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AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES(U)  
ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND FORT  
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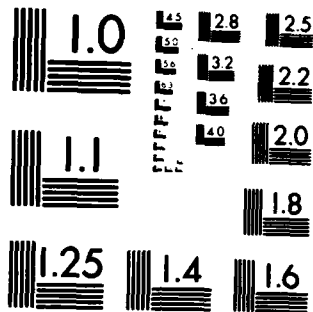
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Report DELNV-TR-0037

AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES

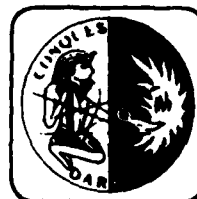
by  
Leonard A. Atkinson  
and  
Jay A. Fox

August 1983

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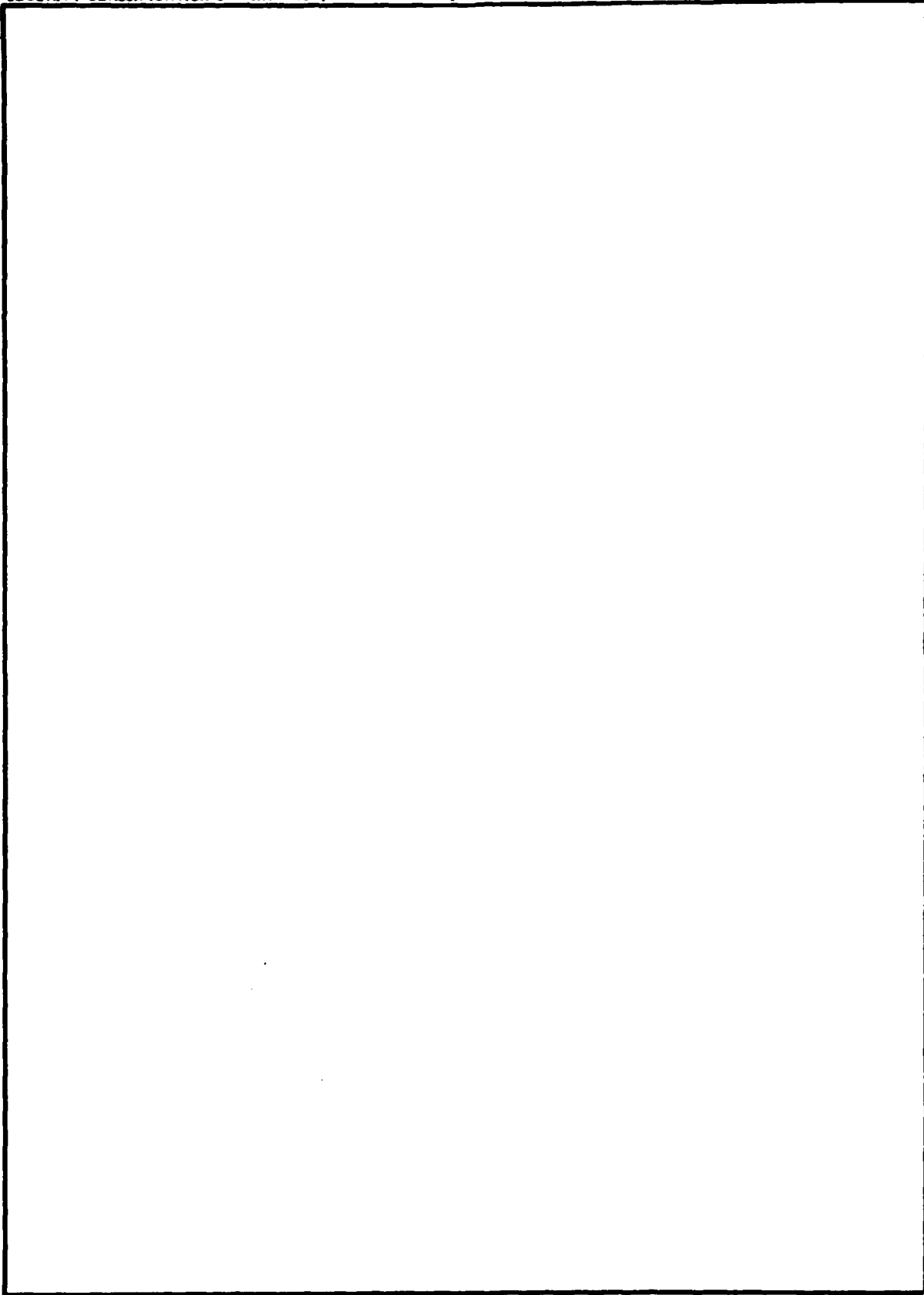
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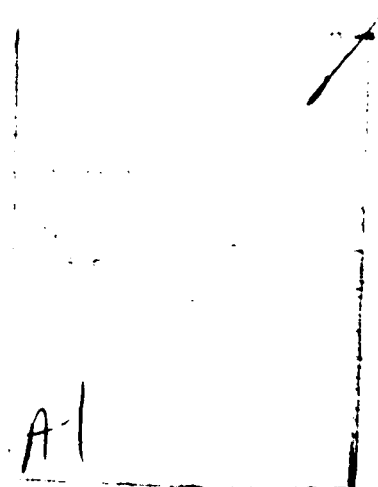


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# AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES

## I. INTRODUCTION

**1. Subject.** This report describes a scheme to calculate laser pulse power, energy, and other parameters by means of a waveform digitizer interfaced with a computer. More specifically, we shall characterize a system which analyzes a pulse emanating from a CO<sub>2</sub> Transversely Excited Atmospheric (TEA) laser. The pulse is detected by a Rofin Model 7441 photon drag monitor, and the waveform is digitized and processed by a Biomation Model 6500 500 MHz-Digitizer and a Hewlett Packard Model 9836 computer, respectively. Although it is this specific system that is described, it is the authors' hope that the techniques utilized will prove to be of general value to laser users. In this spirit, we have included also, a sample BASIC program written for the HP 9836 and shall explain it in depth.

**2. Background.** In order to produce a better TEA laser or to make performance calculations for existing TEA lasers, it is necessary to have an accurate means of determining pulse intensity and energy. There are several types of commercially available detectors for these applications. We shall describe how two of them (a photon drag device and a pyroelectric detector) can be utilized in an automated data recording and processing system.

The photon drag detector utilized in this experiment is a fast ( $< 1$  ns rise time) doped germanium device which produces a voltage proportional to the instantaneous intensity of a laser pulse. This is displayed on an oscilloscope to obtain a record of the temporal history of the pulse. A typical constant of proportionality is given by the manufacturer\*, but an exact value depends on beam profile, input intensity, and experimental set-up. It has even been observed that changes in the internal battery supply voltage will affect the constant. Therefore, it is necessary to determine the photon drag constant for each experimental set-up and periodically check this value to update it if necessary.

The pyroelectric detector employed in this set-up is a Laser Precision Model 314 device which is essentially a capacitor formed by depositing metal electrodes on pyroelectric material. When the radiation strikes the coated surface, the heat produced causes a polarization change which gives rise to an output voltage proportional to input energy. The constant of proportionality can be determined by a calorimeter (e.g., Scientech Model 362), and, therefore, this detector can provide a relatively quick means of measuring the laser pulse energy.

Determining the laser pulse energy and intensity with these detectors can be done manually for a single pulse; but for statistically significant numbers of pulses, this method becomes extremely inconvenient at best. We shall describe a practical method of interfacing the photon drag and pyroelectric detectors with a computer to calculate real time pulse energy

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\* 714 kW/V for this Model 7441 with a built-in X10 amplifier.

and intensity as well as other parameters concerning the temporal history of the pulse. For example, a typical TEA laser pulse has the intensity profile as shown in Figure 1. A high intensity spike containing 20 to 80 percent of the total energy is followed by a long, low intensity tail. Representative values for the spike half width (FWHM) and the total duration of the pulse are 70 ns and 2  $\mu$ s respectively. In addition to the intensity and energy, the system described enables the operator to measure the half width, total duration, and amount of energy contained in the spike. If a number of pulses are to be collected, the average and standard deviation of the ensemble energy and intensity can be displayed.

## II. THEORY

The following analysis is used in order to find the peak power and energy of the laser pulse. The peak power  $P$  incident on the photon drag detector is related to the output voltage  $V_{pd}$  by

$$P = K_{pd} V_{pd}, \quad (1)$$

where  $K_{pd}$  is the photon drag constant (watts/volt).

The total energy of the pulse  $E$  is related to the power by

$$E = \int_0^T P dt, \quad (2)$$

where  $T$  is the total duration of the pulse.

Thus,

$$E = \int_0^T K_{pd} V_{pd} dt. \quad (3)$$

If we assume that the incident intensities are low enough so that  $K_{pd}$  is independent of time, then the photon drag constant may be expressed as

$$K_{pd} = E/A, \quad (4)$$

where  $A$  is the area under the voltage-time curve.

If a pyroelectric detector is used to determine the energy of the pulse, equation (4) becomes

$$K_{pd} = \frac{K_{pe} V_{pe}}{A}, \quad (5)$$

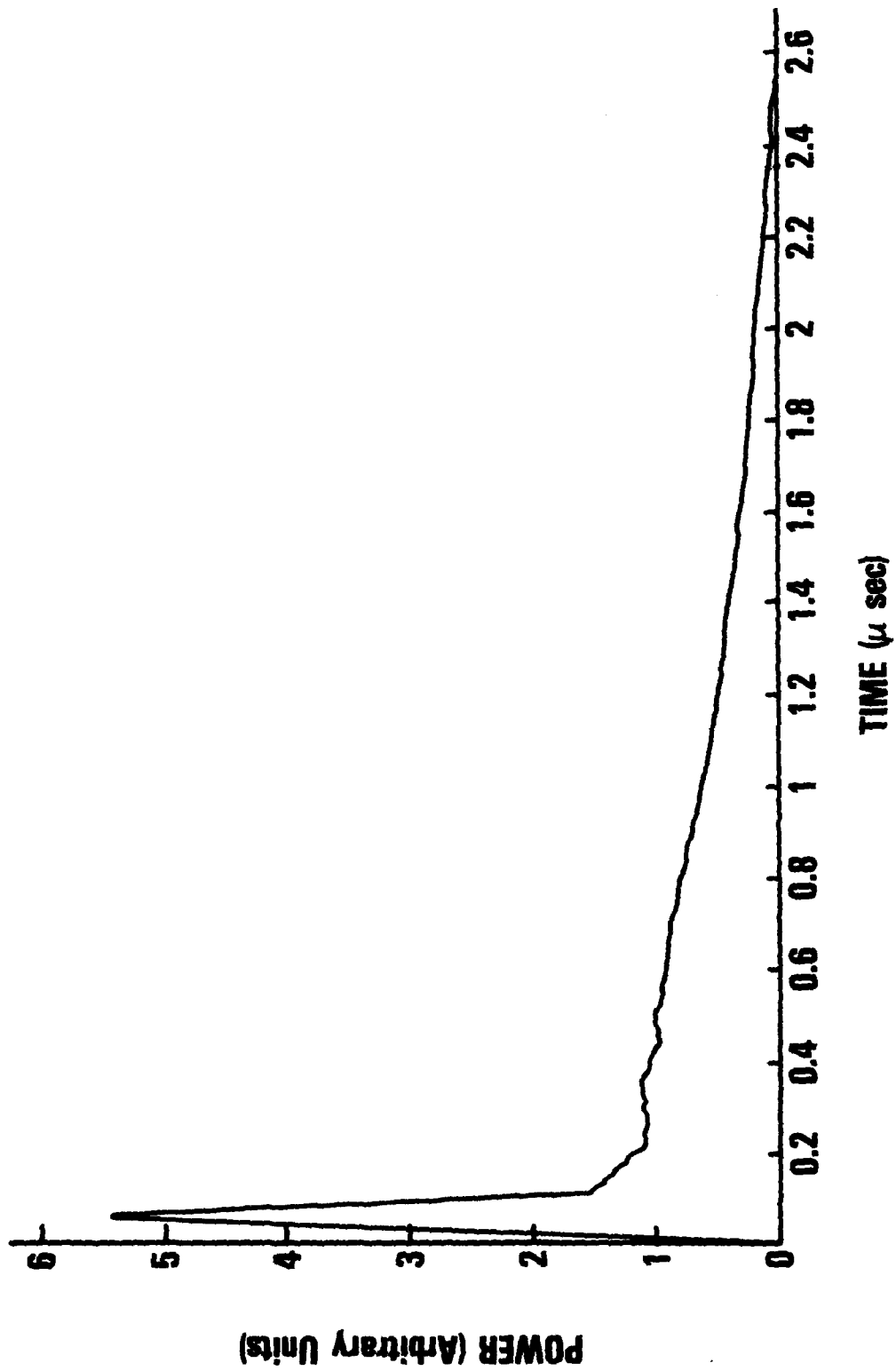


Figure 1. Typical TEA laser pulse.

where

$$K_{pc} = \text{pyro constant (volts/joule),}$$

and  $V_{pc} =$  maximum voltage produced by laser pulse impacting the pyro detector.

The pyro constant can easily be determined by averaging a suitable number of laser pulses of known energy (e.g., from calorimeter measurements) and by dividing that value by the maximum voltage produced by these pulses. The determination of the area  $A$  may be straightforward in principle but in practice may prove to be quite difficult to do accurately. For example, triangular approximations for the pulse are too crude and the presence of a long, low intensity tail that contains a significant portion of the energy makes planimeter measurements, also, inherently inaccurate. It is precisely this consideration that leads one to the choice of digitizing the output of a photon drag detector and using a computer to numerically integrate under the voltage-time curve. At any rate, it is easy to see how the photon drag constant can now be obtained from equation (5) and therefore how the energy and peak power can be measured for any subsequent pulse by the application of equations (3) and (1) respectively.

## II. EXPERIMENTAL SET-UP

Figure 2 illustrates the arrangement of the apparatus schematically. The TEA laser is of conventional design and is preionized by means of an array of sparks. The Rogowski-profiled electrodes are separated by a gap of 1 cm and are approximately 11 cm long by 3 cm wide. When this device is fired by means of a spark gap discharging a 10-nF capacitor charged to 20 to 35 kV, it can produce output energies in the 30 to 150 mJ range and peak powers from 100 to 1000 kW. Note that the photon drag monitor is constructed with an internal beam splitting arrangement that allows part of the incident beam to be transmitted directly to the pyroelectric detector. This allows the photon drag detector to be conveniently calibrated without moving the arrangement. As previously mentioned, the digitizer is a Biomation Model 6500 500-MHz device, and the computer is a Model 9836 manufactured by Hewlett Packard. The digitizer is simply a solid state analog-to-digital converter with a memory. It will record at sample rates up to 2 ns/sample and store 1024 samples (a 6-bit resolution/sample). The interface is a Biomation Model 4880 IEEE 488 coupler that converts the digitizer parallel binary format to an IEEE 488 ASCII format. Implementation of our relatively long and slow BASIC program limits pulse repetition rates to 0.7 Hz or less, but for most applications, this is not a severe restriction.

The biggest problem with this set-up is not directly caused by the digitizer/computer apparatus but, instead, by the device which it is measuring, namely the laser. Because of the nature of the discharge in TEA laser, it is inherently electrically noisy. For many commercial lasers this is no big obstacle since ordinary metal enclosures provide sufficient shielding. However, laboratory breadboarded designs are typically unshielded, and obtaining a

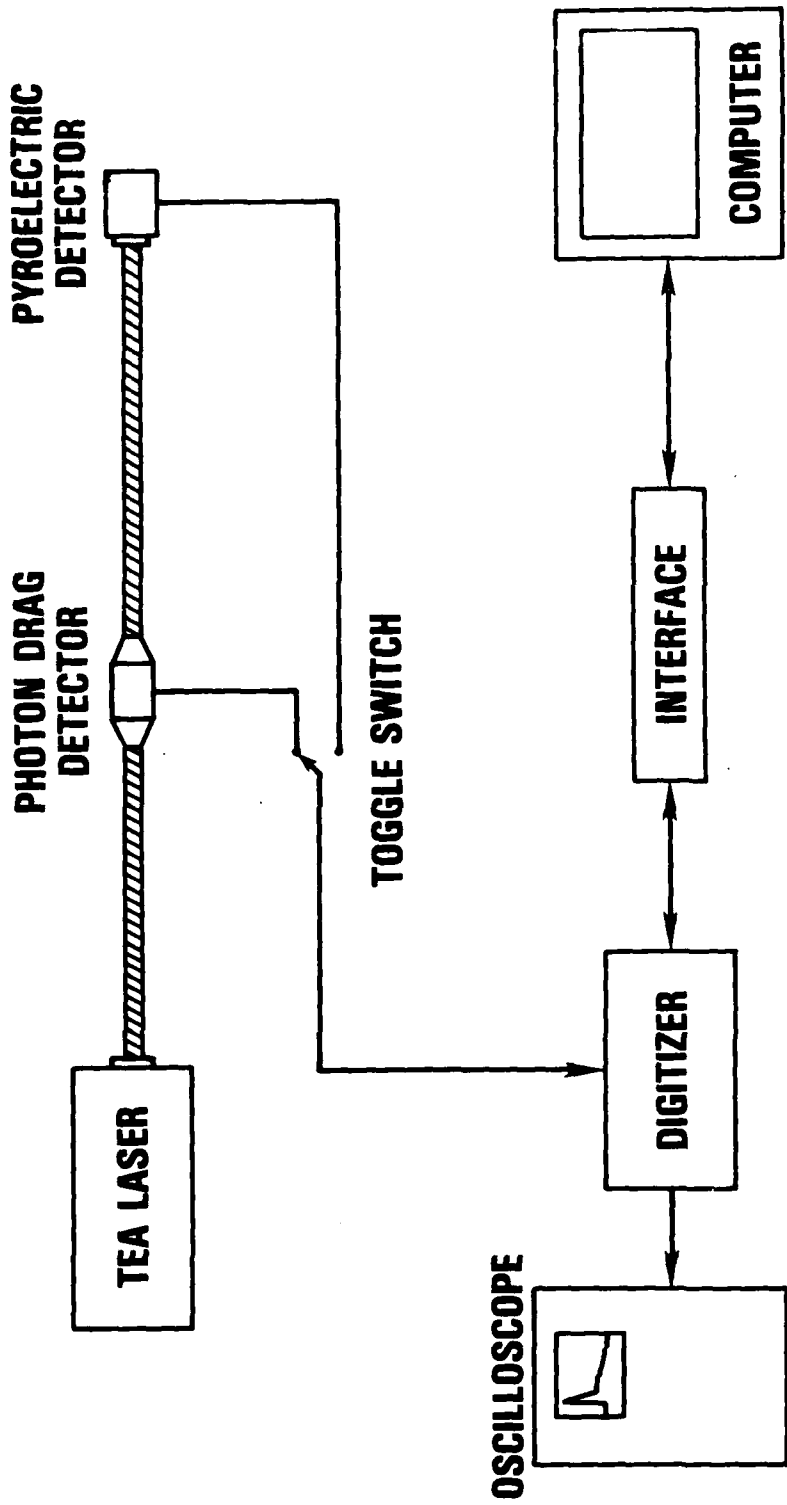


Figure 2. Experimental setup.

*favorable signal-to-noise ratio may pose a problem. Shielding a research laser itself may not be practical since circuitry may need to be changed often, currents and voltages must be monitored, and electrical discharges often need to be visually observed. But without shielding, noise levels may be high enough to activate the registers in the digitizer even with no cable connections.*

In order to deal with this problem, we have found it expedient to utilize several techniques. First, simply moving the digitizer/computer 3 to 4 m away helped greatly. The extra cable length then required the use of double-shielded coaxial cable. As a further precaution, the box was constructed of plexiglass and lined with copper mesh. When the digitizer and interface were placed inside, the combination of these measures provided sufficient shielding for all except the most severe conditions encountered, when extremely high ( $> 32$  kV) voltages were needed to charge capacitors during certain high pressure experiments. In that case, the pulse forming network was enclosed in a shielded box. Workable signal-to-noise ratios were then restored.

#### IV. COMPUTER PROGRAM

For the purpose of clarity to both computer programmer and user, two block flowcharts are presented. The first (Figure 3) is a simplified input/output (I/O) flowchart for the user. After the program is running, the user should be able to follow this flowchart with very little knowledge of the algorithms used to determine the output. The second flowchart (see Appendix, Figure A-1) is for the programmer and gives a much more detailed explanation of the algorithms used in the determination of pulse parameters as well as input and output algorithms. Although the program was written in BASIC for the HP 9836 computer and Biomation 6500 digitizer, the calculation algorithms are universal, however. I/O algorithms will probably be different for other systems. A sample computer program listing and output examples are included in the Appendix.

When the program is run, the photon drag constant and pyroelectric constant are set to default values. These initial numbers are not important, because they can be updated after the sample of pulses has been recorded. The digitizer input voltage and time base settings must be entered into the program. This is done automatically by manually arming and triggering the digitizer when it is prompted by the program. The program is now ready for pulse waveform input. When a sufficient number of pulses has been recorded, the user hits Key 0 and the program goes into a calculations mode. The initial data normalization takes about 9 s/pulse. After this, the individual pulse parameters are calculated and printed out on the CRT sequentially. Finally, the average and standard deviation of energy and maximum intensity for the entire sample of pulses are calculated and printed out.

The program is now idling in an output mode and can be continued by depressing the appropriate user defined key. After the corresponding key function is performed, the program returns to the idling point and awaits another key command. The pulses are referred to by

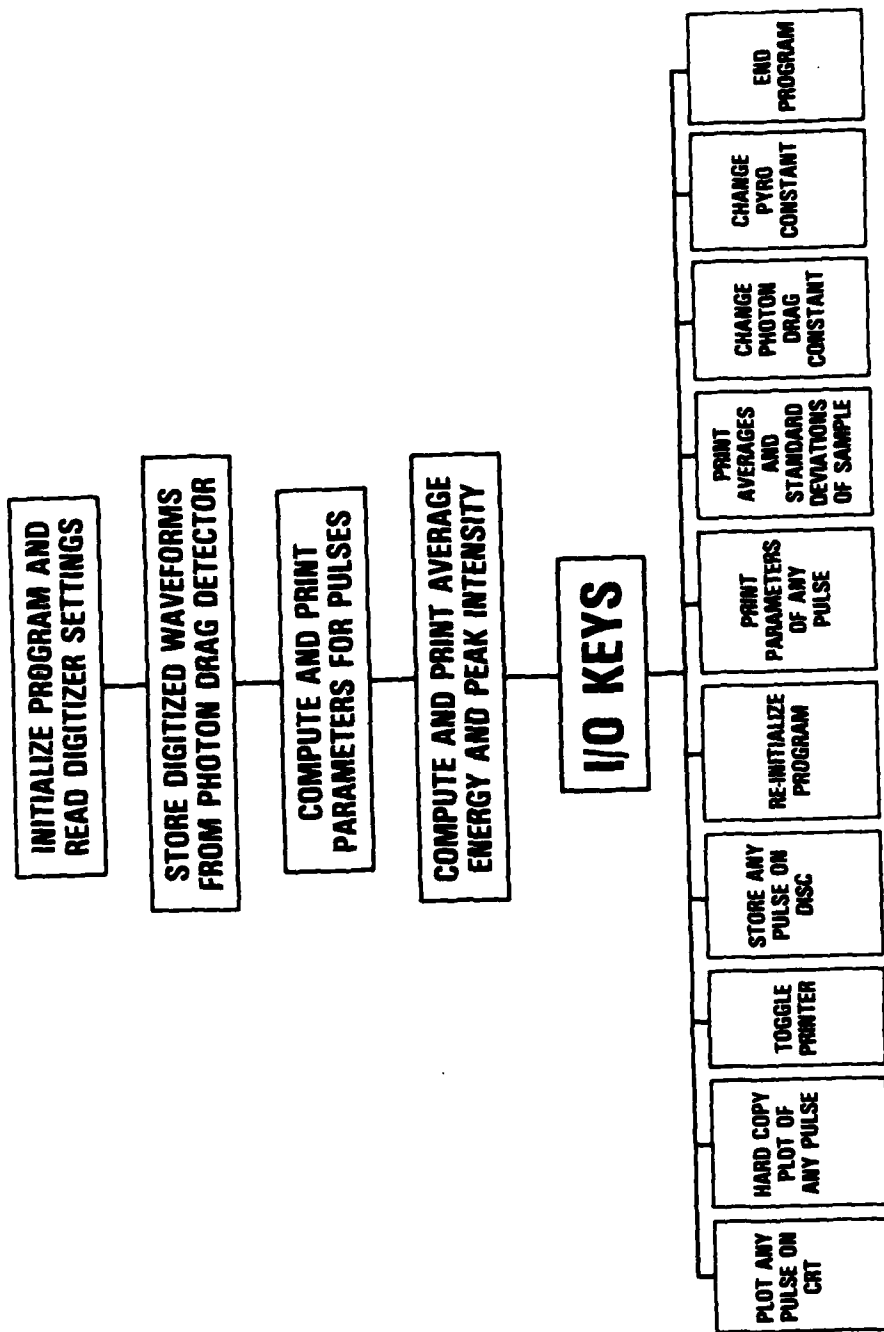


Figure 3. Simplified I/O user flowchart.

number in the sequence in which they were recorded (i.e., the first pulse recorded is No. 1, etc.). Thus, when prompted to refer to a pulse, the operator should be entering an integer less than or equal to the number of pulses in the sample.

A plot of peak power vs. time can be produced on the computer CRT by depressing Key 0. The axes are scaled automatically by the sample intensity. An identical plot can be produced on an external paper plotter by depressing Key 1. A typical output is shown in Figure 4.

If a paper printout is desired, Key 2 is depressed and all further type will be sent to the external printer. If the operator later wishes the type to be printed on the CRT again, depressing Key 2 once more will cause all further output to be displayed on the screen.

A permanent record of any individual pulse may be obtained by pressing Key 3. This enables the user to store a file of pulse intensity on disc, where it can be retrieved later for other analysis.

If the operator desires to measure a new series of pulses, he presses Key 4. At this time, the digitizer sensitivity and time base settings may be changed, if desired. An important feature of this key is that the same values for the photon drag and pyroelectric constants will be retained, whereas they would have been reset to the default values, if the program had been simply started again.

In order to obtain a listing of the parameters for any single pulse, the user need only push Key 5. An example of a typical output can be seen in Figure 5. A printout of the pulse rise time, spike duration, total duration, spike half width, spike energy, total energy, and peak intensity will be sent either to the CRT or to an external printer as specified by Key 2.

Key 6 is used to retrieve the averaged and standard deviation of the energy and peak intensity for the entire collection of pulses. It is important to note that pulses with peak intensities of less than 40 percent of the peak intensity of the series are rejected in calculating this average. This feature prevents the biasing of statistics by false triggering or other random events. However, all pulses, "good" or "bad," are recorded and the information about any one of them is still retrievable even though some are excluded in the averaging process. In addition, the program keeps track of the number of "bad" pulses so that, for example, in an otherwise well-behaved system, the number of laser misfirings during a series of shots can be obtained. This feature has definite utility for those performing laser lifetime tests.

The photon drag constant can be changed so that the average energy of the ensemble agrees with that obtained with either the calorimeter or the pyroelectric detector. (This probably will need to be done after the first run with the default constant.) When the operator presses Key 7, he will be asked whether the energy reading will be done with the calorimeter or the pyroelectric detector. If the reading is obtained with calorimeter, the operator is prompted to enter it via the keyboard in millijoules. If the pyroelectric detector is to be used, the operator is

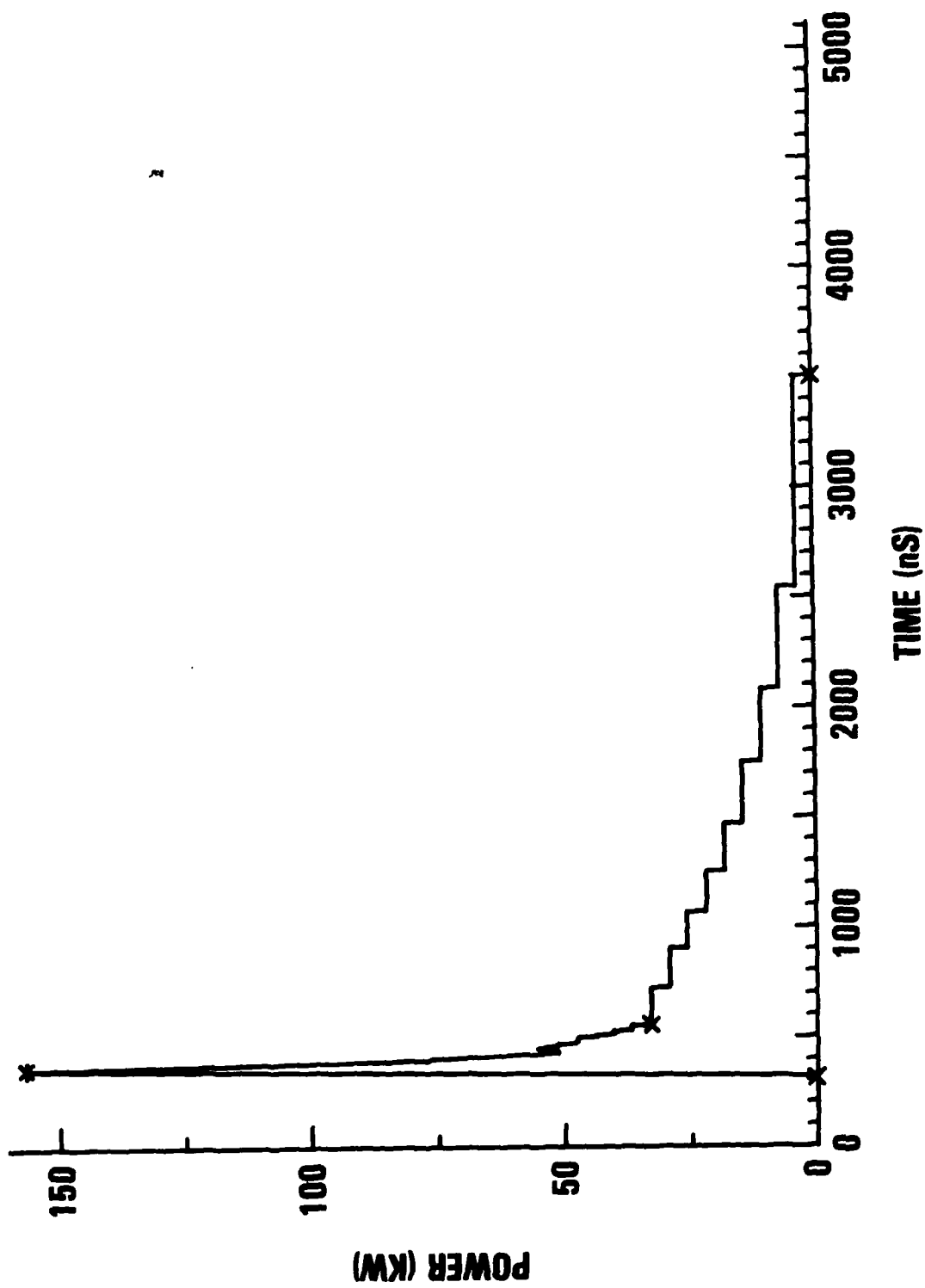


Figure 4. A typical presentation of a laser pulse as seen on the CRT.

**PULSE #1 ANALYSIS**

PULSE RISE TIME ..... 45 ns  
SPIKE HALF-WIDTH ..... 55 ns  
TAIL DURATION ..... 245 ns AFTER START OF PULSE  
TOTAL DURATION ..... 3205 ns  
SPIKE ENERGY ..... 15.69 mJ  
TOTAL ENERGY ..... 54.99 mJ  
PEAK INTENSITY ..... 160.7 kW

**PULSE #2 ANALYSIS**

PULSE RISE TIME ..... 45 ns  
SPIKE HALF-WIDTH ..... 50 ns  
TAIL BEGINS ..... 170 ns AFTER START OF PULSE  
TOTAL DURATION ..... 3235 ns  
SPIKE ENERGY ..... 12.84 mJ  
TOTAL ENERGY ..... 55.24 mJ  
PEAK INTENSITY ..... 175.3 kW

**PULSE #3 ANALYSIS**

PULSE RISE TIME ..... 50 ns  
SPIKE HALF-WIDTH ..... 50 ns  
TAIL BEGINS ..... 265 ns AFTER START OF PULSE  
TOTAL DURATION ..... 3205 ns  
SPIKE ENERGY ..... 16.1 mJ  
TOTAL ENERGY ..... 54.16 mJ  
PEAK INTENSITY ..... 157.1 kW

**PULSE #4 ANALYSIS**

PULSE RISE TIME ..... 50 ns  
SPIKE HALF-WIDTH ..... 55 ns  
TAIL BEGINS ..... 115 ns AFTER START OF PULSE  
TOTAL DURATION ..... 3160 ns  
SPIKE ENERGY ..... 10.75 mJ  
TOTAL ENERGY ..... 55.07 mJ  
PEAK INTENSITY ..... 175.3 kW

**STATISTICS EXCLUDING BAD PULSES**

AVERAGE MAXIMUM INTENSITY = ..... 166.9 kW  
STANDARD DEVIATION OF INTENSITY = ..... 7.9 kW  
AVERAGE ENERGY = ..... 55.0 mJ  
STANDARD DEVIATION OF TOTAL ENERGY = ..... .5 mJ

\*\*\*\*\*PHOTON CONSTANT=116.88

PYRO CONSTANT=459.13\*\*\*\*\*

TOTAL OF 0 BAD PULSES OUT OF 10 RECORDED

Figure 5. Pulse parameter listing.

directed to select that detector via a SPDT switch (see Figure 2) and to fire a number of pulses into it. The average value of the peak voltage is automatically calculated and used to determine the energy of the laser, whereupon this information is used to calculate the new photon drag constant. In either case, all future pulse data will automatically use this updated constant.

In order to use the pyroelectric detector, it is necessary to calibrate it. Pressing Key 8 will facilitate this task. The user is directed to let several pulses impinge on the detector, and as previously stated, the output is averaged. Then, a calorimeter is used to find the actual energy and this value is entered via a prompt. The new pyro constant is displayed and used thereafter.

As indicated in the flowchart (Figure 3), Key 9 is used to end the program. The user should be aware that this key must not be used to simply enter a new series of shots (Key 4 should be chosen for that). Rather, this key reloads the internal disc program directory and, thereby, facilitates the easy transfer to another program.

## V. RESULTS

As noted earlier, we have used this instrumentation to measure pulse characteristics over a wide range of intensities and energies. Generally speaking, the results have been reasonably self-consistent and useful. As an indication of the former, consider the following results. The output from a Marconi T250 TEA laser was measured with the photon drag/digitizer combination. Usually, great pains are taken to ensure optical alignment and rigidity of all components. For example, an optical table and rail are used together with a clamping arrangement that prevents relative motion between the laser under test and the detector. This time, however, we deliberately chose a potentially more unstable configuration to test the sensitivity of this requirement. The laser was set on a lab jack, and the detector was mounted on a simple holder. Neither device was fixed to the table. Four separate measurements of ten shots each were made. After each measurement the detector was removed and replaced before the next set. The positioning was aided by means of a carbon block that sparked when struck by a pulse. No attempt was made to keep the distance from the laser to the detector constant. The measured intensities are given in Table 1.

Table 1. Peak Powers Measured in Four Separate Runs of Ten Shots Each

Trial No.	Power (kW)
1	176.2 $\pm$ 5.4
2	172.9 $\pm$ 8.4
3	168.7 $\pm$ 13.2
4	166.1 $\pm$ 11.4

Since the averages are themselves only spread approximately 3 percent about a central of 171 kW, the reproducibility of this method of measurement has been demonstrated.

It should be noted that the first three trials were taken with a digitizer sampling rate of 5 ns/channel. This relatively crude measurement was necessary in order to make sure that the entire pulse would be recorded. That is, since the pulse lasted almost 3400 ns, then the fastest setting of 2 ns/channel X 1024 channels would not be sufficient and the next setting (5 ns) had to be used. If one chooses, however, to use the faster setting, no useful information is lost except for the total energy and, of course, the total duration. (Trial No. 4 uses the 2 ns setting.) On the other hand, even using the more coarse setting of 5 ns does not drastically change the time measurements. For example, using the 2-ns setting gave a halfwidth measurement of  $50 \pm 6$  ns while the 5-ns setting yielded  $53 \pm 6$  ns for the same measurements. The results using the digitizer compared favorably with those obtained by analyzing oscilloscope traces; e.g., see Table 2.

Table 2. The Halfwidths and Rise Times of Pulses as Measured With a Digitizer and an Oscilloscope

Time	Digitizer	Oscilloscope
$T_{1/2}$ (ns)	$48 \pm 6$	$45 \pm 4$
$T_{rise}$ (ns)	$47 \pm 3$	$43 \pm 1$

The oscilloscope used had a quoted bandwidth of 400 MHz and was a Tektronix 7834 storage device with a 7A19 amplifier and a 7B85 time base. The measurements were made using the 10-ns/div sweep. Digitizer measurements were taken of 40 pulses, while six traces were used for the oscilloscope data. These results indicate that the digitizer can consistently produce measurements that agree with those obtained in a more conventional manner to within 10 percent.

## VI. CONCLUSIONS

It has been demonstrated that the combination of a digitizer and computer is useful in analyzing the output of laser pulses. More specifically, we have shown that important pulse parameters including energy, power, half width, rise time and total duration can be measured with reasonable accuracy and consistency. The purpose in doing this is not to suggest that this instrumentation be used in place of other simpler and more conventional measuring devices, but instead to show that for some applications this technology offers a fairly straightforward means of automatically obtaining and processing large quantities of data.

Although this report specifically deals with the Biomatron 6500/Hewlett Packard 9836 combination of digitizer and computer, it is hoped that it will be at least of some value to those using different apparatus. Even in that case, a more detailed examination of the computer program might yield useful information to the reader. For that purpose, we have included our BASIC program listing and a short discussion appears in the Appendix.

## APPENDIX

This Appendix is a more detailed account of the computer program including a complete flowchart (see Figure A-1) and a program listing (Figure A-2). It is hoped that this will be useful to not only those with the same digitizer/computer combination, but to others who might benefit from exposure to the algorithms for event recognition, energy and intensity calculations, etc. The blocks in the flowchart are numbered sequentially, and further descriptions are keyed to these numbers.

Descriptions of the flow chart blocks follow. The numbers refer to the blocks, line numbers refer to the program listing, and variable names appear in parentheses.

**1. Set Constants (lines 70 to 80).** The program sets the values of the photon drag constant (Constant) in kW/V and the pyroelectric constant (Pyro-const) in mJ/V. These values are typical but have to be changed for each set-up. They can be changed after pulse waveforms are input, so default values are not important.

**2. Read and Decode Digitizer Control Settings (lines 140 to 610).**

**a. Format.** Data input from the 6500 digitizer is in the form of sample elements. There are 1024 time sample elements in a full screen trace, each with a corresponding voltage to create a stepped waveform. The value of each of the 1024 samples can be set from 2 ns to 1 s giving a full screen range of 2048 ns to 1024 s.

There are 252 vertical steps (253 positions) possible for each time sample (-128 to 124). The value of zero is always center screen, the top is always 124, and the bottom is always -128. Each vertical increment is equivalent to 4 steps. The voltage for each vertical increment is determined by the input range setting (Vrange). Since +Vrange corresponds to a value of 124 steps, each increment is  $(4 \text{ steps}/124 \text{ steps}) * Vrange \cong .03 Vrange$ . The value of Vrange can be set from .25V to 5V.

There is an offset which moves the 0 V line within the field of -128 to 124. This offset is set in terms of a fraction of the input range (from -.99 to +.99 x Vrange). The offset progresses in increments of 4 steps (i.e., -.99 to .99 x 124 approximated to the nearest multiple of 4). This is the point of the 0 V line. An example (Figure A-3) is shown for clarity.

**b. Algorithms.** The digitizer control settings are encoded in the last three bytes of data read from the digitizer (1024 to 1026). The code definitions are explained in the "Gould Biomat 4880 Interface Operating and Service Manual," page 32, and are reproduced for reference (Figure A-4).

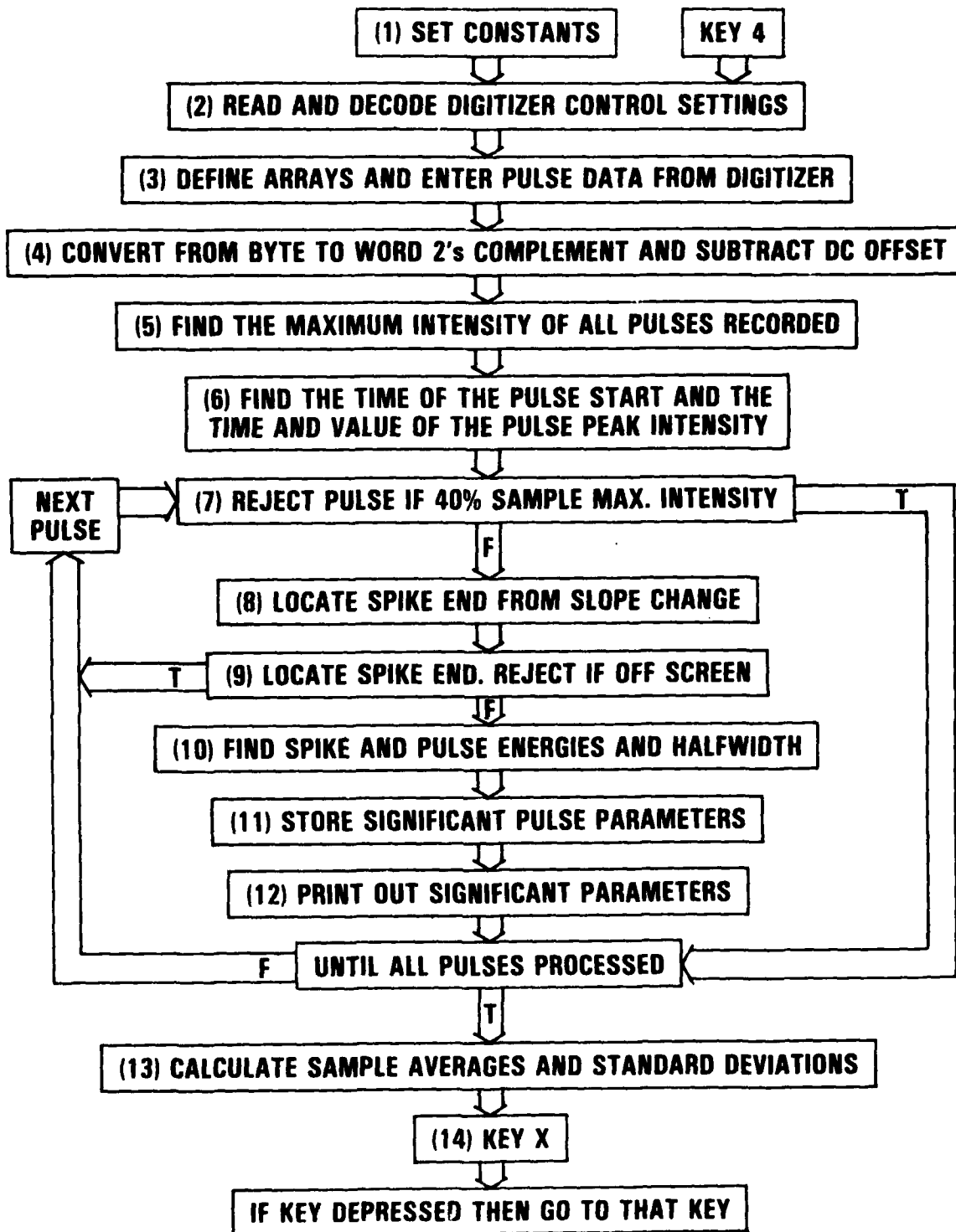


Figure A-1. Complete block flowchart.

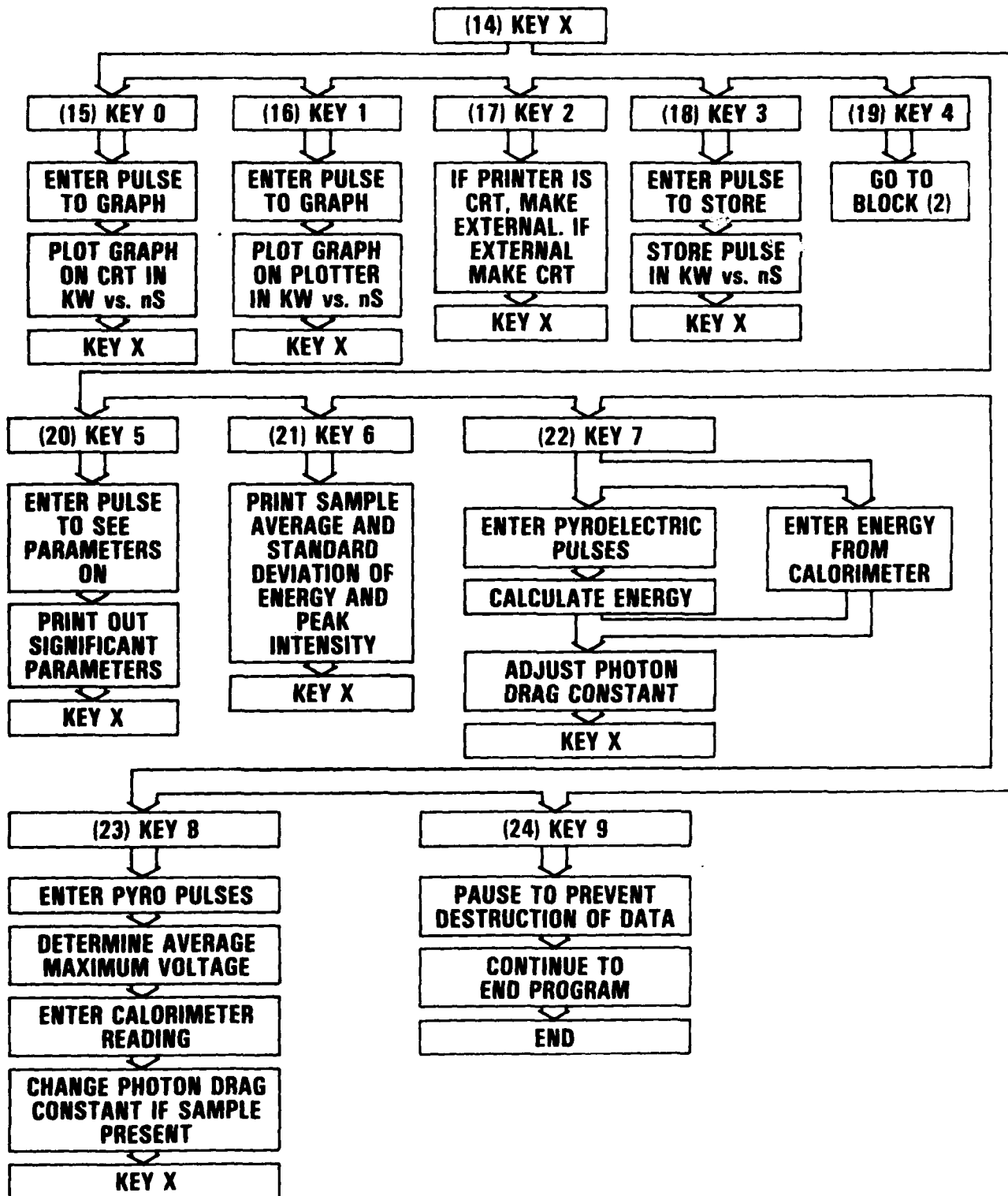


Figure A-1. Complete block flowchart (continued).

## A-2. Program listing.

```

LASER PULSE ANALYSIS PROGRAM

THIS PROGRAM CALCULATES THE INTENSITY VS TIME CHARACTERISTICS, ENERGY
AND OTHER PULSE PARAMETERS FROM A V vs. t WAVEFORM FROM A PHOTON
DRAG DETECTOR AND AN ENERGY READING FROM A CALORIMETER. THE PROGRAM
INTEGRATES UNDER INTENSITY vs TIME TO DETERMINE ENERGY

***** 1) CONSTANT DEFINITIONS AND SETTINGS FROM DIGITIZER *****
.....
70 Constant=999.42 !CONVERSION FACTOR FOR PHOTON DRAG (KW/VOLT)
80 Pyro_const=459.13 !CONVERSION FACTOR FOR PYROELECTRIC (mJ/VOLT)
81 DISP
90 Start: GDSUB Off_keys ! CLEARS KEY FUNCTIONS
100 PRINTER IS 1 ! SETS PRINTER INTERNAL
110 Printer=1
120 PRINT CHR$(12) ! CLEARS SCREEN
130 GCLEAR ! CLEARS GRAPHICS
140 GDSUB Settings
150 GOTO 460
160 Settings:PRINT "MANUALLY ARM AND TRIGGER THE 6500 TO RECORD PANEL SETTINGS."
170 PRINT "(NO SIGNAL AT INPUT) THEN <CONTINUE>"
180 BEEP 80..1
190 PAUSE
200 PRINT CHR$(12) !CLEARS SCREEN
210 OUTPUT 704:11 !PUTS 6500 IN OUTPUT MODE
220 ENTER 704 USING "#.B";B(*) !LOADS BUFFER ARRAY (UNFORMATTED)
230 OUTPUT 704:0 !CLEARS 6500 OF OUTPUT MODE
240 SEND 7:UNL !UNLISTEN COMMAND TO ALL UNITS
250 Irnt=B(1024) !INPUT RANGE NEGATIVE TRUE
260 Opt=B(1025) !OFFSET POSITIVE TRUE
270 Sint=B(1026) !SAMPLE INTERVAL NEGATIVE TRUE
280 Weighing=BINEOR(BINAND(Sint,15),15) !MAKES POS TRUE WORD OF NEG TRUE
BYTE
290 RESTORE 300 !RESTORES DATA (LINE 240)
300 DATA 2.5,10,20,50,100,200,500,1000 ! DATA FOR WEIGHING KEY
310 FOR I=0 TO Weighing
320 ON ERROR GOTO 210
330 READ Interval !DETERMINES WEIGHING ON SAMPLE INTERVAL
340 OFF ERROR
350 NEXT I
360 Offset=BINAND(Opt,127)*(-1)^(BIT(Opt,7))/100 !DETERMINES FRACTIONAL
OFFSET FROM BINARY
370 FOR I=2 TO 5
380 IF NOT (BIT(Irnt,I)) THEN 400 ! BRANCHES OUT WHEN BIT IS LOW
390 NEXT I
400 Range=.25*2^(6-I) ! VOLTAGE RANGE GENERATION
410 IF I=2 THEN Range=5 !EXCEPTION TO RANGE GENERATION
420 PRINT "RANGE=";Range;"VOLTS"
430 PRINT "OFFSET=";Offset;"X INPUT RANGE(";Offset*Range;" VOLTS)"
440 PRINT "INTERVAL=";Interval;"s"
450 RETURN !
.....
460 Printer=1 !PROGRAM FLAG TO KEEP TRACK OF PRINTING DEVICE
470 PRINTER IS 1 !SETS PRINTER INTERNAL
480 PRINT "THIS PROGRAM WILL ARM THE 6500 DIGITIZER AND READ THE PULSE DATA"
490 PRINT "AFTER A TRIGGER IS RECEIVED, MAIN MEMORY HANDLES UP TO 120 PULSES"
CHR$(13)
500 PRINT "PYROELECTRIC CONSTANT=";Pyro_const;"mJ/VOLT"
510 PRINT "PHOTON DRAG CONSTANT=";Constant;"KW/VOLT ";CHR$(12)

```

Figure A-2. Program listing (continued).

```

110 T=TIMEDATE          ! REALTIME SECONDS AT START OF PROGRAM
120
130 R=ABS(Dc_offset*128) !CALCULATION OF APPROXIMATE OFFSET TO CHECK
140 Dc_offset=INT(R/4)+4 ! IF THE DIGITIZER HAS BEEN TRIGGERED
150 IF Dc_offset<0 THEN Dc_offset=-Dc_offset ! CHANGES SIGN FROM ABS
160
170
180 IF B(500)>=128 THEN B(500)=B(500)-256 !CONVERTS BYTE TO WORD IF NEG.
190 PRINT "DC OFFSET=":Dc_offset,"PIXEL OFFSET=":B(500):"(SHOULD BE WITHIN 4)
200
210 IF ABS(Dc_offset-B(500))>4 THEN 140 ! IF OFFSETS DON'T AGREE RE-TRIGGER
220 Dc_offset=B(500) ! PIXEL OFFSET IS CORRECT DC OFFSET (USUALLY)
230 INPUT "ENTER OUTPUT OPTION 1)ALL PARAMETERS 2)ENERGY AND INTENSITY ONLY".
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21950
21960
21970
21980
21990
22000
22010
22020
22030
2204
```



Figure A-2. Program listing (continued).

```

1640 PRINT "SPIKE DURATION..... ":Tedge-Tstart)*Interval:"nS"
1650 PRINT "TOTAL DURATION..... ":Tend-Tstart)*Interval:"nS"
1660 PRINT "SPIKE ENERGY..... ":DROUND(Aspike(P)*Constant*Range/124000.4):
1670
1680 PRINT "TOTAL ENERGY..... ":DROUND(Area(P)*Constant*Range/124000.4):"n
1690
1700 Power=DROUND(Max*Constant*Range/126.4)
1710 PRINT "PEAK INTENSITY..... ":Power:"KW"
1720 PRINT
1730 RETURN !*****
1740 !::::::::::::::::::::: STORES SIGNIFICANT TIMES FOR EACH PULSE :::::::::::::::
1750 Bad_pulse(P)=0 ! GOOD PULSE IF THIS FAR
1760 Parameter(1,P)=Tstart ! TIME START OF PULSE OCCURED
1770 Parameter(2,P)=Tmax ! TIME MAXIMUM INTENSITY OCCURED
1780 Parameter(3,P)=Tedge ! TIME TAIL BEGINS (SPIKE ENDS)
1790 Parameter(4,P)=Tend ! TIME PULSE ENDS
1800 Parameter(5,P)=T1 ! TIME OF RISING HALF INTENSITY
1810 Parameter(6,P)=T2 ! TIME OF TRAILING HALF INTENSITY
1820 NEXT P!*****END OF SEPARATE PULSE ANALYSIS *****
*****
1830 Avarea=0. ! INITIALIZE AVERAGE AREA
1840 Avmax=0. ! INITIALIZE AVERAGE MAXIMUM
1850 FOR I=1 TO Pulse!DETERMINE STATISTICS OF ALL PULSES
1860 IF Bad_pulse(I)=1 THEN 1870
1870 Avmax=Avmax+A(I,Parameter(2,I))/(Pulse-Bad) ! AVERAGE MAX INTENSITY
1880 Avarea=Avarea+Area(I)/(Pulse-Bad) ! AVERAGE TOTAL ENERGY
1890 NEXT I
1900 S2=0 !INITIALIZE SD^2 OF INTENSITY
1910 S2area=0 !INITIALIZE SD^2 OF ENERGY
1920 FOR I=1 TO Pulse
1930 IF Bad_pulse(I)=1 THEN 1940 ! DON'T INCLUDE BAD PULSES IN STATISTICS
1940 S2=(A(I,Parameter(2,I))-Avmax)^2/(Pulse-Bad)+S2 ! SD^2 OF INTENSITY
1950 S2area=(Area(I)-Avarea)^2/(Pulse-Bad)+S2area ! SD^2 OF ENERGY
1960 NEXT I
1970 S=DROUND(SQR(S2),4) ! STANDARD DEVIATION OF INTENSITY (ROUNDED)
1980 Sarea=DROUND(SQR(S2area),5) ! STANDARD DEVIATION OF ENERGY (ROUNDED)
1990 ! END OF STATISTICS CALCULATIONS
2000 Statistics: PRINT CHR$(132),"STATISTICS EXCLUDING BAD PULSES",CHR$(128)
2010 GOSUB Off_keys
2020 PRINT "AVERAGE MAXIMUM INTENSITY=.....":DROUND(Avmax*Constant*Range/126.5):"KW"
2030 PRINT "STANDARD DEVIATION OF INTENSITY=.....":DROUND(S*Constant*Range/124.3):"KW"
2040 PRINT "AVERAGE ENERGY=.....":DROUND(Avarea*Constant*Range/124000.4):"nJ"
2050 PRINT "STANDARD DEVIATION OF TOTAL ENERGY=...":DROUND(Sarea*Constant*Range/124000.3):"nJ"
2060 PRINT
2070 PRINT "*****PHOTON CONSTANT=":Constant:" PYRO CONSTANT=":Pyro_const:"**
2080
2090 PRINT "TOTAL OF ":Bad:" BAD PULSES OUT OF ":Pulse:"RECORDED"
2100 DISP " "
2110 IF Printer=70 THEN Keys
2120 PRINT CHR$(133),"PROGRAM NOW IN GRAPH MODE. USE KEYS TO CONTINUE",CHR$(128)
2130 PRINT
2140 !*****END OF PULSE CALCULATIONS *****

```

Figure A-2. Program listing (continued).

```

2120 Keys: DN KEY 1 LABEL "VIEW GRAPH" GOTO Screen
2130 DN KEY 2 LABEL "END PROGRAM" GOTO Finish
2140 DN KEY 3 LABEL "PARAMETERS" GOTO Params
2150 DN KEY 4 LABEL "SAMPLE STATS" GOTO Statistics
2160 DN KEY 5 LABEL "PLOT GRAPH" GOTO Hard
2170 DN KEY 6 LABEL "TOGGLE PRINTER" GOTO Toggle
2180 DN KEY 7 LABEL "STORE GRAPH" GOTO Disc
2190 DN KEY 8 LABEL "NEW SAMPLE" GOTO Start
2200 DN KEY 9 LABEL "CHANGE PHOTON" GOTO Const
2210 DN KEY 0 LABEL "CHANGE PYRO" GOTO Pyro
2220 ALPHA ON ! TURNS ON ALPHA NUMERIC SCREEN
2230 ! LOOP REPEAT
2240 GOTO 2230
2250 Screen: !***** PLOTS PULSE IN KW vs nS ON CURRENT PLOTTING DEVICE *****
*****
2260 GOSUB OFFKEYS ! SHUTS OFF USER DEFINED KEYS
2270 GRAPHICS OFF ! SHUTS OFF GRAPHICS
2280 INPUT "PULSE NUMBER?".Pgraph
2290 GINIT ! INITIALIZE GRAPHICS
2300 GRAPHICS ON ! TURN ON GRAPHICS
2310 Plot: ALPHA OFF ! SHUT OFF PRINTOUT (NOT GRAPHICS)
2320 VIEWPORT 0,100,10,100 ! SET LIMITS OF GRAPHING AREA (DISPLAY UNITS)
2330 Xmin=-.05*Interval*1024 ! ALLOW ROOM FOR LABELING OF Y AXIS
2340 Axis_top=DT*(Maxval*Range*Constant/1280+1)*10 ! ALTER AXES TO SAMPLE
2350 WINDOW Xmin,(Interval*1024+25*Interval),-.1*Axis_top,Axis_top !SETS RANGE
2360 CLIP 0,1024*Interval,0,Axis_top ! DISABLES GRAPHICS OUTSIDE RANGES
2370 AXES 100,25,0,0.5,2,4 ! DRAWS AXES
2380 CLIP OFF ! ALLOWS GRAPHICS THROUGHOUT VIEWPORT
2390 CSIZE 2.5 ! SETS SIZE OF GRAPHICS CHARACTERS
2400 ! NUMBERING OF THE X-AXIS
-----
2410 LORG 5 ! SETS ORIGIN OF GRAPHICS CHARACTERS(TOP CENTER)
2420 FOR I=0 TO 5000 STEP 1000
2430 MOVE I,0 ! LABELS TIME AXIS EVERY 1000 nS
2440 LABEL I
2450 NEXT I !
2460 ! NUMBERING OF Y-AXIS
2470 LORG 8 ! SETS ORIGIN OF GRAPHICS CHARACTERS (RIGHT CENTER)
2480 FOR I=0 TO Axis_top STEP 50
2490 MOVE 0,I ! LABELS INTENSITY AXIS EVERY 50 KW
2500 LABEL I
2510 NEXT I !
2520 MOVE Interval*500,-.05*Axis_top ! X AXIS LABEL LOCATION
2530 LORG 6 ! SETS ORIGIN OF GRAPHICS CHARACTERS (TOP CENTER)
2540 CSIZE 3.1 ! SETS SIZE OF GRAPHICS CHARACTERS
2550 LABEL "TIME (nS)"
2560 MOVE Xmin,Axis_top/2 ! Y AXIS LABEL LOCATION
2570 DEG
2580 LDIR 90 ! ROTATE GRAPHICS CHARACTERS 90 DEGREES
2590 LABEL "POWER (KW)"
2600 LDIR 0 ! RETURN GRAPHICS CHARACTERS TO HORIZONTAL
2610 MOVE 0,0 ! PLOTTING PULSE
2620 FOR I=1 TO 1023
2630 DRAW I*Interval,A(Pgraph,I)*Range*Constant/128 ! DRAW PULSE(KW vs nS)
2640 NEXT I
2650 LORG 5 !SET GRAPHICS CHARACTER ORIGIN (CENTER)
2660 CSIZE 2.5 !SET SIZE OF GRAPHICS CHARACTERS
2670 FOR I=1 TO Pgraph
2680 X=Param(I)*Pgraph
2690 IF YK=0 THEN 2740 ! IF OUT OF BOUNDS THEN DON'T MARK

```

Figure A-2. Program listing (continued).

```

2700 Y=A(Pgraph.X)*Range*Constant/128 ! CONVERTS TO KILOWATTS
2710 IF Y<0 OR Y>Axis_top THEN 2740 ! REJECT IF OFF GRAPH
2720 MOVE X*Interval,Y
2730 LABEL "*"
2740 NEXT J
2750 MOVE 0,0
2760 PLOTTER IS 3,"INTERNAL" ! SETS PLOTTER TO CRT IN CASE EXTERNAL
2770 GOTO Keys!***** END OF GRAPH SECTION *****
*****
2780 Hard: PLOTTER IS 705,"HPGL" !*****ENABLES EXTERNAL PLOTTER*****
2790 GOSUB Off_keys
2800 DISP "PREPARE PLOTTER AND CONTINUE"
2810 PAUSE
2820 GOTO Plot !*****
2830 Toggle: !***** TOGGLES PRINT DEVICE (INTERNAL/EXTERNAL)*****
2840 GOSUB Off_keys
2850 IF Printer=701 THEN 2900
2860 PRINTER IS 701
2870 Printer=701
2880 DISP "PRINTER IS 701"
2890 GOTO 2930
2900 Printer=1
2910 PRINTER IS 1
2920 DISP "PRINTER IS 1"
2930 GOTO Keys !*****
2940 Params: !***** PRINTS OUT SAMPLE STATS WITH CURRENT CONSTANTS*****
2945 GOSUB Off_keys
2950 INPUT "INPUT THE PULSE YOU WANT TO SEE STATS ON",P
2960 IF P<=Pulse AND P>0 THEN 2970
2961 DISP "SORRY...ILLEGAL PULSE NUMBER. MUST BE BETWEEN 0 AND ";Pulse
2962 GOTO 3050
2970 Tstart=Parameter(1,P) ! SETS PARAMETERS FROM
2980 Tmax=Parameter(2,P) ! PARAMETER ARRAY
2990 Tedge=Parameter(3,P)
3000 Tend=Parameter(4,P)
3010 T1=Parameter(5,P)
3020 T2=Parameter(6,P)
3030 Max=A(P,Tmax)
3040 GOSUB Printout
3050 GOTO Keys !*****
3060 Disc: !*****STORES GRAPH ON DISC *****
3070 GOSUB Off_keys
3080 INPUT "ENTER THE FILE TO STORE PULSE ON",Ds
3090 INPUT "WHAT PULSE DO YOU WANT TO STORE?".Store_pulse
3100 MASS STORAGE IS ":INTERNAL,4,1" ! MASS STORAGE DEVICE LEFT DISC DRIVE
3110 CREATE BDAT Ds,2051,8 ! CREATE DATA FILE OF APROPRIATE LENGTH
3120 ASSIGN @Path TO Ds ! ASSIGN OUTPUT PATH TO DATA FILE
3130 FOR I=1 TO N
3140 Tempy(I)=A(Store_pulse,I)*Constant*Range/128 !DEFINE TEMPORARY ARRAY (KW)
3150 NEXT I
3160 OUTPUT @Path;1020 ! STORE NUMBER OF POINTS FOR GRAPHICS PROGRAM
3170 OUTPUT @Path;Interval ! STORE nS PER ARRAY ELEMENT
3180 OUTPUT @Path;Tempy(*) ! STORE ARRAY (KW) UNFORMATTED
3190 MASS STORAGE IS ":INTERNAL" ! MASS STORAGE DEVICE RIGHT DISC DRIVE
3200 PRINT "PULSE STORED (KW vs. nS) ON FILE NAMED ";Ds
3210 GOTO Keys !*****
3220 Const: !*****CHANGES PHOTON DRAG CONSTANT*****
3230 GOSUB Off_keys
3240 DISP "USE KEYS TO CHOOSE METHOD OF ENERGY DETERMINATION"
3250 ON KEY 1 LABEL "CALORIMETER" GOTO 3280

```

Figure A-2. Program listing (continued).

```

3270 ON KEY 2 LABEL "PYRO ELECT." GOTO 3330
3280 GOTO 3270
3290 GOSUB Off_keys
3300 INPUT "ENTER AVERAGE CALORIMETER READING IN mJ".Millijoules
3310 Constant=Constant*Millijoules/(Avarea*Constant*Range/124000)
3320 PRINT "NEW PHOTON DRAG CONSTANT=":DROUND(Constant,5)
3330 GOTO Keys
3340 GOSUB Off_keys
3350 INPUT "HOW MANY ENERGIES DO YOU WANT TO TAKE".Pyro_rep
3360 DISP "CHANGE INPUT TO PYRO AND CHANGE TIMEBASE TO FIND MAXIMUM, THEN <CONT
INUE>"
3370 PAUSE
3380 DISP "READY FOR PULSE FROM PYRO"
3390 Ave_pyro=0 ! INITIALIZE AVERAGE PYRO READING
3400 FOR J=1 TO Pyro_rep
3410 OUTPUT 704:8 ! ARMS THE 6500 DIGITIZER
3420 OUTPUT 704:11 ! PUTS THE 6500 INTO OUTPUT MODE
3430 ENTER 704 USING "#.B":B(*) ! ENTER BUFFER ARRAY UNFORMATTED
3440 OUTPUT 704:0 ! CLEARS THE 6500 OF DIGITAL OUTPUT
3450 DISP J;" OF ":Pyro_rep;" SHOTS"
3460 Max_pyro=0
3470 FOR I=1 TO 500
3480 IF B(I)<=127 THEN 3490 ! CONVERT TO WORD 2'S COMPLEMENT
3490 B(I)=B(I)-256 ! FROM BYTE 2'S COMPLEMENT
3500 B(I)=B(I)-Dc_offset ! ACCOUNT FOR DC OFFSET
3510 IF Max_pyro>B(I) THEN 3520 ! FINDS THE MAXIMUM VOLTAGE
3520 Max_pyro=B(I)
3530 NEXT I
3540 Ave_pyro=Max_pyro/Pyro_rep+Ave_pyro ! FINDS THE AVERAGE MAXIMUM VOLTAGE
3550 NEXT J
3560 Energy=Ave_pyro*Range*Pyro_const/128 ! FINDS THE ENERGY FROM PYRO CONST
3570 Constant=DROUND(Energy/(Avarea*Range/128000),6) !NEW PHOTON DRAG CONSTANT
3580 PRINT "NEW CONSTANT=":Constant
3590 GOTO Keys !*****
Off_keys: ! SHUTS OFF USER DEFINED KEYS*****
OTHERWISE PROGRAM MAY BRANCH IN MIDDLE OF SUBROUTINE
3600 OFF KEY 0
3610 OFF KEY 1
3620 OFF KEY 2
3630 OFF KEY 3
3640 OFF KEY 4
3650 OFF KEY 5
3660 OFF KEY 6
3670 OFF KEY 7
3680 OFF KEY 8
3690 OFF KEY 9
3700 RETURN !*****
3710 Pyro: ! DETERMINES NEW PYROELECTRIC CONSTANT*****
3720 GOSUB Off_keys
3730 PRINT "OLD PYRO CONSTANT=":Pyro_const
3740 PRINT "ENTER PYROELECTRIC PULSE THRU DIGITIZER"
3750 INPUT "HOW MANY SHOTS DO YOU WANT TO TAKE".Shots
3760 Avmaxvolt=0
3770 DISP "READY FOR DIGITIZER INPUT. HIT <CONTINUE> WHEN READY"
3780 PAUSE
3790 FOR J=1 TO Shots
3800 OUTPUT 704:8 ! ARMS THE 6500 DIGITIZER
3810 OUTPUT 704:11 ! PUTS THE 6500 INTO OUTPUT MODE
3820 ENTER 704 USING "#.B":B(*) ! ENTERS BUFFER ARRAY FROM 6500
3830 OUTPUT 704:0 ! CLEARS THE 6500 OF OUTPUT MODE

```

Figure A-2. Program listing (continued).

```
3840 Maxvolt=0
3850 FOR I=1 TO 500
3860 IF B(I)<=127 THEN 3880 !CONVERT TO WORD 2'S COMPLEMENT
3870 B(I)=B(I)-255 ! FROM BYTE 2'S COMPLEMENT
3880 B(I)=B(I)-Dc_offset ! ACCOUNT FOR DC OFFSET
3890 IF B(I)<Maxvolt THEN 3910 ! FINDS MAXIMUM PYRO VOLTAGE
3900 Maxvolt=B(I)
3910 NEXT I
3920 DISP J:"DF":Shots:"SHOTS TO BE TAKEN"
3930 Avmaxvolt=Maxvolt/Shots+Avmaxvolt ! FINDS AVERAGE MAX PYRO VOLTAGE
3940 NEXT J
3950 INPUT "ENTER ENERGY READING FROM CALDRIMETER IN MILIJOULES ".Milijoul
es
3960 Pyro_const=DROUND(Milijoules/(Avmaxvolt*Range/128).5)
3970 PRINT "NEW PYRO CONSTANT=":Pyro_const ! NEW PYRO CONST. CALIBRATED TO
CALDRIMETER

3980 ON ERROR GOTO 4010
3990 Constant=DROUND(Milijoules/(Avarea*Range/128000).6)!NEW PHOTON DRAG CONST
4000 GOTO 4020
4010 PRINT "NO ENERGY READINGS AVAILABLE TO CHANGE PHOTON DRAG CONSTANT"
4020 OFF ERROR
4030 GOTO Keys!*****
4040 Finish: PRINTER IS 1
4041 PRINT CHR$(12)
4050 GRAPHICS OFF
4060 DISP "HIT <CONTINUE> TO LOAD PROGRAM DIRECTORY"
4070 PAUSE
4080 LOAD "AUTOST"
4090 END
```

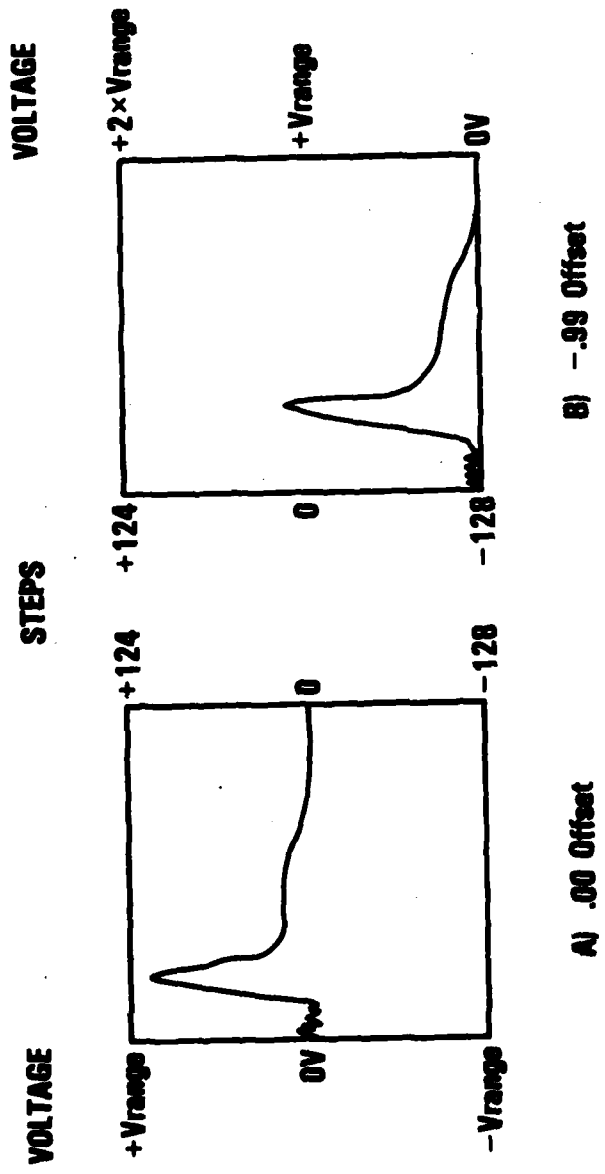


Figure A-3. Point of the OV line.

Y OUTPUTS							
Address	0-1023	1024	1025	1026			
Data bits	Data	Input Range	Offset		Sample Interval		
Y7	MSB	Low:DC	High:AC	Low:+	High:-	Low:INT	High:EXT
Y6		0.25		64		MS	
Y5	↑	0.50		32		MS	
Y4	↓	1.0		16		NS	
Y3		2.0		8		8	
Y2	LSB	5.0		4		4	
Y1	LOW	LOW		2		2	
Y0	LOW	LOW		1		1	
Logic	POS. TRUE	NEG. TRUE		POS. TRUE		NEG. TRUE	
Code	2's Comp	1 of 5		% Full Scale		Weighing:	
Defin.		AC/DC		Signed Binary		0=2	4=50
						1=5	5=100
						2=10	6=200
						3=20	7=500
							8=1000

Figure A-4. Readings from digitizer.

c. **Input Range (lines 360 to 400).** In this case, only bits 2 to 6 are of interest. Since these bits are negative true logic, the low bit corresponds to the input range. Line 320 calculates the input range for  $Y_3$  to  $Y_6$ . The exception to the equation ( $Y_2$ ) is trapped in line 400.

d. **Offset.** The offset is calculated in line 360. The binary AND of the offset byte with 127 masks out the sign bit to give the absolute offset in percent. Divide by 100 to get the fraction of input range. Multiply by  $-1 \wedge (Y_7)$  to account for sign.

e. **Interval (lines 290 to 350).** Bits  $Y_0$  to  $Y_3$  are of interest here. For this application, internal time base in nanoseconds is assumed. Line 270 determines the weighing number. The binary AND of 15 and the interval byte gives only  $Y_0$  to  $Y_3$ . The EX-OR of 15 and  $Y_0$  to  $Y_3$  gives the desired positive true weighing factor. Since there is no simple equation to generate the interval weight, a loop is used to read the proper weighing factor. An array could be used, but would require more memory.

f. **Offset Check (lines 540 to 610).** There is no simple way to calculate the step offset from the percent offset to better than an interval of 4 (percent). To eliminate this possible 3-percent error in voltage, the program prompts the user to arm and trigger the digitizer with 0 V input to check the calculated step offset with the true screen offset. If they differ by more than 4 (percent), the program re-prompts the user. If they are within 4 (percent), the true screen offset is used in the program.

### 3. Array Definitions and Pulse Data Entry (lines 700 to 890).

a. **Integer Arrays A(120, 1023).** Holds pulses in interval step units.

- Room for 120 pulses with 1024 samples each.
- **B(1026).** Buffer array for fast data entry by unformatted ENTER statement.
- **Parameter (6,120).** Holds the times of the six important events of each of 120 pulses.
- **Bad pulse (120).** Marks the bad pulses to be excluded from statistical analysis.

b. **Real Arrays Area (120).** Area under pulse in interval step units.

- **Aspike (120).** Area under spike in interval step units.

- **Tempy (1023).** Temporary storage for pulse intensity in kW used for pulse disc storage.

**NOTE:** Most calculations and storage are left in interval step units to reduce run time and memory use. Conversion to proper units occurs only for I/O.

**c. Pulse Data Entry.** The HP 9836 computer uses an HPIB to interface with the 6500 digitizer. The digitizer address in this program is 704. There are four digitizer I/O commands necessary for this program.

- **OUTPUT 704;8.** Arms the 6500 Digitizer (single sweep mode).
- **OUTPUT 704;11.** Puts the 6500 in output mode.

The 6500 now waits for a trigger pulse and then records waveform data.

● **ENTER 704 USING "#,B";B(\*).** Enters the data from the 6500 into a buffer array (unformatted). This buffer is necessary because an unformatted read into a two-dimensional array is not allowed, and single element entry into a two-dimensional array takes much longer.

- **OUTPUT 704;0.** Clears the 6500 of digital output.

The buffer array is now transferred into the two-dimensional A(120, 1023) array.

**NOTE:** Data stored in the A(120,1023) array is in 2's complement bytes. No further processing is done at this time, because pulse rate is already limited to 0.7 Hz.

**4. Convert to Word 2's Complement and Subtract DC Offset (lines 1000 to 1080).** This program segment converts the byte 2's complement data from the digitizer to the word 2's complement used by the computer. The DC offset is subtracted from each pixel (see Block 2). The pulse is also rectified by taking the absolute value, so that either inverting or non-inverting amplifiers can be used after the detector.

**5. Find Maximum of all Pulses (lines 1050 to 1060).** The maximum intensity of the sample of pulses is found, so that any pulses below 40 percent of this value can be rejected. This maximum is also used to determine the intensity range for graphing the sample pulses.

**6. Find Pulse Start Time and Maximum Value (lines 1160 to 1240).** Ideally, the start of the pulse should be recognized by a change in slope. However, noise frequency limits this option. The method used in the program triggers from zero. The program keeps track of

where the waveform last hit zero (line 1200). If the waveform does not return to zero after 200 sample units, the last zero is considered the pulse start (see Figure A-5). This step of 200 units may have to be decreased for short pulses or long time bases. The program, then, records the maximum intensity (Max) and the corresponding time  $T_{max}$ .

**7. Forty Percent Reject Level (lines 1250 to 1290.)** If a pulse maximum (Max) is less than 40 percent of the sample maximum (Maxval), then the pulse is called "bad" and is not included in statistical pulse analysis. This rejection eliminates false triggers caused by external corona discharge or turning detectors on or off.

**8. Locate Spike End From Slope Change (lines 1320 to 1370).** The spike end (Tedge) is defined at the point where the slope of the waveform suddenly becomes less negative and rises above a certain value. This equation is in line 1360 and may have to be tailored for different time bases. A pulse can be rejected at this point, if the timing sequence is incorrect (line 1400).

**9. Locate Pulse End (lines 1400 to 1440).** The pulse end is defined as the first point after the spike end where the waveform drops to zero  $T_{end}$ . If the waveform does not drop to zero, the pulse is rejected.

**10. Find Spike Energies and Half Widths (lines 1470 to 1560).**

$$E = \frac{K_{pd} \cdot V_{range}}{124000} \int_{T_{start}}^{T_{end}} V_{pd} dt.$$

Since the intensity is a stepped function, rectangular integration is used to determine pulse energy. This segment, also, finds  $T_1$  and  $T_2$  to determine the pulse half width (Figure A-5).

**11. Significant Parameters Stored (lines 1720 to 1790).** The times at which the six significant events occur for each pulse are stored in the Parameter (6,120) array. These times are used later to find corresponding intensities and temporal characteristics.

**12. Print Significant Parameters (lines 1590 to 1710).** Prints single pulse statistics to current printing device. Converts to kW, mJ, and ns on printout using current photon drag constant.

**13. Calculate Sample Statistics (lines 1810 to 1970).** This program section looks at all pulses entered. If the pulse is bad because of low intensity or a timing error, it is not included in the analysis. Energy and maximum intensity averages, and standard deviations are calculated for the group of pulses.

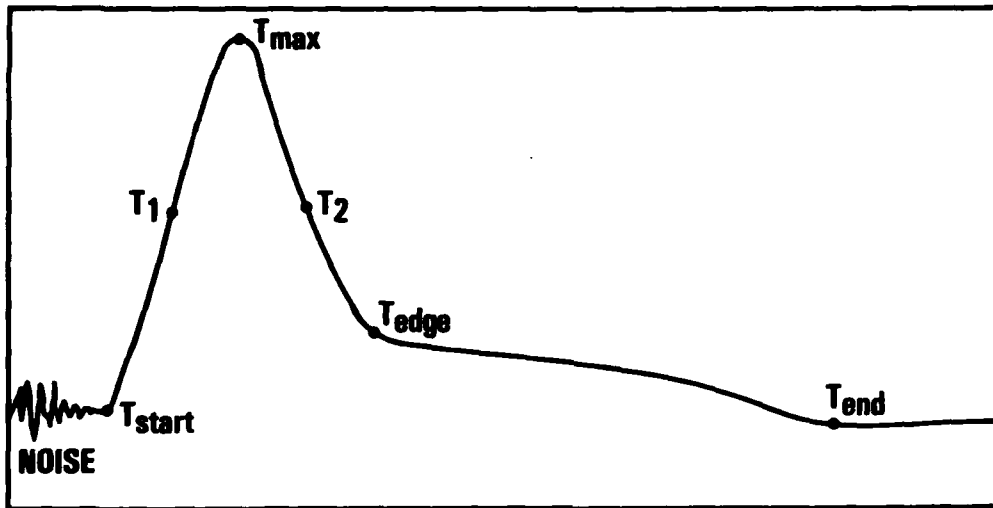


Figure A-5. Pulse event time markers.

14. **Key X (lines 2120 to 2240).** At this point all major calculations are completed. The photon drag or pyroelectric constants can be changed, or data can be sent to external output devices. By hitting a user-defined key, the program executes a subprogram, returns to this spot, and waits for another key to be depressed. Keys are disabled during subprograms so output can be completed.

15. **Key 0 "VIEW GRAPH" (lines 2250 to 2770).** This key produces a graph of power vs. time of the desired pulse number on the computer CRT. The top of the power axis is determined by the maximum sample intensity. The significant points of the laser pulse are marked with a "\*" for reference. The program then returns to Key X.

16. **Key 1 "PLOT GRAPH" (lines 2780 to 2820, 2310 to 2770).** This key transfers control to an external plotter and, then, branches into Key 0 to produce a plot of power vs. time on paper.

17. **Key 2 "TOGGLE PRINTER" (lines 2830 to 2930).** This key is a fast, one step way of changing the printer from internal to external or vice versa (i.e., CRT display or hard copy). Otherwise, the program would have to be stopped, a command executed and, then, the program continued.

18. **Key 3 "STORE GRAPH" (lines 3060 to 3210).** This key stores on disc the pulse intensity in kW. The number of points and the number of nanoseconds per array index is also stored. The format of the data file is compatible with a graphics program to make presentation quality graphs.

19. **Key 4 "NEW SAMPLE" (line 2190.)** This key prepares for a new pulse sample but does not reinitialize the photon drag and pyroelectric constants. The digitizer control settings can be changed for the new sample. Program continues on line 80.

20. **Key 5 "PARAMETERS" (lines 2940 to 3050).** This key initializes the time markers to those of the desired pulse from the parameter (6,120) array. The program then prints out the pulse rise time, half width, spike duration, total duration, spike energy, total energy, and peak intensity using the current photon drag constant. This printout is sent to the current printing device as specified by Key 2.

21. **Key 6 "SAMPLE STATS" (lines 1980 to 2070).** This key prints out the pulse sample averages, and standard deviations of pulse energy and maximum intensity on the current printing device. The energies and intensities are computed using the current photon drag and pyroelectric constants which are, also, printed out.

22. Key 7 "CHANGE PHOTON" (lines 3220 to 3580). This key is used to change the photon drag constant. If the average energy computed by the program does not match a calorimeter reading, the photon drag detector constant can be changed by entering a calorimeter reading or by using the pyroelectric detector as a calorimeter. The photon drag constant is in units of kW/V.

23. Key 8 "CHANGE PYRO" (lines 3710 to 4030). This key calculates a new pyroelectric constant in mJ/V. The average maximum voltage from the pyroelectric detector through the 6500 digitizer is determined. This average voltage is proportional to the average energy which is entered in mJ to determine the constant in mJ/V of the pyroelectric detector. The pyroelectric detector can now be used as a standard to calibrate the photon drag detector.

24. Key 9 "END PROGRAM" (lines 4040 to 4090). This key reloads the disc program directory.

**General Comments.** Some of the algorithms used in this program sacrifice speed in order to reduce memory requirements. In the current program, pulse analysis is limited to 120 pulses. This limit could be considerably increased if comments or unneeded segments are eliminated. LOAD SUB and PURGE SUB commands could, also, be used to load and purge program segments as they are needed on the run.

For lifetime tests, a loop could be put in Section 3 (Pulse Data Entry) to record every 10th or 100th pulse to increase sample range.

All pulse arrays in this program are kept in step units until the time of output. This is done for several reasons. The array as integer step units takes up less room than the real array converted to kW. The processing of integer numbers, also, takes less time than floating point operations. Another advantage is that when the photon drag constant is changed, none of the pulse storage arrays have to be accessed since conversion is done at output.

In some cases, program efficiency is given up for clarity. After the program is understood, efficiency can be improved by removing comments or I/O prompts and combining lines.

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