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TITLE MULTIPULSE

FOCAL ABSTRACTS

PHYSICS

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ABSTRACT

The MULTIPULSE program has been written to check the differential linearity of any multichannel pulse height analyzer.

REQUIREMENTS

Storage

MULTIPULSE is stored in the form of perforated tape which can be read into the memory of the PDP-8. Once MULTIPULSE has been loaded into the PDP-8 essentially all the memory is filled or will be filled as the program progresses.

Subprograms and/or Subroutines

BASIC FOCAL is the only software requirement of MULTIPULSE.

Equipment

A 4K PDP-8 computer and a 33ASR Teletype are the necessary hardware.

USAGE

Loading

The Focal language may or may not be in the memory of the PDP-8. A simple test to see if FOCAL is in memory is to turn the PDP-8 on with the switch key, to place 0200 in the SWITCH REGISTER and to press in succession the LOAD ADD and START keys. If FOCAL is in a dialogue described in part h. of the following instructions on how to load FOCAL will begin. If FOCAL is not in the machine then the following procedure taken from section 1.2 of the "FOCAL Programming Manual" describes the steps for loading FOCAL.

Loading Procedure:

The Binary Loader is used to load FOCAL. Check to see if the Binary Loader is in core. If location 7777 contains 5301, the Binary Loader is in core; if not, refer to Appendix F.

The procedure for loading FOCAL is detailed below:

a. Place the FOCAL binary tape in the tape reader.

b. Put 7777 (the starting address of the Binary Loader) in the SWITCH REGISTER.

c. Press the LOAD key.

To use the high speed paper tape reader, set bit 0 of the SWITCH REGISTER to 0.

d. Press the START key.

e. The tape will stop twice during loading because the program is loaded in three sections for additional ckecksum protection. After each halt, the contents of the accumulator (AC) should be 0; if the AC $\neq$ 0, reload the previous section of tape. If the AC is 0, press the CONTinue key and the tape will continue loading.

f. Place 200 (the starting address of FOCAL) in the SWITCH REGISTER when the tape is completely loaded.

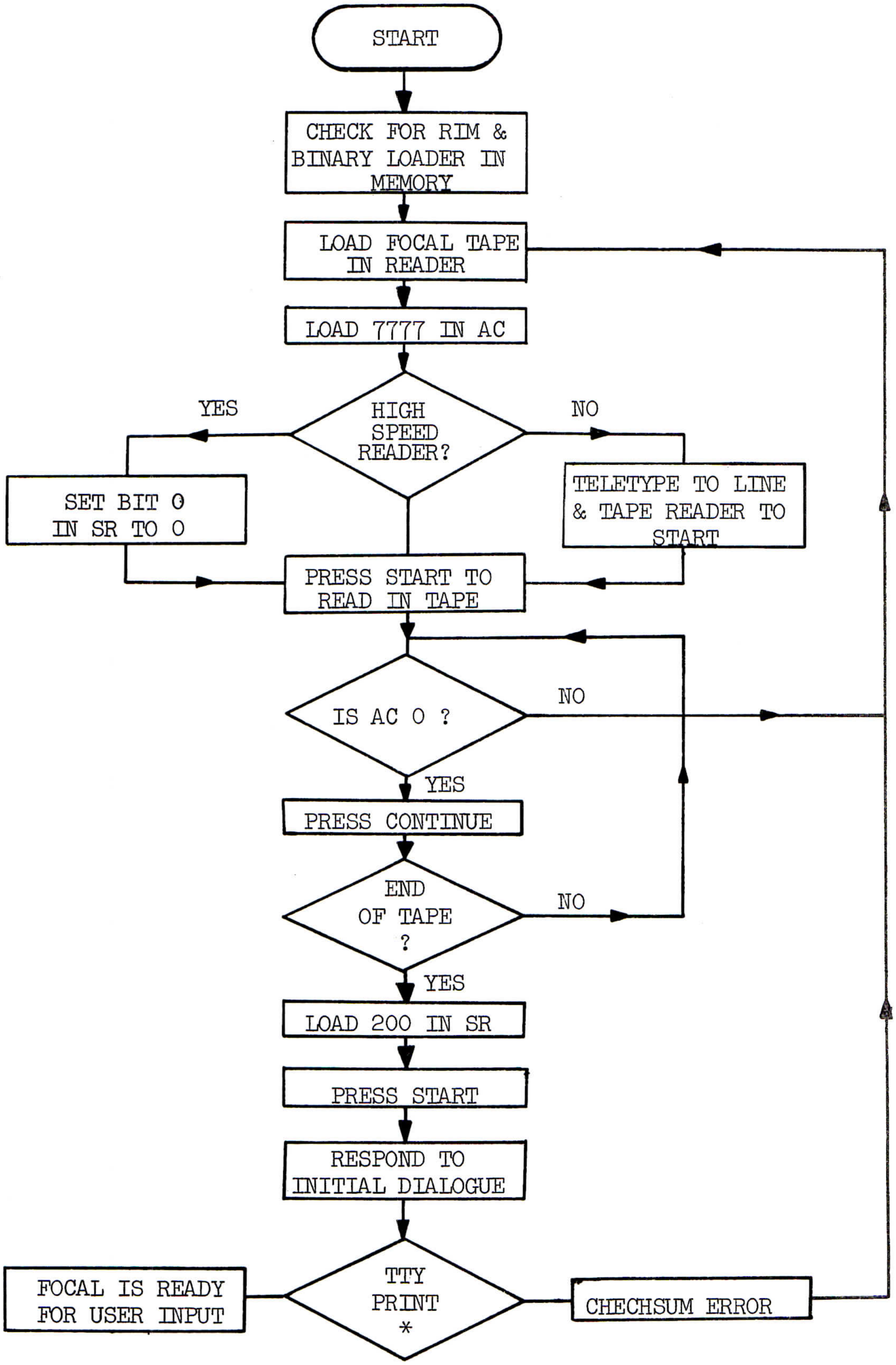
g. Press the LOAD ADDress key.

h. Press the START key. The initial dialogue will begin. This is a question and answer sequence, with FOCAL asking questions and the user providing the answers. The first question offers an option. If you want a full explanation, press the RETURN key on your Teletype. The present version of FOCAL operates in 4K, and so states; future versions will include an option to utilize an additional 4K of memory.

i. FOCAL is correctly loaded and ready for user input when it types an asterisk. If FOCAL is incorrectly loaded, reload the FOCAL tape starting with step a above.

SEE NEXT PAGE FOR LOADING PROCEDURE FLOW CHART

The FOCAL loading procedure is illustrated in the following flowchart.



When it is known that FOCAL is in memory then MULTIPULSE must be loaded. MULTIPULSE like FOCAL is stored in the form of perforated tape and is loaded into the PDP-8 via the Binary Loader. With FOCAL in memory the process for loading MULTIPULSE consists of placing the MULTIPULSE tape in the tape reader on the lower left side of the teletype with the tape reader switch set on STOP. When the MULTIPULSE tape is in place, the switch is moved to START, at which time the program will be read into memory and ready for activation. It may be necessary to switch the tape reader off and back on after a few seconds a couple of times during the read-in to avoid memory input overflow. Figure I shows what the program should look like after read in; if it does not, then the program should be read-in again.

Start Up and Entry Thru Data Introduction Completion

After MULTIPULSE has been loaded into memory, the program is activated by typing the letter G followed by a carriage return (RETURN key). If all has gone well at this time MULTIPULSE will type TRACE: or TRACE depending upon the version of FOCAL which the machine contains. Some versions will type a colon when it desires a data value or parameter; others will not. It will be assumed in the balance of this paper that the version which makes use of the colon is in memory. In other words, when the program desires another parameter or data value, a colon will be typed by the PDP-8.

After the PDP-8 types TRACE:, the user can type in either -1 (minus one) or 1 (plus one) depending upon what output he desires from the program. If a 1 is typed in, the program will list, after introduction of enough data, in a vertical array the channel number and the differential non-linearity of that channel (see Figure II). If -1 is typed in the output will contain no information about any specific channel and gives only overall results (see Figure III). After entering the appropriate response to TRACE:, the spacer bar on the teletype keyboard is activated and the program proceeds to the next line and types # CHANNELS:. The parameter which the program now desires is the number of channels from which data values will be used, or in other words the number of data values. Following the typing into memory of this number, the spacer bar is again pressed and the program proceeds to the next line and types START CH # :. The parameter called for now is the channel number of the channel from which the first count is taken (the program assumes by necessity that the data values be entered by consecutive channels). Again following the entering of the appropriate channel number the spacer bar is pressed and the program proceeds to the next line and types ASSUME % MAX DEV:, at which time the user is asked to enter what he feels will be the largest non-linear differentiality in percent of any of the channels. This parameter must have a value in the range 1 to 10 (percent) and if the actual deviation of any channel exceeds the value typed in, an error message will result and the program will terminate without further compilation. After typing in the percent maximum deviation assumed, the RETURN key is pressed at which time the PDP-8 proceeds to the next line and types : . The user is now to type in the count for the first channel of the Compton spectrum and then press the spacer bar. Again the PDP-8 will type : and the count for the successive channel should be entered; this process is reported until all the data values have been entered.

After the eighth data value has been entered and the spacer bar pressed, the PDP-8 will proceed to the next line, at which time the user merely types in the next data value. If TRACE : had earlier been given a positive value, then after the user types in the ninth data value and presses the spacer bar, the machine will type X.XX DD.DD and proceed to the next line and type : , where X.XX represents the channel number of the channel four channels preceding the last entered data value and DD.DD represents the deviation in percent of the channel whose number has just been printed. The next data value should now be entered and again the machine will type the channel number of the channel four channels behind the last entered data value and the deviation of the channel whose number was typed. This is done after each data value until all the data values have been entered. When all data has been entered, MULTIPULSE takes complete control of the machine for the complete compilation of the results.

If TRACE : has not been activated, then when the skip to the next line occurs after the eighth data value has been typed, then the user continues typing in the data values followed by a space and the machine types : and so on until every value has been entered. It may become necessary after so many data values to skip to the next line; this can be done after entering any data value by pressing the RETURN key instead of the spacer bar. It is suggested for readability that after the

18th, 28th, 38th, etc. data values that the RETURN key be used instead of the spacer.

Errors in Usage

MULTIPULSE contains only one error and error message not contained in FOCAL. As stated before, if the absolute value of the deviation of any channel exceeds the maximum assumed deviation given in response to ASSUME % MAX DEV: then MULTIPULSE types as soon as the larger deviation appears:

MAX DEV > X.X % INCREASE SPAN

where X.X represents the parameter entered by the user as the absolute value of the maximum possible deviation. The program then terminates without further compilation (see Figure IV).

Recovery from such Errors

The only recovery from the error described in section 4.5 is to completely restart the program from the beginning by typing G and so on as in section 4.4. This time though the user should increase the ASSUME % MAX DEV: parameter to a value which he feels will not be exceeded and proceed as before.

As a hint to operation: if the user makes a mistake while typing in a data value and has not terminated the data value he may then type →, (a left pointing arrow), which erases the incorrect number, and then type in the correct value. This is a basic FOCAL operation. For more information see section 2.11 of the "FOCAL Programming Manual." MULTIPULSE contains all of the error messages and recovery procedures as described in the "FOCAL Programming Manual," i.e. contained in FOCAL.

RESTRICTIONS

Restrictions upon Input Parameters and Data Values

MULTIPULSE has certain limits for the input parameters and data values entered; they are as follows:

1) The TRACE: parameter will activate the trace feature if it is given a value equal to or greater than zero. A negative value will cause the trace feature not to be activated.

2) The # CHANNELS: parameter must be equal to or greater than nine, and as many data values (counts) must be entered as the value of this variable. This number should obviously be an integer.

3) The START CH. # : parameter must be equal to or greater than zero and is used only as a means for associating a specific channel with its deviation when the trace feature is in use.

4) The ASSUME % MAX DEV : parameter must be in the range 1 to 10. If some number less than one is used and the program will compile without any error messages, the results still will not be valid. The MEA STD (measured standard deviation) and the CAL STD DIF NON-LIN (calculated standard deviation due to differential non-linearity) and the histogram of deviations will be incorrect. All other computations will be correct.

5) The count in each channel can be any positive number, but for results to be of any value, it is suggested that this variable exceed 50,000 counts in each channel and will give much more useful data if this value is in the 900,000 counts range.

DESCRIPTION

Discussion

MULTIPULSE is essentially a restatement in program form in the FOCAL language of section 3.7 of J. Doub's publication, "HP 5415A ANALOG TO DIGITAL CONVERTER." The mathematical definitions of MULTIPULSE and Mr. Doub's publication are in complete agreement and many of the methods of data analysis used in MULTIPULSE were taken from his publication.

MULTIPULSE is a program in the FOCAL language to measure the differential non-linearity of a multichannel pulse height analyzer. The mathematical techniques used to do this are discussed in section 7 of this paper. MULTIPULSE depends basically upon generation of a fairly flat Compton spectrum which uses all the channels of the analyzer. This spectrum can be generated by using a plastic scintillator to pick up photon emissions from a radioactive source. Preceding or in between the peaks (annihilation, backscatter, characteristic and pair production) of the characteristic spectrum of the source around 0.5 Mev is a region where the Compton effect gives a fairly flat spectrum. The photon energies in this region should be continuous and any deviations from absolute flatness should be linear in nature. This constant distribution then is the basis for the linear differentiality test. If the energy differential for which a photon in the energy differential will be counted in a specific channel is the same for each channel, then any difference in the number of counts per channel should be linear over a segment of a finite number of channels. Any deviation from linearity can be attributed to differences in the width of the energy range for each channel and other effects outlined later. We have now defined in words the differential non-linearity for any channel as the difference in the width of the energy range counted in that channel and the widths of the energy ranges of the surrounding channels; this is expressed mathematically in the next section. In other words, a given channel will absorb, count, photons in the energy range of width Δ_i:

$$\Delta_i = E_i \text{ (uuper)} - E_i \text{ (lower)}$$

Where:

E_i (upper) = energy above which a photon will be counted in a higher channel.

E_i (lower) = energy below which a photon will be counted in a lower channel.

Differential non-linearity results when the Δ_i's are unequal and is a measure of the unequalness.

METHODS

Discussion

Using the fully generated Compton spectrum MULTIPULSE calculates certain quantities assumed to be of general use. The mathematical methods used to calculate these quantities are as follows:

The data reduction process can best be understood by referring to Figure V. Shown in this figure is a segment of the multichannel Compton spectrum. MULTIPULSE calculates the average contents of a nine-channel segment of the spectrum. This average should agree closely with the contents of the center channel (channel 5) of the nine channel segment. Deviation is defined as the difference between the count in channel 5 and the average count, or mathematically:

$$\% \text{ Deviation} = \frac{(\text{Count in center channel}) - (\text{average count})}{(\text{average count})} \times 100$$

Any deviation can be attributed to three sources:

a) differential non-linearity in the pulse height analyzer

b) statistical deviations due to random channel filling

c) second order effects such as curve fitting errors, etc.

The deviation of each channel is quantitized to a one-tenth of the ASSUME % MAX DEV: parameter increment, and a register corresponding to that percentage is incremented by one. The nine-channel segment is moved one channel to the right and the process is repeated. This operation is continued over the entire channel spectrum. At this point each quantitizing register has stored in it the number of channels having its particular channel width deviation. The contents of each register is printed on the data sheet in histogram form as shown in Figure III. After the deviations have been found for each channel, several calculations are performed. The results are typed out on a data sheet such as the one included here in Figure III. First, the set of deviations is searched for the worse-case percentage deviation of channel width.

Second, the standard deviation of the channel width due to the statistical counting effects is calculated from the relationship:

$$\sigma_s (\text{pct}) = \frac{100}{\sqrt{N}}$$

where $\sigma_s(\text{pct})$ = standard deviation in percent due to counting statistic

N = average number of counts per channel

The third calculation yields the standard deviation of the channel width as measured by the Compton spectrum. In this calculation the following expression is evaluated approximately:

$$\sigma_m^2 = \frac{1}{n} \sum_{i=1}^{\ell} (\Delta W_i)^2$$

where σ_m = measured standard deviation of the channel widths

n = number of deviations calculated

ΔW_i = percentage deviation of the i^{th} channel width from the average channel width (taken from the measurement)

Since the initial calculations resulted in a histogram format for the channel width deviation data, the previous expression can be approximated and rewritten as:

$$\sigma_m^2 = \frac{1}{n} \sum_{i=1}^{\ell} N_i [P_i]^2$$

where σ_m = measured standard deviation of the channel widths

n_i = number of channels in the i^{th} histogram slot

P_i = percentage deviation represented by the i^{th} histogram slot

n = number of deviations calculated

The fourth and last calculation is essentially a comparison of the statistical results of the measurement. For normally-distributed non-correlated events it can be shown that for random variables X, Y, Z:

if $Z = X + Y$

then $\sigma_z^2 = \sigma_x^2 + \sigma_y^2$ or $\sigma_x^2 = \sigma_z^2 - \sigma_y^2$

In our case the contents of each channel, and hence its apparent width is dependent upon the two major effects of differential non-linearity and counting statistics. In other words:

$$\sigma_m^2 = \sigma_{de}^2 + \sigma_s^2$$

where σ_m = measured standard deviation

σ_{de} = standard deviation due to differential non-linearity

σ_s = standard deviation due to counting statistics

The fourth computation then calculated:

$$\sigma_{de} = \sqrt{\sigma_m^2 - \sigma_s^2}$$

What is intended here is to provide an indication of how much of the observed deviations in channel widths can be attributed to the differential non-linearity of the analyzer, and how much can be attributed to statistics.

Algorithm

1) Is the trace feature desired?

Yes	type 1	(set TR = 1)
No	type -1	(set TR = -1)

2) What is the number of channels?

set NC = number of data values

3) What is the channel number of the channel from which the first data value is taken?

set CN = number of channel associated with first data value

4) What is the assumed percent maximum deviation that no channel should exceed?

set DS = assumed percent maximum deviation

5) Replace channel number by channel number plus three.

6) Read (Ask) the count in each of the first eight channels.

7) Set Total = sum of counts in first eight channels.

8) Set Average = Total/9

9) Repeat the next eleven steps, the number of channels minus eight, times.

1 10) Read (Ask) the value of the count in the next channel.

2 11) Replace Average by Average plus the quantity latest data value minus data value nine channels back quantity divided by nine.

3 12) Replace Total by Total plus the latest data value.

4 13) Calculate the percent deviation for the middle channel in the present nine channel segment.

5 14) Increase channel number by one.

6 15) If the absolute value of the latest calculated deviation is greater than the absolute value of the maximum deviation then replace the previous value of the maximum deviation with the newly calculated deviation; if not proceed.

7 16) Classify the latest calculated deviation into the correct category of deviation.

8 17) If trace feature is desired, then print out channel number and the newly calculated deviation; if not proceed.

9 18) Increment the counter in the correct deviation category by one to accomodate the newly calculated deviation.

10 19) Redistribute data so that a new data value will be acceptable for the nine-channel segment.

11 20) If the observed maximum deviation exceeds the assumed maximum deviation, then print out error message; if not proceed.

21) Calculate the measured standard deviation.

22) Calculate the statistical standard deviation.

23) Calculate the deviation due to differential non-linearity.

24) Print out: measured maximum deviation, measured standard deviation, statistical deviation, and deviation due to differential non-linearity.

25) Print out histogram of deviations.

26) STOP

Accuracy

The accuracy of this program should be exceedingly good and any discrepancies would arise from the approximation described for calculating the measured standard deviation as presented in section 7.1. The smaller the amount of the deviation span the more accurate this approximation should be, but as stated before, the deviation span has a lower bound of one (percent).

FORMAT

Input Data

Data input is all numerical and is introduced into the PDP-8 when it prints : (colon). The order and type of input has already been described. The only strenous requirement concerning the input of the counts in each channel is that the counts be introduced in order of channel number and remember that either a carriage return or spacer bar activation must follow every data value to show that the complete data value has been typed in. For input instructions see section 4.4.

Output Data

There is possible two correct formats for output. If the trace feature has been taken advantage of, for every channel after the eighth when the spacer bar is pressed to end the data value from a channel, the machine then types on the same horizontal line the channel number of the channel which is four channels back and then the deviation of the channel whose number has been listed. The PDP-8 then skips to the next line to await the value of the number of counts in the next channel. Each horizontal line looks like:

```
:DVDVDV          X.00          Y.YY
```

where DVDVDV represents the data value the user types in; X.00 represents the channel number for which Y.YY is the percent deviation (see Figure III).

If the trace option has not been activated, data input is the only values on the paper until all the data values have been entered.

After all the data values have been entered, the output format from that point on is the same for every program (see Figure III).

The output format is as follows:

```
AVG.   XXXXXX                              (1)
DEVIATION
 MEA MAX    X.XX %                         (2)
 MEA STD    X.XX %                         (3)
 CAL STD    X.XX % STAT                    (4)
 CAL STD    X.XX % DIF NON-LIN             (5)

followed by the histogram of deviations    (6)
```

(1) AVG. -- gives the value of the average number of count per channel over the entire spectrum.

(2) MEA MAX -- gives the measured peak deviation of channel width in percent from linearity of all the deviations calculated.

(3) MEA STD -- gives the measured standard deviation of channel width in percent; the quantity is calculated as illustrated in section 7.1 of this paper.

(4) CAL STD X.XX % STAT -- gives the calculated standard deviation of channel width due to counting statistics, calculated as illustrated in section 7.1 of this paper.

(5) CAL STD X.XX % DIF NON-LIN -- gives the calculated standard deviation of channel width in percent due to the differential non-linearity, calculated as illustrated in section 7.1 of this paper.

(6) the Histogram (see Figure III) -- The histogram generated by MULTIPULSE has two vertical columns of numbers. The column on the left is headed by:

% DEV

Under it, starting with the negative of the ASSUME % MAX DEV: as was supplied by the user, is a vertical list of the deviation categories. The values increase going downward by increments of one-tenth of the ASSUME % MAX DEV: until the positive value of ASSUME % MAX DEV: is reached, listing 21 values in the process.

In the vertical column just to the right of the first column is a column headed by:

CH. AT DEV

is the number of channels at the percent deviation listed on the same horizontal line. This means that if a channel has a deviation whose value is within .05 times the ASSUME % MAX DEV: parameter of a value listed in the first column that the counter listed in the second column has been incremented by one when this deviation value arose. That is, the second column contains the number of channels whose deviation is closer to the number listed to the left than any other number listed in the first column.

Following the second column is a vertical line of X's which serve as a base line for the histogramatic representation of the data presented in the first two columns. The histogram prints a number of X's in the horizontal column; the number of X's relatively approximates the number of deviations at the error given in the same horizontal column.

See Figures II and III for complete output as given by the same data values, Figure III without use of trace option and Figure II with the trace option activated.

Miscellaneous

Data cannot be input by the low speed reader from tape because of command input buffer overflow. See Appendix B of the "FOCAL Programming Manual" for listing of this error and other FOCAL errors and error messages.

EXECUTION TIME

Minimum

Execution time depends obviously upon the speed with which data is input; the maximum time is infinite. The minimum time limited by the PDP-8 is approximately four minutes per 100 channels when the trace feature is in use. Without the trace feature the PDP-8 will process data values almost as fast as they can be typed in. The user should never type in values while the PDP-8 is typing a message out. Always wait for the machine to type : (colon) before typing in a new data value.

PROGRAM

Parameter and Variable List

The following parameter and variables are the identifiers used in MULTIPULSE. Certain of the variable names are used twice to conserve memory space; this redefining of the identifier becomes possible only when the first value if labeled is no longer of any use in the program.

TR - (TRACE:) the parameter used to activate the trace option.

NC - (# CHANNELS) the number of channels or data values which will be typed into the machine; i.e. the number of channels for which the differential non-linearity is to be calculated.

CN - (START CH #:) the channel number of the channel whose deviation is being calculated.

DS - (ASSUME % MAX DEV:) the peak deviation in percent which the user feels will not be exceeded by any of the channels under consideration.

C(I) where I goes from 0 to 9 - the current count in each channel of the segment under study.

A - the average count per channel over the nine-channel segment under study.

I - a counting index or variable identifier.

D - the deviation of the middle channel of the current nine-channel segment under study.

MD - the largest deviation for any channel encountered in the data values already entered.

E - the classification category of the current deviation with respect to the assumed percent maximum deviation; all possible values of E are listed in the left column of the histogram.

ND(E) - the number of channels having deviations in category E; i.d., the number of deviations in E.

J - counting index and variable identifier

TD - the variance; the sum of the squares of the percent deviations divided by the number of deviations.

T - the total sum of all of the counts in all channels entered as data values for computation.

TD (Redefined) - the measured standard deviation in channel width; the square root of the variance.

D (Redefined) - the standard deviation in channel width due to counting statistics.

J (Redefined) - the calculated standard deviation in channel width due to differential non-linearity.

Program Listing

See Figure I.

DIAGRAMS

Flow Chart - See Figure VI

REFERENCES

Digital Manuals

FOCAL Programming Manual; Digital Equipment Corporation, Maynard, Massachusetts.

Periodicals

HP5415A ANALOG to Digital Converter; Doub, J., Hewlett Packard Corporation, February, 1968.

ADDENDA

ACKNOWLEDGEMENTS

ERRATA AS OF JANUARY 9, 1969.

```
 W
C-FOCAL , 8/68

02.01 E
02.03 A ?TRACE?,!;A "# CHANNELS",NC,!
02.09 A "START CH #",CN,!;A "ASSUME % MAX DEV",DS,!
02.10 S CN=CN+3;F I=1,8;A C(I);S T=T+C(I)
02.20 S A=T/9;T !;F I=1,NC-8;D 3
02.25 D 4

03.10 A C(9);S A=A+(C<9>-C<0>)/9;S T=T+C<9>
03.20 S D=(C<5>-A)*100/A;S CN=CN+1;I (FABS<D>-FABS<MD>)3.4;S MD=D
03.40 S E=DS*FITR(<10*D/DS>+.5);I (TR)3.5;T %9.02,CN,D,!
03.50 S ND(E)=ND(E)+1;I (DS-FABS<MD>)5.1;F J=0,8;S C(J)=C(J+1)

04.10 F I=-DS,DS/10,DS;S TD=TD+ND(I*10)*I↑2/(NC-8)
04.15 S TD=FSQT(TD);S D=100/FSQT(T/NC);S J=FSQT(FABS<TD↑2-D↑2>);T ,!
04.30 T %7,"AVG. ",T/NC,!,"DEVIATION",!
04.35 T %6.02," MEA MAX",MD," %",!," MEA STD",TD," %",!
04.40 T " CAL STD",D," % STAT",!," CAL STD",J," % DIF NON-LIN",!
04.61 T ,!,"% DEVIATION    # CH AT DEV",!;F I=-DS,DS/10,DS;D 4.7
04.62 Q
04.70 T %8.02,!,I,ND(I*10)," ";F J=0,NC/90,ND(I*10);T "X"

05.10 T ,!;T %4.02,"MAX DEV >",DS,"% INCREASE SPAN";Q
*
```

Figure I. Program Listing

```
*G
TRACE1
# CHANNELS25
START CH #1
ASSUME % MAX DEV1.5

908769 902789 906435 909876 911234 906547 909870 901900
916987          5.00         0.33
923087          6.00-        0.36
928097          7.00-        0.31
915632          8.00-        1.29
919087          9.00         0.25
909865         10.00         0.93
916754         11.00         1.36
914563         12.00-        0.07
902654         13.00         0.30
918976         14.00-        0.73
908997         15.00         0.20
904659         16.00         0.24
912564         17.00-        1.03
943267         18.00         0.47
924876         19.00-        0.81
911235         20.00-        1.21
931243         21.00-        0.55

AVG.   914398
DEVIATION
 MEA MAX     1.36 %
 MEA STD     0.74 %
 CAL STD     0.11 % STAT
 CAL STD     0.73 % DIF NON-LIN

% DEVIATION    # CH AT DEV

-      1.50      0.00 X
-      1.35      1.00 XXXX
-      1.20      1.00 XXXX
-      1.05      1.00 XXXX
-      0.90      0.00 X
-      0.75      2.00 XXXXXXXX
-      0.60      1.00 XXXX
-      0.45      0.00 X
-      0.30      2.00 XXXXXXXX
-      0.15      0.00 X
-      0.00      1.00 XXXX
       0.15      1.00 XXXX
       0.30      4.00 XXXXXXXXXXXXXXX
       0.45      1.00 XXXX
       0.60      0.00 X
       0.75      0.00 X
       0.90      1.00 XXXX
       1.05      0.00 X
       1.20      0.00 X
       1.35      1.00 XXXX
       1.50      0.00 X*
```

Figure II.

Program Input and Output

with TRACE Option

```
*G
TRACE-1
# CHANNELS25
START CH #1
ASSUME % MAX DEV1.5

908769 902789 906435 909876 911234 906547 909870 901900
916987 923087 928097 915632 919087 909865 916754 914563 902654 918976
908997 904659 912564 943267 924876 911235 931243

AVG.    914398
DEVIATION
 MEA MAX      1.36 %
 MEA STD      0.74 %
 CAL STD      0.11 % STAT
 CAL STD      0.73 % DIF NON-LIN

% DEVIATION    # CH AT DEV

-      1.50      0.00 X
-      1.35      1.00 XXXX
-      1.20      1.00 XXXX
-      1.05      1.00 XXXX
-      0.90      0.00 X
-      0.75      2.00 XXXXXXXX
-      0.60      1.00 XXXX
-      0.45      0.00 X
-      0.30      2.00 XXXXXXXX
-      0.15      0.00 X
-      0.00      1.00 XXXX
       0.15      1.00 XXXX
       0.30      4.00 XXXXXXXXXXXXXXX
       0.45      1.00 XXXX
       0.60      0.00 X
       0.75      0.00 X
       0.90      1.00 XXXX
       1.05      0.00 X
       1.20      0.00 X
       1.35      1.00 XXXX
       1.50      0.00 X*
```

Figure III. Program Input and Output without TRACE Option

```
*G
TRACE1
# CHANNELS25
START CH #1
ASSUME % MAX DEV1.5

900900 909000 908000 903000 901000 909000 914000 916000
917000          5.00-        0.84
903000          6.00         0.01
908000          7.00         0.58
917000          8.00         0.68
904000          9.00         0.78
903456         10.00-        0.79
918000         11.00-        0.35
938000         12.00         0.35
940980         13.00-        1.38
950000         14.00-        1.83

MAX DEV >  1.50% INCREASE SPAN*
```

Figure IV. Example of Maximum Deviation

Exceeding ASSUME % MAX DEV

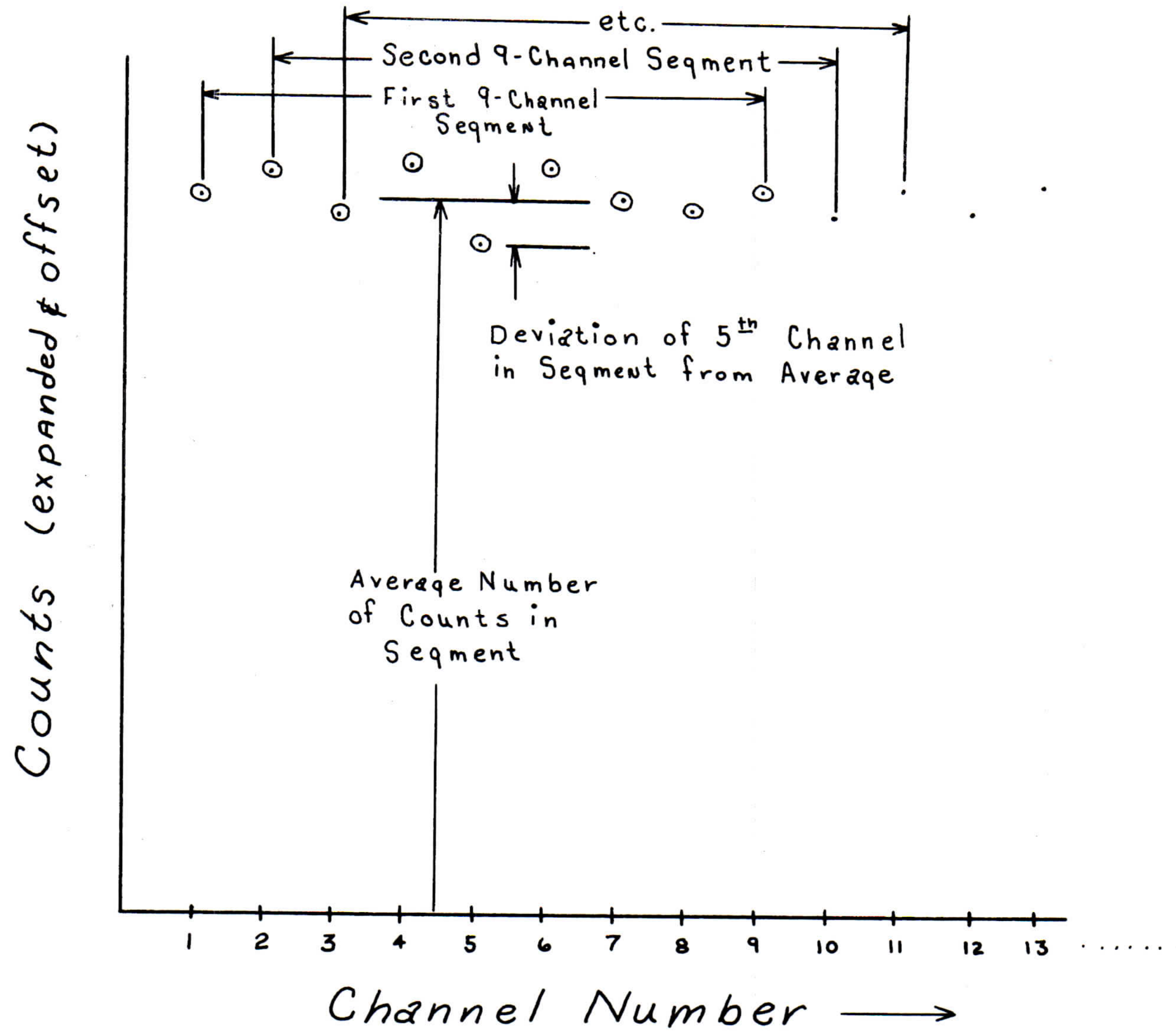


Figure V - Graphic Representation of Data

Reduction Process

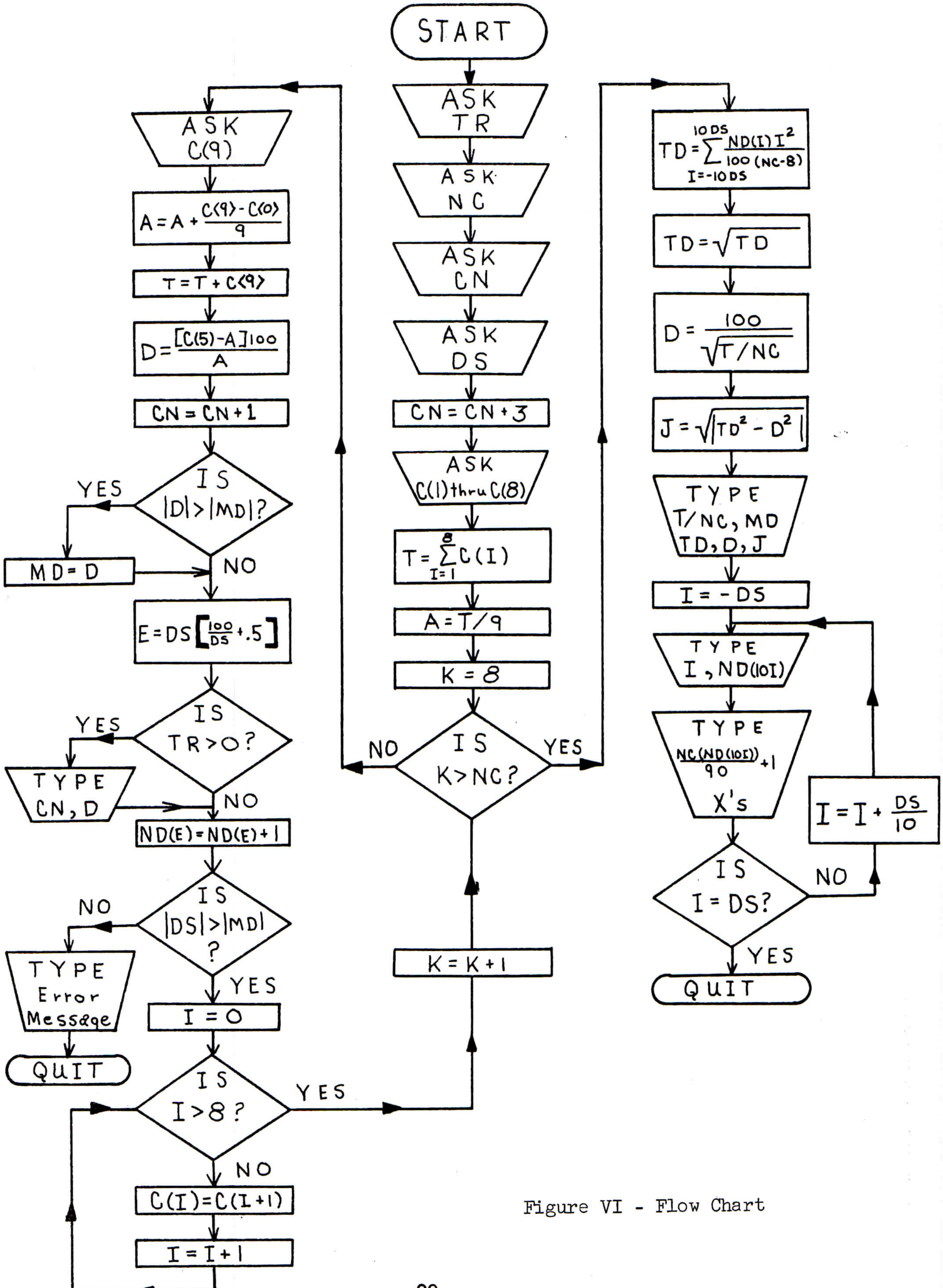


Figure VI - Flow Chart