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Passive Segmented Gamma Scan Operation Manual

by

E. Ray Martin
David F. Jones
L. G. Speir

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

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PASSIVE SEGMENTED GAMMA SCAN OPERATION MANUAL

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ABSTRACT

An operation and maintenance manual for the new computerized segmented gamma scan instrument is presented, which describes routine assay techniques as well as theory of operation treated in sufficient depth so that an experienced assayist can make nonroutine assays on a wide variety of materials and samples. In addition, complete system schematics are included, along with a complete circuit description to facilitate not only maintenance and troubleshooting but also manufacturer reproduction of the instrument if desired. Complete software system descriptions are included, although detailed listings would have to be obtained from LASL in order to make machine-language code changes.

I. INTRODUCTION

Nondestructive assay of fissile content of material in various sample containers depends primarily upon detecting either neutrons or gamma radiations from the nuclei under measurement and relating the number of events detected to the number of nuclei present in the sample. Active interrogation systems employ some means to induce radiations in the nuclei under assay, while passive systems detect emanations emitted spontaneously by the sample.

In the instrument to be described, we are concerned with detecting gamma radiation spontaneously emitted by nuclei of fissile material under assay. There are several serious problems associated with any quantitative assay by means of gamma detection; viz., gamma rays are attenuated by material between the nucleus emitting them and the detector; the detection system must be able to correctly identify only those gammas from the isotope under measurement; the detector and electronics will respond differently to different data rates; and the assay may take a prohibitively long time if detection efficiency is not high enough. The attenuation problem is by far the most serious of the above, since gamma attenuation varies with transition energy as well as the density of material through which the rays pass. Matrix inhomogeneities make this attenuation a very serious matter indeed, since in this case the attenuation factor relating detected counts to fissile content is varying in some unknown manner with sample configuration.

Group A-1 has developed and described previously[1] a passive gamma detection system designed to overcome these and other problems. Unfortunately, this system is sufficiently complex and difficult to operate that it remains strictly a laboratory instrument for use by physicists and nuclear engineers. Also, it suffers from several unique problems of its own that have to do with control of the scan table.

The system to be described is a descendent of the above laboratory model, considerably redesigned and reengineered, and with the operation difficulties greatly minimized. The use of a modern minicomputer permits automation of the scan table as well as automatic calculational capability, free from human error. In addition, it offers something never before available with the segmented gamma scan system: a propagated error calculation yielding an estimate of measurement error. The system, while not suitcase portable, is now at least readily transportable in a light truck or van. In addition, operation personnel need no longer be highly trained scientists or engineers.

II. THEORY OF OPERATION

The detailed theoretical discussion of segmented gamma scanning as an assay technique has been amply documented by Group A-1 personnel[2] and will not be reproduced here, except for the relevant high points involving the calculation formulae. As was mentioned before, the most serious difficulty with NDA involving gamma radiation is the attenuation of the rays in traversing the material between the sample and the detector. It is assumed from the outset that self-absorption (i. e., attenuation of the rays in getting out of the fissile material itself) is not significant, and this technique is not amenable to cases where this assumption is not valid, as for example with fissile metal samples or large pellets, etc. The sample containers are assumed to contain some mix of fissile-containing powder and matrix material of reasonably low density. Radial inhomogeneities are rendered negligible by rotation of the sample. Vertical inhomogeneities are handled by making the gamma scan in discrete segments, which method also vouchsafes a viable indication of fissile material profile within the sample. For each individual segment the transmission is measured and assumed uniform for that segment, though it may vary from segment to segment. The measurement is made by utilizing a separate transmission source which is viewed through the sample being assayed and compared with a known transmission value obtained from a background run taken with no sample present in the system. In addition to the transmission correction a pileup and live-time correction is made by counting a separate peak from a small source placed close to the detector crystal and viewed at all times by the detector. When the count rate from fissile material and transmission sources is high, this live-time source will vary in its counting rate in a manner which permits accurate measurement of live-time correction.

In choosing a source for the transmission measurement, it is always desirable to try for a gamma line as close as possible to the gamma energy from the fissile material being assayed. This minimizes the variation of attenuation factor with gamma energy and permits a better correction. The segmented gamma scan is suitable for assay of ^{238}Pu, ^{239}Pu, or even ^{235}U, but the plutonium assays provide a simpler case than uranium, since the former require only a single transmission peak due to their higher gamma energies. The uranium requires measurement of the 185-keV gamma line, where the attenuation coefficients are varying rapidly with energy. In this case, it is necessary to bracket the uranium line with two transmission lines, and the analysis is slightly more difficult.

In the analysis for ^{238}Pu, the 765-keV gamma line is measured, and the 661-keV gamma from ^{137}Cs is a reasonable peak to use for the transmission measurement. For the case of ^{239}Pu, the measured peak is at 414 keV, and the 400-keV gamma from ^{75}Se provides a convenient transmission measurement. Unfortunately, the 120.4-day half-life of selenium represents a nuisance in that the source must be periodically rejuvenated or replaced. The cesium source has a 30-y half-life and hence is no problem in this regard.

The present instrument uses the 356-keV line from barium for the live-time and pileup measurement, which, with its 10.4-y half-life, is well suited to this application.

The assay consists of measuring the live-time, assay, and transmission peaks, stripping these peaks of their backgrounds, and performing the relevant calculations. For purposes of background stripping, the following linear subtraction method is used. Channel windows are set on each side of the main peak as well as on the peak itself, and the counts in each of these three windows are tallied during a segment assay. The peak count value is then determined from the equation:

$$\text{Corrected Peak Counts} = \sum B - \frac{\Delta B}{2}\left(\frac{\sum A}{\Delta A} + \frac{\sum C}{\Delta C}\right)$$

where ΔA, ΔB, and ΔC are the widths (number of channels) of the three windows, and $\sum A$, $\sum B$, and $\sum C$ are the accumulated counts in each window, B being the window bracketing the main peak. This procedure is described in detail in Section IV-H.

With the values for each of the three peaks so determined, the corrected peak counts, related to fissile content, are calculated for the i^{th} segment as follows:

$$CC_i = C_i \cdot \frac{LT_o}{LT_i} \cdot CF_i(T_i') \cdot CF_{can} \quad , \tag{1}$$

where

$$CF_i(T_i') = \frac{-A \cdot K \ln T_i'}{1 - (T_i')^{A \cdot K}} \quad , \tag{2}$$

$$CF_{can} = \frac{1}{\sqrt{T_c}} \quad , \tag{3}$$

$$T_i' = \frac{T_i}{T_o} \cdot \frac{LT_o}{LT_i} \cdot \frac{1}{T_c} \quad , \tag{4}$$

$$K = \frac{\mu_a}{\mu_t} \quad . \tag{5}$$

In Eq. (1), C_i represents the counts in the plutonium (or uranium) peak, CF_i the correction factor for the i^{th} segment, LT_o/LT_i the live-time correction factor, and CF_{can} a correction factor based on a known attenuation of gammas through the can. The A factor in Eq. (2) is a geometric factor relating the geometry of the sample being assayed and its proximity to the detector. For cylindrical sample containers its value is $\pi/4$, or about 0.7854. The K indicated in Eq. (5) is the ratio of attenuation coefficients for gammas of the assay peak energy to those of the transmission peak energy. It is usually the case that the transmission peak and assay peak are close enough in energy that this constant has the value unity. The T_c of Eq. (4), can transmission factor, is measured for the type of container being used, since the material of the container generally varies substantially from the matrix containing the fissile material.

The values of LT_o and T_o represent live-time and transmission peak values, respectively, in the absence of any intervening material. These must be determined for a given assay configuration by making a preliminary background run. This procedure will be described in the section on operation of the instrument.

III. SYSTEM DESCRIPTION

The new segmented gamma scan instrument is shown in Fig. 1. The teletype, which is used for hardcopy output and program input, as well as the keyboard used for entry of comments, constants, and parameter interrogation is shown to the far left of the figure, with the half-rack containing the stepping motor drivers behind it and not visible. The complete electronics rack is shown in the figure center, containing the following units (starting at the top): the Tektronix storage scope used for

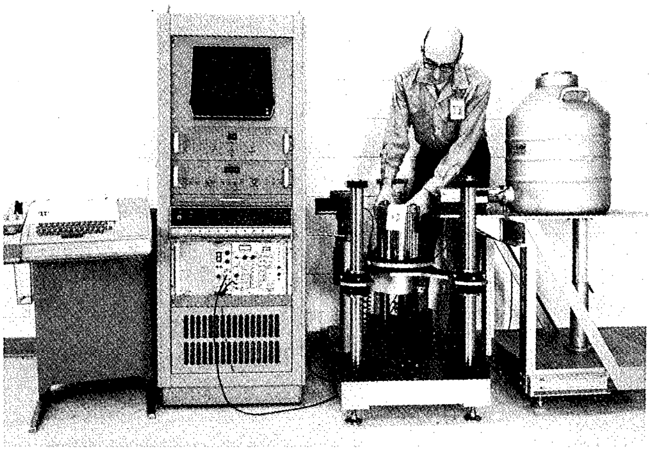

Fig. 1. Segmented gamma scan instrument.

spectrum display, the scan table interface, the general system interface, the Nova 1200 minicomputer, the NIM bin containing the Ortec hv power supply, Tennelec amplifier, and Northern Scientific ADC with stabilizer, and the rack blower at the bottom.

The two units to the right of the rack comprise the scan table and Ge(Li) detector systems. Note that the transmission source is to the left of the sample in this figure, with the detector to the right with its liquid nitrogen dewar. In this figure no collimator is present. Normally, the collimator will sit at the front of the detector on the table overhang. The live-time barium source fits into a small hole bored in the collimator near the detector, or it can be taped to the barrel of the detector itself.

Figure 2 is a closeup view of the display and electronics control panels. The two panels below the display constitute the entire interface system between the computer, data acquisition equipment, display scope, and the scan table. In normal operation, the controls on these two panels are the only system controls used by the operator. It is not necessary to operate any of the computer console switches nor to refer to the computer lights in any way after the program is running. So far as the operator is concerned, the computer itself is totally transparent to the routine assay operation.

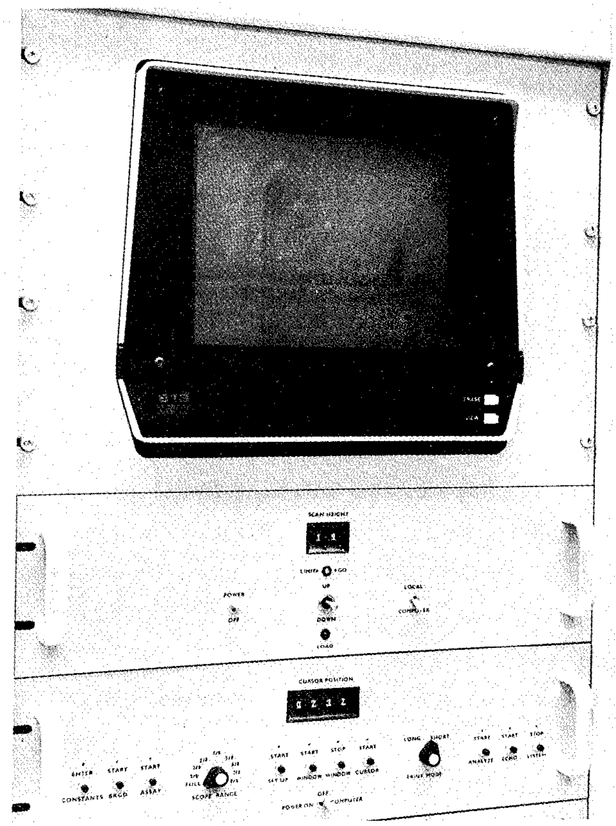

Fig. 2. Electronics control units.

IV. INITIAL SETUP AND OPERATION

A. Physical Setup

After the basic units of the system have been unpacked, they should be physically configured as shown in Fig. 1. This arrangement permits the interconnecting cables to reach each unit. The electronic units should be mounted in the large rack in the order shown in the figure, with the display at the top, since this arrangement not only matches the interconnecting cables, but has been found to be operationally convenient. The physical placement of the small rack containing the motor drivers is not important providing its cables will reach the scan table, since in normal operation these units will not be used by the operator, except to turn on ac power to them. Figure 3 shows the cable arrangement between units as viewed from the back.

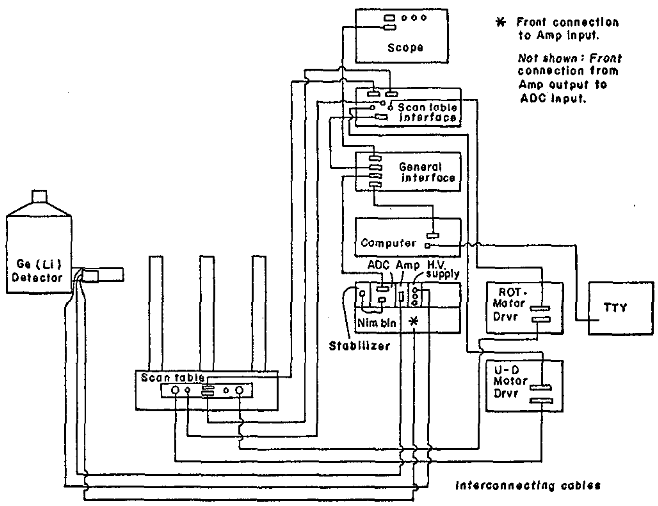

Fig. 3. Interconnecting cables.

Figure 1 shows the few cables which connect to units at the front. All cables should be carefully connected as shown.

The ac line connections to the units are shown in Fig. 4. All of the units of the instrument operate from the standard 110-120 V ac line.

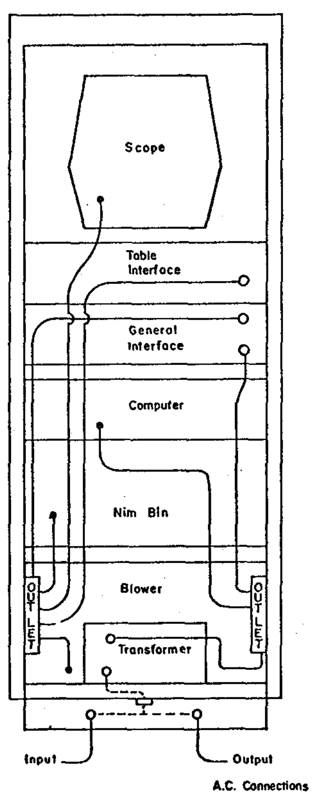

Fig. 4. Alternating current connections.

B. Operation of Power Switches

Providing the units have been connected to ac power as shown in Fig. 4, operation is ready to commence. The operator should first make certain that the hv power supply in the NIM bin is turned down to zero volts output and the NIM bin switch is turned on. The key at the lefthand side of the computer controls ac power to this unit. It can also control power to all other electronic units as follows: When the power switch on the main interface panel is turned to the COMPUTER position, then ac power will be on this and all other units only if the computer key switch is turned on. In other words, with the interface power switch in this position, the computer key controls all ac power to the system. This will be the situation for normal operation. In case power must be placed on the other electronic units with the computer turned off, the power switch on the main interface panel must be placed in the ON position. This will permit power to all electronic units independent of the computer switch. The individual power switches on the other units operate as normal ac line switches when the general interface power switch is in the ON position, or when it is in the COMPUTER position, with the computer key switch turned on.

C. Manual Scan Table Operation

With ac power on, the operator is now ready to familiarize himself with the scan table operation. The scan table interface located immediately below the display scope, in the main rack, controls all operations of the scan table and has no other function. Turning attention to this unit (see Fig. 2), the operator should make sure the power switch is on, and the computer-local switch is in the LOCAL position. This allows the scan table to be raised and lowered manually. The spring-loaded toggle switch in the center of the panel controls this operation. The green load light immediately below this switch will glow whenever the scan table is positioned at the extreme lower (load) position. In any other table position, this light will be off. If the operator should attempt to move the table downward when the load light is lit, the limit-go light above the switch will indicate red, and the table will not move. Likewise, if the operator attempts to move the table upward when it is at the top limit, the limit light will again show red and the table will not move. When the operator attempts to move the table legally (i. e., in either direction if it is not at a limit, or away from a limit if it is on one), this light will show green, indicating that the table is moving.

Manual vertical motion of the scan table is always at high speed, after an initial ramp time. That is, as the motor is started in either direction, it will start slowly and accelerate for about four seconds until it achieves its maximum speed. Likewise, after the switch is released, or a limit is reached, the motor will gradually decrease for four seconds until it comes to a stop. This ramping is necessary to the proper operation of stepping motors at high speed, and may lead to some operator frustration if, for example, rapid changes in table direction are attempted. To illustrate, if the table is being moved rapidly upward and the operator suddenly changes the switch to the down direction, the table will immediately begin decelerating to a stop and then commence accelerating in the opposite direction. The whole reversal process from high speed upward to high speed downward takes eight seconds, during which time the limit-go light remains green. At this point, the operator should manually move the table in each direction several times to acquaint himself with the operation. All assays are begun from the load position, with the table at the bottom, where it is most convenient to place assay samples on the scan table.

At this point it is worthwhile to point out that the operator does not have manual control over the rotation of the table, nor over the slow speed motion vertically. During an assay, the computer will move the table rapidly upward from the load position to the top, and then begin motion slowly downward, stopping the table after each 1/2-in. segment to output a spectrum display on the scope. During this downward assay movement, the table will rotate synchronously with the downward movement. The rotational speed is electronically coupled with the slow downward table motion so that for each segment downward (1/2 in.), the table rotates exactly twice. Synchronizing table rotation for each segment insures that rapid rotation is not necessary to wash out radial inhomogeneities.

D. Final Positioning of Detector and Detector Table

Before actual assay work can be started, it is now necessary to adjust the final position of the detector table relative to the scan table. To do this, the operator must select one of the styrofoam spacers, according to the size of samples to be assayed; place it on the scan table; and place the sample container on top of the spacer. Now the scan table should be moved to its extreme upward position and stopped. In selecting the styrofoam spacer, the smallest spacer which fits the sample containers to be assayed should be selected, as this will permit the detector to be moved as close as possible to the sample. Since the detection efficiency decreases as the inverse square of the distance between the detector and sample, it is desirable to move the detector table as close as possible to the sample holder. To do this, the detector table is now moved to within 1/4 in. of the sample on the scan table. This guarantees that during the assay, there will be adequate clearance between the rotating sample and the detector, while at the same time reducing their separation as much as possible. If a wide range of sample sizes must be accomodated for the same series of runs, it will be necessary to adjust the detector table position to allow clearance for the largest sample to be measured.

Viewing the scan table and the detector table from the top, the operator should now insure that the detector is in a straight line with the transmission source holder on the opposite side of the sample. The detector should be positioned on its table with its crystal 0. 1 m (4 in.) from the end of the table overhang. This allows room for the lead collimator to be installed now. The purpose of the lead collimator is to limit the acceptance of the detector to only gamma rays from the slice of sample being scanned at any given time.

The collimator is built up of lead bricks. Before any lead bricks are placed at the front of the detector table, four or five lead bricks must be put at the back of the lower surface of the table as a counterweight to prevent tipping. The system has been supplied with several lead bricks which have had their sides planed smooth. In addition to these, it will be necessary to supplement them with other standard lead bricks at the point of assay. The collimator should be built up of the special slotted brick supplied and others placed around it to provide vertical collimation. Note that two collimator widths have been supplied with the system, one with a 3/8-in. gap, and one with a 1/2-in. gap. For samples with more than fifty grams of fissile material, the 3/8-in. collimator will give better profile resolution, since the slices for the segmented scan are better defined. However, for smaller samples (i. e., those with small amounts of fissile material) the 1/2-in. collimator should be used. This will result in approximately twice the detector sensitivity. In general, the 1/2-in. collimator can be used for most routine assay work, since it offers the best sensitivity with reasonable segment definition. Note that it is a good idea to place the 1/16-in. thick lead disc in front of the detector, as this will reduce low-energy gamma events.

At this point, the operator should install the live-time and transmission sources. The small barium live-time source fits into a small hole bored in the collimator, so that it is constantly viewed by the detector crystal. In order to get sufficient rate (~ 10-15 K per 10-sec segment) on the live-time peak, it may be necessary to tape this source directly to the barrel of the detector. The holder for the transmission source is physically across the scan table from the detector. This holder is designed to be adjustable both as to height and horizontal position relative to the sample. The vertical positioning must be such that the source in its holder is on a horizontal centerline with the detector crystal and collimator opening. With the sample container again at the top position, place the selenium (in the case of ^{239}Pu assay) source in its lead protector, and place this assembly in the scan table holder. Now move the holder in close to the sample in a manner similar to the positioning of the detector table. When the selenium source is new, it has about 10-mCi activity, which is too hot for the system deadtime. In this case, a 1/16-in. lead disc has been provided to place between the source and the sample. The transmission peak for a background run should be around 5-7 K in 10 s. As the selenium activity decays away with time, this lead shield can be removed to increase the useful life of the source. Now that the sources are in place, the operator is ready to begin adjustment of the amplifier and ADC. A calibration sample should be placed on the scan table and moved up into position where its activity can be viewed by the detector.

E. Setting up the Amplifier and ADC

The operator should now make certain the high voltage cable to the detector is connected to the Ortec high voltage power supply and the supply adjusted to give 3. 5-kV output, and that the signal cable from the detector is connected to the input of the Tennelec amplifier.

For initial adjustment of the Tennelec 202BLR amplifier, it will be necessary to use an oscilloscope connected by means of a coax tee to the output of the amplifier. At the same time, the output should also be connected to the input of the analog-to-digital converter. For these connections see Figs. 3 and 1. Start by setting the amplifier controls as follows:

Coarse Gain	100
Fine Gain	1000
Restorer	Out
Shaping	Unipolar
Rate	Low
Polarity	Direct

Note that the amplifier must be dc-coupled to the oscilloscope and the ADC. The polarity of the amplifier output must be such as to give positive pulses. With the oscilloscope adjusted for 1-μs/cm sweep speed and 1-V/cm vertical sensitivity, a scope display similar to Fig. 5 should be obtained. Check the setting of the pole-zero (P/Z) control by changing the sweep speed on the scope so that several pulses are observed on a single trace, and increase the vertical gain control until the baseline characteristics are readily observable (around 0.5-V/cm vertical gain). Figure 6 shows the correct setting of the P/Z control. Normally, this control will not need to be changed after it is once properly set, unless the controls are changed, but occasional oscilloscope checking on the output waveform is in order. As a matter of information, the time constants on the amplifier have been set internally at 1.6 μs.

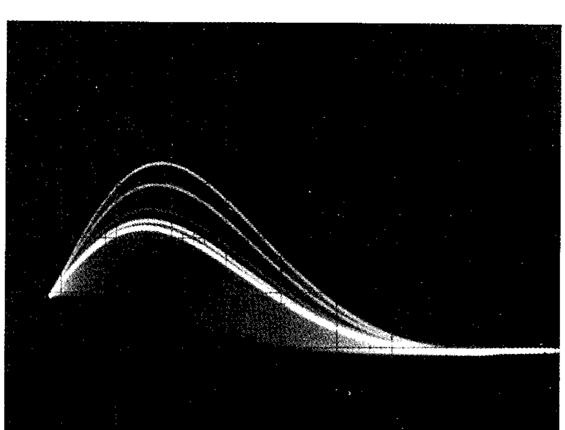

Fig. 5. Output of properly-adjusted amplifier.

Once the operator is satisfied that the pole-zero control is properly set, switch in the baseline restorer, and the amplifier is ready to operate.

The signals from the detector are now being received by the ADC, and it is necessary to make sure this unit and the stabilizer are properly adjusted. Set the coupling switch to DC, the baseline restorer to PASSIVE, gate to ANTICOINCIDENCE, conversion gain to the 2048 position, group size switch to the 2048 position, and all digital offset switches set in the down position. Start out with the discriminator level controls set at zero, and use these controls later to cut out parts of the spectrum which are not wanted in order to reduce system dead time. For the present, the stabilizer must be left in the OFF position until the stabilization peak is determined. At this point, it will be observed that the dead-time meter on the ADC indicates 100% dead time. This is normal, indicating merely that the events received by the ADC are not being serviced by the computer.

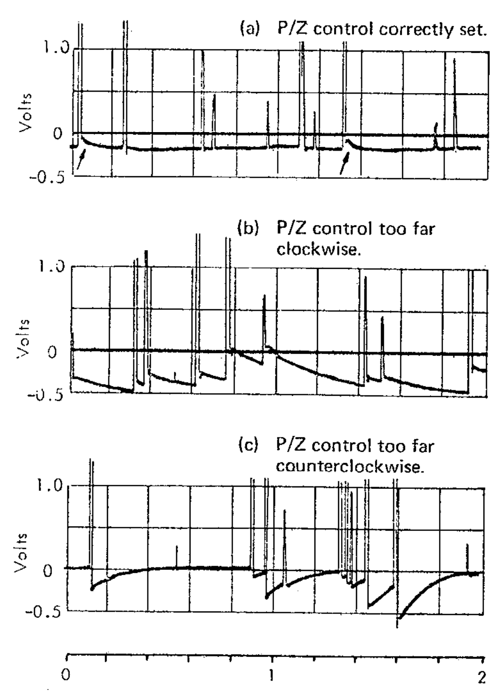

Fig. 6. Setting the pole-zero control.

In normal operation, this meter reading will drop to a value between zero and 20%.

F. Loading the Computer Program

The computer programs (commonly known as software) have been supplied with the system in the form of two paper tapes, which can be read by the paper tape reader at the left side of the teletype. Of the two tapes, one is considerably shorter than the other. This short tape has as its function the preparation of the computer for reading the longer tape, which has a much more complicated format. Therefore, the short tape should always be read into the computer before the long tape is read.

Start by making certain that the computer key switch is turned to the ON position, and that the teletype switch is in the LINE position. Place the shorter of the two tapes in the tape reader on the teletype, and flip the reader switch to the START position. Now place the computer data switches down, except for switch number 12, which must be up. Press RESET on the computer and then PROGRAM LOAD. The short tape will now be read. When it reaches the end of the short program, the tape will automatically stop. Remove the short tape from the reader and place the long tape in the machine, ready for reading. Pressing CONTINUE on the computer now will result in the long tape being read. This long tape will take about twenty minutes to read into the computer. It too will automatically stop reading at the end of the program. If it should halt before the end of the tape is reached, it is an indication that the reader on the teletype has malfunctioned, and the tape must be restarted from the beginning. To restart the long tape without rereading the short one, the operator must set computer data switches 3 through 15 in the up position, press RESET and START.

After the long tape has been completely read into the computer, set computer data switches 7, 11, 12, 13, and 15 up (all others down), press RESET and START, and the computer is running.

G. Initial Electronic Setup

With the computer operating, data acquisition runs can now be made. In order to begin initial setup runs, the operator should place a calibration sample on the scan table and manually run the table up so that the collimator views the sample.

At this point the operator should consider Fig. 2 and familiarize himself with the main control panel. This panel consists of the main power switch, already discussed in detail, ten pushbutton switches, two rotary switches, and one four-digit thumbwheel switch. Note that above each of the pushbutton switches is an LED indicator. The purpose of these indicators is to show the operator when an individual switch is permissive. This indicator will glow green whenever its pushbutton switch is active. This is necessary since certain operations are not permitted with other operations currently in progress. For example, if an assay run has been started, no other function is permitted until the SYSTEM STOP has been pressed or the run has been completed. In this regard the SYSTEM STOP pushbutton is somewhat unique. It may interrupt any action in progress at any time. For example, if a data display is being written, it will immediately be terminated by pushing SYSTEM STOP. Similarly, if the scan is under computer control, and an assay has been started, pushing SYSTEM STOP will cause the table to immediately return to the load position and the run to be terminated.

Certain other conditions will affect the permissive condition of certain switches. For example, the START BKGD and START ASSAY buttons will not be permitted unless the local-computer switch on the scan table controller is in the COMPUTER position. Also, the START SETUP condition is permitted only when the switch is in the LOCAL position. This is because the setup run requires that the calibration sample be moved manually into the collimator window.

The PRINT MODE switch cannot institute a computer interrupt, since it is used only for control of the printout mode to be described later. The SCOPE RANGE switch is unique in that it can interrupt the system and force an updating of the display anytime the computer is otherwise idle. During the setup run, this switch will change the part of the spectrum being observed but cannot initiate an interrupt. The designations on the SCOPE RANGE switch indicate which part of the ADC spectrum is being displayed. The ADC is limited to 2048 channels for this system. The range switch breaks this spectrum into eight equal parts of 256 channels each. The first 256 channels of this spectrum will be displayed with the switch set at the 1/8 position, and similarly for the rest of the spectrum. The entire spectrum is plotted with the switch in the FULL position. However, the user is cautioned that it will be very difficult to visually resolve the spectrum peaks with the switch at this setting.

At this point, the operator should change the COMPUTER-LOCAL switch back and forth several times and see that the permissive indicators above the run pushbuttons do indeed change back and forth. When satisfied that things are working as described, press the START SETUP pushbutton, note that the only switch now permissive is the SYSTEM STOP, and observe the display scope.

It will now be noted that as the data are received, points corresponding to their position in the energy spectrum are indicated on the scope as bright points of light. In this case, the scope is being operated as a nonstorage device solely for the information of the operator so that he may see where data are coming from. After thus gathering data for a few minutes, press SYSTEM STOP and note now that the accumulated data will be plotted according to the setting of the range switch previously described.

At this point, the operator should press the START CURSOR pushbutton and note that the data are again plotted as before, but a cursor has been added to the display so that the exact position (channel number) of various peaks may be located. The CURSOR POSITION thumbwheel switches control the position of this cursor, and the number in the switches corresponds exactly to the channel number of the cursor. The operator should now determine the position of the 356-keV gamma peak from the barium live-time source. By alternately adjusting the amplifier gain and making setup runs, the position of this peak should be forced to correspond to approximately channel 720 as indicated in the thumbwheel switches. At this gain setting each channel of the ADC corresponds to about 0.5 kV gamma energy, which makes it simpler to locate subsequent peaks. Having made this gain adjustment, the operator should make another setup run and note that the ^{75}Se transmission line is at about 810 in the thumbwheel switches and the 414-keV ^{239}Pu assay peak about channel 825.

After locating exactly the channel number of the 356-keV barium line (peak center), the operator should now set this number digitally into the switches on the ADC gain stabilizer by placing the digital switches in the UP position on numbers which add up to the barium channel number. The stabilizer should now be turned to the ON position. If, during the course of routine assays, it is ever noted that the meter on the stabilizer shows a correction significantly different from the center zero position, the stabilizer should be turned to the SETUP position, and then to ON again. This should bring the correction back to zero unless the amplifier gain has drifted beyond the correction range of the stabilizer.

The lower and upper discriminator levels on the ADC can now be adjusted to cut out the lower and upper portions of the spectrum and thus reduce the system dead time. This is most easily done by observing the data points during a setup run and adjusting the discriminator levels until no data are received above or below the points of interest. A

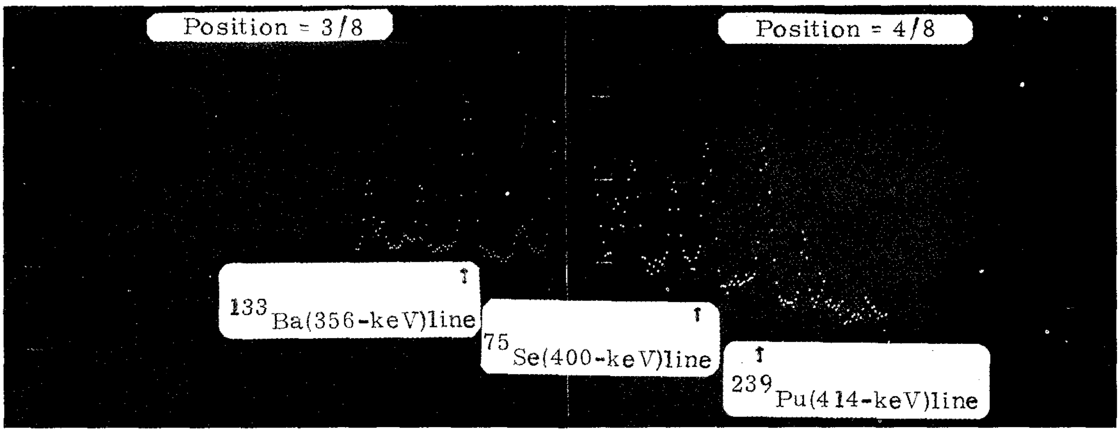

Fig. 7. Spectrum following setup run with amplifier properly adjusted.

final setup run should now be taken, to make certain that all peaks are being properly received. Figure 7 shows the spectra for the three relevant peaks with the system properly adjusted. Note the blank regions to the left and right of the region of interest, indicating the proper settings of the lower and upper discriminator levels on the ADC.

H. Setting Up the Window Limits

Having made a setup run, the operator is now ready to set up the window limits. In accordance with the previous discussion on peak calculations, the background will be subtracted from the peak by means of background windows on each side of the peak. Figure 8 shows these background windows on each side of an assay peak. This clearly indicates that for each peak in the assay calculation (i. e., the live-time peak, transmission peak, and fissile peak) there will be three windows, two for the background and one bracketing the actual peak itself. Referring to the control panel shown in Fig. 2, note that the START WINDOW and STOP WINDOW buttons are permissive only after the START CURSOR button has been pressed, as indicated by the green enable lights. The method of entering the window limits is as follows. Select first the live-time peak. Starting from left to right, determine the leftmost limit of the left background window and set the CURSOR POSITION thumbwheel switches so that the intensified cursor is at this position. Then press the START WINDOW pushbutton once. Now move the cursor by means of the thumbwheel switches to the position represented by the "A_2" designation in Fig. 8, i. e., to the righthand limit of the left background window. Press the STOP WINDOW button. This sequence of alternate START WINDOW and STOP WINDOW entries is now continued until the six limits for the live-time peak have been entered.

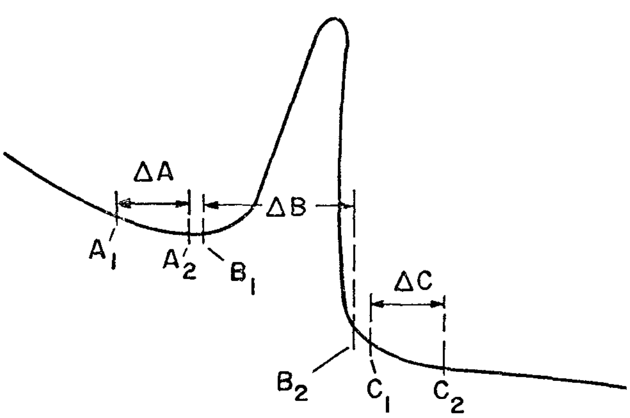

Fig. 8. Windows around a peak.

The next peak for which window limits must be entered is the transmission peak. After its six window limits have been similarly entered, the assay peak should be entered. Several points are now in order for the information of the operator. This method of window limit entry ought to minimize errors on the part of the operator, since the cursor is visibly at the position desired before the entry pushbutton is pressed. If, nonetheless, an error is made, the operator can simply move the cursor to the correct position and press again either the STOP or START WINDOW pushbutton, whichever had just been pressed when the error was made, and the new limit will simply overwrite the old. That is, two consecutive starts or stops result in only the last position being entered.

In other words, to enter the values for one peak, it is necessary to press three START WINDOW and three STOP WINDOW pushbuttons, in alternate order. Another critical point is that the first peak so entered must correspond to the live-time peak, the second to the transmission peak, and the third to the assay peak, regardless of their relative positions in the spectrum. Note, also, that one limit of one window may overlap the limit of the next window without any error being incurred. For example, in Fig. 8, the actual value of A_2 could be greater than the value of B_1.

After the 18 limits for the windows of the three peaks have been entered, the operator can press SYSTEM STOP. If the windows have been entered properly (i. e., the correct number of limits have been entered) the computer will now output the limits by typing them out on the teletype for operator inspection. Check to make certain that these windows are correct. Should an error be detected at this point, the operator must correct the error by entering the windows again from the beginning. If the operator has entered any window with a negative width (i. e., the stop value is less than the start value), the computer will so inform, and the operator must reenter the window limits.

I. Setting in Constants

With the detector table, collimator and transmission source properly adjusted, and with windows entered for the live-time, transmission, and assay peaks, the operator is now ready to make routine background and assay runs with the system. The first step is to press the ENTER CONSTANTS pushbutton and answer the questions asked by the teletype. The first question "COUNTS PER GRAM?" assumes the operator has obtained a calibration constant relating these two quantities. If not, the operator can simply type the answer "1" and a carriage return. In order to determine this quantity, which depends upon the geometric configuration for any given setup, it is necessary to make a calibration run, to be described later.

The next question "GEOMETRIC FACTOR?" asks for the number of the constant A in Eq. (2). For cylindrical geometry, this number is very close to $\pi/4 = 0.7854$. Since this will be the typical case, the operator simply types "0.7854" and a carriage return.

The next question "CONTAINER TRANSMISSION?" asks for the constant T_c in Eq. (3). It will depend upon the material and thickness of the walls used in the sample container. Typically, it varies between 0.7 and 0.95. Its value can be determined by making a transmission measurement (see the instructions on making a background run) of an empty container similar to the ones being used for sample containers in the assay runs. The operator enters the number and a carriage return.

The final question "MU RATIO?" involves the constant K in Eq. (5). For the case where the transmission and assay peaks are very close in energy, this value will be unity. The option of using a different number is included here to permit assays to be made where a transmission source must be used which differs widely in energy from the assay peak. For example, if a cesium source (transmission energy ~ 661 keV) is used in the assay of ^{239}Pu, the mu ratio will be quite different from unity. After the operator has entered this constant and a carriage return, the computer will return to an idle condition, waiting for a run to be made.

J. Making a Background Run

Preparatory to making a background run, the operator should now move the scan table to the load position at the bottom and change the local-computer switch to COMPUTER. It is necessary to make a background run before assay runs are taken in order to acquire information regarding LT_o and T_o of Eq. (2). This run will be made without any material in the collimator window at all, so the first step is to remove the calibration sample and the styrofoam spacer on which it sits, leaving the scan table empty.

The scan height thumbwheels (see Fig. 2) control the number of segments which will be scanned in a given assay, and hence the length of sample assayed. The number set into these switches is the length of the total scan in inches. Since each segment is exactly 1/2 in., there will be twice as many segment scans made as the number set into the scan height thumbwheel switches. For a background run, it is desirable to set these switches to 19 (the largest permissible) in order to obtain the best possible statistical accuracy for the live-time and transmission background peaks.

The operator should now press the START BKDG pushbutton. The scan table will move rapidly to the top position and start slowly downward, rotating as each segment is assayed. At the end of each segment assay, the computer will display the data gathered for that particular segment on the scope, according to the setting of the SCOPE RANGE switch. This between-segments display will cause the table to halt briefly to give the computer time to make the display. It will also permit the operator to observe the segment-by-segment fissile content of the sample. During the background run, the display of course will display only the transmission and live-time peaks. At the end of the background run, the scan table moves at high speed back to the load position at the bottom of its travel.

Upon completion of the background run, the computer will print out on the teletype the values obtained for the live-time and transmission peaks which represent an average of values obtained for the 38 segments assayed. No action by the operator is necessary at this point; these values are printed out solely for future information if needed. The values are automatically stored within the computer program and used in all subsequent calculations until their values are superseded by a new background run. Note that a background run must always be made before the initial assay run is begun, since otherwise the computer has no way of making the proper calculations for the assay run. It is also advisable to make at least one additional background run per day to be sure the system is stable.

K. Determining the Calibration Constant

The styrofoam spacer and calibration sample are now placed back on the scan table preparatory to determining the calibration constant (counts per gram). At this point, it is reasonable to describe a feature available to the operator at any time the system is idle. Pressing the START ECHO pushbutton at any time when this switch is permissive will cause the computer to echo any message typed on the teletype. This permits, for example, sample identification numbers or pertinent run comments to be made on the output copy. The return from this condition, as with all others, is the SYSTEM STOP pushbutton.

The operator should now set the SCAN HEIGHT thumbwheel switches to the number corresponding to the height of the calibration sample container in inches. Pressing the START ASSAY pushbutton at this point will result in an assay run being started in exactly the same manner as the background run, except that only the preset number of segments will be assayed, and "RUN ENDED" will be printed at the end of the run.

L. Print Mode Options

The PRINT MODE switch (see Fig. 2) selects between two forms of data printout. Set in the LONG position, the switch will cause the data to be printed for each segment on a segment-by-segment basis, giving the values for live-time correction factor, transmission correction factor, actual assay peak values (corrected for background subtraction), and the correction factor, CF_i, in Eq. (1). The purpose of this information is to permit the operator to gain an actual profile of fissile material in the sample as well as to make certain that nothing unexpected has occurred with either live-time or transmission measurements. Should any of the correction factors exceed the value six, the computer automatically substitutes 6.0 for this value. However, the operator should be warned that any value greater than about five should cause serious suspicions as to the validity of that particular measurement. Usually, this will be an indication that the transmission has become very small, which causes the assay to be suspect. Where no accurate transmission measurement can be made, it is not possible to accurately measure the sample by gamma scanning techniques.

The short printout mode will omit the segment-by-segment information and give simply the total corrected counts, the grams of material, and an estimate of the propagated error on the measurement. The advantage of the short printout is that for fairly routine assays, where the samples are characterized by rather narrow limits on fissile content and matrix material, the short printout permits a faster total assay, since the teletype is a rather slow device. On the other hand, the long printout not only gives more information, it permits the operator to select the exact segments for assay. At the end of a long printout, the teletype will ask "FIRST AND LAST SEGMENTS FOR ASSAY?" at which point the operator has the choice of which segments will be used in the final calculation. He does this by typing two numbers separated by a space or comma, followed by a carriage return. Should he select illegitimate values (i.e., the last segment having a smaller value than the first, or more than 38) the computer will simply repeat the question and wait for legal values. For example, if the sample can happens to be mostly empty, this will be reflected by the absence of assay peak counts for most of the segments, and by selecting only those segments where actual fissile material is present, the operator can effectively reduce the estimate of error on his assay. In the case of the short printout, the computer automatically uses all segments assayed in the final calculation.

Regardless of the mode of printout chosen, no analysis will be made until the START ANALYZE pushbutton is pressed. As with all other functions, the printout can be terminated at any point by pushing the SYSTEM STOP. Incidentally, the process of outputting the data in no way destroys the information from a run. A single run could be analyzed any number of times. This feature is useful if, for example, the operator desires to use different segments in a single assay or if a short printout has been made and the operator then questions the assay and wants a long printout. He has only to change the setting of the PRINT MODE switch and repeat the analysis by pressing START ANALYZE again.

Following the analysis of the calibration assay run, the operator will have the calculated number for the corrected counts from the assay, as well as the known value for the actual amount of fissile material in the sample. The quotient of these two values is the number of counts per gram requested by the computer on the first ENTER CONSTANTS query. The operator is well advised to use two calibration standards and make several assay runs for each to obtain an average for this calibration constant, as well as to check to make certain the value is the same for differing values of fissile material. Should different calibration samples give significantly different calibration constants, something is not properly set up, and the operator is advised to carefully repeat the above setup procedures.

After this calibration constant has been determined, the operator should press ENTER CONSTANTS, and answer the first query with the value just obtained, followed by a carriage return. Should he not desire to change any of the other constants already entered, he has only to press SYSTEM STOP to terminate the interrogation.

With the system set up according to the foregoing instructions, the operator is now free to make assays by simply placing samples on the scan table, pressing START ASSAY, waiting until "RUN ENDED" is typed out, selecting the desired mode of printout, pressing START ANALYSIS, and obtaining his fissile content together with an accurate estimate of error.

V. MAINTENANCE OF SCAN TABLE

A. Elevator Drive (refer to Figs. 9 and 10)

Always run the elevator plate to the lowest position (load position) and block support in a level position before loosening the adjustable idler. This prevents inadvertent dropping of the elevator.

After each forty hours of operation, check and perform the following:

a) Check motor belt B for proper tension. Tighten the belt by loosening motor base plate screws, moving motor away from center of unit applying tension to belt, and retightening motor base plate screws.

b) Check elevator belt D for proper tension. Tighten belt by loosening the adjustable idler E housing screws, moving idler toward center of unit, thus applying tension to belt, and retightening idler housing screws.

c) Apply five to six drops of spindle oil to the thrust bearing at each of the three drive-screw assemblies.

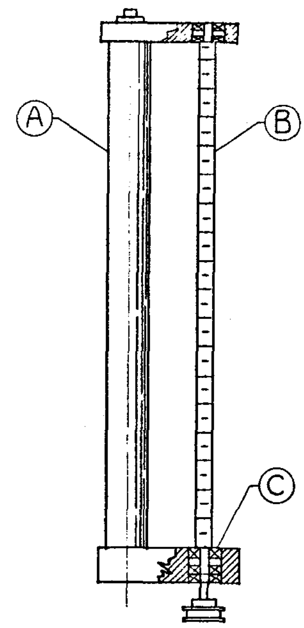

Fig. 9. Typical elevator drive (three per unit). A: 2-in.-diam ball-bushing rod; B: lead screw; C: thrust bearing.

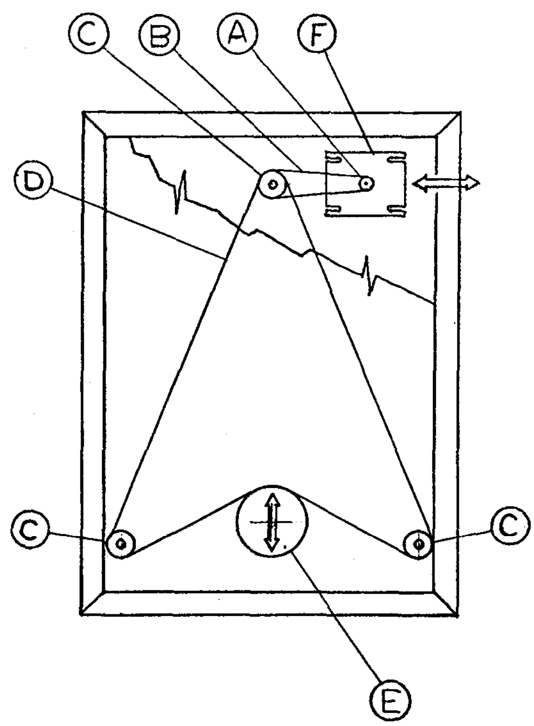

Fig. 10. Scan table main base, bottom view. A: motor pulley (16-tooth); B: motor belt; C: driven pulley (32-tooth); D: elevator belt; E: adjustable idler (smooth); F: adjustable motor base plate.

d) Using light-grade oil applied sparingly to a rag, wipe down the 2-in.-diam ball-bushing rods and lead screws.

All pulleys and couplings are pinned to associated shafts with 1/8-in.-diam roll pins.

B. Turntable Drive (refer to Fig. 11)

After each forty hours of operation, remove the turntable belt cover and inspect the belt for wear and proper tension. To tighten the belt, loosen the knurled brass knob associated with the adjustable idler B, move the idler in toward the belt and tighten the knurled knob. Replace the belt cover.

C. Stepping Motor Fluid Dampers

On each of the two stepping motors is connected a fluid damper. The purpose of these is to supply the motor with a load sufficient to dampen out as much vibration as possible. This cuts down on noise and wear of parts, but most importantly carries the motor through various speed resonances to which stepping motors are particularly prone. Without the use of such dampers these motors may stop, lose torque, change speed, or even change directions at certain stepping frequencies. When properly functioning, these dampers will effectively eliminate these problems.

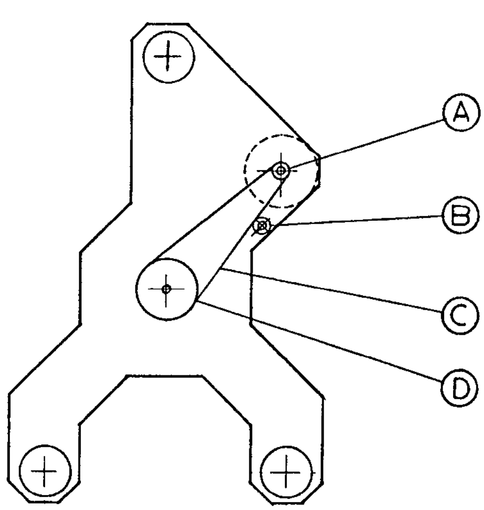

Fig. 11. Scan table elevator plate, bottom view. A: motor pulley (12-tooth); B: adjustable idler (24-tooth); C: turntable belt; D: turntable pulley (60-tooth).

The dampers are made up of an aluminum housing which is connected rigidly to the motor on one end and to the load on the other. Inside the housing is a brass or tungsten disk rotating around a center shaft. The only friction between the outside housing and the internal disk is a film of grease. The viscosity of this grease determines the amount of damping.

The primary difficulty with the damper is the grease itself. The grease undergoes great stresses and after long running times at high temperatures may chemically break down or separate into its component elements. This materially changes the viscosity and hence the damping effect. If this occurs, the only remedy is to repack the damper.

Repacking the damper is accomplished by removing the damper from the system and performing the following steps (note that the vertical movement motor damper is pinned at both ends with roll pins):

1. Remove the eight #4 Allen head screws holding the cover plate.
2. Take note of the two positioning pins through the cover into the main housing. The alignment of these pins is not symmetrical, so a scribe mark on the edge of the cover and main housing will facilitate alignment on reassembly.
3. Using caution not to ruin the gasket; pry the cover up, at the pin positions,until it comes off.
4. With the cover plate removed, note the two threaded holes in the brass disk. These are intended to be used for pulling the disk with 4-40 screws. By inserting screws in these holes and locking the screws in a vise, pull off the disk.
5. Clean all parts. Freon TMC solvent in an ultrasonic cleaner works very well for this cleaning.
6. Spread a slight excess of light "Celvacene" vacuum grease on the inside of the housing.
7. With the bottom Teflon washer in place, press the disk back into the housing. A vise will

accomplish this easily. Leave pressure on the unit until all excess grease has been squeezed out and the disk has bottomed in the housing.

8. Install the top Teflon washer and spread a layer of grease, free from bubbles, across the top of the disk. Level this layer with a straight edge to match the rim of the housing.

9. After making sure the gasket is in good condition, realign the top plate on the housing and install the retaining screws. If a new gasket must be made, use oil resistant paper 1/32 in. thick.

VI. SYSTEM SOFTWARE

A. Philosophy

In order to optimize the efficiency tradeoffs between software and hardware, and in order to get the total operating system into 8K of 16-bit core memory, the system software is written in machine language. This, of course, permits the most versatile possible handling of custom interfaces and control functions, as well as minimizing system dead time due to data sorting and handling. The complete machine language program listings are not included here due to space limitations; they are available in Group A-1.

The software has been written in modular form, as a series of relocatable subroutines with a floating point interpreter. This permits easy modification or addition to the system software without rewriting the entire program.

The software package breaks rather naturally into the following basic categories: a) interrupt handler, b) teletype drivers, c) display routines, d) data handlers, e) set window routines, f) analysis codes, g) error calculation routine, and h) information storage.

B. Handling Interrupts

In order to permit proper operation of interrupting sources, the system has been provided with both hardware and software masks to disable each interrupting device upon demand. The single hardware mask is tied to the local-computer switch on the scan table control panel. In the COMPUTER position, the START BKGD and START ASSAY pushbottons are enabled while the START SETUP is disabled. The LOCAL position is the opposite. The computer has no control over this mask. All other masks are under computer control.

The computer program adjusts the masks under its control in such a way as to create five separate interrupt conditions as follows.

1. The first condition is the "ready" state in which the following pushbutton switches are permissive (i. e., can generate interrupts): ENTER CONSTANTS, START BKGD, START ASSAY, CURSOR ON, START ANALYZE, and START ECHO. Note that the START BKGD and START ASSAY may be replaced by START SETUP, as described previously. In addition to these pushbutton interrupts, the range switch is also allowed to interrupt in this state. Interrupts from the scan table are never masked out but are ignored in the "ready" state.

2. The second condition is essentially a run mode, where only the SYSTEM STOP pushbutton, the ADC, and the scan table sensors are allowed to interrupt the program. It is in this condition that the computer is accepting data from the ADC and storing it, as well as servicing segment information from the scan table. Any interruption for plotting or teletype communication would affect the system dead time, which is not permitted during data runs.

3. The third condition is one in which windows are being entered, and the following pushbuttons may interrupt: WINDOW START, WINDOW STOP, and SYSTEM STOP. In this condition, the range switch may also generate interrupts, with the same effect as in condition one; namely, it causes the replotting of data on the scope to correspond to the new switch setting. In this condition, table interrupts are again ignored.

4. In the fourth condition, only the SYSTEM STOP is permissive. This will be the case, for example, when the data from a run are being analyzed or typed out, data are being plotted, or when error calculations are being made.

5. The fifth condition appears to the operator to be identical to condition four, but it is somewhat different from the software implementation. It permits the SYSTEM STOP to interrupt a display during actual display time, or to interrupt a run which has been commenced. To illustrate the need for this condition, consider the case where SYSTEM STOP has been pressed to terminate a background or assay run. The computer will immediately terminate the run and start to display the final segment data on the storage scope. In order to abort this display without having to wait for its completion, the operator has only to press SYSTEM STOP again, and the run will be terminated without doing the display.

These inhibit masks are controlled by software bits on the data lines. Data bit 3 will mask out the ADC. Data bit 4 disables the range switch interrupt. Data bit 5 enables the window switches, START WINDOW and STOP WINDOW. Data bit 6 reverses the "ready" mask; i.e., it enables SYSTEM STOP and disables the other pushbutton switches. These data bits are always given with a MSKO command to set the masks.

In order to identify an interrupting device, a combination of different device codes coupled with data bits are used in a polling procedure. The device codes used are as follows: The storage scope uses device code 34_8; the panel switches interrupt with device code 42_8; the ADC uses device code 44_8; and the scan table and motor controller use 74_8. The storage scope does not use the interrupt facility. Once an interrupt has been recognized by sensing busy set on device 42_8 (switch panel), the relevant switch is recognized by checking the data bits set by giving a DIA command with code 42_8. Bit 15 is the SYSTEM STOP; bit 14 is the SCOPE RANGE interrupt; bit 13 is START WINDOW; bit 12 is STOP WINDOW; bit 11 is ENTER CONSTANTS; bit 10 is START ASSAY; bit 9 is START BKGD; bit 8 is START SETUP; bit 7 is START ECHO; bit 6 is START ANALYZE; bit 5 is START CURSOR; bits 4 through 1 gives the setting of the range switch coded in BCD with bit 4 as the LSD; bit 0 gives the setting of the printout mode switch (bit set is the "long" condition).

The scan table interrupts with busy set on device code 74_8 if the interrupt corresponds to the end of a segment, or with done set if it corresponds to the end of the assay (all segments complete). The ADC interrupts with busy set on device 44_8.

C. Storage Allocation

In addition to storing the various constants which enter into the equations detailed earlier in this manual, certain large blocks of storage are allocated within the computer memory for specific data. The window limit data are stored as actual octal addresses pointing to specific addresses in the data buffer. The pointer WINLM points to the starting address of this storage, while WNSTR is used as a floating pointer to store the address of the next limit to be stored. Since there is provision made for storing 24 limits (four data peaks), this data block is 30_8 words in length.

DATAD is a page zero pointer to the basic data storage, where ADC data are stored for spectrum information. Since we have limited the ADC to a 2048 channel spectrum, this storage is 4000_8 words in length. BUFAD is used as a floating pointer in this storage to indicate to the display routine where the starting address for a given display is.

At the end of each segment, the 4000_8 word data storage is purged in anticipation of the next segment data; hence, it is necessary to sort through these data and save the peak information for the segment just completed. These data are stored as two-word floating point numbers. Since a maximum of 38 segments are allowed, this storage buffer is 1420_8 words in length. DASTR is the permanent pointer to its starting address, with DASEK used as a floating pointer to the current segment data block.

The floating point interpreter uses a block of scratch-pad memory for number storage 144_8 words in length, but this is transparent to the user or programmer. It is pointed to by WSA in page zero. There are smaller blocks of storage within the calculation routines for temporary storage of floating point numbers in order to permit calculation on a segment-by-segment basis, but these are of no interest to the casual programmer.

D. Plotting Routines

For purposes of writing on the scope, both x and y information must be given to the interface DACs, as well as an intensify pulse to store the information. All information is stored as dots on the oscilloscope. The maximum resolution of this device is 1024 dots in either orthogonal direction; hence, 10-bit DACs are used, and 10 data bits must be given for each coordinate. This information is passed to the interface by giving a DOA instruction for the x-coordinate, and a DOB for the y, together with 10 bits of information passed on data lines 15 through 6 (15 is the LSB and DC 34). The intensify pulse is given by the "start" pulse appended to any instruction with device code 34_8. The IOPLS pulse and DC 34 will place the storage scope in the "nonstore" condition, from which it is returned to the store mode by giving an erase command, CLR with code 34_8, or an IORST.

HRZLN is a subroutine which writes a horizontal line on the scope. This subroutine expects the x and y coordinates of the starting point to be passed in accumulators 0 and 1, with the line length in dots in accumulator 2.

FIND is a subroutine which interrogates the range switch and sets up the proper pointers to output the desired section of the spectrum from the data buffer. It also sets cell FLAG to zero if the entire 2K spectrum is to be plotted, or to -1 if 256 points are to be plotted. It then sets the appropriate starting address of the section to be plotted in BUFAD.

PLOT is a subroutine which interrogates FLAG and BUFAD and makes the appropriate display. It starts the display by making ordinate fiducials at the decade points of the graph. For a 256-point display each datum is plotted with four horizontal spaces between it and its neighbor. The full 2K spectrum demands that every two points be averaged and plotted as a single point. In either case, all points are plotted on a logarithmic scale; hence, the vertical scale runs from unity to 100K in decades.

ERASE is a short subroutine which simply erases the scope in preparation for the next plot.

E. Teletype Subroutines

Subroutines have been provided for printing on the teletype as well as for fetching characters from the keyboard. PUTC is a subroutine which requires either a starting address or an ASCII character in accumulator zero. If an ASCII character is passed, it will simply output the character and return. If an address is passed, it will output the entire message pointed to by the address, until a null word is detected. In either case, a carriage return (ASCII code 15_8) causes a line feed to be echoed as well. Hence, this subroutine can be used to output whole messages or single characters.

GETC is a subroutine which simply fetches a character from the keyboard and echoes it back to the printer as well as returning it to the program right justified in accumulator zero. The floating point interpreter uses both of these subroutines in its operation. SBNDC is a subroutine to output the contents of a memory in decimal to the teletype with leading zeroes suppressed. DBIN is a subroutine which converts an ASCII character string from the teletype to internal binary numbers.

F. Handling the Window Limits

Window limits are set only when the cursor is on. This condition is handled by a subroutine called CURSE, which calls in FIND and PLOT to first output the desired data display, and then continually reads the thumbwheel switches related to the cursor position and displays an intensified dot accordingly. These thumbwheel switches are read by a DIB command with device code 42_8. The data thus obtained are in the form of a four-digit BCD number, which the program then translates to binary and fetches the data from the cell thus addressed and displays it. This subroutine also allows for interrupts which will set window limits. Thus, this subroutine is reentrant.

WNFLG is a page zero pointer which signals which window limit has just been entered, zero if "start" and -1 if "stop". STRWN is the subroutine which handles actual storing of these limits as they are entered. At the termination of entering window limits, when SYSTEM STOP is pressed, subroutine DIFF determines the window widths, signals the operator if any of these are negative, and stores the differences for future program use. Subroutine LIMS prints out in decimal the limits just entered for operator information.

G. Handling Data Runs

Upon receiving any interrupt which signals the start of a data run (setup, assay, or background), the interrupt program sets RNFLG and jumps to the appropriate subroutine. RNFLG is zero for an assay run, 1 for a background run, and -1 for a setup run.

SETUP handles setup runs by simply storing the data as received, and displaying every twentieth point in the nonstore mode, so that the operator has an idea of where most data are being stored in the spectrum.

As regards data storage, both background and assay runs are identical. Subroutine PNT stores the data as they are received from the ADC. At the termination of each segment, data are sorted, the spectrum displayed, and the buffer cleared for the next segment. At the end of the run, a determination is made of whether a background or an assay run is involved. In the case of background run, subroutine STHRU receives control and calculates the transmission and live-time peaks, printing out these values on the teletype and storing the numbers for future use. In the case of an assay run, the idle condition is entered, preparatory for operator action in doing the analysis as desired.

Subroutine INIT is used to clear the relevant data storage and prepare the system for the beginning of a run or for the start of the next segment.

SEGCT is a page zero cell used for counting the number of segments in the particular run. This number is used later for printout as well as for short form calculation.

H. Analysis Codes

When the START ANALYZE interrupt is recognized, a determination is made whether short or long printout is desired by reading the toggle switch, and cell PO is set accordingly, PO = 0 for short printout or -1 for long. Henceforth all analysis proceeds with its output depending upon the setting of this flag. For a short printout, each segment is calculated and saved, but not printed out. For a long printout, the printout on the teletype is made. The calculation is made according to the equations detailed in the section on theory in this manual. Subroutine ANLYZ is used to perform this function, which draws heavily on the floating point interpreter for its calculations. If the long printout has been requested, the code gives the operator the choice of which segments to include in the final calculation and error analysis. In the case of a short printout, all segments involved in the run under analysis are included in the calculation and error computation. In either case STRT and ENDY contain the addresses of the starting and ending storage for the segments to be included.

Subroutine PKCOR is used to perform the background subtraction of the peak being analyzed. This is a linear subtraction based on the two windows bracketing the peak itself and has been described in the section on theory. As with all other calculations in the analysis codes, this correction deals with two-word floating point numbers exclusively.

I. Error Calculations

The error calculation is a propagated error analysis based on Poisson statistics on a segment-by-segment basis. It is implemented by subroutines LUPE and MOST.

For the purposes of calculating the error it is assumed that LT_o and T_o are known so well that their statistics do not significantly alter the error estimate. This is a reasonable assumption, since the background with 38 segments is sufficiently long that the counting statistics in determining these two parameters are so much better than those involved in an assay run as to contribute negligibly to the error. Also, it is assumed that the geometrical factor A and the attenuation constant K are accurately known, since no estimate of error in these constants can be gleaned from the data available to the computer at assay time. However, no assumptions are made about the relative errors involved in the live-time, transmission, or assay peaks; the errors from all of them are propagated through the calculation for each segment. Assuming Poisson statistics, the following equation is found for the deviation:

$$\delta^2(CC_i) = \left(\frac{LT_o}{LT_i}\cdot CF_i(T_i')\cdot CF_{can}\right)^2 \delta^2(C_i)$$
$$+ \left(\frac{C_i\cdot LT_o\cdot CF_i(T_i')\cdot CF_{can}}{(LT_i)^2}\right)^2 \delta^2(LT_i)$$
$$+ \left(\frac{C_i\cdot LT_o\cdot CF_{can}}{LT_i}\right)^2 \delta^2[CF_i(T_i')] \quad ,$$

where

$$CF_{can} = \frac{1}{\sqrt{T_c}} \quad ,$$

$$CF_i(T_i') = \frac{-A\cdot K\cdot \ln T_i'}{1-(T_i')^{A\cdot K}} \quad , \text{ and}$$

$$T_i' = \frac{T_i}{T_o}\cdot\frac{LT_o}{LT_i}\cdot\frac{1}{T_c} \quad ,$$

and where the individual deviations are given by

$$\delta^2(T_i') = \frac{1}{T_c^2}\left\{\left(\frac{LT_o}{T_o\cdot LT_i}\right)^2 \delta^2(T_i) + \left(\frac{T_i\cdot LT_o}{T_o\cdot LT_i^2}\right)^2 \delta^2(LT_i)\right\} \quad , \text{ and}$$

$$\delta^2[CF_i(T_i')] = \left\{A\cdot K\left[\frac{1-(T_i')^{A\cdot K}+A\cdot K(T_i')^{A\cdot K}\ln T_i'}{T_i'[1-(T_i')^{A\cdot K}]^2}\right]\right\}^2 \delta^2(T_i')$$

and the individual peak error deviations are computed from:

$$\delta^2(\text{peak}) = B + \left[\frac{\Delta B}{2\Delta A}\right]^2 A + \left[\frac{\Delta B}{2\Delta C}\right]^2 C$$

where A, B, and C are the counts in a background window delta A below the peak and a background window delta C above the peak, respectively. These equations are solved for each segment involved in the final analysis, and then the results are added in quadrature and the square root is taken.

J. Floating Point Calculations

Calculations are made with floating point numbers via an interpreter to which program control is transferred for calculational purposes, rather than having special subroutines for each floating point function. In this way, programming for floating point calculations is simply an extension of machine language arithmetic instructions, and the interpreter is transparent to the programmer.

Floating point numbers are internally stored in two consecutive 16-bit words. Of these 32 bits, one is used for the sign of the number, seven are used for the characteristic, and 24 for the mantissa; hence, the approximate range of numbers which the interpreter can handle is from 2.4×10^{-78} to 7.2×10^{75}. The maximum error of a normalized mantissa is less than 6×10^{-8}.

The interpreter requires a writable storage area for calculational purposes of 144_8 memory locations, which must be contiguous. This area is pointed to by cell WSA in page zero.

The detailed algorithms will not be given here, but are standard in the industry, requiring milliseconds for their completion in this machine. In all calculations performed in the present codes, the maximum relative error is approximately 10^{-7}, which is much less than would be noticed for any of the numbers produced in these routines.

VII. SYSTEM HARDWARE

A. Overall Operation

The special electronic interfaces consist of two chassis, the motor control box and the main control box. These will be described in that order.

Figures 12 and 13 show the block diagrams of the motor control box. The function of this unit is to control the two stepping motors of the scan table after receiving commands from the front panel (manual operation) or communicating with the computer through the main interface box. This latter unit will be described later.

As the block diagram shows, the heart of the motor control unit consists of two oscillators which drive commercial bipolar chopper motor drivers through a gating system which switches between the two oscillators. One is a high frequency crystal oscillator with divider network, which is used to get a stable speed for table motion during actual data taking. The other is a ramp oscillator used to move the table rapidly from one limit to the other when data are not being taken.

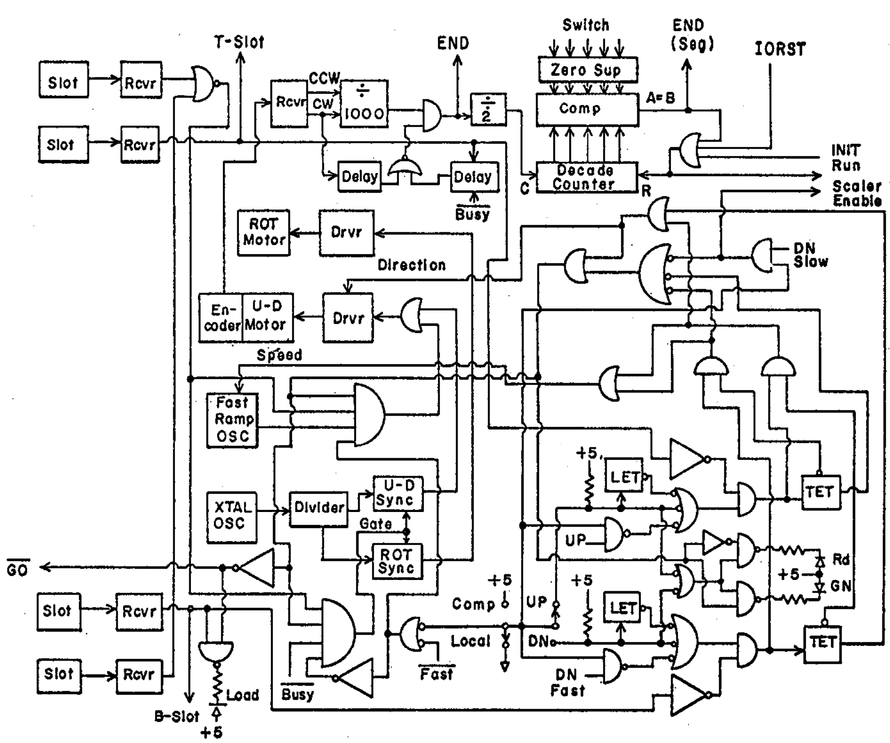

Fig. 12. Block diagram, motor control box, general section.

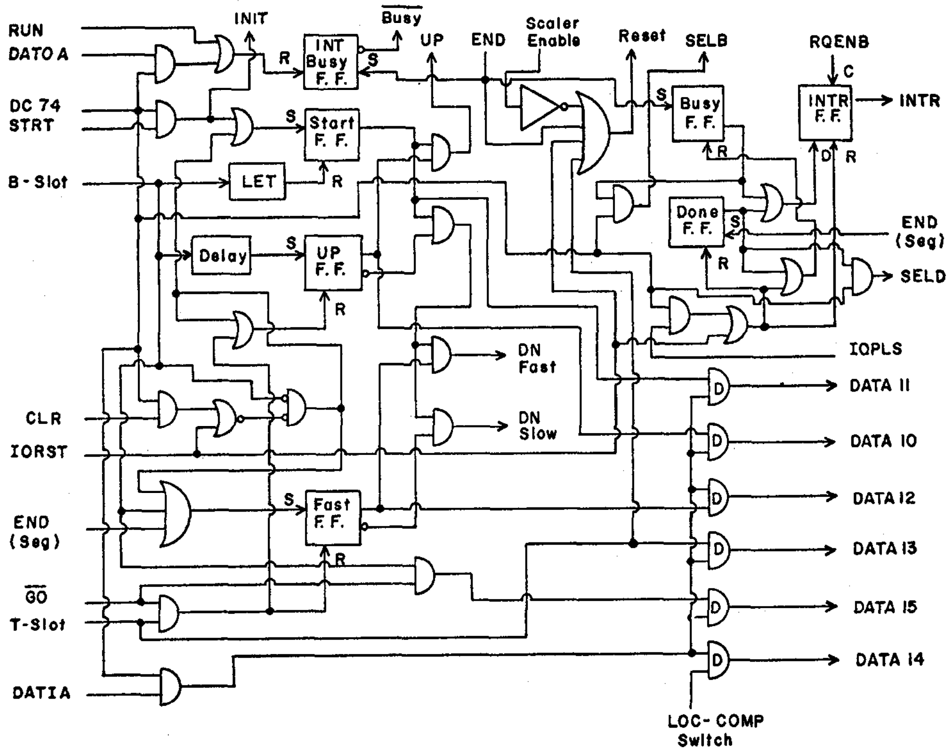

Fig. 13. Block diagram, motor control box, computer section.

Also shown in Fig. 12 are four "slots" (limit switches) that are mounted on the scan table itself to detect the two extremes of travel up and down. The two middle slots initiate control action to change direction or ramp down and stop. The two outside slots are emergency stops. If the table ever reaches either of these positions, something has failed and both oscillators are immediately gated off.

Figure 12 also shows circuitry to clean up switch bounce and drive an indicator light associated with the "up-down" switch. Following this is circuitry designed to make sure the ramp oscillator has time to ramp down before the computer or the front panel switch can change directions or stop. The remaining portion of this diagram is a counter chain that watches the vertical motor's encoder and determines the end of a segment and the end of an assay (last segment).

Referring now to Fig. 13 the four control flipflops are along the left half, and the computer I/O lines continue to the right. All four control flipflops can be accessed by the computer, and the lower three (start, up, fast) also by hardware controls. The three lower flipflops serve the functions implied by their names. The "start" flipflop instructs the table to start or stop, the "up" determines the direction, and the "fast" dictates the speed. The "internal busy" flipflop gates the oscillator off to keep the table stopped until the computer resets it.

Moving to the computer I/O side of Fig. 13 we find three more flipflops whose outputs are gated onto computer sense lines. At the end of a segment the "interrupt" and "busy" flipflops are set, and at the end of an assay (last segment) the "interrupt" and "done" flipflops are set. Only the computer can reset these flipflops.

Notice also on this diagram there are two busy flipflops. The only difference between these two is the line used to reset them. This enables the computer to reset its own busy line and talk to the scope while leaving the internal busy (table movement) set.

Directly below the computer flipflops are gates that gate status information into the computer upon command. This status information includes "load position", "local-computer", "top slot", "fast flipflop", "start flipflop", and "up flipflop".

The block diagram of the main control box is shown in Fig. 14 and 15. The former contains the front panel switch control interface. Starting with the thumbwheel switches, their outputs go directly into a tri-state bus through tri-state gates on command from the computer.

The 10 pushbutton switches first go to the mask gates, which in turn are gated by the three mask flipflops set by the computer and the local-computer switch on the motor control box. If the mask is permissive for the switch activated, it sets into the latch its own unique bit and also sets the computer interrupt and busy flipflops. The output of the latches connects to the output tri-state bus on command from the computer.

The range switch also goes through a mask gate to set the computer interrupt and busy flipflops as well as to the tri-state bus, through gates, on command from the computer. The mode switch, like the thumbwheels, is gated directly on the tri-state bus by the computer.

Moving to Fig. 15 we have on the left side the ADC control interface and on the right side the scope control interface. Starting with the ADC interface we receive data lines (A0-A10) from the ADC and go into a set of latches. Since the ADC will store an event until reset, the ADC itself is one buffer and the interface latch is a second data

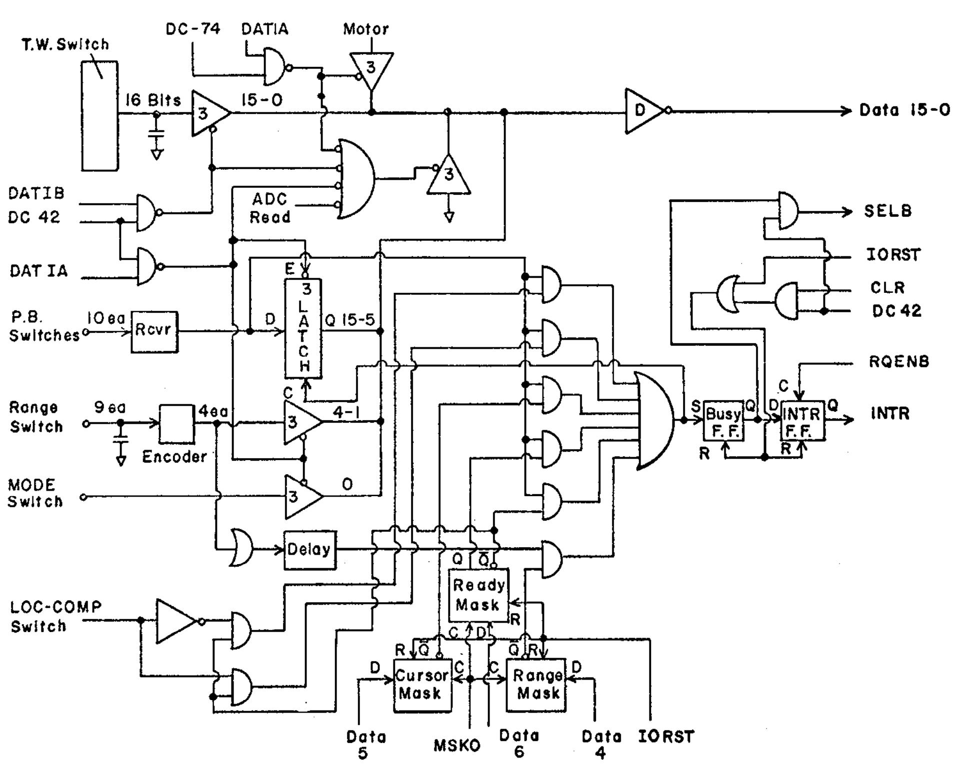

Fig. 14. Block diagram, computer interface to main control panel.

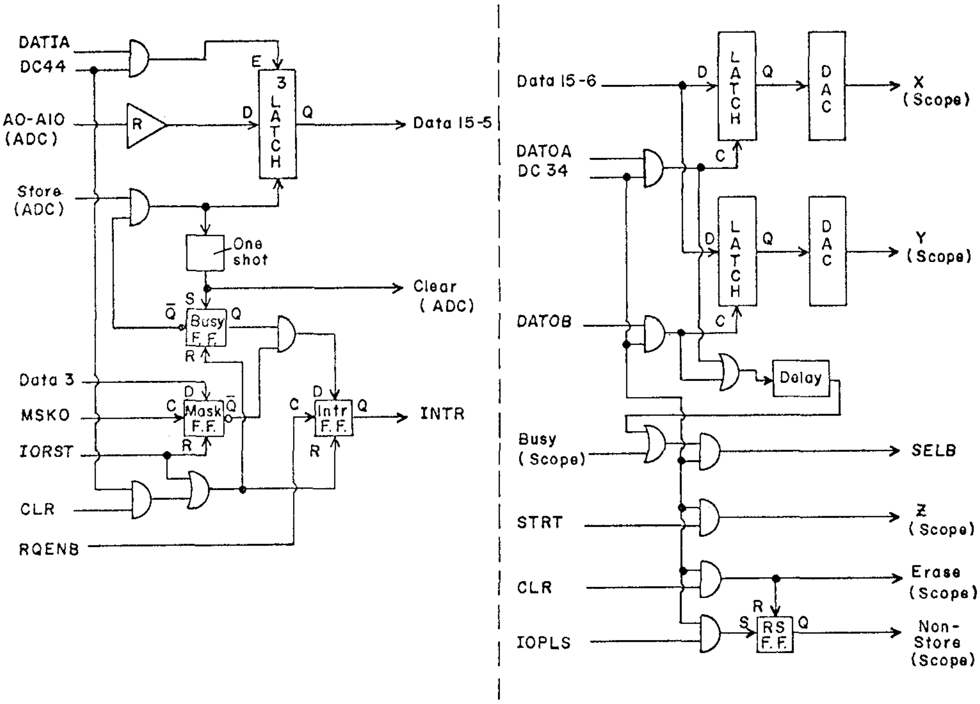

Fig. 15. Block diagram, computer interface to ADC and storage scope.

buffer, making this a double-buffered system and increasing its instantaneous data rate capability.

The busy flipflop keeps track of the latch and doesn't allow the ADC to write into it until the computer retrieves its data. The busy and interrupt flipflops tell the computer the latch has data to be read. The mask flipflop enables the computer to stop interrupts from the ADC if it is busy with something else.

The scope control interface on the right half of Fig. 15 is the only interface that cannot interrupt the computer. Its only line to the computer is the busy line, which it uses to indicate to the computer when it has reached a new location and is ready to intensify. The computer loads a 10-bit word into the x-latch and the y-latch to define a dot location and then gives an intensify pulse after waiting for the busy line to go down. Other computer pulses as shown can erase or put the scope into a nonstore mode for a setup run, as described in detail in the software section.

B. Detailed Circuit Description

This section will discuss the interface, board by board, in enough detail to facilitate repair or alignment. Reference should be made to the individual board schematics as indicated. Note that on these schematics some numbers and letters have circles or squares around them. The numbers circumscribed by squares are card edge pins, and the ones with circles around them indicate IC numbers. These two interface chassis with boards installed are shown in Figs. 16 and 17.

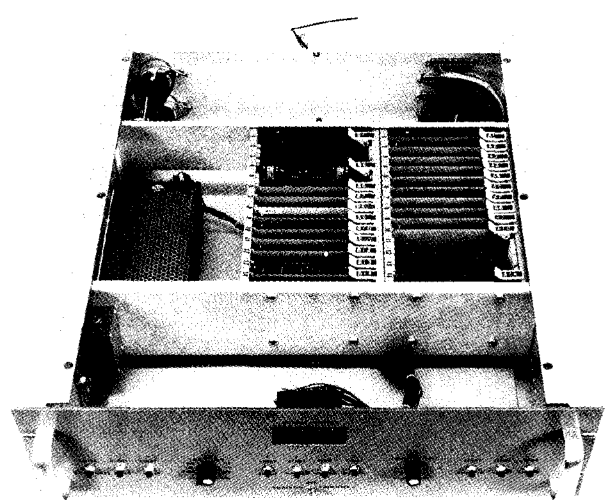

Fig. 16. Main control box.

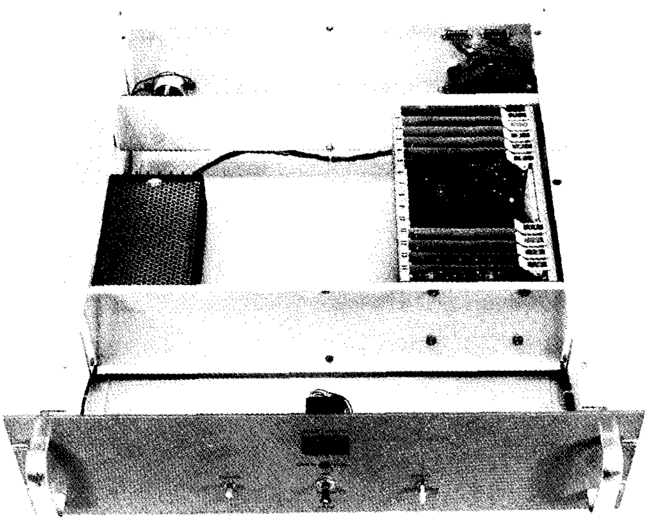

Fig. 17. Motor control box.

1. Motor Control Box. Board 1 of the motor control box (Fig. 18) is a general purpose differential receiver card containing DM8820 differential line receiver ICs. The board is used to receive control lines from the main interface box. The 0.01-μf capacitors allow an internal resistor to terminate the twisted-pair line in 120 ohms for ac signals, but they do not draw excessive current for dc signals. The 160-ohm resistors are pull-up resistors for the DM8820's open collector outputs. Pin J goes to the local-computer switch and gates these receivers off when in the local mode.

Board 2 of the motor control box (Fig. 19) is a general purpose differential line driver board using DM8830 differential line driver ICs. Pin #3 goes to the local-computer switch to prevent hanging on the computer interrupt, busy, or done lines while in local. Pin Z brings in a signal initiated by the computer which gates the status signals into the main interface box.

Board 3 of the motor control box (Fig. 20) has three main functions: limit switch receivers, oscillator control gating, and indicator light control. Starting with the limit switch section, the four limit switches are shown along the left side

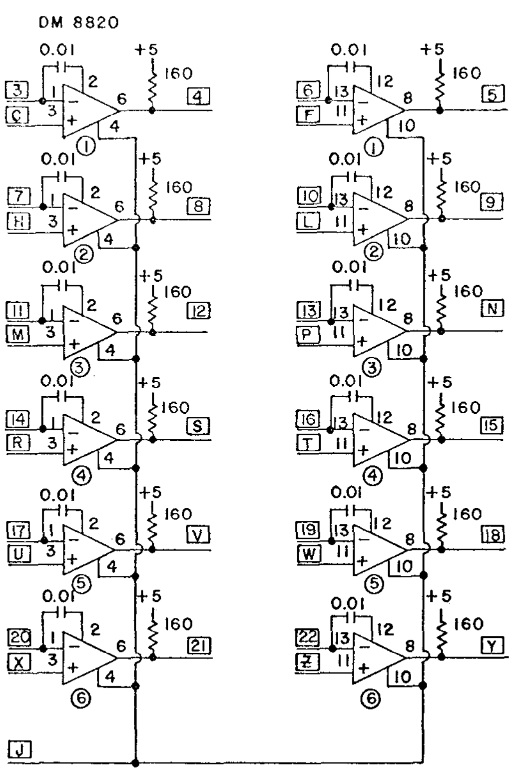

Fig. 18. Board #1, motor control box.

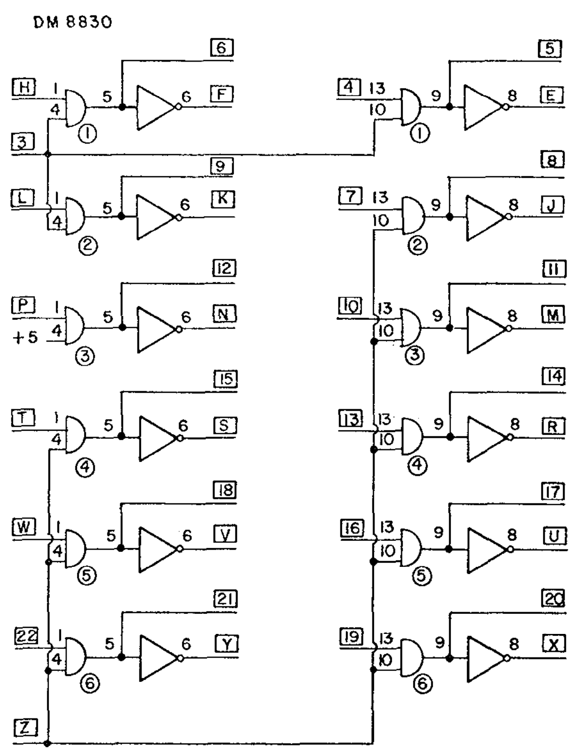

Fig. 19. Board #2, motor control box.

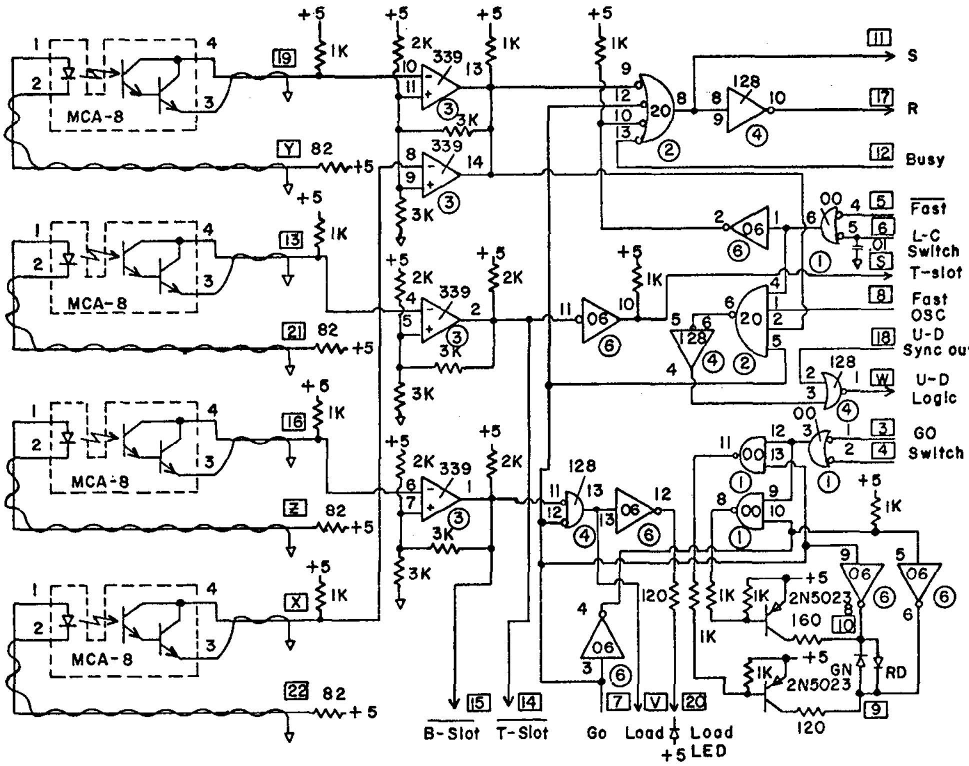

Fig. 20. Board #3, motor control box.

of the schematic. These are actually on the scan table and not the board itself. They are MCA-8 slotted pairs consisting of a gallium-arsenide infrared-light-emitting diode and a silicon photo-darlington looking through an air gap. These have a very good light/dark ratio and are not bothered by ambient light sources, since they operate in the infrared region. These are hooked up in a fail-safe configuration such that an opening in the cable or a power failure will cause the motors to stop. A minor disadvantage is their high saturation voltage (0.8 V), which we overcome by going into an LM339 connected as a Schmitt trigger with a high threshold (2.5 V) and a large hysteresis (1 V). The resistor chain between 5 V and ground on the positive inputs of the LM339 provide a reference voltage (3 V) and the 3K resistor from this positive input to the output provides positive feedback and hence the large hysteresis. Note that the top and bottom switches are ORed together, and either one will gate off both oscillators via the gates in the upper right-hand corner of this figure. This gating of the oscillators is straightforward, except for the R and S lines leaving the board. These points go to a pulse synchronizer which does the actual gating of the crystal oscillator.

Pin W is the actual output to the up-down motor driver. The circuitry in the bottom right-hand corner of the schematic controls the red-green LED. The LED has only two leads, which necessitates considerable circuitry for proper operation.

Board 4 of the motor control box (Fig. 21) contains the three scan table control flipflops. Starting with the "start" flipflop, IC-7 output #6 and IC-6 output #6, there are several points worthy of special note. First, the B-SLOT resets the flipflop through an edge detector, IC-1 output #10 and IC-6 output #3, to allow it to be started in an up direction while on the bottom limit. On the falling edge of B-SLOT pin #2 of IC 6 goes up and stays up. Pin #1 on IC 6 was up and stays up until

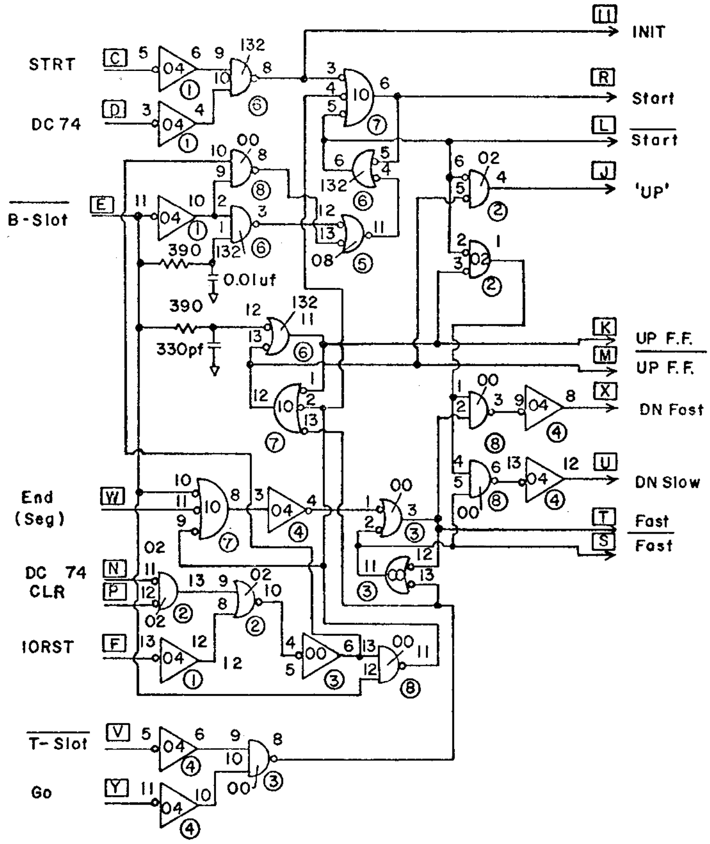

Fig. 21. Board #4, motor control box.

the 0.01-μf capacitor discharges through the 390-ohm resistor. While these two inputs are up, the output goes down and stays down until the 0.01-μf capacitor is discharged, at which time the output goes back up. This makes the output width the same as the R-C time constant, regardless of how long B-SLOT stays set.

Another point of interest involving the "start" flipflop is the stop command coming in through IC-8 output #8. The purpose of this is to allow the computer to stop the motors after the table has been started in the up direction, but it is still on the bottom limit.

Moving down to the "up" flipflop, IC-6 output #11 and IC-7 output #12, there is a slow-down R-C network on the set, IC-6 pin #12. The purpose of this time constant is to guarantee that the "start" flipflop gets reset to stop before the "direction" flipflop changes to "up". This prevents the table from backing off the bottom limit.

For all three flipflops, IC-8 output #11 prevents a computer reset (which would set the three flipflops to move the table down to the load point at the bottom limit at high speed) if the table is already on a bottom limit. Without this guard successive computer resets would drive the table beyond the bottom limit because the start flipflop is coupled to the bottom limit through the edge trigger, which would recognize the bottom limit after the first contact.

Notice also that the two lines on this board using slowdown circuits, IC-6 pin #1 and IC-6 pin #12, are received by a 74132 Schmitt trigger to prevent oscillation on the slow rise and fall.

Board 5 of the motor control box (Fig. 22) houses the two oscillators and the pulse synchronizers which gate the crystal oscillator output. This is the only board in the system built on a ground-plane board.

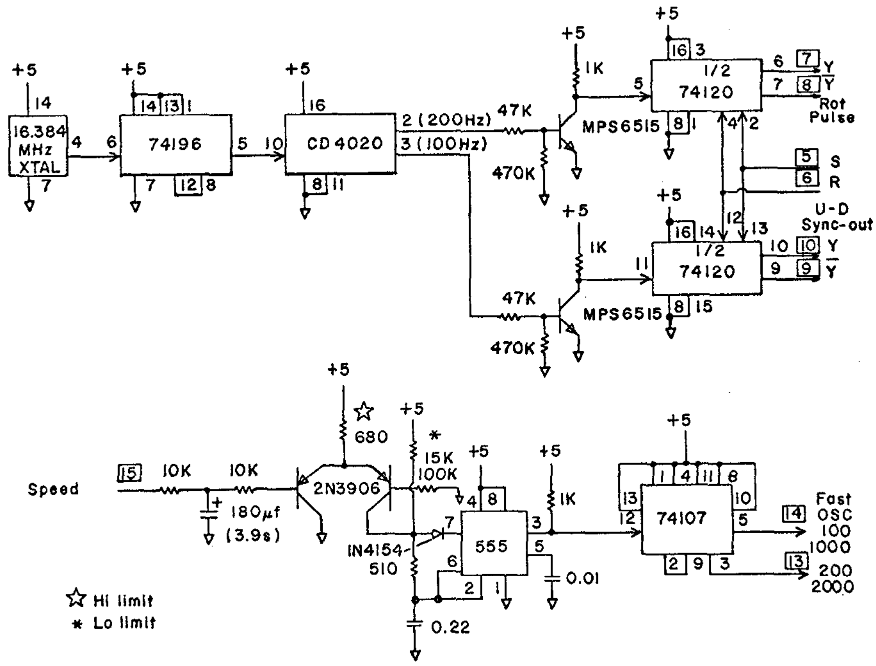

Fig. 22. Board #5, motor control box.

Starting with the crystal oscillator along the top half of the figure there is a crystal oscillator packaged in a 14-pin DIP IC package. It has a 16.384-MHz TTL-compatible output, which goes into a divide-by-five and a divide-by-two counter embodied in the 74196. The next IC, a COSMOS CD4020 divides by 2^{13} to achieve 200 Hz, and by 2^{14} for the 100-Hz output. Only COSMOS permits such divisions in a single package. However, COSMOS suffers two main disadvantages: low-speed and low-drive capability. The low speed dictates the previous IC, 74196, be hooked up in a divide-by-five and then -by-two rather than the reverse, so its output is a square wave of proper speed. The low drive makes the two transistor drivers necessary. The 74120 IC is a pulse synchronizer that permits gating the pulse trains while making sure the first and last pulses are full width. This is necessary because the motor drivers and motors are so much slower than the counters which track the stepping. Without this precaution, the first and last steps of a segment might be counted by the scalers but not by the motors.

Moving to the high-speed ramp oscillator at the bottom of Fig. 22, note that the oscillator itself is built around the NE555 timer IC. The 0.22-µf capacitor charges through the 510-ohm and 15-kΩ resistors and discharges through the 510-ohm and the 1N4154 diode into pin #7. The 1N4154 diode supplies a silicon forward junction voltage drop to insure self-starting of the oscillator when power is turned on. The 0.01-µf capacitor provides noise decoupling on the internal control voltage, and the 1-kΩ resistor in pin #3 provides a pull-up on the output. The two transistors are connected as a differential current pair that opens (high speed) or closes, placing a resistor in parallel with the 15-kΩ charging resistor. The speed input on pin #15 uses a standard TTL output to charge and discharge the 180-µf capacitor through the first 10-kΩ resistor. This R-C time constant determines the ramp duration. The ramp duration, high speed, and low speed can be changed within limits by changing the values of the 180-μf capacitor through the first 10-kΩ resistor. This R-C time constant determines the ramp duration. The ramp duration, high speed, and low speed can be changed within limits by changing the values of the 180-μf capacitor, the 680-ohm resistor, or the 15-kΩ resistor, respectively.

The 74107 IC following the oscillator is a dual flipflop that squares up the output and divides the frequency to 100-1000 Hz or 200-2000 Hz. At present we are using the 100-1000-Hz output.

Board 11 of the motor control box (Fig. 23) provides two basic functions. The circuitry at the lower half of the figure watches the scan height thumbwheel switches and changes a 00 to a 01 so that even if the operator mistakenly sets the switches to 00, he will still get a two-segment assay (1 in.). Without this precaution the interface would give a constant interrupt to the computer with the switches set at 00. This system hangup is prevented by the circuitry described, which thus effectively makes zero a forbidden setting for assay length.

The upper portion of Fig. 23 requires a short preface. The position of the motors is indicated by an optical encoder mounted on the nameplate end of the up-down motor. Each time the motor takes a step, depending on load, the encoder may see bounces up to one step off in either direction until the motor settles down. The IC 4 is the last stage of an up-down counter that counts the pulses from this encoder. The associated circuitry and the gate to the right of this counter gate off its output when the encoder could be bouncing and thus cause a premature end-of-segment command. The IC-7 output #13 provides a delay triggered by the table coming off the top limit or by the computer starting a new segment. The IC-3 output #1 and IC-7 output #5 monitor the CW line from the encoder and initiate a delay on the first CW pulse. The feedback from IC-7 pin #5 to IC-3 pin #3 prevents updating on subsequent CW pulses until the end of the delay. This gates the end signal off until the last half of a motor step, when bouncing should have died out.

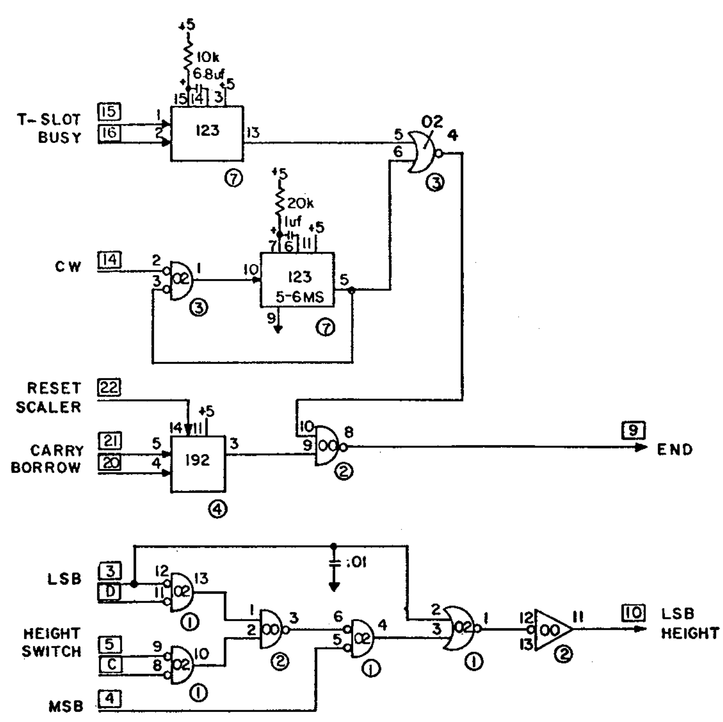

Fig. 23. Board #11, motor control box.

Board 12 of the motor control box (Fig. 24) contains the computer interrupt, busy, and done flipflops as well as scaler reset gating, the internal busy flipflop, and the motor encoder receiver.

Starting with the scaler reset circuitry, IC-3 output #2 and IC-2 output #8, we see that a computer general reset, IORST, into IC-2 pin #9 will reset the scaler that counts steps to determine the end of a segment. The pulse signalling the end of a segment will also loop back and reset the scalers, IC-2 pin #10. In addition, the scalers are held in a reset mode, preventing counting if the table is on the top limit, IC-2 pin #12, and until the table is going down slowly, IC-3 pin #1.

Moving to the flipflop section we see that at the end of a segment the internal busy, IC-5 outputs #4 and #10, the computer interrupt, IC-7 output #11 and IC-2 output #6, and in turn the computer interrupt, IC-6 output #5, flipflops are set. Only signals from the computer can reset these flipflops. The two busy flipflops are needed so that the computer can reset its own busy line, thus removing the interrupt in order to communicate with other system elements while leaving the table busy flipflop set.

At the end of the last segment the two busy flipflops and the interrupt flipflop are set; but nanoseconds later the done flipflop, IC-6 output #8, is set, resetting the two busy flipflops.

The circuitry at the bottom of this schematic is the optical encoder receiver. Output from the encoder is in the form of two pulse trains, "gate" and "count". The receiver consists of a positive edge detector, IC-4 output #6, a negative edge detector, IC-4 output #11, and gates controlled by the gate signal to pass "up" and

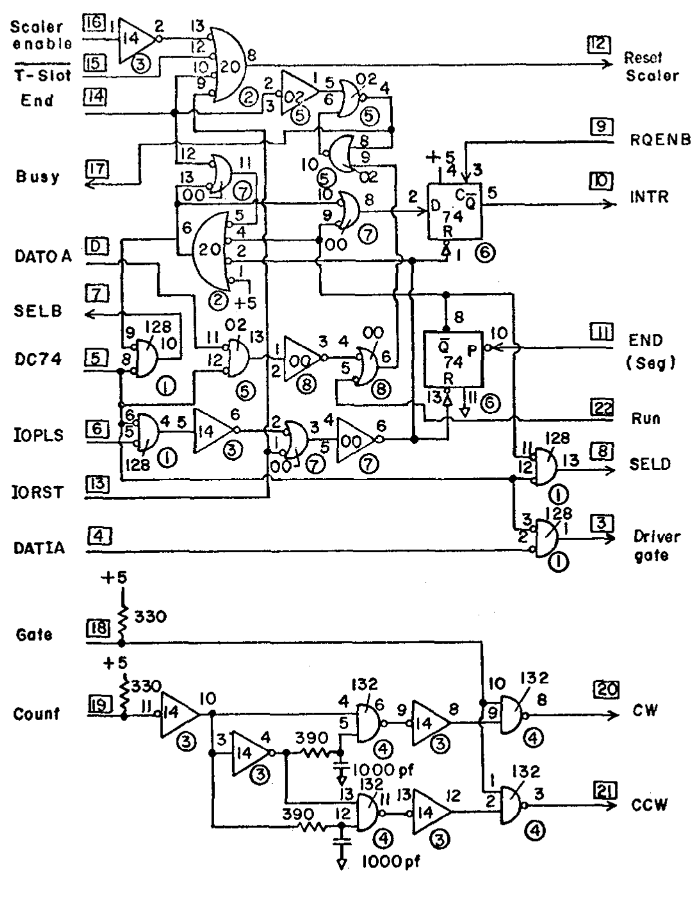

Fig. 24. Board #12, motor control box.

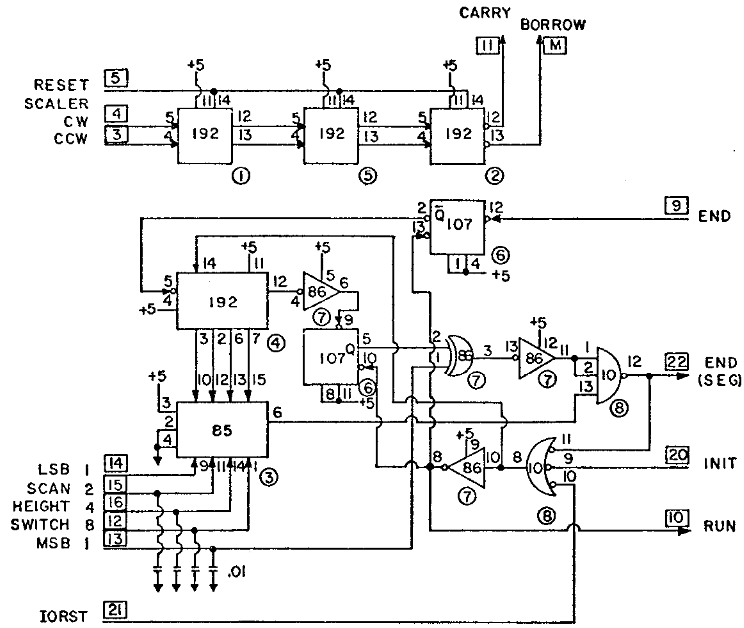

Fig. 25. Board #13, motor control box.

"down" pulses. A positive transition on the count line while the gate line is up indicates a CW motion of the motor. Conversely, a negative transition on the count line while the gate line is up indicates CCW movement of the motor. These edge detectors are the same as described on board 4 of the motor control box; the R-C slow-down circuits are received by 74132 Schmitt triggers to prevent oscillation.

Board 13 of the motor control box (Fig. 25) houses the bulk of the two counter chains for determining the end of a segment and the end of the last segment. ICs 1, 2, and 5 are the first three stages of a four-stage up-down counter that counts 1000 steps of the vertical movement motor which signals the end of a segment. This signal comes back into the board from the fourth counter section on pin #9 and into IC-6 pin #12 where it is divided by two by a flipflop. This division is necessary because the scan height switches used for comparison give the height in inches, and a single segment is 1/2 in.

From this point the signal goes to a counter made up of IC 4, IC-7 output #6, and IC-6 output #5. The output of this counter is compared with the scan height switch by a comparator made up of IC 3, IC-7 output #3, IC-7 output #11, and IC-8 output #12. When the two are equal this comparator sends out an end signal, indicating the end of the last segment, and then resets itself. The 0.01-μf capacitors on the switch lines are used to minimize the effects of noise on the lines.

Board 14 of the motor control box (Fig. 26) contains circuitry to clean up switch bounce on the up-down switch, give the fast oscillator time to ramp down before changing direction or stopping, and gating which determines speed and direction of table motion.

Beginning with the switch bounce problem, we see the "up" side and the "down" side of the switch coming into IC 5 as well as the OR gates, IC 2. On the first contact of the switch, IC 5, a univibrator, starts its output. The UV time constant is long enough that it holds IC-2 pin #5 or #9 until the switch stops bouncing and pin #3 or #10 can take over.

Notice that the outputs of the direction and speed flipflops also come into this section. The

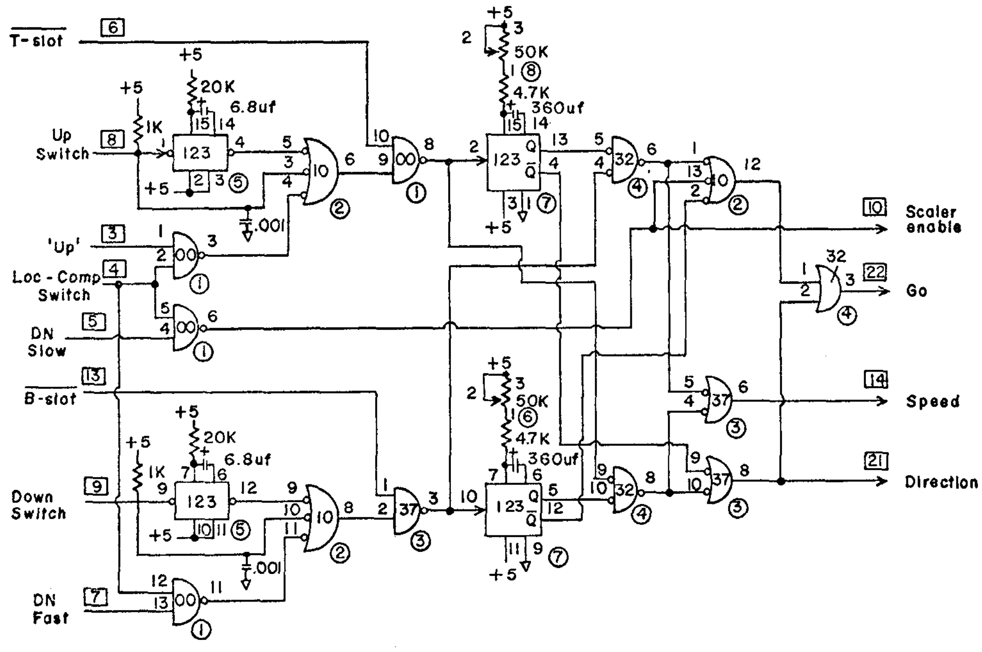

Fig. 26. Board #14, motor control box.

"up" and "down" fast signals come into IC-2 pins #4 and #11, respectively, and are treated just like the switch. The "down slow" goes past the ramp circuits straight to the "go" output. The "fast" and switch signals are first gated by the limit switches and then go into univibrators, IC 7, and gating that drives the "go", "speed", and "direction" outputs. These univibrators are connected as trailing edge detectors that act to prevent a change of direction or a stop until they have timed out. This time constant can be changed by adjusting the associated 50-kΩ potentiometer. The time constant is set up to match the charging and discharging time of the 180-μf ramp capacitor on board 5, motor control box. The speed output goes out to charge or discharge this capacitor. The direction output goes straight out to the motor driver.

2. Main Control Box

Board A-1 of the main control box (Fig. 27) receives the data lines from the ADC. The resistor chain terminates the twisted-pair cable in 132 ohms to prevent reflections and present a low

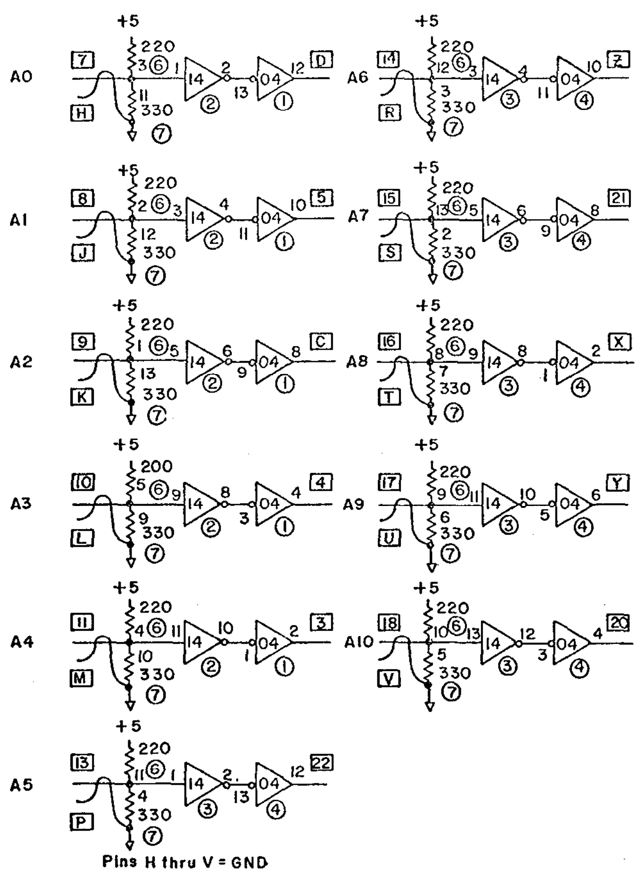

Fig. 27. Board A-1, main control box.

impedance to noise while still being driven by a standard TTL output. The 7414 is a Schmitt trigger which provides still greater noise immunity.

Board A-2 of the main control box (Fig. 28) receives and drives bidirectional lines from the computer. Notice that as on board A-1 this cable is made up of twisted pair and is terminated by a resistor chain feeding into a Schmitt trigger. The difference is that these are bidirectional lines and are terminated at both ends of the line. This dictates higher resistor values if it is to be driven by a TTL output. Also, we see the addition of the 7406 open-collector output drivers for sending signals to the computer.

Board A-3 of the main control box (Fig. 28) is for receiving and driving bidirectional lines from the computer. It is identical to board A-2 main control box except for the addition of one inverter, IC-3 output #10.

Board A-4 of the main control box (Fig. 29) receives control lines from the computer. It terminates twisted-pair cable with a resistor chain (see board A-1) and is received by 7414 Schmitt triggers.

Board A-5 of the main control box receives control lines from the computer. It is identical to board A-4.

Board A-6 of the main control box (Fig. 30) is another general purpose board used to receive signal lines from the motor control box. The ICs are DM8820 differential line receivers which terminate the twisted-pair cable with an internal resistor through the external 0.01-μf capacitor. This ac coupling allows good termination but prevents dc power drain. The transistor amplifier watches the +5 V power supply in the motor control box and gates off the receivers when the power is off. This prevents hanging on the computer lines if power is not on.

Board A-7 of the main control box (Fig. 31) is a general purpose differential line driver board

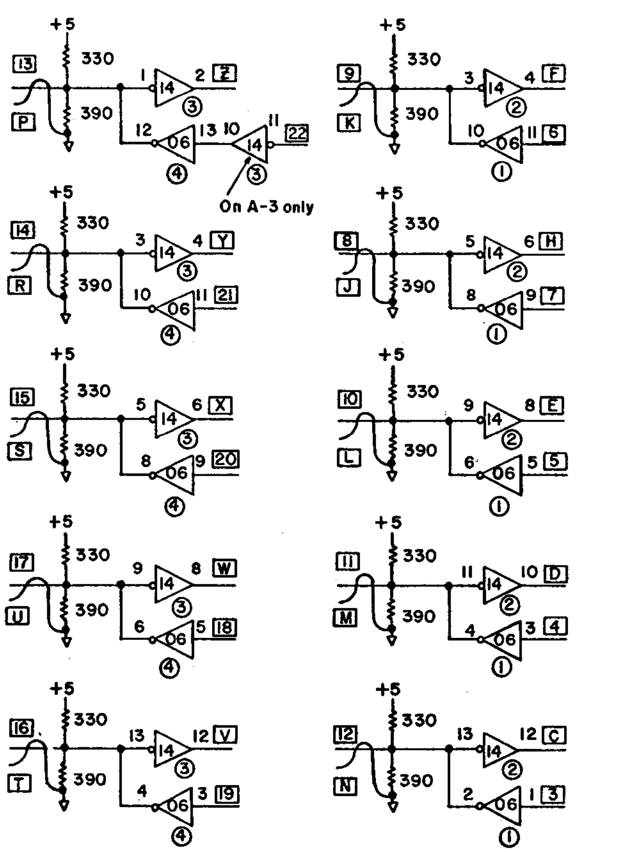

Fig. 28. Boards A-2 and A-3, main control box.

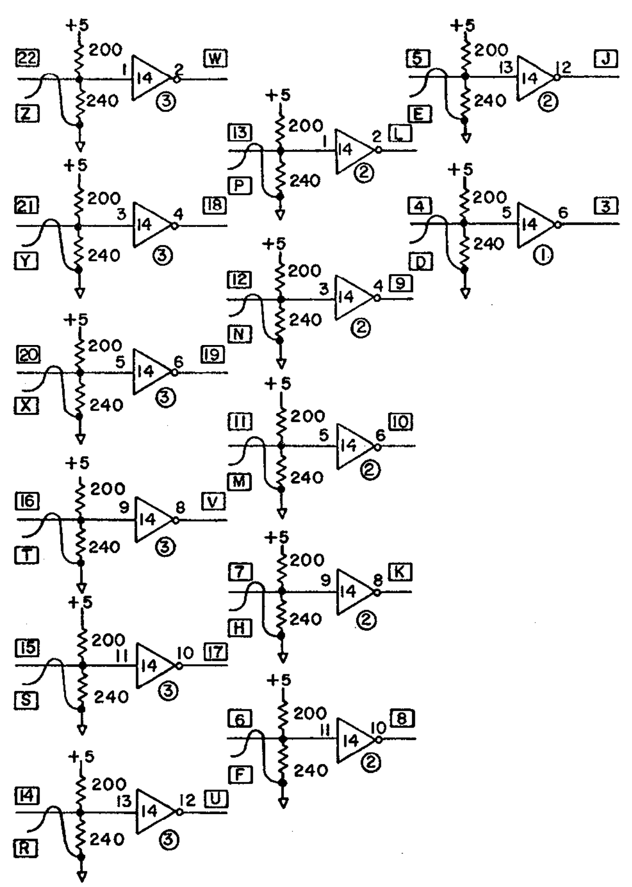

Fig. 29. Boards A-4 and A-5, main control box.

used to drive the control lines to the motor control box. It uses DM8830 differential line driver ICs. Pin Z is a gate not used on this board. It is hooked to +5 V to hold the drivers on at all times.

Board A-8 of the main control box (Fig. 32) is a general purpose 16-bit latch board with tri-state outputs. ICs 1, 2, and 3 are used for latching the data lines from the ADC, and IC 4 is used for holding data lines 0-3 of the tri-state bus down when not in use. Notice that IC-4 pin #15 is tied to +5 V. This holds it in a constant reset mode. In ICs 1, 2, and 3 information is latched on the rising edge of the clock pulse which comes in on pin #21 and is transmitted to the tri-state bus when the output control line, pin #3, is interrogated.

Board A-9 of the main control box (Fig. 33) contains the ADC control logic. It receives from the ADC the "store" command on pin #22 and sends

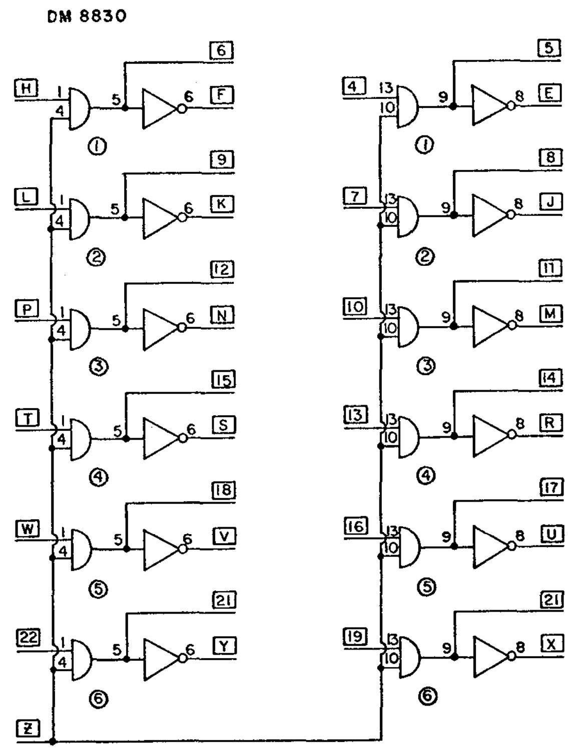

Fig. 31. Board A-7, main control box.

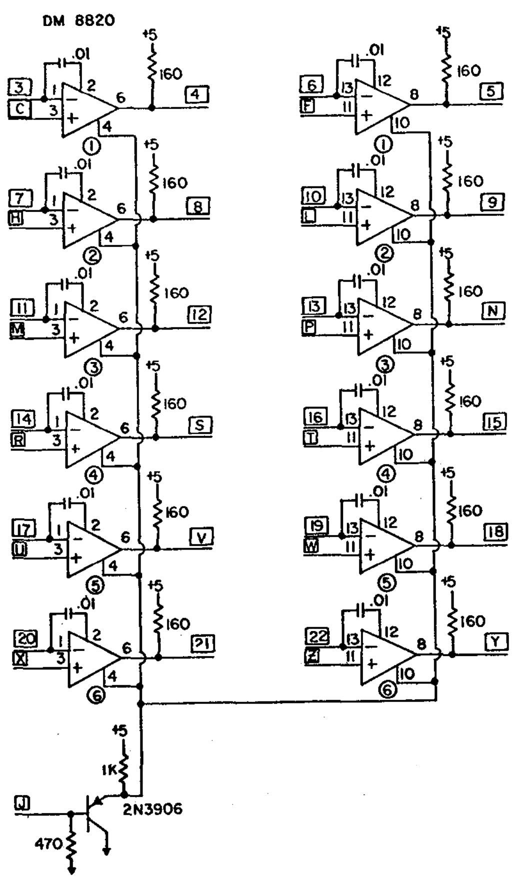

Fig. 30. Board A-6, main control box.

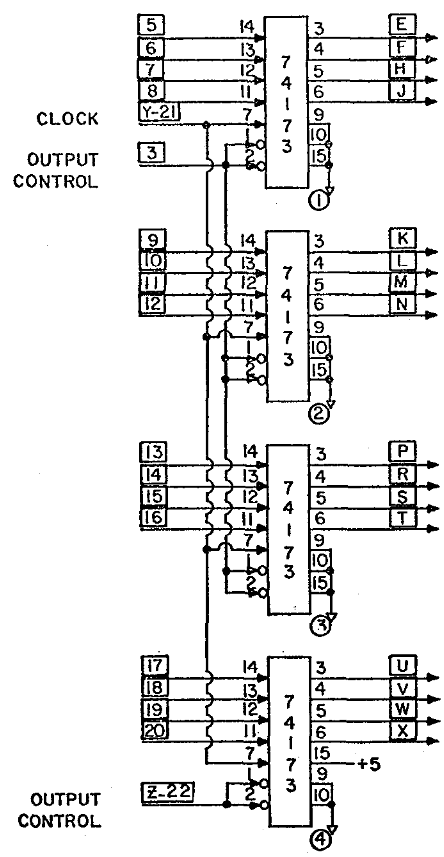

Fig. 32. Boards A-8 and B-12, main control box.

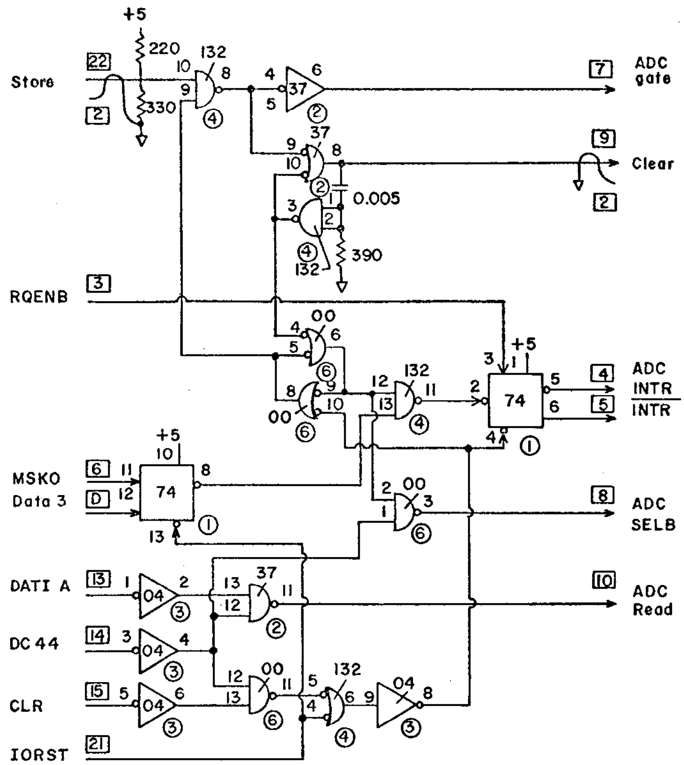

Fig. 33. Board A-9, main control box.

out to the ADC the "clear" signal on pin #9. Notice once again that these are twisted-pair lines in a cable and that the receiving is done through a resistor chain into a Schmitt trigger. On the first "store" command the ADC gate signal goes out to latch the data into the interface latches as well as a "clear" signal to start the ADC again. Notice that the "clear" pulse is generated by a univibrator, IC-2 output #8 and IC-4 output #3, which widens the pulse as required by the ADC circuitry. This pulse also sets the busy flipflop, IC-6 outputs #6 and #8, which in turn sets the computer interrupt flipflop, IC-1 outputs #5 and #6, if the mask flipflop, IC-1 output #8, has not been set by the computer.

Notice that until the computer resets the busy flipflop, the "store" signal from the ADC is gated off, and the ADC must hold new data while the computer retrieves the first data from the interface latches, thus providing double buffering on input data.

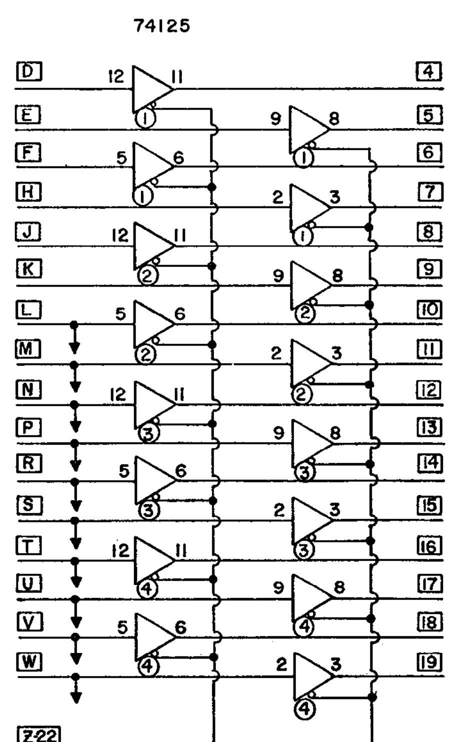

Fig. 34. Board A-10, main control box.

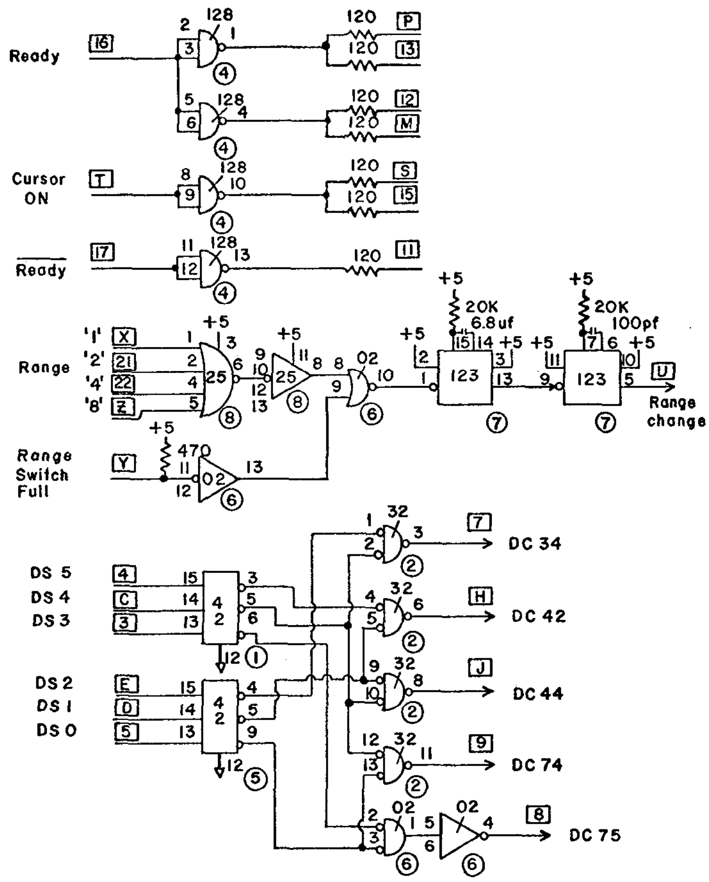

Fig. 35. Board A-14, main control box.

Board A-10 of the main control box (Fig. 34) is another general purpose board containing 74125 tri-state driver ICs. In this case the board serves to gate the motor status bits onto the tri-state bus to the computer. Since there are only six bits of information, the remaining inputs are grounded. A signal on pin #22 opens the gates to the bus.

Board A-14 of the main control box (Fig. 35) drives the switch-enable LEDs, detects a change in the range switch, and decodes the device codes from the computer. The cathodes of the enable LEDs hook to the 120-ohm current limiting resistors, and the anodes connect to +5 V.

The range switch code lines are watched by the OR circuits IC-8 output #6 and IC-6 output #10. When any line changes, a univibrator is triggered, IC-7 output #13. The time constant of this univibrator is long enough that switch bounce dies out before the end of this output pulse. At the falling edge of the output, the second univibrator, IC-7 output #5, is triggered. The output of this second univibrator is long enough to be TTL compatible.

The bottom of Fig. 35 shows the device code decoder. The computer furnishes a six-line code to indicate which device is to be interrogated or controlled. This circuit changes these codes, used in this interface, into a one-line command.

Board B-1 of the main control box houses a commercial ± 15 V power supply. Caution: 115-V ac comes in on pins #19, #20, #21, and #22. Pins #3 and #4 are the -15-V output, pins #5 and #6 are the output common, and pins #7 and #8 are the +15-V output. This power supply furnishes power to the digital-to-analog converters which drive the x- and y-deflection inputs on the oscilloscope.

Board B-4 of the main control box (Fig. 36) contains the oscilloscope x- and y-digital-to-analog

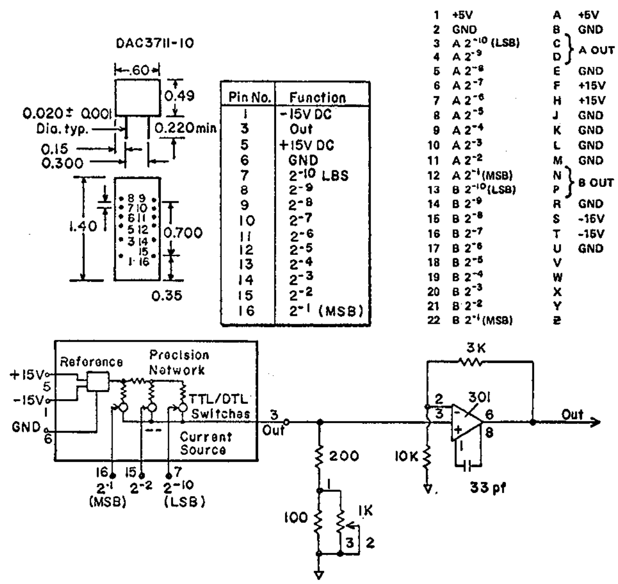

Fig. 36. Board B-4, main control box.

converters. These are in a 16-pin DIP package and have 10-bit resolution. The output of these converters is a current signal which connects to a variable resistor network to ground to produce a voltage signal. To boost this voltage and lower the impedance to the requirements of the oscilloscope, the signal is amplified by an LM301 operational amplifier with a fixed gain of about 1.3. The 33-pf capacitor sets its frequency response down to a stable point. The 1 kΩ potentiometer permits adjustment of the output voltage between narrow limits to match the oscilloscope gain requirements.

Board B-6 of the main control box (Fig. 37) is a general purpose latch board used in this case to store the oscilloscope x-input ten-bit address. The unused sections are left unconnected. The output control pin Z is tied to ground to enable the tri-state output at all times. The clock signal is a computer control pulse which gates in a new address on the rising edge of the pulse.

Board B-7 of the main control box (Fig. 37) is a general purpose latch board used here for storage of the ten-bit address of the y-input scope deflection. It is the same board and is used in the same way as board B-6.

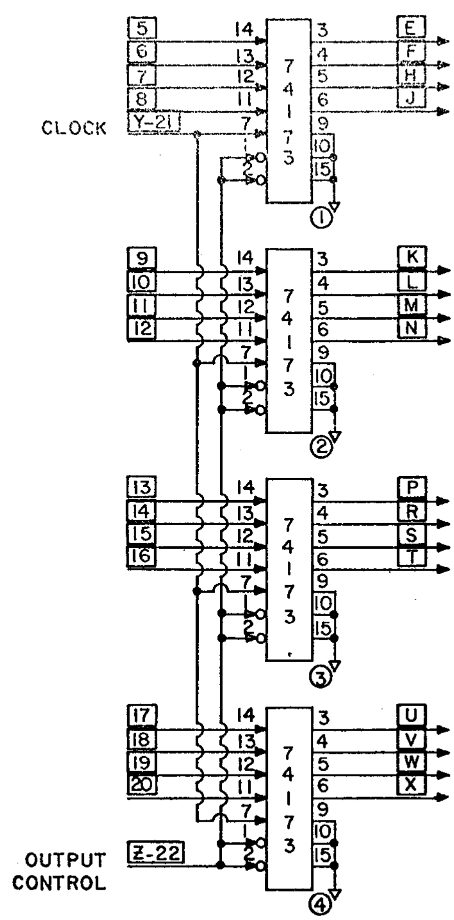

Fig. 37. Boards B-6 and B-7, main control box.

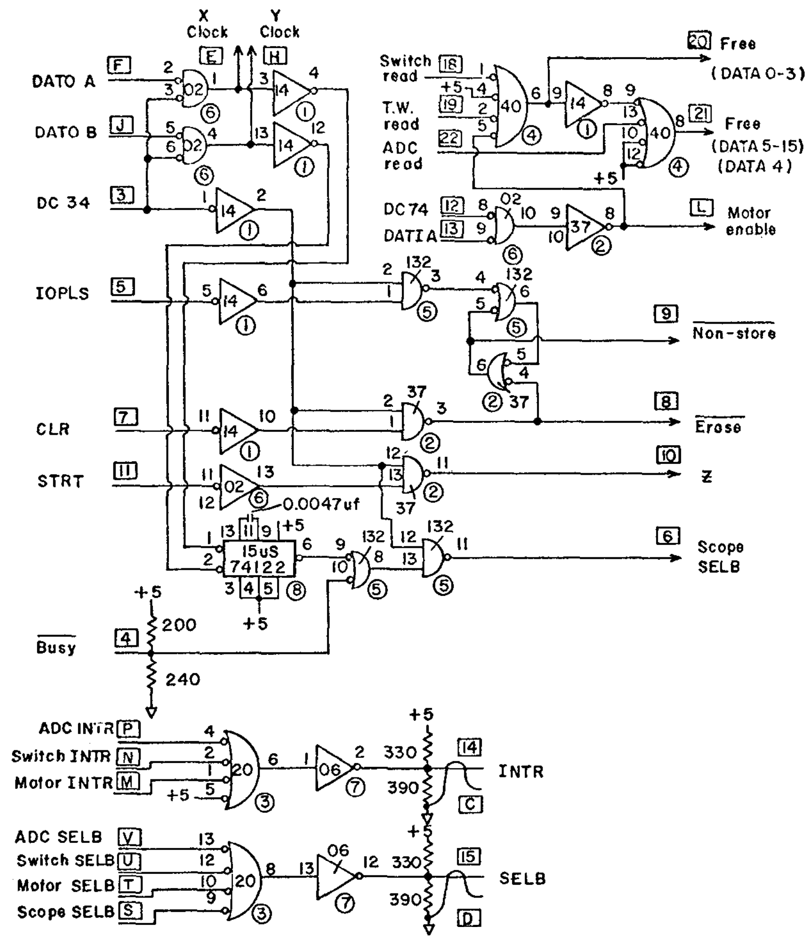

Fig. 38. Board B-8, main control box.

Board B-8 of the main control box (Fig. 38) contains the oscilloscope interface, line drivers for the computer interrupt and busy lines, and gating involved in tying down unused lines on the tri-state bus.

The main portion of the scope interface transforms combinations of computer pulses into signals which drive the oscilloscope. The only part requiring detailed discussion is the busy section. This section must present a busy signal to the computer after it gives a new x- and/or y-position until the scope has had time to respond. The Tektronix 613 oscilloscope watches for a change in its coordinate inputs and furnishes a 613 busy signal, but it will not see a small change of only one or two bits in the 10-bit digital-to-analog converter. For this reason, IC-8 output #6 is a univibrator designed to trigger on an x- or y-latch signal. The time constant here is long enough to insure that the scope is ready or has given out its own busy signal. These two busy signals are ORed together before being sent to the computer.

The interrupt and busy signals from all parts of the interface come into the appropriate section of IC 3, where they are ORed together, after which they go through open collector twisted-pair line drivers, IC-7 outputs #2 and #12, to the computer.

The section in the upper right-hand corner of the above schematic gates on or off pull-down gates on the tri-state bus as needed. Without such pull downs the TTL inputs will float up and be subject to noise. This could drag down the

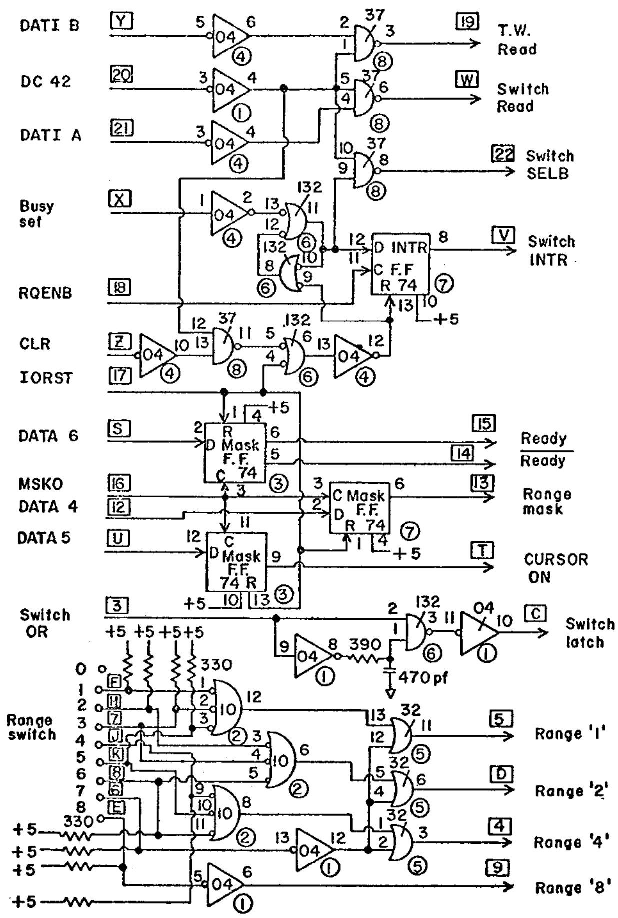

Fig. 39. Board B-9, main control box.

computer data lines and prevent proper operation of the computer program.

Board B-9 of the main control box (Fig. 39) handles several portions of the front panel switch interface. It contains the computer busy and interrupt flipflops related to the switches, IC-6 outputs #11 and #8, and IC-7 output #8, respectively. It also contains the three mask flipflops, IC-3 outputs #5 and #6, IC-7 output #6, and IC-3 output #9, which are set up by the computer program to control access to the computer interrupt line by the switches.

IC-6 output #3 is set up as a leading edge detector designed to clean up the ORed switch output before storing the switch identity in the switch latches.

The remaining section at the bottom of Fig. 39 codes the range switch in a four-bit BCD format.

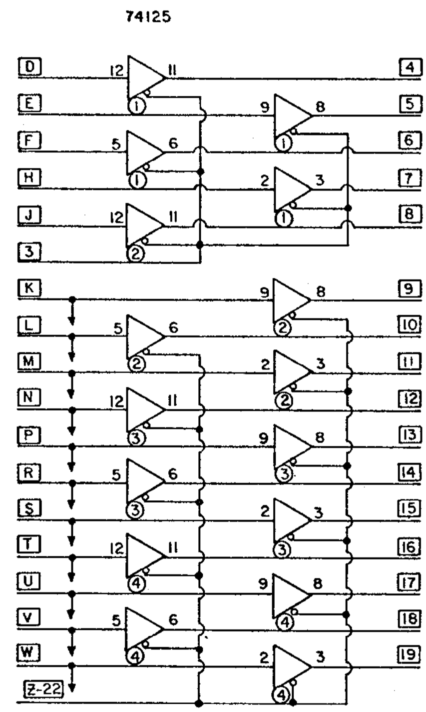

Fig. 40. Board B-10, main control box.

Board B-10 of the main control box (Fig. 40) is a general purpose tri-state buffer board divided for this application into two sections. The upper five bits gate the four-bit range switch position, and the one-bit print mode switch position onto the tri-state bus on request of the computer. The lower portion of the board is used for pull-down of bits 5-15 on the tri-state bus when they are not in use. This prevents the inerface from dragging down the computer lines when not being interrogated.

Board B-11 of the main control box (Fig. 41) contains the logic that masks and ORs the signals from the interrupting front panel switches. The inverted signals from the board go to latches which set a particular bit on the computer data lines corresponding to the activated pushbutton. The gating signals come from the three mask flipflops and the local-computer switch to enable only relevant switches at any given time. After filtering through the mask gates the signals are ORed and go out to set the latches and computer interrupt.

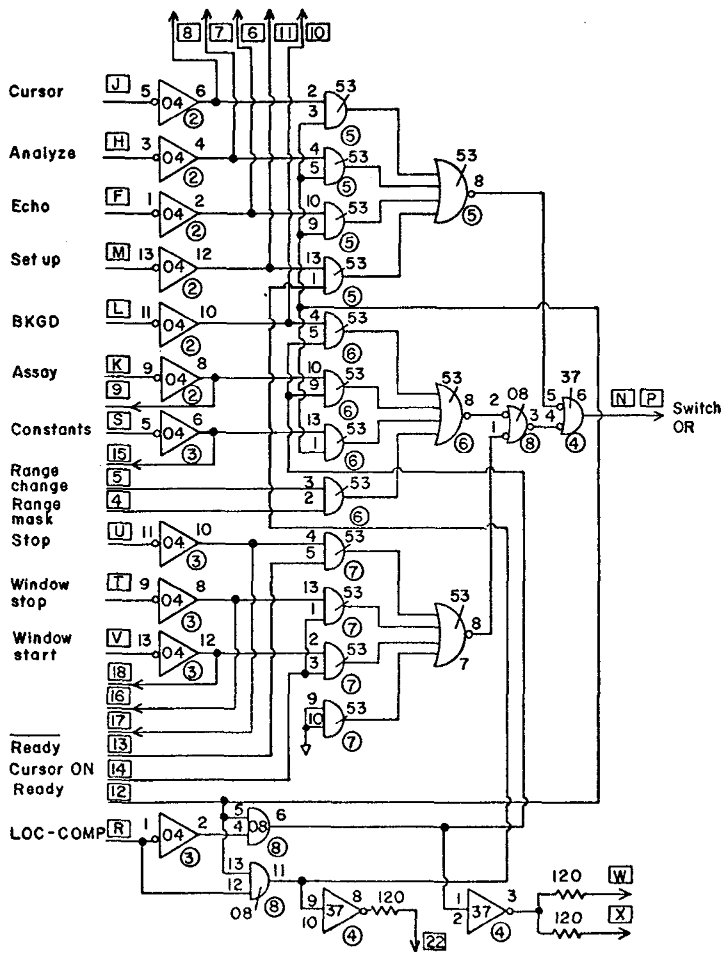

Fig. 41. Board B-11, main control box.

The three "run enable" LED drivers, IC-4 outputs #3 and #8, are also on this board. The 120-ohm resistors hook to the cathode of the LEDs, and the anode is connected to the +5-V bus.

Board B-12 of the main control box (Fig. 32) is a general purpose tri-state latch board. IC's 1, 2, and 3 gate the identities of the interrupting front panel switches onto the tri-state bus upon request from the computer. IC 4 is used to pull down bit 4 on the tri-state bus when not in use.

Board B-13 of the main control box (Fig. 42) contains receiver debouncer circuits for the I/O pushbutton switches on the front panel. These are built around the MCS-2 photo-SCR opto-isolator driving into a 7414 Schmitt trigger. When the switch is closed, 5 V is applied across the 100-ohm current limiting resistor and the LED. This triggers the SCR which discharges the 0.001-μf capacitor into the 510-ohm resistor. This creates a voltage drop across the 510-ohm resistor which triggers the 7414. This R-C time constant creates a 1-μs output pulse. Switch bounce is eliminated since the SCR, once triggered, will not turn off until it has discharged the 0.001-μf capacitor. After discharging the capacitor, the 10-MΩ resistor cannot furnish sufficient holding current, and the SCR turns off. The capacitor then charges through the 10-MΩ resistor, and the circuit is armed again. This last charging time constant is long enough that accidental double triggering of the switch will result in only one output pulse.

Board B-14 of the main control box (Fig. 43) is a general purpose tri-state driver board used here to gate the cursor position thumbwheel

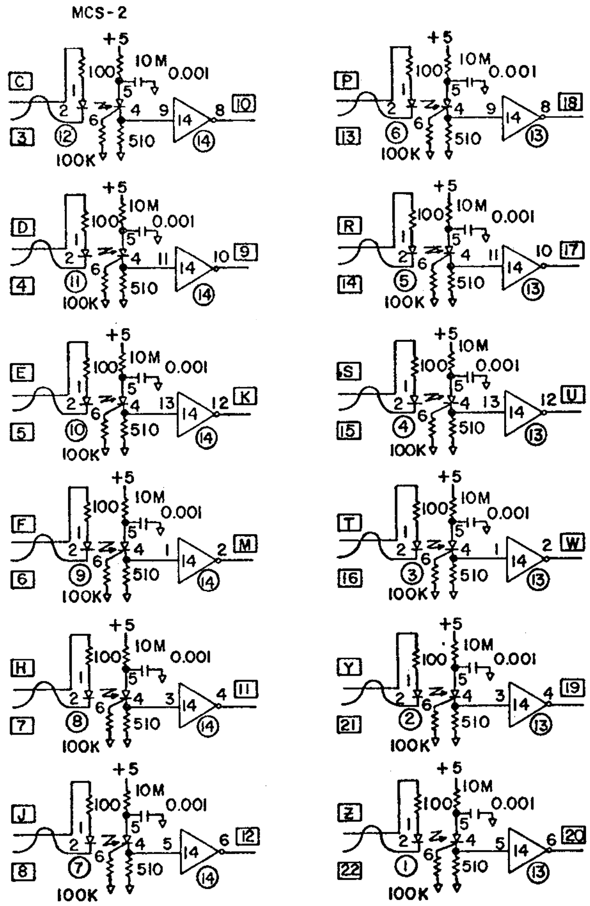

Fig. 42. Board B-13, main control box.

switches onto the tri-state bus upon request from the computer. The 0.01-μf capacitors suppress noise on the switch lines.

Figure 44 indicates the method of connecting and switching the 115-V ac line.

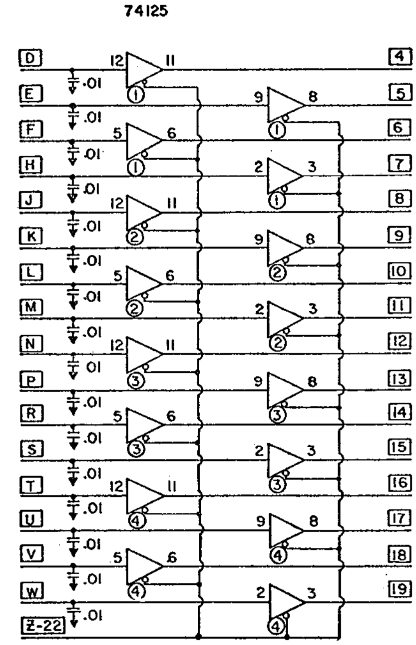

Fig. 43. Board B-14, main control box.

C. Wiring Lists

The wiring connections for the board-to-board hookup of the motor control and main control boxes are given in Tables I and II, respectively. Each line of the tables calls out the two ends of a single wire and names its function. Each wire end is designated first by a letter, either J indicating a connector on the back panel, or A or B designating the card cage. Next the socket or connector number is given, 1-14, and finally the pin number or letter on the connector; e.g., B-12-Z calls out card cage B, connector 12, pin Z.

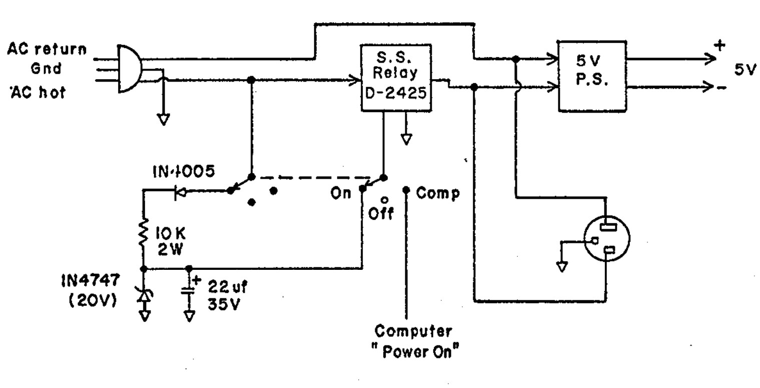

Fig. 44. Alternating-current wiring.

TABLE I

MOTOR CONTROL BOX WIRING LIST

Connections		Function	Connections		Function
J 1 1*	A 3 19	TOP F SLOT	J 6 34*	A 1 10	DATIA -
J 1 6*	A 3 2	GND	J 6 14*	A 1 M	RQENB +
J 1 2*	A 3 Y	TOP F SLOT SUPPLY	J 6 33*	A 1 11	RQENB -
J 1 7*	A 3 2	GND	J 6 13*	A 1 P	STRT +
J 1 3*	A 3 13	TOP SLOT	J 6 32*	A 1 13	STRT -
J 1 8*	A 3 B	GND	J 6 12*	A 1 R	CLR +
J 1 4*	A 3 21	TOP SLOT SUPPLY	J 6 31*	A 1 14	CLR -
J 1 9*	A 3 B	GND	J 6 9*	A 2 F	SELB +
J 2 1*	A 3 16	BOTTOM SLOT	J 6 28*	A 2 6	SELB -
J 2 6*	A 2 B	GND	J 6 8*	A 2 E	INTR +
J 2 2*	A 3 2	BOTTOM SLOT SUPPLY	J 6 27*	A 2 5	INTR -
J 2 7*	A 2 B	GND	J 6 7*	A 2 K	SELD +
J 2 3*	A 3 X	BOTTOM F SLOT	J 6 26*	A 2 9	SELD -
J 2 8*	A 2 2	GND	J 6 6*	A 2 8	DATA 15 +
J 2 4*	A 3 22	BOTTOM F SLOT SUPPLY	J 6 25*	A 2 J	DATA 15 -
J 2 9*	A 2 2	GND	J 6 5*	A 2 N	DATA 14 +
J 3 A*	A 12 19	COUNT	J 6 24*	A 2 12	DATA 14 -
J 3 B*	A 12 2	GND	J 6 4*	A 2 11	DATA 13 +
J 3 H	A 1 A	+5 V	J 6 23*	A 2 M	DATA 13 -
J 3 E*	A 12 18	GATE	J 6 3*	A 2 15	DATA 12 +
J 3 D*	A 12 2	GND	J 6 22*	A 2 S	DATA 12 -
J 4 A*	A 3 W	U-D PULSE	J 6 2*	A 2 14	DATA 11 +
J 4 B*	A 3 B	GND	J 6 21*	A 2 R	DATA 11 -
J 4 E*	A 14 21	DIRECTION	J 6 1*	A 2 18	DATA 10 +
J 4 D*	A 14 2	GND	J 6 20*	A 2 V	DATA 10 -
J 4 H	A 1 B	GND	A 3 11	A 5 5	S
J 5 A*	A 5 8	ROT PULSE	A 3 17	A 5 6	R
J 5 B*	A 5 2	GND	A 3 12	A 12 17	BUSY
J 5 H	A 1 2	GND	A 3 5	A 4 S	$\overline{\text{FAST}}$
J 5 E*	A 1 1	+5 (ROT DIRECTION)	A 3 8	A 5 14	FAST OSC
J 5 D*	A 1 2	GND	A 3 18	A 5 10	U-D SYNC OUT
J 6 19	A 1 2	GND	A 3 7	A 14 22	GO
J 6 18*	A 1 C	DC 74 +	A 3 14	A 4 V	$\overline{\text{T-SLOT}}$
J 6 37*	A 1 3	DC 74 -	A 4 V	A 12 15	$\overline{\text{T-SLOT}}$
J 6 17*	A 1 F	IOPLS +	A 12 15	A 14 6	$\overline{\text{T-SLOT}}$
J 6 36*	A 1 6	IOPLS -	A 3 15	A 4 E	$\overline{\text{B-SLOT}}$
J 6 16*	A 1 H	IORST +	A 4 E	A 14 13	$\overline{\text{B-SLOT}}$
J 6 35*	A 1 7	IORST -	A 3 S	A 2 10	T-SLOT
J 6 15*	A 1 L	DATIA +	A 3 V	A 2 7	LOAD

* twisted pair

TABLE I

MOTOR CONTROL BOX WIRING LIST (CONT.)

Connections		Function
A 4 C	A 1 N	STRT
A 4 D	A 1 4	DC 74
A 4 W	A 13 22	ENG (SEG)
A 13 22	A 12 11	ENG (SEG)
A 4 F	A 1 8	IORST
A 4 F	A 12 13	IORST
A 12 13	A 13 21	IORST
A 4 D	A 4 N	DC 74
A 4 N	A 12 5	DC 74
A 4 P	A 1 S	CLR
A 4 R	A 2 13	START
A 4 J	A 14 3	"UP"
A 4 K	A 2 W	UP F. F.
A 4 X	A 14 7	DN FAST
A 4 U	A 14 5	DN SLOW
A 4 T	A 2 T	FAST
A 4 Y	A 3 7	GO
A 5 15	A 14 14	SPEED
A 12 16	A 14 10	SCALER ENABLE
A 12 14	A 13 9	END
A 12 7	A 2 H	SELB
A 12 6	A 1 5	IOPLS
A 12 4	A 1 9	DATIA
A 12 12	A 13 5	RESET SCALER
A 12 9	A 1 12	RQENB
A 12 10	A 2 4	INTR
A 12 8	A 2 L	SELD
A 12 3	A 2 Z	DRIVER GATE
A 12 21	A 13 3	CCW
A 12 20	A 13 4	CW
A 3 20	LED	LOAD LED
A 3 9	LED	LED
A 3 10	LED	LED
A 14 4	SWITCH	L-C SWITCH
A 14 4	A 3 6	L-C SWITCH
A 3 6	A 1 J	L-C SWITCH
A 14 9	SWITCH	DOWN SWITCH
A 14 8	SWITCH	UP SWITCH
A 11 3	SWITCH	1 LSB
A 13 15	SWITCH	2 HEIGHT SWITCH
A 13 16	SWITCH	4
A 13 12	SWITCH	8 MSB
A 14 8	A 3 3	UP SWITCH
A 14 9	A 3 4	DOWN SWITCH
A 2 3	A 3 6	L-C SWITCH
A 1 1	J 6 11	+5 ON
A 2 P	A 2 3	L-C SWITCH
J 6 10	A 1 T	DATOA +
J 6 29	A 1 16	DATOA -
A 1 15	A 12 D	DATOA
A 12 22	A 13 10	RUN
A 13 11	A 11 21	CARRY
A 13 M	A 11 20	BORROW
A 12 14	A 11 9	END
A 11 10	A 13 14	LSB HEIGHT
A 13 15	A 11 D	HEIGHT
A 13 16	A 11 5	HEIGHT
A 13 12	A 11 C	HEIGHT
A 13 13	A 11 4	MSB HEIGHT
A 11 22	A 13 5	RESET SCALER
A 11 14	A 13 4	CW
A 11 16	A 12 17	BUSY
A 11 15	A 3 S	T-SLOT
A 4 11	A 13 20	INIT

TABLE II

MAIN CONTROL BOX WIRING LIST

Connections		Function
B 1 3*	B 4 5	-15 V
B 1 5*	B 4 R	GND
B 1 6*	B 4 E	GND
B 1 8*	B 4 F	+15 V
B 4 2	B 6 2	GND
B 4 3	B 6 E	X BIT 15
B 4 4	B 6 F	X BIT 14
B 4 5	B 6 H	X BIT 13
B 4 6	B 6 J	X BIT 12
B 4 7	B 6 K	X BIT 11
B 4 8	B 6 L	X BIT 10
B 4 9	B 6 M	X BIT 9
B 4 10	B 6 N	X BIT 8
B 4 11	B 6 P	X BIT 7
B 4 12	B 6 R	X BIT 6
B 4 13	B 7 E	Y BIT 15
B 4 14	B 7 F	Y BIT 14
B 4 15	B 7 H	Y BIT 13
B 4 16	B 7 J	Y BIT 12
B 4 17	B 7 K	Y BIT 11
B 4 18	B 7 L	Y BIT 10
B 4 19	B 7 M	Y BIT 9
B 4 20	B 7 N	Y BIT 8
B 4 21	B 7 P	Y BIT 7
B 4 22	B 7 R	Y BIT 6
B 6 5	A 2 C	BIT 15
B 6 6	A 2 D	BIT 14
B 6 7	A 2 E	BIT 13
B 6 8	A 2 H	BIT 12
B 6 9	A 2 F	BIT 11
B 6 10	A 2 V	BIT 10
B 6 11	A 2 W	BIT 9
B 6 12	A 2 X	BIT 8
B 6 13	A 2 Y	BIT 7
B 6 14	A 2 Z	BIT 6
B 6 5	B 7 5	BIT 15
B 6 6	B 7 6	BIT 14
B 6 7	B 7 7	BIT 13

Connections		Function
B 6 8	B 7 8	BIT 12
B 6 9	B 7 9	BIT 11
B 6 10	B 7 10	BIT 10
B 6 11	B 7 11	BIT 9
B 6 12	B 7 12	BIT 8
B 6 13	B 7 13	BIT 7
B 6 14	B 7 14	BIT 6
B 6 Z	B 6 B	ENABLE
B 7 Z	B 7 B	ENABLE
B 6 Y	B 8 E	X LATCH
B 7 Y	B 8 H	Y LATCH
B 8 F	A 4 10	DATOA
B 8 J	A 4 9	DATOB
B 8 3	A 14 7	DC 34
B 8 5	A 5 9	IOPLS
B 8 7	A 4 3	CLR
B 8 11	A 5 19	STRT
A 1 D	A 8 5	A0
A 1 5	A 8 6	A1
A 1 C	A 8 7	A2
A 1 4	A 8 8	A3
A 1 3	A 8 9	A4
A 1 22	A 8 10	A5
A 1 Z	A 8 11	A6
A 1 21	A 8 12	A7
A 1 X	A 8 13	A8
A 1 Y	A 8 14	A9
A 1 20	A 8 15	A10
A 8 16	A 8 2	GND
B 8 18	B 9 W	SWITCH READ
B 8 19	B 9 19	T. W. READ
B 8 22	A 9 10	ADC READ
B 8 20	A 8 Z	DATA 0-3 FREE
A 8 3	A 9 10	ADC READ
A 8 Y	A 9 7	ADC GATE
B 8 6	B 8 S	SELB
A 8 E	A 2 3	DATA 15
A 8 F	A 2 4	DATA 14
A 8 H	A 2 5	DATA 13

* twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function
A 8 J	A 2 7	DATA 12
A 8 K	A 2 6	DATA 11
A 8 L	A 2 19	DATA 10
A 8 M	A 2 18	DATA 9
A 8 N	A 2 20	DATA 8
A 8 P	A 2 21	DATA 7
A 8 R	A 2 22	DATA 6
A 8 S	A 3 3	DATA 5
A 8 T	A 3 4	DATA 4
A 8 U	A 3 5	DATA 3
A 8 V	A 3 7	DATA 2
A 8 W	A 3 6	DATA 1
A 8 X	A 3 19	DATA 0
A 9 13	A 4 J	DATIA
A 9 14	A 14 J	DC 44
A 9 8	B 8 V	SELB
A 9 3	A 5 V	RQENB
A 9 4	B 8 P	INTR
A 9 15	A 4 3	CLR
A 9 21	A 5 L	IORST
B 8 21	B 10 22	DATA 5-15 FREE
B 10 Z	B 12 22	DATA 4 FREE
B 13 10	B 11 U	STOP
B 12 5	B 11 17	STOP
B 13 9	B 11 V	WINDOW START
B 12 7	B 11 18	WINDOW START
B 13 K	B 11 T	WINDOW STOP
B 12 8	B 11 16	WINDOW STOP
B 13 M	B 11 5	ENTER
B 12 9	B 11 15	ENTER
B 13 11	B 11 K	ASSAY START
B 12 10	B 11 9	ASSAY START
B 13 12	B 11 L	BKGD START
B 12 11	B 11 10	BKGD START
B 13 18	B 11 M	SETUP
B 12 12	B 11 11	SETUP
B 13 17	B 11 F	ECHO
B 12 13	B 11 6	ECHO
B 13 U	B 11 H	ANALYZE

Connections		Function
B 12 14	B 11 7	ANALYZE
B 13 W	B 11 J	CURSOR
B 12 15	B 11 8	CURSOR
A 14 U	B 12 6	RANGE CHANGE
B 12 6	B 11 5	RANGE CHANGE
B 12 Y	B 9 C	SWITCH LATCH
B 9 3	B 11 P	SWITCH OR
B 12 3	B 9 W	SWITCH READ
B 12 E	A 8 E	DATA 15
B 12 F	A 8 F	DATA 14
B 12 H	A 8 H	DATA 13
B 12 J	A 8 J	DATA 12
B 12 K	A 8 K	DATA 11
B 12 L	A 8 L	DATA 10
B 12 M	A 8 M	DATA 9
B 12 N	A 8 N	DATA 8
B 12 P	A 8 P	DATA 7
B 12 R	A 8 R	DATA 6
B 12 S	A 8 S	DATA 5
B 11 N	B 9 X	SWITCH OR
B 11 14	B 9 T	MASK
B 11 13	B 9 14	MASK
B 11 12	B 9 15	MASK
B 9 Y	A 4 8	DATIB
B 9 20	A 14 H	DC 42
B 9 21	A 4 J	DATIA
B 9 18	A 5 V	RQENB
B 9 17	A 5 L	IORST
B 9 Z	B 8 7	CLR
B 9 S	B 7 14	DATA 6
B 9 16	A 5 U	MSKO
B 9 U	A 3 C	DATA 5
B 13 S*	SWITCH	ANALYZE
B 13 15*	SWITCH	RTRN
B 13 T*	SWITCH	CURSOR
B 13 16*	SWITCH	RTRN
A 14 11	LED	$\overline{\text{READY}}$
A 14 15	LED	CURSOR ON

* twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function	Connections		Function
A 14 S	LED	CURSOR ON	J 2 32*	A 7 M	STRT -
A 14 M	LED	READY	J 2 12*	A 7 15	CLR +
A 14 12	LED	READY	J 2 31*	A 7 S	CLR -
A 14 P	LED	READY	A 6 12	B 11 R	LOC-COMP
A 14 13	LED	READY	B 9 19	B 14 22	T. W. READ
B 11 22	LED	READY • LOCAL	B 9 W	B 10 3	SWITCH READ
B 11 W	LED	READY • COMP	B 9 22	B 8 U	SELB
B 11 X	LED	READY • COMP	B 9 V	B 8 N	INTR
B 8 L	A 10 22	MOTOR READ	B 9 15	A 14 16	MASK
B 8 12	A 14 9	DC 74	B 9 14	A 14 17	MASK
B 8 13	B 9 21	DATIA	B 9 T	A 14 T	MASK
A 10 4	A 8 E	DATA 15	B 9 5	B 10 J	RANGE "1"
A 10 5	A 8 F	DATA 14	B 9 D	B 10 H	RANGE "2"
A 10 6	A 8 H	DATA 13	B 9 4	B 10 F	RANGE "4"
A 10 7	A 8 J	DATA 12	B 9 9	B 10 E	RANGE "8"
A 10 8	A 8 K	DATA 11	B 10 8	A 3 4	DATA 4
A 10 9	A 8 L	DATA 10	B 10 7	A 3 5	DATA 3
A 10 10	A 8 M	DATA 9	B 10 6	A 3 7	DATA 2
A 10 11	A 8 N	DATA 8	B 10 5	A 3 6	DATA 1
A 10 12	A 8 P	DATA 7	B 10 4	A 3 19	DATA 0
A 10 13	A 8 R	DATA 6	B 14 4	B 12 E	DATA 15
A 10 14	A 8 S	DATA 5	B 14 5	B 12 F	DATA 14
A 10 15	A 8 T	DATA 4	B 14 6	B 12 H	DATA 13
A 10 16	A 8 U	DATA 3	B 14 7	B 12 J	DATA 12
A 10 17	A 8 V	DATA 2	B 14 8	B 12 K	DATA 11
A 10 18	A 8 W	DATA 1	B 14 9	B 12 L	DATA 10
A 10 19	A 8 X	DATA 0	B 14 10	B 12 M	DATA 9
J 2 19	A 1 B	GND	B 14 11	B 12 N	DATA 8
J 2 18*	A 7 6	DC 74 +	B 14 12	B 12 P	DATA 7
J 2 37*	A 7 F	DC 74 -	B 14 13	B 12 R	DATA 6
J 2 17*	A 7 5	IOPLS +	B 14 14	B 12 S	DATA 5
J 2 36*	A 7 E	IOPLS -	B 14 15	B 10 8	DATA 4
J 2 16*	A 7 9	IORST +	B 14 16	B 10 7	DATA 3
J 2 35*	A 7 K	IORST -	B 14 17	B 10 6	DATA 2
J 2 15*	A 7 8	DATIA +	B 14 18	B 10 5	DATA 1
J 2 34*	A 7 J	DATIA -	B 14 19	B 10 4	DATA 0
J 2 14*	A 7 12	RQENB +	A 14 4	A 5 8	DS 5
J 2 33*	A 7 N	RQENB -	A 14 C	A 5 J	DS 4
J 2 13*	A 7 11	STRT +	A 14 3	A 5 3	DS 3

* twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function
A 14 E	A 4 W	DS 2
A 14 D	A 4 18	DS 1
A 14 5	A 4 19	DS 0
B 8 10*	J 1 4	Z
B 8 2*	J 1 5	GND
B 8 8*	J 1 18	$\overline{\text{ERASE}}$
B 8 2*	J 1 17	GND
B 8 9*	J 1 6	$\overline{\text{NONSTORE}}$
B 8 C*	J 1 19	GND
B 8 4*	J 1 7	$\overline{\text{BUSY}}$
B 8 D*	J 1 9	GND
A 1 7*	J 3 1	A0
A 1 H*	J 3 20	GND
J 2 9*	A 6 C	SELB +
J 2 28*	A 6 3	SELB -
J 2 8*	A 6 F	INTR +
J 2 27*	A 6 6	INTR -
J 2 7*	A 6 H	SELD +
J 2 26*	A 6 7	SELD -
J 2 6*	A 6 L	DATA 15 +
J 2 25*	A 6 10	DATA 15 -
J 2 5*	A 6 M	DATA 14 +
J 2 24*	A 6 11	DATA 14 -
J 2 4*	A 6 P	DATA 13 +
J 2 23*	A 6 13	DATA 13 -
J 2 3*	A 6 R	DATA 12 +
J 2 22*	A 6 14	DATA 12 -
J 2 2*	A 6 T	DATA 11 +
J 2 21*	A 6 16	DATA 11 -
J 2 1*	A 6 U	DATA 10 +
J 2 20*	A 6 17	DATA 10 -
A 10 D	A 6 9	DATA 15
A 10 E	A 6 12	DATA 14
A 10 F	A 6 N	DATA 13
A 10 H	A 6 S	DATA 12
A 10 J	A 6 15	DATA 11
A 10 K	A 6 V	DATA 10
A 7 H	A 14 9	DC 74

Connections		Function
A 7 4	A 5 9	IOPLS
A 7 L	A 5 L	IORST
A 7 7	A 9 13	DATIA
A 7 P	A 9 3	RQENB
A 7 10	A 5 19	STRT
A 7 T	A 9 15	CLR
A 6 4	B 8 T	SELB
A 6 5	B 8 M	INTR
A 6 8	A 3 22	SELD
A 7 Z	A 7 A	+5 V
A 9 6	A 5 U	MASKO
A 9 D	A 3 E	DATA 3 (RCV)
A 14 X	B 9 5	RANGE "1"
A 14 21	B 9 D	RANGE "2"
A 14 22	B 9 4	RANGE "4"
A 14 Z	B 9 9	RANGE "8"
A 14 Y	SWITCH	RANGE 0
B 9 13	B 11 4	RANGE MASK
B 9 12	A 3 D	DATA 4 (RCV)
B 9 F	SWITCH	RANGE 1
B 9 H	SWITCH	RANGE 2
B 9 7	SWITCH	RANGE 3
B 9 J	SWITCH	RANGE 4
B 9 K	SWITCH	RANGE 5
B 9 8	SWITCH	RANGE 6
A 1 8*	J 3 2	A1
A 1 J*	J 3 21	GND
A 1 9*	J 3 3	A2
A 1 K*	J 3 22	GND
A 1 10*	J 3 4	A3
A 1 L*	J 3 23	GND
A 1 11*	J 3 5	A4
A 1 M*	J 3 24	GND
A 1 13*	J 3 6	A5
A 1 P*	J 3 25	GND
A 1 14*	J 3 7	A6
A 1 R*	J 3 26	GND
A 1 15*	J 3 8	A7
A 1 S*	J 3 27	GND

* twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function	Connections		Function
A 1 16*	J 3 9	A8	A 2 10*	J 4 16	DATA 13
A 1 T*	J 3 28	GND	A 2 L*	J 4 1	GND
A 1 17*	J 3 10	A9	A 2 11*	J 4 17	DATA 14
A 1 U*	J 3 29	GND	A 2 M*	J 4 1	GND
A 1 18*	J 3 11	A10	A 2 12*	J 4 18	DATA 15
A 1 V*	J 3 30	GND	A 2 N*	J 4 1	GND
A 9 22*	J 3 12	STORE	A 4 5*	J 4 19	DATIA
A 9 2*	J 3 31	GND	A 4 E*	J 4 1	GND
A 9 9*	J 3 13	CLEAR	A 4 6*	J 4 20	DATIB
A 9 2*	J 3 32	GND	A 4 F*	J 4 1	GND
A 4 4*	J 4 2	CLR	A 4 7*	J 4 21	DATIC
A 4 D*	J 4 1	GND	A 4 H*	J 4 1	GND
A 3 16*	J 4 3	DATA 0	A 4 11*	J 4 22	DATOA
A 3 T*	J 4 1	GND	A 4 M*	J 4 1	GND
A 3 9*	J 4 4	DATA 1	A 4 12*	J 4 23	DATOB
A 3 K*	J 4 1	GND	A 4 N*	J 4 1	GND
A 3 8*	J 4 5	DATA 2	A 4 13*	J 4 24	DATOC
A 3 J*	J 4 1	GND	A 4 P*	J 4 1	GND
A 3 10*	J 4 6	DATA 3	A 4 14*	J 4 25	DCHA
A 3 L*	J 4 1	GND	A 4 R*	J 4 1	GND
A 3 11*	J 4 7	DATA 4	A 4 15*	J 4 26	DCHI
A 3 M*	J 4 1	GND	A 4 S*	J 4 1	GND
A 3 12*	J 4 8	DATA 5	A 3 17*	J 4 27	DCHM 0
A 3 N*	J 4 1	GND	A 3 U*	J 4 1	GND
A 2 13*	J 4 9	DATA 6	A 3 15*	J 4 28	DCHM 1
A 2 P*	J 4 1	GND	A 3 S*	J 4 1	GND
A 2 14*	J 4 10	DATA 7	A 5 21*	J 4 29	DCHO
A 2 R*	J 4 1	GND	A 5 Y*	J 4 1	GND
A 2 15*	J 4 11	DATA 8	A 4 16*	J 4 30	DCHP
A 2 S*	J 4 1	GND	A 4 T*	J 4 1	GND
A 2 17*	J 4 12	DATA 9	A 3 14*	J 4 31	DCHR
A 2 U*	J 4 1	GND	A 3 R*	J 4 1	GND
A 2 16*	J 4 13	DATA 10	A 4 20*	J 4 32	DS 0
A 2 T*	J 4 1	GND	A 4 X*	J 4 1	GND
A 2 9*	J 4 14	DATA 11	A 4 21*	J 4 33	DS 1
A 2 K*	J 4 1	GND	A 4 Y*	J 4 1	GND
A 2 8*	J 4 15	DATA 12	A 4 22*	J 4 34	DS 2
A 2 J*	J 4 1	GND	A 4 Z*	J 4 1	GND
			A 5 4*	J 4 35	DS 3

* twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function	Connections		Function
A 5 D*	J 4 1	GND	B 10 12	B 12 N	DATA 8
A 5 5*	J 4 36	DS 4	B 10 13	B 12 M	DATA 9
A 5 E*	J 4 1	GND	B 10 14	B 12 L	DATA 10
A 5 6*	J 4 37	DS 5	B 10 15	B 12 K	DATA 11
A 5 F*	J 4 1	GND	B 10 16	B 12 J	DATA 12
A 5 7*	J 4 38	INTA	B 10 17	B 12 H	DATA 13
A 5 H*	J 4 1	GND	B 10 18	B 12 F	DATA 14
A 5 11*	J 4 39	INTP	B 10 19	B 12 E	DATA 15
A 5 M*	J 4 1	GND	B 13 C*	SWITCH	STOP
B 8 14*	J 4 40	INTR	B 13 3*	SWITCH	RTRN
B 8 C*	J 4 1	GND	B 13 D*	SWITCH	WINDOW START
A 5 12*	J 4 41	IOPLS	B 13 4*	SWITCH	RTRN
A 5 N*	J 4 1	GND	B 13 E*	SWITCH	WINDOW STOP
A 5 13*	J 4 42	IORST	B 13 5*	SWITCH	RTRN
A 5 P*	J 4 1	GND	B 13 F*	SWITCH	ENTER
A 5 14*	J 4 43	MSKO	B 13 6*	SWITCH	RTRN
A 5 R*	J 4 1	GND	B 13 H*	SWITCH	ASSAY START
A 5 15*	J 4 44	OVFLO	B 13 7*	SWITCH	RTRN
A 5 S*	J 4 1	GND	B 13 J*	SWITCH	BKGD START
A 5 16*	J 4 45	RQENB	B 13 8*	SWITCH	RTRN
A 5 T*	J 4 1	GND	B 13 P*	SWITCH	SETUP
B 8 15*	J 4 46	SELB	B 13 13*	SWITCH	RTRN
B 8 D*	J 4 1	GND	B 13 R*	SWITCH	ECHO
A 3 13*	J 4 47	SELD	B 13 14*	SWITCH	RTRN
A 3 P*	J 4 1	GND	B 9 6	SWITCH	RANGE 7
A 5 20*	J 4 48	STRT	B 9 E	SWITCH	RANGE 8
A 5 X*	J 4 1	GND	B 14 D	SWITCH	T. W. 1 (LSB)
B 4 N†	J 1 15	Y +	B 14 E	SWITCH	T. W. 2
B 4 M†	J 1 16	Y -	B 14 F	SWITCH	T. W. 4
B 6 2†	J 1 3	Y SHIELD	B 14 H	SWITCH	T. W. 8
B 4 C†	J 1 1	X +	B 14 J	SWITCH	T. W. 1
B 4 B†	J 1 2	X -	B 14 K	SWITCH	T. W. 2
B 7 2†	J 1 14	X SHIELD	B 14 L	SWITCH	T. W. 4
B 12 U	B 10 8	DATA 4	B 14 M	SWITCH	T. W. 8
B 10 9	B 12 S	DATA 5	B 14 N	SWITCH	T. W. 1
B 10 10	B 12 R	DATA 6	B 14 P	SWITCH	T. W. 2
B 10 11	B 12 P	DATA 7	B 14 R	SWITCH	T. W. 4
			B 14 S	SWITCH	T. W. 8
			B 14 T	SWITCH	T. W. 1

*twisted pair

†shielded twisted pair

TABLE II

MAIN CONTROL BOX WIRING LIST (CONT.)

Connections		Function
B 14 U	SWITCH	T. W. 2
B 14 V	SWITCH	T. W. 4
B 14 W	SWITCH	T. W. 8 (MSB)
B 10 D	SWITCH	PRINT MODE
A 6 J	J 2 11	+5 ON
J 2 10*	A 7 14	DATOA +
J 2 29*	A 7 R	DATOA -
A 7 13	A 4 10	DATOA
J 4 49	SWITCH	POWER ON
J 4 1	SWITCH	GND

* twisted pair

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