DOCUMENT RESUME

ED 055 844 SE 012 444

AUTHOR	Karl, John H.
TITLE	Computerized Experiments Using an A/D Converter.
PUB DATE	Jun 71
NOTE	14p.; Paper presented at the Dartmouth Conference on Computers, June 1971
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	Analog Computers; *College Science; *Computer Oriented Programs; Digital Computers; *Laboratory Experiments; On Line Systems; *Physics

ABSTRACT

The indroduction of on-line data collection and data processing techniques into an intermediate physics laboratory is described. Using a minimum configuration PDP-8L and a Digital Equipment AD01 analog to digital converter, an interface is developed with two existing experiments. These are a microwave apparatus used to simulate Bragg diffraction of X-rays in crystals and a nuclear magnetic resonance station. The FOCAL language is used with sample programs included. The figures referenced in the paper are of marginal readability. (TS)

COMPUTERIZED EXPERIMENTS USING AN A/D CONVERTER

JOHN H. KARL

PHYSICS DEPARTMENT, WISCONSIN STATE UNIVERSITY, OSHKOSH, WISCONSIN

The Physics Department at WSU-O has placed emphasis on the use of the computer as a computer in its introduction into the physics curriculum. Due to the large amount of resources required to embark upon an experimental educational project in computer assisted instruction (CAI) or its related areas, we have decided to confine our initial efforts to instructing both our non-physics majors and our majors in the use of this important powerful tool.

Our efforts can be divided into two areas: (1) stand-alone processing of numerical data and (2) on-line data collecting and data processing. We feel that since our physics majors go on to advanced research projects in either graduate schools or industrial laboratories, they should have as much grounding in state-of-the-art experimental techniques as possible.

Our purpose here is to report on the introduction of on-line data collection and data processing techniques into our intermediate physics laboratory.

Using a minimum configuration PDP-8L (4K) and a digital Equipment AD01 analog to digital converter we have developed an interfacing to two existing physics experiments in our intermediate laboratory. The first is a microwave apparatus used to simulate Bragg diffraction of X-rays in crystals. The second experiment is a nuclear magnetic resonance (NMR) station. Planned, but not yet developed, experiments include Fourier analysis using the fast

Fourier transform, pulse height analysis, and the study of the Poisson distribution in nuclear decay. Data collection on the Bragg diffraction apparatus, signal averaging on the NMR station, and digital filtering of the NMR signal have been developed and will be discussed here.

FACILITIES

All of the above experiments are based on using the AD01 A/D converter in conjunction with the PDP-8/L computer. The 10 bit A/D converter has up to 32 analog channels selected by program control. The conversion thruput time is 16 usec with a 10 usec aperture. The accuracy is ± .05% full scale over a 10 volt range which can be divided into four smaller ranges by program control.

Programs were written in PAL-III assembly language so that the A/D converter could be called using the FNEW function in FOCAL, a DEC (Digital Equipment) supplied conversational interpretive language for the PDP-8. All of the students in intermediate laboratory have been exposed to FORTRAN programming to some extent so that using FOCAL requires little effort. Thus time can be spent on the techniques of on-line data collection and processing rather than on learning a new assemble language. An additional bonus is the interactive character of the language which is especially valuable in on-line operation. The price paid for using FOCAL is the large amount of core it requires and the large amount of execution time involved. There is a maximum of 1100 locations left for the users program. Calling the A/D converter through a FOCAL subroutine which selects scale range, channel, and does the conversion to the FOCAL decimal floating point word formal results in a thruput time of 15 msec compared to the basic 16 usec thruput of the AD01 alone.

This relatively slow thruput rate can be tolerated in many research and instructional experiments.

The Bragg Microwave-Diffraction Experiment

The Bragg microwave diffraction apparatus used is commercially available from Welch Scientific Company. This apparatus was chosen for our first experiment with on-line data collection and processing because of its simplicity and because of the tedium it presented in the manual collection of data. The apparatus, shown in figure one, consists of a 4 x 4 x 4 array of steel spheresimbedded in a plastic foam matrix, a three cm modulated (1000 cycle) microwave klystron transmitter, and a crystal diode receiver connected to a tuned AC voltmeter (HP 415B). The recorder output of the AC voltmeter is interfaced (biased with an inversion of polarity) to the AD01. A slide wire variable resistor attached to the degree circle at the base of the apparatus allows voltage pick offs by contacts connected to the transmitter, receiver, and "crystal" mount.

A FOCAL program (see figure two) continuously reads the output of the detector, the angle of the transmitter, receiver, and crystal. If the relative orientation of the transmitter, receiver, and crystal satisfies the Bragg condition, the detector output is stored in an array vs. the Bragg angle. The student moves the arms that support the transmitter and receiver so as to keep them at equal angles about a fixed reference point. When the computer has collected all the acceptable data the program types out "Data Complete" and plots the output vs. angle. The results of such a plot are shown in figure three. The student has the responsibility of determining the angle at which the Bragg maximum occurs and calculating the distance between reflecting planes from the Bragg

Law. This of course can be accomplished by a FOCAL program written by him. Due to the high data collection rate the student can extend the experiment in several ways. For example, by rotating the entire transmitter, receiver, and crystal combination a fixed amount, spurious maxima from room reflections can be distinguished from the Bragg diffraction. The Bragg maxima will occur at the same angles, but the background spurious responses will be shifted to new positions. Alternately data collected with the "crystal" removed could be subtracted from the "crystal"-plus-background data. Such ideas will be left for the student to explore next semester (Spring, 1971) when the "computerized" version of this experiment will be introduced into our intermediate laboratory.

<u>The NMR Experiment</u>

The second experiment used for on-line data collection and processing in Atomic Laboratories Inc.'s combination nuclear magnetic resonance (NMR) and electron spin resonance (ESR) spectrometer. (Cenco No. 71913). A current regulated supply feeding an Atomic Laboratories' 3" magnet provides the DC magnetic field. Since the NMR experiment has rather poor signal to noise ratio, it was selected for introducing the student to the technique of signal averaging. Data previously used in this experiment was displayed on an oscilloscope screen. (See figure four.)

Since the magnetic field in this apparatus is swept by a 60 cycle line source, the coherence required for signal averaging can be obtained by using line voltage as a timing reference. Advantage was taken of the fact that the output of the unipolar AD01 is zero when the input signal is negative. Thus the 60 cycle AC line voltage looks like a half rectified wave when viewed through the

A/D converter.

A second PAL-III program was written, (copies are available from the author), that can be called from FOCAL to provide the required timing. Arguments of the subroutine are the scale range, the channel number, and the time at which the channel is to be sampled. The time parameter is the number of 400 usec intervals elapsed after the 60 cycle line frequency passes through zero with positive slope. The period of a 60 cycle wave form can then be divided into about 40 time slots. The timing is determined by searching for the first positive value of the rectified AC line after the line was at zero. Then the program enters a no operation 400 usec loop for the desired number of times and then samples the signal channel called for by FOCAL. Consistency of timing obtained in this manner is ± 14 usec with a constant time delay from the 60 cycle zero to the first time bin of 27 usec.

A FOCAL program calls the A/D converter timing routine thru the function named FNEW (figure five). This FOCAL program [illegible] 46 time bins with N values to average out the noise. The resulting array of signal vs. time is scaled and plotted on the Teletype. Results for N = 1 and N = 500 are shown in figures six and seven. Since the aperture of the A/D converter is ~~15~~ 10 usec and the data is taken at rather widely spaced intervals (every 400 usec), the results for N = 1 appear poorer than the scope display. The results for N = 500 are rather impressive when compared to the scope display. Considerably more dramatic results could be presented if a plotter output were available. The signal to noise ratio of the proton resonance in tap water is about one-to-one in our NMR rig. It is hoped that the students will be able to enhance this signal considerably by using this signal averaging technique next semester in intermediate laboratory. Aside from the usual NMR studies, the students will be expected to study the dependence on signal to noise ratio on the number of averages. Another problem the student faces is that of plotting the resonance vs. magnetic field, as is customary, rather than vs. time as is done here. This can readily by accomplished within the PDP-8 FOCAL language.

Digital Filtering

From the NMR data a considerable 60 cycle component can be seen (perhaps most easily in the oscilloscope trace, figure four). Of the various techniques which could be used to eliminate this component from the signal, possibly the least known to our students and physics students in general, is digital filtering. With the greatly increased number of on-line applications of digital computers for collecting and processing data in the fields of science and engineering, digital filtering has become increasingly important. The NMR signal provides an opportunity for introducing digital filtering techniques into our physics curriculum.

The object is to remove the 60 cycle noise and other low frequency components that may be present. Hence a high pass filter is called for with a low frequency cut-off of, say, 120 cycles. One way this can be accomplished in the computer is by calculating the Fourier components of the averaged signal by numerical integration. Then the filtered function can be sythesized by summing the components and omitting the 60 cycle (the fundamental) and the 120 cycle component. Using this approach, one must truncate the Fourier series somewhere and therefore one is lead to a band-pass filter with some high frequency cut-off. From inspection of the NMR data, it can be seen that the resonance width is about one-eighth of the 60 cycle period or about 2 msec or 5 Kc which requires about 85 harmonics. This can readily be accomplished within the limits of the FOCAL language.

We are currently writing digital filtering programs for this type for experimentation within our intermediate laboratory. Many facets of digital filter design may be explored by the students experimentally. For example, the limitations of the numerical integration will result in less than ideal response. The student can determine the actual response of the filter by experiment. The effect of various cut-off frequencies on the signal may be studied in regard to both low and high frequency noise. This may also be an excellent place to introduce the student to the fast Fourier transform algorithm. Introductory material and standard reference works on digital filtering will be provided for the student.

Conclusion

The above "computerized" experiments will be "student tested" for the first time this spring semester, 1971. We believe that we have made an important step toward introducing modern data treatment techniques into the physics curriculum. It is such technical skills that allow the physicist to bridge disciplines and make himself valuable to a wide spectrum of employers.

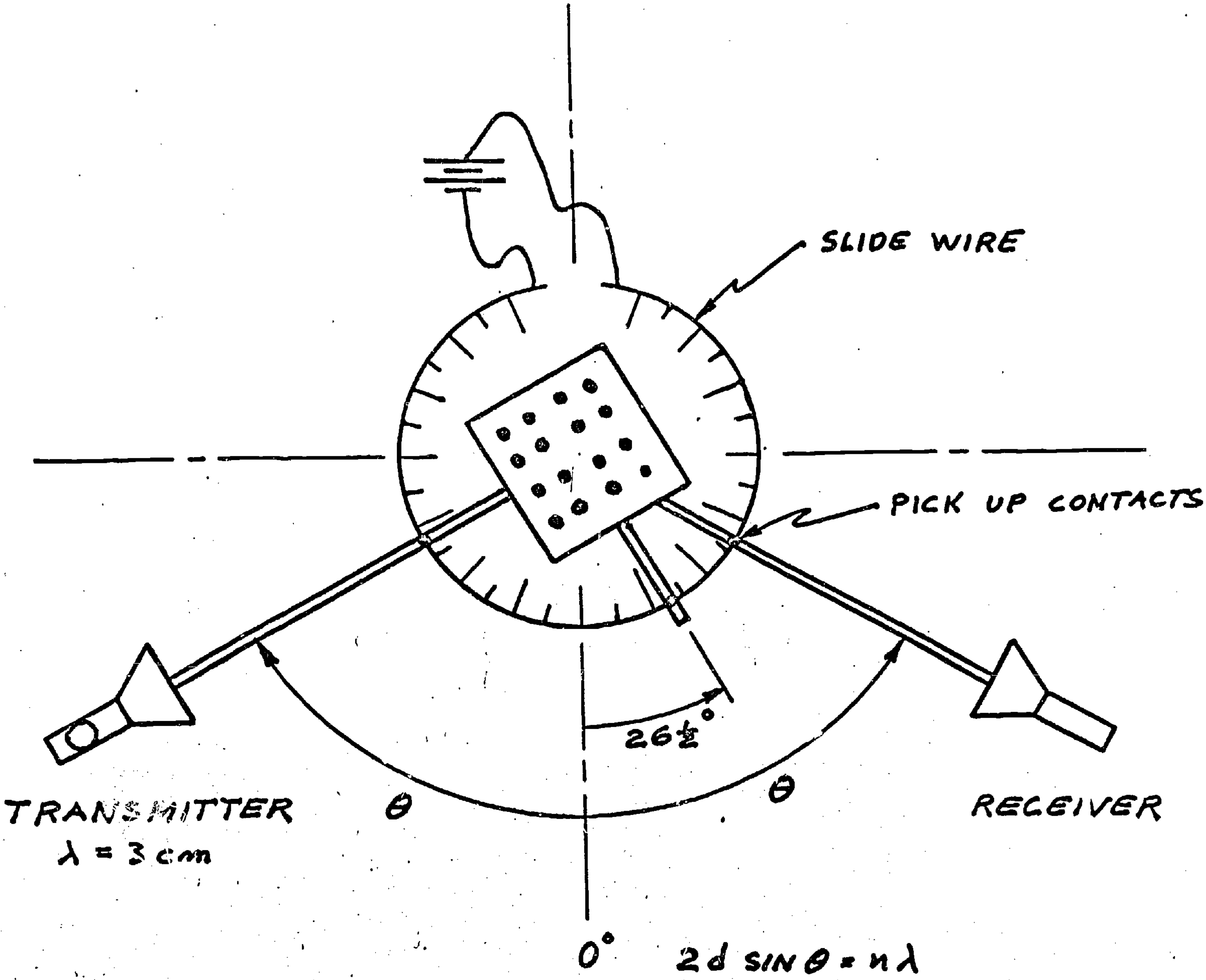

Fig. 1

Bragg diffraction apparatus. Crystal is shown offset 26 1/2° for the (210) lattice orientation.

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C-FOCAL,1969

01.10 T "PROGRAM FOR BRAGG DIFFRACTION"!!!!.

02.05 S R1=1; S R2=1
02.10 A "MAX DEGREES",UD;A "MILLER OFFSET",MO;A "PRECISION",PP
02.15 T "DIGITIZE MAXA"; A DUMMY
02.20 S DV=2*UD/(FNEW(R1,2)-FNEW(R1,1));T "DIGITIZE MINA"; A DUMMY
02.25 S LD=FITR((FNEW(R1,2)-FNEW(R1,1))*DV)
02.30 F I=LD,PP,UD;S D(I)=0.0

03.10 S X=FNEW(R2,0); S T=FITR(FNEW(R1,1)*DV)
03.11 S R=FITR(FNEW(R1,2))*DV;S C=FITR(FNEW(R1,3)*DV)
03.15 I (FABS(C-(T+R)/2-MO))-PP) 3.20,3.20,3.10
03.20 S A=(R-T)/2;I (A-UD) 3.30,3.30,3.10
03.30 I (A-LD) 3.10,3.40,3.40
03.40 S D(A)=X;F I=LD,PP,UD;D 4.0

04.10 I (D(I)) 5.60,3.10,4.20
04.20 C

05.10 T "DATA COMPLETE";T !!!!!!
05.50 GOTO 10.10
05.60 T "ERROR OCCURED";QUIT

10.10 F I=LD,UD;DO 11.0

11.10 T %3,I;T %7.07,D(I);F J=0,D(I);T" ";T "*"!

12.10 T!!!!!!
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
```

Fig. 2

FOCAL program for the Bragg diffraction experiment. The function FNEW (A,B) calls the A/D converter for range A and channel B.

```
20 0.1678     *
21 0.1476    *
22 0.1427    *
23 0.1738     *
24 0.1543    *
25 0.1444    *
26 0.1405    *
27 0.1553    *
28 0.1430    *
29  .1397    *
30 0.1721      *
31 0.1792      *
32 0.1899      *
33 0.2163       *
34 0.2096       *
35 0.17[illegible]      *
36 0.1367    *
37 0.1275     *
38 0.1343    *
39 0.1671      *
40 0.2356       *
41 0.4204            *
42 0.5579               *
43 0.8332                      *
44 0.8536                       *
45 0.9819                          *
46 0.7172                   *
47 0.4722             *
48 0.3125         *
49 0.1729      *
50 0.1541    *
51 0.1648      *
52 0.1992      *
53 0.2254       *
54 0.2592       *
55 0.1732      *
56 0.1395     *
57 0.1319    *
58 0.1573     *
59 0.1986      *
60 0.2377       *
61 0.2295       *
62 0.1432     *
63 0.1387     *
64 0.1623      *
65 0.4251            *
66 0.6140                 *
67 0.9868                         *
68 1.6314                                          *
```

Fig. 3

Teletype plot of Bragg diffraction data. The numbers in the first column are the angle θ of fig. 1 in degrees. The second column is the detector output in volts. This plot is for the (100) orientation. Note the secondary maxima on each side of the primary peak.

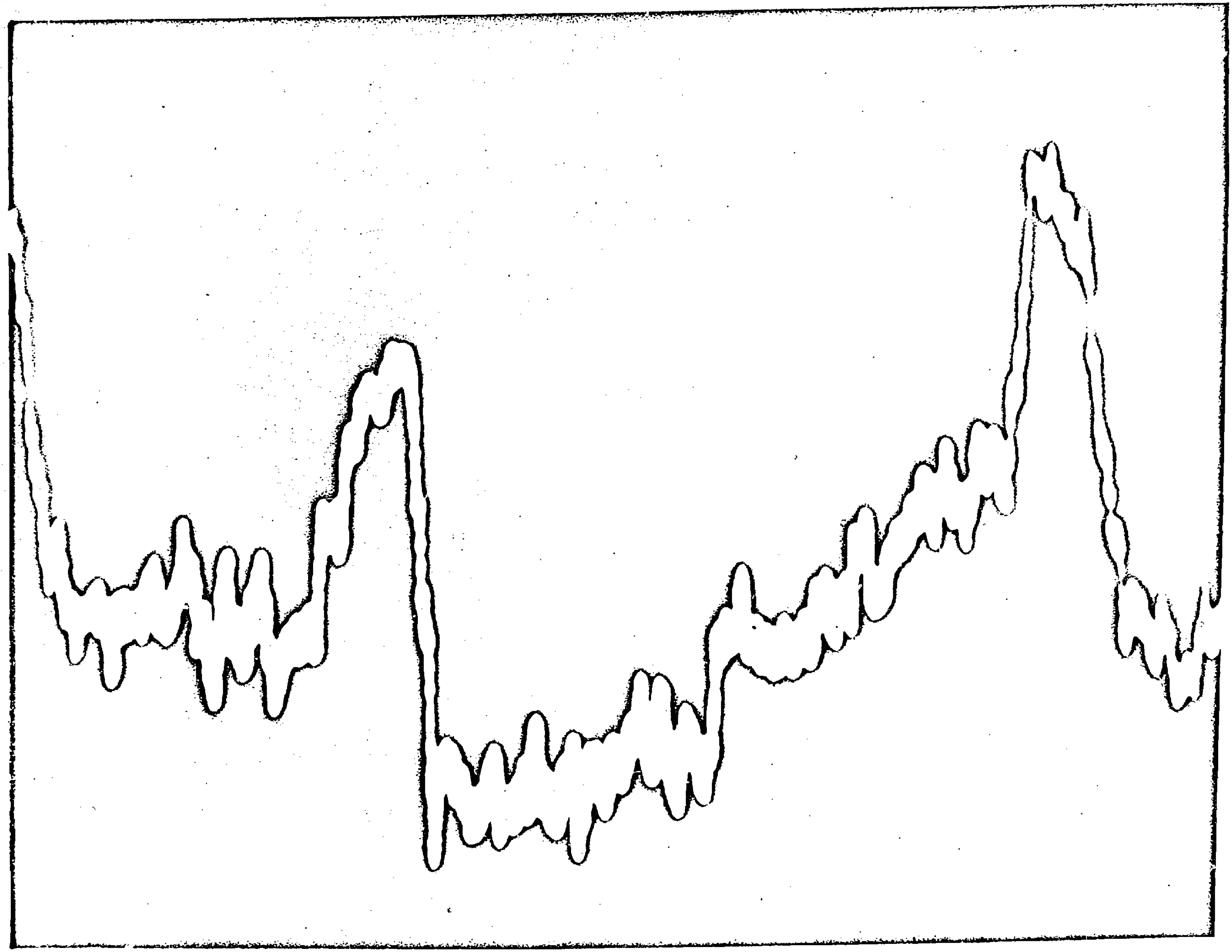

Fig. 4

Oscilloscope trace of the proton resonance in a copper sulfate solution. The trace covers about 16 uses. Note the 60 cycle background and the high frequency noise.

```
01.05 A " N",N," I",BI," F",BF
01.06 T !,!,!,!,!,!,!,!,!,!,!,!
01.07 T " NUMBER OF EVENTS",N,!
01.08 T " INITIAL BIN",BI,!," FINAL BIN",BF,!
01.20 F J=1,N; D 2
01.25 F I=BI,BF; D 4
01.30 G 5.01

02.05 F I=BI,BF; D 3

03.05 S A(I)=A(I)+FNEW(0,6,I)

04.05 S A(I)=A(I)/N

05.01 D 7; D 9; S G=50/(UA-LA)
05.05 F I=BI,BF; D 6
05.10 G 1.06

06.05 T %3,I,%8.4,A(I); F K=0,G*(A(I)-LA); T " "
06.10 T "*",!

07.50 S UA=0; F I=BI,BF; D 8

08.10 I (A(I)-UA) 8.3
08.20 S UA=A(I)
08.30 C

09.50 S LA=UA; F I=BI,BF; D 10

10.10 I (LA-A(I)) 10.3
10.20 S LA=A(I)
10.30 C
*
```

Fig. 5

The FOCAL time averaging program. The function FNEW in line 3.05 calls the A/D converter. Arguments are scale range, channel number, and the time of sampling.

```
NUMBER OF EVENTS 1.0000000
INITIAL BIN 0.0000000
FINAL BIN 45.000000
  0 1.3281300      *
  1 1.7890600          *
  2 1.9921900            *
  3 1.0546900    *
  4 1.9218800           *
  5 2.4531300               *
  6 1.9765600           *
  7 1.6015600        *
  8 1.8203100          *
  9 2.3125000              *
 10 1.4921900       *
 11 2.0625000            *
 12 2.3281300              *
 13 2.0546900            *
 14 2.5234400                *
 15 5.0625000                                      *
 16 2.5546900                *
 17 4.1406300                              *
 18 4.5312500                                 *
 19 5.2812500                                       *
 20 2.0859400            *
 21 1.8593800          *
 22 1.7187500         *
 23 0.7578130 *
 24 2.1640600             *
 25 2.6406300                 *
 26 1.7265600         *
 27 1.5937500        *
 28 1.6093800        *
 29 1.3359400      *
 30 1.5156300        *
 31 1.9375000           *
 32 2.6093800                 *
 33 3.6484400                         *
 34 3.1796900                     *
 35 2.1171900             *
 36 2.6406300                 *
 37 3.4531300                        *
 38 6.0546900                                              *
 39 6.5828100                                                     *
 40 5.7578100                                           *
 41 4.0312500                            *
 42 4.9609400                                     *
 43 3.0312500                    *
 44 1.8515600         *
 45 1.8593800         *
```

Fig. 6

The NMR signal with one data sample in each bin. The 46 bins cover approximately one 60 cycle period. The first column is the bin number; the second is the detector output in volts.

```
NUMBER OF EVENTS 500.00000
INITIAL BIN 0.0000000
FINAL BIN 45.000000
  0 0.0331094  *
  1 0.0498594  *
  2 0.0719062   *
  3 0.0990312    *
  4 0.1041560    *
  5 0.1154530     *
  6 0.1380470     *
  7 0.1533280      *
  8 0.1997970        *
  9 0.3154840            *
 10 0.5306090                    *
 11 0.9141410                                  *
 12 1.2342700                                               *
 13 1.3621700                                                   *
 14 1.3627000                                                   *
 15 1.0471900                                        *
 16 0.6382030                        *
 17 0.3415470             *
 18 0.1118280     *
 19 0.0462344  *
 20 0.0188281 *
 21 0.0175625 *
 22 0.0282656 *
 23 0.0353906  *
 24 0.0498438  *
 25 0.0739844   *
 26 0.0900469    *
 27 0.1767660       *
 28 0.3458440             *
 29 0.6738280                         *
 30 0.9344370                                   *
 31 1.1632700                                           *
 32 1.2415600                                              *
 33 1.0659100                                        *
 34 0.5890160                      *
 35 0.2551560          *
 36 0.0111719 *
 37 0.0021406 *
 38 0.0039688 *
 39 0.0043906 *
 40 0.0066719 *
 41 0.0046719 *
 42 0.0048594 *
 43 0.0121250 *
 44 0.0283437 *
 45 0.0436406  *
```

Fig. 7

e time averaged NMR signal with 500 samples in each bin. The scale is such that ns higher than 35 are plotted as zero on the Teletype. Fig's 6 and 7 are phase shifted from fig. 4.