

512 CHANNEL ANALYZER

MODEL ND 130A

SERIAL NUMBER 61-682A

INSTRUCTION MANUAL

NUCLEAR
DATA,
INC.

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INTRODUCTION

In writing this manual, emphasis has been placed upon the operation rather than maintenance of the Model ND130A analyzer. It has been necessary to include remarks concerning some of the elementary principles of scintillation spectrometry as a foundation upon which to base discussions of operating principles. Those using the analyzer for alpha particle analysis, or other applications requiring the use of a pulse amplitude distribution analyzer, may find much of the introductory material inapplicable, except in the sense that some of the characteristics of the analyzer explained with reference to gamma analysis, also apply to the analysis of energy distribution of other particles, and even to such applications as experiments utilizing the Mossbauer effect.

In earlier pulse height analyzer instruction books, emphasis was usually placed more on main-

tenance and circuit design theory than upon operation. Such manuals have been less than completely successful in their objective of allowing non-factory personnel to properly service the analyzers in cases of failure. Two factors have made this objective even more difficult in the case of modern analyzers. One is that the instruments are appreciably more complex and difficult to understand. The second is that although an analyzer may at one time be quite well understood, the interval between failures is now far longer. It is virtually impossible to describe all of the intricacies of circuit design sufficiently well to qualify the reader to correct a malfunction without introducing more problems in the process. Those skilled enough in transistorized circuit design to perform their own servicing should be able to understand the outline description of analyzer design adequately from that outline and from the circuit diagrams.

I. PRINCIPLES OF PULSE HEIGHT ANALYSIS

A. Multi-channel Analyzer Development and Outline of Operation

A little over a decade ago, most multichannel pulse height analyzers were of a type called "discriminator" analyzers. In these instruments, a voltage sensitive discriminator was used in each counting channel, one of which would produce a pulse whenever an input signal occurred which fell within preadjusted voltage limits. A scaler was included with each channel, and a count of the number of pulses which occurred within each of the several voltage ranges was made. The resulting data indicated the distribution of pulse amplitudes which had occurred during the measurement. While such devices had the advantages of simplicity in electrical structure and of high operating speed, the disadvantages included such matters as high cost-per-channel, inconvenience of readout, and others.

Wilkinson introduced a new concept, in 1950, which has been the most popular method since. The Nuclear Data Model ND130A analyzer uses this concept. In this method, each input pulse is digitized (as will be described briefly) and the re-

sulting number for a particular pulse ^{produces} ~~products~~ a count in some form of pulse counter, with the selection of which counter is to receive a pulse determined by ordinary digital circuitry. The advantages instantly gained include the possibility of using a digital computer to count the pulses, and to store in its memory the information relating to each channel. The cost of such a computer is relatively small, and the number of counting channels provided has little effect upon the overall system cost. It permits the use of automatic curve plotting, automatic digital readout, cathode ray tube curve presentation, and even (in the case of the Model ND130A analyzer) internal data reduction.

The special purpose digital computer comprises the greater part of the analyzer system, in bulk and in cost. However, from an engineering point of view, and from the point of view of the scientist using the equipment, the most important portion of the analyzer is the analog-to-digital converter which produces, in response to each input pulse, a number whose magnitude is a linear function of the peak amplitude of the input pulse.

There has been little change, in the last ten years, in the basic method used for conversion.

Wilkinson employed a circuit which caused a capacitor to become charged to a voltage proportional to the peak voltage of the input pulse. Following this charging operation, the capacitor was linearly discharged, with the time required for this discharge therefore a linear function of the input pulse magnitude. During the discharge, pulses from a periodic pulse generator were counted by means of a simple scaler; the state of the scaler at the end of the process indicating in digital form the magnitude of the input pulse.

This description of the Wilkinson conversion method may also be used in describing the operation of the converter (generally referred to as the ADC) in the case of the Model ND130A analyzer. This description is, of course, not complete, in that nothing has been said of such things as coincidence gating, generation of "end of conversion" signals, and the like. For a preliminary understanding of the complete analyzer, however, no further discussion is needed of the ADC, in order to understand the overall structure of the pulse height analyzer.

The storage of information in the memory is accomplished by means of an arithmetic process which is serial-decimal rather than parallel decimal as is used in some analyzers. In serial decimal storage or readout, information is handled one decimal digit at a time, rather than as whole numbers. When adding two whole numbers, a human uses serial decimal arithmetic, for he adds the least significant digits, records on paper the result, considers the carry required when adding the next most significant digits, and so on. In "reading out" a whole number from a written notation, he vocalizes or re-writes the number one digit at a time, most significant digit first. The parallel arithmetic, used in most earlier analyzers, is less natural from the point of view of mechanical recording media such as magnetic or paper tape and of typewriters, which record one digit at a time. By use of serial decimal arithmetic, the need for conversion of whole numbers to serial form is avoided. Numbers read from tape need not be translated to parallel form as required in parallel systems.

B. Definition of Terms, and Description of Common Spectral Features

Before discussing the principles of radiation analysis, it will be helpful first to define, with explanatory remarks, the terms to be used in the discussion.

Some of these terms emerge from a description of the spectrum shown in Figure 2 which shows the distribution of energy of gamma radiation detected by means of a scintillation crystal, NaI (Tl), which is one of the most commonly utilized detectors. While the general shape of the Cs^{137} spectrum is peculiar to this form of detector, the observations usually apply to other detectors.

The presentation is in logarithmic form, wherein the vertical position of each point is at a level which is a linear function of the logarithm of the number of counts recorded in the corresponding analyzer counting channel. The horizontal calibration lines are decade lines, indicating the 1, 10, 100, etc., count levels. Various features of the spectrum are indicated by Figure 3, the legend underneath the figure, and the following explanation.

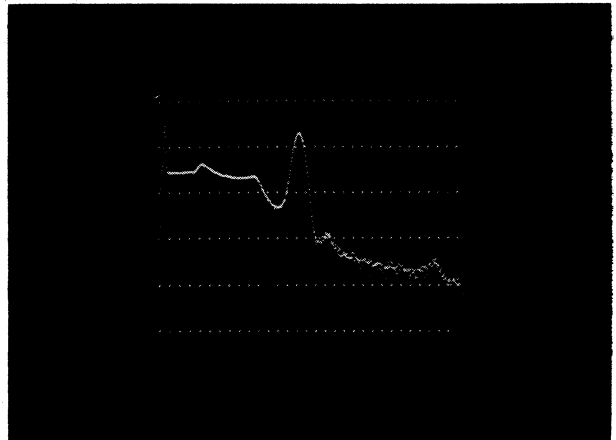


Figure 2. Typical spectrum of cesium 137, taken with energy scale set at about 1.3 m.e.v. full scale. Figure 3 indicates some of the more important features of this spectrum.

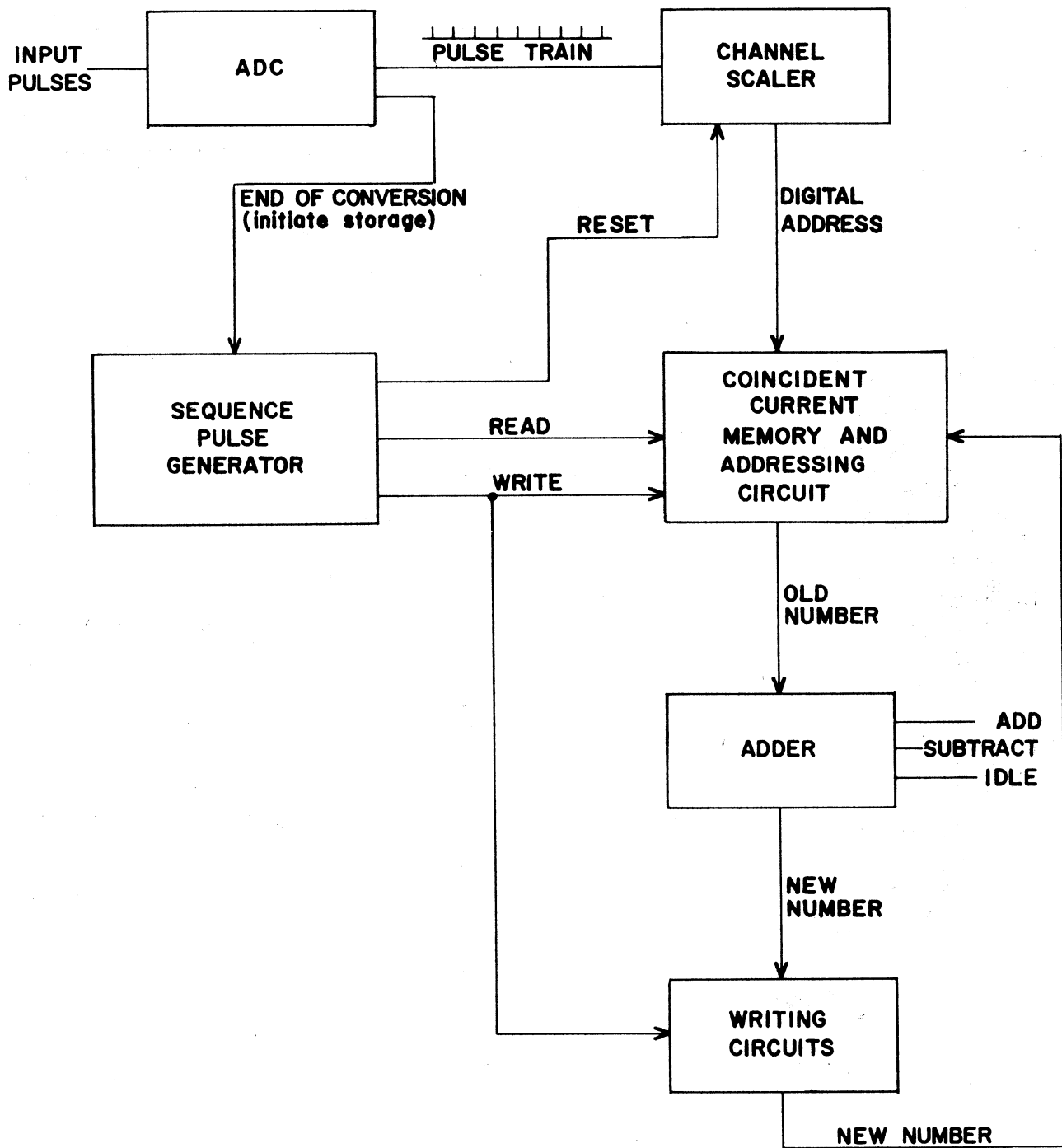


Figure 1. Block diagram of analyzer in analyze mode.

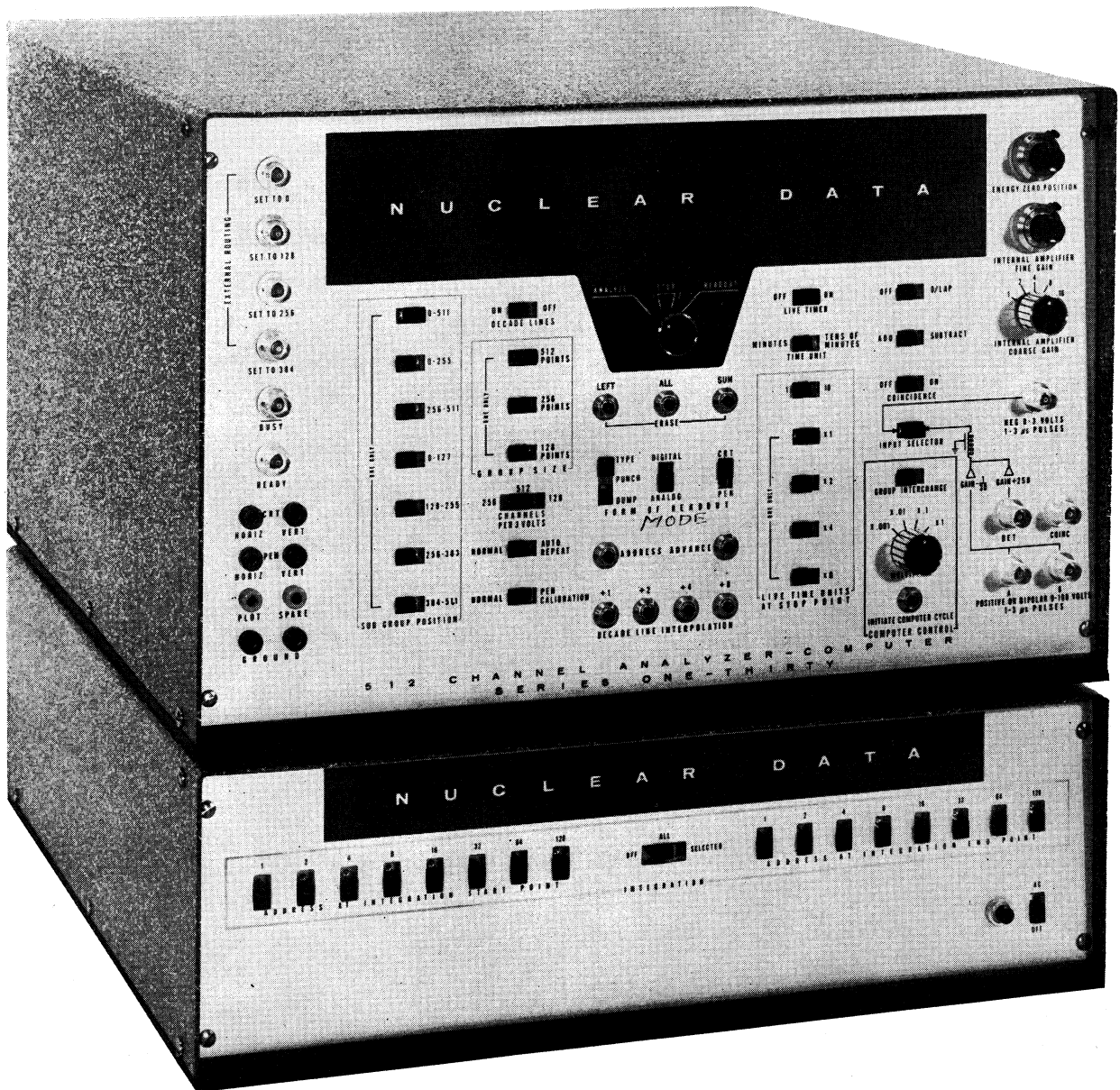


Figure 19. Front panel of ND130A multi-channel analyzer.

a. barium x-ray, 32 k.e.v.

This x-ray, shown in more detail in Figure 4, is useful from the operator's point of view in setting the analyzer zero energy position. It can be removed from the spectrum by use of an absorber such as a one-millimeter thick iron disk. There should be a flat region on the low energy side of this line, extending back to the photomultiplier noise region. Typical noise, at room temperature, does not extend beyond the equivalent of ten k.e.v. Slightly incorrect amplifier adjustments can cause this noisy region to extend up to the low energy side of the x-ray line, at high counting rates. Amplifier misadjustments (discussed in a later section) can be distinguished from photomultiplier noise by decreasing the counting rate. At low counting rates amplifier misadjustments produce proportionately less apparent noise, whereas photomultiplier noise is not affected appreciably by counting rate, and becomes proportionately a greater part of all recorded information.

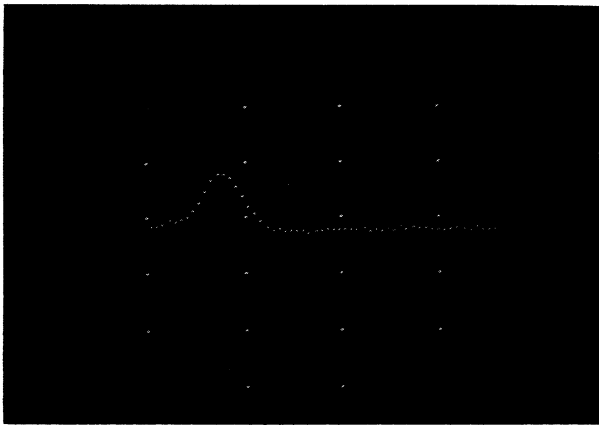


Figure 4. Expanded view of x-ray peak shown in spectrum of Figure 2.

b. Backscatter peak

This broad line is produced by gamma photons which are scattered back at about 180° from surrounding material. The amount of scattering is a function of the distance of the source from the material, decreasing with increasing distance. The proportion of backscattered gammas entering the crystal to the number of gammas directly received, for a fixed sample-to-surrounding-shield distance obviously decreases as the distance from the source to the detector decreases. The shielding around the detector and source should not be nearer than approximately one foot, and the source should not be more than two or three inches from the detector.

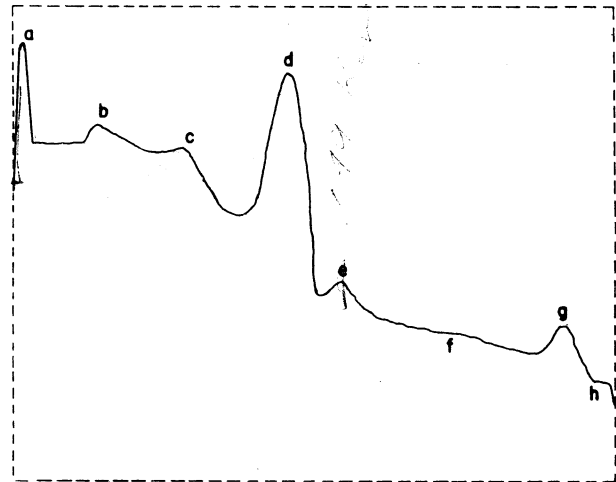


Figure 3. Principal features of typical cesium 137 spectrum shown in Figure 2. (Detailed explanation given on pages 2, 3, 4 and 5)

- a. 32 k.e.v. Barium x-ray line.
- b. Backscatter peak.
- c. Compton edge.
- d. Photopeak, cesium 137, 0.662 m.e.v.
- e. 749 k.e.v. photopeak of cesium 134 impurity.
- f. Continuum due to accidental self-coincidences producing partial sum pulses.
- g. Accident sum coincidence peak.
- h. Detail due to background radiation.

c. Compton distribution

Although the cesium 137 source emits a nearly monochromatic gamma, the sodium iodide crystal does not absorb all of the energy of all of the gamma photons entering the crystal. The amount of energy absorbed in the crystal is quite random, except that there is a minimum amount of energy with which any gamma may escape after interacting. The probability of any gamma, which has lost only part of its energy in an interaction with an atom within the crystal, losing all or part of its remaining energy in interactions subsequent to the initial "collision" increases with crystal size. The resolution of the crystal-photomultiplier combination usually decreases somewhat as the crystal size increases, but the slight loss in resolution is much less important than the effect of a large number of gammas escaping the crystal after losing only part of their energies.

d. The 0.662 m.e.v. photopeak.

Those gammas which loss all of their energies within the crystal produce a large number of scintillations in the crystal. The number of light photons produced is, on the average, proportional to the gamma energy absorbed, but unfortunately only a small percentage of light photons produce photoelectrons at the photomultiplier cathode. Since the number of scintillations and the number

of photoelectrons produced is subject to statistical variations, the pulse height produced at the photomultiplier anode differs from individual gamma photons, despite the fact that all of the absorbed gamma photons were virtually identical in energy. The width of the photopeak, at half height, is approximately equal to $2\sqrt{N}$, where N is the average number of photoelectrons produced at the phototube cathode. A typical width, at half height, for the cesium 137 photopeak, is 53 k.e.v. Excellent photomultiplier-crystal combinations provide a width of 46 k.e.v. The difference in effectiveness is surprising. An interesting observation in this connection is that users who would not accept an analyzer which had a resolution not nearly perfect are frequently content to save a few dollars by ordering an unselected photomultiplier-crystal combination. Using a crystal which has a resolution of 60 k.e.v. (which many detectors have) makes it impossible to detect the presence of a percent of cesium 134 (gammas at 0.605 and 0.794 m.e.v.), whereas a detector with a resolution of 54 k.e.v. can detect the presence and indicate the amount of cesium 134 to less than a tenth of a percent of the amount of cesium 137 in the source. It is highly recommended, for gamma analysis, that every effort be made to obtain the highest resolution detectors. If a large (at least 3" x 3") crystal and good photo-multiplier is obtained, it should be treated with great care, particularly in avoiding rapid temperature changes (a degree or two an hour, or less). Figure 5 shows a radium 226 spectrum taken with a good detector and Figure 6 shows the spectrum with the same source and geometry but using an indifferent detector.

e. The 0.794 m.e.v. cesium 134 photopeak.

f. Accidental self-coincidence continuum.

At any counting rate, there is a finite probability of two gammas entering the crystal at nearly the same time. Even if these gammas are of identical energies, there is a certain chance that one, or neither, will lose all of their energies, or that both will be totally absorbed. There is a greater chance that they will enter at slightly different times, perhaps a microsecond apart, than nearly coincidentally. There will always be a photomultiplier output pulse which is greater than if only one of the gammas had entered, if the two are coincident within a microsecond. The "sum" pulse produces the apparent continuum beyond the photopeak, and in fact produces a continuum at lower energies also, obscured by the non-coincident gamma counts. The number of counts in this continuum is directly proportional to the source intensity, for a given isotope. It is obvious that not only is this continuum capable of completely obscuring very weak lines, but what is quite as important in some cases is the fact that counts appearing in this continuum represent counts which have been "swept out" of some other region of the spectrum by the accidental self-coincidences. Analyzers capable of perfect, dead time corrected, timing of experiments are frequently accused of incorrect timing because of the absence of counts in a line, swept out by accidental coincidences. Errors of a percent can occur at counting rates of 10,000 pulses per second while the accuracy of the timing should be better than one percent. The sweepout effect must be considered during tests of timing accuracy or during quantitative measurements of activity.

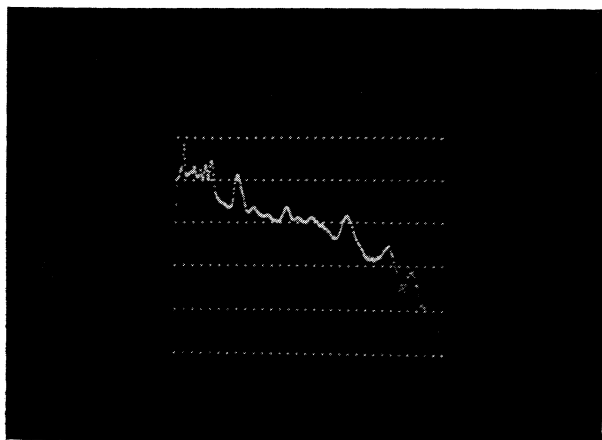


Figure 5. Spectrum of radium 226 taken with good resolution crystal and photomultiplier combination. Compare this with Figure 6.

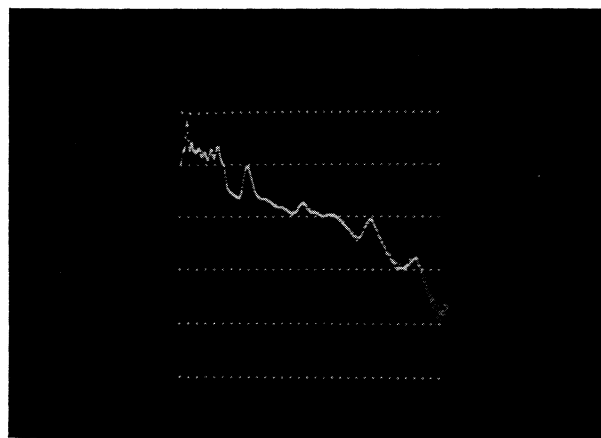


Figure 6. Spectrum of radium 226 taken with poor resolution crystal and photomultiplier combination. Compare this with Figure 5.

g. The accidental self-coincidence sum peak.

Calculation of the shape of the self-coincidence component of the complete spectrum would be difficult, since the amplifier and analyzer characteristics enter the situation. It is not difficult to see, however, that it is not unreasonable to expect that two completely absorbed gammas virtually in coincidence will occur frequently enough to produce a sum peak at the region corresponding to 1.324 m.e.v. Such "accidental" or quasi-sum peaks can

readily be distinguished from true sum peaks by changing the counting rate without changing the source-to-detector position (use a weaker sample). True sum peaks do not vary in intensity, relative to other lines in the spectrum, as a function of source intensity.

h. Background detail.

The detector used in this measurement was not shielded.

C. Principles of Radiation Analysis

In this section will be discussed the numerous concepts and instrument requirements which are encountered in the analysis of the energy distribution of events detected by various radiation detectors. The discussion will be general in the sense that it will usually not refer to the use of Nuclear Data analyzers but to matters encountered in the use of any pulse height analyzer. It should not be taken to represent universally accepted interpretations, but it is a reasonably objective discussion.

In any interpretation of a multi-channel analyzer spectrum, it is important that all the effects of experimental conditions be carefully considered. For example, in the spectrum shown in Figure 2, experimental conditions can alter the shape of the spectrum in many ways. The amount of X-radiation detected depends upon the material between the source and the sodium iodide crystal, and the backscatter peak magnitude depends upon the nature and location of the surrounding material.

The reasons for which these changes in condition can alter the spectral shape are for the most part beyond the scope of this discussion. But it is important to appreciate that conditions which might appear irrelevant to those not well acquainted with the techniques, can markedly affect the spectrum shape. Not only can experimental results be misinterpreted, if the experimental conditions are improperly controlled, but the operation of the analyzer cannot properly be evaluated unless test conditions are quite well reproduced.

The effect of counting rate, that is to say, source intensity, upon the shape of the spectrum is evident from the comparative measurements shown in Figures 7 and 8, of two measurements made under the same conditions except for source intensity. The apparent continuum of radiation beyond the photopeak is at a higher level for the case of higher counting rate than for the low counting rate measurement. This is to be expected, for the following reasons.

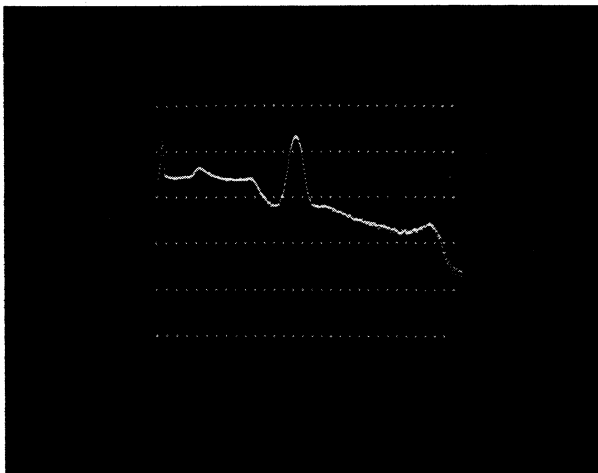


Figure 7. Spectrum of cesium 137 taken at high counting rate. Note the large number of counts beyond the photopeak due to pulse pile-up. Compare this spectrum with that shown in Figure 8.

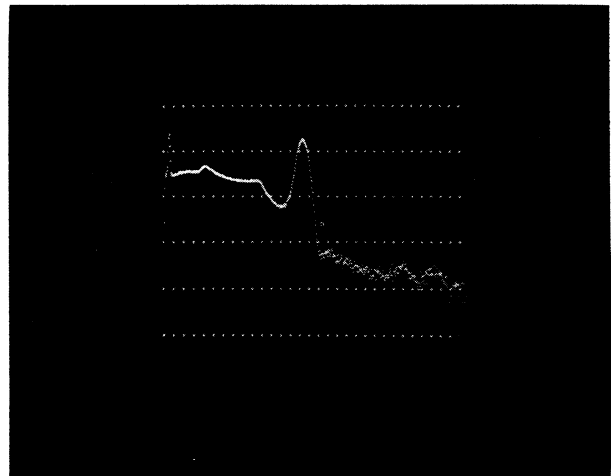


Figure 8. Spectrum of cesium 137 taken with same detector and geometry as for Figure 7, but at reduced counting rate. Note the fewer pulse pile-up counts beyond the photopeak compared with the spectrum taken at high count rate, also cesium 134 (0.794 m.e.v.) photopeak not visible in Figure 7.

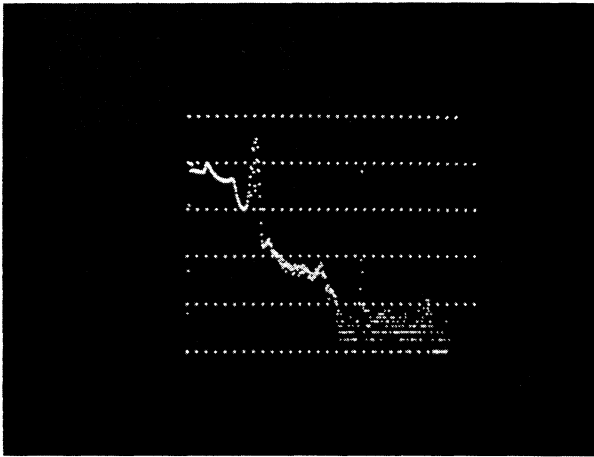


Figure 9. Spectrum taken with pulser superimposed on cesium 137 source to show how counts are "swept out" by coincidences between the cesium and the pulser pulses.

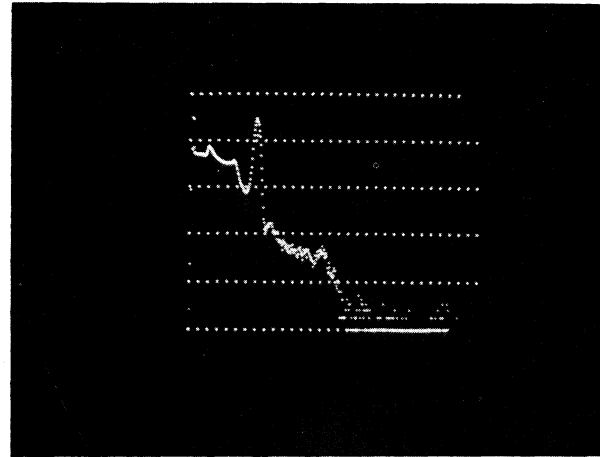


Figure 10. Spectrum taken with identical source, detector, and geometry as in Figure 9, but without pulser. Note the few "swept out" counts in this spectrum compared with that of Figure 9.

The probability of two events being nearly coincident, by accident, at any given counting rate can readily be calculated. If the input pulses are one microsecond wide, after amplification and shaping, then at 10,000 events per second at the radiation detector, about one percent of the events will be to some degree improperly reported by the detector. It is not always important that the number of accidental self-coincidences be minimized, but in some measurements if such coincidences occur once per hundred pulses, the error may be important. What is more, there may well be information of interest obscured by the presence of large numbers of "accidentals". The illustration shown in Figure 7 is an excellent illustration of this effect. The cesium 137 source used contained a small amount of cesium 134 as an impurity. The relative amounts have the ratio of perhaps one part in five hundred, in this particular sample. In the illustration showing the spectral shape at low counting rates, this trace impurity can be seen, but at high counting rates, it is completely obscured. Where accurate quantitative measurements are involved, and whenever experimental conditions permit, analysis should be at a sufficiently low counting rate to reduce the number of accidental coincidences to an acceptably low level. The effects produced by accidental self-coincidence are commonly referred to as pulse pile-up effects.

Figure 9 shows, in an artificial situation, this effect in a manner which makes quite clear that it is not only the obscuring effects of scattering which results from accidental self-coincidences which are undesirable. It is the fact that counts are *missing* from the spectral lines involved which is often misleading. In the example shown in Figure

9, a cesium 137 spectrum is shown, with a low amplifier gain. Superimposed upon the signals from the detector was a periodic, constant amplitude pulse. In the absence of detector signals, the periodic pulse would be analyzed as a monochromatic line at about channel 296, and there would be about 7000 counts in the line. However, frequently this periodic pulse occurred at the same time that a gamma photon entered the detector, and was analyzed as an event of higher energy than the energy corresponding to that of the monochromatic line. Counts have been "swept out" of the monochromatic line, and the intensity of the line appears less than it actually is. Obviously this effect should be considered in interpreting the spectrum, particularly in this case where it can be seen so clearly. Figure 10 shows the same situation without the presence of the periodic pulses. The "sweep out" effect can easily be overlooked, or forgotten in error, however, and in such cases either data will be misinterpreted, or what is even less to our liking, the correctness of the analyzer timing circuits may be suspected.

More frequently than in the past, automatic data reduction techniques are utilized in interpreting accumulated data. The method most commonly used is to subtract, point by point, one or more components of the spectrum by use of a previously measured or computer-derived standard spectrum. If the standard spectrum was compiled at low counting rate, then the remainder of the complex spectrum, after subtracting out a single component, may be in error if the complex spectrum was measured at high counting rates. The same sort of error will be made if the source-detector geometry has been changed from that used in accumulating

the standard. This is further evidence that for highly accurate work, source intensities should be kept as low as economics and other experimental factors permit. Carefully standardized detector-source geometries, and standardized energy scales are recommended in applications involving activation analysis.

A large proportion of the applications made with

this type instrument do not involve gamma analysis, of course, and in some cases alpha radiation, rather than gamma radiation is involved. Some mention of these applications will be made in later sections, but inasmuch as the input signals are of the same general shape and randomness as those encountered in gamma analysis, the requirements upon the analyzer are roughly the same.

II. CHARACTERISTICS RELATING TO MEASUREMENT PRECISION

Various analyzer characteristics are of importance in influencing the precision of the data accumulated. It is important that these characteristics be evaluated initially, and perhaps monthly thereafter. Linearity, stability, resolution and scatter-freedom, and live timer accuracy are the most directly important of these characteristics. These will be considered in this order, with illustrations of their meaning given where applicable, and various tests to determine these characteristics will be discussed.

A. Linearity

The characteristic curve, for a particular analyzer, indicates the channel number into which a pulse of any amplitude will be recorded. Ideally this should be a straight line. The departure of this characteristic curve from a straight line passing through zero amplitude and channel zero, at any abscissa, is a measure of the non-linearity. This measure is expressed in two ways, both of which are of importance.

The *integral linearity* is the ratio of the departure, at any point, to the pulse amplitude corresponding to full scale. Generally the term *integral linearity* is intended to mean the ratio defined above at the worst part of the characteristic.

As a practical matter, this is a poor description of the quality of an analyzer's linearity. It is a well entrenched definition, however, and it is important to understand its meaning and limitations. The principal limitation lies in the fact that the percentage error of pulse height (or particle energy) expressed as the ratio of the actual error in energy to the correct energy may be very great in the lower pulse height regions, and yet the integral linearity, as defined above, may be apparently excellent. An integral linearity of $1/2\%$ may produce actual energy errors, in the lower energy regions, of several percent.

A second definition of linearity is referred to as the *differential linearity*. This is an indirect sort of description of absolute linearity, meaning the uniformity of channel widths over the entire range. A differential linearity of 2%, as an example, means that no channel departs by more than 2% in width from the average channel width over the entire range. This description has the merit that it fixes the maximum limit of the ratio of the absolute energy error to the energy, at any point, and therefore assures those interested that the analyzer does not become highly non-linear at the low energy regions.

A more meaningful description of linearity, which to distinguish it from the other definitions may be called *absolute linearity*, is the ratio of the error in energy to the true energy, at any region.

These various definitions have arisen because of the peculiarities of multichannel analyzers. It is usually more difficult to achieve absolute accuracy in the lower energy regions than the middle or high energy regions. A definition which fairly indicates the limitations in the low energy regions presents a picture of quite inadequate linearity in the higher energy region. On the other hand, the common definition of integral linearity, which is a realistic way of describing performance in the higher energy regions, may suggest far better precision in the low energy regions than actually exists. At least two definitions must be utilized in order to adequately describe an analyzer's performance.

There are two methods which may be used to check linearity. One is by means of a precision pulse generator, which may be used to provide pulses of full scale amplitude, half full scale, a quarter of full scale, and so on. This is the most rapid means for testing, but the tests must be made with care, for such effects as overloading of the pulser (some of which are designed for operating

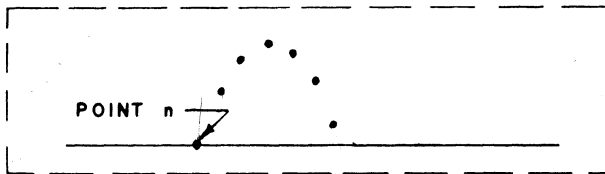


Figure 11. Determination of peak location.

1. Select some arbitrary count level, preferably near half height, and preferably passing through a data point such as point n.
2. Count the number of channels between this point and the intercept of the curve with the selected count level line.
3. Divide the number of channels by two. In this illustration there are 6.3 approximately, which gives the number $6.3/2 = 3.15$. The peak is centered in channel $n + 3.15$.

into an infinite impedance), use of improper pulse rise time or decay time, and others, can give results suggestive of excessive analyzer non-linearity. Many laboratories do not own a precision pulser, so other methods should be devised.

The engineer quite naturally thinks of utilizing a pulser for linearity checks, since he frequently employs such a device in the process of design. The scientist is more likely to consider the direct approach of measuring various radiation sources, and calibrating the analyzer by observation of the positions of the various spectral lines. This method is slower, inasmuch as a few minutes are required to determine, with accuracy, the actual line positions. Care must be used to avoid the use of spectral lines falling upon the Compton edge corresponding to gammas of higher energy, if gamma radiation is involved, for the position of the line may be altered measurably if it occurs at a position where the count levels due to higher energy radiation are rapidly changing as a function of channel position.

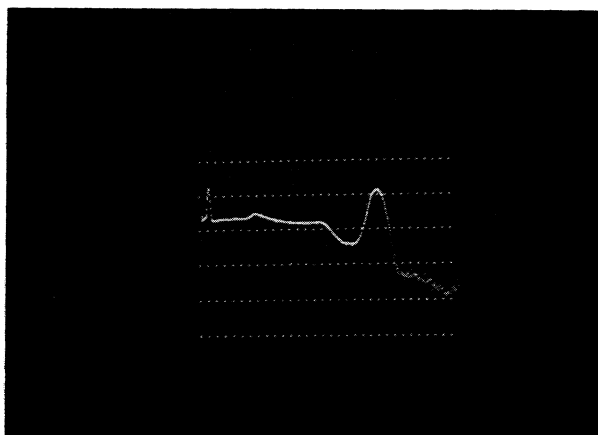


Figure 12. Spectrum of cesium 137 taken with gain of about 0.89 m.e.v. full scale. With good linearity, spectral shapes should be similar at high and low gains. See Figures 13 and 14.

In determining line positions, it is not permissible to use the highest point in a "peak" as the indication of line center point. Figure 11 indicates a more accurate method. The "highest point" method can easily be in error by as much as one channel, whereas the method indicated is accurate to a degree limited only by the slightly asymmetrical shape of the photopeaks. Accuracies of a small fraction of one percent in determining absolute energies are easily obtainable. Generally the multi-channel analyzer precision does not justify determining energies with such accuracy, but in this application the object is to determine the analyzer accuracy from the known energies of different lines. An excellent combination of sources is cobalt 60 and cesium 137. Lines at 2.5, 1.33, 1.17, and 0.662 m.e.v. are provided. A second measurement of the same source, with the gain set at one half

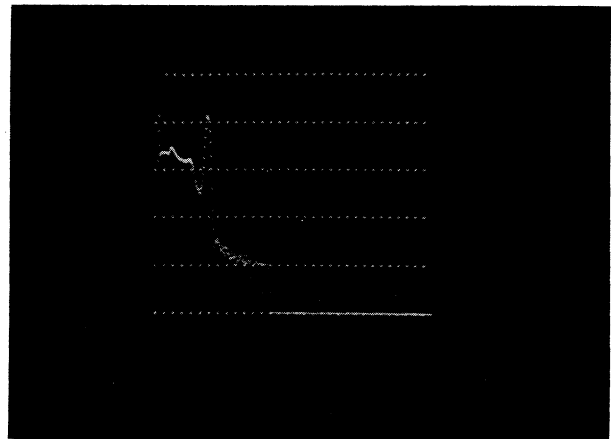


Figure 13. Spectrum of cesium 137 taken with gain of about 3.53 m.e.v. full scale. Expanded view of this spectrum is shown in Figure 14.

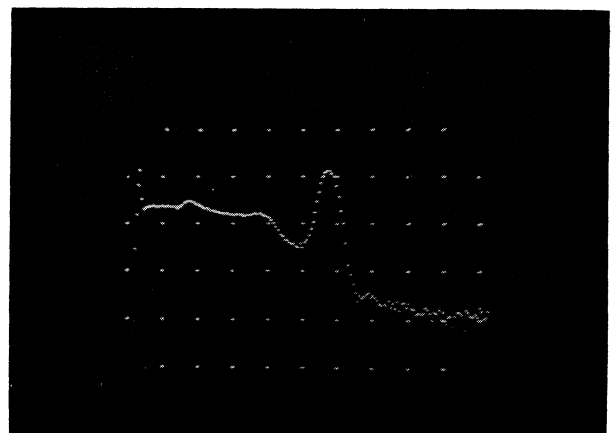


Figure 14. Expanded view of spectrum shown in Figure 12. This spectral shape should be compared with that of Figure 12.

that of the first measurement, allows calibration of the lower pulse height regions. While it is true that it is not practical to determine whether or not the gain setting has been reduced by exactly one half, if both measurements indicate high linearity it is reasonable to assume that the entire linearity characteristic is good.

A rapid indication of the differential linearity of an analyzer can be obtained by making two measurements of a simple spectrum, such as that of cesium 137, at two widely different gain settings. If the spectral shape is the same for both cases, this is an indication of excellent differential linearity. Figures 12, 13, and 14 indicate such a comparison test.

There is a great difference between the linearity required in some applications as compared with others. Just as a micrometer need not be linear or accurate at all, providing it does not change in characteristics, if it is to be used for comparison, so an analyzer need not be very linear if comparison methods are to be used, or if the intensity of lines of known energy is the only variable of interest. Nevertheless, excellent linearity is required in many cases.

If the information accumulated is to be compared with standard spectra, or with information obtained with another analyzer, it is important that the linearity be good. If automatic data reduction techniques are to be employed, using standard spectra as a basis for "stripping" various components from a complex spectrum, the linearity must be excellent. An exception to this, of course, is the case in which the same analyzer is to be used for both the accumulation of standard spectra and for measurement of the new unknown, for in such cases the non-linearities of each analysis match.

B. Stability

There are two types of drift encountered in the use of pulse height analyzers. One of these is the shift of the entire spectrum left or right; this is a shift of zero energy intercept, and is referred to as "zero shift". Such drift is almost always a fault of the ADC. The other is a drift in gain, which may occur at the detector, in the amplifier, or in the ADC, or all three. It is obviously easy to detect the presence of either of these types of drift, and quite easy to distinguish between them. It is always necessary, in the case of gain drift, to determine which of the three components is at fault. If the drift is extreme (e.g. two or three percent), the isolation process is not difficult, and steps as outlined below can be taken to determine the fault. For drifts of a smaller amount, special methods are often necessary.

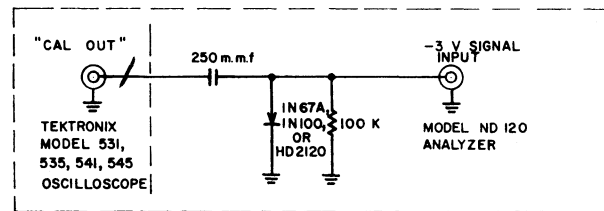


Figure 15. Use of Tektronix oscilloscope calibration signals for analyzer tests.

The most fruitful first step in determining the source of gain drift, where the drift is considerable in amount, is simply to examine the signals from the detector by means of an oscilloscope. A good oscilloscope is sufficiently stable to allow drifts of as little as five percent per day to be measured. The oscilloscope should be directly connected to the detector output, without connecting to the analyzer. If there is drift, this may be due to a faulty detector or to an unstable high voltage supply. If possible, the voltage supply should be replaced by another, to determine the fault as being either the supply or the detector proper. Where this is not possible, a good voltmeter can usually show supply instability. For the best sensitivity, the technique of measuring the supply voltage with the voltmeter returned to a nearly equivalent voltage from a battery stack (using great care to avoid electrical shock), can be used. If the batteries have not been loaded with more than a microampere, for a few days, and if they are maintained at nearly constant temperature, drifts of a few hundredths of a percent in voltage can be detected.

If the tests indicate that the detector is at fault, the difficulty can sometimes be corrected without changing the photomultiplier tube. Magnetic field changes, for example, produced by altering the position of the detector with respect to the earth's field, can produce substantial (several percent) gain changes, if the detector is not shielded. Permanent magnets in nearby equipment, or in voltmeters, can produce fields which will alter detector gain. *Photomultiplier tube gain is a function of temperature*, it cannot be expected that operation will be satisfactory in ambients which vary considerably in temperature.

To distinguish between amplifier gain changes, and drift in the ADC gain, it is necessary to introduce constant amplitude pulses directly into the ADC. These should be fairly short, perhaps ten microseconds in duration, with a rise time of one or two microseconds to the maximum point. Such a pulse can be obtained from the voltage calibrator of most Tektronix oscilloscopes, using the circuit shown in Figure 15.

The amplitude stability of such a pulse source is only fair, so something should be done to accelerate the drift of the faulty part of the analyzer, if there is in fact a fault as indicated by careful examination of the detector stability. Almost all drift in the analyzer circuits is produced by temperature changes. For rapid determination of drift location, therefore, it is useful to either cool or warm the analyzer below or above room temperature. Then apply the constant amplitude pulse, in the analysis mode, and observe the system behavior. If a change of fifteen or twenty degrees fahrenheit does not produce drift of consequence, then it is generally reasonable to assume that the portion of the system being tested is stable. *Do not heat and cool scintillation detectors*, for they will fracture at even very low rates of temperature change.

If any portion of the analyzer is found to be the cause of the drift, Nuclear Data should be notified, unless highly skilled personnel are available to attempt to correct the malfunction. The best procedure to follow in the event it is elected to correct the malfunction is to cool individual ADC or amplifier circuits, using a cooling spray such as "Zero Mist", to isolate the faulty component.

C. Resolution and Scatter Freedom

In using this analyzer for alpha radiation analysis, either solid state diode detectors or proportional gas detectors are used. In either case, spectral lines are far better resolved than with scintillation detectors. The reason for the better resolution is simply that many more ionizing events are produced and the mean deviation is therefore a smaller percentage of the average number, for a given alpha particle energy, than is the case for the mean deviation of the number of photomultiplier photoelectrons emitted per event involving a gamma of the same energy.

In order to avoid degrading the resolution of the overall measurement, it is necessary that the analyzer not introduce a spreading of an otherwise nearly monochromatic spectral line.

The simplest test of this quality, on a short time basis, is to apply signals from the Tektronix voltage calibrator output terminal, or from a precision pulser, to the analyzer. The details of connections, and pulse shapes required, are discussed in the section concerning input pulse shapes (section IV). The pulses should all fall into a single channel, if the pulse source is stable, and if the pulse amplitude does not lie at a value corresponding to the end or beginning of the channel. A slight amplitude or amplifier gain adjustment should always finally result in all counts being recorded into a single channel. Where 512 channel operation is involved, the channels are quite narrow, and it is

possible that the small transients produced in switching to the analyze mode of operation may cause the first two or three pulses to be improperly recorded. This effect may be eliminated by holding the analyzer erase button depressed until after the analyzer is in the analyze mode. Typically, the scattering of such effects as amplifier noise, supply voltage ripple, and the like, introduces about one half of one channel of "jitter". If the pulse amplitude is adjusted to fall in the center no counts will occur in adjacent channels. Performance can be considered adequate if there is no more than plus or minus one half channel of "jitter."

Quite as important as short term "jitter" is long term gain and zero stability. For measurements of, say, eight hours duration, it is necessary that the gain and zero shift, and short term "jitter" be appreciably less than the natural width of the spectral lines of interest. To minimize drift, the analyzer should be operated under the most favorable conditions. It should be operated in a reasonably cool (75°F) environment, with constant temperature of environment. The line voltage should be stabilized, and it is preferable to keep the analyzer continuously on for an hour or two before highly demanding measurements. Such measures are not required for scintillation counter applications, since gain or zero drifts of a fraction of a percent are not serious. A half percent drift, when utilizing a high resolution counter, however, may decrease the measuring resolution by more than a factor of two. It is not possible to state exactly what stability can be expected of the analyzer proper, under such favorable conditions, but in at least one application the ADC circuits used in this analyzer have permitted a five day measurement of a line 0.35% in width without noticeable loss of resolution.

In high resolution measurements, it is usually necessary to use special low noise, high stability, preamplifiers. It is recommended that all amplification be accomplished external to the analyzer. The internal amplifier is designed for sodium iodide scintillation detector applications only. Amplifiers are discussed in Section IV.

Whatever type detector is employed, scattering due to accidental near coincidences will occur and an artificial "monochromatic" line will be widened at high input signal rates. A comparison of line position at higher pulse rates is an important measurement. This comparison may be made by superimposing periodic pulser signals upon random detector signals, and varying the random pulse rate. There should be no shift in position, and at least half of all counts corresponding to the pulser "line" should fall into one channel, if the pulser was initially set to a value corresponding to the center of a channel. These conditions should

apply at input signal rates of 10,000 counts per second, in the case of scintillation spectrometry. Greater loss in resolution than this, or even a single channel of position shift, indicate possible malfunctioning of the analyzer. Care should be taken not to reach this conclusion too quickly, of course. The pulse source stability should be verified, and no experimental conditions should be changed, except removal of the radiation source, in making the comparison. A shift of one channel in the position of the pulser line is not ordinarily serious, particularly since high precision and counting rates this high are generally incompatible because of the almost unavoidable effects of accidental self-coincidences.

A very practical and simple test of the effects of counting rate upon analysis accuracy is to make two measurements of a combination of radiation sources, as follows. For gamma analysis, a cobalt 60 source and a cesium 137 source may be used. A one microcurie cobalt 60 source, placed directly upon the crystal, and a one microcurie cesium 137 source placed about 3 centimeters away is a suitable geometry for the first measurement. After a two or three minute measurement, remove the cobalt 60 source, and subtract cesium 137 counts, only, for the same live time. At the end of the measurement, the remainder will be cobalt 60 spectrum, with no differences noticeable from that of a measurement of the cobalt, alone, if the analyzer is perfect, and if "sweep out" effects are neglected. Figure 16 shows the results of such measurement. It can be seen in this measurement that there was evidently a slight shift in the position of the 0.662 m.e.v. cesium photopeak, in the second measurement, for more counts were subtracted from the low energy side than the high energy side. The "wobble" shown in this example, in the remainder spectrum at 0.662 m.e.v., corresponds to the effect of about a fifth of one channel shift in position at the higher counting rate. A one channel shift would have produced a "wobble" of about a third of a decade in amplitude.

Only a considerable malfunction would produce as much as a one channel shift at the higher counting rate present when both sources are in position. However, amplifier or detector misadjustments can produce such a shift, as explained in the section on amplifiers. Drastic gain changes occur in some photomultipliers, when high counting rates are involved, with the original gain re-assumed only after minutes or hours after the sources are removed. This characteristic is almost intolerable, and should be corrected by changing photomultipliers. Photomultiplier tubes which satisfy the requirement of virtually no gain shift with counting rate, as well as providing high resolution, are valuable and should be treated accordingly.

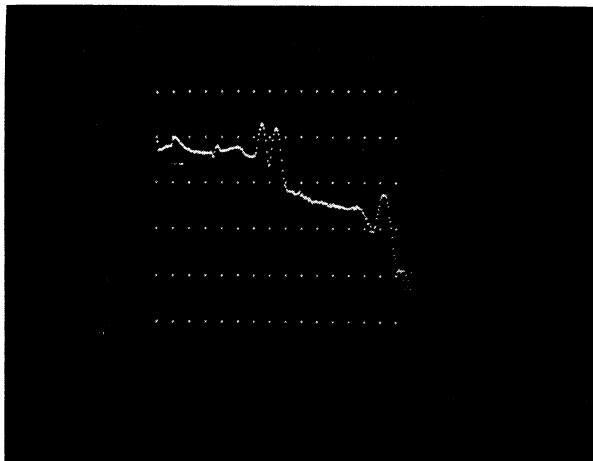


Figure 16. Cobalt 60 spectrum after subtraction of cesium 137 showing 'wobble' at 662 k.e.v. due to shift of about 1/5 channel during subtraction.

Where some doubt exists as to the cause of gain changes with counting rate, a constant amplitude pulse should be superimposed upon the random signals. If the photopeak of a spectrum shifts with counting rate increases, but the monochromatic pulser line does not, the phototube should be strongly suspected. Amplifier misadjustments can produce the effect, however, so if possible the pulser signals should be introduced through a small condenser directly at the phototube anode, so that they suffer the same amplifier effects as the detector signals. Spurious lines produced by this makeshift way of introducing monochromatic pulses at this point may be ignored; the pulser line change, as a function of counting rate, is the only variable of immediate interest. It is well to "look" at the detector anode signals with an oscilloscope as an aid in adjusting the periodic pulse amplitude. The pulser signal shape is not critical, for this experiment, but its rise time should be about one microsecond or less.

D. Timing

The dead time of an analyzer may be defined as the total length of time during a measurement in which signal pulses, if they occurred, would not be recorded as counts in the analyzer. The live time, naturally enough, is the time during which the analyzer is not dead. To a first approximation, the experiment live time is equal to the elapsed calendar time minus the total time taken during the actual analysis and storage of the events recorded. This is only an approximation, for many pulses will occur during times in which the analyzer is not actually busy, but during times in which the linear gate is reopening after an earlier

analysis. Such signals are rejected by the ADC, despite the fact that it was not actually busy at the time of occurrence, to avoid accepting possibly distorted pulses. This "rejection sensitive" time is an important part of the actual dead time in the sense that it is counting rate dependent, and can amount to several percent of an experiment's live time.

Some analyzers provide a live time indication by integrating the entire time during which the analyzer is neither dead nor in a "rejection sensitive" state. This integration is accomplished by counting pulses from an oscillator, during the "live" intervals. The total number of such pulses is proportional to the integrated live time.

This concept is very easy to understand, of course. The mental picture which this description usually produces is one of an oscillator operating at a megacycle rate, or thereabouts, so that each live time interval can be measured with an accuracy of about a microsecond, which is a reasonable situation. There is a disadvantage to this approach, however, in that measurements are sometimes made for several hours, which means that several billion oscillator pulses must be counted. A ten decade counter is expensive, so an alternative means has been devised for determining live time, using a much lower frequency.

This method uses the same concept of counting oscillator pulses which occur during live intervals. Even if the oscillator pulses were at a one pulse per second rate, after a sufficient interval enough such pulses would be counted to represent accurately the percentage of time the analyzer was live. The method is really a periodic sampling of the state of the analyzer. If the "clock" frequency were in fact one cycle per second, then after ten thousand clock pulses were counted, a live time of ten thousand seconds must have elapsed. The calendar time elapsed may well have been twenty five thousand seconds, but a little consideration shows that the elapsed live time is very nearly ten thousand seconds. The process introduces statistical errors, but generally not of consequence, since at the relatively low counting rates (e.g. 5,000 input pulses per second into the ADC) used where precision of analysis is required, the clock counting process is not completely random, and in fact the mean deviation is only a small fraction of a percent, in a sampling of 10,000 accepted clock pulses. A one cycle per second clock is excessively slow; the N130A analyzer utilizes a ten thousand per minute clock frequency, in order that a good statistical sampling can be obtained in one live minute.

The analyzer is automatically stopped after some preselected number of clock pulses have occurred during live intervals. The preselected number is always at least 10,000 or one live minute, and the maximum selectable live time is 800 minutes.

The accepted clock pulses are stored in the first analyzer counting channel, and circuits within the analyzer constantly "monitor" the clock pulse channel for the purpose of stopping the analysis when the preset level is reached. If the analysis is manually stopped, the clock channel retains the information showing the duration of the measurement, and if a subsequent measurement is made in the subtract mode of operation, the analysis is automatically stopped when the clock channel is emptied. This feature is referred to as the "experiment time memory".

Because a single channel can store only one million counts, and since the minimum number of clock pulses that can be preselected is 10,000 in order to insure good statistical accuracy, evidently the total range of measurements which could possibly be preselected is 100 to 1, or 100 minutes. To increase the range covered, the clock oscillator frequency may be set by switch selection to 1000 pulses per second, which allows timed measurements of up to 1000 minutes. Practical considerations dictated that the maximum preset time for automatic stop of analysis be 800 minutes, because the clock channel monitor is of simpler design if it need recognize only times for which the most significant digit is an integral power of two, with the exception of 1000.

The present discussion is not intended to describe the mechanical operating details associated with selection of live time, but rather to outline the basic approach used. The essential facts can be reviewed simply by stating that the total live time elapsed during a measurement is determined by a periodic sampling of the state of the analyzer. Each time a clock pulse occurs during a time in which the analyzer is not dead, a count is stored in channel zero, the "clock channel" of the analyzer. When 10,000 counts are recorded in this channel, evidently one live minute has elapsed. A greater number of clock pulses counted in this channel indicates that proportionately greater live time has elapsed.

There is of course a little dead time introduced by the act of storing so many clock pulses. Storage requires approximately 18 microseconds, so a total of 180,000 microseconds is used each minute of live time. This dead time is not considered by the live time circuits, of course, since no clock pulse is ever missed on account of storage of an earlier clock pulse, for they are separated by six milliseconds. However, the error is less than one third of one percent, normally negligible, constant, and easily correctable.

The greatest source of error in analyzer timing circuits is usually in the determination of when the analyzer is actually dead, and when it is not. Most analyzers do not consider the "rejection sensitive" time as dead time, and there are certain other less

important effects not considered. To avoid this problem, the clock pulses counted in the Model ND130A analyzer are introduced as "tagged" signal pulses, at the ADC input circuits. If the clock pulse is accepted by the ADC, and not rejected on any basis, then the storage of a count in the clock channel is immediately started, and the attempt by the ADC to actually analyze the "tagged" signal pulse is aborted. There is no difference, whatever, in the probability of the clock pulse being accepted than that of any real signal pulse being accepted. The percentage of clock pulses accepted, therefore, is virtually identical to the percentage of real signals which are accepted. When 10,000 clock pulses have been accepted, then with proper consideration of possible statistical errors, one live minute has elapsed. For longer measurements, or at relatively low signal pulse rates, the timing accuracy is a function only of the stability of the clock oscillator. Tests at 10,000 signal pulses per second should show an accuracy to well under a percent.

There are a number of ways in which the timing process may be checked. The frequency of the clock oscillator should be occasionally measured by observing the length of a measurement in which there is no dead time produced by detector signals. Live time, under these conditions, is equal to real time, so the correctness of the clock oscillator may be easily determined. The oscillator is not crystal controlled and is therefore subject to some drifts. The drift should not exceed a percent per month nor a percent per 20°F temperature change. The frequency can be readjusted, if necessary, by adjusting the two potentiometers located on the front panel circuit board, located inside the cabinet, just above the clock on-off switch.

As indicated earlier, the major problem in timing is not associated with oscillator frequency stability, but with determination of effective dead time. To measure the overall accuracy, it is not necessary to use precisely calibrated radiation sources, as might at first be supposed, but instead the simple experiment described below is adequate.

The reasoning used in the measurement of accuracy is as follows. At zero dead time, the accuracy is perfect, since every oscillator pulse will be counted in the clock channel. For the same reason, the accuracy is nearly perfect, for any analyzer, at low counting rates, since if the dead time is only a few percent, and if the amount of dead time involved is known reasonably well, then the overall error is therefore very small. (The poorest analyzers can determine dead time to within a few percent. If the dead time is high, say 90%, a few percent error produces drastic errors in the live time indication, but if the dead time is only 10%, then a few percent error in determining this pro-

duces only a fraction of one percent error in live time indication.)

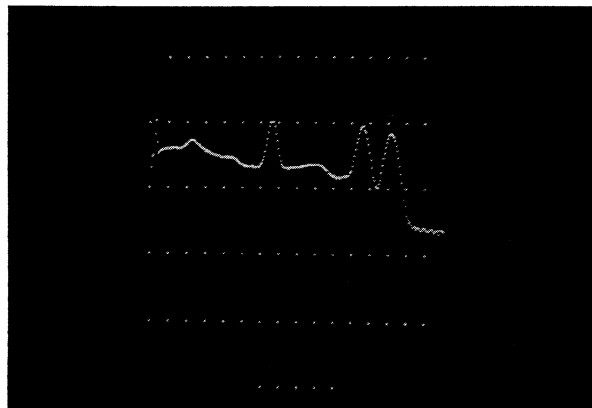


Figure 17. Combined cobalt 60 and cesium 137 spectrum taken for live time test.

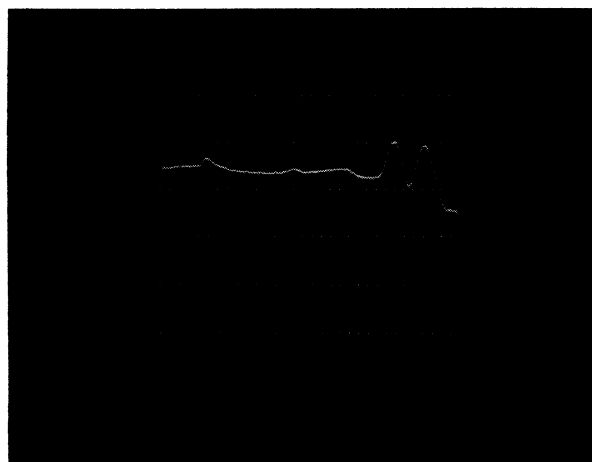


Figure 18. Spectrum of Figure 17 after subtraction of cesium 137.

If a low intensity source, preferably cesium 137, is used in combination with a relatively intense cobalt 60 source, and both measured together, a spectrum such as shown in Figure 17 results. If the cobalt 60 source is then removed, and cesium 137 is subtracted from this spectrum, the result should be as shown in Figure 18. *Since the mixture has been measured at high counting rates, and the cesium line subtracted at low rates, the live time determination is correct if the cesium line is completely subtracted out in the proper amount.*

The "sweep out" effect discussed in an earlier section must be considered. Accidental coincidences between gamma photons from the cobalt source with those from the cesium source produce sum peaks and partial sum peaks not visible in the spectrum. Such accidentals do not occur when

cesium, alone, is the source during the subtraction. For the ND130A analyzer, the amount of "sweep-out" is about 1.5% per 10,000 cobalt counts per second. It is normal, therefore, that the cesium line will be over-subtracted by 1.5% if this counting rate is used. If the test is made at this high counting rate, it is preferable that at least a four minute measurement be used, since statistical errors in the clock channel, in a one minute measurement at very high counting rates can amount to a substantial fraction of one percent.

In making the test, no change in position of the cesium sample should be made after the first part of the test. If the photomultiplier gain changes during the measurement, when the counting rate is decreased, it is necessary to integrate the counts in the general region of the cesium 137 photopeak, to determine whether or not the average number of counts is the same in this region as for a cobalt spectrum separately measured under identical conditions. The gain change would produce an excessive number of counts subtracted on one side of the cesium 137 photopeak, and too few on the other.

Other methods can be used to verify the correctness of timing. Some involve the use of periodic pulse generators. It is quite undesirable to utilize such devices in checking, since there is a possibility of momentary locking-in of either the pulser oscil-

lator or the clock oscillator, which can produce very large apparent errors. If great care is used to avoid such effects, it is permissible to use periodic pulses.

The "mixture" method is a very direct test, measuring exactly the variable of ultimate interest, the independence of spectral line indicated intensity from the effects of high overall counting rates. Refinements of the method can be devised without great difficulty. In some radiochemical analysis, tenth percent accuracy is desirable, and to confirm timing accuracy to this value requires considerable care.

Where precision as fine as 0.1% is desired, it is recommended that the clock oscillator be replaced with a 60 cycle (power line frequency) square wave generator, or a 120 cycle per second pulser controlled by the power line. Alternatively, a crystal controlled oscillator may be used. To connect such an oscillator, a simple single wire alteration must be made in the analyzer wiring, to allow bypassing the built-in timing oscillator. The oscillator used should supply a five volt square wave, with one microsecond rise times, at any d.c. level. *The built-in oscillator, in environments appropriate to overall analyzer optimum precision, is probably accurate to within a tenth of one percent per day.* This should be verified by occasional careful measurements at zero dead time.

III. OPERATING PROCEDURES

A. Analyzer Front Panel Controls

1. Read-Stop-Analyze switch.

This switch permits the operator to stop any operation, and to initiate either analysis or readout. The switch has only a momentary effect in the read or analyze positions, sufficient to initiate the operation. The analyzer controls the operations after they have been initiated, except that by placing the switch in the Stop 1 position, the operations can be stopped. The Stop 2 position is actually an open position in the switch. The analyzer is not held in the stopped condition, but is free to accept such externally produced signals as those from the address advance buttons, or (where appropriate wires have been included) external start analysis or start readout signals. In the Stop 1 position, the address and digit scalers are positively held in a particular state, and the control circuits are positively held in an off condition.

2. Readout Mode switches.

The operation of these switches is partly self-explanatory. The only switch in this set which has much effect upon the general nature of the readout operations is the Digital-Analog switch. In the digital mode of readout, information is read out a digit at a time, sequentially, at a constant rate. This continues until all channels have been read out, after which readout operations are automatically discontinued. In the analog mode of readout, however, information is rapidly "fetched" from a given channel, an analog signal proportional to the logarithm of the information in that channel is generated, and the process is halted sufficiently long to plot a point. The next channel is then read out, and a point plotted, with the process continuing indefinitely if the readout is by cathode ray tube display. If readout is by pen recorder, then readout stops after the recording is complete. Decade line points are automatically plotted in both CRT or Pen readout.

The function of the Type-Punch-Dump switch is solely to change the speed of readout. There is no difference whatever in the sequence or nature of readout in these cases, except that data is presented to external devices at different rates. In the Type mode of operation, appropriate solenoid drive currents are provided at the rear of the analyzer to operate an IBM output typewriter. In all digital readout modes, binary coded decimal signals are provided at the same connector to operate paper tape punch control devices such as the Nuclear Data model 130T paper punch and reader control. The Dump mode has been provided to make it possible to use such devices as magnetic tape recorders, without altering the analyzer.

Nearly the only function of the CRT-Pen switch is to alter the speed of readout. The exception is that in the Pen mode of operation, readout is not repeated, but ends after the decade line points have been plotted.

3. Sub-group position switches.

The operation of these switches is self explanatory. As indicated on the front panel, one only should be operated at a time. No serious effect occurs if they are incorrectly altered, but if they are not properly set, analysis may be into an unexpected portion of the memory.

The 0-511 group switch is not connected to any circuit, but has been included only to make the operation of the switches more self-explanatory. This switch may be used for other functions, if necessary, if the analyzer is modified for some reason.

4. Group Size switches.

It is necessary that these switches be set in a position corresponding to the size group desired. The group size chosen must correspond to the group size selected by inference in the selection of the group position to be utilized. That is, it is not correct to operate with the group size switches set at 512 channels if, for example, the sub-group location switches are set to select operation in the last half of the memory. No data is lost from the memory if incorrect settings are used, except that the analysis can be incorrect in such cases.

5. Ramp Slope switch.

The ADC accepts pulses from zero to negative three volts in amplitude. The spectrum will be spread out over a number of channels indicated by the setting of the Ramp Slope switch. *This switch only selects approximately the amount of spread. It should not be used as a gain change switch.*

6. Auto-repeat switch.

When this switch is in the Auto-repeat position, after each readout operation *in the digital mode*, the memory is cleared, and a new analysis operation

is initiated. Otherwise the analyzer is stopped after readout, which is non-destructive.

7. Pen Calibration switch.

In making a recording of a spectrum where logarithmic representation is used, it is frequently desirable to expand the vertical scale so that the entire spectrum, or a region of interest, extends over the entire recorder span. Typically three decades are adequate. To set the recorder zero level and full scale level, it is necessary to have voltages corresponding to the top of the top decade of interest and of the bottom decade of interest. When the Pen Calibrate switch is on, the vertical deflection output voltage to the pen recorder corresponds to the one count level. If the +1 decade calibration line button is depressed, the voltage then corresponds to the level of the 10 count decade line. Depressing the +2 calibration button increases the voltage to correspond to the 100 count level, and so on. Using these buttons, it is therefore possible to adjust the pen recorder without making a trial recording first. *Always return this switch to normal, after calibrating the recorder.*

8. Live Time Control switches.

a. Clock On-Off.

The only effect of this switch is to stop the clock oscillator. This switch may be used when very long (week-end duration, for example) measurements are to be made, and it is not desired to stop after 800 minutes, the longest measurement ordinarily possible if the clock oscillator is on. Very long measurements seldom involve appreciable dead time, for they are usually long for the reason that counting rates are so low that it requires a great deal of time to accumulate statistically valid information. For a 512 channel measurement, the total dead time is about two minutes per million accumulated counts.

b. Clock Frequency switch.

This switch selects the unit of time involved, either minutes or tens of minutes, by altering the oscillator frequency. The time unit used should be minutes, where measurements are of 100 total minutes or less in duration. The mean deviation in the number of clock pulses accepted during a measurement, MD, is given by:

$$MD = \left(N \times \frac{\text{Dead time}}{\text{Total time}} \right)^{1/2}$$

where N is the number of clock pulses accepted and recorded into the clock channel. If the percentage dead time is great, then the value of N should be kept high, so the higher frequency clock should be used.

c. Live Time Units at Stop Point.

The settings of these switches determine the counting level, in the clock channel, at which the analysis will be stopped. The product of all of the switch settings, times the live time units used, is the actual live time at which the experiment will be stopped.

It is worth repeating that any experiment may be manually stopped. It may be re-started without affecting the accuracy of the live time information recorded into the clock channel. The experiment will eventually be automatically stopped, despite possible interruptions, after the preselected live time has been reached.

9. Overlap switch.

When this switch is on, the horizontal deflection voltage decoders are reconnected in such a manner that data in the second half of the memory is superimposed upon data in the first half.

10. Amplifier controls.

These controls are conventional. The accuracy of the coarse gain control is one percent.

11. Energy Zero Position (Window).

This control has two separate functions. In most cases, it is used as a fine adjustment of the zero energy intercept position. In some cases it is utilized to shift the entire spectrum a substantial amount "left" of its normal position, so that zero energy falls at a negative channel number.

A switch has been provided at the rear of the analyzer, labelled "Window", to enable the operator to select which function he desires to be provided by the position control. When the switch is in the "on" position, the front panel position control is biased in such a manner that as much as three volts position shift can be obtained with the ten turn potentiometer. When the Window switch is "off", the position control has far less effect, and it may readily be used for fine readjustments of the zero position.

The purpose of the switch is not so much to alter the sensitivity of the control as to introduce a bias to a threshold circuit (transistor T2 of the ADC circuit) whenever the zero energy position is several channels left of channel zero, a situation that can only occur if there is a positive bias applied to the position control. This threshold is not necessary if the zero energy position corresponds to channel zero. It is undesirable to utilize a threshold in most such cases, for a non-linearity of analysis occurs over the first six or eight channels when a threshold is used. Nevertheless, for reasons beyond the scope of this discussion, the threshold is mandatory if the zero energy position of the spectrum has been suppressed. This threshold is automatically applied when the bias is applied to the Zero Energy Position Control by means of the Window switch.

When using a suppressed energy zero, it is not allowable to make a drastic shift in the zero position of the spectrum without proper consideration of the demands upon the amplifier. Before any portion of the spectrum can pass the "window" circuit (transistors T1 and T2 of the ADC circuit), the bias voltage must be exceeded. If a three volt bias is used (position control full counterclockwise, with the window switch "on"), then only pulses in excess of three volts will be analyzed. The internal amplifier saturates at four volts, so only a one volt region, the first 80 channels if a conversion gain of 256 channels per three volts is in use, would be properly analyzed.

12. ADC Input Selector switch.

As indicated by the front panel engraving, this switch selects the means for gaining access to the ADC. In the case of external negative three volt input pulses, there is no time delay provided, which means that if coincidence operation of the analyzer is anticipated, those signals must be externally delayed. Coincidence operation is separately discussed in SECTION III E.

13. Decade Line Interpolation switches.

The count level at which the decade lines normally lie is at the bottom of each decade. Depressing the + 1 interpolation button raises all decade lines, but not the spectrum, to the 2, 20, 200, etc., count levels, to allow quantitative estimates of the level of some point of interest in the spectrum to be made more easily. For other points, other interpolation buttons may be depressed, raising the decade line positions to 3, 30, 300, etc.

B. Data Reduction Controls.

1. Group Interchange Switch.

This switch transposes information stored in the left half of the memory to the right half, and vice versa. The transfer operation of this analyzer invariably causes information stored in the right half of the memory to be added to, or subtracted from, information at the left. The right half should always be thought of as the donor, and the left as the acceptor. Often it is desired to reverse this situation; rather than reversing the analyzer logic circuits to operate from left to right, the data is transposed. This switch should never be operated if the analyzer is in operation. It should first be placed in the "Stop 1" mode. Failure to do this may result in lost information. (Most model ND130A analyzers are purchased with paper tape readout and read in devices. Valuable information should always be read out on tape before data reducing operations are started. Despite the fact that it is always possible to restore data to its original form if alterations are made during data reduction, merely by reversing the arithmetic operations, it is quite possible that the operator could forget which opera-

tions he had already performed and could therefore not reverse them. Incorrect operation of the group interchange switch can cause direct loss of several data points.)

2. Multiplier Switch.

Operation of this switch is for the most part self explanatory. Some of the implications of the results of using different switch settings are not. It might be supposed, for example, that ten additions, using the .001 multiplier should result in the same sum as one addition using the .01 multiplier setting. It is not, for the reason that round-off errors are involved. The number 000359, multiplied by .001 produces the number 00000.359 in standard arithmetic operations. The analyzer, however, cannot add a fraction of one count to the acceptor channel involved. No number of transfer operations (computer cycles) would result in alteration of the number in the acceptor channel. However, one transfer operation, using a .01 multiplier, would result in the number 3 being added to the channel involved. Further discussion of round off errors is given later.

3. Initiate Computer Cycle Switch.

The analyzer must be in the CRT readout mode of operation, using all 512 channels, and the decade lines must be on, before operation of this pushbutton switch will have a proper effect. Press the switch until it is seen that a computation cycle has been initiated, then release it. The results will be automatically displayed after each channel has been operated upon. For addition operations, the analyzer Add-Subtract switch should be on "add", otherwise on "subtract".

If the resulting information is read out by means of typewriter, it will be observed that channel zero, ordinarily used for live time accumulation, is not affected in the same manner as the other channels, and that channel zero information is lost or altered in a rather meaningless manner.

If the analyzer is in a 256 point display mode, and the initiate button is pressed, there may be a slow and improper operation upon the data in the memory. After the "pass", it will appear that the spectrum has been destroyed. Place the analyzer in the opposite arithmetic mode (add or subtract), and press the button again. The data will be restored. This false operation, i.e. using a 256 point, instead of a 512 point, display mode for data reduction, and failure to have the decade lines "on" during display with the result that the computer cycle will not begin, are the most common operator errors to be expected.

C. Integration Controls. (Switches located on power supply cabinet front panel)

1. "Off-All-Selected" switch

This switch determines the type of data reduction to be utilized. When in the "off" position, the operation resulting after an initiate computer cycle signal has occurred is point by point addition or subtraction of the donor spectrum to or from the acceptor spectrum. When in the "All" position, the operation is integration of the entire 256 point donor spectrum, except the first channel, with the sum recorded in channel 1 (the second channel) of the acceptor channel group. When in the "Selected" position, the integration includes only the range selected by means of the switches on either side of the center "off-all-selected" switch.

2. "Address at Integration Start Point", "Address at Integration End Point" switches.

The purpose of these switch groups is to select, when "Off-All-Selected" switch is in the "Selected" position, the portion of the donor spectrum which is to be integrated.

A little practice is required before the operation of the range selection switches can be made easily and without hesitation. It is necessary to always use a lower channel number for the region of interest beginning point than the end point. Therefore it is mandatory that all of the "end point" switches be "up" while selecting the starting point. The starting point is indicated by a discontinuity in the displayed spectrum, located at the point which has been selected by the switches. After the starting point has been set, a similar operation is carried out for the end point. A process, such as will be described, should be followed in setting the switches which determine the start point. Turn "on" the switch labelled "128"; if the discontinuity moves too far right, turn it off, otherwise leave it on. Then turn on the switch labelled "64". If the discontinuity occurs too far to the right, turn it off, otherwise leave it on. Repeat for each switch. *This systematic approach is easy to learn, and can make it possible for almost anyone to set both the upper and lower boundaries to the desired location, as indicated by visual examination of the CRT display, in ten or fifteen seconds.* Without a systematic approach it is possible to waste a great deal of time. It is important that the exact mechanical routine described above be followed, despite the temptation to anticipate that the next switch in the sequence need not be turned on because it may be obvious that it will simply have to be turned off again. This is not to say that the optimum time of setting the boundaries can be reached using that method, but consistently easy and quick operation will result after a few minutes practice.

In setting the right hand boundary, no discontinuity (not even the starting point discontinuity) will be evidenced until the right hand boundary is located at a higher channel number than the left. *The absence of any discontinuity indicates that the upper boundary is too far left.* Before setting the right hand boundary, turn all of the right hand boundary switches off (down), in order that the mental processes involved in setting that boundary can be identical to those used in setting the left boundary.

For easiest operation, *first identify the exact point to which the boundary is to be positioned and adjust the boundary to that position.* If it is required to alter the boundary position after it has been set, it is best to repeat the entire sequence of switching as described above, starting with the "128" switch. However, once proficiency in the use of the switches has been acquired, it is not difficult to adjust the boundaries without repeating the entire sequence.

D. Data Reduction and Integration Processes.

1. General Methods of Use.

The mechanics of switch operation to allow various simple computations to be made upon accumulated data have been made in the preceding section. Some remarks concerning the use of the available facilities will be made in the present section.

Two separate types of computation are available; integration of selected energy regions, and the point-by-point addition or subtraction of two 256 point sets of data, with multiplication of one set of points by any constant during the process. The latter process has been called "spectrum stripping" or "spectrum peeling", for the reason that that process is often used to "strip" one component of a complex spectrum by subtraction of a (typically) non-complex spectrum from the former. A more concise name for the process is perhaps *nesting*, taken from the terminology used in computer programming, in which a very similar operation is carried out. Since the end object of "stripping" is not necessarily the only object, it is wrong to encourage that terminology even though it may be phonetically more pleasing and perhaps traditionally understood to really mean point by point addition of two sets of numbers.

2. Operations involving nesting.

To determine the activity of a radiation source an energy distribution analysis is made, using the analyzer in a conventional manner. The resulting spectrum may indicate one or more than one nuclide, but in either event, the determination of absolute intensity is made by comparison of the results with the previously determined response of

the radiation detector and analyzer to a source of the same composition, and comparable known intensity.

If the radiation is from a single nuclide, the final result can be readily obtained, for it is only necessary (in the simplest cases) to compare the total number of accumulated counts in the spectrum with those obtained in a similar measurement of a known standard. Even if the analysis includes a significant amount of background radiation, if the background is known to be constant the same simple method can be used merely by taking into account the known background radiation. Sometimes, of course, either the background or other components in the sample of interest are unknown, but the nuclide of interest provides a line of known energy. If a standard spectrum of this nuclide of interest has previously been made, with the same energy scale (kev/channel) and detector-source geometry, this standard can be experimentally subtracted in repeated operations using an appropriately small multiplier constant, until the line vanishes from the complex spectrum. The amount of the standard which was subtracted in order to cause the line to vanish, in the complex spectrum, is obviously proportional to the intensity of the nuclide of interest.

Some situations lend themselves to this technique; the line of interest may be of considerable intensity in relation to the continuum in the same general energy region, and therefore there is little uncertainty involved in deciding when the line has "vanished". The spectrum shown in figure 18 is such an example, although even here it is difficult to determine within a percent when the vanishing "point" has been reached. It may be necessary, in a case such as this, to utilize the integration function, to determine the average number of counts in the "peak" region, and compare this with the average just preceding and just following that region. Perhaps, in this example, it would have been easier to determine the intensity of the line by use of integration in the first place. However, the "stripping" method does frequently clarify the remaining distribution curve, for the standard in some cases is complex, and removal of that component from the unknown is sometimes necessary, in order to expose other interesting components.

In the use of the method of step by step removal of one or more components of a complex spectrum, a new or at least renewed appreciation of the difficulties introduced due to statistical variations in the recorded counts is developed. Subtraction of a standard from the unknown frequently clearly exposes those statistical variations introduced by both the known and unknown spectra. While it is sometimes out of the question to obtain new measurements relatively free of statistical error, it is cer-

tainly not out of the question to obtain standard spectra which are virtually free of statistical error. Such standards may be computer derived, or they may simply be standards obtained by making very long measurements, to reduce statistical errors. Some care is required, however, to avoid errors that result when "rounding off" individual numbers in a set, as always occurs when multiplying factors less than unity are involved. A number such as 001318, when multiplied by 0.001, for example appears as 000001 and is indistinguishable from the number 001999 after a similar multiplication, in the arithmetic circuits of the ND-130A analyzer, for the counting channels cannot recognize fractional "counts", so the resulting numbers as stored in the memory appear as 000001 in both cases. It is not usual that such round off errors are of consequence, but where they are considered to be of consequence, it is preferable to multiply the "unknown" spectrum by an appropriate decimal multiplier (10, 100, or 1000), and to subtract the standard from this, using a multiplier correspondingly larger than otherwise. There then is little or no round-off error introduced.

An example of an unsatisfactory set of circumstances, and the resulting possible errors, will be given. Suppose an excellent standard has been obtained, and that this has above five times the number of counts, per channel, in the regions of interest as the corresponding component of the unknown. Since subtraction of the standard is ordinarily "experimental", or trial and error, the operator may decide to use a small multiplier, perhaps 0.01, in order to be certain that he does not over-subtract. To be sure, better judgment would result in his use of a 0.1 multiplier at least for one "pass", but in this case, rather than changing the multiplier, he may hold the "initiate computer cycle" button during about 20 passes. If, however, the numbers in the region of interest in the standard were a little over a thousand or just a few thousand, the round off error could be as much as 5% (001999 appears as 000019, but so does 001900). While the operator obviously is prepared to accept some rather large statistical errors, since it has been, for this example, assumed that the unknown component of interest has an intensity level of about a hundred counts per channel in that region, he may not be prepared to accept systematic errors of as much as 5%. He should, first of all, always use the largest multiplier he can, rather than many operations with a smaller multiplier. Second, where experience dictates that round off errors can be appreciable, he should multiply the "unknown" spectrum by 10 or 100 before reducing the data. It was in anticipation of such requirements that the analyzer memory capacity has been made six decades, despite the fact that it is very rare that such capac-

ity is actually needed for ordinary analysis operations. Multiplication by 10 rarely causes data overflow, and in cases where multiplication by 100 might seem justified, this is ordinarily because there are relatively few counts in the "unknown" spectrum, and therefore data overflow can hardly be expected.

To multiply data points by 10, the spectrum should be transferred, using a multiplier of unity, into an empty memory group, and without erasing, this should be repeated 9 more times. To multiply by 100, this "times ten" spectrum should be multiplied by 10.

One of the most frequently used operations that is made, using the spectrum subtraction facilities, is the subtraction of a standard background spectrum from new measurements. One of the real merits of the provisions for subtracting fractional amounts of a standard from a new measurement is that it becomes possible to use a measuring time different than that used for accumulating the standard background spectrum. Another is that it allows almost statistical-error free background standards to be used. It is often frustrating to observe the almost complete loss of information that results when a weak radiation source is measured for some time, followed by an "on line" subtraction of background, which can introduce extremely large statistical errors in the remainder. The use of a statistically accurate background spectrum measured over a much longer period does not introduce *new* errors of consequence providing that round-off errors are avoided in the manner described above. When the data is read out by typewriter, it must be kept in mind, of course, that the decimal point position has been altered. The "fractional" counts are not meaningless parts of each number.

In the use of standard spectra, it is clearly necessary to carefully reproduce the energy scale and zero energy position of the new measurements. An error in the positioning of a spectral line of much more than five percent of the width of the line at half height can result in a pronounced "wiggle" in the remainder spectrum after subtraction. This "wiggle" is less offensive than might first be supposed, but the need for highly accurate setting of energy scale soon becomes apparent to the user. The temperature effects upon radiation detector gain must be considered, in measurements which are to be followed by data reduction involving subtraction of standard spectra. The effects upon the photomultiplier, as counting rates change, must also be considered. It is usually found that gain shifts of amounts which are unacceptable are not produced by the analyzer proper, under reasonable conditions. For optimum gain stability, the analyzer should be operated in an environment which does not change in temperature by more than

four or five degrees fahrenheit during measurements. Temperature control of the environment of the radiation detector is generally far more necessary; a few tenths of a degree, for example, can alter the gain of some photomultiplier tubes a significant amount.

3. Integration.

Many measurements can be interpreted without utilization of the spectrum subtraction operations, except for possible use of background subtraction. (Usually little spectral detail is encountered in background radiation. It is not important that energy scales be very exact, in such cases.) The desired information can often be obtained by means of the integration facilities of the analyzer. It is necessary to point out that round-off errors can be significant in integration, more frequently than for spectrum subtraction. The round-off is "biased"; that is, the rounded off digits are treated as zeros, so the final result is always too small, except in cases where the last digits of all the numbers stored are zeroes. If large areas are to be integrated, it is necessary to use a constant multiplier of such value that the sum channel does not overflow. There may therefore be cases in which multipliers of small values are used during integration. The final answers will be too small by about 0.45 times the number of channels involved, divided by the constant multiplier used. This may be as many as 23,040 counts, for 512 channels and a multiplier of 0.01. Such an error is not negligible, even though there would be no purpose in using such a multiplier unless more than ten million counts were the estimated total in the region of integration. The correction for the effect can readily be applied, however, since it is fixed, except for statistical variations. An important point to be made, however, is that round-off errors always occur in any of the data reduction processes involved in this analyzer unless multipliers equal to or greater than unity are used; smaller multipliers can often be avoided, and in integration processes round-off errors can be quickly calculated and proper correction made. Naturally, if the existence of round-off errors is unknown to the operator, he may use very small multipliers out of habit, and his results could be in error by *indefinitely large percentages*, e.g., if no channel contained more than 999 counts, but a multiplier of 0.001 were used!

E. Front Panel Connectors

1. Routing Signal Connectors.

In some applications it is desirable to store information in different quadrants or halves of the memory on the basis of some externally observed circumstance.

The mechanism involved in routing to different quadrants is as follows. The analyzer should be set up in such a way that the group size is 128, but the sub-group position is "0 to 511". Ordinarily the analysis scale would be 3 volts per 128 channels. Information signals from multiple detectors, if they are involved, must be linearly mixed (as they are, for example, in the ND-500 Dual Amplifier, and also as they are mixed when separately applied to the external amplifier BNC's marked A and B), and coincident (plus or minus a microsecond or two) with the event which is to be stored in the associated memory quadrant. For two 256 point measurements, the scale should be 256 channels per 3 volts, and group size 256 points.

The routing signals can be condenser coupled, if desired, but it is preferable that they be directly coupled. For non-routing, the voltage should be two or three volts negative, but not more than ten volts negative. For routing, they should become positive three volts, but not more than ten volts. The loading upon the routing signals is 2 m.a. The pulses should last for at least a microsecond, and no longer than two microseconds, for best results.

The Nuclear Data dual amplifier model ND-500 may be used as a source of routing pulses, as well as for amplification of signals from two detectors. In a simple situation, this dual amplifier may be used to allow independent analysis of events detected by two detectors, without any experimental relationship between the two. Ordinarily, such an application should involve only low counting rates, for accidental coincidences cannot be avoided any more easily than in the case of single detector analyzer operation. The effect of accidental coincidences in the times of occurrence of events detected in two detectors is more serious than simple "sweep-out", for swept out events are recorded into the wrong portion of the memory. This does not decrease the value of using two detector operation, however, for there is no justification for such operation (where simple time sharing of an analyzer among two or more detectors is involved) unless the samples being measured are of low activity. If high activity is involved, the measurements are usually made in sequence, since this requires but slightly longer than if they are measured simultaneously.

Another type of measurement, referred to earlier, involves analysis of actually coincident and related events detected in two detectors. The difficulty usually involved in this type measurement is that if the signals from the detectors are linearly mixed, after amplification, as is the case for the ND-500 dual amplifier, the only events which can be recorded by the analyzer are either non-coincident and therefore uninteresting, or coincident events which will be recorded as sums of the energies of the two events. To avoid this problem, the Nuclear

Data model ND-501 two channel temporary pulse storage unit may be used. This device receives the signals from the detectors, and stores them in voltage form, until they can be stored digitally by the analyzer. Proper routing pulses are provided by that unit. By various alterations in interconnections it is possible to record non-coincident events observed at the two detectors into separate memory quadrants, with coincident events separately analyzed and stored in the remaining two quadrants.

2. Busy BNC.

This output signal indicates when the analyzer is not in the process of analyzing or storing an event. It is used as a signal to control the model ND-501 pulse storage unit, and it may also be used for rough indications of percent dead time by connecting a voltmeter between the terminal and ground through a diode. The signal is positive when the analyzer is not busy, otherwise it is negative. If the anode of the diode is connected to the meter, and the other end to the BNC, a reasonably linear indication of percent dead time is provided. Calibration of the meter is not difficult, but varies for each analyzer. A continuous indication of percent dead time is often useful in initial experiment set-up processes, where no knowledge of source intensity is available. No analysis should be attempted, except for cursory examinations, if the dead time exceeds 90%; the use of a dead time meter permits rough estimates which avoids measurements with excessive dead times.

3. Ready BNC.

This is also an output signal. It is intended as an indicator that the analyzer has completed an analysis, and is ready for a new sample, when automatic sample changers are involved. It may also be used to control an elapsed (calendar) time indicator, or to control other equipment which must be aware of the current operating mode of the analyzer. This signal is positive approximately two volts when the analyzer is in the analysis mode of operation, and otherwise negative approximately three volts. It should not be loaded with more than one milliamperes in either direction.

4. Coincidence BNC.

This BNC is an input BNC to which is applied either a negative signal, to block the analyzer linear gate, or a positive voltage to unblock it. The signals applied from the radiation detector to the internal amplifier, or to the inverter stage of that amplifier, are delayed two microseconds to allow external devices to reach a decision on whether the signal should or should not be blocked by the linear gate. The coincidence signal must be delayed sufficiently to allow the related signal pulse through the gate, if the external device natural

delay is less than two microseconds. It is important that the coincidence signal straddle, in time, the signal pulse as it enters the ADC. It is obviously important that the coincidence signal not be excessively long, for if it is, there may accidentally be later signals which are unrelated to the event of interest, which may enter the ADC and be accepted. This is not of importance where there is always a signal which accompanies the coincidence pulse, as is normally the case, for the ADC closes its linear gate immediately after the pulse of interest has entered. Nor is it important at low counting rates, where accidental coincidences are rare.

The coincidence signal should be normally negative about three volts, and should become positive a volt or two to allow the input signal to pass. It is advisable that the total change in the coincidence BNC voltage not be much in excess of four or five volts, to avoid possible feed-through of the coincidence pulse during the entry of the real signal pulse.

Anti-coincidence operation is similar, except that the coincidence BNC must be held normally positive a volt or two, and must be made negative three or four volts to block a signal. Anti-coincidence pulses must be longer than the duration of coincidence pulses, for it may well be that the signal to be blocked is very large, and therefore abnormally long. Ten microsecond long anticoincidence signals are recommended. It is imperative that these signals completely straddle the anticipated detector signal, in time.

In anti-coincidence operation there is normally a memory cycle produced by the transient caused by closing and reopening the linear gate. There is ordinarily no count due to this effect stored above channel two or three. There is a similar effect produced in coincidence operation in situations where a coincidence pulse arrives but no detector signal occurs.

Proper coincidence signals are provided by the model ND-500 dual amplifier.

5. Signal Input BNC's.

a. Negative 0-3 volt signals.

Where such devices as external transistorized amplifiers, external pulse storage units, and similar instruments are employed, it is preferable to connect directly to the ADC, in which case this BNC is utilized as an entry point. The ADC operates with negative input pulses, with the following restrictions.

The rise time of the pulses, to the maximum voltage point, must not be longer than five microseconds, and they should "break away" fairly rapidly after this point. Figure 20 indicates the ideal signal waveform.

The input pulses must not be shorter in duration than one microsecond from beginning to the max-

imum voltage point. For maximum resolution pulse widths of two or more microseconds are desirable. For maximum linearity, all pulses must have identical waveforms, although linearity is not a sensitive function of waveform. Input pulses should not exceed five volts in amplitude; if the device used to provide the pulses occasionally produces somewhat large pulses, this is permissible, but it is not advisable to use a device such as an amplifier which has a ten or fifteen volt range. The output of such a device should be attenuated by a factor of two or three in order that full scale output signals from the device will be about four volts.

It is permissible to operate the ADC with a direct connection to the photomultiplier, without use of any amplification, where scintillation counting is involved. In such cases, the RC time constant of the photomultiplier anode circuit should be about four or five microseconds.

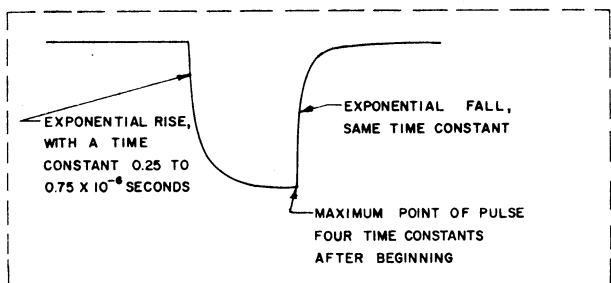


Figure 20. Ideal input pulse shape.

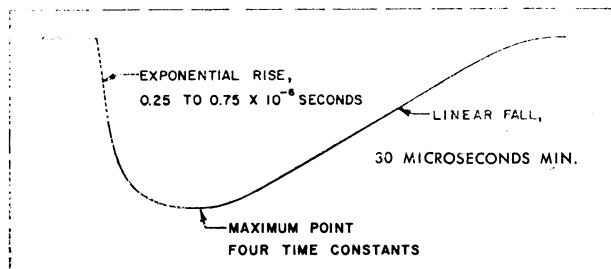


Figure 21. Acceptable input pulse shape.

In the case where d.c. voltages, or slowly changing a.c. voltages are to be sampled, and an analysis made of the distribution of the voltages found during the sampling intervals, for example in certain

experiments involving the use of the Mossbauer effect, it is necessary to bypass the condenser coupling between the input BNC and the ADC circuits. A short circuit or 1000 ohm resistor across that condenser is sufficient. (The condenser involved is the 0.002 microfarad condenser connected to pin 4 of the upper left hand ten pin amphenol connector on the ADC board). The coincidence BNC connector terminal must be held negative 3 volts at all times, except when it is desired to analyze the present value of the input voltage. The information accumulated during such a measurement is simply the distribution of voltage values existing during the samplings. The input voltages must be negative with respect to ground, and should not vary more than four or five volts from ground. Full scale amplitude of the voltages is about three volts.

In the analysis of "d.c." voltages, the act of holding the coincidence gate closed, until it is desired to determine the value of the voltage, effectively shapes the signal for the ADC conversion circuitry. The "coincidence" pulse should last for two or three microseconds, although pulses of as little as one microsecond duration are tolerable.

b. Detector BNC.

This BNC is the point to which the anode of the photomultiplier should be connected, through a capacitor if necessary. Discussions of detector anode circuit requirements are given in a later section. This point may also be used to accept signals from preamplifiers which amplify signals from solid state alpha detectors, providing those signals have the same waveform as is provided by a scintillation detector photomultiplier, as described in Section IV. The internal amplifier is designed only for signals of the type provided by scintillation counters.

c. External Amplifier BNC.

Two BNC's are provided for accepting signals from vacuum tube amplifiers such as the Oak Ridge DD-2, A-8, A1D, or similar amplifiers. Such signals are either positive, with an amplitude of 0-100 volts, or bipolar. The signals are inverted in the last stage of the internal amplifier, and are delayed two microseconds before reaching the ADC circuits.

tion at the detector collector, and would not indicate precisely the total charge. The detector usually provides a total charge which on the average is proportional to the energy of the event detected. There are statistical variations but these are basic limitations of the detector. To minimize the error, the voltage pulse produced at the analyzer ADC circuits should have an amplitude proportional to the total charge received. An integrating circuit of some kind is needed, yet some method is required to "chop" the pulse after it has reached nearly its maximum level.

The integrated charge produces a voltage across a capacitor at the detector collector, and as shown in Figure 22, this charge is permitted to flow to ground at a relatively slow rate through a resistor. The voltage signal produced is inverted, delayed an appropriate amount, and linearly mixed with the original voltage signal, producing the "ideal" voltage signal of Figure 20.

The delayed and inverted signal must be of proper amplitude. If the value of the RC circuit time constant at the collector of the detector is large, then the delayed signal should have virtually the same amplitude as the condenser voltage. However, if the RC time constant is small, then it is necessary that the delayed and inverted signal be somewhat smaller in peak amplitude than the signal at the condenser, for fairly obvious reasons. Improper attenuation of the delayed signal will result in either an overshoot or an undershoot in the final pulse, both of which are highly undesirable.

The RC time constant at the collector of the detector may be varied, to produce an overshoot-free amplifier output signal, or the adjustment potentiometer on the internal amplifier board may be trimmed to provide an optimum signal. In examining pulse waveforms, it is preferable to "look" at the signal at the base of transistor number 1, on the ADC board, rather than at the amplifier output terminal. The photographs of Figures 23, 26 and 25 indicate the undesirable "undershoot" and "overshoot" conditions, quickly correctable to the form shown in the center photograph, which indicates the waveform when adjustment is proper. Incorrect adjustments do not produce any apparent error in the accumulated distribution curve, except at high input pulse rates, since the adjustment influences only that portion of the pulse which occurs after the maximum voltage point has been reached. At high pulse rates, signals which occur during the overshoot or understoot intervals of earlier pulses will be analyzed incorrectly since they will be "riding" on a voltage other than the normal baseline voltage. At low pulse rates, there is not much chance that there will be accidental coincidences of the existence of an incorrect baseline voltage and a new pulse. This suggests that

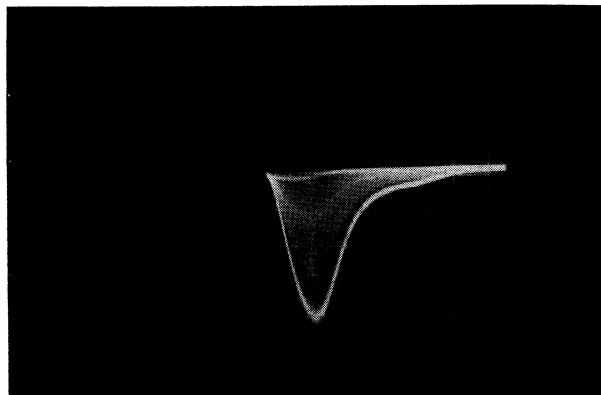


Figure 23. Input pulse with too much "undershoot".

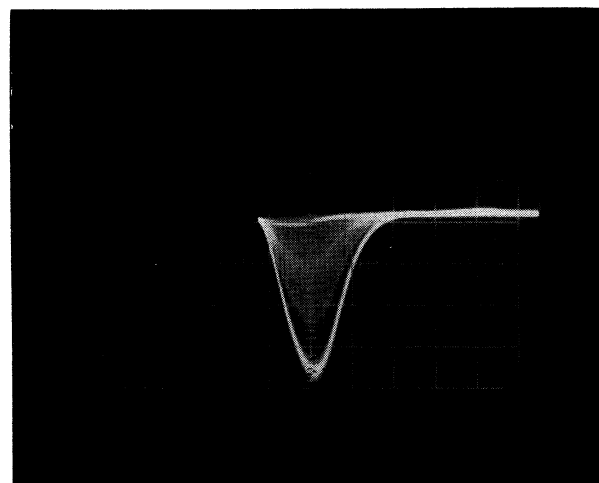


Figure 24. Correctly adjusted input pulse.

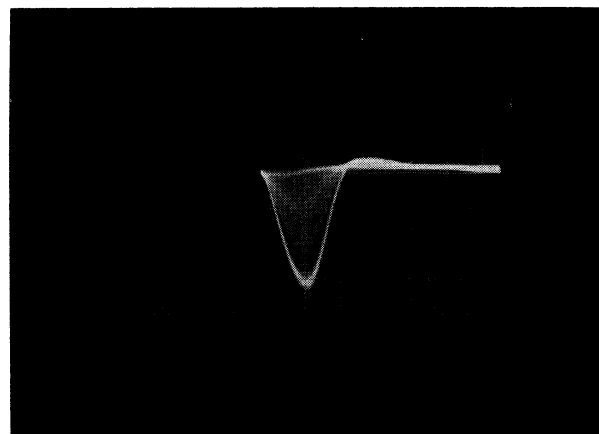


Figure 25. Input pulse with too much "overshoot"

IV. AMPLIFIERS AND PULSE SHAPING

A. General

The model ND130A analyzer, as is the case for most multichannel analyzers, determines the distribution of the peak pulse amplitudes of input signals. The nature of the ADC in the ND130A is such that it is necessary that the pulse remain at nearly its maximum voltage level for two or three tenths of a microsecond, and further that the pulse duration from start to the peak value be at least one microsecond. The best stability and linearity are achieved if input signals are even slower in rising, and have a longer "flat top".

There is an upper limit to the length of the pulse, in the case of the ND130A analyzer, although this is not an inherent limitation and can readily be avoided by a simple modification, to allow even indefinitely long pulses to be analyzed precisely. For the standard unmodified analyzer, it is recommended that pulses no slower than three or four microseconds be utilized.

It should be said, in the way of dispelling concern about the problem of pulse shapes, that a respectable job of analysis can be done by the analyzer with "any old" waveform, except that there should not be pulse "overshoots" or "undershoots". Each pulse must return with reasonable speed to its initial voltage level, referred to as the baseline, and voltages should be monotonically increasing or decreasing before and after the peak.

The requirements become more stringent as anticipated pulse rates increase, however, and the more nearly ideal the pulse waveform the more nearly perfect will be the analyzer performance. The ideal waveform is shown in Figure 20 with an acceptable shape shown in Figure 21. Such pulse waveforms are approximated by the internal amplifier, and most vacuum tube type amplifiers. The analyzer accepts positive pulses of this form, with a range of 0 to 100 volts, for an inverter and attenuator are included in the analyzer. Bi-polar pulses (positive followed by negative pulses) are also acceptable, at the signal input BNC's for 0-100 volt pulses, but not into the pulse amplifier and not directly to the ADC. The inverter "clips" the negative portion of the pulse.

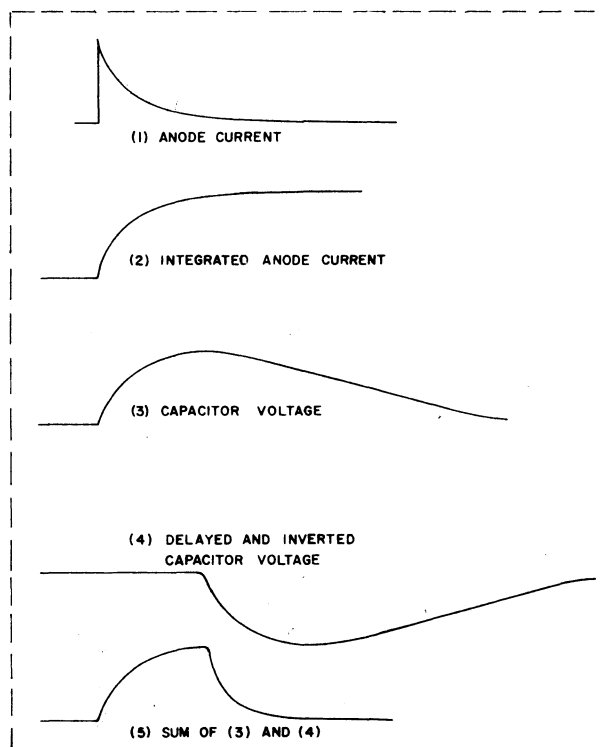


Figure 22. Current and voltage relationships at photomultiplier anode.

B. Amplifier Input Requirements

Radiation detectors usually provide a quantity of charge at the detector anode or cathode. This charge is provided over a period of time which varies from a few millimicroseconds to several microseconds, depending upon the type of detector used. It is not generally advisable to generate a voltage pulse directly by allowing this current to flow through a simple resistive circuit, utilizing the resulting voltage pulse as the signal to be applied to the analyzer, despite the fact that this would be a very simple approach free of some of the problems encountered in conventional systems. The reason that this approach is bad is that the maximum value of the voltage pulse would then indicate only the maximum rate of charge deposi-

the manner in which the trimming adjustment should be made is by examination of a spectrum taken at high pulse rates, and adjusting until the spectrum has the appearance (at the low energy region) of one measured at lower rates. Either method of adjustment is satisfactory.

The internal amplifier is designed for use only with scintillation detectors. The same general principals should be followed for other detectors. In the case of solid state detectors, the collection time is very short, and in theory it should be possible to produce pulses which accurately indicate the total charge received, with pulse widths which are well under a tenth of a microsecond. However, the analyzer cannot operate well with pulses less than a microsecond in width, and in fact it is advisable that the pulses be even longer in order that the excellent resolution of such detectors not be slightly degraded by the use of pulses only one microsecond wide. In the case of proportional gas counters, the collection time is much longer; total pulse widths of five microseconds may be required. *It is advisable that delay line shaping of the signals be utilized for such long pulses, to produce the ideal pulse waveform shown in Figure 16; the relatively sharp breakaway is particularly important for long pulses.* The ADC can recognize the occurrence of a maximum point in a pulse only on a rate of change basis. Any signal which changes at a rate less than five millivolts per microsecond will not be recognized at all by the ADC. For optimum response, it is necessary that the voltage pulse return to the baseline voltage at a rate of at least 25 millivolts per microsecond at some point in the return process, preferably within a microsecond of the peak value time. When estimating the adequacy of a contemplated pulse waveform, the smallest pulse of interest, not the largest, must be the basis of calculation.

For the analysis of extremely slow pulses, or d.c. voltages, the analyzer should be operated in the coincidence mode, with the coincidence BNC voltage held at negative 3 volts until the signal of interest has reached a maximum value, or when it is desired to sample the d.c. or slowly changing voltage. It is necessary to apply the signal to be analyzed directly at the base of transistor number 1 on the ADC board, through a 1000 ohm resistor, in such cases. The action of the linear gate, which opens at the time the coincidence pulse becomes positive and closes at the end of the coincidence pulse, forms a nearly ideal pulse at the input to the actual ADC conversion circuits. Coincidence pulse widths of one or two microseconds are recommended for such applications.

C. Gain and Zero Position Calibration

Though an operator often has no need to be concerned about the actual gain and zero settings of an analyzer, in many situations it is really important that the zero and gain adjustments be virtually perfect. Such situations always exist when automatic data reduction, internal or external to the analyzer, is involved. The most stable existing analyzers, under the most favorable conditions, cannot be depended upon to maintain correct zero and gain settings for long periods of time. For this reason, some possibly helpful hints will be given to assist in rapidly calibrating these settings.

For ordinary purposes, in which it is simply desired to make a measurement in which the gain and zero settings are reasonably correct, just on principle, a source of radiation with two or three lines of known energy should be analyzed. It is well to spend a few minutes in considering which channels the lines should fall into, for correct zero and gain values. After the trial measurement, readjust the gain so that the most energetic line falls into the correct channels. Then adjust the zero, with appropriate readjustment of the gain so that the highest energy line will again fall into the correct channel.

The choice of source for this use is of some importance. In the case of gamma analysis, a good source is cesium 137. If the photopeak is placed in channel 221, and the 32 keV x-ray line is placed in channel 10.6, the gain and zero are correct for a 3.0 k.e.v. per channel measurement. The use of a source with a high and very low energy line permits more rapid zero adjustments than if the two lines are not so well separated. There is a limit to the amount of difference that is desirable, however, since the lower energy end of the analyzer characteristic is rarely as linear as the higher energy end, and the detector itself may be non-linear at low energies. It is usually more important that the straight line portion of the analyzer characteristic pass through the 0, 0, coordinate than it is for an extremely low energy line to be recorded into exactly the proper low numbered channel. If this is the case, then such a source as a combined cobalt 60 source and cesium 137 source should be used. The 2.5 m.e.v. sum peak, and the 0.662 m.e.v. cesium photopeak should be adjusted to fall into, say, channel 250 and 66.2, respectively. Both the detector and the analyzer are linear in these regions. The method outlined in the illustration shown in Figure 10 should be used in determining line centers.

Once the zero intercept has been properly adjusted, the amplifier or detector gain may be varied as desired, without appreciable effect upon the zero intercept adjustment.

If information must be analyzed with nearly perfect settings, it is usually for the reason that standard spectra are to be subtracted from new information by automatic means (by means of a digital computer, or the Nuclear Data model ND-130A analyzer-computer). Such operations require adjustments to be correct to within a few percent of the width of the spectral lines involved. It is usual that the model ND130A analyzer involved in these operations would have a punched paper tape input and output. The paper tape input device should be used to read into the analyzer a standard spectrum **utilizing the same energy scale and zero setting of the standard spectra to be utilized in data reduction.** This spectrum need not be the same as those to be involved in data reduction, for those may well be from difficult to obtain, short lived isotopes. If the standard spectra have, as they should, standard energy scales (e.g. 5 k.e.v. per channel, or 10 ke.v. per channel), and if the standards have been made with appropriate care, then any com-

mon standard spectrum available using the desired energy scale may be selected, read into the analyzer, and the proper analyzer gain and zero settings may be made with great accuracy by utilizing the overlap display mode of operation to compare a new measurement of that isotope with the standard.

Standard spectra normally contain information accumulated over long measuring periods. It is not reasonable to make trial measurements of the common "test" isotope for sufficiently long periods of time to allow exact overlapping of the test spectrum and the standard. It is desirable that the data reduction facilities be used to manufacture a standard test tape or two which have the selected standard isotope recorded after multiplying all points by some fraction such as one-tenth or even one one-hundredth. In a minute it is possible to have sufficient statistical accuracy to precisely determine the analyzer calibration, using the modified standard tape and display overlap.

V. ANALOG TO DIGITAL CONVERTER

A. Design

1. Linear Circuitry.

The object of the converter circuits is to provide a digital representation of the amplitude of the input signal pulses, in such a form as to allow the analyzer storage circuits to tally a count in a memory channel corresponding to that digital representation. The storage control circuits can accept a number in the form of a series of short pulses, in which a number N is represented by a sequence of N pulses, separated typically by $\frac{1}{2}$ microsecond. These pulses are counted by the storage circuit "address scaler", and at the end of the pulse train the state of the scaler corresponds to the number of pulses in the train. The storage circuits tally a count in the memory channel corresponding to the state of the scaler.

In a sense, the most important group of circuits in the entire analyzer are illustrated in Figure D3. These are the circuits which generate a pulse of duration proportional to the amplitude of the input signal, which pulse is used to gate a two megacycle oscillator in order to generate the required sequence of address scaler advance pulses (ADCA). The output of this circuit is the signal

ADCB (called "Y" in this diagram; some further shaping of this signal is required elsewhere on the ADC Board. The signal "Y" is essentially the pulse-length modulated pulse of interest).

The mechanism for generating the length modulated pulse, ADCB, is entirely contained in the portion of the circuits shown in this diagram labelled "Sweep Circuit". The linear gate, and window level control circuits are important enough circuits, but are used for preliminary handling and control of the analyzer input pulses, which arrive at the sweep circuit pretty much in the same form as received from the internal or external linear pulse amplifier.

Transistors 6, 7, 8, and 9, comprise a rather ordinary feedback circuit which tends to maintain the voltage at the base of transistor 7 (T7) to be the same as that of T6. The voltage at the base of T7 is essentially equal to the voltage across the two paralleled 1000 microfarad condensers. If the voltage at the base of T7 is more negative than that at the base of T6, T9 is cut off and the proper voltage is produced at the condensers by means of

the five microampere current through the 10M resistor connected to +50 volts. If the base voltage of T7 is higher than that of T6, transistor T9 conducts, and through the diodes between that transistor and the condensers, charges the condensers appropriately. Transistor T10 is normally not conducting and therefore has no effect upon the circuit. The diode to the signal called "CLOCK" is also normally non-conducting.

A property of this feedback circuit is, obviously, that any tendency of the base voltage of T7 to be more positive than that of T6 is corrected quickly. If the opposite voltage error exists, however, the correction is very slow, for the diodes to T9 are not capable of conducting in the direction to cause the condenser to charge more positively. The correction is solely by means of the current through the ten megohm resistor.

When an input pulse arrives, the condensers are rapidly charged to the same voltage as the negative input pulse, until the input pulse has reached a maximum value. The condenser voltage then remains almost constant, except for the slow charging action. The voltage "Y" becomes several volts positive, and soon after this, transistor T10 conducts (typically 60 microamperes) for other circuits cause the signal "F" to become positive, allowing current to flow through the 499 K resistor. The signal called "RAMP" is a steady voltage of about 8, 16, or 32 volts depending on the setting of the Analyzer "channels per 3 volts" front panel switch.

The effect of the current through T10, which is very constant, and the nearly constant current through the 10 megohm resistor, is to linearly discharge the condensers. When they have returned to zero volts (the voltage at the base of T6 is always essentially zero when the linear gate is closed, as it always is during conversion processes), the voltage "Y" (ADCB) quickly returns to a slightly negative value. The length of time during which "Y" is positive is therefore proportional to the peak voltage of the input signal pulse.

The window level control circuit is simply a coupling circuit to provide d.c. restoration for the condenser coupled input signals, and to establish a quiescence voltage value (baseline) of about zero volts (normally). The two diode-connected 2N393 transistors in this circuit comprise a temperature compensated diode clipping circuit which holds the baseline voltage nearly equal to the window level voltage (from the front panel Zero Energy Position control) despite the action of the 330K resistor connected to +8 volts. The trim-pot shown slightly changes the voltage baseline to allow long-term drifts to be compensated, in order that the settings of the Zero Energy Position control will be the same during the life of the instru-

ment. The network diodes at the lower portion of that circuit are protective circuits to minimize the effects of possible excessively large input pulses accidentally applied to the ADC.

The linear gate circuits, transistors T1, T2, T3, T4, and T5 operate as follows. Normally T2 is non-conducting and therefore T1 and T3 are simple emitter followers. T39, not actually part of the operation of this circuit, is non-conducting, so the diode between T39 and T3 is also non-conducting.

Any voltage pulse appearing at the base of T1 also appears at the output of emitter follower T3, if and only if T4 and T5 are non-conducting. The output of the linear gate is within a few millivolts of zero volts if T4 and T5 are conducting, whether an input pulse is present or not. Thus signals pass through the gate circuits either virtually "untouched", if T4 and T5 are cut off, or do not pass through at all if T4 and T5 are conducting.

Transistor T2, though normally non-conducting, has the function of preventing the linear gate output voltage from becoming positive when the window level voltage, from the front panel zero energy position control, becomes positive. If the window level voltage has been set to be positive E volts, no negative input signal less than E volts in magnitude will pass the linear gate circuits, since the emitters of T1 and T2 cannot be appreciably more positive than the base of either due to the basic characteristics of any PNP transistor, for a level setting of E volts.

It may not be obvious why it would not be allowable to permit the linear gate output to be normally positive. In fact, except for a major difficulty which occurs after the whole analysis and storage operation is completed correctly, there is no reason for including transistor T2. The analyzer, under normal conditions (Zero Energy set at channel zero) will operate perfectly without it.

Suppose the window level voltage is positive, however, as is the case when the zero energy position is set at some location well to the "left" of channel zero. If a signal pulse of substantial size occurs, the sweep circuit would respond normally, and an analysis would occur. The output pulse train would be shorter than if the energy zero level were normal. This should be expected since the whole pulse height spectrum is to be shifted left. After storage of a count in the appropriate memory channel, the linear gate will re-open. When it does, the linear gate output voltage will rise to the same value as the (positive) window level voltage. This means that the sweep circuit will react, for the sweep condenser voltage was approximately zero before the gate opened, and now must be allowed to charge positively. When it does, the signal "Y" (ADCB) becomes positive which causes address advance pulses and in fact an

entire "nonsense" analysis and storage cycle. This is to say that there is a very good reason for the existence of transistor T2, if the spectrum zero energy position is ever to be shifted to the left of channel zero on the intensity-energy plane. Without it the Analyzer will continuously go through meaningless analysis operations.

This transistor is not introduced to the circuit without penalty, however. Transistors T1 and T3, as tandem emitter followers, are very linear in performance. But if the base voltage of T2 is zero (for a case in which the baseline voltage at the base of T1 is also zero) the transfer characteristic of T1 and T2, for a negative going voltage, is quite non-linear for the first 100 millivolts of change in the input voltage. This means that the lower three percent of a three volt spectrum will be quite non-linear. Since T2 is necessary only if the window is used to suppress the zero energy position, it is biased off completely by the analyzer rear deck WINDOW switch when that switch is off. When that switch is on, T-2 has a bias of about 50 millivolts negative applied to it, which causes it to prevent "nonsense" analysis cycles. When the WINDOW switch is on, therefore, the lower three or four percent of the recorded spectrum will be non-linear whatever window level setting is used. When the switch is off, the analysis is reasonably linear even at channel number three or four, for 256 point analysis. The window level control is then usable only as a trimming adjustment of the zero position, with a sensitivity of several dial turns per channel.

There is a great difference in the usefulness of the lower three or four percent of the channels when zero energy is set at channel zero, and when it has been suppressed. In normal operation it is not suppressed, and a standard energy scale (10 k.e.v. per channel is particularly convenient) should be utilized. If the analyzer is useable from, say, 50 k.e.v. to 2.56 m.e.v., it is rarely necessary to alter gain settings. If, due to insensitivity over the lower eight or ten channels, the region up to 100 k.e.v. is inaccessible frequent gain changes may be required. Where the window level control is used, there evidently is a disinterest in lower energy information. Then the loss of the lower three or four percent of the measurement means only that there is a few percent loss in total channels available. In the case of non-suppressed zero, however, the difference between proper linearity over 98% of the range and 96% of the range means a factor of two differences in the total range of energies which can be measured using one gain setting.

There is a good reason for providing a switch to control the use of the energy zero position control. The same switch which provides a voltage to that control to allow many channels of zero suppression

applies a 50 millivolt safety bias to T2. The energy zero control has a less drastic effect per dial revolution in normal operation, with the WINDOW switch off.

The analyzer is sensitive to very small signal pulses. It is mandatory that the signal source be relatively free of noise, for noise will be analyzed, and much time will be lost in the process. If noise is a problem, the WINDOW switch should be placed on. This causes the analyzer sensitivity to decrease even when the zero energy intercept is at channel zero, with a penalty only of a few channels of analyzer non-linearity.

2. ADC Logic Circuits

The linear circuits described in the preceding section are relatively independent of the analyzer computer and ADC logic circuits, except that the linear gate is blocked during appropriate times, by those circuits. The computer and ADC circuits, on the other hand, are highly dependent upon the single output signal from the linear circuits, ADCB.

When that signal becomes positive, the following sequence of events occur. (Refer to Figure 27, which shows the time sequence.) First, a two megacycle per second continuous pulse train applied to a control flip-flop (F) (see ADC Logic Circuit Diagram) through diode gate 2 is allowed to turn on that flip-flop. The flip-flop turns on, therefore, in synchronization with the two megacycle per second oscillator. Two microseconds later, the same two megacycle signals are allowed to advance the analyzer channel scaler, for the shaping circuit (T36 and T37) is unclamped when the base of T35 is allowed to become positive, which happens two microseconds after the control flip-flop is turned on, for at that time gate 1 is energized. The address scaler advances as long as T35 is non-conducting, which continues until ADCB becomes negative again. When the control flip-flop (F) is on, the linear sweep operation is initiated, for the signal called "F" from that flip-flop becomes positive, allowing T10 to conduct, typically 60 microamperes.

Since the F flip-flop turns on in synchronization with the address advance pulses, and since the linear sweep does not start (in earnest) until the F flip-flop is on, therefore the ramp start point and the first address advance pulse are always fixed in time relative to each other, so there is negligible time jitter regardless of the exact moment of arrival of the input signal pulse.

When the sweep circuit has completed the required sweep action, ADCB becomes negative, gate 1 closes which ends the address advance pulses (ACS), and gate 6 provides a positive ADCS (initiative storage) signal. This causes a

count to be stored in a channel, the number of which equals the number of ACS pulses which occurred.

At the end of storage, the signal P4 Rep (which means "end of memory cycle") occurs, which resets the F flip-flop. The linear gate then reopens.

P4 Rep also triggers the reject trigger pair (T24 and T25). If ADCB occurs while that trigger circuit is on, gate 4 produces a signal called ADCR, which causes the next memory cycle to be a non-add memory cycle, for the control circuit "ALTER" flip-flop is turned off by any ADCR signal. Only if ADCB occurs very soon after a previous memory cycle will gate 4 produce a positive signal. Therefore only radiation signals occurring during the end of a memory cycle are rejected. The reason for the rejection circuits being included is to prevent events, which may be distorted by the transient state of affairs at that time, from being recorded, for they would be recorded incorrectly.

A "tagged" artificial signal pulse shown in Fig. 26, is periodically applied to transistor T3, in the linear gate circuit. This signal pulse is distinguished from real signal pulses by virtue of its size. It is larger than any signal pulse. This tagged pulse is the clock pulse, used for analyzer live-time determinations. If it passes the linear gate, the analyzer ADC circuits make an attempt to analyze it. However, the discriminator transistor, T15, detects such pulses, and when one occurs, the clock trigger pair, T20 and T21, is triggered. This causes gate 1 to close, preventing ACS signals. It quickly discharges the linear sweep circuit, and so despite the large size of the tagged input signal applied to the linear gate, storage of a count occurs very soon after occurrence of the periodic tagged clock pulse, and storage is in channel zero.

Other signals may cause storage of counts in channel zero, except for the action of gate 5, which rejects any count from channel zero unless the clock trigger is on. Naturally it is essential that only periodic timing pulses be stored in that chan-

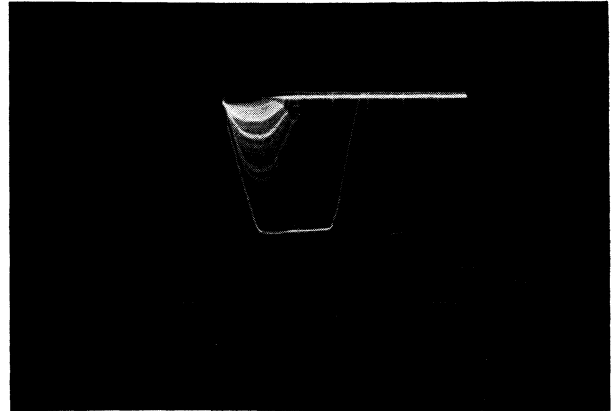


Figure 26. Linear Gate output signals showing large "tagged clock" pulse.

nel. It should be observed that the tagged clock pulses, if they occur during or just after the last part of a storage cycle, will be rejected by the action of gate 4, just as real signal pulses are.

B. Adjustments

The ADC circuits should normally require no adjustments during the life of the instrument.

The trim-pot shown in the window level control circuit diagram may be readjusted to cause the zero energy intercept of the amplitude versus channel number characteristic of the analyzer to be shifted. The front panel control accomplishes the same purpose, but it may be desired to maintain the setting of the front panel control the same, during very long periods, to make operation easier. A convenient "zero" position (not necessarily full counterclockwise) front panel control setting should be selected and locked. Then the analyzer zero intercept should be adjusted correctly using the trim-pot.

VI. Digital Circuitry

A. General

The Nuclear Data Model ND130A Analyzer is essentially a simple count tally computer with an analog-to-digital converter to control the counting channels into which counts are to be tallied. Except for relatively complex operations involved during readout, the instrument would be quite easy to understand and easy to describe. There are some intricacies introduced to allow more flexibility during even simple analysis operations; for example, it is frequently desirable to utilize only a portion of the memory for a particular measurement, and to provide for external determination of which section is to be used for a particular count. Also, it is desirable to record the measurement live time into one of the analyzer's channels during data accumulation.

It is well to separate discussions of operations during data accumulation, without live time tally functions, from operations during readout. It will be seen that certain basic major components of the analyzer, such as the memory array, the adder, the address scaler, and the like, are utilized for both analysis and readout functions. An initial understanding of their use in data accumulation, descriptions of which are largely in English rather than symbolic language, is helpful in understanding the largely symbolic explanations given of the readout operations.

The analyzer utilizes a memory and arithmetic circuits which are serial decimal in structure, rather than parallel decimal as used in some analyzers. A discussion of the analyzer digital circuits should therefore be preceded by an explanation of the difference in the two systems.

As far as the actual arithmetic process is concerned, there is virtually no difference between a parallel system and a serial system. Just as a person adds two whole numbers by considering the sum of the two least significant digits first, then the next, and so on, with proper consideration of the carries involved, so also do the arithmetic circuits of multichannel analyzers of either type. In a parallel system, the whole number is read into a register of twenty or twenty-four binary digits. Since incremental addition is usually involved, a "one" is added to the first decade, the least significant digit of the number. If there is a carry (if the number had a 9 in the least significant digit position), an increment is added to the next digit, and so on. The process is really a several step process, with the operation upon any digit not initiated until it has been completed in all less significant digit positions. After the process is completed, the new number is restored to the memory, in the same position from which it was read. The process requires

only one or two microseconds, plus the actual length of time required in reading and writing from and into the memory.

In serial decimal arithmetic, the same process is used, but only one decimal digit at a time is read from the memory. Only if there is a carry involved is more than one digit operated upon. The object of serial decimal systems is to avoid the need for the twenty or more stage memory output register, for each such stage requires a sense amplifier to amplify memory output signals, a combination binary scaler-shift register stage, and a memory writing circuit. In a serial system a four stage simple register with sense amplifier, writing circuit, and a logical adder is used to handle the information read from the memory. Nine times out of ten, only the least significant digit is operated upon, for if there is no carry, there is no need to operate upon successive digits of the whole number involved. If there is a carry, the next digit is read from the memory, and an increment is added to it. Whenever a carry is involved, the next digit is read from the memory. For a given memory speed, the average time required for arithmetic operations is 11.111 percent greater than if a parallel system is used.

Frequently subtraction is involved, instead of addition. The logical adder circuit, comprised of a network of diodes and resistors, is wired in such a way that when a signal called "ADD" is present, the output of the network is an increment greater than the input, and when the signal called "SUBTRACT" is present, the output is one less than the input. Where neither addition or subtraction is involved, as during readout, the adder circuitry does not alter the number presented.

A simplified block diagram of the memory, shown in the analysis mode of operation, is given in figure 1. After the analyzer ADC has produced the desired channel scaler state, that circuit provides a signal called ADCS, which causes a storage cycle to be initiated. The program pulser, in response to this signal, generates four pulses in sequence, each on a separate wire. These signals, called P1, P2, P3, and P4, are spaced about four microseconds apart and except for P4 which is one microsecond long, are each four microseconds in duration. These, successively, reset the M register, produce memory read currents and a strobe pulse for the M register reading amplifiers, write currents, and finally scaler reset signals. The act of reading the four binary digits from the selected channel and decimal digit position causes those magnetic cores associated to be reset to the zero state. When the memory write and inhibit currents occur, the selected cores are placed in a new state corresponding to that of the adder output.

There are a considerable number of operations which are not basically necessary, yet are very useful in certain situations, not shown in this block diagram, simply because it is not practical to devise a drawing type symbolism which is literally correct and also understandable. It is important to recognize the limitations of the block diagram presentation, in order to appreciate the need for a more concise notation. Some of the functions actually included in the analyzer, but not indicated on the block diagram, because their inclusion cannot but confuse the presentation are as follows:

Frequently it is desired to limit storage to one half of the memory, or a quarter of it. To absolutely block storage of counts which would fall into the wrong quadrant in the event the ADC makes an attempt to advance the address beyond the quadrant of interest, a signal must be provided to indicate that (in case of 128 point, or quadrant operation) the channel scaler has been advanced more than 127 steps. The signal which indicates this is called "AO" in the terminology of the diagrams for this analyzer. It is a positive pulse which occurs after 128 advance pulses have occurred, if quadrant operation has been switch selected, or 256 or 512 advance pulses otherwise, depending upon the size of the memory group in use at the time. When the signal AO occurs, it is mandatory that there be no count storage associated with the analysis operation which produced that signal. Two methods could be used to prevent that storage; one would be to block the "initiate storage" signal, but this, it happens, would disturb the entire analyzer logic since various flip-flops and registers set during the analysis operations are ordinarily reset at the end of a storage cycle. If the storage cycle did not occur, means would have to be provided to reset all applicable registers when AO occurred. Another method, the one used in this analyzer, is to allow the normal operations to proceed, but with the adder circuit in a "non-add" state. A flip-flop, called the ALTER flip-flop, has been included to remember for whatever time may be required, that the current memory cycle should be a non-add operation.

A further function, not shown, is that of forcibly setting the address to the desired quadrant or half, as determined by the front panel group position selector switches. Still another important function is that of setting the M register to state 0010 immediately after the last memory cycle in an arithmetic operation. If the M register, in a non-add memory cycle, should happen to result in the reading of the digit 9 into the M register, then the carry recognition circuits would initiate a new memory cycle as soon as the ALTER flip-flop was turned back on, as it absolutely must be, following the non-add memory cycle. Resetting the M regis-

ter to state 0010 (2), during the interval subsequent to the end of the memory cycle until the next analysis, prevents this from happening. Resetting to state 0000 would do just as well, and would be simpler, but unfortunately the same problem exists when non-add memory cycles occur when subtraction is involved, in which case a zero in the M register introduces the carry recognition, since it is necessary to carry when subtracting from zero.

Another highly important function performed during analysis but not shown in figure 1 is that of tallying the live time of the measurement into one memory channel. The analog-to-digital converter performs the greater part of the task. If the tally computer possessed any awareness of the processes involved in tallying, it would nevertheless not be aware of any difference between tallying time, and tallying radiation events, except that there would be a certain periodicity with which counts were tallied into channel zero. Whenever the ADC provides an initiate storage command, without any address advance pulses, and providing there is no count reject signal given, the count will be recorded into channel zero. This can happen if, and only if, the ADC has received and accepted a "Clock" pulse from the clock oscillator, meaning that the ADC was not busy at the time of occurrence of that pulse.

Included in the tally computer circuitry, however, is a monitor circuit which continuously examines the state of affairs in channel zero. If a memory cycle occurs, in address zero, a signal called "auto stop" (AS) is generated if the value of the number stored in that channel has reached a preselected level. For example, if a one minute measurement were operator-selected, then the monitor circuit provides the AS signal whenever any access is made to the fifth digit of channel zero of the memory. Such access would only be made if there had previously been 9999 counts recorded in that channel, for only then would there be a sufficient number of arithmetic carries to result in a memory cycle in digit five. For a two minute measurement, the front panel experiment time selection switches are so wired that not only must an access have been made to digit five, but the decimal digit 1 must have been read from that location. Only if there had been 19999 previously recorded counts in that channel would the conditions be satisfied. For ten minute timing, the sixth digit must have been interrogated, and for twenty minute timing a "1" must be seen during an interrogation of that digit. Similar requirements are placed for 4, 8, 40, and 80 minute timing.

An exception occurs for automatic stop operations during subtraction. The only time the analyzer will automatically stop during subtraction is

when the sixth digit is interrogated, a situation which happens whenever the previously tallied live time has been subtracted one count beyond zero.

These special functions could be used as illustrations of the considerable difficulty that would be involved in attempting to literally display the analyzer interconnections by means of block diagrams, even in this simple operating mode. This might in part suggest that perhaps a slightly different logical design could have been used, which would lend itself to block diagram representation more easily. The use of an "ALTER" flip-flop, for example, can easily be avoided, insofar as the functions already described are concerned. There are other uses of this flop-flop, however, particularly in the Model ND130A Analyzer-Computer. For easy conversion from one analyzer model to another, the concept of utilizing the "ALTER" flip-flop has been retained.

Actually, the description problem is not one of analyzer complexity, but one of representation means. In this instruction manual, a very simple Boolean notation is used to indicate the various functions which are performed under certain conditions. Clearly, it is as literally correct to state in abbreviated English (Boolean notation) the conditions under which a scaler is reset, for example,

as to draw a rectangle labeled "scaler" with signal lines connected to it, and with an English label at each such line in order to show that the scaler is reset under certain conditions.

The object of considering any representation at all beyond the circuit diagrams is to condense all of the information available in the circuit diagrams to a form which does not require the reader to recognize individual circuits as gates, or flip-flops, or scalers, and the like.

B. Symbolic Representation

It has been seen that during data accumulation, several major components are involved. These are shown in figure 1, and include the magnetic core memory, program pulser, M register, channel scaler, digit scaler, and adder. It would be impractical to formally symbolize these major circuits, which are digital in nature, by anything like a set of logical symbols. They are quite well known computer components, and the properties of these will be described in ordinary English. However, the operations upon these components (i.e. reset, advance, start, etc.) occur only under certain conditions. These conditions can be listed more or less systematically, and such a listing literally describes the operation of the computer, providing that the response of each major component to the operations upon that component is understood.

DESCRIPTION OF MAJOR COMPONENTS

1. Magnetic Core Memory.

This memory has a capacity of 3072 decimal digits. Any digit desired may be read from the memory by application of suitable binary addressing signals to it. In response to a particular address, in the form of a twelve bit binary number from the address and digit scalers, and in response to a timing signal (P2, described earlier), it provides the decimal digit stored in the selected address. The output is in the form of positive signals of in the order of a volt amplitude on each of four lines. These signals set the M register, described below, to any of ten possible states. These states, and the decimal value associated, are:

State	Value
0000	Zero
0001	One
0010	Two
0011	Three
0100	Four
0101	Five
0110	Six
0111	Seven
1000	Eight
1001	Nine

When another timing signal, P3, occurs, a number is written into the same address (since the channel and digit scalers have not been changed, as is always the case during a given memory cycle) and the value of this number is dictated by the output signals from the adder circuit, described below. The same decimal coding, of course, is used for reading into the memory as reading out.

In the interest of brevity, the memory will be considered to consist of not only the magnetic core array, but also the current generators used to drive the array. Whenever a memory cycle has been initiated, it invariably follows that the memory register, M, is set according to the value of the digit read from the memory during the P2 pulse, and the digit provided by the adder is always restored to that same address location.

2. M Register.

This is a set of four flip-flops, which may be set to any state by the signals from the memory. It provides output signals called M^0 , M^1 , M^2 , and M^3 , as well as the complement of these signals. It can be reset to state 0000 by a signal called RM, and can be set to state 0010 by a signal called RDSO.

3. Adder.

This circuit responds to the output signals from the M register, and three signals called ADD, SUBTRACT, and IDLE. The response is such that the value of the number applied is increased, decreased, or unchanged, at its output terminals, according to the presence of any one of the three signals commanding a particular arithmetic.

If addition is involved, the output is normally an increment greater than the input except if the input is the digit nine, in which case the output is zero. A similar exception is involved in the case of subtraction, in which a nine appears at the output if the input is zero. The adder provides a further output signal, called REP, and its complement $\overline{\text{REP}}$. This signal indicates that a repeat memory cycle is called for, whenever a nine appears at the adder input during addition, or a zero during subtraction.

4. Channel Scaler.

This is a binary scaler of nine stages. Its state can be advanced one step at a time by an input signal called ACS. Its state can be advanced sixteen steps at a time by a signal called ACS16. It can be reset to state 00000000 by means of a signal called RCSO. The last two stages, the most significant binary stages, can be set to any of four possible states by means of signals called RC^0 , RC^1 , RC^0 , and RC^1 . The outputs of the scaler, C^n and the complement, \overline{C}^n , corresponds to the output of the nth stage. The signal C^n is affirmative, that is positive, whenever the nth stage is in the "1" state. It provides a signal called AO whenever it has been advanced a greater number of steps than the number of channels in the operator-selected group, during the advance provided by the ADC.

5. Digit Scaler.

This is a binary scaler, which provides output signals D^n and \overline{D}^n from the nth stage of its three stages. This scaler can be altered one step at a time, forward or backward, in response to an input signal called ADS. Operation is forward if an input signal called DSF is present, and backward if the signal DSB is present. This scaler can be reset to state 000 or to state 101 by signals called RDSO and RDS5 respectively. It provides signals DO, D4, D5, D6, and D7, respectively, when it is in state 000, 100, 101, 110, and 111.

6. Program Pulser.

This is a pulse sequence generator, previously described.

7. ALTER Flip-Flop.

This is a control flip-flop, providing an output called ALT when on, otherwise it provides the positive signal $\overline{\text{ALT}}$. It is set or reset according to

the conditions shown in the logic tables following. The output signals, modified by the front panel ADD-SUBTRACT switch, control the operation of the logical adder (3).

8. READ Flip-Flop.

This is a control flip-flop, providing signals R and \overline{R} according to whether it is on or off. The signal R is utilized directly in some cases, but from that signal is derived two more signals called RT and $\overline{\text{RT}}$, which are positive when R is positive and, respectively, when the readout mode switch is in the digital position or the analog position. The symbol RT can be taken to mean READ-TYPE, or READ-TYPE NOT. Since the logic of the entire analyzer is the same for paper tape punch or read operations as for typing, it is correct to observe that a better symbol would be RD and $\overline{\text{RD}}$, after READ-DIGITAL. The symbol RT, however, has been used in several other analyzer models and was retained. These remarks are included to emphasize the point that most of the abbreviated symbols used in this analyzer are derived from the first letters of the operations involved. Examples are RDSO, which means reset digit scaler to 0, or RC^1 , which means reset the C^1 stage (of the channel scaler) to state 1. After reading the present descriptions of the basic analyzer components it is well to spend a little time studying the definitions of symbols given in section VII. The section IX Logic Tables are more understandable if repeated back references to definitions can be avoided.

When this flip-flop is in the on state, the analyzer is in the readout mode of operation. It will be seen from the logic table that numerous gates are blocked when R is negative. The logical structure is changed by switching the READ flip-flop on or off.

9. ANALYZE Flip-Flop.

This control flip-flop provides the outputs A and \overline{A} . Whenever this flip-flop is on, the analyzer is in the analyze mode of operation. The structure of the analyzer logic during such times can be seen from an examination of the logic table. It is possible to have both the READ and the ANALYZE flip-flops on at the same time only if there is a misoperation such as might occur if the analyzer power is switched on with the operating mode switch on a position other than "Stop 2". The logic tables (which should be only cursorily examined at this point) indicate that the signal "Start R" which is a signal from the front panel operating mode switch, or the end of analysis signal (derived by differentiating the signal A) can turn on the READ Flip-Flop. Neither can happen while the ANALYZE Flip-Flop is still on.

10. MR Register.

This is a register used exclusively for readout purposes, in the Model ND120 Analyzer. It is used to store one decimal digit of the channel being read out when the analog readout mode is involved. Information can be shifted into it from the M register through a set of transfer gates, upon a command called Transfer to MR (TMR). Transfer of this digit frees the M register to receive the next most significant decimal digit from that channel. Analog decoders connected to both the M and MR register generate a current proportional to the magnitude of the two most significant digits. These currents are applied to a logarithmic diode, which generates a voltage proportional to the logarithm of that current. To this is added a voltage proportional to the digit position of the most significant digit read from the channel. The sum of these voltages therefore is the logarithm of the number stored in that channel, with very high accuracy except for the round-off error introduced by ignoring all digits except the most significant two digits.

Another use of this register is to sense when a digit other than zero has been read from the channel currently being interrogated. A signal output, called \overline{MR} , is positive when this register contains no binary "1's". During analog readout, continuous memory cycles occur until this signal becomes negative, once interrogation of a channel has begun. In the event no non-zero digits are found in the channel, it is artificially set to state 0001, which stops the search process. A slight disadvantage of this method is that zero looks the same as one count, in analog readout. There is very good reason for using this logical structure, however, and it has therefore been used despite this generally minor limitation. During decade line generation, the M register and the MR register must be in state zero and 0001, respectively, in order to simulate 1, 10, 100, etc., counts at the six decade line levels. In the model 130 analyzer this register is also used as a scaler.

11. PHASE Flip-flop.

This flip-flop provides output signals PH1 and PH2, which are respectively plus and minus when the flip-flop is "on", and vice-versa. The logical structure during readout is changed when this flip-flop is "on". During Phase 1 operations, if readout is analog, data is read from the memory and displayed point by point. During Phase 2, decade lines are plotted. In digital readout, the typewriter is caused to carriage return during Phase 2. A "dummy" interrogation of the current channel is made while the carriage is returning. That channel

had previously been read out by typewriter (or punch or magnetic tape), so the "dummy" interrogation causes no loss of typed information, and has the purpose of "marking time" while the carriage is physically returning.

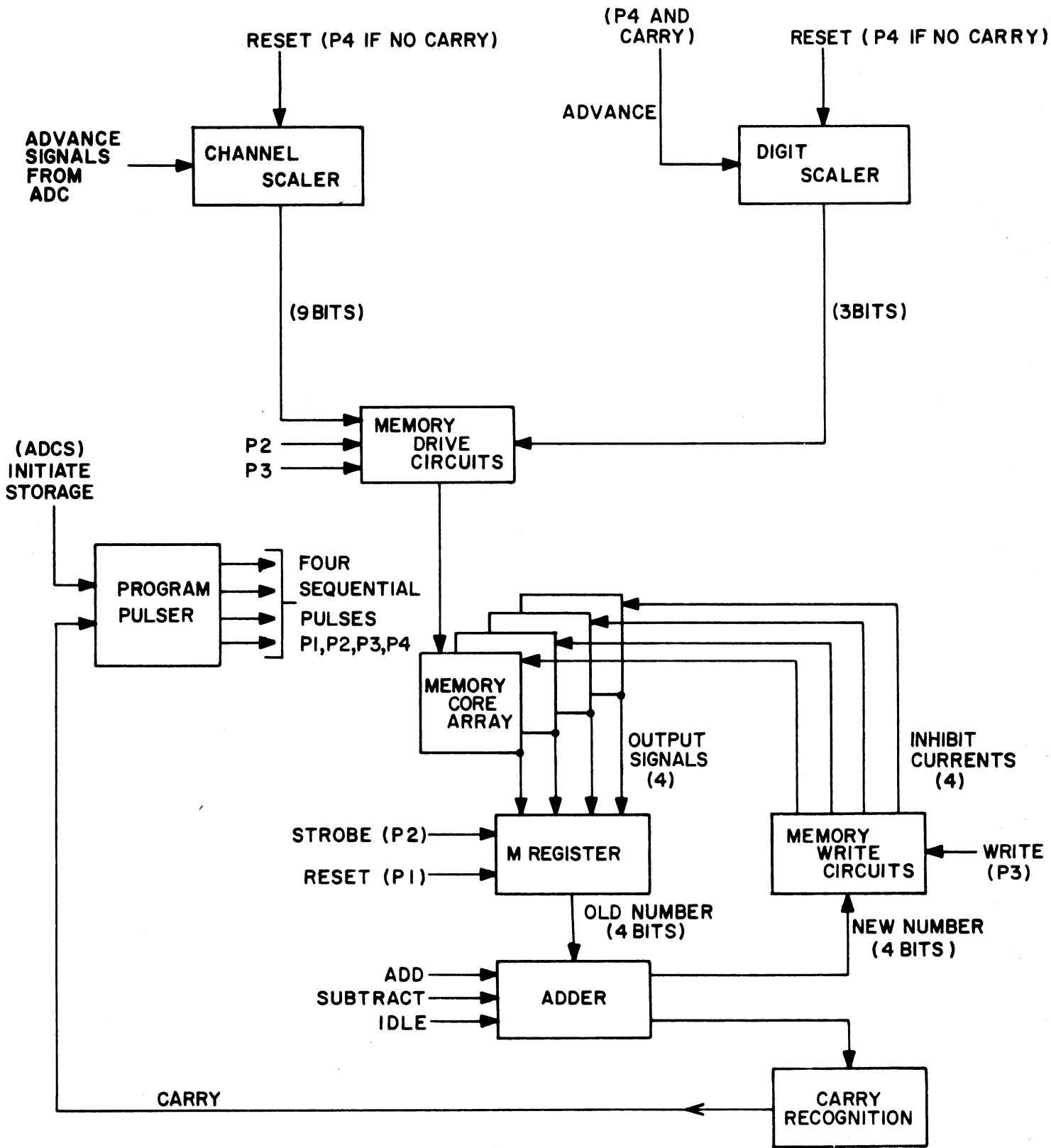
C. Overall Operation

Reference should be made again to the list of symbols, definitions, and general remarks given in section VII. The circuit equivalents given in figure 26 should be examined. A study of section IX, showing the overall computer logic, should now give an accurate picture of the analyzer structure. From this table, and the information in sections VII and IX, a literally correct block diagram could be constructed, although such construction is not a recommended aid to understanding. The logic table could have been constructed from the circuit diagrams, but this is exceedingly tedious since it requires sufficient understanding of transistor circuitry to be able to interpret the individual gates, differentiating circuits, and the like. The logic tables should, instead, be an aid to understanding the circuitry, for these tables tell the intended functions of individual circuits.

No attempt will be made to translate into plain English the meaning of each operation shown in the logic table. Some of the operations can conceivably seem inefficient or redundant, but an explanation of the design philosophy would almost always be a convincing justification of the method used. However, the purpose of this manual is not to teach design philosophy, but only to provide sufficient information that those who are interested in complete understanding of the analyzer circuits can, in fact, achieve any level of understanding desired. One thing is certain; whatever the presentation might be, an understanding can only be achieved after a great deal of thought and time.

D. Wiring Tabulations

Section X of this manual lists the signals which are interconnected from board to board, and connector to connector. Preceding these tabulations is a "map" of connector locations. This "map", used in conjunction with the silk-screen markings on the circuit board, can be used to rapidly locate any circuit of interest. Generally the use of transistor numbers, as shown on the circuit diagrams (the board name is indicated on the circuit diagram), is the best way of locating a circuit. The transistor markings are for the most part orderly, with the transistors which are adjacent usually having numbers which are adjacent.



ANALYZER BLOCK DIAGRAM IN ANALYSIS MODE OF OPERATION

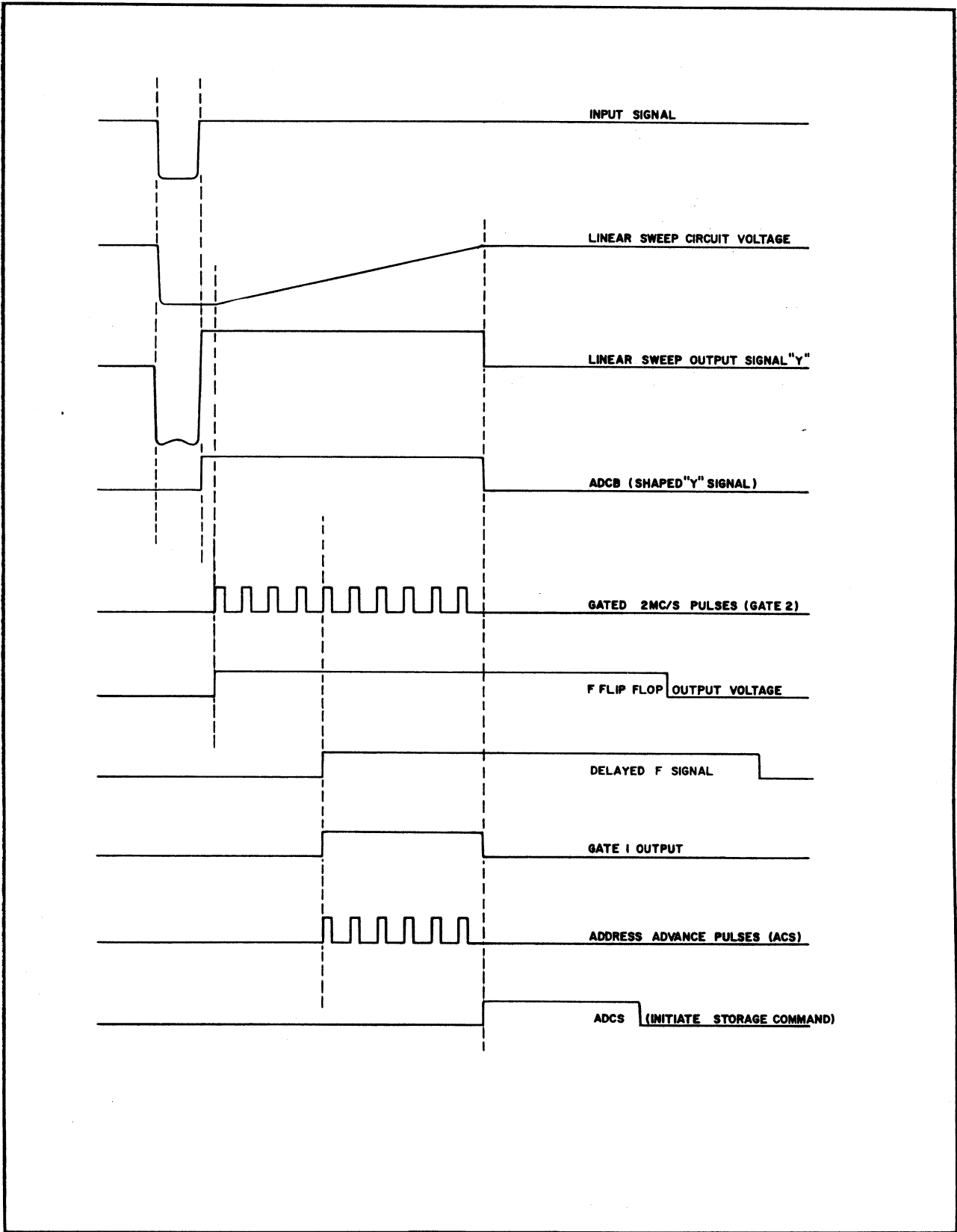


Figure 27. Timing sequence, analog-to-digital Converter.

VII. LIST OF SYMBOLS USED IN ND130 COMPUTER LOGIC

SIGNAL	MEANING		
A	Output of A flip-flop. Positive when this flip-flop is "on". Signals that the ANALYSIS mode of operation is in process.		when the state of the scaler changes from 127 to 0; for 256 or 512 point operation it occurs when the state changes from 255 or 511 to 0. (see MS).
\bar{A}	A not.		
ACS	Pulse which advances channel scaler state one unit, during analysis or readout.	AR	This is a switch derived signal, positive when it is desired to operate in the AUTO-REPEAT mode. It is positive only when the front panel AUTO-REPEAT switch is ON, and when the readout mode switch is in the DIGITAL position.
ACS16	Pulse which advances channel scaler sixteen units, during decade line generation only.		
ADD	Signal derived from front panel ADD-SUBTRACT switch. This signal, when positive, causes an increment to be added to any digit read from the memory. The control circuit "alter" flip-flop must be on, and the front panel switch must be in the ADD position for this signal to be positive. (see SUBTRACT).	AS	Autostop. This signal becomes positive when conditions, switch selected by the experiment time selector controls on the front panel, are satisfied. Used to turn off the Analyze flip-flop when further conditions are also met. See logical structure tabulations (Set A).
ADCR	Signal generated by ADC, to turn off "alter" flip-flop when it is desired to not tally a particular count. Referred to as "ADC Reject" pulse.	CHO	Signal which is positive when channel scaler is in a state corresponding to the first channel of a selected group position.
ADCS	Command from ADC to cause a storage cycle following analysis of a signal.	C^n, \bar{C}^n .	Output signals from the 'n'th stage of the channel scaler.
ADS	Signal which alters digit scaler by one step. May be forward or backward, depending upon the condition of signals DSB and DSF.	\bar{C}^7G .	One of the input signals to gate whose output signal is CHO. \bar{C}^7G is identically equal to \bar{C}^7 for 512 and 256 point operation. For 128 point operation it is open.
ALT	Signal from "Alter" flip-flop, positive when that flip-flop is on. When this signal is positive, the next digit to be read from the memory is altered by plus or minus one depending upon whether addition or subtraction is involved.	C^8G .	One of the input signals to channel scaler decoding matrix. C^8G is controlled by the overlap switch. With this switch in the normal position, C^8G is identically equal to C^8 . In the overlap position it is held at -4 volts.
\bar{ALT}	ALT not.	\bar{C}^8G	One of the input signals to gate whose output signal is CHO. \bar{C}^8G is identically equal to \bar{C}^8 for 512 point operation. For 256 and 128 point operation it is open.
AO	Address scaler overflow. This signal is a positive pulse which occurs whenever the channel (address) scaler overflows as a result of resetting (RCSO) pulses. For 128 point operation, this occurs	CH7.DO	Signal positive when the channel and digit scalars are in states corresponding to the least significant digit of channel 7.

CLOCK	Timing oscillator output signal.		
CR	Driving pulse for typewriter carriage return solenoid.		
CR'	Signal which, when positive, energizes carriage return solenoid driver.		
D^n, \overline{D}^n .	Output signals from the 'n'th stage of the digit scaler.		
D5	Signal positive when digit scaler is in the 101 state.		
$\overline{D5}$	Signal positive when digit scaler is not in the 101 state.	\overline{MB}	Output signals from memory register M. This register receives information from the memory array, a digit at a time, and controls the logical adder circuits as well as various analyzer control circuits. This is the memory output register from which the typewriter, punch, and analog readout devices receive digital information. M^n is positive when the nth stage is "on", or in the "1" state. It is otherwise negative. \overline{M}^n is of the opposite polarity.
D6	Signal positive when digit scaler is in the 110 state.		
D7	Signal positive when digit scaler is in the 111 state.	\overline{MR}	Signal which is positive when memory register MR contains all zeros. This register receives information from the M register; the contents of the M register being transferred to the MR register at the beginning of each memory cycle. The function of the MR register is to retain the most significant digit of each channel during display time so that the outputs of the M and MR registers can be decoded to provide vertical deflection voltages for CRT and pen operation. The MR register plays no part during the analysis mode or during digital readout.
$\overline{D7}$	Signal positive when digit scaler is not in the 111 state.		
DLS	Signal positive when decade line switch is in 'off' position.		
DSF	Signal positive when digit scaler alterations are to be 'forward' when ADS occurs.		
DSB	Opposite of DSF		
ERASE	Signal when positive prevents "I's" being written into the memory.		
EXT.IS.	Pin connection for external initiation of storage.	$MR^0 \dots 1$	Signal positive when 1st stage of MR register has to be set to the "1" state.
G	Ground.		
H.DEF.	Output from channel scaler analog decoders.	\overline{MS}	Signal which gives AO. For 128 point operation, \overline{MS} is identically equal to $\overline{C^6}$; for 256 point operation it is equal to $\overline{C^7}$; and for 512 point operation it is equal to $\overline{C^8}$. (See AO)
i_D from address.	Output from digit scaler analog decoders.		
i_D to MR.	Output from digit scaler decoders, or from decade line interpolation switches, depending on front panel PEN CALIBRATION switch setting.	\overline{NDB}	Signal positive when analyzer is not busy.
L_m	Output from M and MR register analog decoders.	P1	First pulse from program pulser.
		P2	Second pulse from program pulser.
I_0, I_1, I_2, I_3 .	Output signals from inhibit current generators.	P3.	Third pulse from program pulser.

P4.	Fourth pulse from program pulser.	$\overline{\text{REP}}$	Opposite of REP.
P4. $\overline{\text{REP}}$	Positive signal occurring at the end of the last memory cycle in an arithmetic operation.	RM	Reset M register.
PEN	Signal positive when READOUT MODE switch is in the PEN position.	RT	Signal positive when READOUT MODE switch is in the type position and the R flip-flop is on.
PH1	Signal positive when "phase" flip-flop is in the phase 1 state. This signal is positive during curve plotting part of analog readout process, and also positive during analysis. It is negative on analog readout during the decade line plotting process, and on digital readout at the end of every eighth channel during the time required for the typewriter carriage to return.	$\overline{\text{RT}}$	Signal positive when READOUT MODE switch is not in the type position but the R flip-flop is on.
PH2	The opposite of PH1.	$S_0, S_1, S_2, S_3.$	Signals from memory sense amplifiers.
R	Signal positive during readout mode of operation.	SIG. GND.	Ground bus on Address Board separate from Power Supply ground.
$\overline{\text{R}}$	Signal negative during readout mode of operation.	SOI	Shaped output signal of readout oscillator.
$R_0, R_1, R_2, R_3.$	External read-in signals which, when positive, set corresponding M register stages to '1' state.	SPACE	Driving pulse for typewriter space solenoid.
RAMP	Voltage which determines ADC linear ramp slope.	SP'	Signal which, when positive, energizes space solenoid driver.
RC ⁴ 0	Set channel scaler fifth stage to state "0"	START A	Signal pulse which occurs at time the main mode switch is placed into the ANALYZER position.
RC ⁴ 1	Set 5th channel scaler stage to "1" state.	START R	Signal pulse which occurs at time the main mode switch is placed into READ position.
RC ⁷ 0	Set 8th channel scaler stage to "0" state.	STOP	Steady signal from main mode switch when in the STOP position.
RC ⁷ 1	Set 8th channel scaler stage to "1" state.	SUBTRACT	Signal derived from front panel ADD-SUBTRACT switch. This signal, when positive, causes an increment to be subtracted from any digit read from the memory. The control circuit "alter" flip-flop must be on, and the front panel switch must be in the "subtract" position for this signal to be positive.
RC ⁸ 0	Set 9th channel scaler stage to "0" state.	TMR	Transfer contents of M register to MR register.
RC ⁸ 1	Set 9th channel scaler stage to "1" state.	TWS	Control signal which initiates driving pulse for operating typewriter, punch, or reader solenoids.
RCSO	Reset channel scaler to state corresponding to the first channel of a selected group position.	V. DEF.	Output from logarithmic transducer that provides vertical deflection signals for CRT and PEN displays.
RDSO	Reset digit scaler to state 000	"0" "9"	Connect directly to typewriter solenoids 0 through 9.
REP	Signal which is positive when the M register contains 9 during addition or 0 during subtraction.		

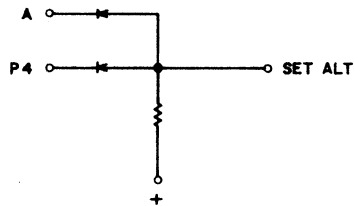
SO20	Twenty millisecond pulse generated by a trigger pair in response to each TWS signal.		is changed from ordinary readout to the data reduction logic indicated in Section IX.
OSC	Periodic pulse from an oscillator circuit which has a frequency of about 4 kc/s during CRT readout and DUMP modes of operation, 50 cps during PUNCH mode of readout, 10cps during TYPE readout, and 1/2 cps during PEN readout.	\overline{DR}	Complement of DR.
		MR15	Signal which is positive when MR register contains the binary number 1111, which is equivalent to fifteen.
		$\overline{MR15}$	Complement of MR15.
		AMR	Signal to step MR scaler one unit.
C	Output of "C" flip-flop, which is positive when this flip-flop is "on". This flip-flop is set whenever a carry is involved subsequent to the addition or subtraction of two decimal digits, during data reduction processes.	CMR	Signal which permits carry signals to be coupled between stages of the MR register.
\overline{C}	Complement of C.	DRSW	Signal which is positive when "initiate computer cycle" push-button is depressed.
DR	Output of DR flip-flop, when that flip-flop is "on". When this signal is positive, the computer logic	FTC+	Force to channel 1. Signal which causes address to temporarily change to channel 1.
		FTC—	Complement of FTC+.

EXAMPLES OF CIRCUIT EQUIVALENTS
OF SIMPLE BOOLEAN NOTATIONS

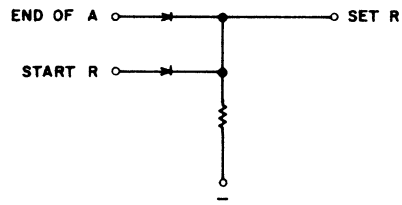
NOTATIONS

SET ALT = $A \cdot P4$

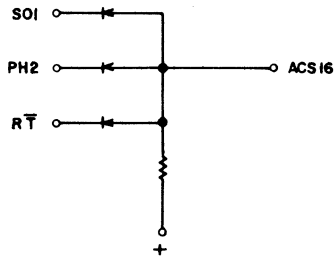
TYPICAL CIRCUITS



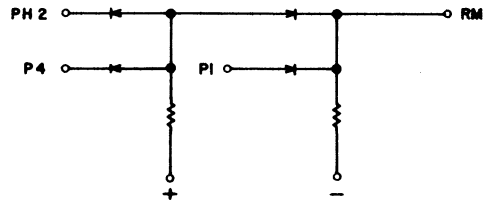
SET R = END OF A + START R



ACS 16 = $SO1 \cdot PH2 \cdot R\bar{T}$



$RM = P1 + PH2 \cdot P4$

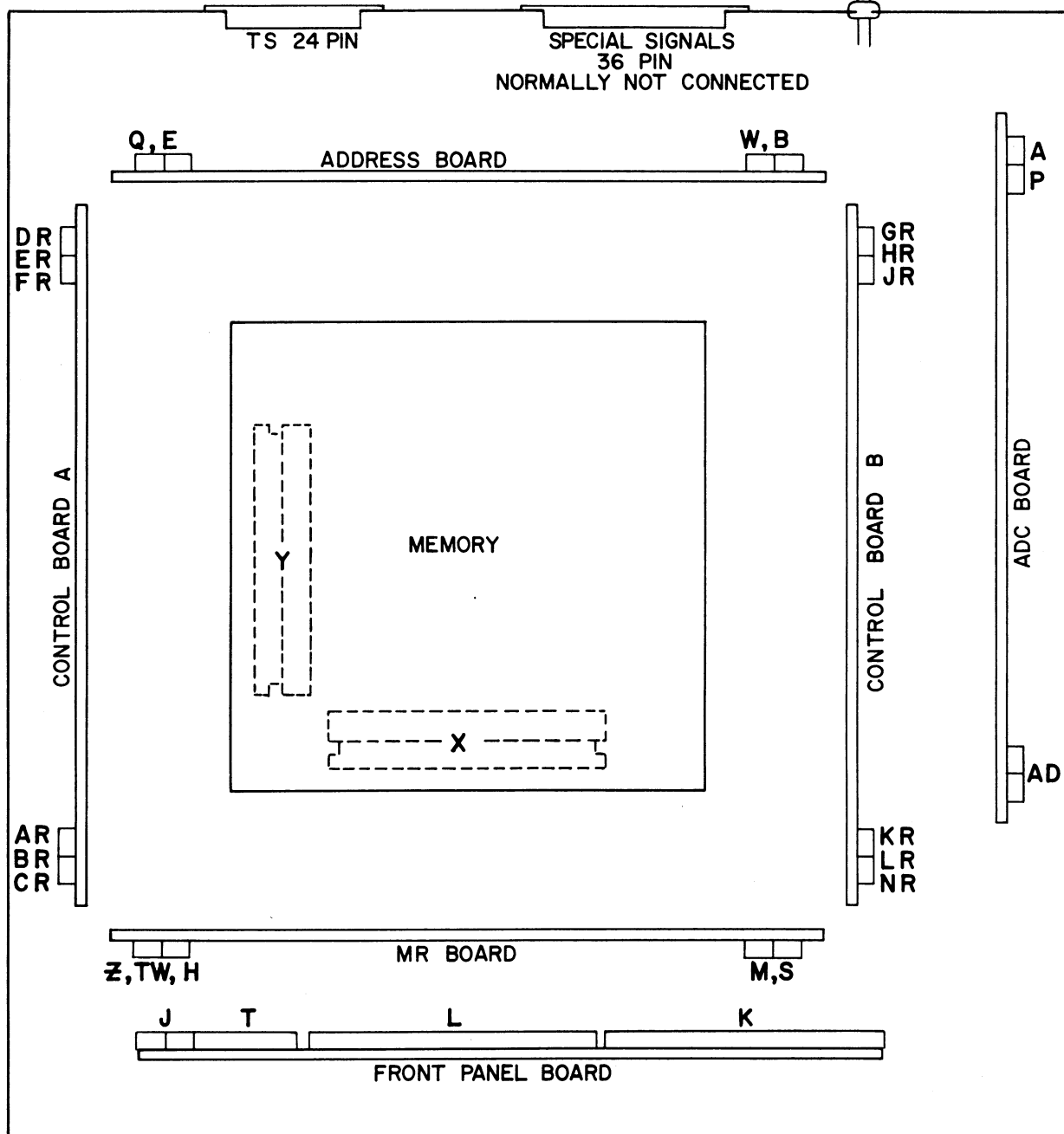


NOTE:

ENGLISH EQUIVALENT OF $RM = P1 + PH2 \cdot P4$:
"RESET M REGISTER WHEN P1 OCCURS OR
WHEN P4 OCCURS DURING PHASE 2."

TO TYPEWRITER

TO 14 PIN CONNECTOR
ON REAR OF POWER
SUPPLY



CONNECTOR LOCATIONS

VIII. SERVICING

It has been our experience that when analyzer servicing is needed the best method is to return the instrument to the factory. In this way the work can be done quickly and efficiently by trained personnel; there is no danger of makeshift repairs that are sometimes found necessary where work has to be done in the field without the complete test facilities and equipment that exist at the factory. Also, when servicing is carried out in the factory, the analyzer can be given proper heat, cold, and marginal tests before being returned.

In the ND130A, all circuit boards are replaceable, including the front panel, and it might be thought that board replacement would be considered the most efficient form of servicing. For a simple fault confined to one board this might be true, but it is not always easy for the user to decide if the trouble lies on a board, or in the cable harness, or the front panel, or with auxiliary equipment.

There are penalties attached to any form of servicing, and the only satisfactory way to avoid these penalties is to have extremely high reliability. The

user can help to maintain the reliability of the instrument by discouraging modifications, alteration, or repair by other than the most skilled engineers.

In a surprising number of instances, analyzers of an earlier type, returned for repair, have been found to be not faulty in any way. Apparent malfunctions have involved several misunderstandings by the user, but one of the most common types of apparent failure has been due to detector malfunctions, which produce symptoms that are often interpreted incorrectly by the user as analyzer malfunctions. As measurement precision improves, gain drifts and timing errors much less than those earlier considered tolerable become important errors. As a result effects which are inherent in the analysis of random signals produce results that are often mistaken for analyzer imperfections by all but the most experienced users. It is in order to avoid these misunderstandings that much of the information in this manual has been written, and it is interesting to note that the ND-130 performance is sufficiently good that a large part of this information concerns effects not often observed in the use of earlier analyzers.

IX. COMPUTER LOGIC

Set A	7B	6B	AR. End of R Start A	RM2			$\overline{\text{DR}} \cdot \text{RDSO}$
Set $\overline{\text{A}}$	9B	10B 8B	CHO. P4. D6 ADD. CHO. $\overline{\text{REP}}$. AS. P4 STOP DR	MR ⁰ 1	44A	43A 42A	$\overline{\text{DR}} \cdot \text{P2} \cdot \text{D7} \cdot \overline{\text{MR}}$ P2. PH2
ACS	17A	16A 15A 18A	ADCA RT. D7. PHI. P1 PHI. SO1. $\overline{\text{RT}}$ DR. $\overline{\text{C}}^* \cdot \text{P1} \cdot \text{D6} \cdot \text{MR15}$	Set PHI	14B	16B 15B	P4. CH7. DO. PHI2. RT D7. $\overline{\text{RT}}$. AO. PH2 STOP (DR forces PHI negative)
ACS16	3A		SO1. PH2. $\overline{\text{RT}}$	Set PH2	11B	13B 12B	RT. P4. CH7. DO. PHI $\overline{\text{RT}}$. AO. PHI (DR forces PH2 negative)
ADD			ADDSW. ALT	Set R		1B	End of A Start R (DR forces R negative)
ADS	9A	8A 7A 6A 5A 4A	P4. RT REP. P4. $\overline{\text{DR}}$ PH2. AO. $\overline{\text{RT}}$ P4. PHI. $\overline{\text{RT}}$ DR. $\overline{\text{C}}^* \cdot \overline{\text{MR}}$. SO1	Set $\overline{\text{R}}$	4B	5B STOP 2B	CHO. RT. P3. D7 STOP (AR + Pen). AO. DO. PHI2 (DR forces $\overline{\text{R}}$ negative)
Set ALT	27B	28B 25B 24B	P4. A DR. $\overline{\text{C}}^* \cdot \text{C} \cdot \text{MR15} \cdot \text{P2}$ DR. $\overline{\text{C}}^* \cdot \overline{\text{MR15}} \cdot \text{P2}$	RC ⁰		2A	DR. $\overline{\text{C}}^* \cdot \text{P4}$
Set $\overline{\text{ALT}}$	31B		ADCR	RC ¹		34A	DR. $\overline{\text{C}}^* \cdot \text{MR15} \cdot \text{P4}$
		32B 30B 29B	AO. $\overline{\text{DR}}$ A. $\overline{\text{DR}}$ DR. P4	RC ⁰	14A		Start of $\overline{\text{A}} \cdot \overline{\text{R}}$ P4. $\overline{\text{REP}} \cdot \text{A}$
AMR	39A		DR. $\overline{\text{C}}^* \cdot \text{P1}$	RDSO	20A	19A 18A	P4. $\overline{\text{REP}} \cdot \text{A}$ DR. $\overline{\text{C}}^* \cdot \text{P1} \cdot \text{D6} \cdot \text{MR15}$
Set C	17B	18B	DR. $\overline{\text{C}}^* \cdot \text{REP} \cdot \overline{\text{MR15}} \cdot \text{P4}$	RDS5	12A	10A 11A	$\overline{\text{A}} \cdot \overline{\text{R}}$ PHI. SO1. $\overline{\text{RT}}$
Set $\overline{\text{C}}$	19B	20B	DR. RC ¹ . $\overline{\text{REP}}$	RM	30A		P1
Carr. Ret.	24A		PH2. D5. (SO20)			29A	PH2. P4
Set DR	21B	22B	DRSW. PH2. D5. CHO. P4	RMR	41A	40A 38A	SO1. $\overline{\text{DR}}$ P1. DR. $\overline{\text{C}}^*$
Set $\overline{\text{DR}}$	23B	26B	CHO. DO	SO1			OSC (R + DR)
DSB	23A		PH2	SPACE	28A		PHI. D5 (SO20)
		22A 21A	RT $\overline{\text{MR}} \cdot \overline{\text{RT}}$ DR. P2	STOP			STOPSW. $\overline{\text{MB}} \cdot \overline{\text{DR}}$
DSF	23A		$\overline{\text{DSB}}$	SUBTRACT			ADDSW. ALT
IS	49A		ADCS	TMR	37A	36A	$\overline{\text{DR}} \cdot \text{P1}$ DR. $\overline{\text{C}}^* \cdot \text{P4} \cdot (\text{D5} + \text{x1})$
		48A 47A	SO1 REP. $\overline{\text{DR}}$ RT. D5. $\overline{\text{MR}} \cdot \text{PHI}$	TWS	45A	46A	RT. P2. $\overline{\text{D7}} \cdot (\text{PHI} + \text{D6})$

SECTION X. CONNECTOR PIN DESIGNATIONS

ADC BOARD

ND 130 A HARNESS		
CONNECTOR AD (ADC)	To	
1 Red	F. P. Board "To Amp"	Coinc.
2 Green	Energy O Pot	
3 Grey	W.C. Switch	Win. Lev.
4 Orange	F.P. Board "To ADC"	Sig.
5		
6 White/Red	F. P. Board "From Amp"	+8
7		
8 Yellow	PreAmp Board "-8"	-8
9 Violet	PreAmp Board	Und. Sig.
10 Black	Energy O Pot	GND
Black	PreAmp Board "G"	GND

ND 130 A HARNESS		
CONNECTOR P (ADC)	To	
1 #22 Black	JR 1	+50
#22 Black	Q 1	+50
2 #22 Brown	JR 2	-50
#22 Brown	Q 2	-50
3		
4 #22 Red	JR 4	+8
#22 Red	Q 4	+8
5 #22 Orange	JR 5	-8
#22 Orange	Q 5	-8
6 #22 Green	JR 6	+4
#22 Green	Q 6	+4
7 #22 Blue	JR 7	-4
#22 Blue	Q 7	-4
8 #22 White	JR 8	G
#22 White	Q 8	G
9		
10		

ND 130 A HARNESS		
CONNECTOR A (ADC)	To	
1 White/Violet	Switch	TC
2 Black	J 16	NDB
3		
4 Brown	J 7	RAMP
5		
6 Red	HR 1	ADCR
7		
8 Orange	BR 18	ADCS
9		
10 Yellow	B 13	CHO
11		
12 Green	BR 4	A
Green	J 8	A
13		
14 Blue	FR 9	MB
Blue	L 5	MB
15		
16 Violet	BR 6	P 4. \overline{REP}
17		
18 Grey	E 7	ACS
19		
20 Grey/Brown	ER 4	P1
21		
22 Black/White	K 19	CLOCK

ADDRESS BOARD

ND 130 A HARNESS CONNECTOR W (ADDRESS)

	To		
1	Black/White	Y 9	C ⁷
2	Violet/Orange	NR 3	C ⁷
	Violet/Orange	Y 10	C ⁷
3	Brown/White	Y 7	C ⁶
4	Blue/Orange	NR 4	C ⁶
	Blue/Orange	Y 8	C ⁶
5	Red/White	Y 5	C ⁵
6	Green/Black	Y 6	C ⁵
7	Yellow/White	Y 3	C ⁴
8	Green/Red	Y 4	C ⁴
	Green/Red	J 15	C ⁴
9	Violet/Black	Y 1	C ³
10	Grey	Y 2	C ³
11	Grey/White	X 5	C ²
12	Yellow/Black	X 6	C ²
13	Brown/Green	X 3	C ¹
14	Red/Green	X 4	C ¹
15	Yellow/Grey	X 1	C ₀
16	Yellow/Green	X 2	C ₀
17	Blue/Green	X 8	D ₀
18	Violet/Green	X 7	D ₀
19	Grey/Green	X 10	D ₁
20	White/Green	X 9	D ₁
21	White/Black	X 12	D ₂
22	Brown/Blue	X 11	D ₂

ND 130 A HARNESS CONNECTOR Q (ADDRESS)

	To		
1	#22 Black	P 1	+50
	#22 Black	T 1	+50
2	#22 Brown	P 2	-50
	#22 Brown	T 2	-50
3			
4	#22 Red	P 4	+8
	#22 Red	DR 4	+8
5	#22 Orange	P 5	-8
	#22 Orange	DR 5	-8
6	#22 Green	P 6	+4
	#22 Green	T 6	+4
7	#22 Blue	P 7	-4
	#22 Blue	DR 7	-4
8	#22 White	P 8	G
	#22 White	DR 8	G
9	#26 Black/Yellow	Dr 1	RI
10	#26 Blue/Red	BR 17	DR.C ⁸

ND 130 A HARNESS CONNECTOR B (ADDRESS)

	To		
1	Brown/White	LR 14	C ⁸
	Brown/White	J 2	C ⁸
2	Red/White	K 10	C ⁸
3	Green/Black	K 11	C ⁸ G
4	Yellow/White	J 4	C ⁸ G
5	Green/White	J 5	C ⁷ G
6	Violet/Black	J 17	RC ⁸ 1
7	Grey/Black	J 22	RC ⁸ 0
	Grey/Black	AR 2	RC ⁸ 0
8	Grey/White	J 18	RC ⁷ 1
9	Black/Grey	J 20	RC ⁷ 0
10			
11	Black/Orange	K 9	H.DEF
12	Red/Violet	J 13	D
	Red/Violet	ER 2	D
13	Yellow	A 10	CHO
	Yellow	GR 8	CHO
14	Orange/Violet	GR 11	CH 7.DO
15	Yellow/Violet	K 18	D4
C 8	Yellow/Violet	GR14	D4
16	Green/Violet	ER 5	D7
17	Violet/Grey	BR 9	D6
18	Grey/Violet	K 14	D5
	Grey/Violet	ER 22	D5
19	White/Violet	GR 9	D0
20	White/Black	BR 19	D5
21			
22	Red/Blue	BR 21	D7

ND 130 A HARNESS CONNECTOR E (ADDRESS)

	To		
1			
2			
3			
4			
5	White	AR 1	Sig. Gnd.
6	White/Brown	AR 3	ACS 16
7	Grey	A 18	ACS
	Grey	AR 7	ACS
8	Grey/Green	AR 6	RCSO
9	Yellow/Orange	AR 4	ADS
10	Green/Orange	L 13	RC'0
11	Blue/Orange	L 19	RC'1
12	Violet/Green	AR 8	RDSO
13	White/Green	AR 5	RDS5
14	Blue/Green	AR 10	DSB
15	Yellow/Green	AR 9	DSF

CONTROL A BOARD

ND 130 A HARNESS CONNECTOR DR (CONTROL A)

	To	
1	#26 Black/Yellow	Q 9
2	#26 Grey/Black	PS 34
3	#26 White/Green	PS 33
4	#22 Red	Q 4
	#22 Red	T 4
5	#22 Orange	Q 5
	#22 Orange	T 5
6	#26 Grey/Orange	PS 32
7	#22 Blue	Q 7
	#22 Blue	T 7
8	#22 White	Q 8
	#22 White	T 8
9	#26 Grey/Blue	PS 31
10		

RI
End
Start
+8
+8
-8
-8
All
-4
-4
G
G
Selected

ND 130 A HARNESS CONNECTOR AR (CONTROL A)

	To	
1	White	E 5
2	Grey/Black	B 7
3	White/Brown	E 6
4	Yellow/Orange	E 9
	Yellow/Orange	HR 10
5	White/Green	E 13
6	Grey/Green	E 8
7	Grey	E 7
8	Violet/BGreen	E 12
9	Yellow/Green	E 15
10	Blue/Green	E 14

Sig.Ground
RC⁸O
ACS 16
ADS
ADS
RDS5
RCSO
ACS
RDSO
DSF
DSB

ND 130 A HARNESS ND 130 A HARNESS CONNECTOR ER (CONTROL A)

	To	
1		
2	Red/Violet	B 12
3	Violet/Blue	GR 10
4	Grey/Brown	A 20
	Grey/Brown	LR 6
5	Green/Violet	B 16
	Green/Violet	KR 6
6	Orange/Green	M 13
7	Violet/Yellow	L 4
	Violet/Yellow	HR 5
8	White/Blue	L 7
	White/Blue	KR 3
9	Blue/Yellow	L 3
	Blue/Yellow	KR 2
10		
11		
12	Red/White	LR 15
13	Brown/Grey	GR 3
14		
15	Brown/White	LR 14
	Brown/White	T 10
16	Black/Green	GR 2
17	Key	
18	Orange/Black	M 4
19		
20	Red/Brown	HR 11
21	Yellow/Black	M 2
22	Grey/Violet	B 18

iD
REFP
P1
P1
D7
D7
RM → 2
Stop
Stop
A
A
R
R

C^s
DR

C^s
C^s
DR
SP'
MR 15
MR
D5

ND 130 A HARNESS CONNECTOR BR (CONTROL A)

	To	
1	Black/Blue	LR 7
2		
3		
4	Green	A 12
	Green	KR 5
5	Red/Black	M 1
6	Violet	A 16
7	Key	
8	Grey/Yellow	L 17
	Grey/Yellow	GR 12
9	Violet/Grey	B 17
	Violet/Grey	KR 10
10	Grey/Blue	M 7
	Grey/Blue	KR 9
11	White/Grey	GR 7
12	Orange/Grey	L 20
	Orange/Grey	GR 5
13	Violet/White	KR 8
	Violet/White	J 19
14	Blue/White	HR 3
15	Brown/Green	GR 6
16	White/Orange	L 18
	White/Orange	GR 13
17	Blue/Red	HR 8
	Blue/Red	Q 10
18	Orange	A 8
19	White/Black	B 20
	White/Black	M 6
20	Blue/Violet	LR 11
21	Red/Blue	B 22
22		

P3+

A
A
CR'
P4.REP

RT
RT
D6
D6
REP
REP
P4
PH2
PH2
PH1
PH1
DR.C^s
AO
RT
RT
DR.C^s
DR.C^s
ADCS
D5
D5
P2
D7

ND 130 A HARNESS CONNECTOR FR (CONTROL A)

	To	
1	White/Yellow	M 14
2		
3	Violet/Black	KR 13
4	Green/Grey	M 12
5		
6	Yellow/Grey	J 6
7	Black/Violet	HR 6
8	Blue/Grey	M 11
9	Blue	A 14
	Blue	LR 8
10	Yellow/Red	L 16
	Yellow/Red	KR 1

RM
RC^s1
TMR

MS
X.001
AMR
MB
MB
R
R

ND 130 A HARNESS CONNECTOR CR (CONTROL A)

	To	
1	Violet/Brown	LR 9
2	Orange/Red	M 20
3	Brown/Red	M 10
4	Grey/Red	M 9
	Grey/Red	PS 14
5		
6	Red/Grey	L 15
7	Orange/White	HR 15
8	Green/Red	LR 1
9	Brown/Orange	KR 14
10		

IS
RWS
TM → 1
RMR
RMR

OSC
P 13
DPO
SET DR

CONTROL B BOARD

ND 130 A HARNESS CONNECTOR KR (CONTROL B)

	To	
1	Yellow/Red	FR 10
2	Blue/Yellow	ER 9
3	White/Blue	ER 8
4	Grey/Orange	J 11
5	Green	BR 4
6	Green/Violet	ER 5
7	Black/Yellow	L 1
8	Violet/White	BR 13
	Violet/White	PS 9
9	Grey/Blue	BR 10
10	Violet/Grey	BR 9
11		
12	Red/Yellow	J 9
13	Violet/Black	FR 3
	Violet/Black	J 21
14	Brown/Orange	CR 9
15		

ND 130 A HARNESS CONNECTOR GR (CONTROL B)

	To	
1	Red/Orange	K 8
2	Black/Green	ER 16
3	Brown/Grey	ER 13
4		
5	Orange/Grey	BR 12
6	Brown/Green	BR 15
7	White/Grey	BR 11
8	Yellow	B 13
9	White/Violet	B 19
10	Violet/Blue	M 8
	Violet/Blue	ER 3
11	Orange/Violet	B 14
12	Grey/Yellow	BR 8
13	White/Orange	BR 16
14	Yellow/Violet	B 15
15	Brown/Violet	K 4

ND 130 A HARNESS CONNECTOR LR (CONTROL B)

	To	
1	Green/Red	CR 8
2	Violet/Orange	L 6
3	Brown/Yellow	L 2
4		
5	Green/Blue	L 10
6	Grey/Brown	ER 4
7	Black/Blue	BR 1
8	Blue	FR 9
9	Violet/Brown	CR 1
10		
11	Blue/Violet	BR 20
12	Yellow/Blue	L 22
13	Orange/Blue	J 3
14	Brown/White	B 1
	Brown/White	ER 15
15	Red/White	K 10
	Red/White	ER 12

ND 130 A HARNESS CONNECTOR HR (CONTROL B)

	To	
1	Red	A 6
2	Black/Red	K 1
3	Blue/White	BR 14
4	Brown/Blue	K 2
5	Violet/Yellow	ER 7
6	Black/Violet	K 3
	Black/Violet	FR 7
7	Red/Green	J 10
8	Blue/Red	BR 17
	Blue/Red	M 5
9		
10	Yellow/Orange	AR 4
11	Red/Brown	ER 20
	Red/Brown	M 3
12		
13		
14	Violet/Red	M 61
15	Orange/White	CR 7

ND 130 A HARNESS CONNECTOR NR (CONTROL B)

	To	
1	Blue/Black	Y 11
	Blue/Black	K 5
2	Black/Brown	Y 12
	Black/Brown	K 6
3	Violet/Orange	W 2
4	Blue/Orange	W 4
5	Black/Orange	X 22
6	White/Brown	X 20
7	Green/Orange	X 17
8	Yellow/Orange	X 19
9	Red/Orange	X 18
10	White	Y 21

ND 130 A HARNESS CONNECTOR JR (CONTROL B)

	To	
1	#22 Black	S 1
	#22 Black	P 1
2	#22 Brown	S 2
	#22 Brown	P 2
3		
4	#22 Red	S 4
	#22 Red	P 4
5	#22 Orange	S 5
	#22 Orange	P 5
6	#22 Green	S 6
	#22 Green	P 6
7	#22 Blue	S 7
	#22 Blue	P 7
8	#22 White	S 8
	#22 White	P 8
9		
10		

FRONT PANEL BOARD

ND 130 A HARNESS CONNECTOR K (FRONT PANEL)

	To	
1	Black/Red	HR 2
2	Brown/Blue	HR 4
3	Black/Violet	HR 6
4	Brown/Violet	GR 15
5	Blue/Black	NR 1
6	Black/Brown	NR 2
7		
8	Red/Orange	GR 1
9	Black/Orange	B 11
10	Red/White	LR 15
	Red/White	B 2
11	Green/Black	B 3
12	Green/Yellow	M 17
13	Orange/Yellow	M 18
14	Grey/Violet	B 18
15		
16		
17		
18	Yellow/Violet	B 15
19	Black/White	A 22
20	Green/Brown	H 10
21	Yellow/Brown	H 9
22	Orange/Brown	H 8

ND 130 A HARNESS CONNECTOR L (FRONT PANEL)

	To	
1	Black/Yellow	KR 7
2	Brown/Yellow	LR 3
3	Blue/Yellow	ER 9
4	Violet/Yellow	ER 7
5	Blue	A 14
6	Violet/Orange	LR 2
7	White/Blue	ER 8
8		
9		
10	Green/Blue	LR 5
11		
12		
13	Green/Orange	E 10
14		
15	Red/Grey	CR 6
16	Yellow/Red	FR 10
17	Grey/Yellow	BR 8
18	White/Orange	BR 16
19	Blue/Orange	E 11
20	Orange/Grey	BR 12
21		
22	Yellow/Blue	LR 12

ND 130 A HARNESS CONNECTOR J (FRONT PANEL)

	To	
1	Brown/Black	M 22
2	Brown/White	B 1
3	Orange/Blue	LR 13
4	Yellow/White	B 4
5	Green/White	B 5
6	Yellow/Grey	FR 6
7	Brown	A 4
8	Green	A 12
9	Red/Yellow	KR 12
10	Red/Green	HR 7
11	Grey/Orange	KR 4
12	Blue/Brown	M 19
13	Red/Violet	B 12
14	White/Red	M 21
15	Green/Red	W 8
16	Black	A 2
17	Violet/Black	B 6
18	Grey/White	B 8
19	Violet/White	BR 13
20	Black/Grey	B 9
21	Violet/Black	KR 13
22	Grey/Black	B 7

ND 130 A HARNESS CONNECTOR T (FRONT PANEL)

	To	
1	#22 Black	Q 1
2	#22 Brown	Q 2
3		
4	#22 Red	DR 4
	#26 Red	Switch
5	#22 Orange	DR 5
	#26 Orange	Switch
6	#22 Green	Q 6
7	#22 Blue	DR 7
8	#22 White	DR 8
9	#26 Blue/Yellow	PS 35
10	#26 Brown/White	ER 15

MR BOARD

ND 130 A HARNESS
CONNECTOR Z (MR)

	To	
1		
2 Black	X 16	I ₃
3 Brown	X 15	I ₂
4 Red	X 14	I ₁
5 Orange	X 13	I ₀
6 White	X 21	G
7 Yellow	Y 13	S ₀
8 Green	Y 14	S ₁
9 Blue	Y 15	S ₂
10 Violet	Y 16	S ₃

ND 130 A HARNESS
CONNECTOR S (MR)

	To	
1 #22 Black	PS 1	+50
#22 Black	JR 1	+50
2 #22 Brown	PS 2	-50
#22 Brown	JR 2	-50
3		
4 #22 Red	PS 4	+8
#22 Red	JR 4	+8
5 #22 Orange	PS 5	-8
#22 Orange	JR 5	-8
6 #22 Green	PS 6	+4
#22 Green	JR 6	+4
7 #22 Blue	PS 7	-4
#22 Blue	JR 7	-4
8 #22 White	PS 8	G
#22 White	JR 8	G
9		
10		

ND 130 A HARNESS
CONNECTOR TW (MR)

	To	
1 Black	TS 17	"9"
2 Brown	TS 5	"8"
3 Red	TS 16	"7"
4 Orange	TS 8	"6"
5 Yellow	TS 15	"5"
6 Green	TS 3	"4"
7 Blue	TS 14	"3"
8 Violet	TS 2	"2"
9 Grey	TS 13	"1"
10 Black/White	TS 1	"0"
11 Brown/White	TS 6	Space
12 Red/White	TS 18	CR
13 White	TS 21	G
14		
15 White/Black	TS 7	$\overline{D^5}$
White/Black	M 6	$\overline{D^5}$
16		
17		
18		
19		
20		
21		
22 Green/Black	TS 4	-48V

ND 130 A HARNESS
CONNECTOR M (MR)

	To	
1 Red/Black	BR 5	CR'
2 Yellow/Black	ER 21	MR
3 Red/Brown	HR 11	MR 15
4 Orange/Black	ER 18	SP'
5 Blue/Red	HR 8	$\overline{DR.C^8}$ (CMR)
6 White/Black	BR 19	$\overline{D5}$
White/Black	TW 15	$\overline{D5}$
7 Grey/Blue	BR 10	REP
8 Violet/Blue	GR 10	REP
9 Grey/Red	CR 4	RMR
10 Brown/Red	CR 3	MR ⁰ →1
11 Blue/Grey	FR 8	AMR
12 Green/Grey	FR 4	TMR
13 Orange/Green	ER 6	(RM→2)
14 White/Yellow	FR 1	RM
15		
16 Violet/Red	HR 14	\overline{ALT}
17 Green/Yellow	K 12	ADD
18 Orange/Yellow	K 13	SUBTRACT
19 Blue/Brown	J 12	¹ D to MR
20 Orange/Red	CR 2	TWS
21 White/Red	J 14	¹ M
22 Brown/Black	J 1	V.DEF

ND 130 A HARNESS
CONNECTOR H (MR)

	To	
1		
2 Orange/Red	TS 24	TWS
3 Violet/Red	RS 12	R ³
4 Grey/Red	TS 11	R ²
5 White/Red	TS 10	R ¹
6 Black/Orange	TS 9	R ⁰
7 Red/Blue	TS 23	M ³
8 Orange/Brown	TS 22	M ²
Orange/Brown	K 22	M ²
9 Yellow/Brown	TS 20	M ¹
Yellow/Brown	K 21	M ¹
10 Green/Brown	TS 19	M ⁰
Green/Brown	K 20	M ⁰

REAR DECK

ND 130 A HARNESS CONNECTOR PS (POWER CABLE)

	To	
1 #22 Black	S 1	+50
2 #22 Brown	S 2	-50
3 #26 Green/Orange	SC 1	
4 #22 Red	S 4	+8
5 #22 Orange	S 5	-8
6 #22 Green	S 6	+4
7 #22 Blue	S 7	-4
8 #22 White	S 8	G
9 #26 Violet/White	KR 8	PHI
10 #26 Red/White	SC 3	
11 #26 Green/White	SC 4	
12 #26 Blue/White	SC 5	
13 #26 Black/Orange	SC 6	
14 #26 Grey/Red	CR 4	RMR
15 #26 Black/White	Y 9	C ⁷
16 #26 Violet/Orange	Y 10	C ⁷
17 #26 Brown/White	Y 7	C ⁶
18 #26 Blue/Orange	Y 8	C ⁶
19 #26 Red/White	Y 5	C ⁵
20 #26 Green/Black	Y 6	C ⁵
21 #26 Yellow/White	Y 3	C ⁴
22 #26 Green/Red	Y 4	C ⁴
23 #26 Violet/Black	Y 1	C ³
24 #26 Grey	Y 2	C ³
25 #26 Grey/White	X 5	C ²
26 #26 Yellow/Black	X 6	C ²
27 #26 Brown/Green	X 3	C ¹
28 #26 Red/Green	X 4	C ¹
29 #26 Yellow/Grey	X 1	C ₀
30 #26 Yellow/Green	X 2	C ₀
31 #26 Grey/Blue	DR 9	Selected
32 #26 Grey/Orange	DR 6	All
33 #26 White/Green	DR 3	Start
34 #26 Grey/Black	DR 2	End
35 #26 Blue/Yellow	T 9	CHI'
36		

ND 130 A HARNESS CONNECTOR TS (24 Pin Amphenol Blue Ribbon on Analyzer Rear Panel)

	To	
1 Black/White	TW 10	"0"
2 Violet	TW 8	"2"
3 Green	TW 6	"4"
4 Green/Black	TW 22	-48V
5 Brown	TW 2	"8"
6 Brown/White	TW 11	Space
7 White/Black	TW 15	D ⁵
8 Orange	TW 4	"6"
9 Black/Orange	H 6	R ⁰
10 White/Red	H 5	R ¹
11 Grey/Red	H 4	R ₂
12 Violet/Red	H 3	R ₃
13 Grey	TW 9	"1"
14 Blue	TW 7	"3"
15 Yellow	TW 5	"5"
16 Red	TW 3	"7"
17 Black	TW 1	"9"
18 Red/White	TW 12	CR
19 Green/Brown	H 10	M ⁰
20 Yellow/Brown	H 9	M ¹
21 White	TW 13	G
22 Orange/Brown	H 8	M ²
23 Red/Blue	H 7	M ³
24 Orange/Red	H 2	TWS

ND 130 A HARNESS CONNECTOR SC (SPECIAL)

	To
1 #26 Green/Orange	PS 3
2	
3 #26 Red/Blue	PS 10
4 #26 Green/White	PS 11
5 #26 Blue/White	PS 12
6 #26 Black/Orange	PS 13
7	
8	
9	
10	

ND 130 A HARNESS WINDOW CONTROL SWITCH (REAR DECK)

Upper right	Orange
Upper left	Grey/Yellow
Center right	White/Violet
Center left	Grey
Lower right	Red
Lower left	

Switch Terminals are as viewed from front of Analyzer

To	
T 5	-8
Energy O Pot	
A 1	TC
AD 3	Win.Lev.
T 4	+8

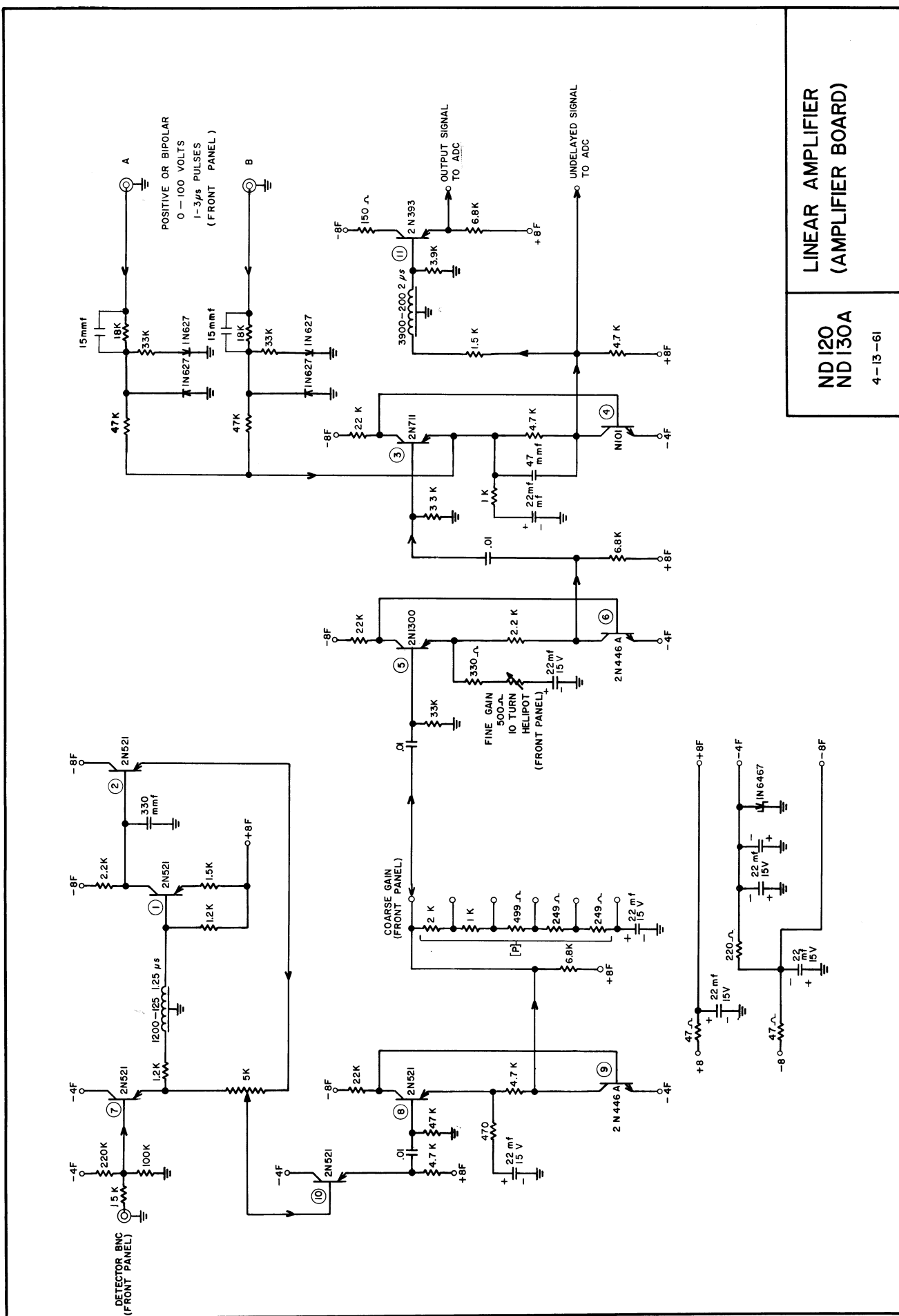
MEMORY STACK

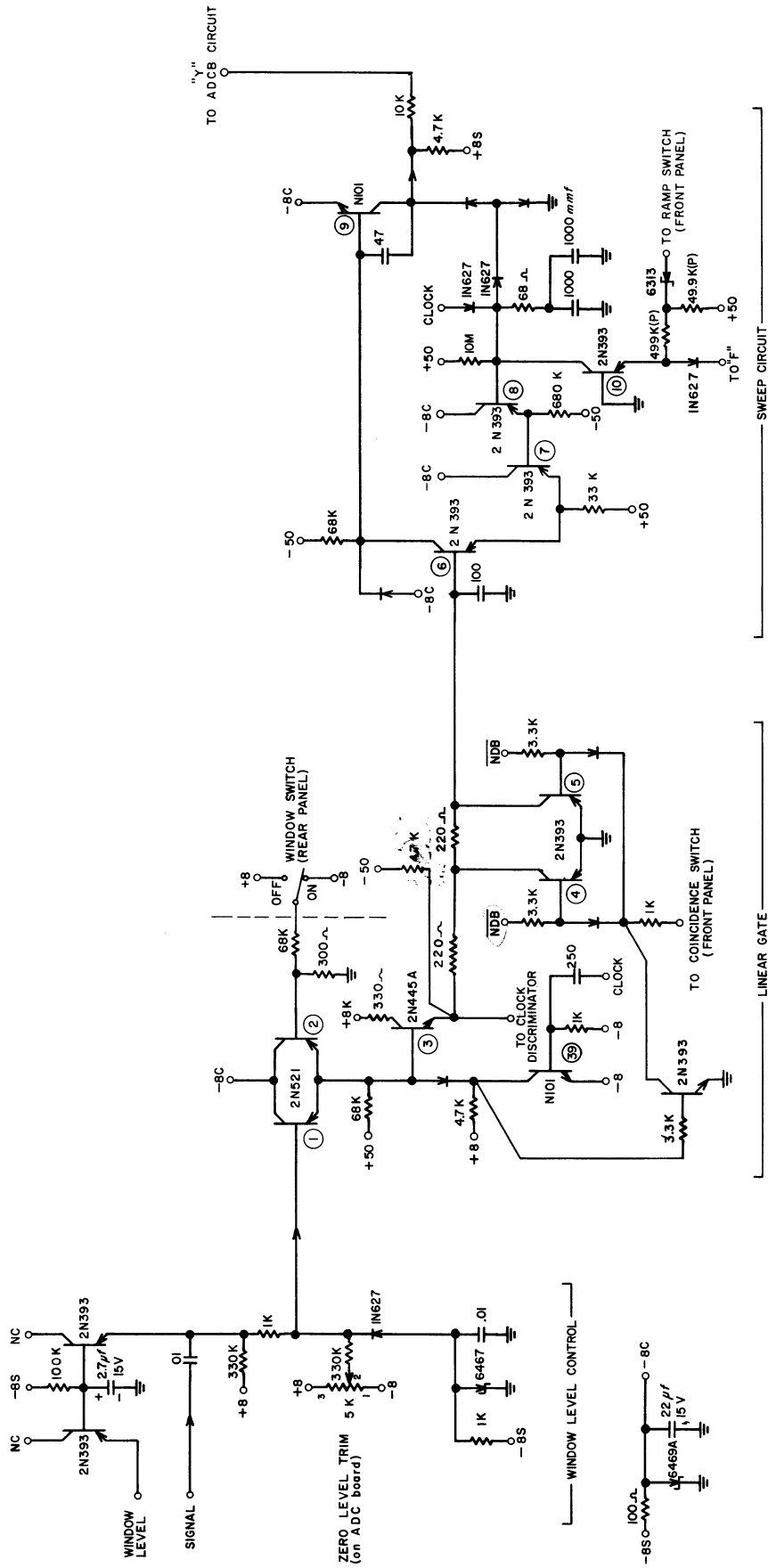
ND 130 A HARNESS CONNECTOR X (MEMORY)

	To	
1	Yellow/Grey	W 15
	Yellow/Grey	PS 29
2	Yellow/Green	W 16
	Yellow/Green	PS 30
3	Brown/Green	W 13
	Brown/Green	PS 27
4	Red/Green	W 14
	Red/Green	PS 28
5	Grey/White	W 11
	Grey/White	PS 25
6	Yellow/Black	W 12
	Yellow/Black	PS 26
7	Violet/Green	W 18
8	Blue/Green	W 17
9	White/Green	W 20
10	Grey/Green	W 19
11	Brown/Blue	W 22
12	White/Black	W 21
13	Orange	Z 5
14	Red	Z 4
15	Brown	Z 3
16	Black	Z 2
17	Green/Orange	NR 7
18	Red/Orange	NR 9
19	Yellow/Orange	NR 8
20	White/Brown	NR 6
	White/Brown	Y 20
21	White	Z 6
	White	Y 21
22	Black/Orange	NR 5
	Black/Orange	Y 22

ND 130 A HARNESS CONNECTOR Y (MEMORY)

	To	
1	Violet/Black	W 9
	Violet/Black	PS 23
2	Grey	W 10
	Grey	PS 24
3	Yellow/White	W 7
	Yellow/White	PS 21
4	Green/Red	W 8
	Green/Red	PS 22
5	Red/White	W 5
	Red/White	PS 19
6	Green/Black	W 6
	Green/Black	PS 20
7	Brown/White	W 3
	Brown/White	PS 17
8	Blue/Orange	W 4
	Blue/Orange	PS 18
9	Black/White	W 1
	Black/White	PS 15
10	Violet/Orange	W 2
	Violet/Orange	PS 16
11	Blue/Black	NR 1
12	Black/Brown	NR 2
13	Yellow	Z 7
14	Green	Z 8
15	Blue	Z 9
16	Violet	Z 10
17		
18		
19		
20	White/Brown	X 20
21	White	X 21
	White	NR 10
22	Black/Orange	X 22

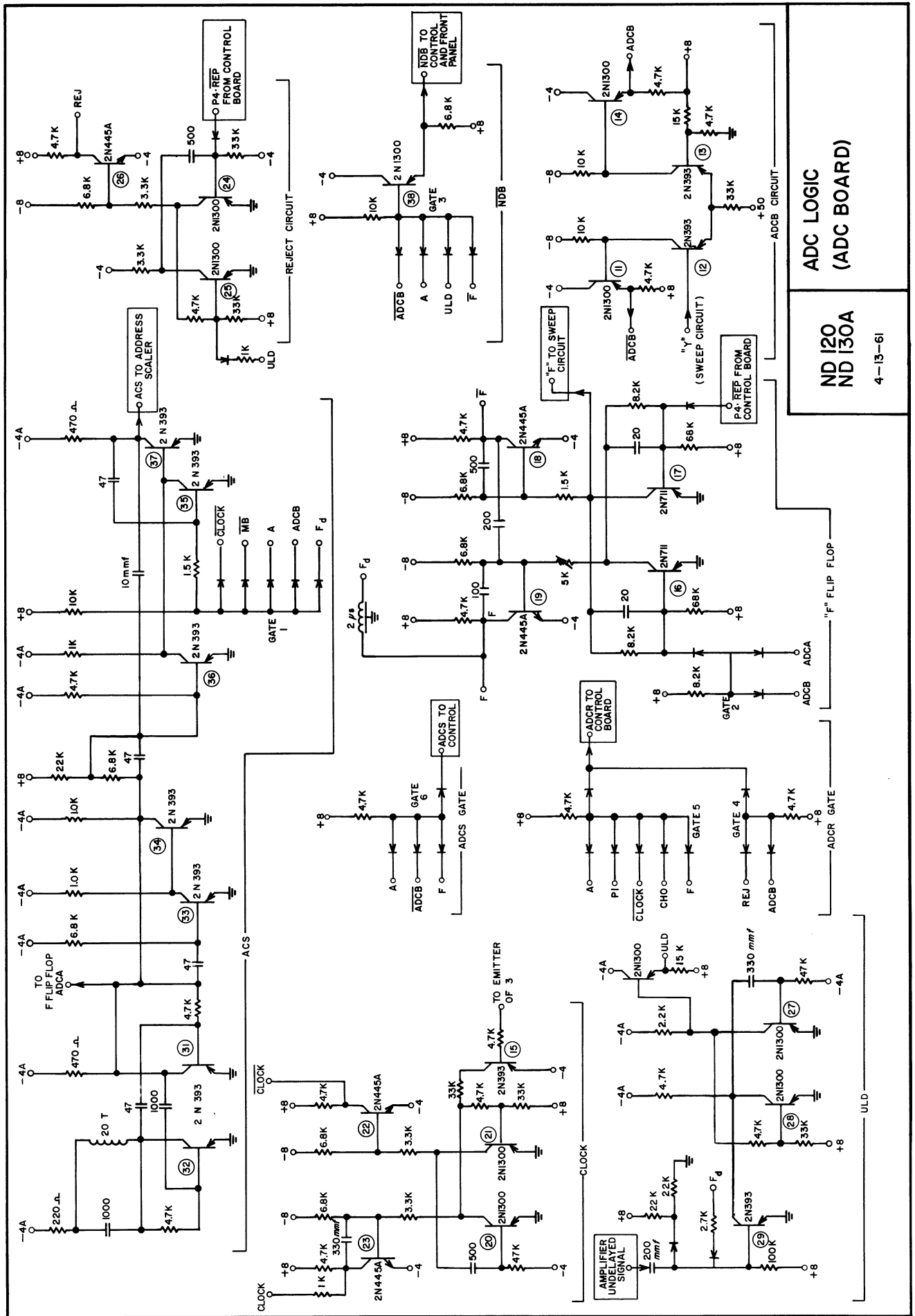




ADC SWEEP CIRCUITS
(ADC BOARD)

ND 120
ND 130A

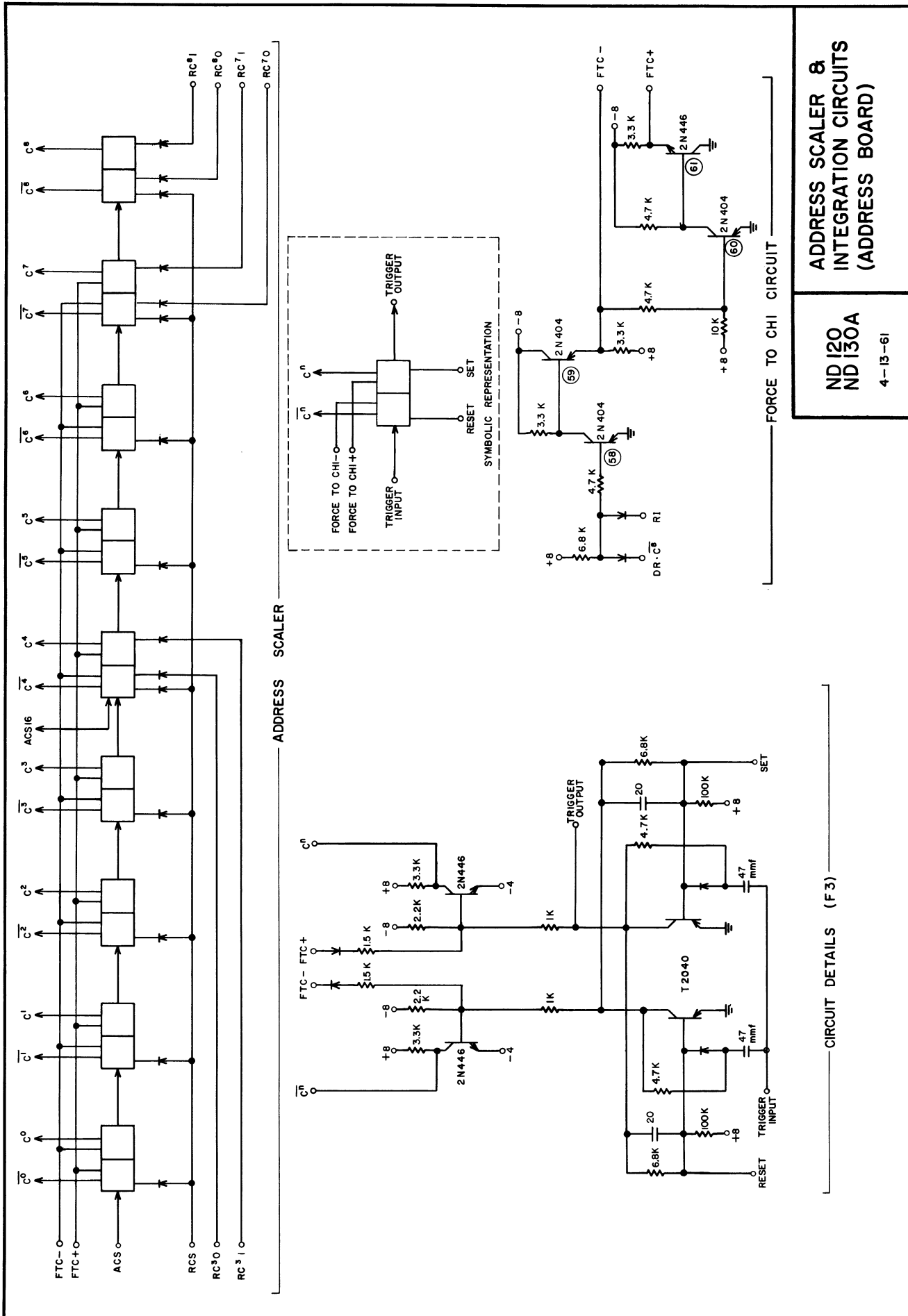
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**ADC LOGIC
(ADC BOARD)**

**ND 120
ND 130A**

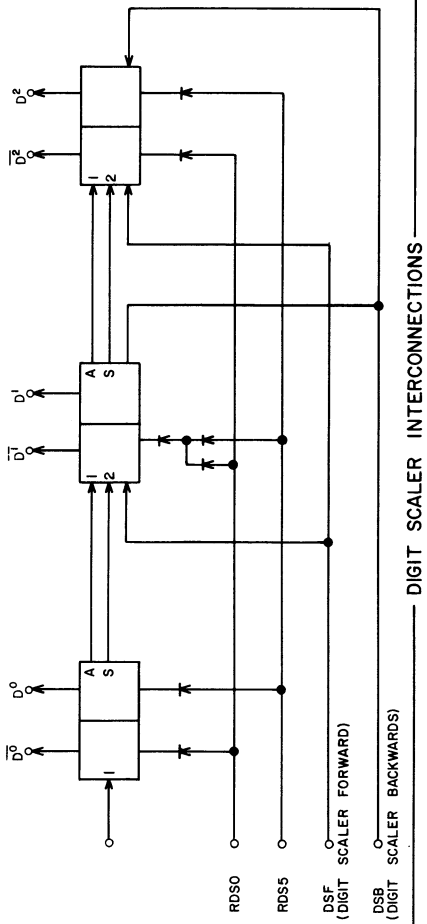
4-13-61



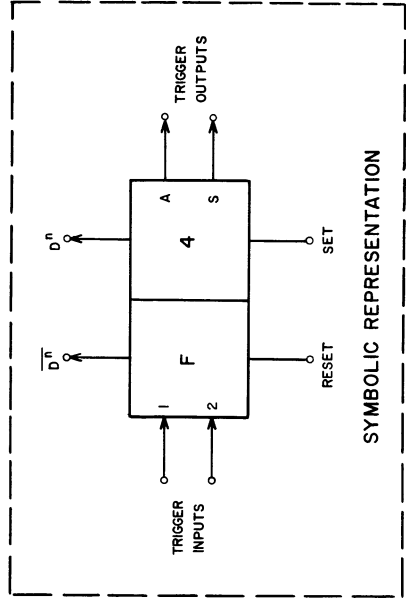
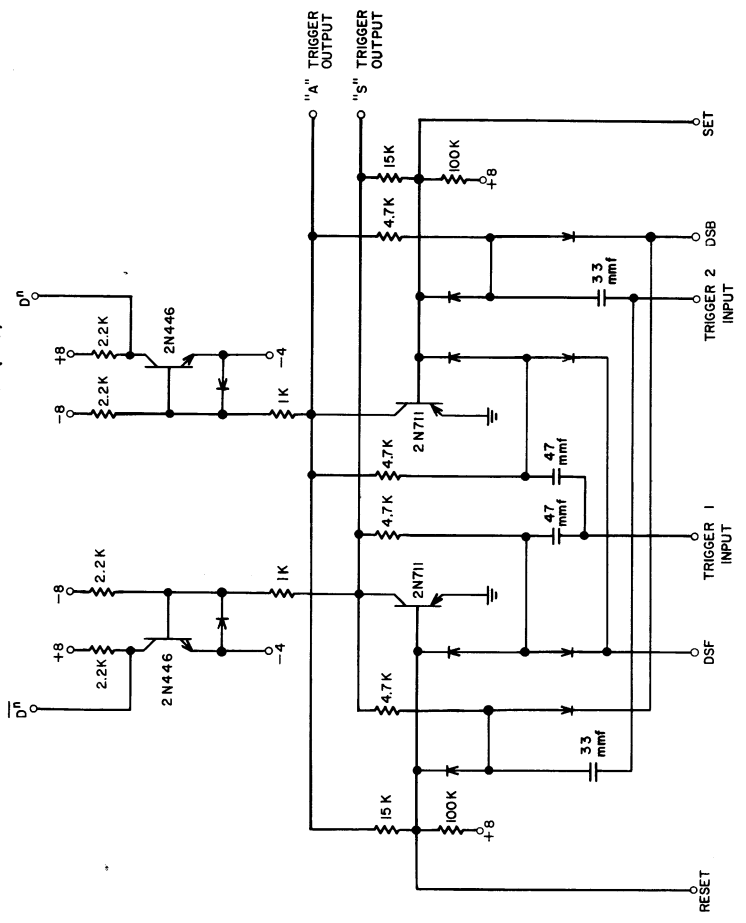
ADDRESS SCALER &
INTEGRATION CIRCUITS
(ADDRESS BOARD)

ND 120
ND 130A
4-13-61

CIRCUIT DETAILS (F3)

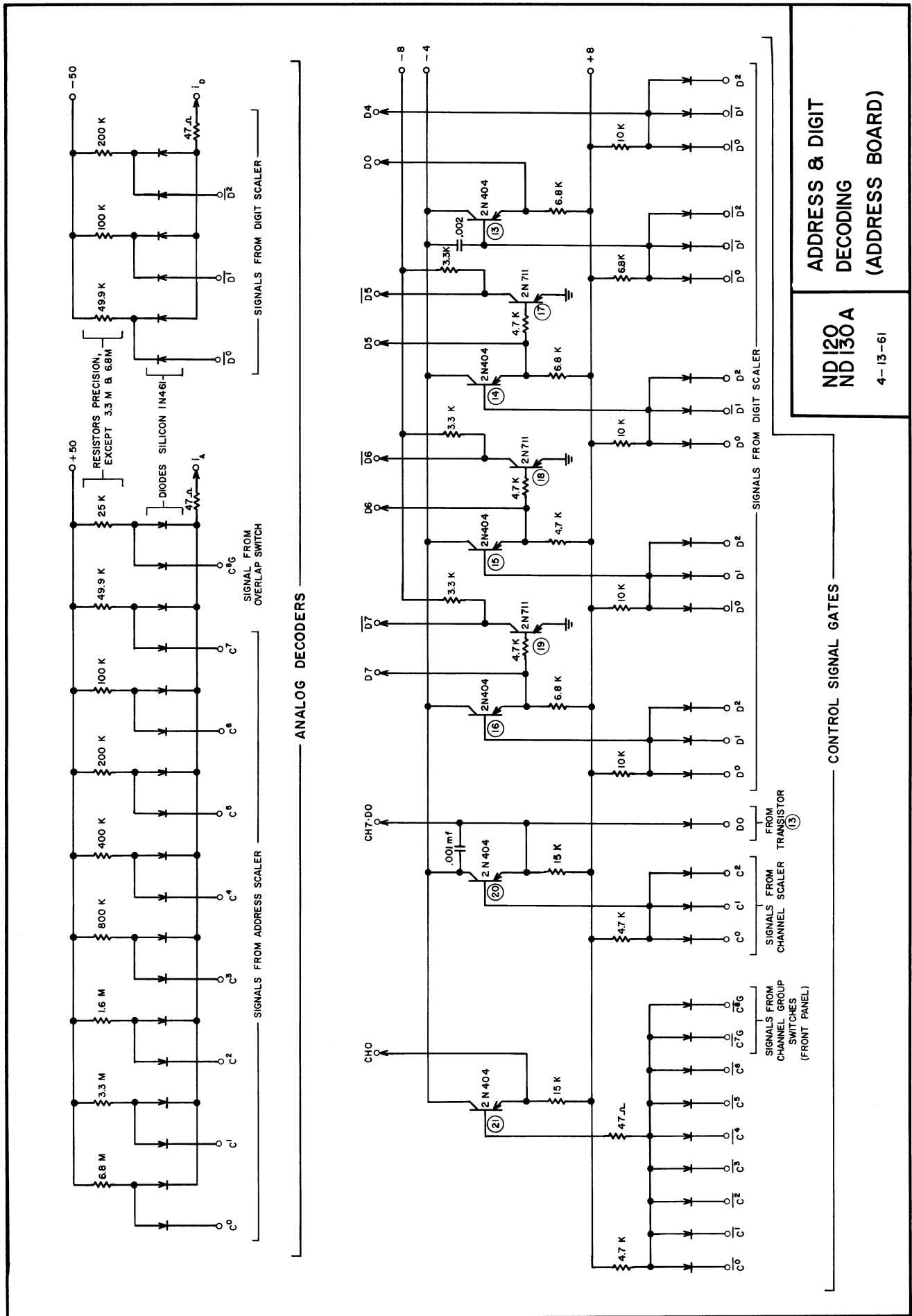


CIRCUIT DETAILS (F4)



NDI20
NDI30A
4-13-61

DIGIT SCALER
(ADDRESS BOARD)

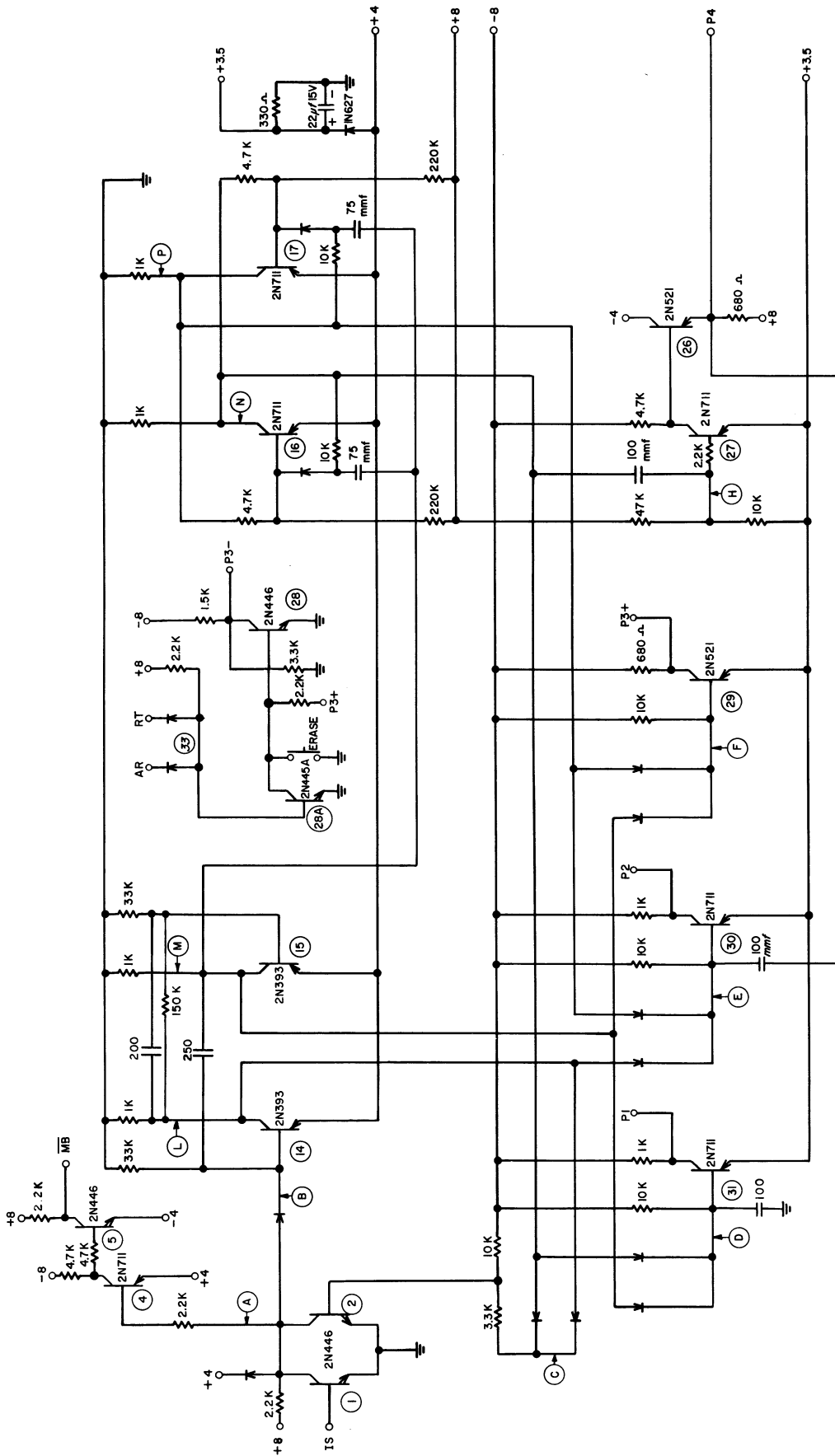


**ND 120
 ND 130A**

4-13-61

**ADDRESS & DIGIT
 DECODING
 (ADDRESS BOARD)**

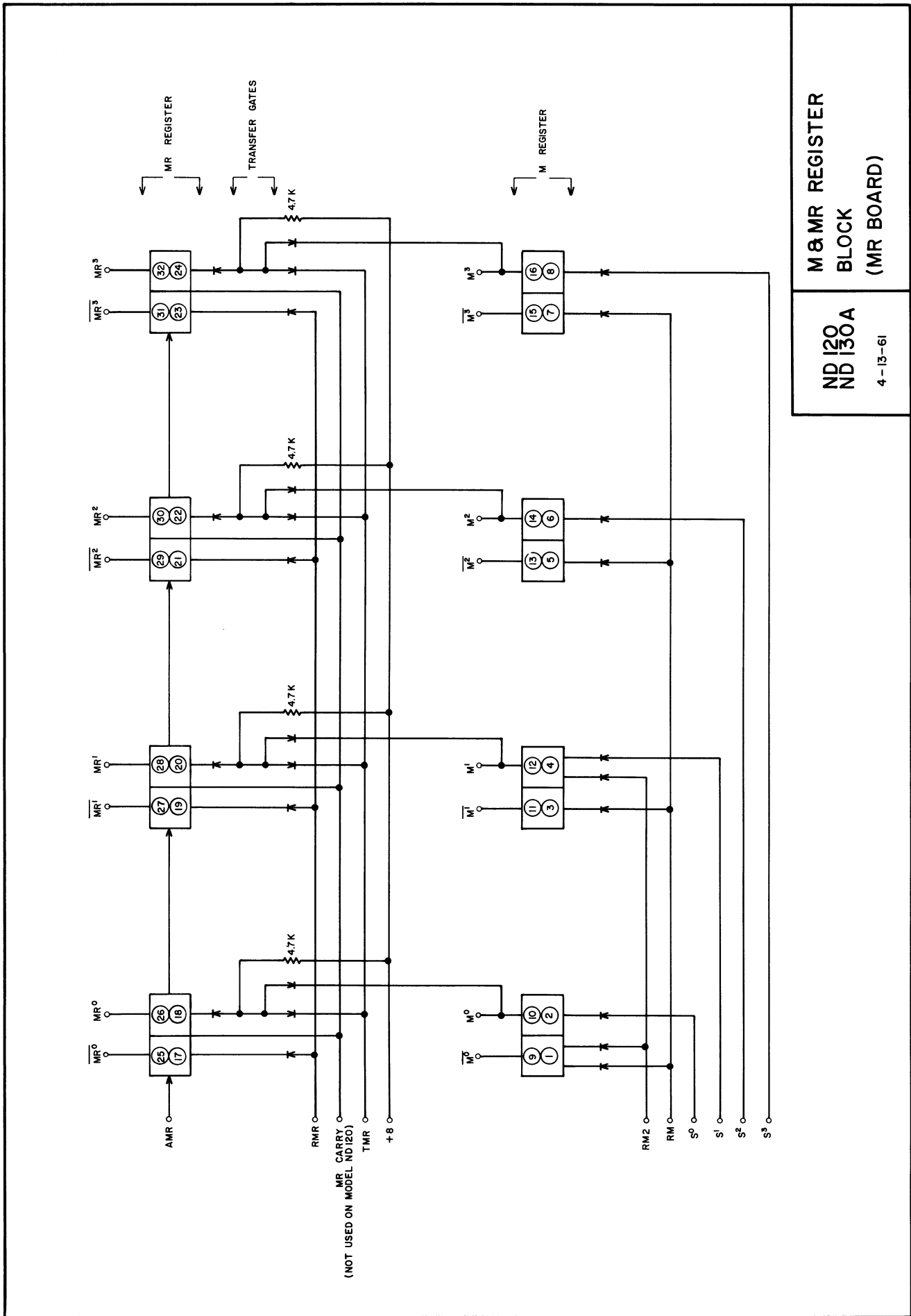
CONTROL SIGNAL GATES

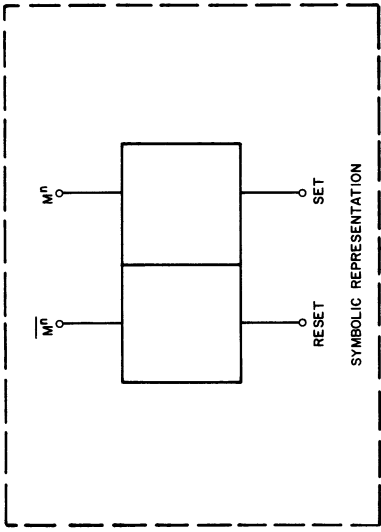


PULSE GENERATOR
(CONTROL BOARD)

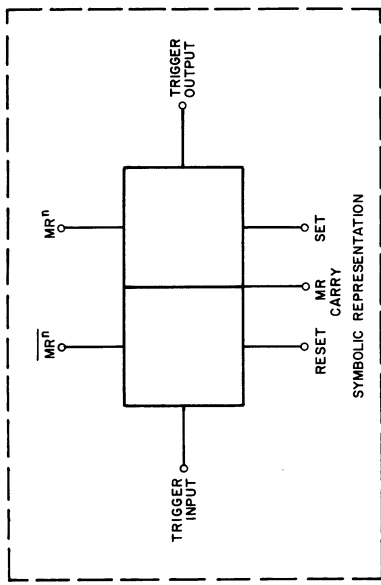
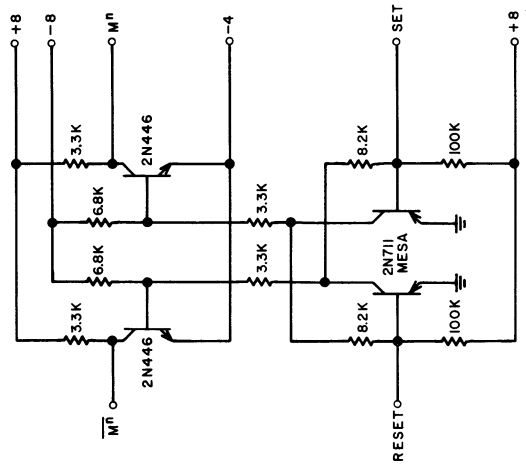
ND 120

4-13-61

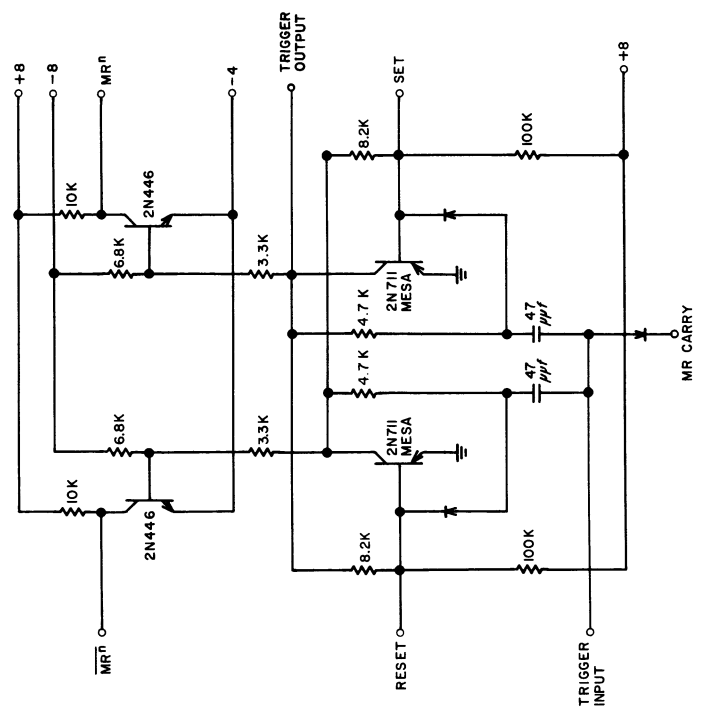




CIRCUIT DETAILS, M REGISTER STAGE



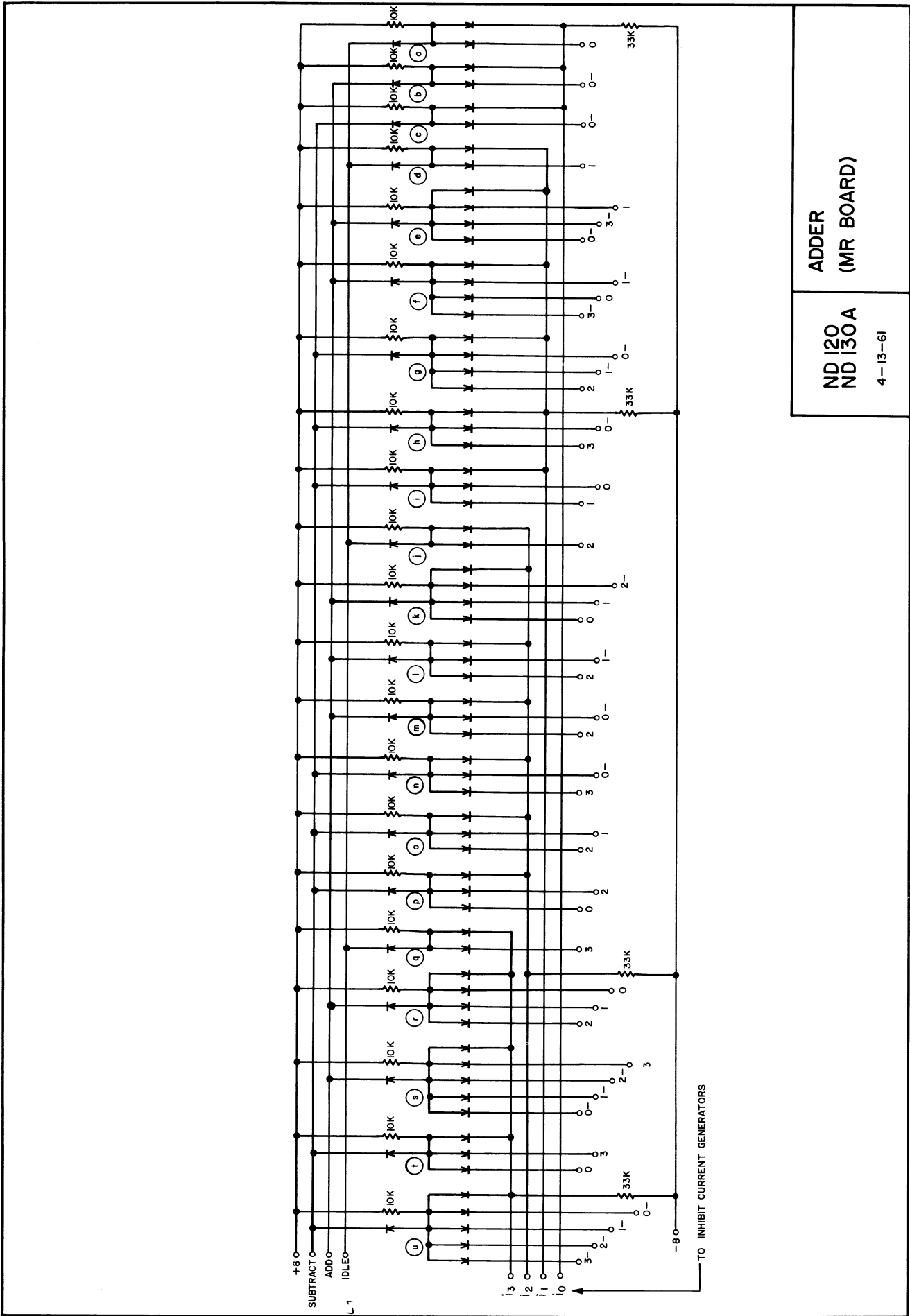
CIRCUIT DETAILS, MR REGISTER STAGE



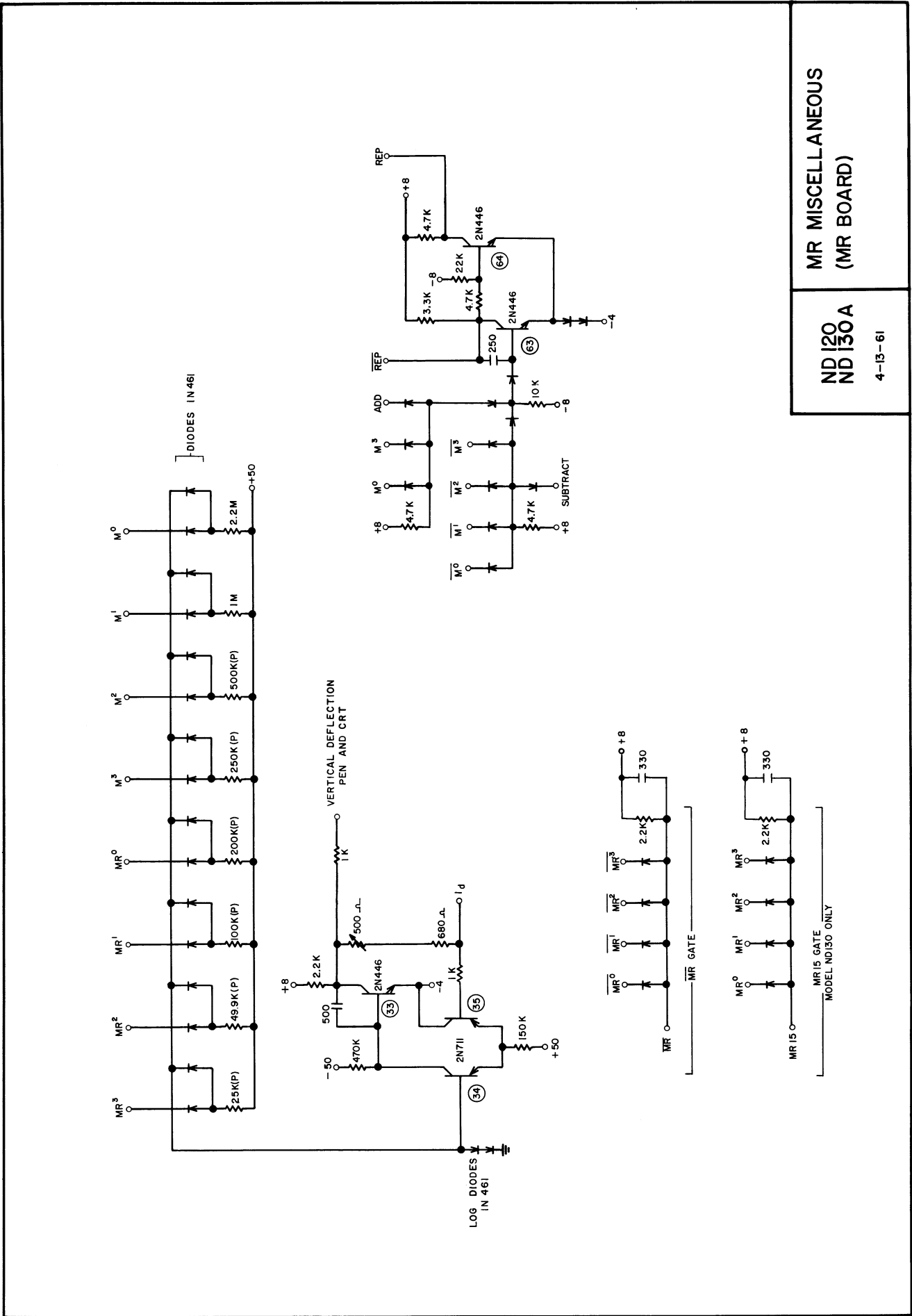
M & MR REGISTER
CIRCUITS
(MR BOARD)

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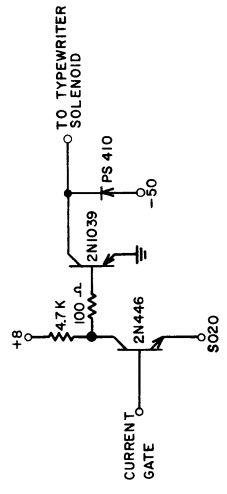
ADDER
 (MR BOARD)
 ND 120
 ND 130A
 4-13-61



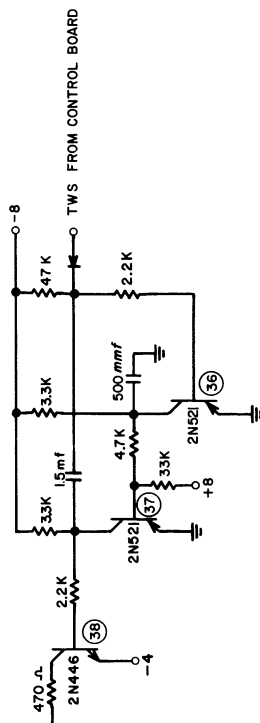
**MR MISCELLANEOUS
(MR BOARD)**

**ND 120
ND 130A**

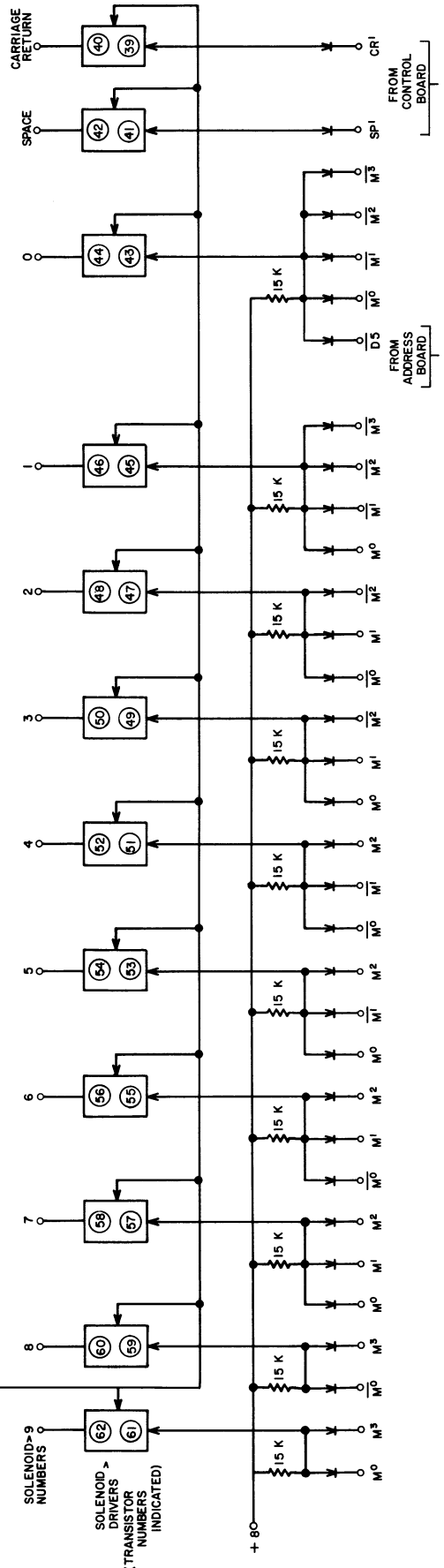
4-13-61



SOLENOID DRIVER CIRCUIT



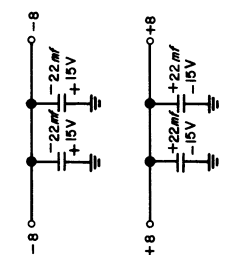
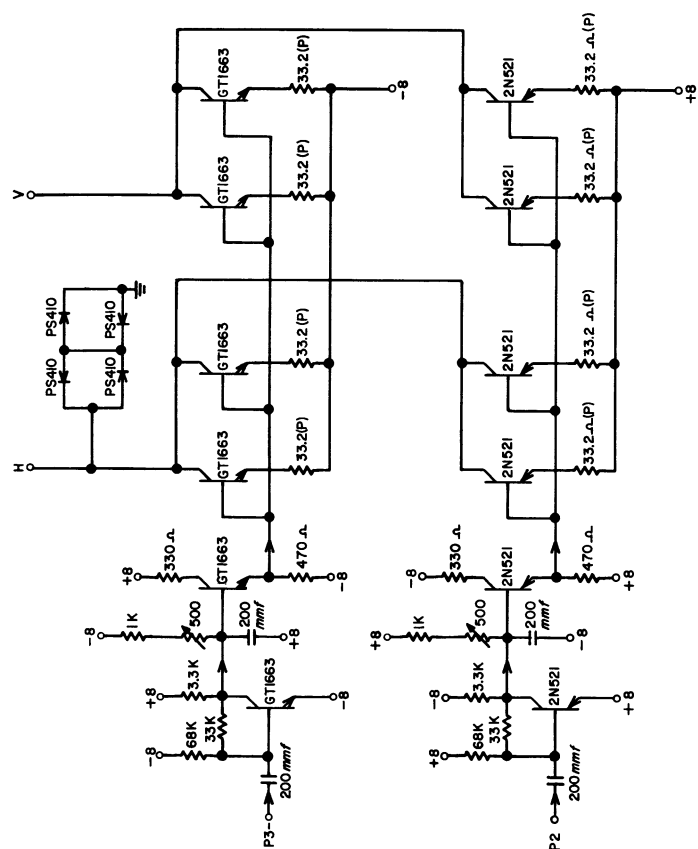
30 MILLISECOND TIMING TRIGGER CIRCUIT



TYPEWRITER DRIVE
(MR BOARD)

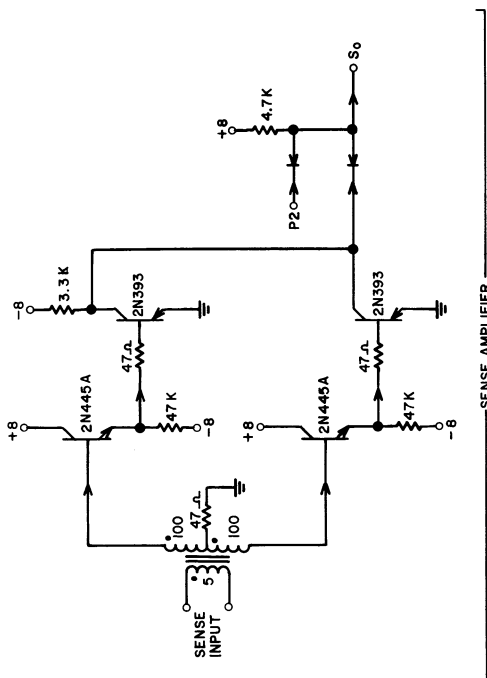
ND 120
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4-13-61

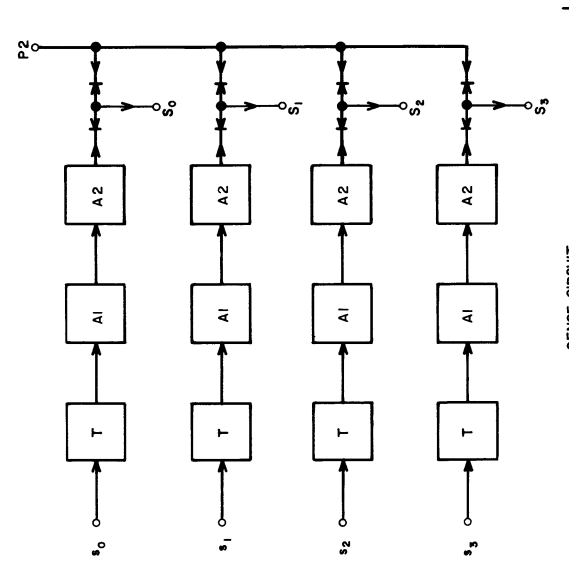


MEMORY CURRENT
GENERATOR
(MEMORY ASSEMBLY)

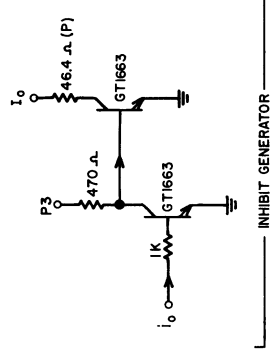
ND 120
ND 130 A
4-13-61



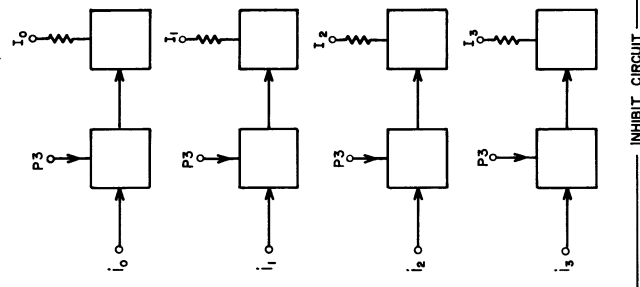
SENSE AMPLIFIER



SENSE CIRCUIT

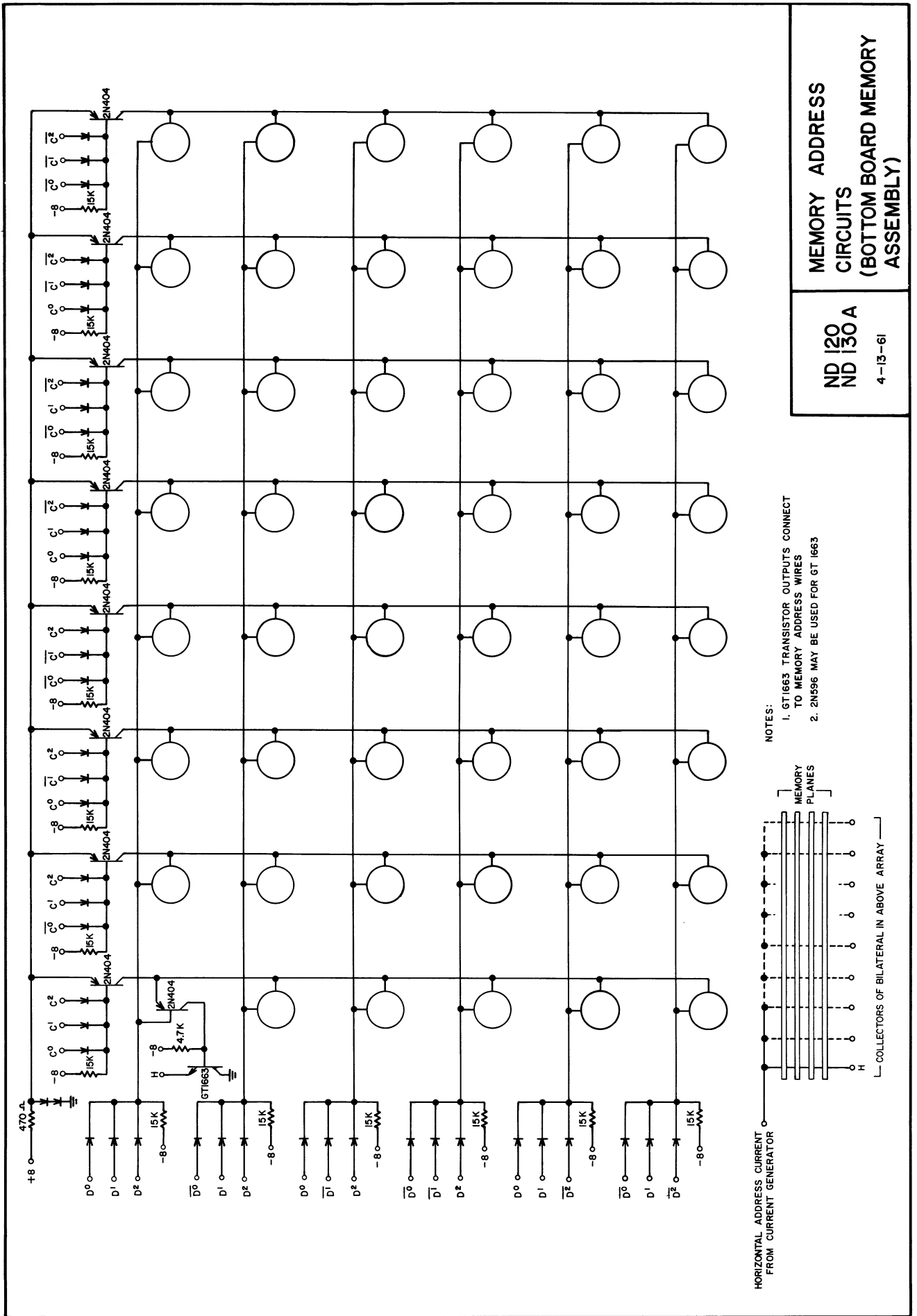


INHIBIT GENERATOR

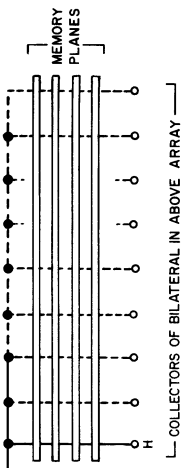


INHIBIT CIRCUIT

ND 120 ND 130A	SENSE AMPLIFIER & INHIBIT GENERATOR (MEMORY ASSEMBLY)
4-13-61	



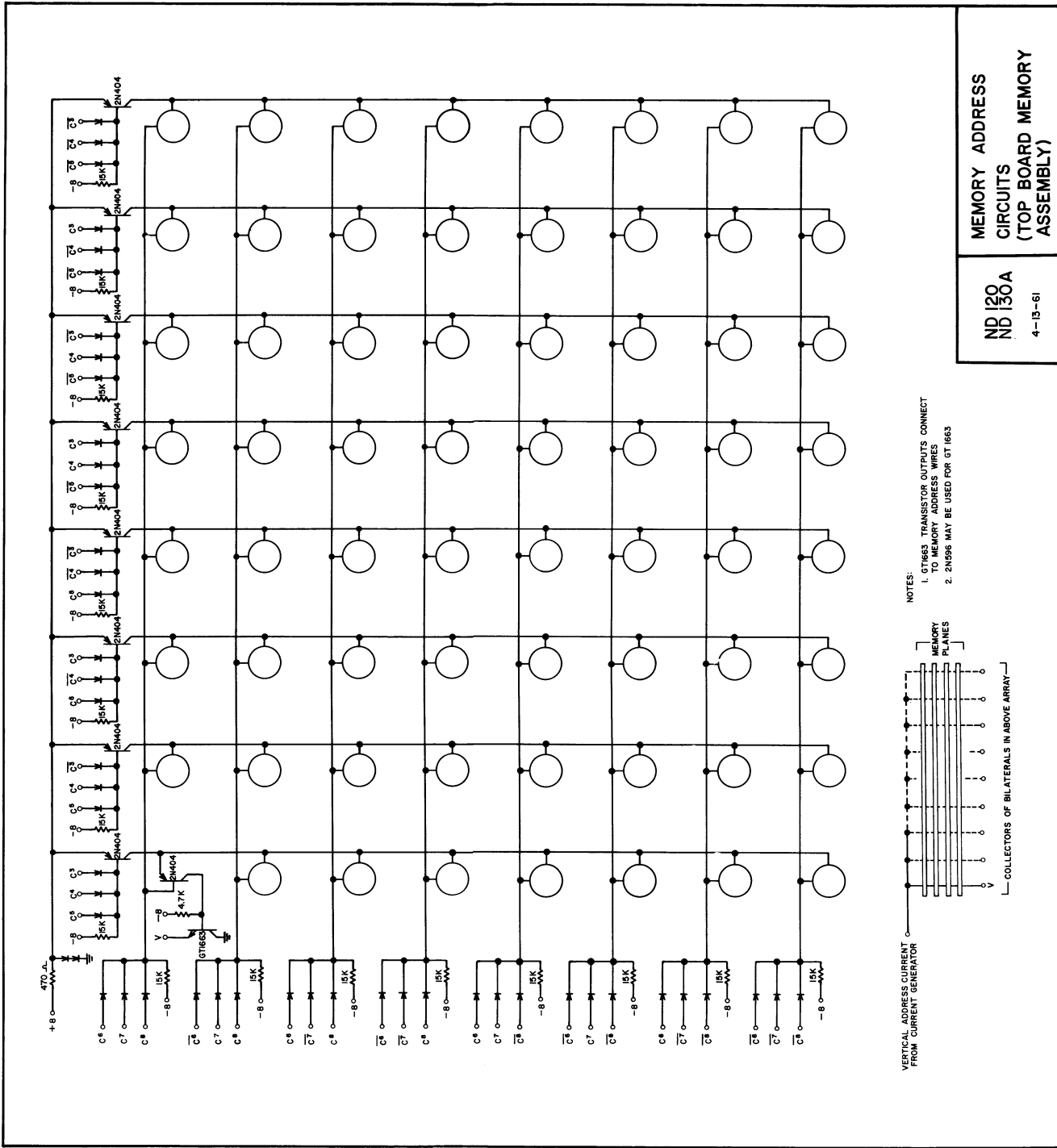
NOTES:
 1. GT1663 TRANSISTOR OUTPUTS CONNECT TO MEMORY ADDRESS WIRES
 2. 2N596 MAY BE USED FOR GT 1663



HORIZONTAL ADDRESS CURRENT FROM CURRENT GENERATOR

MEMORY ADDRESS CIRCUITS (BOTTOM BOARD MEMORY ASSEMBLY)

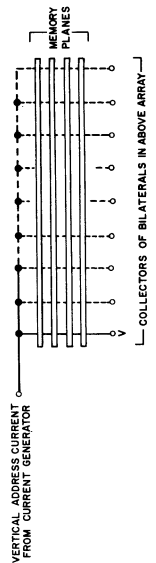
ND 120
 ND 130 A
 4-13-61

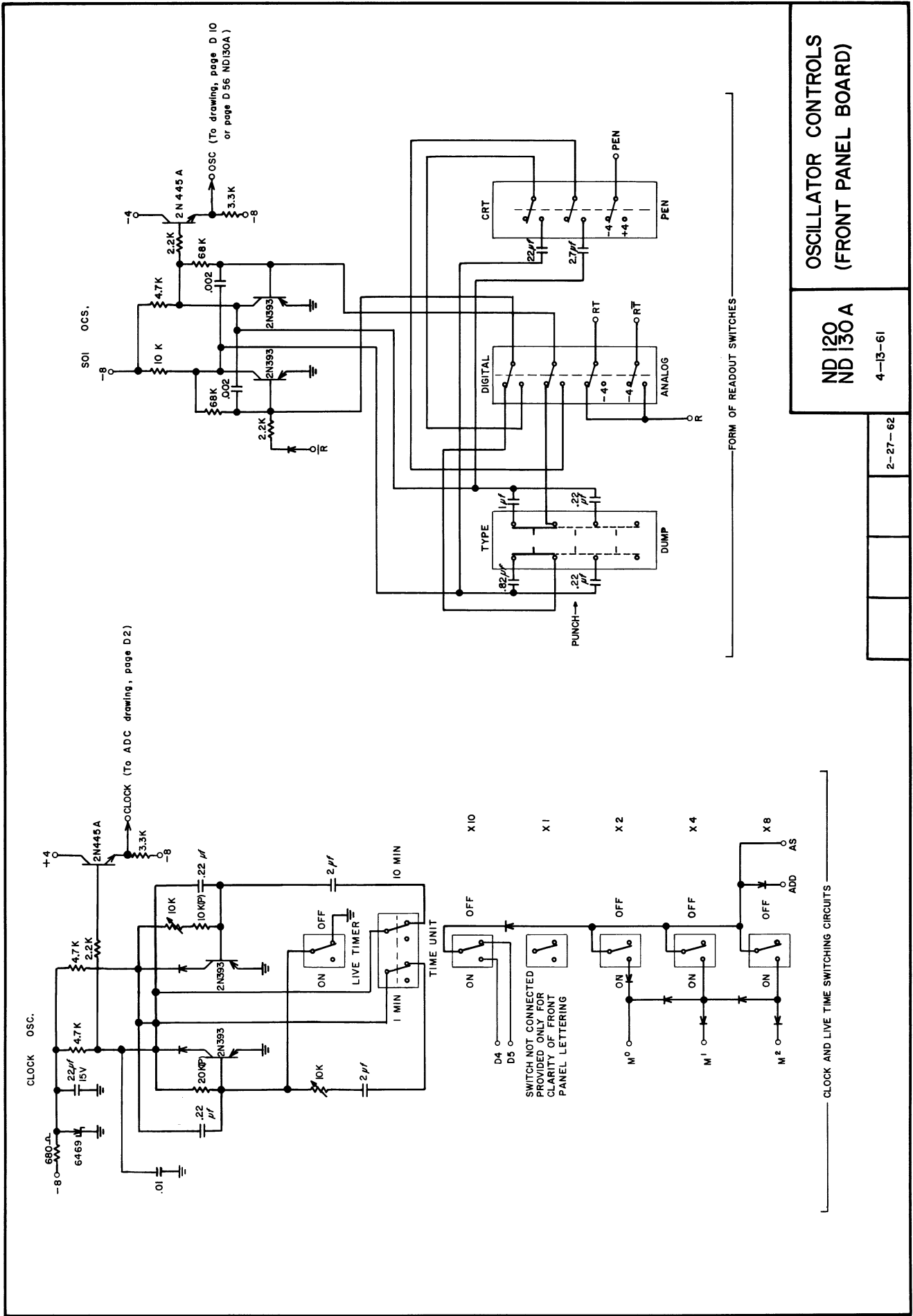


MEMORY ADDRESS
CIRCUITS
(TOP BOARD MEMORY
ASSEMBLY)

ND 120
ND 130A
4-13-61

- NOTES:
1. GT1663 TRANSISTOR OUTPUTS CONNECT TO MEMORY ADDRESS WIRES
 2. 2N404 MAY BE USED FOR GT 1663

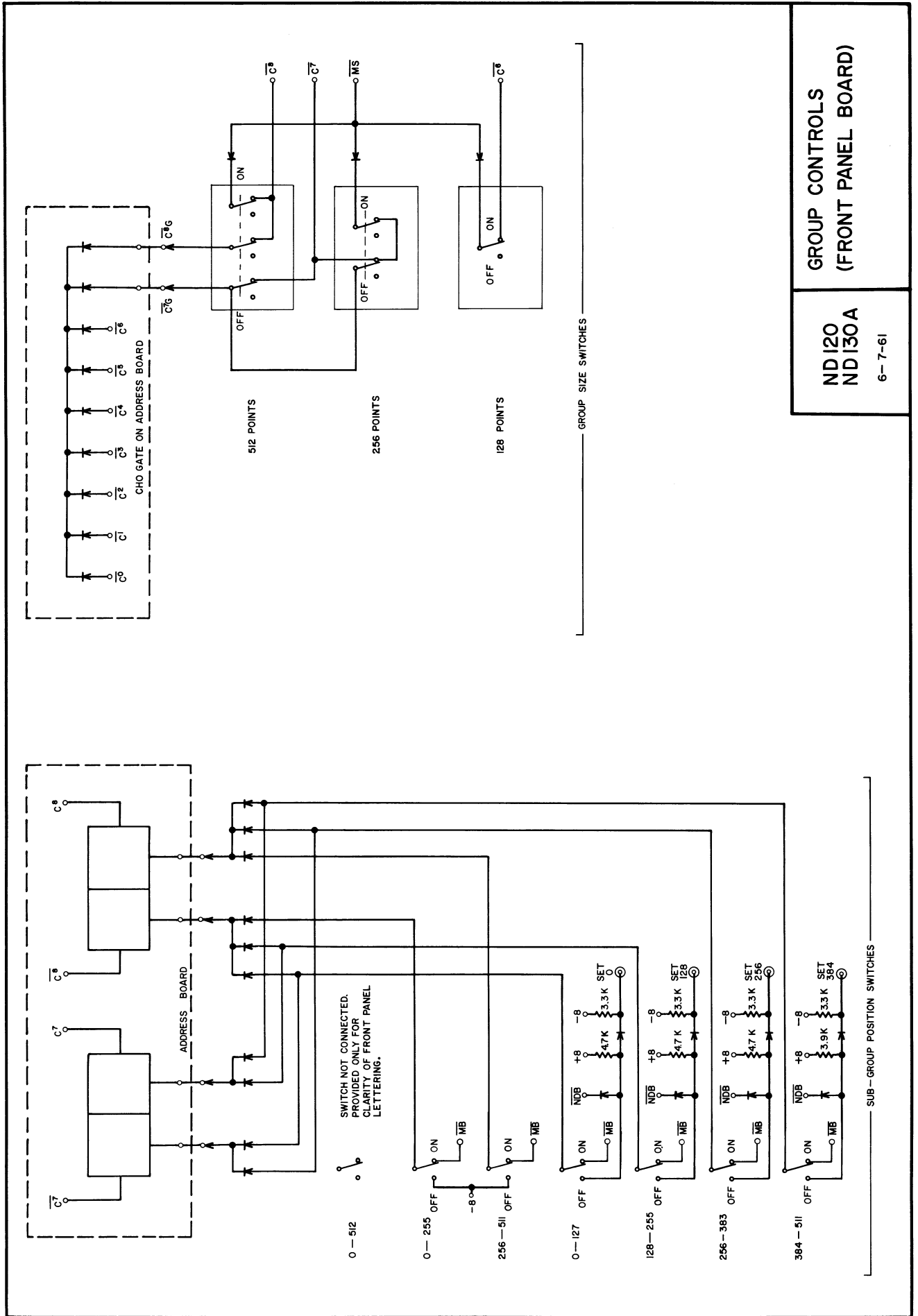


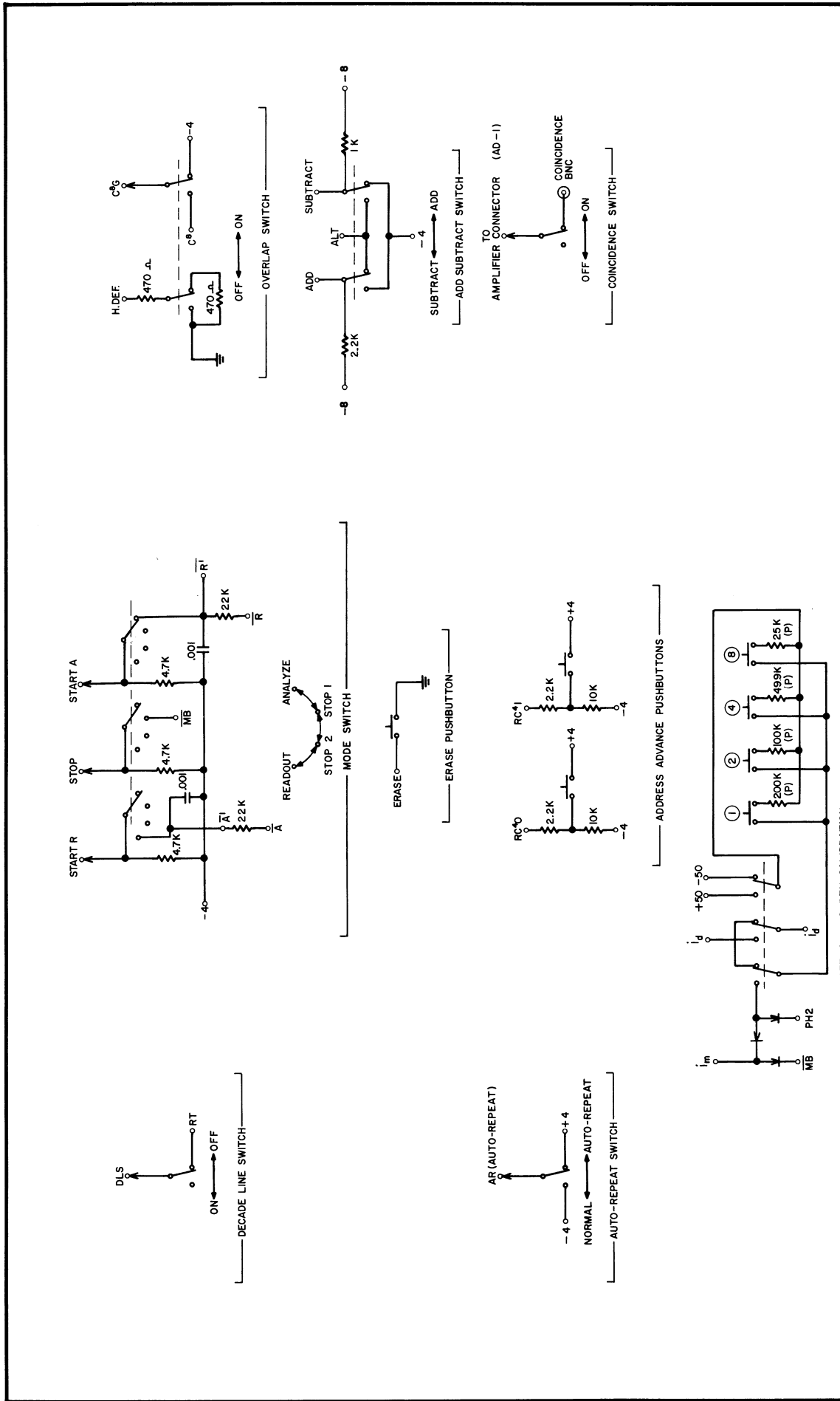


OSCILLATOR CONTROLS
(FRONT PANEL BOARD)

ND 120
ND 130 A
4-13-61

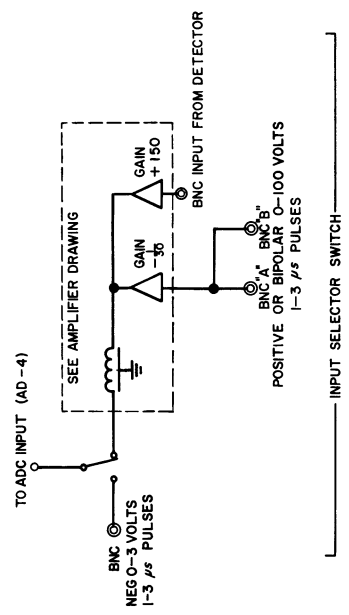
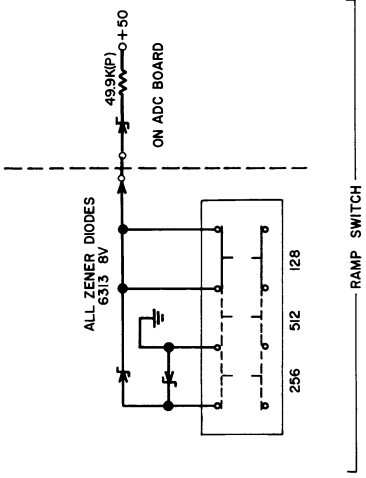
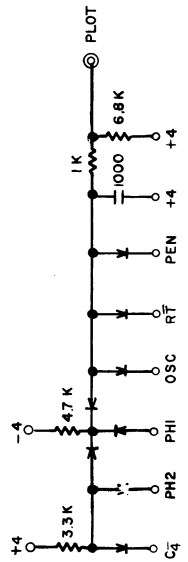
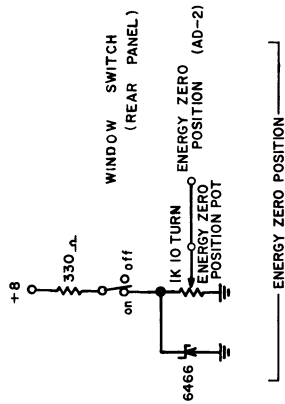
2-27-62





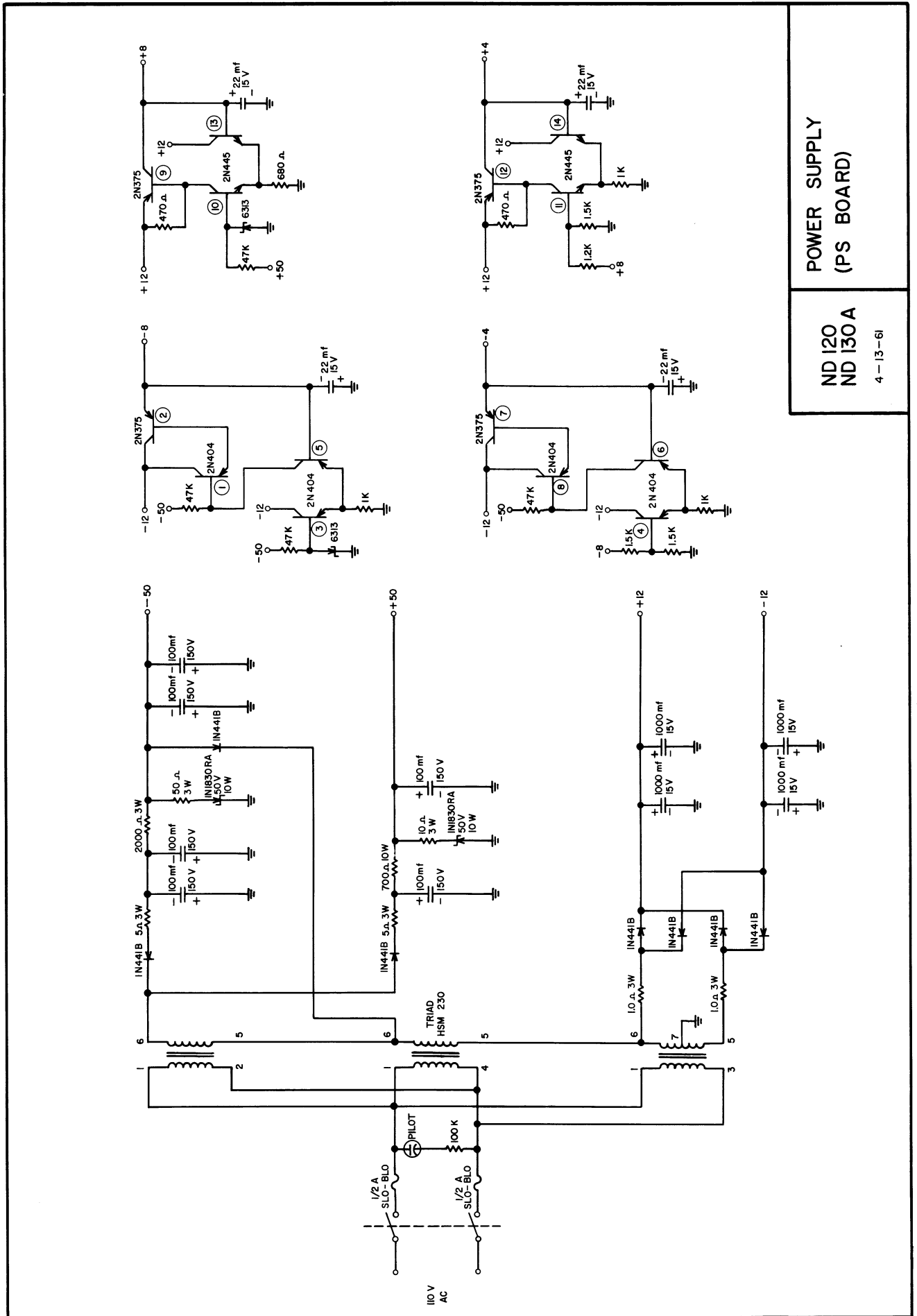
MISCELLANEOUS
CIRCUITS
(FRONT PANEL BOARD)

ND 120
ND 130A
4-13-61



ND 120
ND 130A
4-13-61

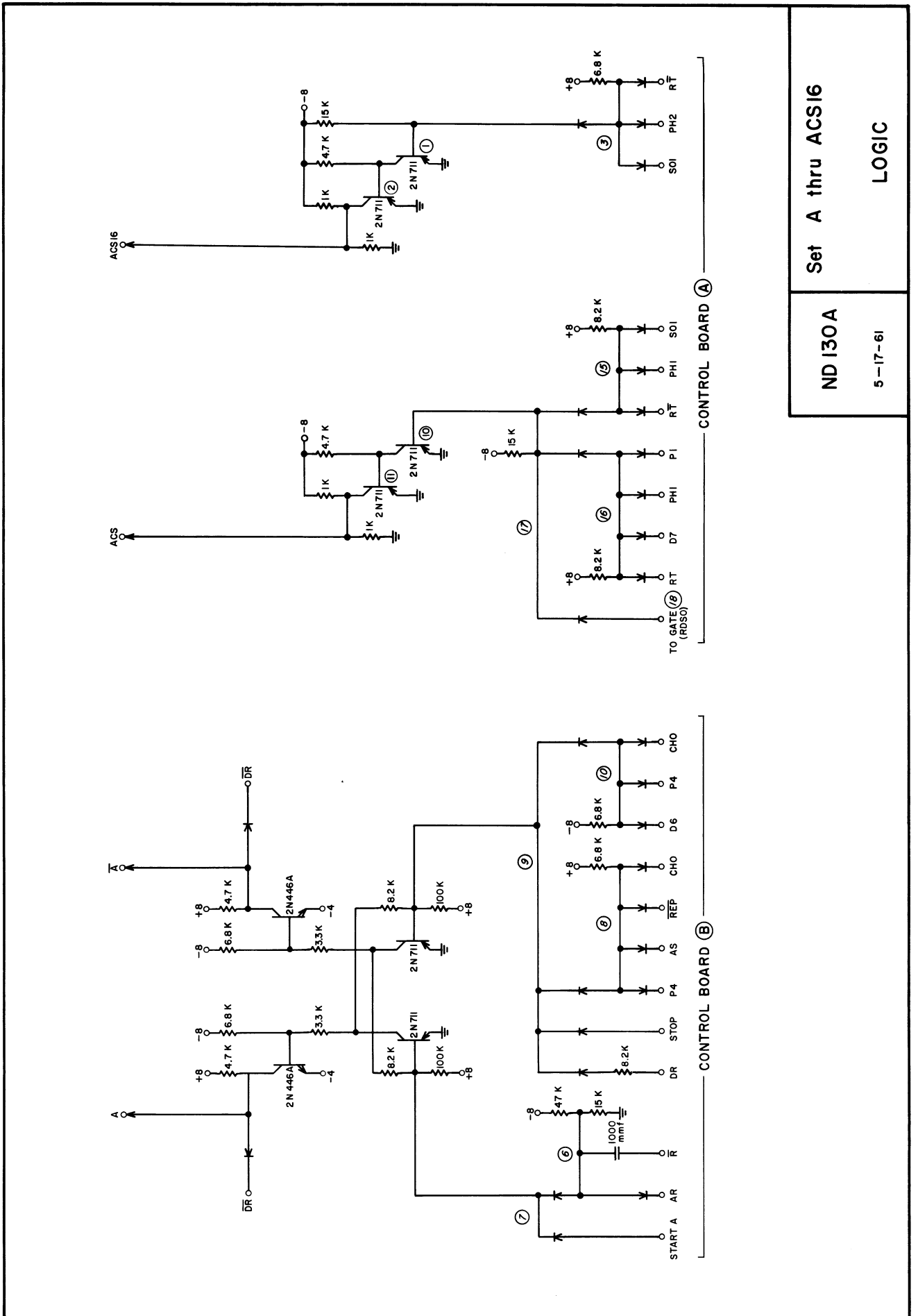
MISCELLANEOUS FRONT
PANEL CIRCUITS
(FRONT PANEL BOARD)



POWER SUPPLY
(PS BOARD)

ND 120
ND 130A

4-13-61

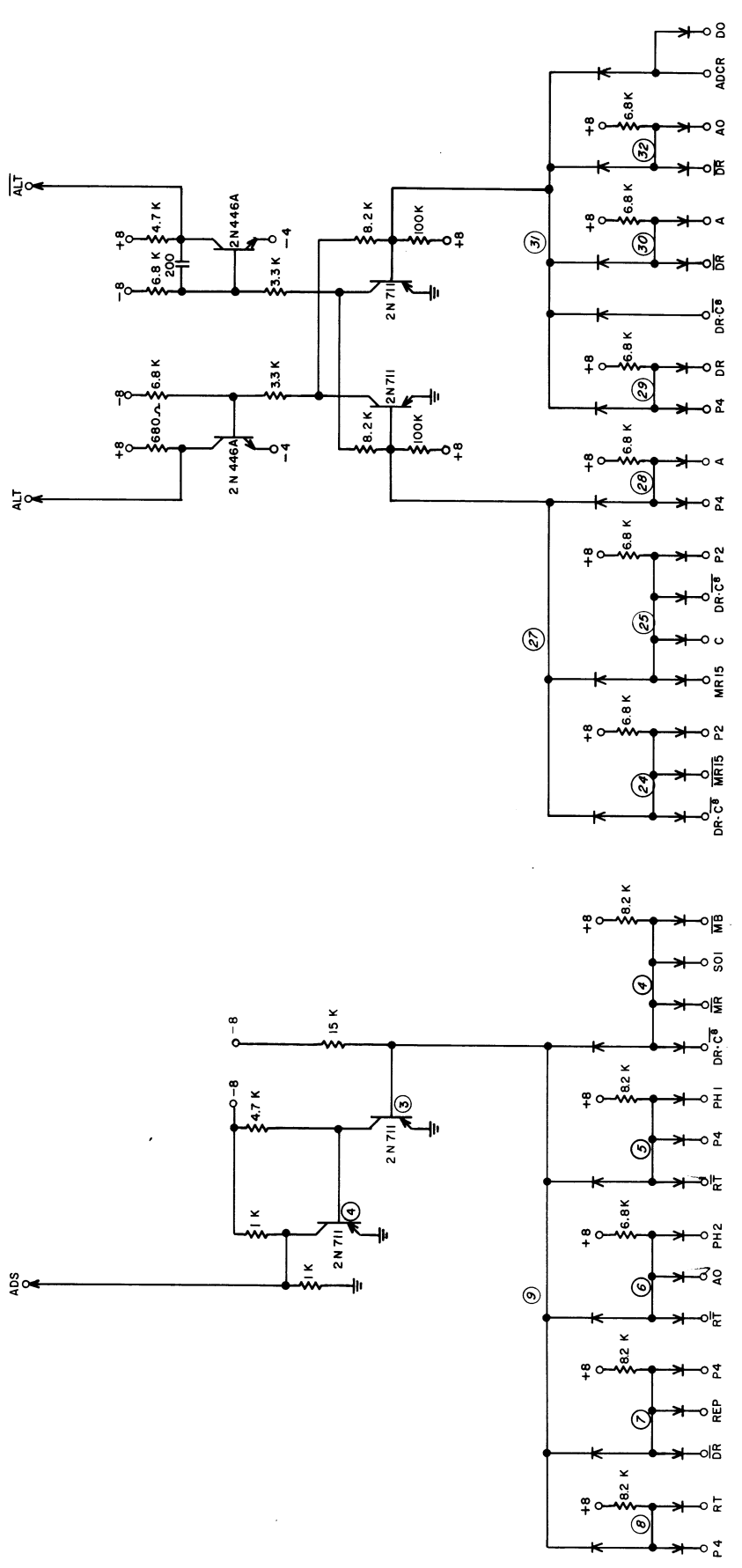


Set A thru ACS16

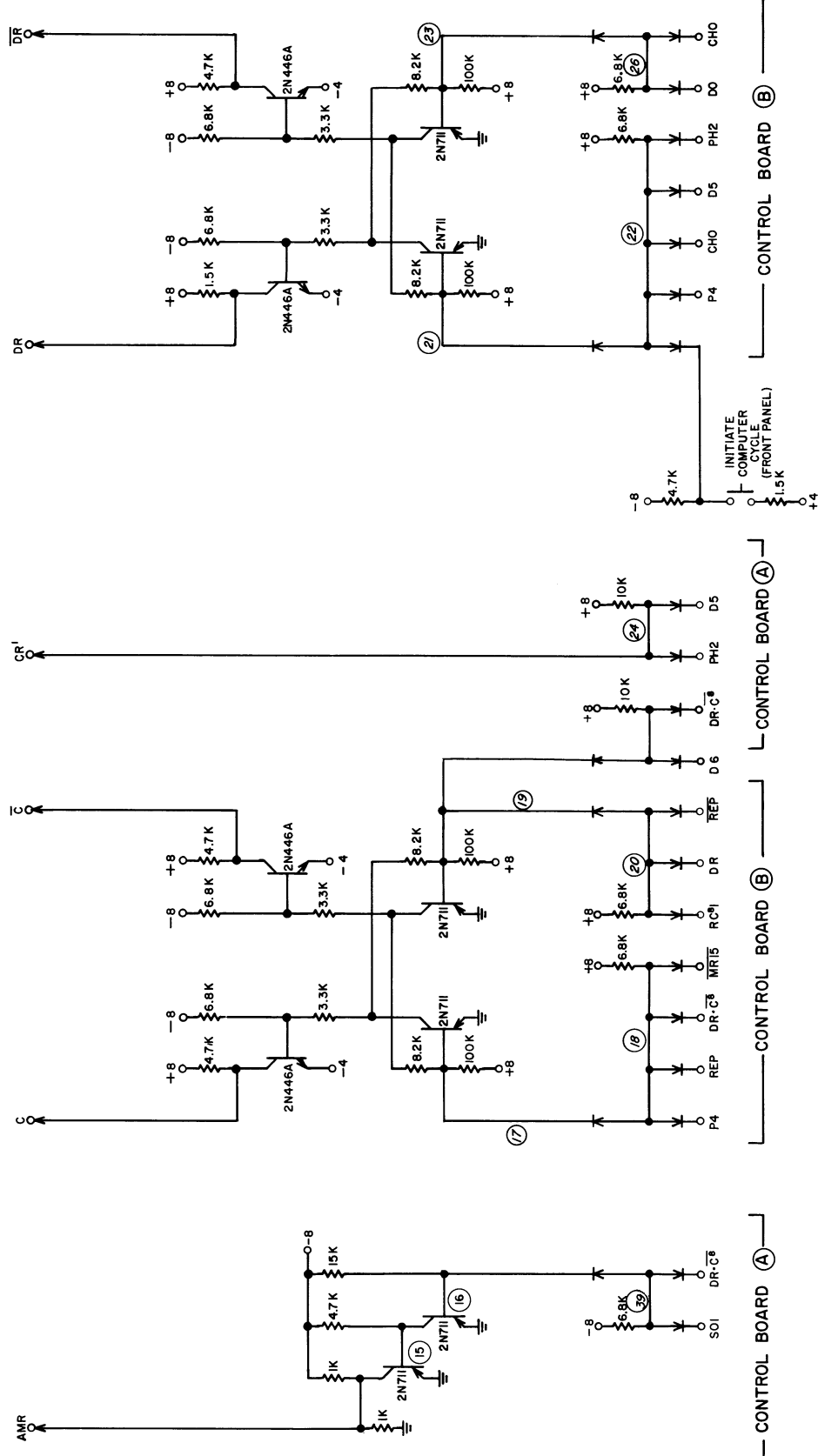
ND 130A

5-17-61

LOGIC

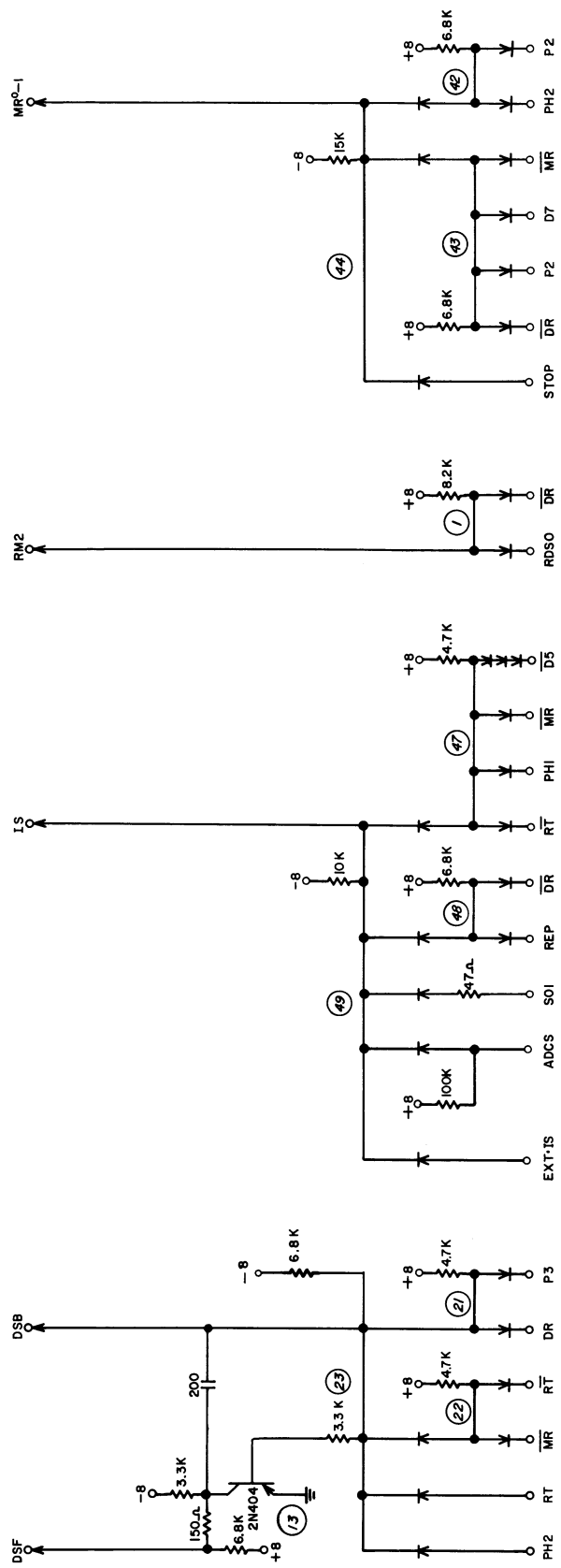


ND 130A	ADS thru Set ALT
5-17-61 LOGIC	



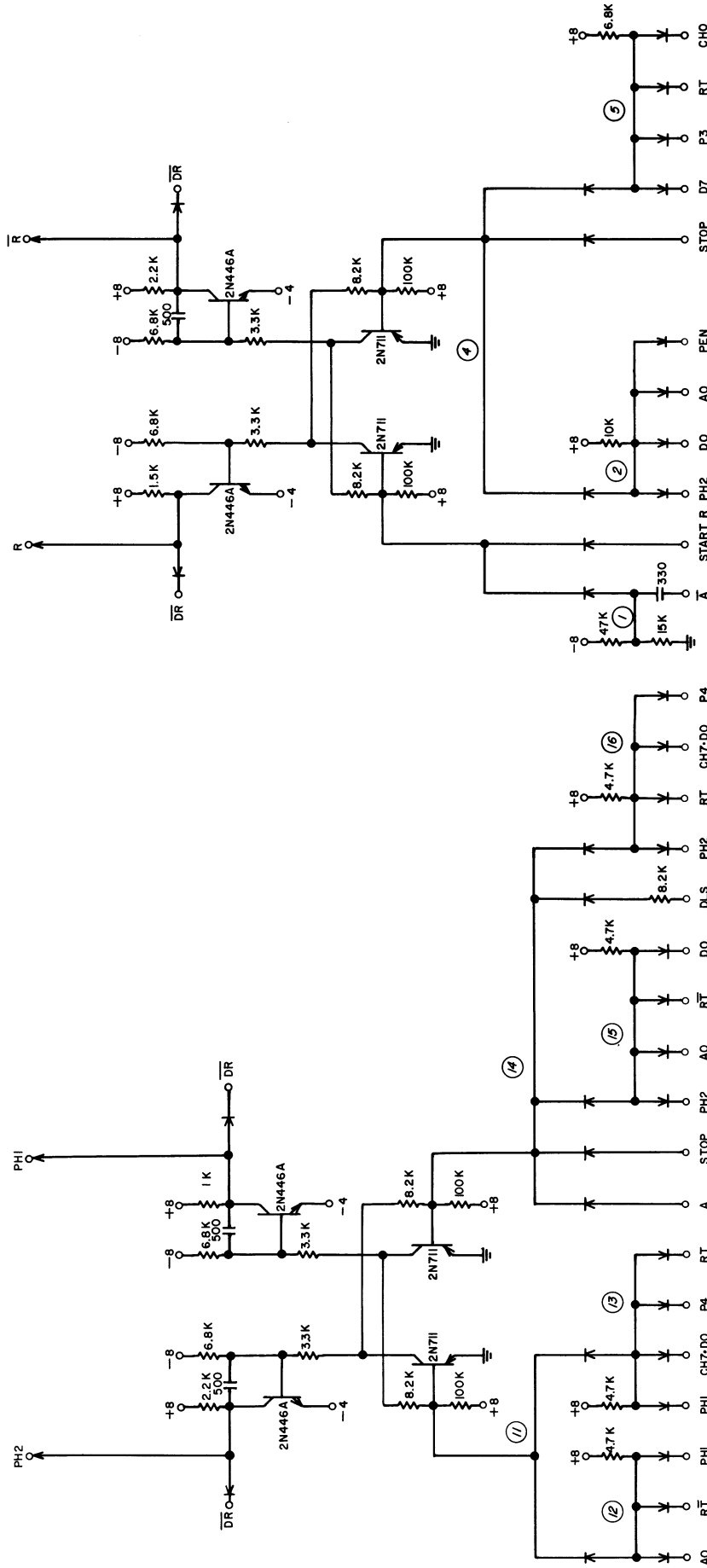
ND130A
5-17-61

AMR thru Set DR
LOGIC



CONTROL BOARD (A)

ND 130 A	DSB thru MR ⁰ -1
5-17-61	LOGIC

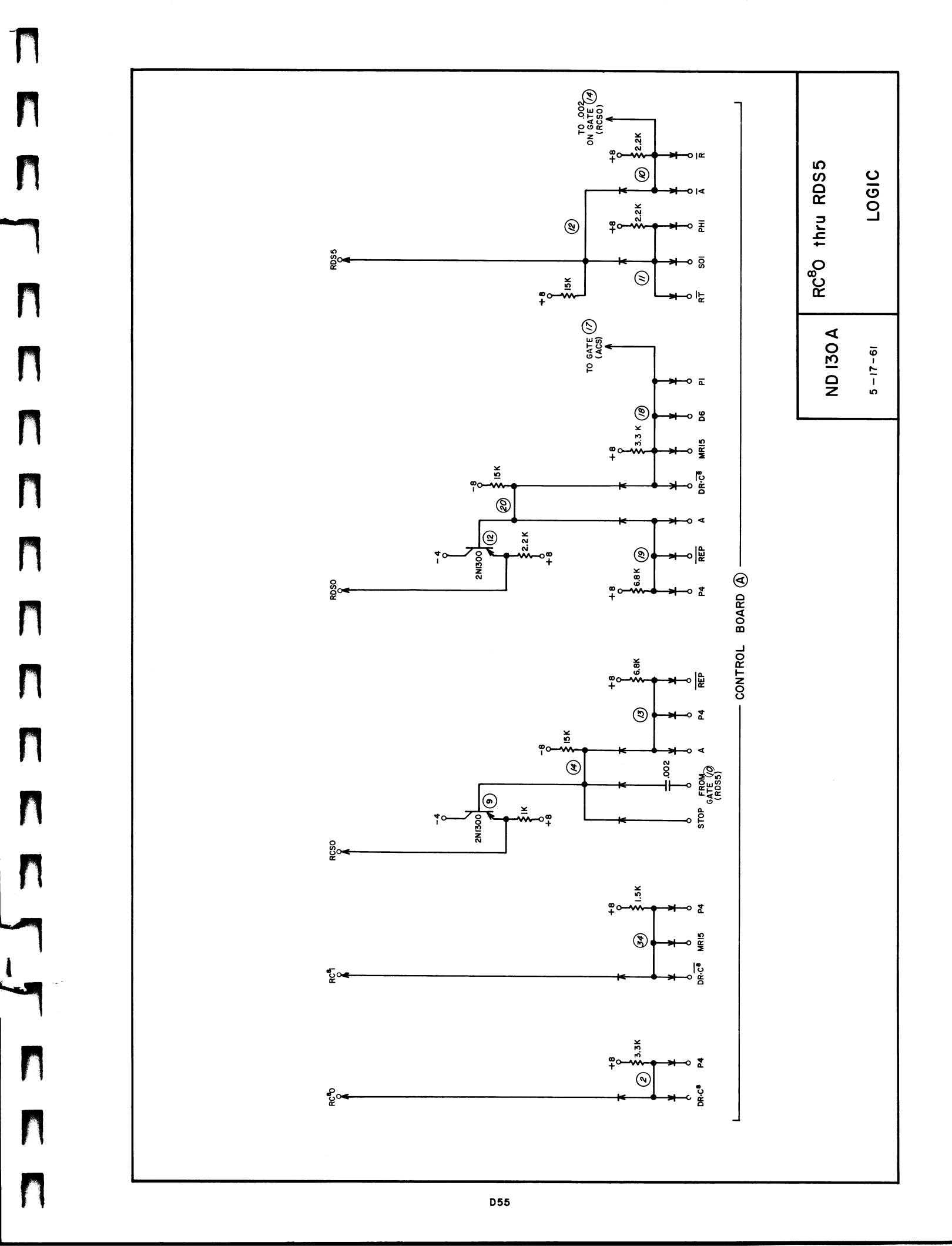


Set PH1 thru Set R

ND 130A

5-17-61

LOGIC



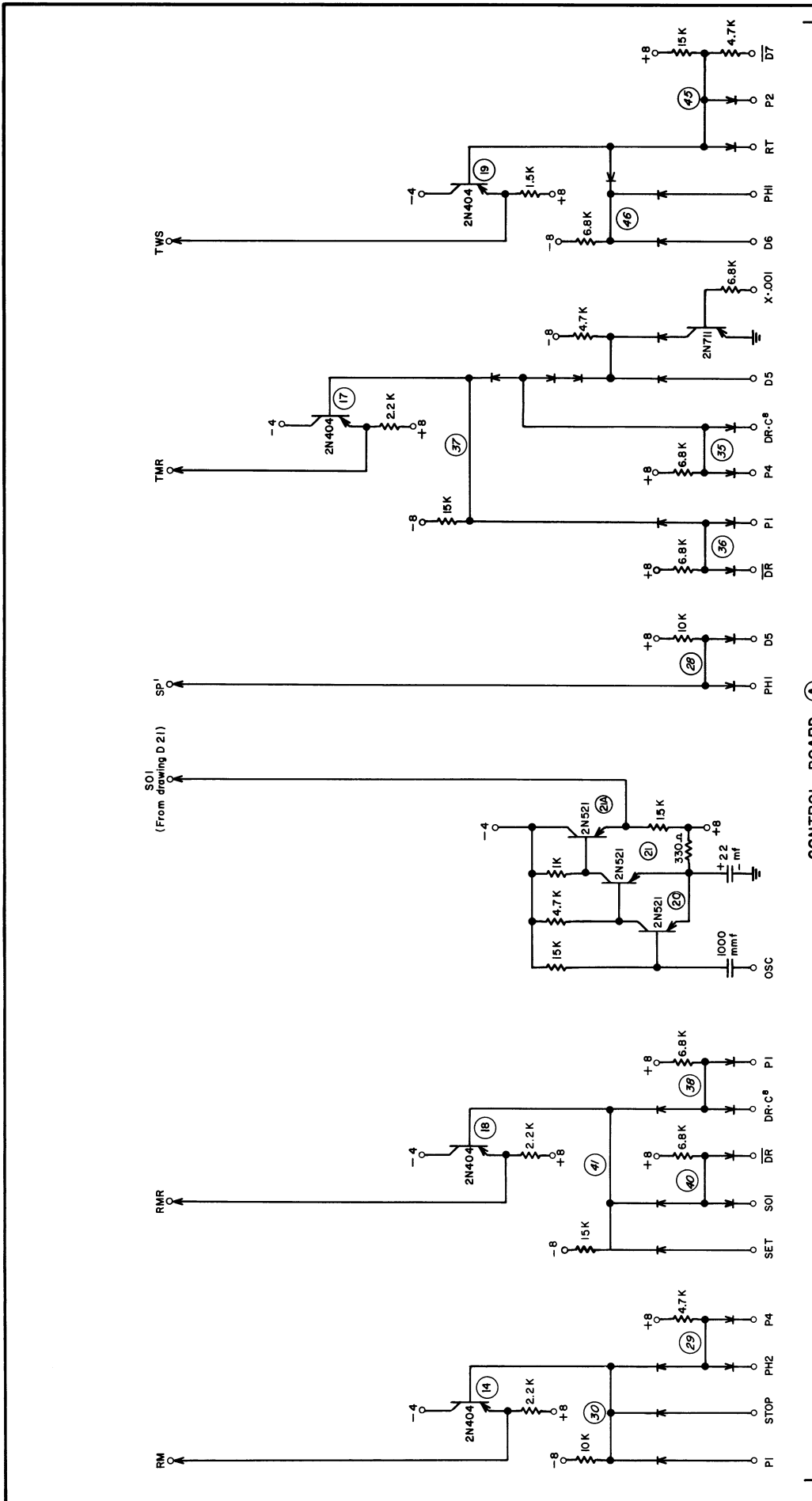
CONTROL BOARD (A)

RC^B thru RDS5

ND 130A

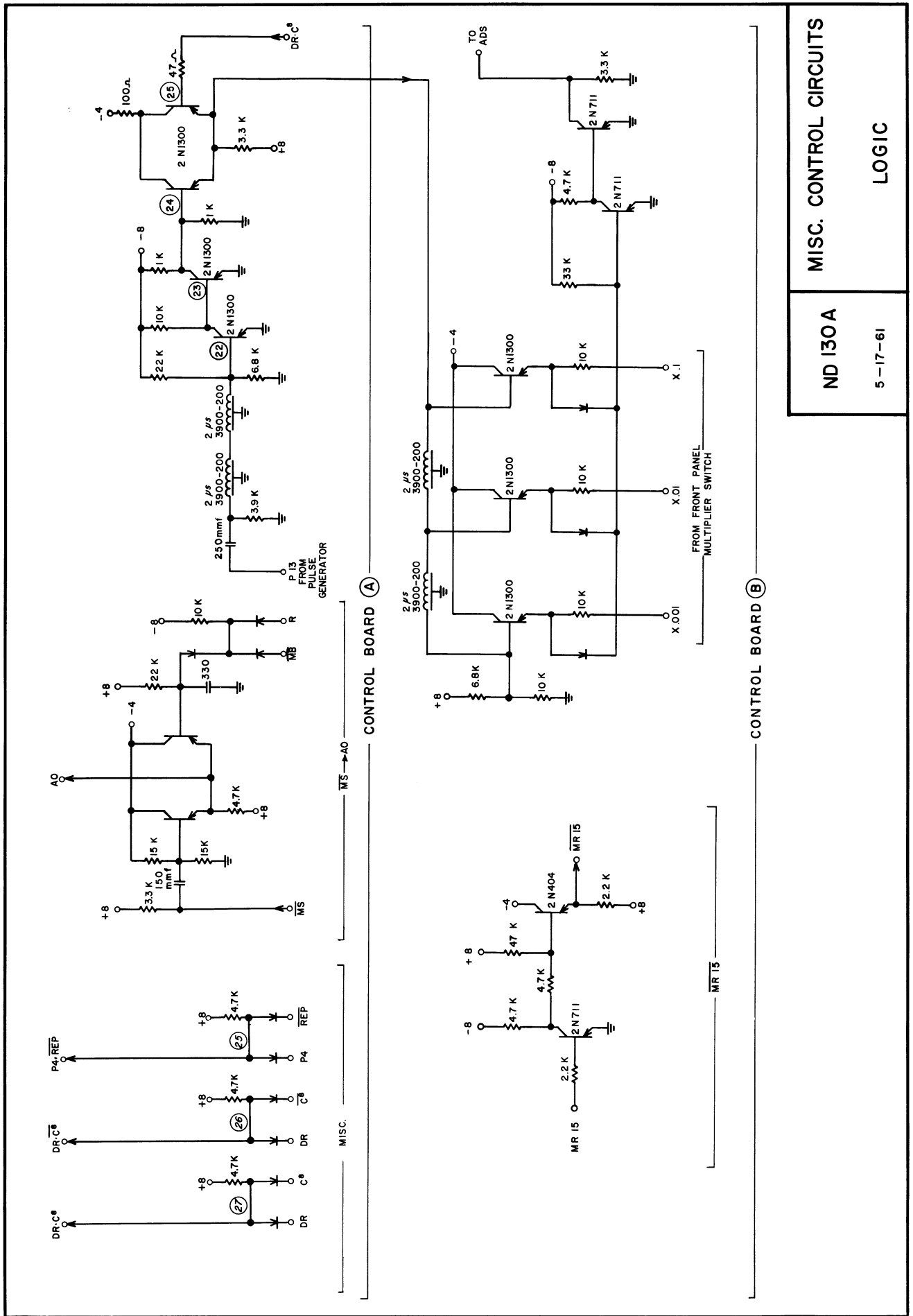
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LOGIC



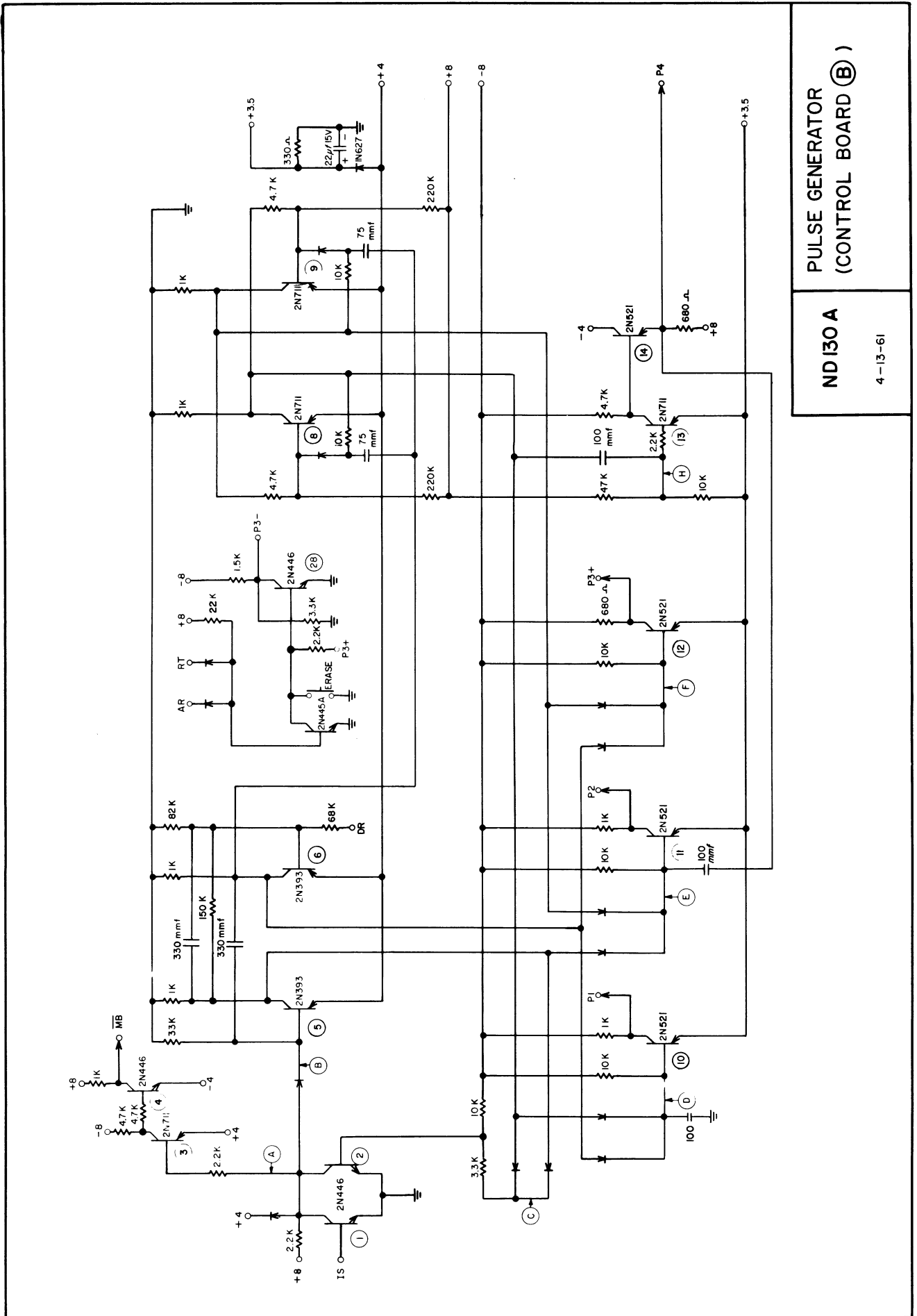
CONTROL BOARD (A)

RM thru TWS
 ND130A
 5-17-61
 LOGIC



ND 130A
5-17-61

MISC. CONTROL CIRCUITS
LOGIC

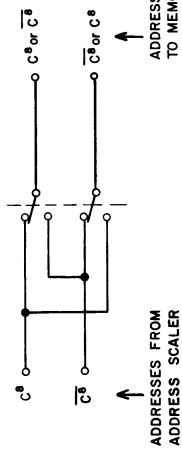
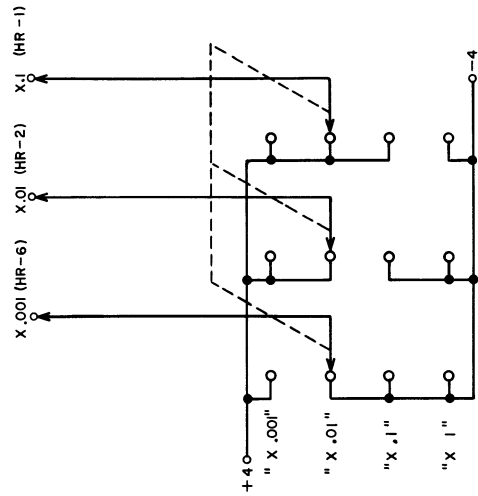


ND 130 A

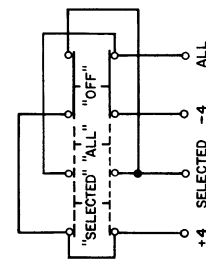
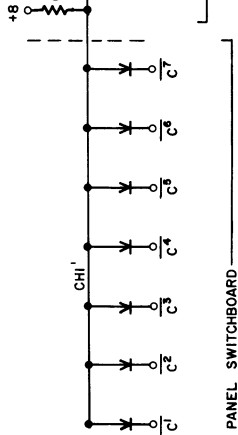
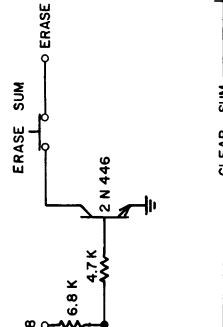
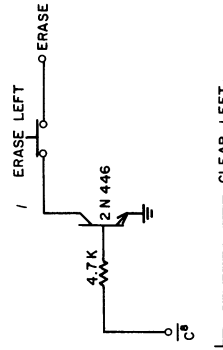
PULSE GENERATOR
(CONTROL BOARD (B))



MISCELLANEOUS CONTROL CIRCUITS
PAGE D57



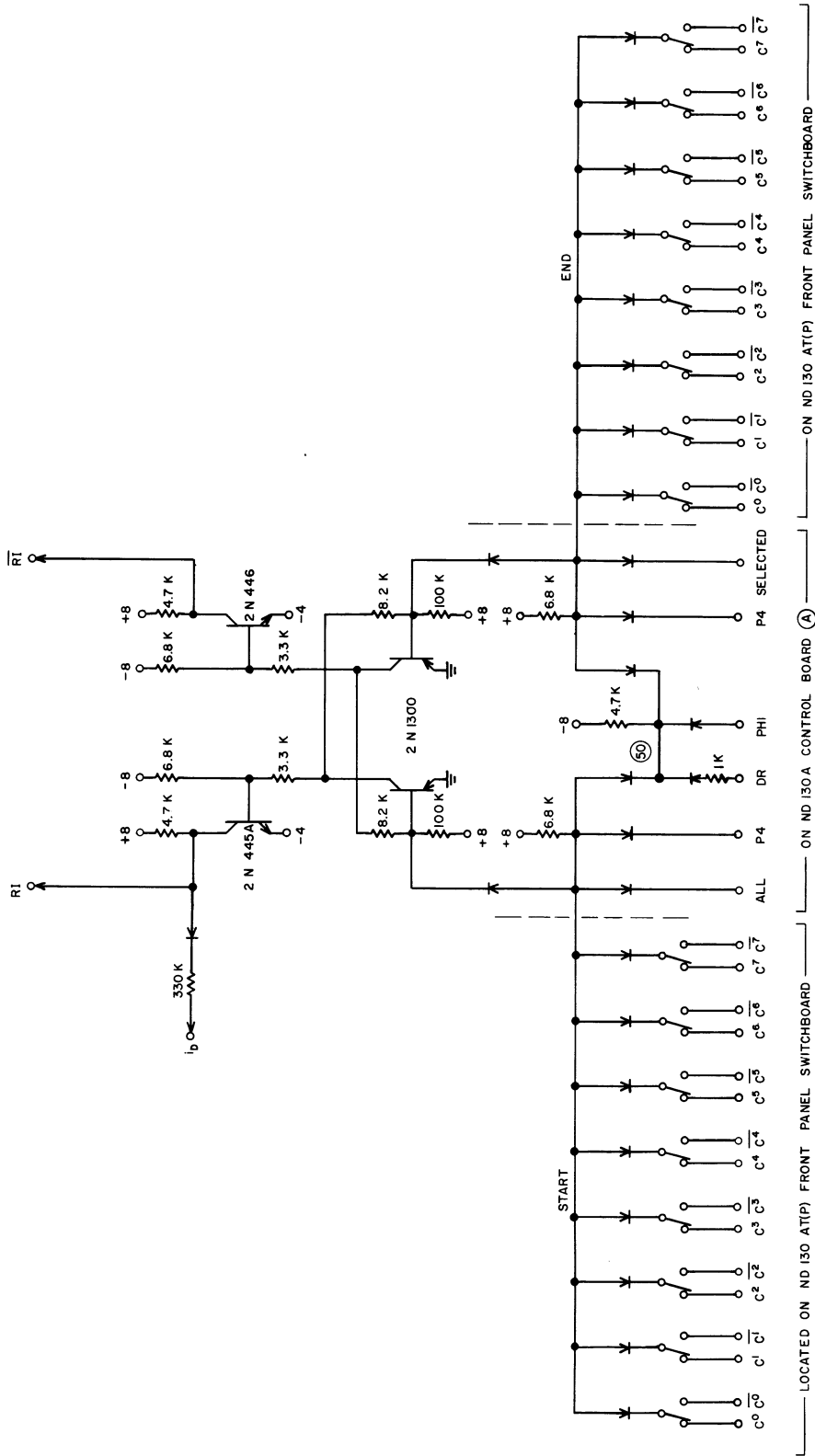
MULTIPLIER SWITCH



FRONT PANEL CONTROLS

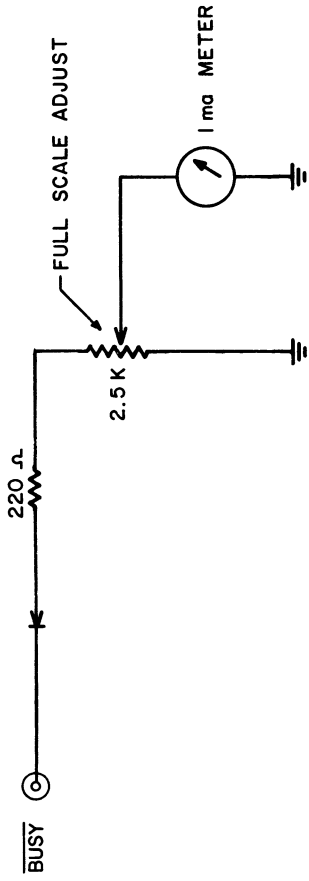
ND 130 A

5-22-61

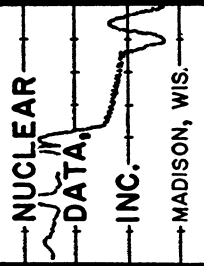


INTEGRATION START-STOP
CONTROL CIRCUITS

ND 130 A

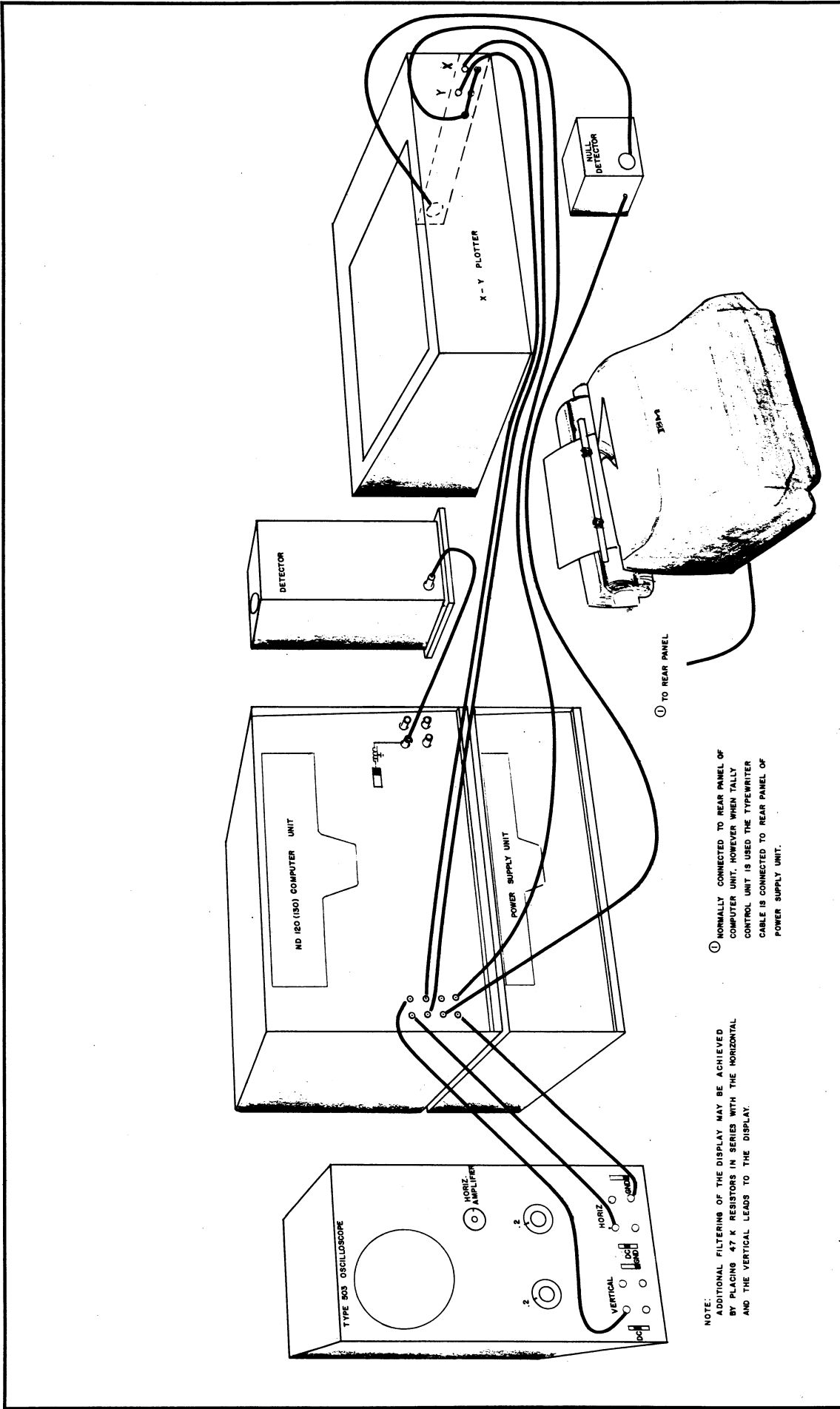


CIRCUIT FOR DEAD TIME MONITORING




12-20-61

W.E.P.



① NORMALLY CONNECTED TO REAR PANEL OF COMPUTER UNIT. HOWEVER WHEN TALLY CONTROL UNIT IS USED THE TYPEWRITER CABLE IS CONNECTED TO REAR PANEL OF POWER SUPPLY UNIT.

NOTE: ADDITIONAL FILTERING OF THE DISPLAY MAY BE ACHIEVED BY PLACING 47 K RESISTORS IN SERIES WITH THE HORIZONTAL AND THE VERTICAL LEADS TO THE DISPLAY.



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CONNECTION OF ND 120 (130) AND ACCESSORIES

5-26-61
 RIX

Following are the wiring instructions to be used between the I.B.M. Output Writer and the ND120, ND130 or ND102 Analyzers:

Typewriter Connector Amphenol Type 57 - 30240

<u>PIN</u>	(ND120) (ND130) <u>NAME</u>	(ND102) <u>NAME</u>	<u>PIN</u>	(ND120) (ND130) <u>NAME</u>	(ND102) <u>NAME</u>
1	0	0	13	1	1
2	2	2	14	3	3
3	4	4	15	5	5
4	-48	-48	16	7	7
5	8	8	17	9	9
6	Space	Space	18	Carriage Return	Carriage Return
7	NC	Ground	19	NC	Limit Switch
8	6	6	20	NC	-4
9	NC	+12E	21	Ground	NC
10	NC	NC	22	NC	-90E
11	NC	+90E	23	NC	NC
12	NC	+180E	24	NC	-12E

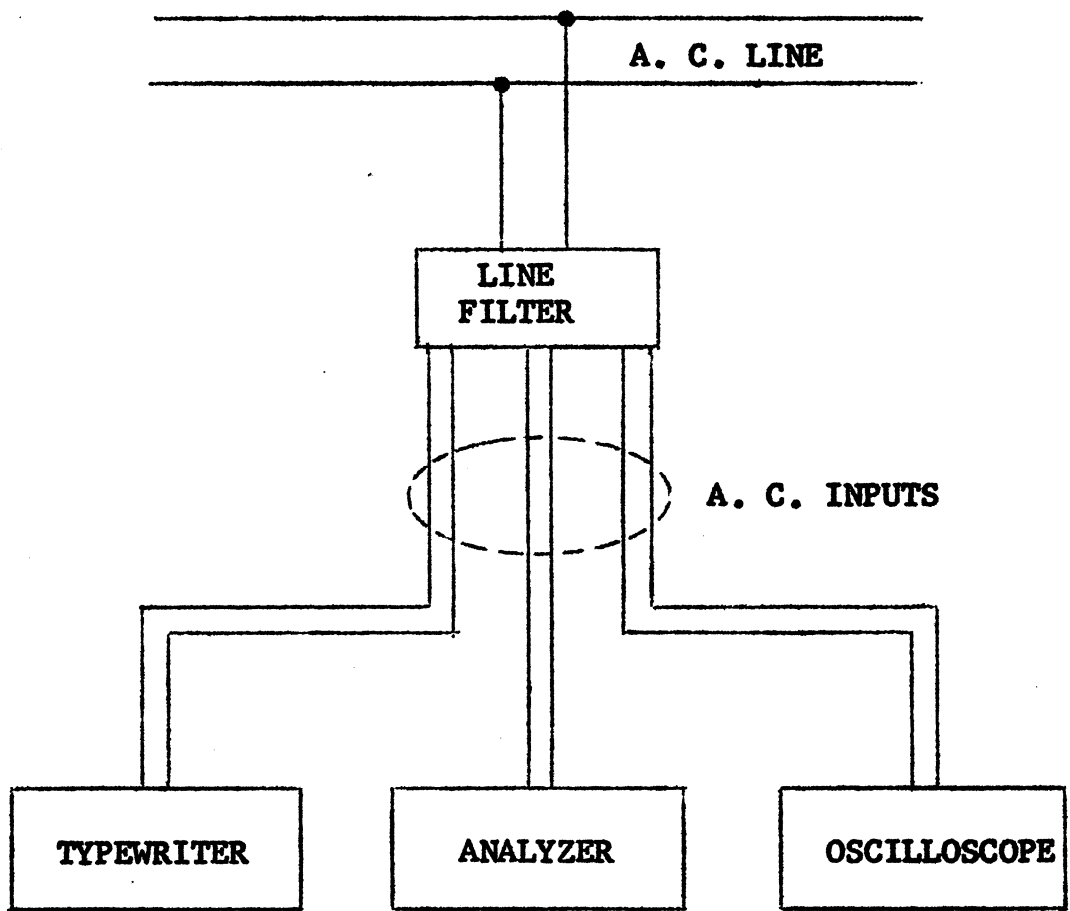
NOTE:

If converting Output Writer from ND102 operation to ND120 or ND130

operation, perform the following modifications:

- 1) Remove and tape wires on pins 19 and 20.
- 2) Remove ground wire on pin 7 and reconnect to pin 21.

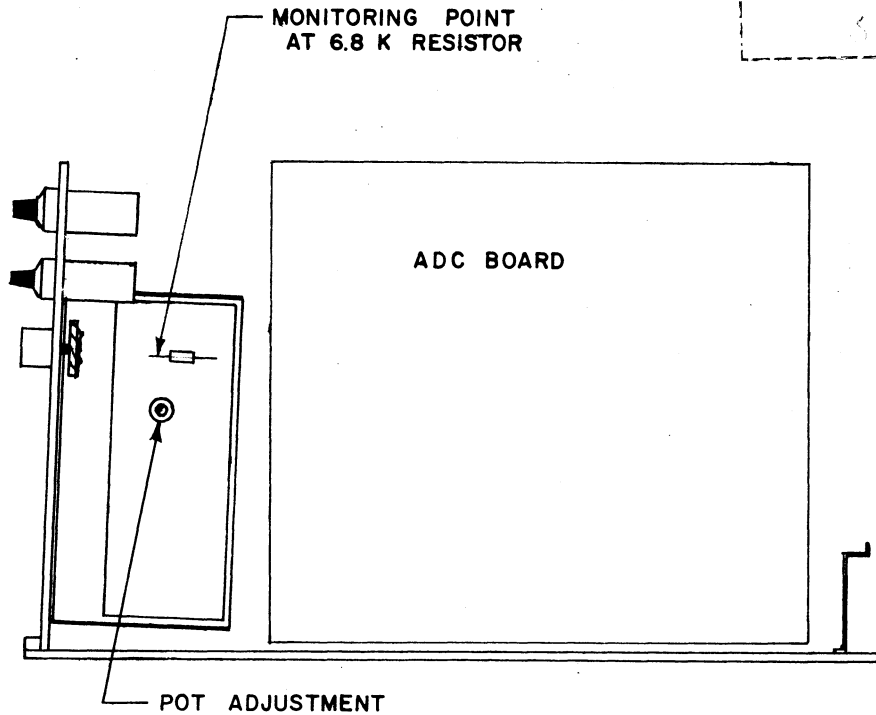
NC = No Connection



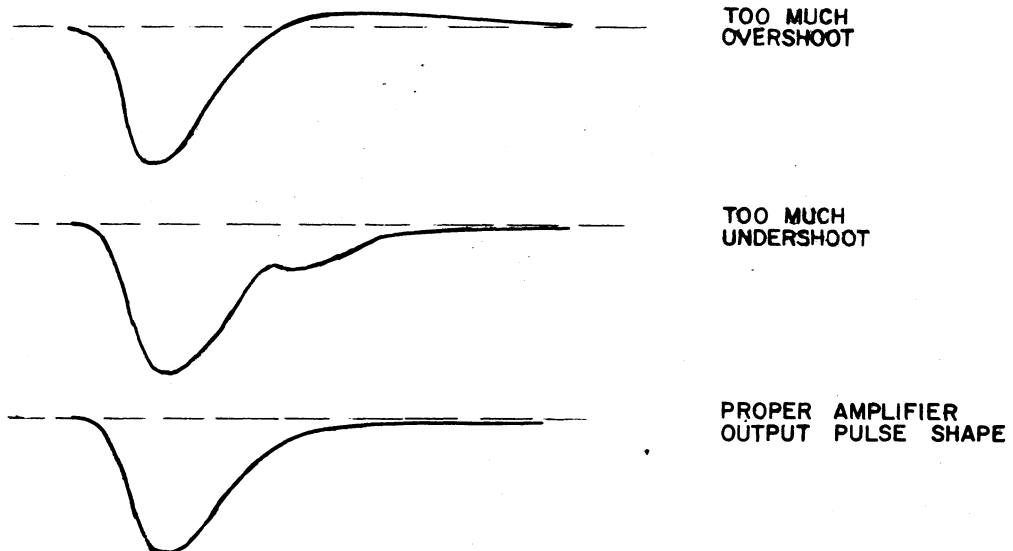
NOTES:

1. A line filter should be used if the A. C. source is noisy. The Typewriter, Analyzer and Oscilloscope should be connected to the filter which is connected to the A. C. Line.
2. If other auxiliary equipment is to be used, another filter is necessary.

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Area Code 312



THE INTERNAL AMPLIFIER SHOULD BE MATCHED TO THE DETECTOR AND LENGTH OF INPUT CABLE USED BY ADJUSTING THE POT FOR OPTIMUM PULSE SHAPE. (SEE PAGE 22 IN INSTRUCTION MANUAL)



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SPECIAL NOTICE

POINT PLOTTING WITH NUCLEAR DATA ANALYZERS

Nuclear Data Analyzers are designed to do point plotting with the Moseley Model 2S (Nuclear Data #ND600) X-Y Recorder, or a Model 2D2 (Nuclear Data #ND 603) X-Y Recorder, a modified Moseley G-1 Null Detector (Nuclear Data #ND 602) or (Nuclear Data #ND 605) and the Moseley D-1A (Nuclear Data #ND 601) or D-1B (Nuclear Data #ND 604) Character Printer.

CAUTION:

AN UNMODIFIED NULL DETECTOR MAY
DAMAGE THE ANALYZER.

Null Detectors supplied by Nuclear Data are already modified and users desiring to modify their own Null Detectors may obtain instructions by applying directly to Nuclear Data, Inc.



**NUCLEAR
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INC.**

3833 WEST BELTLINE
MADISON 5, WISCONSIN

SAMPLE _____	GAIN _____
DETECTOR _____	DATE _____
GEOMETRY _____	CST _____
VOLTAGE _____	LIVE MINUTES _____

0	0
	8
8	16
	24
16	32
	40
24	48
	56
32	64
	72
40	80
	88
48	96
	104
56	112
	120
64	128
	136
72	144
	152
80	160
	168
88	176
	184
96	192
	200
104	208
	216
112	224
	232
120	240
	248
128	256
	264
136	272
	280
144	288
	296
152	304
	312
160	320
	328
168	336
	344
176	352
	360
184	368
	376
192	384
	392
200	400
	408
208	416
	424
216	432
	440
224	448
	456
232	464
	472
240	480
	488
248	496
	504