - ACQUIRE TEMPERATURE DATA  FREQUENCY DATA, COMPUTE
        ;THE FFT AND THE POWER SPECTRUM - IS PERFORMED TEN TIMES FORMING
        ;THE AVERAGE POWER SPECTRUM AND THE AVERAGE TEMPERATURE.
        ;   THESE AVERAGE VALUES ARE THEN USED TO COMPUTE THE CUMULATIVE
        ;DAMAGE FACTOR
        ;
        EXEC:   JSR     PC,INITAL       ;INITIALIZE VARIABLES
        BEGIN:  MOV     @#ADBFR R0      ;CLEAR AD BUFFER AND DONE FLG.
                MOV     #ADCSR,R0       ;MOVE ADDRESS OF ADCSR AND ADBFR
                MOV     #2400,(R0)      ;SET TEMP CONVERSION  CH=05
                                         AND START TEMP CONVERSION.
                MOV     #ADBFR R1       ;INTO REGISTERS FOR FASTER
                                        ;INSTRUCTION EXECUTION IN THE
                                        ;TIME CRITICAL LOOP (LOOP2)
                                        ;WHICH FOLLOWS.
        ;
                INC     (R0)            ;START TEMP ACQUISITION.
        LOOP    TSTB    (R0)            ;WAIT FOR TEMPERATURE CONVERSION
                BPL     LOOP            ;TO BE COMPLETED
                BIT     #100000,(R0)    ;CK FOR A/D ERROR
                BNE     TMPERR
                MOV     (R1),R3         ;GET TEMP.
                SUB     #4000,R3        ;REMOVE BIAS
                ADD     R3,TSUM         ;ADD TEMP TO FORM A AVERAGE TIMES
                                         12(OCTAL)
                MOV     #7040,(R0)      ;LOAD ADCSR- CH=16,INTERRUPT
                                        ;DISABLED
          NOTE:
        ;*****************************************************************
        ;
         THE ADGAIN OF THE VIBRATION SIGNAL AMPLIFIER WILL BE DETERMINED
        ;HERE.  THIS HAS NOT YET BEEN IMPLEMENTED SO THE VARIABLE
        ;"ADGAIN" IS SET EQUAL TO 1, SO THAT IT HAS NO EFFECT ON THE
        ;POWER SPECTRUM CALCULATION MADE IN POWERSPECTRUM
        ;
                MOV     #1,ADGAIN
        ;
         *****************************************************************
        ;
                MOV     ADDATA R3       ;LOAR R3 WITH LOC FOR DATA
                MOV     N,R2            ;LOAD R2 WITH THE # OF DATA POINTS
                MOV     RTCRATE,@#RTBFR ;SET RT COUNTER TO -RTRATE
```

PROCESSING CONTROL

```
 1              MTPS    #340            ;DISABLE ALL INTERRUPTS
 2                                      ;(TIME INTERRUPTS)
 3      ERRTN:  MOV     RTCMODE,@#RTCSR ;START RTC MODE 1,10K HZ.
 4      ;
 5      ;NOTE:
 6      ;-----
 7      ;
 8       THE LOOP STARTING AT "LOOP:" AND GOING THROUGH   SOB  R2,LOOP  IS
 9      ;A TIME CRITICAL LOOP. IT IS THE A/D CONVERSION ROUTINE WHICH IS
10      ;FASTER THAN AN INTERRUPT ROUTINE.
11      ;  THE EXECUTION TIME OF THE LOOP MUST BE LESS THAN THE AD CONVERSION
12      ;TIME OR THE SAMPLING PERIOD, WHICHEVER IS SMALLER.
13      ;
14      ;
15      LOOP2:  TSTB    (R0)    ;WAIT FOR AD CONVERSION
16              BPL     LOOP2           ;TO FINISH.
17              BIT     #100000,(R0)    ;DONE: CK FOR A CONVERSION ERROR
18              BNE     ERROR           ;ERROR: GO TO ERROR ROUTINE
19              MOV     (R1),(R3)       ;MOVE DATA INTO DATA ARRAY
20              SUB     #4000,(R3)+     ;REMOVE 4000 BIAS AND INC R3
21              SOB     R2,LOOP2                ;GO GET MORE DATE UNTILL ALL
22                                      ;DATA POINTS HAVE BEEN PROCESSED
23      ;
24      ;
25      END OF TIME CRITICAL SECTION
26      .
27              CLR     @#RTCSR         ;STOP RTC.THE RTC MUST BE STOPPED
28                                       SO THE PROPER START-UP SEQUENCE
29                                      ;STARTING AT LOOP2 IS EXECUTED.
30              MTPS    #0               ENABLE INTERRUPTS
31              JSR     PC,FFT
32      ;NOTE:
33      ;-----
34      ;       AT THIS POINT, THE VALUE OF SFACTR WILL SHOW
35              THE NUMBER OF BITS THE FOURIER TRANSFORMED ARRAY
36              HAS BEEN SHIFTED 1-BIT TO THE RIGHT.
37      ;
38      ;
39              JSR     PC,POWERSPECTRUM
40
```

PROCESSING CONTROL

```
1       ;
2       ;
3       ;
4               TST     PRCLOP          ;IS PRCLOP=0
5               BEQ     TEMP            ;IF NOT GO BACK
6               DEC     PRCLOP          ;COMPUTE ANOTHER SET OF
7               JMP     BEGIN           ;POWER SPECTRUM.
8       ;
9
10      ;NOTE:
11      ;
12      ;BEFORE DF IS CALCULATED, THE
13      ;THE TEMPERATURE INTERVAL IS
14      ;DETERMINED, AND "TFLG" IS
15      ;LOADED WITH THE APPROPRIATE
16      ;VALUE.
17      ;
18      ;
19       TEMP:  MOV     #TINTVL,R1
20              MOV     #13,R2
21              MOV     #1 TFLG
22       IN3:   CMP     TSUM,(R1)+
23              BLE     IN5
24              INC     TFLG
25              SOB     R2,IN3
26       IN5:   BR      DAMGE
27      ;
28      ;INTVL     1       2       3       4
29      TINTVL  164413,170452,174561 000737
30      ;TEMP:   -37.5  -12.5  12.5   37.5
31      ;INTVL     5       6       7       8
32              005166,011466,016034,022453
33      ;TEMP:   62.5   87.5   112.5  137 5
34      ;INTVL: 9       10      11      12
35              027022,033371 040010.044427
36      ;TEMP: 162.5   187.5   212.5   237.5
```

PROCESSING CONTROL

```
1       :
2       ;PROCESSING CONTROL CONTINUED.......
3       ;
4
5       DAMGE:  JSR     PC DAMAGEFACTOR  COMPUTE DF
6       ;
7       ;NOTE: ONCE THE DF IS COMPUTED, THE WHOLE LOOP
8       ;      IS REPEATED AGAIN. THE FOLLOWING CLEARS
9       ;      THE REQUISITE VARIABLES AND ARRAYS.
10      ;
11      ;
12              CLR     TSUM
13              MOV     #11 PRCLOP
14      ;
15              MOV     #PWRSPC R0      ;THE POWER SPECTRUM
16                                       IS NOW CLEARED.
17              MOV     NINTVL,R1       ;LOAD R0 WITH THE
18                                       STARTING ADDRESS AND
19                                      ;R1 WITH ITS SIZE.
20
21      CLEAR:  CLR     (R0)+
22              SOB     R1,CLEAR
23      ;
24      ;PTIME IS A GLOBAL VARIABLE INITIALIZED IN
25      ;SUBROUTINE SETUP IN MFDM. IT IS THE TIME  IN MINUTES,
26      ;FOR WHICH THE TEST SHOULD RUN. RTIME IS A GLOBAL
27      ;VARIABLE WHICH IS THE ACTUAL RUN TIME RETURNED
28       TO MFDM .
29      ;RTIME IS NOW CHECKED AGAINST PTIME AND
30      ;IF RTIME IS LESS THAN PTIME  PROCESSING CONTINUES
31      ;ELSE CONTROL IS RETURNED TO MFDM OR THE SYSTEM
32      ;HALTS (IF RUNNING WITH OUT A TERMINAL).
33      ;
34              CMP     PTIME,RTIME     ;IF PLANNED RUN TIME
35              BGT     BEGIN           ;> RUN TIME CONTINUE
36              RTS     PC              ;ELSE RETURN
37      ;
38      ;
39      END OF PROCESSING CONTROL
```

DATA STRUCTURE AND VARIABLES USED

```
1       .SBTTL DATA STRUCTURE AND VARIABLES USED
2       ;
3       ;
4       ·6. DATA STRUCTURE AND VARIABLES USED:
5       ;-----------------------------------
6       ;  THE DATA STRUCTURE WHICH IS USED TO STORE ACQUIRED
7       ;DATA AND DIFFERENT VARIABLES USED ARE GIVEN BELOW:
8       ;
9       ;
10      .PSECT NINTVL RW,D,GBL,REL OVR
11              NINTVL  .WORD   0
12      .PSECT TFLG,RW,D,GBL,REL,OVR
13              TFLG:   .WORD   0
14      .PSECT ADDATA RW D,GBL,REL,OVR
15              DATALOC .REPT   400
16                      .WORD   0
17                      .ENDM
18      ;
19              ADDATA· DATALOC
20      ;
21      .PSECT PTIME RW,D,GBL,REL,OVR
22              PTIME   .WORD 0
23      ;
```

INITIALIZE

```
1       .SBTTL INITIALIZE
2       .PSECT
3       ;
4
5       ;1. DESCRIPTION
6       ;--------------
7       ;
8       ;THIS SUBROUTINE IS USED TO INITIALIZE VARIOUS
9       ;PARAMETERS USED IN EXEC AND FOURIE.  TWO PARAMETERS
10      ;(B AND INDX) ARE INITIALIZED BY SUBROUTINE SETUP WHICH
11      ;IS CALLED BY MFDM. THESE TWO VARIABLES ARE USED TO
12      ;INITIALIZE THE REST OF THE VARIABLES IN THIS ROUTINE.
13      ;
14      ;THE VARIABLES WHICH ARE INITIALIZED IN THIS
15      ;SUBROUTINE ARE:
16      ;
17      ;BITCOUNT        A COUNTER USED IN THE FOURIE
18      ;                BIT INVERSION ROUTINE  IT IS
19      ;                EQUAL TO THE NUMBER OF BITS
20                       IN THE NUMBER - (2**B)-1.
21      ;                OR BITCOUNT=B-1.
22      ;
23      ;COUNT           A COUNTER USED IN FOURIE AND
24      ;                INITIALIZED TO HALF THE NUMBER
25      ;                OF COMPLEX DATA POINTS.
26      ;                POSSIBLE VALUES ARE 64 32,16,8
27      ;
28      ;ER              A COUNTER USED IN EXEC WHICH
29      ;                CONTAINS THE NUMBER OF TIMES
30      ;                THE ERROR ROUTINE WAS ENTERED
31      ;
32      ;INTCELNUM       AN INITIAL VALUE FOR "CELNUM"
33      ;                WHICH IS USED IN FOURIE-
34      ;                "2ND PASS AND ONWARD" ROUTINE.
35      ;                POSSIBLE VALUES ARE 32,16,8,4
36      ;
37      ;N               THE NUMBER OF DATA POINTS TO BE
38      ;                PROCESSED. USED IN EXEC AND
39      ;                FOURIE. POSSIBLE VALUES ARE
40      ;                256,128,64,32.
41      ;
42      ;N2              THE NUMBER OF "COMPLEX" DATA POINTS
43      ;                USED IN FOURIE  POSSIBLE VALUES
44      ;                ARE 128 64,32 16.
45      ;
46      ;NM              AN INDEX USED IN FOURIE- POST
47      ;                PROCESSING" ROUTINE. IT IS
48                       INITIALIZED TO THE RELATIVE
49      ;                LOCATION OF THE N-1 COMPLEX
50      ;                DATA POINT. POSSIBLE VALUES ARE
51      ;                774 374,174 74.
```

```
1       ;
2       ;2. INITIALIZATION
3       ;-----------------
4       ;
5       INITAL  MOV     #TIMEINT,@#100  ;PUT INTERRUPT ADDR. IN LOC 100
6               MOV     #0,@#102        ;INTERRUPT PRIORITY=0
7               MOV     #1,R0           ;N=2**B
8               ASH     B,R0
9               MOV     R0,N
10      ;
11              MOV     R0,NM           ;NM=2(N-2)
12              SUB     #2,NM
13              ASL     NM
14
15              ASR     R0              ;N2=N/2
16              MOV     R0,N2
17      ;
18              ASR     R0              ;COUNT=N2/2
19              MOV     R0,COUNT
20      ;
21              ASR     R0              ;INTCELNUM=COUNT/2
22              MOV     R0,INTCELNUM
23      ;
24              CLR     ER              ;ER=0
25              CLR     RTIME           ;INITIALIZE RUN TIME
26              CLR     TIME            ;AND THE TIME COUNTERS.
27      ;
28              MOV     B,BITCOUNT      ;SET BITCOUNT=B-1
29              SUB     #1,BITCOUNT
30              CLR     TSUM
31      ;
32      ;
33              MOV     #PWRSPC,R0      ;THE POWER SPECTRUM
34                                      ;IS NOW CLEARED
35              MOV     #360,R1         ;LOAD R0 WITH THE STARTING
36                                      ;AND R1 WITH THE SIZE OF
37      CLEAR1: CLR     (R0)+           ;THE ARRAY (127 DECIMAL).
38              SOB     R1,CLEAR1       ;CLEAR THE ARRAY.
39              MOV     #CDFDATA,R0     ;REPEAT FOR THE CDF ARRAY.
40              MOV     #5500,R1
41      CLEAR2: CLR     (R0)+
42              SOB     R1,CLEAR2
43              RTS     PC
```

DEFINITION OF DEV

```
1               .SBTTL DEFINITION OF DEV
2       .PSECT RTCRATE,RW,D,GBL.REL OVR
3
4       RTCRATE:.WORD 0          ;REAL TIME CLOCK OVERFLOW
5                                ;RATE CONTROL. OVERFLOW SIGNAL
6                                 RATE   CLOCK FREQUENCY/RTC-RATE
7
8       .PSECT RTCMODE RW.D.GBL.REL,OVR
9
10      RTCMODE:.WORD 0          ;REAL TIME CLOCK SETTING FOR
11                               ;THE RTC CSR.
12      TSUM    .WORD 0
13      TIME:   .WORD 0
14      N       .WORD 0
15      .PSECT N2,RW,D GBL,REL,OVR
16      N2:     .WORD 0
17      NM      .WORD 0
18      COUNT:  .WORD 0
19      INTCELNUM: .WORD 0
20      .PSECT ER,RW.D,GBL.REL,OVR
21      ER      .WORD 0
22      .PSECT B RW D.GBL,REL,OVR
23      B:      .WORD 0
24      BITCOUNT:  .WORD 0
25      .PSECT INDX,RW,D,GBL,REL,OVR
26      INDX:   .WORD 0
27      .PSECT RTIME RW,D,GBL.REL,OVR
28      RTIME   .WORD 0
29      .PSECT PWRSPC RW,D,GBL,REL.OVR
30      PWRSPC: .REPT   360
31              .WORD   0
32              .ENDM
33      .PSECT CDFDATA,RW.D.GBL,REL,OVR
34
35      CDFDATA: .REPT  5500
36              .WORD   0
37              .ENDM
38              .END
```

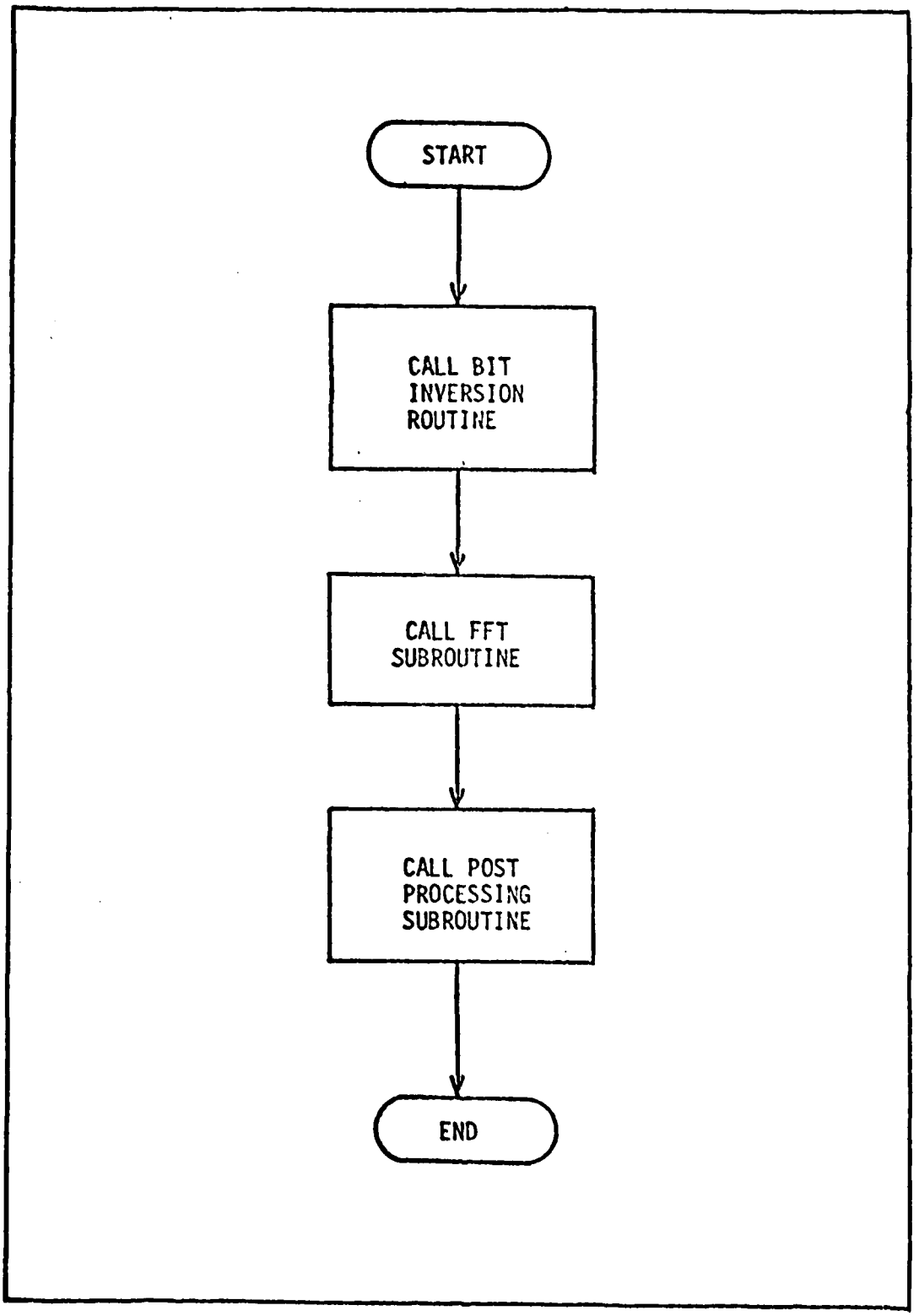

Fig 25. Flow Chart for FFT (Ref 7:78-90)

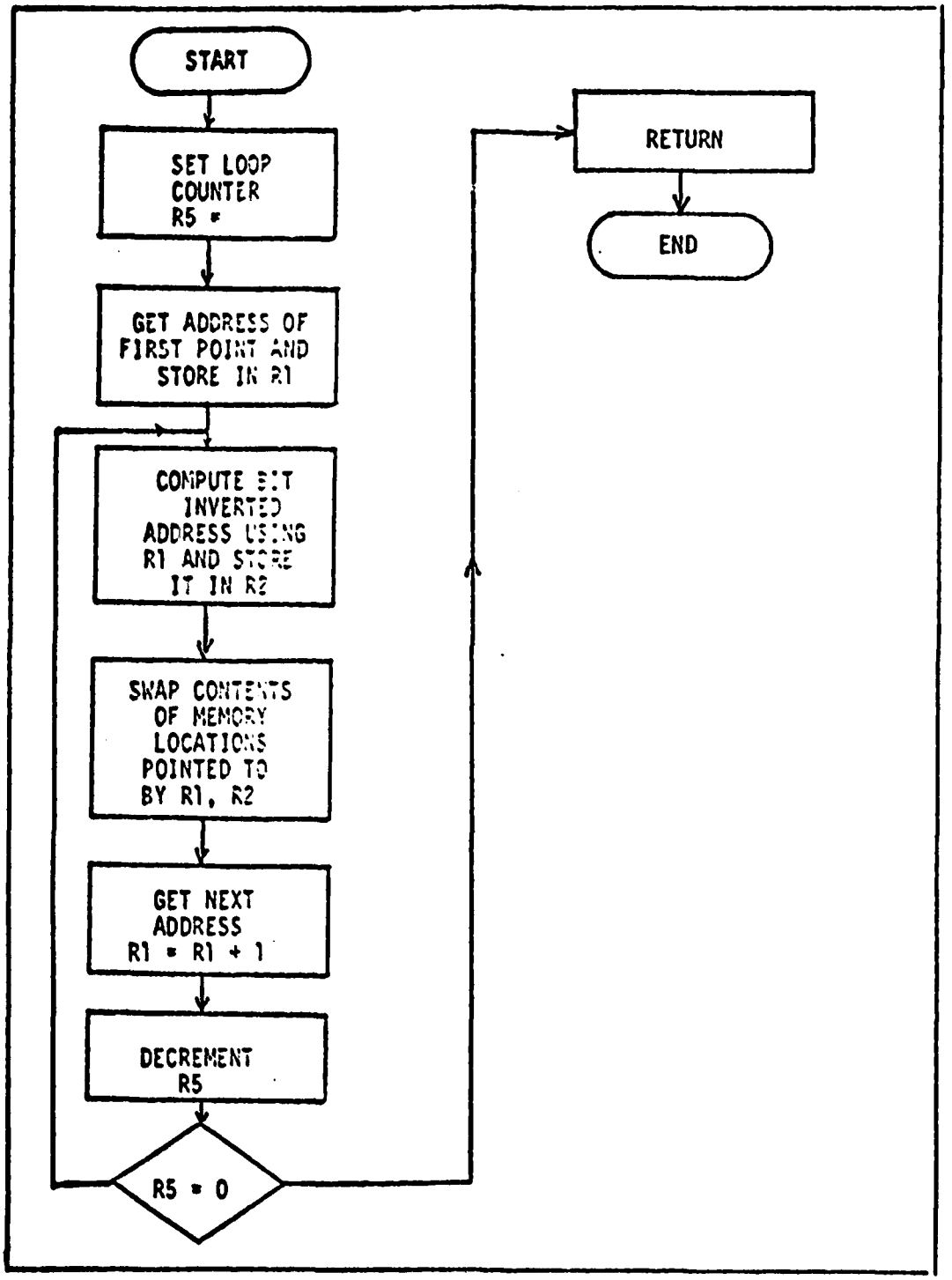

Fig 25. Flow Chart for FFT (cont) - Bit Inversion Routine

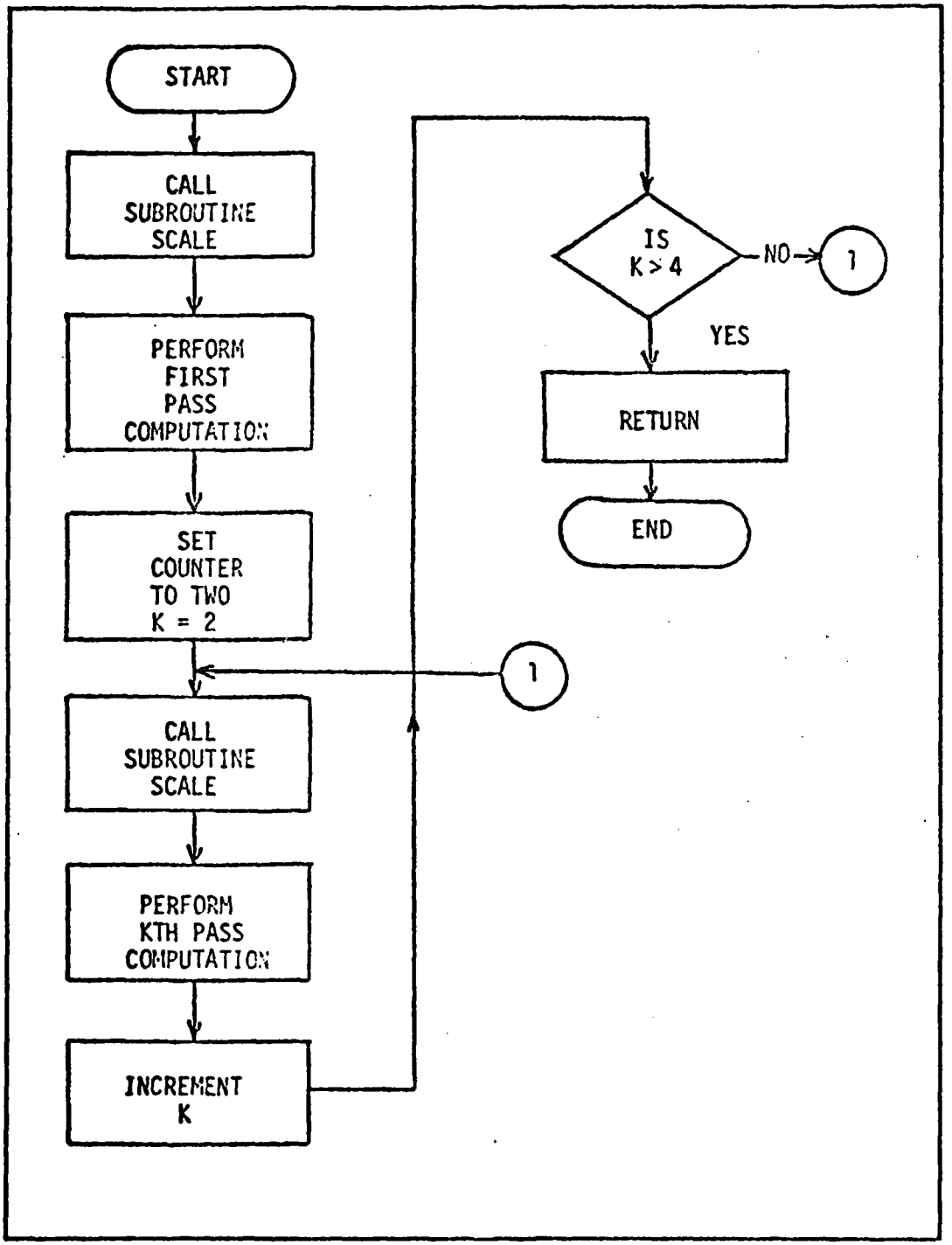

Fig 25. Flow Chart for FFT (cont) - Fast Fourier Transform

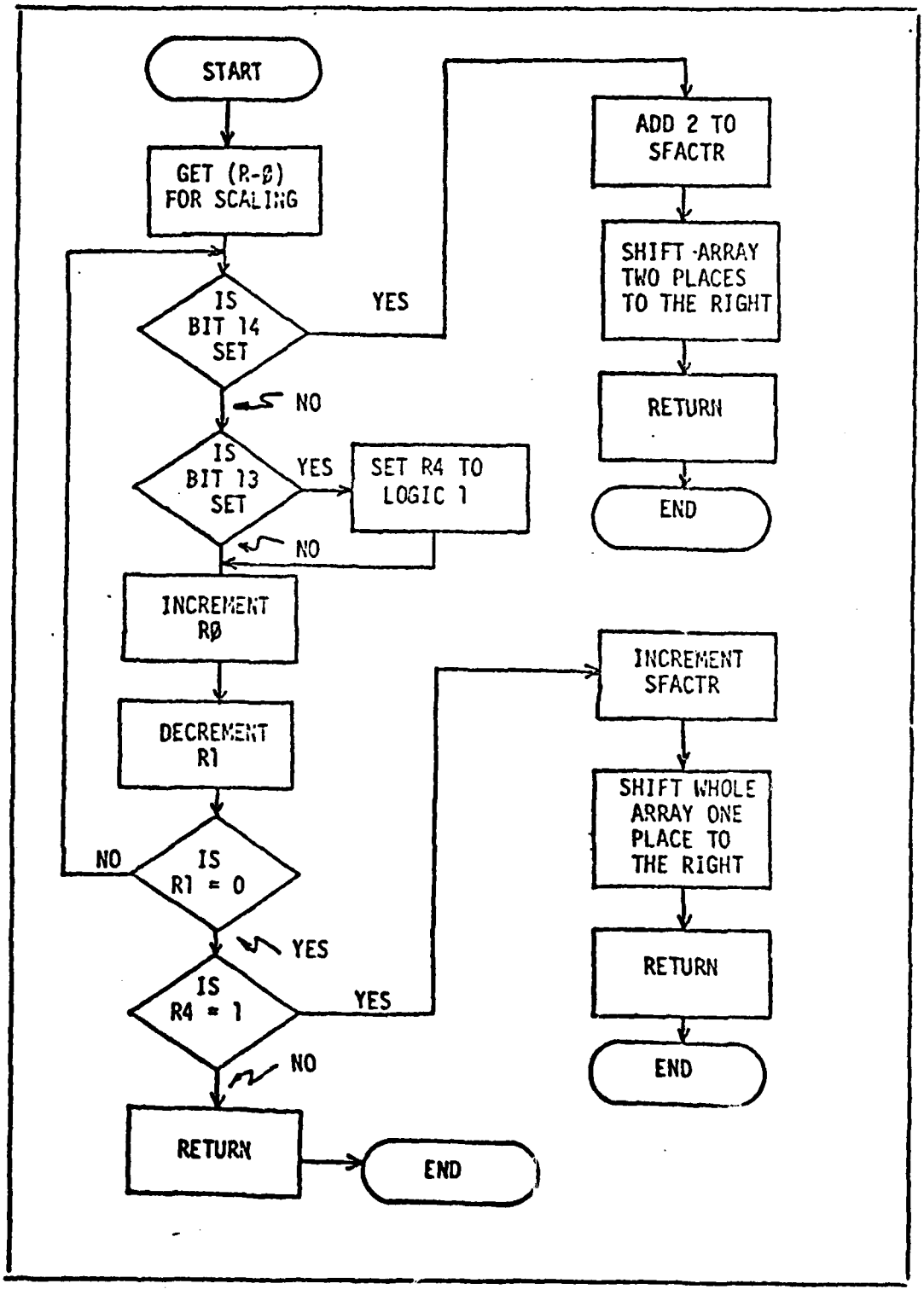

Fig 25. Flow Chart for FFT (cont) - Scale Routine

```
 1
 2       .TITLE FFT --FFT SUBROUTINE
 3       .SBTTL INTRODUCTION --INTRO  TO FFT AND ITS USE.
 4       .CSECT
 5       ;
 6
 7       ; 1. DESCRIPTION:
 8       ; ---------------
 9       ;    THIS SUBROUTINE CAN BE USED TO TRANSFORM "N" REAL
10       ; DATA POINTS. IT ASSUMES THE DATA EQUIVALENT TO "N2"
11       ; COMPLEX POINTS (THE ODD REAL POINTS ARE CONSIDERED
12       ; REAL PARTS AND THE EVEN PARTS ARE CONSIDERED COMPLEX)
13       ; AFTER THE TRANSFORMATION, A POST PROCESSING OF DATA GIVES
14       ; "N2" FOURIER TRANSFORMED FREQUENCY COMPONENTS (THE OTHER
15       ; "N2" COMPONENTS ARE THE COMPLEX CONJUGATES OF THESE
16       ; VALUES).
17       ;
18       ;
19       ; 2. GLOBAL SYMBOLS:
20       ;   -----------------
21       ;       THE FOLLOWING SYMBOLS OF "FFT" ARE INITIALIZED
22       ; OR USED IN OTHER ROUTINES THAT ARE CALLED BY EXEC.
23       ;
24        .GLOBL FFT ADDATA,N,N2 NM,COUNT,INTCELNUM,INDX
25        .GLOBL BITCOUNT,SFACTR
26       ;
27       ;
28       ; 3. REGISTER DEFINITION
29       ; ----------------------
30       ;
31        .MCALL .REGDEF
32        .REGDEF
33       ;
34       ;
35       ;
```

```
      1       ; 4. DEFINITION OF PARAMETERS USED
      2       ; ---------------------------------
      3       ;    THE FOLLOWING ARE THE DIFFERENT PARAMETERS USED
      4       ; IN THE FFT SUBROUTINE "FFT" WHICH ARE DEFINED
      5       ; IN EXEC.
      6       ;
      7       ;
      8       ;       N               N IS THE # OF REAL DATA
      9       ;                       POINTS IN OCTAL FORMAT
     10       ;
     11       ;       N2:             N2 IS THE ASSUMED # OF
     12       ;                       COMPLEX POINTS IN OCTAL.
     13       ;
     14       ;       B               B IS THE EXPONENT OF 2
     15       ;                       WHICH SATISFIES THE RELA
     16       ;                       -TIONSHIP  N2=2**B.
     17       ;
     18       ;       ADDATA          ADDATA IS A POINTER THAT WILL
     19       ;                       CONTAIN THE STARTING ADDRESS
     20       ;                       OF THE INPUT (REAL) POINTS THAT
     21       ;                       ARE TO BE TRANSFORMED.
     22       ;
     23       ;       COUNT:          A COUNTER SET TO HALF THE
     24       ;                       NUMBER OF COMPLEX POINTS.
     25       ;
     26       ;
     27         5. DATA STORAGE AREA ALLOCATION:
     28       ; ---------------------------------
     29       ;
     30       ;       THE CONSTANT "ADDATA" IS DEFINED IN EXEC
     31       ; AND IS THE STARTING ADDRESS OF AN "N" WORD ARRAY
     32       ; WHICH CONTAINS THE DIGITIZED DATA AND WILL
     33       ; CONTAIN THE TRANSFORMED DATA
     34       ;
     35       ;
```

FFT --DIFFERENT PARTS AND THEIR CODE.

```
                .SBTTL FFT --DIFFERENT PARTS AND THEIR CODE.
        ; 1. THE BIT INVERSION ALGORITHM
        ; ------------------------------
        ;   THE INPUT DATA POINTS ARE BIT INVERTED (OR SHUFFLED) SO
        ;   THAT THE FINAL TRANSFORMED ARRAY IS IN CORRECT ORDER.
        ;
        FFT     CLR     SFACTR          ;SET SCALE FACTOR TO 0
                CLR     R0               R0 WILL COMTAIN THE
                                        ;STARTING ADDRESS OF DA
                                         -TA TO BE TRANSFORMED.
                CLR     R1              ;R1 WILL CONTAIN BIT
                                        ;INVERTED ADDRESS.
                MOV     N2 R5           ;COUNTER TO KEEP TRACK
                                        ·OF # OF DATA POINTS.
        BIV10:  MOV     BITCOUNT.R4     ;BIT SHIFTING COUNTER
                CLR     R2
        BIV20:  CLC                     ;CARRY FLAG IS CLEARED
                                         BECAUSE BITS WILL BE
                                        ;COPIED INTO C-FF BY
                                        ;ROTATATIONS, WHICH WILL
                                        ;ACCOMPLISH SHIFT FROM R1
                                        ;INTO R2 OF LSB.
                ROR     R1
                ROL     R2
                SOB     R4,BIV20        ·AT THIS POINT 4 LSB OF
                                        ;R1 ARE COPIED INTO R2
                                         IN BIT REVERSED ORDER.
                MOV     R0,R1           ;COPY FOR SWAP
                CMP     R2,R1           ;COMPARE TO PREVENT
                                        ;DOUBLE SWAP.
                BLT     BIV30
                ASL     R1              ;LEFT SHIFT R1 FOR
                                        ;BYTE ADDRESSING.
                ASL     R1
                ASL     R2
                ASL     R2
                ADD     ADDATA,R2       ;STARTING ADDRESS
                ADD     ADDATA R1       ;DESTINATION ADDRESS
                JSR     PC SWAP
                CMP     (R1)+,(R2)+     :ADVANCE TO IMAG PART
                JSR     PC SWAP         ;SWAP DATA
        BIV30:  INC     R0              ;GO TO NEXT POINT.
                MOV     R0,R1           ;COPY R0.R1 FOR
                                         INVERION.
                SOB     R5 BIV10
        ; NOTE:
        ; -----
        ;       AT THIS POINT THE BIT INVERSION IS COMPLETE
        ;       AND DATA IS READY TO BE TRANSFORMED.
```

FFT --DIFFERENT PARTS AND THEIR CODE.

```
1       ; 2. FAST FOURIER TRANSFORMATION (FIRST PASS):
2       ; ---------------------------------------------
3       ;  DURING THIS PASS THERE ARE NO MULTIPLICATIONS, AND
4       ; THE FOLLOWING EQUATIONS ARE IMPLEMENTED
5       ;
6       ;       R(M)'=R(M)+R(N)
7       ;       I(M)'=I(M)+I(N)
8       ;       R(N)'=R(M)-R(N)
9       ;       I(N)'=I(M)-I(N)
10      ;
11      ;
12      FPASS:  MOV     ADDATA R0       ;LOAD STARTING ADDRESS
13                                      ;OF DATA FOR SCALING.
14              MOV     N R1            ;LOAD # OF POINTS.
15              JSR     PC,SCALE        ;ALWAYS SCALE DATA TO
16                                      ;PREVENT OVERFLOW.
17              MOV     ADDATA R0
18              MOV     R0,R1           ;FIRST POINT R(M)
19              CMP     (R1)+,(R1)+      2ND POINT R(N)
20              MOV     COUNT,R5        ;COUNTER=N2/2
21      ;
22      PASS1:  MOV     (R0) R2         ;SAVE R(M)
23              ADD     (R1),(R0)+      ;R(M)'=R(M)+R(N)
24              SUB     (R1),R2         ;R(N)'=R(M)-R(N)
25              MOV     R2,(R1)+
26              MOV     (R0),R2
27              ADD     (R1),(R0)+      ;I(M)'=I(M)+I(N)
28              SUB     (R1),R2         ;I(N)'=I(M)-I(N)
29              MOV     R2,(R1)+
30              CMP     (R0)+,(R1)+
31              CMP     (R0)+,(R1)+      GO TO NEXT PAIR
32              SOB     R5,PASS1        ;GO BACK N2/2 TIMES
33              BR      SPASS
34      ;
35      ; NOTE:
36        -----
37      ;       FIRST PASS IS OVER NOW GO TO SECOND PASS.
```

FFT --DIFFERENT PARTS AND THEIR CODE

```
1       ; 3. FAST FOURIER TRANSFORM (2ND PASS AND ONWARD):
2       ; ------------------------------------------------
3       ;    THE 2ND 3RD AND 4TH PASS USE THE SAME LOOP,
4       ; HOWEVER IN EACH PASS THE PARAMETERS DEFINED
5       ; BELOW TAKE DIFFERENT VALUES:
6       ;
7               DELTAY  0       ;SIZE OF INCREMENT FOR EXPO
8       ;                       -NENT OF "W" WHICH SATISF
9       ;                       -IES THE FOLLOWING RELATIO
10      ;                       -NSHIP:
11      ;                           W=EXP(2*PI*K/N)
12      ;                               K=0.1,2. ....N-1
13      ;                               N= # OF POINTS
14      ;
15              CELNUM: 0       ;# OF CELLS IN EACH PASS.
16      ;
17              PAIRNM: 0       ;# OF PAIRS IN EACH PASS.
18      ;
19              CELDIS: 0       ;DISTANCE (BYTES) BETWEEN A PAIR OF
20                              ;POINTS IN A CELL.
21      ;
22              POINT:  0       ;TEMPORARY POINTER TO STARTING
23      ;                       ADDRESS OF DATA TO TRANSFORMED.
24      ;
25              CELCNT: 0       ;CELL COUNTER TO KEEP TRACK
26      ;                       OF # OF CELLS IN EACH PASS.
27      ;
28              PARCNT: 0       ;COUNTER TO KEEP TRACK OF
29      ;                       # OF PAIRS IN EACH CELL.
30      ;
31              SINE:   0       ;TEMPORARY STORAGE TO HOLD
32      ;                       VALUE FOR SIN(Y).
33      ;
34              COS:    0       ;TEMPORARY STORAGE TO HOLD
35      ;                       VALUE FOR COS(Y).
36      ;
37              Y       0       ;THIS INDICATOR HOLDS THE
38      ;                       VALUE OF "Y" BEFORE SINE/
39      ;                       COSINE LOOK UP TABLES ARE
40      ;                       SEARCHED.
41      ;
42      ;       INTCELNUM:      THE INITIAL VALUE FOR "CELNUM"
43      ;                       WHICH IS DEFINED IN EXEC
```

FFT --DIFFERENT PARTS AND THEIR CODE

```
1       ; 4. CODE FOR 2ND PASS AND ONWARD·
2       ; - ----------------------------
3       ;       THE EQUATIONS THAT ARE IMPLEMENTED IN 2ND 3RD
4       ; AND 4TH PASS ARE GIVEN BELOW:
5       ;
6       ·       R1'=R1+R2*COS(Y)+I2*SIN(Y)
7       ;       I1'=I1-R2*SIN(Y)+I2*COS(Y)
8       ·       R2'=R1-R2*COS(Y)-I2*SIN(Y)
9       ;       I2'=I1+R2*SIN(Y)-I2*COS(Y)
10      ;
11      ; WHERE Y=2*PI*K/N2, N2=# OF COMPLEX POINTS, AND
12      ; K=0,1,2.. N2/2-1
13      ;
14      ;
15      ; NOTE:
16      ; -----
17      ;       3RD AND 4TH PASSES START FROM LABEL "NEWPASS"
18      ;       WHEREAS 2ND PASS STARTS AT LABEL "SPASS".
19      ;
20      SPASS:  MOV     #200,DELTAY     ·INITIALIZE DELTAY TO
21                                      ;HALF THE SIZE OF THE
22                                      ;LOOK-UP TABLE
23
24              MOV     INTCELNUM,CELNUM
25              MOV     #2 PAIRNM
26              MOV     #10,CELDIS
27      ;
28      NEWPAS: MOV     ADDATA R0       ;GET STARTING ADDRESS
29                                      ·AND # OF POINTS BEFORE
30                                      ·CALLING SUB:"SCALE"
31              MOV     N,R1
32              JSR     PC,SCALE
33      ;
34              MOV     CELNUM,CELCNT   ·SET UP CELL COUNTER.
35              MOV     ADDATA POINT
36              BR      NEWCEL
```

FFT --DIFFERENT PARTS AND THEIR CO[illegible]

```
1       ;NOTE: EACH NEW CELL [illegible]IN A PASS STARTS HERE.
2       ;----  SOME TEMPORARY STORAGE VARIABLES ARE DEFIN
3       ;      -ED BELOW:
4
5               I2SINY  0       ;I2*SIN(Y) IS STORED HERE.
6               R2SINY  0       ;R2*COS(Y) IS STORED HERE.
7               I2COSY: 0       ;I2*COS(Y) IS STORED HERE.
8               R2COSY: 0       ;R2*COS(Y) IS STORED HERE.
9       ;
10      NEWCEL  MOV     PAIRNM PARCNT
11              CLR     Y                CLEAR Y
12      NEWC10: MOV     POINT,R0
13              MOV     R0 R1
14              ADD     CELDIS R1
15              MOV     Y,R2             ;LOAD REG 2 WITH THE VALUE
16                                       ·TO GET THE SIN & COS FOR·
17              MOV     SINTAB(R2),SINE  ·GET THE VALUE OF THE
18                                        SINE(R2)
19              MOV     COSTAB(R2) COS   ;COS(R2)
20              MOV     (R1),R2          ;GET REAL PART R2
21              MUL     COS,R2           ;R2*COS(Y).
22              ASHC    #1,R2            ;LEFT SHIFT FOR FRACTIO
23                                       ;-NAL MULTIPLICATION.
24              MOV     R2,R2COSY        ;R2COSY=R2*COS(Y).
25              MOV     (R1),R2          ;GET REAL PART R2.
26              MUL     SINE R2          ;R2*SIN(Y)
27              ASHC    #1 R2
28              MOV     R2,R2SINY        ;R2SINY=R2*SIN(Y).
29              MOV     R1,R4            ;COPY PRESENT ADDRESS·
30              TST     (R4)+            ;GET ADDRESS OF IMAG.
31              MOV     (R4),R2          ;THIS IS VALUE OF I2.
32              MUL     SINE,R2          ;I2*SIN(Y).
33              ASHC    #1,R2
34              MOV     R2 I2SINY        ;I2SINY=I2*SIN(Y).
35              MOV     (R4),R2
36              MUL     COS R2           ;I2*COS(Y).
37              ASHC    #1,R2
38              MOV     R2 I2COSY        ;I2COSY=I2*COS(Y).
```

FFT --DIFFERENT PARTS AND THEIR CODE·

```
1       ; NOTE:
2       ; -----
3       ;       NOW COMBINE TERMS TO GET THE VALUES FOR
4       ; R1',R2',I1' ANDI2'.
5
6               MOV     (R0),(R1)
7               ADD     R2COSY (R0)     ;(R0)=R1+R2*COS(Y)
8               ADD     I2SINY (R0)     ;R1'=R1+R2*COS(Y)+I2*SIN(Y).
9               SUB     I2SINY,(R1)     ;(R1)=R1-I2*SIN(Y).
10              SUB     R2COSY,(R1)     ;R2'=R1-T2*SIN(Y)-R2*COS(Y).
11              MOV     R4 R1
12              TST     (R0)+
13              MOV     (R0),(R1)
14              SUB     R2SINY (R0)     ;(R0)=I1-R2*SIN(Y).
15              ADD     I2COSY (R0)     ;I1'=I1-R2*SIN(Y)+I2*COS(Y).
16              ADD     R2SINY,(R1)     ;(R1)=I1+R2*SIN(Y).
17              SUB     I2COSY (R1)     ;I2'=I1+R2*SINY-I2*COS(Y).
18      ;
19      ;
20      ; NOTE:
21      ; -----
22      ;       ONE PAIR OF POINTS HAS BEEN DONE  NOW DO
23      ;       NEXT PAIR
24      ;
25      ;
26              ADD     #4 POINT        ·NEXT ADDRESS IN THE CELL.
27              ADD     DELTAY,Y        ;INCREMENT EXPONENT OF W.
28              DEC     PARCNT          ;ONE PAIR DONE.
29              BNE     NEWC10          ;DO NEXT PAIR,EXIT IF ALL
30                                       PAIRS WITHIN A CELL ARE
31                                      ;DONE.
32      ;
33      ;
34      ; NOTE:
35      ; -----
36      ;       ONE CELL DONE  NOW RESET EXPONENT OF W AND
37      ;      PAIR-COUNTER (PARCNT).
38      ;
39      ;
40              ADD     CELDIS POINT    ;ADDRESS OF NEXT CELL.
41              DEC     CELCNT          ;ALL CELLS DONE?
42              BNE     NEWCELL         ;NO,GO BACK.
```

FFT —DIFFERENT PARTS AND THEIR CODE.

```
1       ; NOTE:
2       ; -----
3       ;       ONE PASS IS DONE NOW GO ON TO NEXT PASS,
4       ;       SET NEW VALUES OF PARAMETERS DEFINED
5       ;       IN PARA 3.
6       ;
7               ASR     CELNUM          ;LESS CELLS THIS TIME
8               BEQ     POST            ;ALL DONE WHEN VARIABLE
9                                       ;CELNUM=0.
10              ASL     PAIRNM          ;THIS TIME THERE ARE
11                                      ;MORE PAIRS IN EACH CELL.
12              ASL     CELDIS          ;PAIRS ARE FURTHER APART.
13              ASR     DELTAY          ;LESS INC OF Y PER CELL.
14              BR      NEWPAS          ;GO BACK AND DO NEXT PASS
15      ;
16      ;
17      ;
18
19      ;
20      ;
21      ; END OF FFT ALGORITHM.
```

POST PROCESSING ALGORITHM

```
                .SBTTL POST PROCESSING ALGORITHM
                ;
                ;


                 1. INTRODUCTION TO POST PROCESSING ALGORITHM
                ; ------------------------------------------
                ;    POST PROCESSING OF THE TRANSFORMED ARRAY IS DONE
                ; BECAUSE THE INPUT (REAL) DATA WAS ASSUMED TO BE COMPLEX
                ; AND THE OUTPUT OF THE FFT IS NOT IN CORRECT FORM.
                ;     THE EQUATIONS THAT ARE IMPLEMENTED IN THIS PASS
                ; ARE GIVEN BELOW:
                ;
                ;       AR(M)=(RP+IP*COS(T)-RM*SIN(T))/2
                ;       AI(M)=(IM-IP*SIN(T)-RM*COS(T))/2
                ;       AR(N-M)=(RP-IP*COS(T)+RM*SIN(T))/2
                ;       AI(N-M)=(-IM-IP*SIN(T)-RM*COS(T))/2
                ;
                ; WHERE T=PI*M/N, N=16 AND M=0,1,2    N/2-1, AND
                ; RP=I(M)+I(N-M), RP=R(M)+R(N-M),IM=I(M)-I(N-M) AND
                ; RM=R(M)-R(N-M).
                ;
                ;     SOME TEMPORARY VARIABLES THAT ARE USED IN
                ; THIS PASS ARE DEFINED BELOW:
                ;
                        RP:     0
                        IP:     0
                        RM:     0
                        IM:     0
                        ARM     0       ;ARM=AR(M)
                        ARNM    0       ;ARNM=AR(N-M)
                        AIM     0       ;AIM=AI(M)
                        AINM:   0       ;AINM=AI(N-M)
                ;       INDX:           INDEX TO GET SIN,COS VALUES.
                ;                       (INITIALIZED IN SETUP)
                ;       NM              A RELATIVE OFFSET EQUAL TO
                ;                       THE N-1 COMPLEX DATA POINT
                ;                       NM=2(N-2) AND IS INITIALIZED
                ;                       IN EXEC.
```

POST PROCESSING ALGORITHM

```
1       ; 2. CODE FOR POST PROCESSING :
2       ; ------------------------------
3       ;
4         NOTE:
5       ; -----
6       ;       SET UP ADDRESS POINTERS AND OTHER RELATED
7       ;       COUNTERS.
8       ;
9       ;
10      POST:   MOV     ADDATA R0       ;SET ADDRESS POINTER
11                                      ;AND # OF POINTS BEFORE
12                                      ;SCALING DATA ARRAY.
13              MOV     N,R1
14              JSR     PC,SCALE
15              MOV     ADDATA R0
16              MOV     COUNT R1        ;SET COUNTER TO DECIMAL 8.
17              MOV     INDX R5         ;INCREMENT FOR SINE POINTER.
18              MOV     NM.R4           ;OFFSET FOR ADDRESS OF
19                                       POINT.
20              ADD     ADDATA.R4
21      ;
22      ;
23      ; NOTE:
24        -----
25      ;       THE POST PROCESSING OF FIRST POINT IS DONE
26      ;       SEPARATELY BECAUSE WE DO NOT PHYSICALLY GE
27      ;       -NERATE THE (N+1)ST POINT.
28      ;
29      ;
30      POST1:  MOV     2(R0) R2        ;GET IMAG PART OF 1ST
31                                      ;POINT.
32              ADD     R2 (R0)         ;ADD IT TO REAL PART.
33              ASL     (R0)+           ;DOUBLE THIS RESULT TO
34                                       MAINTAIN SCALE.
35              CLR     (R0)+           ;CLEAR THE LOCATION WH
36                                       -ERE THE IMAG WAS STORED.
37      ;
38
39      ; NOTE:
40        -----
41      ;       NOW THE REST OF THE POINTS ARE PROCESSED.SO
42      ;       GET RM IM,RP AND IP FOR ALL EXCEPT THE FIRST
43      ;       POINT
```

POST PROCESSING ALGORITHM

```
 1      POST5:  MOV     SINTAB(R5),SINE  SINE=SINE(R5)
 2              MOV     COSTAB(R5),COS   ;COS=COS(R5)
 3              MOV     (R4),RP          ;RP(N-M)
 4              MOV     (R4),RM          ;RM=R(N-M)
 5              NEG     RM               ;RM=-R(N-M)
 6              MOV     2(R4),IP         ;IP=I(N-M)
 7              MOV     2(R4),IM         ;IM=I(N-M)
 8              NEG     IM               ;IM=-I(N-M)
 9              ADD     (R0),RP          ;RP=R(M)+R(N-M)
10              ADD     (R0),RM          ;RM=R(M)-R(N-M)
11              ADD     2(R0),IP         ;IP=I(M)+I(N-M)
12              ADD     2(R0),IM         ;IM=I(M)-I(N-M)
13      POST10: MOV     RP ARM
14              MOV     IM AIM           ;ARM=AR(M) AND AIM=AI(M).
15              MOV     RP,ARNM
16              MOV     IM,AINM          ;ARNM=AR(N-M) AND
17                                       ;AINM=AI(N-M).
18              NEG     AINM             ;AINM=-AI(N-M).
19              MOV     IP R2
20              MUL     COS,R2           ;IP*COS(T)
21              ASHC    #1 R2
22      POST20: ADD     R2,ARM           ;ARM=A(M)+IP*COS(T)
23              SUB     R2,ARNM          ;ARNM=AR(N-M)-IP*COS(T)
24      POST25: MOV     IP,R2
25              MUL     SINE,R2          ;IP*SIN(T)
26              ASHC    #1,R2
27              SUB     R2,AIM           ;AIM=AI(M)-IP*SIN(T)
28              SUB     R2,AINM          ;AINM=AI(N-M)-IP*SIN(T).
29              MOV     RM R2
30              MUL     SINE,R2          ;RM*SIN(T)
31              ASHC    #1 R2
32              SUB     R2,ARM           ;ARM=AR(M)+IP*COS(T)-RM*SIN(T)
33              ADD     R2,ARNM          ;ARNM=AR(N-M)-IP*COS(T)+RM*SIN(T)
34              MOV     RM,R2
35              MUL     COS,R2           ;RM*COS(T)
36              ASHC    #1,R2
37      POST50: SUB     R2 AIM           ;AIM=AI(M)-IP*SIN(T)-RM*COS(T9
38              SUB     R2,AINM          ;AINM=AI(N-M)-IP*SIN(T)-RM*COS(T)
39      POST55: MOV     ARM,(R0)
40              MOV     ARNM,(R4)
41              MOV     AIM,2(R0)
42              MOV     AINM,2(R4)
```

POST PROCESSING ALGORITHM

```
1       ; NOTE:
2       ; -----
3       ;       ONE PAIR OF POINTS HAS BEEN DONE, NOW
4       ;       GO ON TO NEXT PAIR OF POINTS.
5       ;
6       ;
7               ADD     INDX R5             ;INCREMENT SINE INDEX
8               CMP     (R0)+,(R0)+         ;INC R0 BY 2
9               CMP     -(R4),-(R4)         ;DEC R4 BY 2
10              DEC     R1                  ;R1<-R1-1
11              BNE     POST5
12              DEC     SFACTR              ;DIVIDE DATA ARRAY BY 2
13              RTS     PC
14      ;
15      ;
16      ;
17      ;
18      ;
19
20      .
21      ;
22      ;
23      ;
24      ; END OF POST PROCESSING ALGORITHM.
```

SUBROUTINE SCALE

```
1       .SBTTL SUBROUTINE SCALE
2       ;
3       ;
4       ;
5
6         1. INTRODUCTION TO SUBROUTINE "SCALE":
7       ; ---------------------------------------
8       ;    THIS SUBROUTINE CHECKS BITS 13-14 AND SHIFTS THE
9       ; WHOLE ARRAY TO THE RIGHT BY TWO BITS IF BIT-14 IS SET,
10      ; AND SHIFTS THE ARRAY ONE BIT TO THE RIGHT IF BIT-13
11      ; IS SET.
12      ;     BEFORE CALLING THIS SUBROUTINE  IT SHOULD BE
13      ; ENSURED THAT THE STARTING ADDRESS OF THE ARRAY
14      ; IS LOADED IN R0 AND THE LENGTH OF THE ARRAY IS LO
15      ; -ADED IN R1. THE SUBROUTINE IS CALLED BY GIVING THE
16        COMMAND "JSR  PC SCALE .
17            THE VARIABLE "SFACTR", WHICH IS DEFINED BELOW,
18      ; KEEPS TRACK OF THE # OF TIMES THE ARRAY HAS BEEN
19      ; SHIFTED TO THE RIGHT BY ONE BIT.
20      ;
21      ;
22      ;
23      ;
24      .PSECT SFACTR,RW,D,GBL,REL,OVR
25              SFACTR: 0       ;SFACTR IS DEFINED HERE.
26      .PSECT
```

SUBROUTINE SCALE

```
1       ; 2. CODE FOR SUBROUTINE SCALE
2       ; ----------------------------
3       ;
4       SCALE:  MOV     R0 R5           ;GET STARTING ADDRESS
5                                       ;AND STORE IN REG  R5.
6               MOV     R1,R3           ;GET ARRAY LENGTH AND
7                                       ;STORE IN REG  R3.
8               CLR     R4              ;CLEAR R4 WHICH IS A FLAG
9                                        TO KEEP TRACK WHETHER BIT
10                                      ;-14 OR BIT-13 IS SET.
11      SCAL1:  MOV     (R0)+,R2        ;GET EACH POINT
12              BPL     SCAL2           ;SKIP NEXT INSTRUCTION IF
13                                      ;VALUE IS POSITIVE.
14              NEG     R2              ;GET ABS VALUE
15      SCAL2:  BIT     #40000,R2       ;IS BIT-14 SET?
16              BNE     RDUCE2          ;YES,SCALE TWICE.
17              BIT     #20000 R2       ;IS BIT-13 SET?
18              BEQ     SCAL3           ;NO,GET ANOTHER POINT.
19              MOV     #1 R4           ;YES,SET FLAG AND CHECK
20                                      ;NEXT POINT.
21      SCAL3:  SOB     R1,SCAL1        ;ALL POINTS CHECKED?
22              TST     R4              ;TEST IF SCALING IS REQUIRED.
23              BNE     RDUCE1          ;YES IT IS REQUIRED.
24              RTS PC
25      ;
26      ; NOTE:
27      ; -----
28      ;       SHIFT ENTIRE ARRAY EITHER ONE OR TWO BITS
29      ;       TO THE RIGHT.
30      ;
31      RDUCE2: CLR     R4
32              INC     SFACTR
33      RDUCE1: INC     SFACTR
34              TST     R4
35              BNE     RDUCE4
36      RDUCE3: ASR     (R5)            SHIFT EACH POINT TWO
37                                      ;BITS TO THE RIGHT.
38              ASR     (R5)+
39              SOB     R3,RDUCE3       ;ALL POINTS SCALED?
40              RTS     PC              ;YES
41      RDUCE4: ASR     (R5)+
42              SOB     R3 RDUCE4
43              RTS     PC
44      ;
45      ;
46      ;
47      ;
48      ;
49      ; END OF SCALING SUBROUTINE.
```

SUBROUTINE "SWAP"

```
                .SBTTL  SUBROUTINE "SWAP"
        ;
        ;
        .
        ;
          1. SUBROUTINE "SWAP" (INTRODUCTION AND CODE):
        ; ---------------------------------------------
        ;     THIS SUBROUTINE IS USED TO SWAP THE CONTENTS OF
          MEMORY LOCATIONS POINTED TO BY REGISTERS R1 AND R2.
        ; BEFORE CALLING THIS SUBROUTINE IT SHOULD BE ENSURED
        ; THAT THE ADDRESS OF MEMORY LOCATIONS THAT ARE TO BE
        ; SWAPPED ARE LOADED IN R1 AND R2.
        ;

        ;
        .
        SWAP:   MOV     (R1),R3
                MOV     (R2) (R1)
                MOV     R3,(R2)
                RTS     PC
        ;
        ;
        ;
        .
        ;
        ;
        ;
        ;

        ; END OF SUBROUTINE SWAP.
```

SUBROUTINE "LOOKUP"

```
                .SBTTL SUBROUTINE "LOOKUP"
;

;
; 1. INTRODUCTION TO "LOOKUP":
; ----------------------------
;
;       THIS SUBROUTINE IS USED IN TWO PLACES, "PASS2 AND
  ONWARD", AND "POST PROCESSING". THE LOOK-UP TABLE CONTAINS
; THE SINE AND COSINE VALUES FOR K*PHI/N2, K=1 2,.. .N2/2.
; THE TABLE IS CONSTRUCTED FOR THE LARGEST ALLOWED VALUE OF
; N2 (128) WITH THE VALUES FOR THE SINES STARTING AT SINLOK,
; AND FOR COSINES STARTING AT COSLOK. EACH FUNCTION HAS 128
; ENTRIES (THE LAST HALF OF THE SINE TABLE IS THE FIRST HALF
  OF THE COSINE TABLE). THE "PASS2 AND ONWARD" SECTION USES
; EVERY OTHER VALUE (K*PHI/(N2/2)) AND THE "POST PROCESSING"
; SECTION USES EVERY VALUE.
;
```

SUBROUTINE "LOOKUP"

```
1       ; 2. LOOK UP TABLE
2       ; ----------------
3       ;
4         SINE(K*PHI/128), K=1 2,     128 STARTS HERE
5       ;
6       SINTAB: 000000,001444,003110,004552,006214,007653,011310
7               012742,014371 016013,017432,021044,022450,024047
8               025437 027021,030374,031737 033272 034615 036127
9               037427,040716 042173,043435,044664,046100,047300
10              050464,051633,052766,054103,055202,056264,057327
11              060354,061362 062350,063317,064246,065155,065044
12              066712,067537,070343,071125,071666,072405,073102
13              073554,074204,074612,075175,075535,076052,076344
14              076612,077035,077235,077412,077542,077647,077730
15              077766
16      ;
17      ; COSINE LOOK-UP TABLE STARTS HERE
18      ;
19      COSTAB: 077777,077766,077730,077647,077542,077412
20              077235,077035,076612,076344,076052,075535,075175
21              074612,074204,073554,073102 072405,071666,071125
22              070343,067537 066712,066044,065155,064246 063317
23              062350,061362 060354,057327,056264,055202,054103
24              052766,051633,050464 047300,046100,044664,043435
25              042173 040716,037427 036127,034615,033272 031737
26              030374 027021,025437,024047,022450,021044,017432
27              016013,014371 012742,011310,007653,006214 004552
28              003110,001444,000000
29      ;
30      ; END OF SINE LOOK-UP TABLE
31      ;
32              176334,174670,173225,171564,170125 166470,165036
33              163407,161764,160346,156734,155330,153731,152341
34              150757,147404,146041,144506,143163,141651,140351
35              137062 135605,134343,133114,131700,130500,127314
36              126145,125012,123675,122575,121514 120450,117424
37              116416,115427,114460,113531,112622,111734,111066
38              110241,107435,106653,106112,105373 104676,104224
39              103573,103166,102603,102243,101726 101434,101166
40              100742,100543,100366,100236 100131,100047,100012
41              100000
42      ;
43      ; END OF COSINE LOOK-UP TABLE
44      ;
45              .END
```

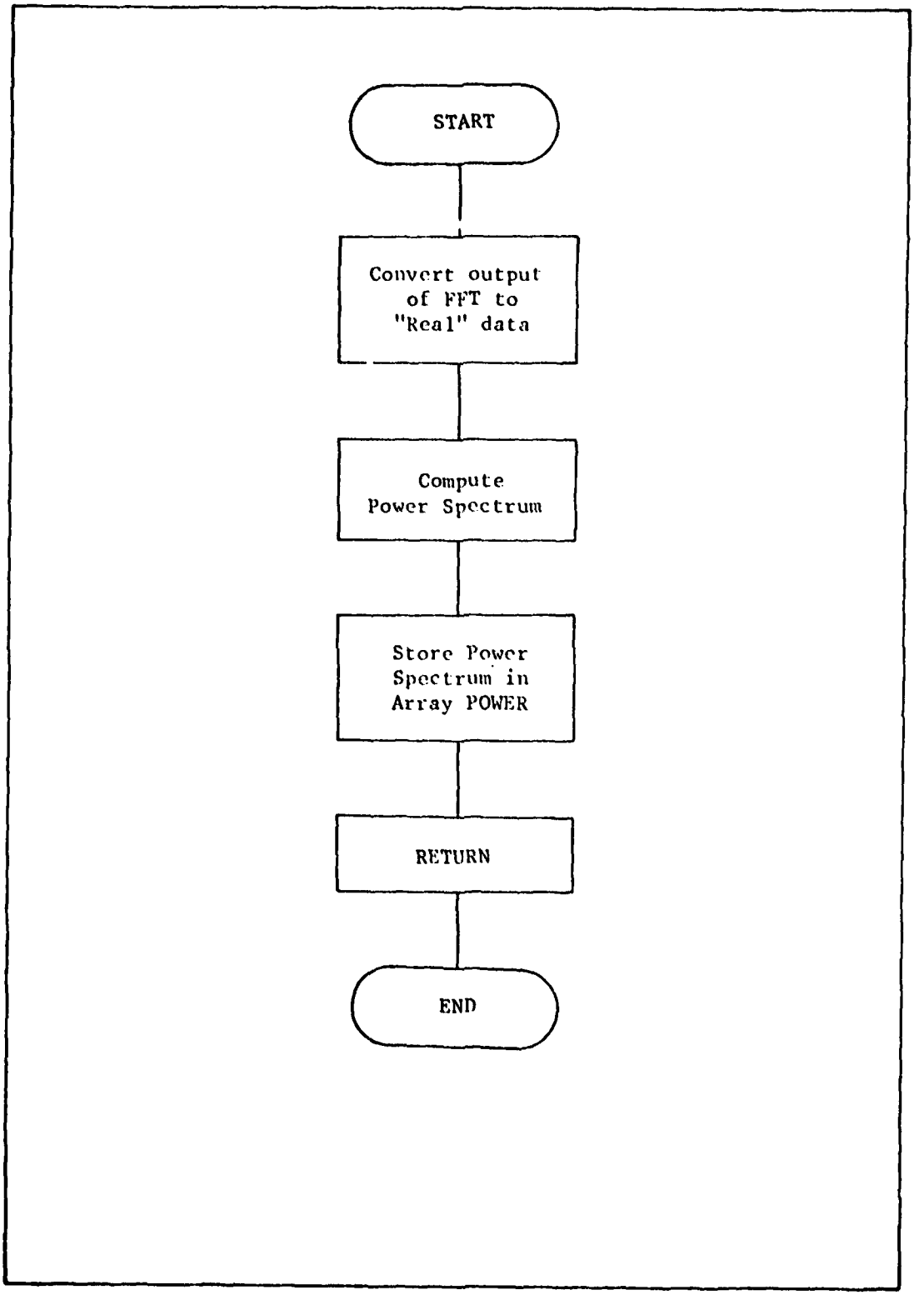

Fig 26. Flow Chart for POWERSPECTRUM

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 12:46 06                PAGE 001
0001          SUBROUTINE POWERSPECTRUM
      C
      C     INTRODUCTION
      C
      C     THIS ROUTINE COMPUTES THE POWER WITHIN EACH OF THE FREQUENCY
      C     INTERVALS IN THE FREQUENCY SPECTRUM.  THE GLOBAL ARRAY ADDATA
      C     CONTAINS THE "COMPLEX" FREQUENCY SPECTRUM AND THE ARRAY "POWER"
      C     CONTAINS THE SUM OF THE SQUARE OF THE REAL AND COMPLEX
      C     COMPONENTS OF THE FREQUENCY SPECTRUM.
      C
      C     THE POWER SPECTRUM ARRAY (POWER) IS USED TO SUM TEN POWER
      C     SPECTRUMS TO FORM THE AVERAGE POWER SPECTRUM.
      C     AN ARITHMETIC STATEMENT IS USED TO CONVERT THE FIXED POINT
      C     VALUES IN THE FREQUENCY ARRAY (DATA) TO FLOATING POINT VALUES.
      C     THE SCALE FACTOR AND THE GAIN OF THE TEMPERATURES' LINEAR
      C     AMPLIFIER (GAIN) IS USED TO CONVERT THE DATA TO REAL FORMAT.
      C
      C
      C     DEFINITION OF VARIABLES
      C
      C   LOCAL      GLOBAL          DEFINITION
      C
      C   ADATA      ADDATA          THE OUTPUT OF THE DFT MODULE
      C                              CORRESPONDING TO THE FREQUENCY
      C                              SPECTRUM.
      C
      C   GAIN       ADGAIN          THE GAIN OF THE VIBRATION SIGNAL
      C                              AMPLIFIER.
      C
      C   NFREQ      NINTVL          THE NUMBER OF FREQUENCY INTERVALS
      C                              IN THE DFT. POWER SPECTRUM. AND
      C                              CDF OUTPUTS.
      C
      C   POWER      PWRSPC          THE ARRAY WHICH IS USED TO FORM
      C                              THE AVERAGE POWER SPECTRUM.
      C
      C   SCALE      SFACTR          THE SCALE FACTOR FROM THE DFT
      C                              ROUTINE.  IT INDICATES HOW MANY
      C                              TIMES THE DFT ARRAY (ADATA) HAS
      C                              BEEN SHIFTED TO THE RIGHT.
      C
      C    VARIABLE TYPE DEFINITION
      C
0002          INTEGER*2 ADATA(256),SIZE.K,I,SCALE,GAIN,NFREQ
0003          REAL*4 POWER(120)
0004          COMMON /PWRSPC/POWER./ADGAIN/GAIN,/NINTVL/NFREQ
0005          COMMON /ADDATA/ADATA,/SFACTR/SCALE
```

```
      C
      C     ARITHMETIC STATEMENT FUNCTION TO COMPUTE THE FLOATING POINT
      C     VARIABLE EQUAL TO THE VALUE OF THE FIXED POINT FREQUENCY
      C     SPECTRUM COMPUTED IN FOURIER TIMES THE GAIN OF THE LINEAR
      C     AMPLIFIER.
      C
0006        FPDATA(I)= FLOAT(ADATA(I))*(2.**SCALE)*FPGAIN
      C
      C  PROGRAM EXECUTION STARTS HERE.
      C
0007        FPGAIN=FLOAT(GAIN)
0008        K=3
0009        DO 100,I=1,NFREQ
0010        POWER(I)=POWER(I)+FPDATA(K)**2+FPDATA(K+1)**2
0011        K=K+2
0012   100  CONTINUE
0013        RETURN
0014        END
```

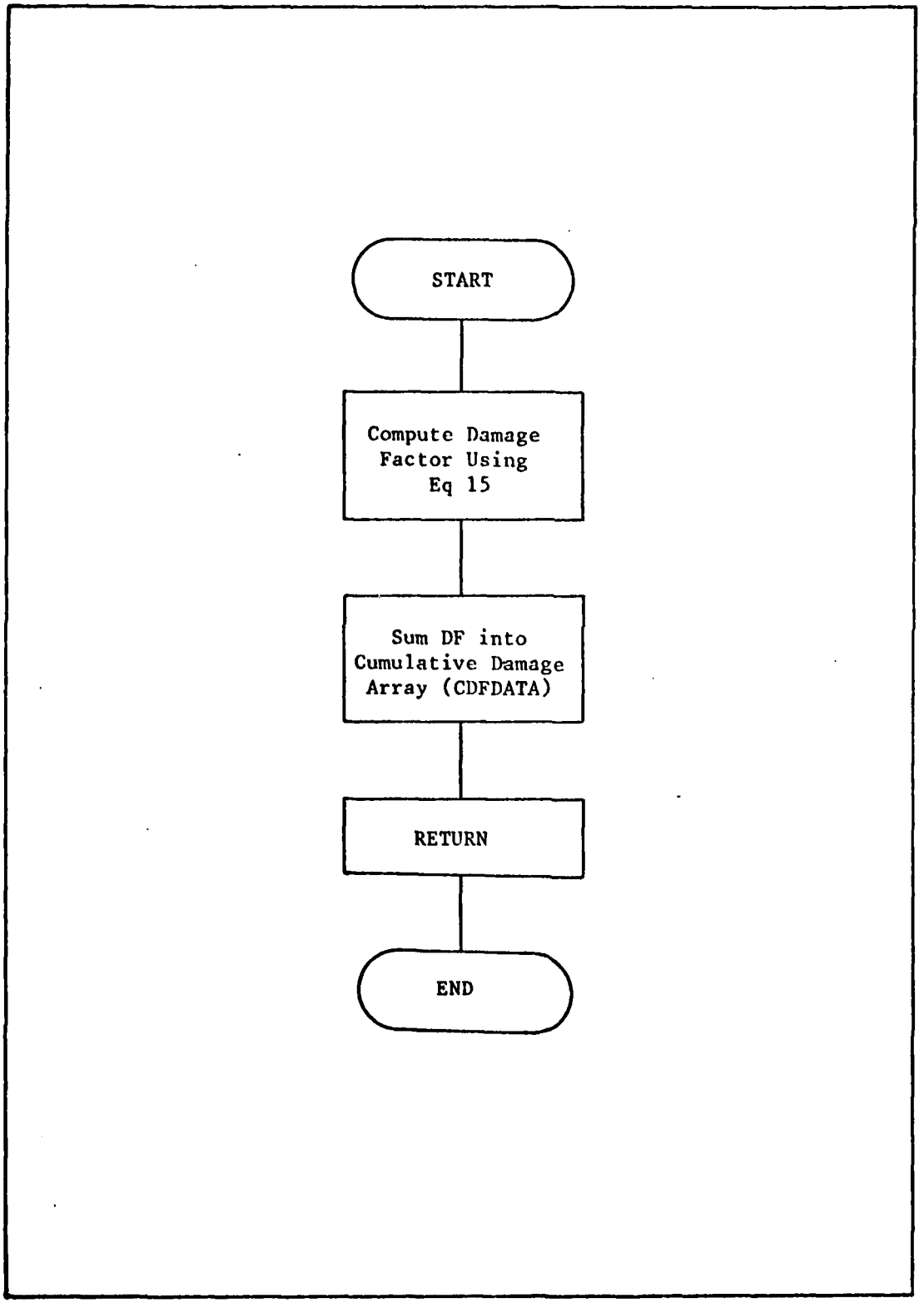

Fig 27. Flow Chart for DAMAGEFACTOR

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 12:47 09                PAGE 001
0001          SUBROUTINE DAMAGEFACTOR
      C INTRODUCTION
      C
      C THIS MODULE COMPUTES THE CUMULATIVE DAMAGE FACTOR (CDF)
      C BY SUMMING THE DAMAGE FACTORS.  THE DAMAGE FACTORS ARE
      C COMPUTED USING AN ARITHMETIC STATEMENT FUNCTION -
      C DAMAGE (K,FREQUENCY)WHICH IMPLEMENTS EQUATION 15.
      C
      C
      C     VARIABLE DEFINITION
      C
      C LOCAL   GLOBAL        DEFINITION
      C
      C CDF     CDFDATA   DATA THE ARRAY WHICH CONTAINS THE CUMULATIVE
      C                   DAMAGE FACTORS. I RANGES FROM 1 TO 127
      C                   AND TEMP RANGES FROM 1 TO 12.
      C
      C DELTAF  DELTA     DELTA THE FREQUENCY INTERVAL
      C
      C FREQUENCY         THE FREQUENCY AT WHICH THE CACULATION
      C                   IS TAKING PLACE.
      C
      C NFREQ   NINTVL    THE NUMBER OF FREQUENCY INTERVALS IN
      C                   THE POWER AND CDF ARRAYS.
      C
      C POWER   PWRSPC    AN  ARRAY WHICH CONTAINS THE POWER
      C                   SPECTRUM.
      C
      C TEMP    TFLG      THE TEMPERATURE ARRAY IN CDF FOR WHICH
      C                   THE DATA TAKEN.
      C
      C  VARIABLE TYPE DEFINITION
      C
0002          INTEGER*2 TEMP NFREQ
0003          REAL*4 POWER(120),CDF(120.12) FREQUENCY,DELTAF
      C
      C  GLOBAL VARIABLE DEFINITION
      C
0004          COMMON /PWRSPC/POWER,/CDFDATA/CDF /TFLG/TEMP
0005          COMMON /NINTVL/NFREQ,/DELTA/DELTAFV
      C
      C     ARITHMETIC STATEMENT FUNCTION TO DETERMINE THE
      C     DAMAGE FACTOR
      C
0006          DAMAGE(K,FREQUENCY)=((POWER(K)**1.65)/(FREQUENCY**5.4))
0007          FREQUENCY=DELTAF
0008          DO 100,I=1.NFREQ
0009          CDF(I.TEMP)=CDF(I.TEMP)+DAMAGE(I,FREQUENCY)
0010          FREQUENCY=FREQUENCY+DELTAF
0011    100   CONTINUE
0012          RETURN
0013          END
```

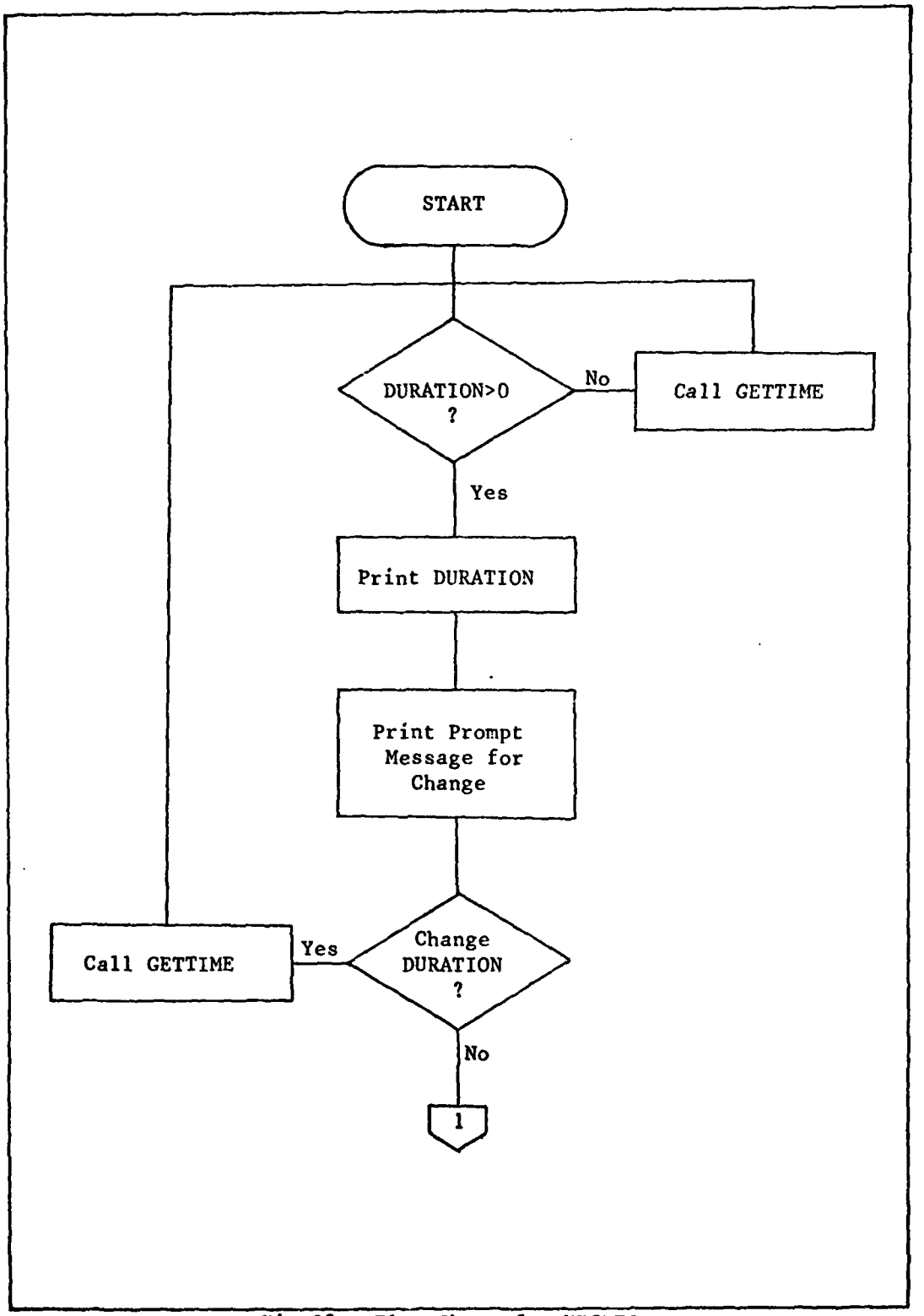

Fig 28. Flow Chart for XECUTE

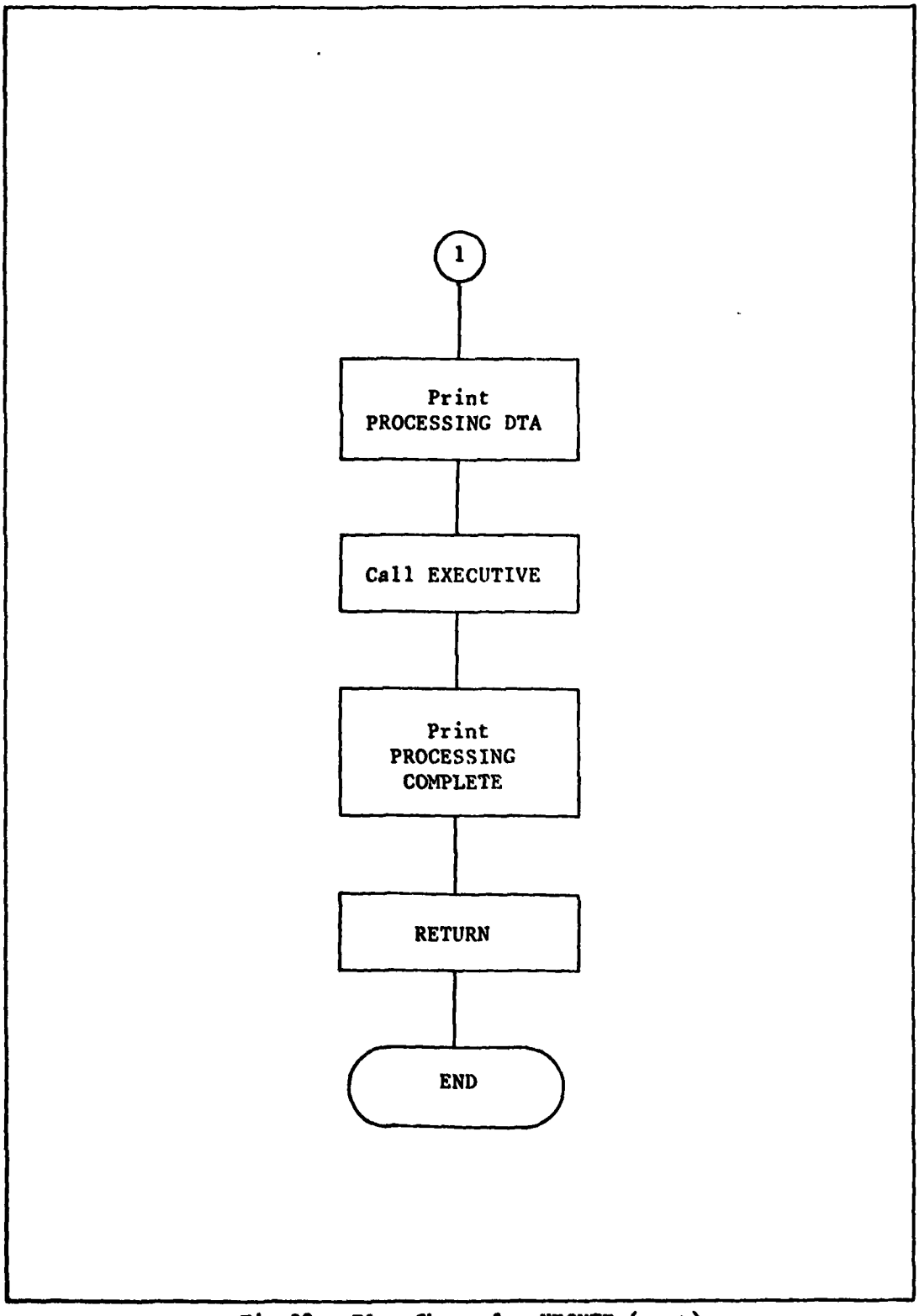

Fig 28. Flow Chart for XECUTE (cont)

```
FORTRAN IV   V02.1-11   Fri 23-Nov-79 14:57:19                PAGE 001
0001          SUBROUTINE XECUTE
      C
      C
      C     IF THE TIME IS LESS THAN OR EQUAL TO ZERO, A NEW TIME IS
      C  OBTAINED BY CALLING SUBROUTINE TIME. AND THEN
      C  THE DATA PROCESSING STARTS.
      C
      C  VARIABLES DEFINED HERE
      C
      C
0002          LOGICAL*1 ANSWER,ERR
0003          INTEGER*2 MINUTES
0004          REAL*4 DURATION
0005          COMMON /PTIME/MINUTES
      C
      C  THE RUN TIME IS CHECKED AND IF IT IS GREATER THAN
      C  ZERO DATA PROCESSING IS STARTED.  IF NOT A NEW TIME
      C  IS REQUESTED.
      C
0006          IF (MINUTES .LT. 0) CALL GETTIME(DURATION)
0008    100   TYPE 200,MINUTES/60.
0009    200   FORMAT(2X,'THE DURATION IS ',F5.2 ' HOURS')
      C
      C  THE USER IS OFFERED ONE LAST CHANCE TO CHANGE THE RUN DURATION.
      C
0010          TYPE 225
0011    225   FORMAT(/2X,'DO YOU WANT TO CHANGE IT ?  Y/N<CR>'$)
0012          ACCEPT 250,ANSWER
0013    250   FORMAT(A1)
0014          IF (ANSWER.EQ.'Y') GO TO 500
0016          IF ((ANSWER.NE.'Y').AND.(ANSWER.NE.'N')) GO TO 600
0018          TYPE 300
0019    300   FORMAT (2X,'DATA BEING PROCESSED')
0020          CALL EXEC
0021    399   TYPE 400
0022    400   FORMAT (2X,'DATA PROCESSING COMPLETE'/)
0023          RETURN
0024    500   CALL GETTIME (DURATION)
0025          GO TO 100
0026    600   CALL ERROR('INPUT MUST BE A Y OR A N')
0027          GO TO 100
0028          END
```

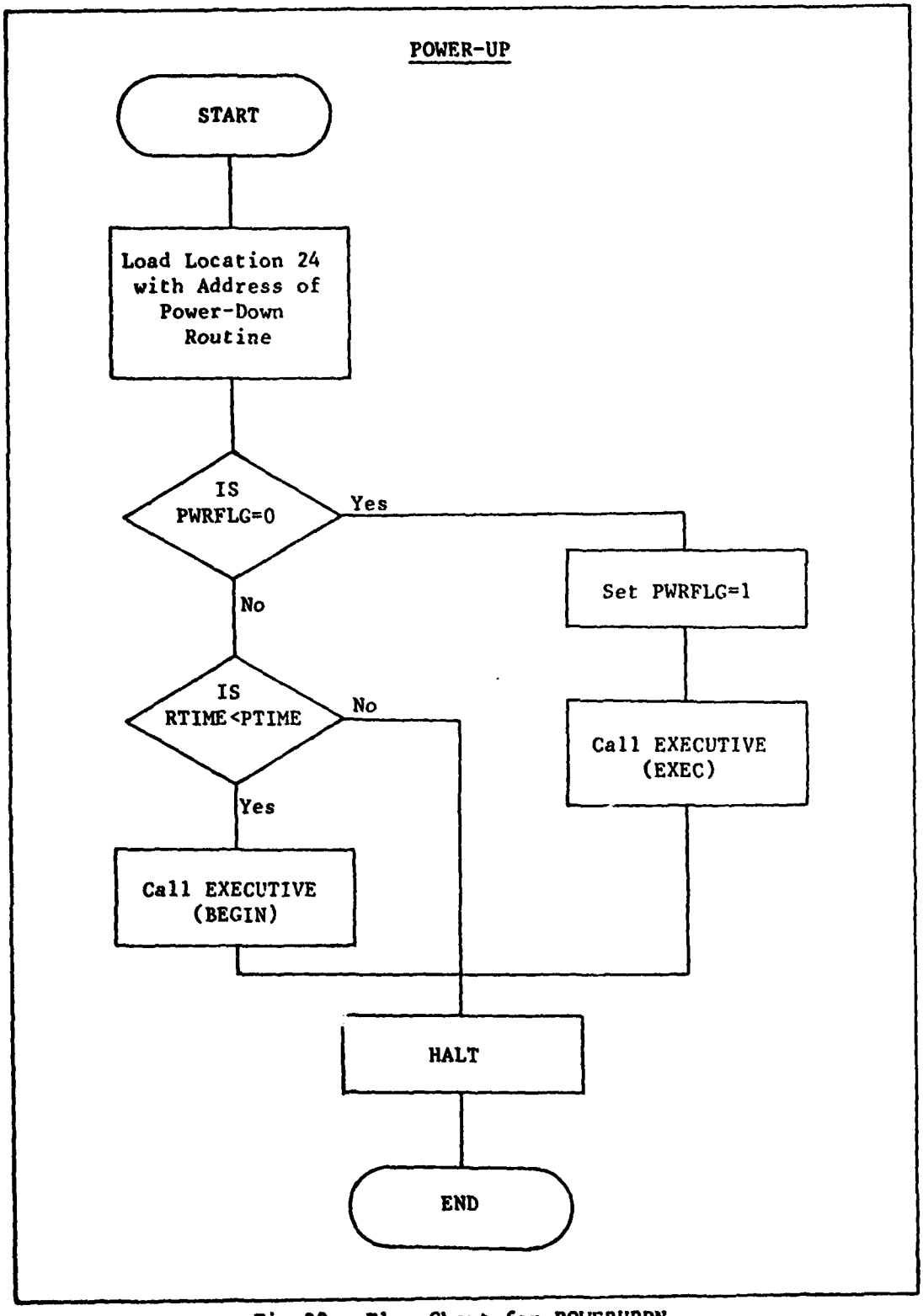

Fig 29. Flow Chart for POWERUPDN

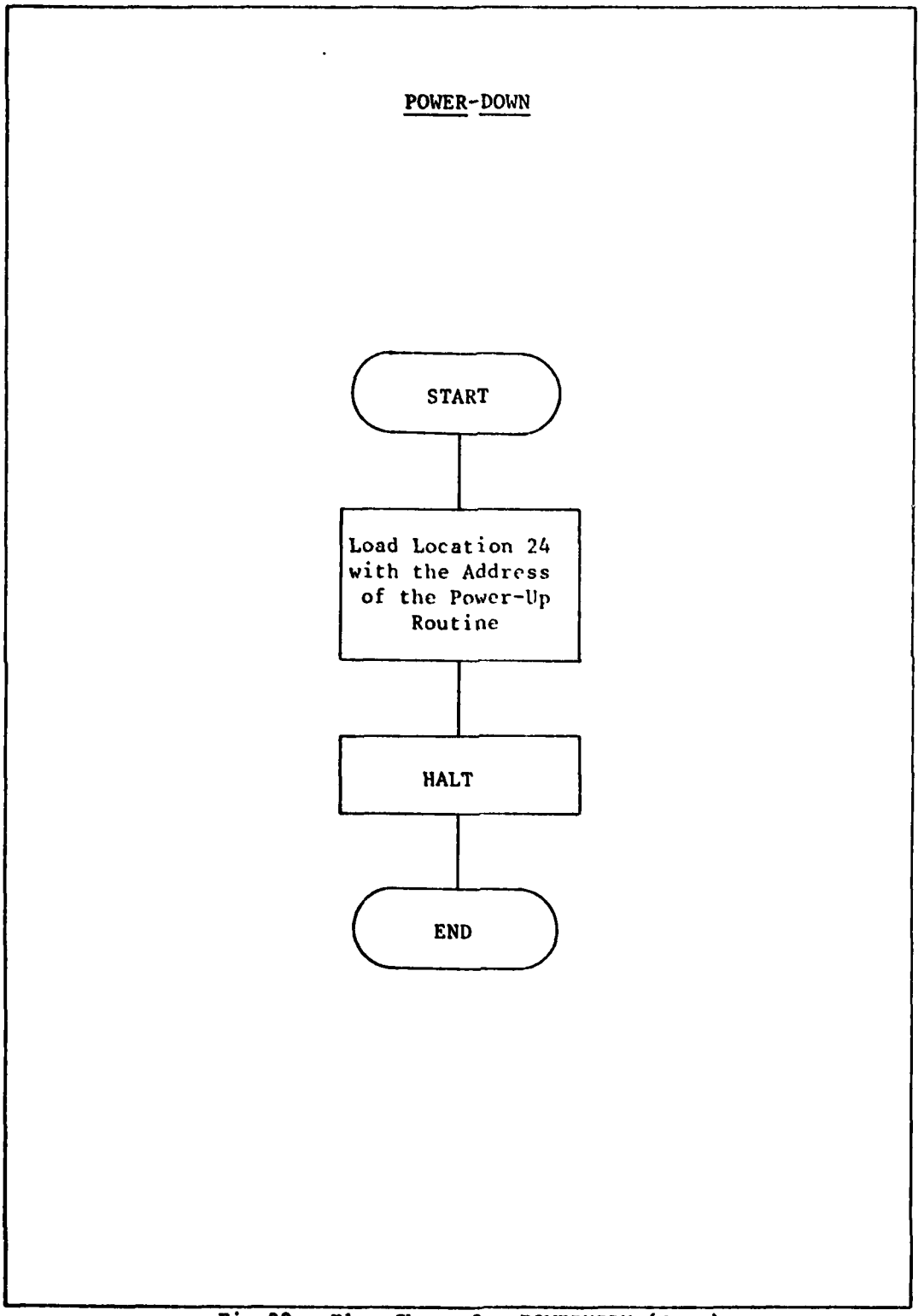

Fig 29. Flow Chart for POWERUPDN (Cont)

```
 1   .TITLE POWERUPDN PROCEDURE
 2   .SBTTL  INTRODUCTION
 3   ;
 4   ;1.  INTRODUCTION:
 5   ;----------------
 6   ;
 7   ;       THIS PROCEDURE IS USED WHEN THE AUTOMATIC STARTING MODE
 8   ; IS SELECTED.  WHEN SYSTEM POWER IS TURNED ON, WITH THE RUN/HALT
 9   ; SWITCH IN THE RUN POSITION (LSI-11 OPERATING IN MODE 0,) PROGRAM
10   ; EXECUTION STARTS AT LABEL "PWRUP".   FIRST, THE ADDRESS OF THE
11   ; POWER DOWN LABEL "PWRDN" IS STORED AT LOCATION 24.  THEN THE
12   ; GLOBAL VARIABLE "PWRFLG" IS CHECKED.  IF IT IS EQUAL TO ZERO
13   ; MEANING IT IS THE FIRST POWER-UP, "PWRFLG" IS SET EQUAL TO
14   ; ONE AND PROGRAM EXECUTION JUMPS TO THE LABEL "EXEC" IN THE
15   ; EXECUTIVE MODULE  IF "PWRFLG" DOES NOT EQUAL ZERO, THE RUN
16   ; TIME IS CHECKED AND IF IT IS LESS THAN OR EQUAL TO THE PLANNED
17   ; TIME  PROGRAM EXECUTION JUMPS TO THE LABEL "BEGIN" IN THE
18   ; EXECUTIVE MODULE. IF THE RUN TIME IS EQUAL TO OR GREATER THAN THE
19   ; PLANNED RUN TIME  PROGRAM EXECUTION STOPS.
20   ;
21   ;
22   ;2. GLOBAL VARIABLES:
23   ;-------------------
24   ;
25   .GLOBL PWRFLG,EXEC,BEGIN,PTIME,RTIME
26   .MCALL .REGDEF
27   .REGDEF
28   ;
29   ;
30   .PSECT PWRFLG RW,D,GBL REL,OVR
31   PWRFLG: .WORD   0        POWER FLAG USED TO DETERMINE IF IT IS THE
32                           ;FIRST POWER-UP.
33   .PSECT
34   ;
35   ;
36   ;3. CODE FOR POWER-UP:
37   ;--------------------
38   ;
39   PWRUP   MOV     #PWRDN @#24     ;SET UP VECTOR FOR THE
40           MOV     #200,@#26       ;POWER-DOWN ROUTINE.
41           TST     PWRFLG          ;CK IF IT IS THE FIRST
42                                   ;POWER-UP; IF NOT,
43           BNE     RESTRT          ;CHECK THE RUN TIME
44           MOV     #1 PWRFLG       ;PWRFLG INDICATES THAT
45                                   ;THE FIRST POWER-UP
46                                   ;HAS OCCURRED.
47           JSR     PC,EXEC         ;START DATA PROCESSING
48                                   ;AT LABEL "EXEC" IN THE
49                                   ;EXECUTIVE MODULE
```

```
50   ;
51   ;       WHEN EXECUTIVE RETURNS PROGRAM CONTROL TO THIS
52   ; MODULE, RTIME WILL BE EQUAL TO PTIME SO PROGRAM WILL
53   ; HALT.
54   ;
55   RESTRT: CMP     PTIME,RTIME      CK RUN TIME
56           BGE     HLT              ;STOP IF RTIME=>PTIME  OR
57           JSR     PC,BEGIN         ;ELSE FINISH PROCESSING
58                                    ;THE DATA.
59   HLT:    HALT
60
61   ;
62   ;4. CODE FOR POWER DOWN MOD
63   ;----------------------
64   ;
65   PWRDN:  MOV     #PWRUP,@#24      REPLACE THE POWER-DOWN
66                                    VECTOR WITH THE POWER-
67           HALT                     ;UP VECTOR  AND STOP.
68           .END
```

Appendix C

Users' Manual

Introduction

The purpose of this manual is to explain how to use the existing bench model of the MFDM. First, the physical configuration of the system is discussed, and then its operation is discussed. The procedure for the automatic start-up mode is not discussed, since this mode of operation was not incorporated in the bench model.

Physical Configuration

The bench model system is designed to be used with a Lear Siegler ADM-3 terminal, a Heathkit H27 dual floppy disk drive and a Heathkit H14 printer. A block diagram for the system is shown in figure 30 with the backplane configuration shown in figure 31. The cable for the floppy disk must be connected to the disk interface module with the red dot on the connector on the top (visible). The bus expansion cable must be connected between the two backplanes with the M9400-YE module in the first backplane (with the processor board in it).

The baud rate should be set at 4800 at the computer, the terminal, and the printer. A slower baud rate can be used, if desired, as long as all three baud rates are the same. The accelerometer is connected to the signal amplifier, with the output of the amplifier connected to the channel 16 leads of the A/D converter. Since the computer control of the auto ranging gain has not yet been implemented, the thumb wheel switch must be manually set to a value between 0 and 7; thus, manually setting the gain of the amplifier. The value to be set depends upon

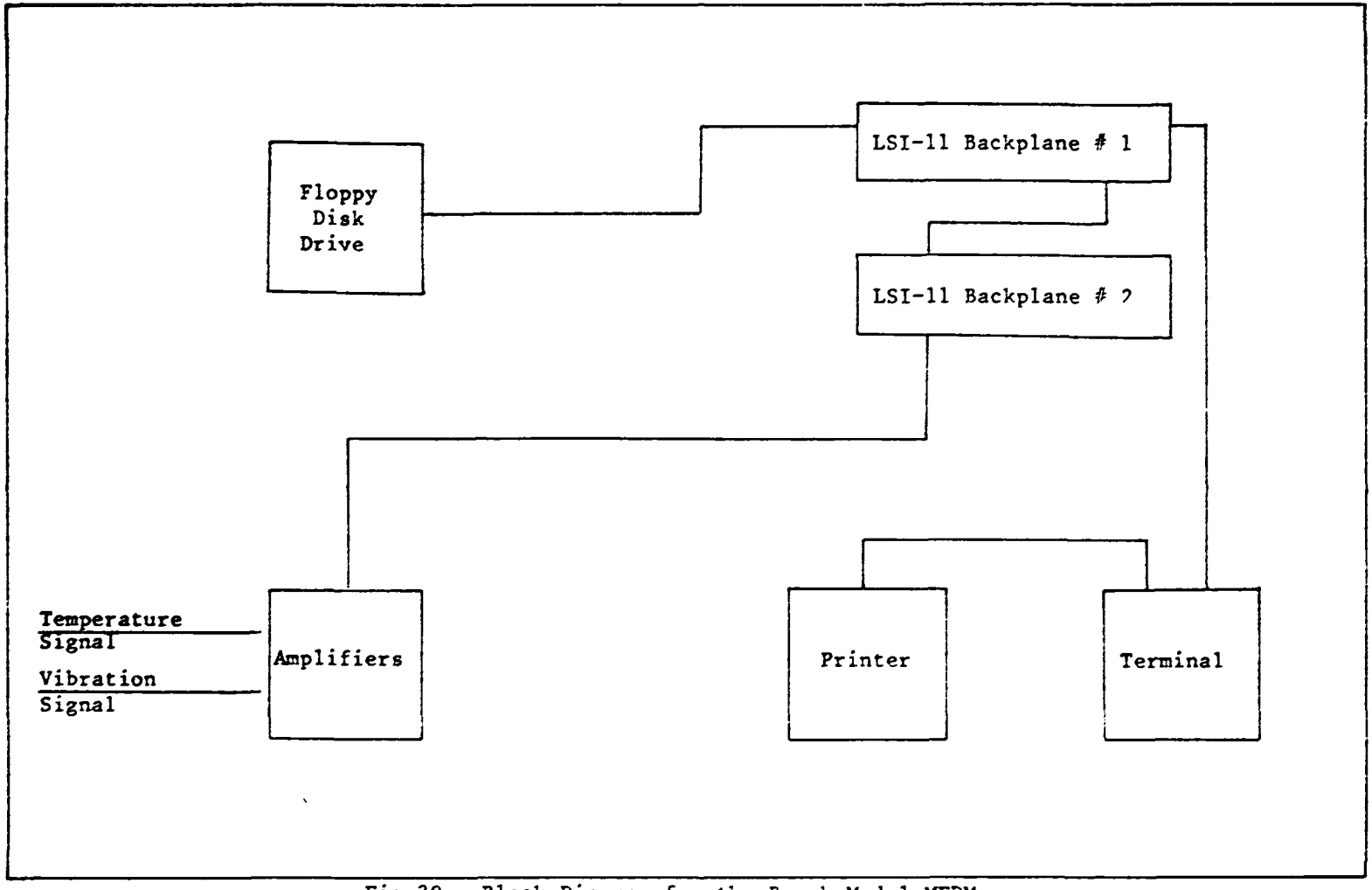

Fig 30. Block Diagram for the Bench Model MFDM

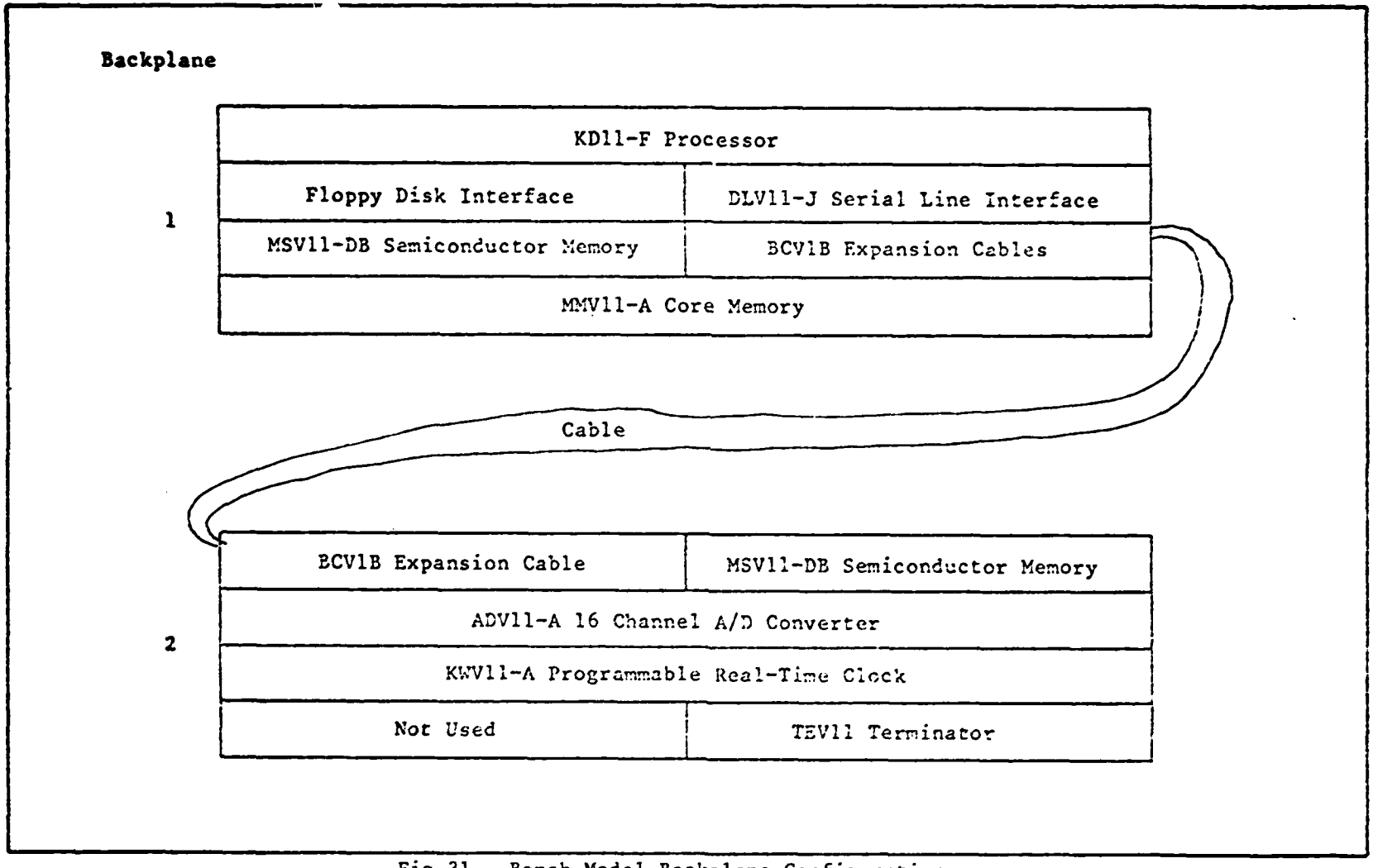

Fig 31. Bench Model Backplane Configuration

the intensity of the input signal. In order to determine what value to use, observe the output of the amplifier with an oscilloscope and set the switch to a position which keeps the magnitude of the strongest signal below 5 volts. The gain of the amplifier, as a function of the switch setting, is shown below.

Switch Setting	Gain (db)
0	-10
1	0
2	10
3	20
4	30
5	40
6	50
7	60
8	DO NOT
9	USE

For the temperature input, the output of the temperature amplifier is connected to the channel 5 leads from the A/D converter (the thermocouple leads are permanently connected to the ampifier). This completes the connections for the vibration and temperature signals The system is now ready to be turned on and to be configured for data acquisition and processing for the required frequency range and interval.

System Start-Up Procedure

First, the power should be turned on for all components (the computer, the terminal, the printer, and the amplifiers). After application of system power, the "RUN/HALT" switch should be placed in the "RUN" position, and then the "DC Power" switch should be turned on. A "$" should appear on the terminal. If it does not check that all

units have power, and that all baud rates are set to the same value. Insert a system disk with MFDM.SAV on it, in the left disk drive (drive 0) and enter a "DX", followed by a carriage return, at the terminal. If the system disk has a STARTF.COM file which contains the instruction "R MFDM", then the system program will start executing automatically. If not the following commands must be entered from the terminal:

```
SET TT:FORM
SET TT:WIDTH=96
R MFDM
```

The first two commands configure the system to send form feeds to the terminal, and to set the length of a line to 96 characters. The last command starts the MFDM system program.

Operating the MFDM

The R MFDM command starts the execution of the MFDM system program. After starting, the user is greeted with the following lines:

```
MICROPROCESSOR FLIGHT DAMAGE MONITOR
ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - ?<CR>
```

The first letter of the function to be performed is entered, followed by a carriage return (<CR>), and that procedure is executed. The following sections describe each of the functions and their uses.

SETUP. If an "S" is entered, the setup procedure is executed. This procedure allows the user to configure the system. The current system configuration is printed at the terminal, along with the

following prompt line:

CHANGE D(ATE, C(OMMENTS, F(REQUENCY, R(UN, DURATION,
V(ERIFY, Q(UIT - ?<CR>

The first letter of the desired procedure should be entered, followed by a carriage return, and that procedure will be executed. If a "V" is entered, the current system configuration will be displayed again, thus allowing the configuration to be checked. If a "Q" is entered, the set-up procedure will terminate, and the MFDM command line will be displayed.

DATE. If the date (which will be printed on the cumulative damage matrix table) is to be changed, a "D<CR>" is entered, and the following message is printed:

ENTER NEW DATE (13 characters max.) - ?<CR>

The new date is then entered in any form desired. For example these dates would be valid 15-DEC-79, 12-15-79, or 15 DECEMBER 79. However, the date must be no more than 13 characters long, and must end with a carriage return.

COMMENTS. By entering a "C<CR>", the comments can be changed. The following line is printed:

ENTER COMMENTS <CR>

Up to 40 printable characters can then be entered just as the user wants them to appear on the output table followed by a carriage return. These comments can be used for identification purposes such as the flight number, test object and location.

FREQUENCY. When an "F<CR>" is entered, the following lines are printed:

FREQ. RANGE (K Hz)	DELTAF (Hz)	ENTER
0 - 6.0	100.2	1
0 - 6.0	50.1	2
0 - 3.0	100.2	3
0 - 3.0	50.1	4
0 - 3.0	25.0	5
0 - 1.5	100.2	6
0 - 1.5	50.1	7
0 - 1.5	25 0	8

ENTER THE NUMBER CORRESPONDING TO THE DESIRED COMBINATION.
ENTER AN INTEGER BETWEEN 1 AND 8 - ?<CR>

The frequency range for which the cumulative damage factor (CDF) will be obtained is 0 through the frequency selected, with the corresponding frequency interval - DELTAF. The frequency range and interval are initialized in the system by entering the integer (1 to 8) corresponding to the desired frequency range and intervals. Only the combinations shown above are available and any entry other than an integer between one and eight will result in an error message with a request for a new entry.

RUN DURATION. The run duration is the time for which data will be acquired and processed once execution begins It can be set by entering an "R" followed by a carriage return, and then the desired duration should be entered. It should be entered in decimal hours, and followed by a carriage return.

Any of the four items can be changed, but all four do not have to be changed. When all of the desired changes have been made, entering a "Q" followed by a carriage return will terminate the set-up routine, and the MFDM command line will be printed as follows:

ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - ?<CR>

This completes the SETUP procedure. The next procedure is EXECUTE

EXECUTE. The execute procedure is initialized from the MFDM command line by entering an "E" followed by a carriage return. The following message will then be printed:

THE RUN DURATION WILL BE XX HOURS
DO YOU WANT TO CHANGE IT? Y/N<CR>

where the XX represents the current run time, which must be greater than zero. If the time needs to be changed, this is accomplished by entering a "Y" followed by a carriage return. The new duration should then be entered. If the time does not need changing, entering an "N" followed by a carriage return will result in the initiation of data processing. The following message will be printed at the terminal:

DATA BEING PROCESSED

Upon expiration of the run time, data processing will terminate, and the following lines will be printed:

DATA PROCESSING COMPLETE
ENTER S(ETUP, E(XECUTE, O(UTPUT, Q(UIT - ?<CR>

The data is now ready to be printed, and this is accomplished by the output routine.

OUTPUT. This routine prints out a table of the cumulative damage factor vs temperature for the frquency range selected, an example of which is shown in figure xx. The table is designed to be printed on a

96-column printer. In order to be able to print all of the data in 96 columns, the data has been divided into two categories depending on temperature. The first set of tables covers a temperature range of -50 degrees Fahrenheit to +100 degrees Fahrenheit, in 25 degree increments, printing 41 lines per page until all the frequency intervals have been printed. Then the printing process is repeated for a second temperature range of +75 degrees Fahrenheit to +225 degrees Fahrenheit.

After printing the CDF table, the MFDM command line is displayed, and the system is ready to repeat the test run using the same configuration (enter an "E"), to be re-configured for a new test (enter an "S"), or to print another copy of the CDF table (enter an "O").

Stopping Program Execution

When all of the testing has been performed, the system should be shut off. This is accomplished by removing the disk switching the DC power switch to the position, and then turning off all AC power off.

Summary

This completes the instructions on the operation of the MFDM bench model system. The procedures to configure the system and to run the programs have been discussed. If, for any reason, the system does not respond in the correct way, remove the disk. shut down the power, and check the system configuration. Then re-start the MFDM. If the system still fails to operate. check Chapters V-VII for the operation of the programs, in order to determine the problems.

Vita

Brian Charles Johnson was born July 24, 1948 in Minneapolis, Minnesota. He attended St. Louis Park High School in Minneapolis, graduating in 1966. He then attended the University of Minnesota, graduating in 1970 with a Bachelor of Physics Degree.

In 1971 he joined the U.S. Air Force, and received his navigator rating in 1972. He was stationed at Plattsburgh AFB, New York between 1972 and 1978, where he flew in the KC-135 aircraft. In 1978 he was selected to attend the Air Force Institute of Technology where he graduated with a Master of Science Degree (Computer Systems) on December 15, 1979.

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In order to design a constrained layer damping treatment for aircraft components, the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Ohio requires a knowledge of vibration and temperature variations which a component encounters during its life. This report discusses the design and implementation of a microprocessor based system to acquire vibration and temperature information, and computes the cumulative damage factor

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versus frequency and temperature in real-time. The cumulative damage factor is computed for one of eight user selectable frequency ranges and for a temperature range of -50 to +225 degrees Fahrenheit, and is stored in a non-volatile memory.

The designed system used an LSI-11 microcomputer system consisting of an LSI-11 processor, an analog-to-digital converter, a real-time clock, PROM, a non-volatile memory, and a serial interface. The software developed for this system controls the data acquisition, the computation of a fast Fourier transform (FFT), the power spectrum of vibration data, and the subsequent computation of the cumulative damage factor. The data acquisition and FFT modules were coded in assembly language, and the other modules were coded in FORTRAN. The output of the system consists of a table containing the cumulative damage as a function of frequency and temperature. A bench model system was constructed and tested, and a proposal for a flight-worthy system is made.