CA82059608

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CANALPH-3
A PORTABLE THREE-CHANNEL ALPHA SPECTROMETER FOR MEASURING THE DAUGHTER PRODUCTS OF RADON AND THORON

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JULY 1979

Project MRP-4.3.6.0.01
Underground Environment

MINERALS RESEARCH PROGRAM

MINERAL SCIENCES LABORATORIES
REPORT MRP/MSL 79-108 (TR)

CANALPH-3

A PORTABLE THREE-CHANNEL ALPHA SPECTROMETER FOR MEASURING THE DAUGHTER PRODUCTS OF RADON AND THORON

by

D.W. Carson*

ABSTRACT

A portable three-channel alpha spectrometer for the measurement of radon and thoron daughters in uranium mines or homes is described. The computer programs for analysing the data to give the working levels of radon and thoron by both the alpha spectrometric and modified Kusnetz methods are included along with some typical results.

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INTRODUCTION

The determination of the working levels of radon and thoron in the environment, in light of the health risk to personnel, has become a major interest in the past few years. The working levels of radon and thoron are deduced from a measure of their daughter products.

The first version of the spectrometer, based on the design of an alpha counter developed at the Argonne National Laboratory(1), was a two-channel instrument to measure RaA and RaC'. When thoron became an issue, the design was modified further to include the counts from ThC'. With the introduction of the third energy channel, the instrument came to be known as CANALPH-3.

This instrument will supply the data for the determination of the daughter concentrations and thus the working levels of radon and thoron by two methods; an alpha spectrometric method which relies on the counting of individual daughter products (RaA at 6.0 mev and RaC' at 7.68 mev for radon and ThC' at 8.78 Mev for thoron) and a modified Kusnetz method which is a total alpha counting scheme that does not require energy descrimination.

Appendix 3 contains a listing of the two Fortran computer programs which are used to analyse the data. Program RTSPEC is used to analyse the data obtained from the instrument for the spectrometric method and program KUS is used to analyse the data for the gross alpha or Kusnetz method.

The original counting scheme for the determination of the working levels using the spectrometric method required five counts as follows.

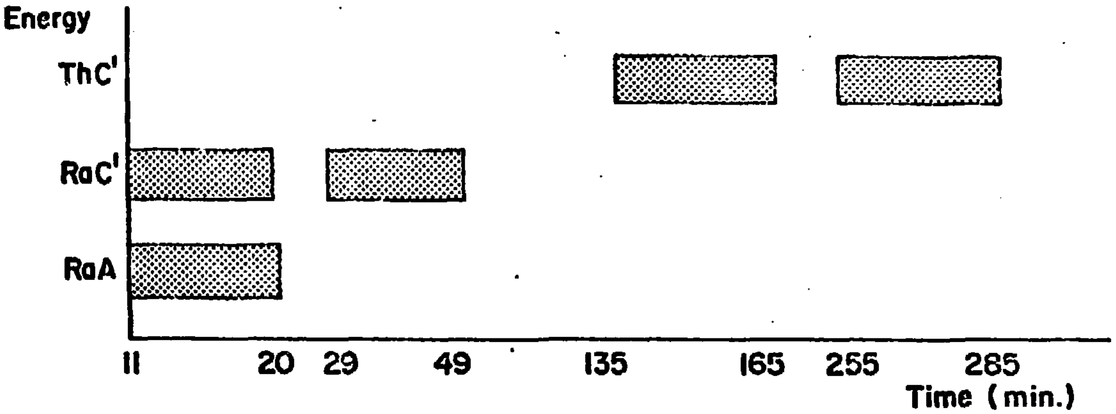

Figure 1. Original Counting Scheme

The instrument will give the following counts which appear in windows A and C' on the front panel:

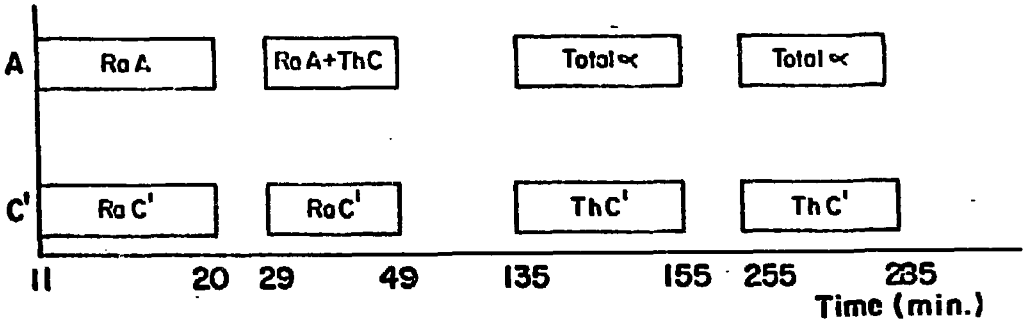

Figure 2. Counts Provided by CANALPH-3

The times indicated are the times from the start of the sample period. In the case illustrated, the sampling time is ten minutes and the sample transfer time is one minute.

The optimum counting periods for determining the working levels by both the alpha spectrometric and the modified

Kusnetz methods were subsequently determined theoretically(2), and then verified experimentally by the use of CANALPH-3.

DESCRIPTION

The CANMET portable alpha spectrometer, CANALPH-3, consists of an ORTEC ruggedized silicon surface barrier detector, a charge sensitive amplifier, comparator circuitry to discriminate RaA, RaC' and ThC', and associated digital circuitry to provide the necessary counts required for the Townsend/Coté procedure(2) of determining the total working level of radon and thoron. The counts from the various counting intervals, displayed on seven segment LED displays, are used as input to a Fortran computer program* to give the concentrations of RaA, RaB, RaC, ThC and ThC' in atoms per liter, picocuries per liter and the working level of both radon and thoron. The spectrometer circuitry and power supply (a bank of rechargeable nickel-cadmium batteries) are housed in an extruded aluminum case measuring 10 x 17 x 27 centimeters (4 x 7 x 11 inches) and weighing 4.15 kilograms (≈9 lbs).

An air sample is obtained using an external sampling pump (DUPONT Model P-4000 or equivalent) and a Millipore 0.8-micron filter which is manually transferred to the spectrometer after the sampling period. With the counting intervals preset on the spectrometer, the counting procedure procedes automatically after manual initialization.

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*Appendix 3

A series of four LED indicator lamps located on the front panel of the instrument indicate the state of the internal timing sequence; an alarm is provided to indicate the end of the counting cycle.

A program switch is provided to select either the spectrometric or the total alpha mode of operation.

There are three voltages required for the circuitry. ±12 volts are required for the operational amplifiers and +5 volts is used for the logic circuitry. These voltages are supplied by nickel-cadmium batteries which are charged, in situ, by means of a battery charger via a connector mounted at the rear of the instrument. The battery charger provides independently variable charging currents for each of the three battery banks.

A BNC connector provides output of the total α-spectrum suitable for input to an oscilloscope or multi-channel analyser. By means of this signal, the instrument can be easily calibrated.

A display switch located on the front panel is used to vary the intensity of the data displays. The switch is normally placed in the dim position to preserve battery charge. In a mine environment, the display can be easily read in this position.

OPERATING PROCEDURE

To obtain a complete set of radon and thoron daughter counts for the spectrometric method, the mode switch (SCA/GROSS) is first placed in the SCA position. With the appropriate times selected, by the front panel thumb-wheel switches, the three radon counts are accumulated. The mode switch is then placed in the GROSS position and the thoron count period selected. The two thoron count periods are then started manually, at the appropriate times, by means of a stop watch or wrist watch.

There are two display windows marked A and C' on the front panel of the instrument. The counts detected during the first radon time interval are continuously displayed with the counts from RaA appearing in the A window and the counts from RaC' in the C' window. At the end of the first time period, the internal transfer function is disabled (see chapter on counting circuitry) and the numbers displayed are the total counts of RaA and RaC' for the first time interval. The internal counter will continue accumulating data until the end of the nine-minute wait period. At this time a reset pulse is generated and sent to the counter circuitry. The internal counters are momentarily zeroed but remain active. At the end of the radon counting period, the STOP function is generated which inhibits the counting and the buzzer sounds to give an audible indication to the operator. Thus, the total counts of RaA and RaC' for the first time period are displayed and the RaC' count for the second time period remains in the internal data register. Pressing the TRANSFER button on the front panel will transfer the data from the internal data register to the display.

To obtain the thoron count, the mode switch is placed in the GROSS position and the counter started manually at the appropriate time. The buzzer will signal the end of each of the thoron count periods. Pressing the transfer button will transfer the ThC' counts to the C' window and the total alpha counts will appear in the A window.

In summary, to operate the portable α-spectrometer:

- Set the SCA/GROSS switch to SCA,
- Set the first count interval in minutes (9) on the left-hand delay switch and the total count interval (38) on the right-hand delay switch,
- Turn power switch on,
- Press STOP,
- Press RESET, then one minute after end of sampling,
- Press START.

The buzzer indicates the end of the counting period. Turn the display on and record the first two counts from the A and C' displays. These are the counts from RaA and RaC' for the time interval from 11 to 20 minutes. Press the transfer button and record the second two counts which are the counts from the interval from 29 to 49 minutes. Next:

- Set the SCA/GROSS switch to GROSS,
- Set the right-hand delay switch to the time interval in minutes required for the thoron count (30),
- Set the left-hand switch to zero,
- Press RESET, 155 minutes from start of sampling,

- Press START.

At the sound of the buzzer, press TRANSFER, and record readings, which are the total α-counts displayed in the A window and the counts from ThC' in the C' window.

- Press RESET, 255 minutes from start of sampling
- Press START, at the sound of the buzzer
- Press TRANSFER,
- Record the final set of readings.

To obtain data for the modified Kusnetz method, the mode switch is placed in the GROSS position and the count period (15) dialled into the right-hand timer switch. The left-hand timer switch is set to zero.

- Press STOP, RESET,
- One minute after the sampling period, press START. The buzzer will sound at the end of the 15-minute count period.
- Press TRANSFER, and record the first reading.

Repeat the above steps at 155 and 255 minutes to obtain the three total α-counts.

DETECTOR/AMPLIFIER CIRCUITRY

An air sample is collected on a 25-mm Millipore 0.8-micron filter by means of an external sampling pump. The filter is then manually transferred to the sample holder which locates the sample in front of an Ortec, ruggedized silicon surface barrier detector. The detector is essentially a reverse biased diode. Alpha particles hitting the front surface of the detector break down the diode releasing charged carriers. The number of carriers produced is in proportion to the energy of the ionizing radiation. Thus, integrating the current by means of a charged coupled amplifier yields a voltage pulse directly proportional to the alpha radiation energy. With -8 volts on the detector, (Fig. 5) the voltage pulses from the first amplifier (AD507J) are positive and approximately 20 millivolts in amplitude. The second amplifier multiplies this signal by 50 to give voltage pulses in the range of 1 volt corresponding to 6 mev alphas (RaA) and about 2.5 volts for 7.7 mev alphas (RaC'). The noise level at this point is about 0.2 volts, well out of the signal range. The third amplifier provides an isolated output of the total signal to a BNC connector mounted on the front panel. Thus, the signal can be observed with an oscilloscope or a multi-channel analyser.

DISCRIMINATOR/SUBTRACT CIRCUITRY

The signal voltage pulses after amplification are split by the discriminator circuitry into three components by the three comparators (National Semiconductor Type 319H) of Figure 5. A temperature compensated zener diode, type 1N938A, and the three 10-turn potentiometers provide the voltage reference for the three discriminators. Any signal voltage pulse greater than the set voltage will cause the amplifier to saturate producing an output pulse. The voltage level set by potentiometer ③ is made equivalent to 8 Mev (see appendix 1). Signal pulses produced by thorium C' will produce voltage pulses from this comparator. The voltage level set by potentiometer ② is made equivalent to 7 Mev. Signal pulses produced by thorium C' and radium C' will produce pulses from this comparator. The voltage level set by potentiometer ① is equivalent to 4 Mev which is above the noise level, and thus signal pulses produced by all four sources (RaA, RaC', ThC and ThC') will produce pulses from this comparator.

The ThC' signal is, at this stage, isolated from the other signals. By means of subtraction, the other two signals, RaA and RaC', can also be extracted. In the circuitry of Figure 6a, the ThC' signal is eliminated thus isolating the RaC' signal. This is accomplished by using the ThC' signal to turn the control gate (A11) off. When a pulse from ThC' appears simultaneously at the input of A9A-5 and A10-6, the flip-flop will immediately toggle, and the output pulse produced by the monostable will be delayed. The 0 output of the flip-flop will turn gate A11 off before the delayed signal pulse arrives. Thus, the ThC' signal is eliminated. The output of A9A feeds the input of monostable A9B. The output of A9B which is also delayed resets the flip-flop which in turn restores the control gate to the on state. Any signal at the input of A9A will appear at the reset input of flip-flop A10, after an appropriate delay provided by monostable A9B, and will condition the control gate to the ON state. This same principle is applied in the circuitry of Figure 6b to eliminate the RaC' and ThC signals from the output of the total signal channel.

Since the ratio of ThC' to ThC is 2 to 1 within 12% and since the number of counts from ThC during the first count period is small, the ThC' signal, divided by 2, is used in the subtraction process in place of ThC. In Figure 6b flip-flop ⑤ provides the divide-by-two function.

CLOCK AND TIMING CONTROL CIRCUIT

The one pulse per minute clock signal is derived from a one megahertz crystal controlled oscillator (Fig. 7a) which is divided by 10 by the 4518 BCD counter and then 10^5 by the 4534 5-decade counter. The 4566, wired in the divide-by-sixty configuration, provides the desired one pulse per minute clock signal. From there, the dual BCD counter (Fig. 7b) along with the bank of inverters provide dual polarity pulses of one-minute duration at 1-, 2-, 4-, 8-, 10-, 20-, 40- and 80-minute intervals. These pulses are then routed to the front panel digi-switches of Figure 9a. The first switch will provide an output pulse selectable from 0 to 9 minutes in 1-minute intervals and the second switch will provide an output pulse selectable from 0 to 99 minutes in 1-minute intervals.

The first switch is used to select the desired time interval for the first count period and the second switch, for the total time counting period. This means that the time selected on the second switch is the sum of the first count interval plus the 9-minute wait period plus the second count interval.

When the STOP button on the front panel is pushed, a 1 level is applied to the reset input (pin 2) of the divider chip A3 (Fig. 7a). When a 1 level is applied to the master reset (pin 2) of the timer chip A2, an unwanted output pulse is generated at pin 13. By differentiating this input, the output pulse will be of short duration, A3 will still be under reset condition and this unwanted pulse will be eliminated.

The use of the diodes and the inverted signals in the switch circuitry insures that an output pulse will be generated at the selected time only. This concept is demonstrated in the example of Figure 8b.

If 4 minutes is set on the digi-switch, then the 4 signal is selected which automatically deselects $\bar{4}$. The 4, $\bar{8}$, $\bar{2}$, and $\bar{1}$ lines are selected and the 1, 2, $\bar{4}$, and 8 lines are not selected. Thus, the diodes form and AND gate to produce an output pulse only during the 4 minute time interval.

MAIN CONTROL CIRCUIT

As previously described, the STOP, RESET and START switches are depressed, in that order, to initiate a count cycle. The following tables outline the functions of each switch and describe the internal operation of the counter.

TABLE 1

Front Panel Switch Functions

STOP	RESET	START
Inhibit Count Inhibit Clock Reset Clock	Reset Counters Transfer Off Delay Timer Off Thoron Subtract Function On	Start Clock Start Count Transfer on

TABLE 2

Internal Operations

FUNCTION	DISPLAY LAMPS	DESCRIPTION
Start	● O O O	Same as above
End of First Count Period	O ● O O	Transfer off, Delay Timer on, Thoron Subtract off
Start Second Count Period	O O ● O	Reset Counters
End of Cycle	O O O ●	Inhibit count, Inhibit clock, Reset clock, Sound buzzer

Activating the STOP switch performs four functions. It inhibits and resets the clock, inhibits the counts and also illuminates the fourth display lamp.

As seen in Figure 9, the output (pin 3) of the AND gate A8 is initially at a 0 level. By depressing the STOP switch, this output changes to the 1 state placing a 1 level at the SET input (pin 8) of flip-flop A7b. This sets the Q output (pin 13) to the 1 state and the $\bar{Q}$ output to 0. The Q output is applied to the START/STOP input of the clock chip A1 (Fig. 7a) inhibiting the clock. The 1 output pulse of gate A8-3 is also applied to the second and third divider chips (A2 and A3) of the clock circuit to provide the RESET function. The counts from the two counting channels are input to the control gates A8-8 and A8-13. When the $\bar{Q}$ output of flip-flop A7b (pin 12) is 0, the two gates are turned off and the counts are blocked. The Q output of A7b also resets the LED lamp counter A12 and lights the fourth lamp.

The RESET switch also performs four functions. It resets the data counters, turns the TRANSFER function off, resets the nine-minute delay timer and turns the thoron substract function on.

When the RESET switch is activated (Fig. 10), an output pulse is produced by the monostable multivibrator A6-6 which is applied to the reset inputs of all four data counter chips. The RESET switch also places a 1 level at the reset input of flip-flop A10. This results in a 1 level at the $\bar{Q}$ output (pin 12) and a 0 level at the Q output (pin 13). Pin 12 is attached to the reset input of the nine-minute delay timer A1. This counter provides the none-minute wait period between the two count periods of radon. The Q output of flip-flop A10 is tied to the reset input of flip-flop ③ (Fig. 6b). This flip-flop controls the thoron subtract function. With a 0 level on the reset input, the thoron subtract function is on. With a 1 level at pin 10, the $\bar{Q}$ output is forced to the 1 state which holds the control gate ① on, turning the thoron subtract function off. The RESET switch also conditions the TRANSFER flip-flop A7a of Figure 9, via A15, to turn the TRANSFER function off.

Activating the START switch starts the clock, starts the counting, turns the transfer function on and lights the first lamp.

Depressing the START switch (Fig. 9) places a 1 level at the set input of flip-flop A7a and at the reset input of A7b. Thus, both flip-flops change state with pin 13 of A7b going low and pin 12, high. This high level at pin 12 which is transferred to the input pins of the control gates A8 turns both gates on allowing the data counting to begin. The 0 level at pin 13 is fed to the clock circuitry to start the clock and also to the input of the monostable A6 to light the first indicator lamp. The $\bar{Q}$ output of A7a going low (by depressing the START switch) produces a high level at the output (pin 4) of the TRANSFER control gate A8 which is fed to the data counting circuitry to turn the TRANSFER function on.

At the end of the first count period, a 1 level is produced by the timing control circuit ((09)) and fed to the reset input (pin 4) of flip-flop A7a to produce a 1 level at the

$\bar{Q}$ output (pin 2). This 1 level at the input of gate A8 (pin 6) places a 0 level at the output (pin 4) which turns the TRANSFER function off. The $\bar{Q}$ output of A7a is applied to the input of the monostable A6 to turn the second lamp on indicating the wait period. The (09) signal (1 level) at the set input of flip-flop A10 (Fig.10) produces a 0 level at pin 12 to turn the 9-minute delay timer on and produces a 1 level at pin 13 to turn the thoron subtract function off.

The nine-minute interval between the two radon count periods is produced by the BCD counter A1 and the two gates A14 of Figure 10. Initially, the RESET switch places a 1 level at the reset input A1-15. Both outputs are held low and counting is inhibited. The output of A14-10 (1 level) is fed back to the input of the control gate A14-13 to turn this gate on. At the end of the first radon count period, the (09) function is generated. This toggles A10 and places a 0 level at A1-15, allowing pulses to accumulate in the counter.

After 9 one-minute pulses, pins 11 and 14 go high which produces a 0 level at the output (pin 10). This 0 level is fed back to the control gate to inhibit further input pulses to the counter and is also fed to the monostable A6 to produce two output pulses. One pulse is sent to the reset input of the data counting registers and the other, to the lamp circuitry to light the third lamp indicating the start of the second count period.

At the end of the second count period, the timing control circuitry generates another positive signal (99) which is fed to the control gate A8-1 of Figure 9 to perform the same function as the STOP switch. A 0 level is also produced at the output of inverter A5-15 and routed to the alarm circuit of Figure 11 to produce an audible indication at the end of the radon counting period.

COUNTING CIRCUITRY

At the heart of the data counting circuitry is the General Instrument four-digit counter/display driver chip AY54007A. Each of the four chips used has two internal registers, a data register and a storage register. Also included is a multiplexer and a seven-segment decoder driver to display the contents of the storage register. The data is transferred from the data register to the storage register under control of the TRANSFER function. With the transfer input high, the contents of the data register will transfer to the storage register and with the input low, the storage register will remain unchanged. The RESET function resets to zero the data register only, unless the transfer input is high, at which time both registers will be cleared.

Two counter chips are tied together for each data channel by using the carry output of the first chip to feed the data input of the second. In this way each data channel can accumulate up to 100,000,000 - 1 counts.

The data pulses to the two data input chips, D2 and D4 of Figures 12a to 12d, are preconditioned by the two monostable multivibrators D8a and D8b.

The displays are Litronix type DL34M four-digit common-cathode driven by display driver chips, type 75492.

To provide a more even current drain on the batteries, an external digit select clock is provided (Fig. 13) to drive the displays for each channel on opposite cycles.

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2. Coté, P., Carson, D.W., Leclerc, A., Townsend, M.G., Tremblay, R.J. "Optimisation of Radon and Thoron Daughter Counting Procedures"; CANMET, Energy, Mines and Resources Canada; Lab Report MRP/MSL 78-201 (J); 1978.

APPENDIX 1

Calibration Procedure

Proper calibration of the instrument requires the adjustment of the discriminator levels by means of the potentiometers of Fig. 5, such that the counts from each of the daughter products (RaA, RaC' and ThC') are routed to the proper counting channel. To do this requires the use of a standard source and a multi-channel analyser (Canberra model 3100 or equivalent). The standard source used provides alpha counts from RaA and RaC'. This spectrum, available from the BNC output connector mounted on the front panel of the spectrometer, is displayed on the CRT screen of the analyser for comparison with the counts displayed on the spectrometer.

If using the Canberra analyser:

- Set the input level switch to HIGH ,
- Set the lower discriminator level (LLD) to 0.6 ,
- Set the upper discriminator level (ULD) fully clockwise ,
- Set the ADC OFFSET switch to 0 and the GAIN to 1024 ,
- Set the preset timer switch N to 6 and M to 1 and the COUNT/T_L/CURSOR switch to T_L ,
- Set the acquire switch (ACQ) to PHA and the ADD/SUB switch to ADD ,
- Turn the power switch on,and press the CLEAR DATA and CLEAR ROI switches to clear the CRT screen.

On CANALPH-3 remove the outer cover to expose the three discriminator potentiometers.

- Set the mode switch (SCA/GROSS) to GROSS,
- Set the first and second timer switches to 01,
- Turn power switch ON,
- Press STOP and RESET,
- Insert the standard source in the sample holder,
- Press the COLLECT switch on the analyser and the START switch on the spectrometer simultaneously.

Counts from the same decay products will now accumulate in both instruments for a one-minute period. Using the integration and region-of-interest facilities of the analyser, determine the number of counts produced by the standard. Repeat the counting procedure, adjusting potentiometer ① until that number appears in the A window of the spectrometer. Setting the lower discriminator in this way eliminates the low order noise.

By repeating the one-minute counting procedure, potentiometer ③ is adjusted until less than ten counts (approx. 5-6) appear in the C' window. This places the upper discriminator between the RaC' and ThC' peaks.

Now set the mode switch (SCA/GROSS) to SCA. Again with repeated one-minute counts, adjust potentiometer ② until the number of counts produced by RaA appears in the A display and the number of counts produced by RaC' appears in the C' display.

The instrument is now calibrated and ready for use. The counting efficiency of the sample holder/detector system was determined using a standard source (Amersham/Searle type AMR43) and calculated to be 27%.

APPENDIX 2

Power Supply/Charger

Three banks of rechargeable nickel-cadmium batteries supply the three voltages (+5, ±12) required for the instrument. The +5 volts is derived from a series of from 1.25 volt 2.2 ampere-hour batteries (Eveready type CH 2.2). The +12 volts is derived from two 12.5 volt 0.225 ampere-hour batteries (Eveready type Y5383) in parallel and the -12 volts, from four of the same type of batteries also in a parallel configuration. The extra current capability of the minus supply is provided due to the -12 volt requirement of the decade counter circuits. Access to the batteries is provided by two connectors. One connector behind the front panel allows easy disassembly of the instrument for modification or repairs and the other connector, mounted on the back of the instrument, under the removable cover, provides easy access for the charging circuit.

Since the operational amplifier circuitry requires well regulated supply voltages, the ±12 volts supplied by the batteries is regulated down to ±8 volts by the voltage regulator chips 7808 and 7908, respectively.

The battery charger (Fig. 14), supplied in a separate case,consists of three independent adjustable charging circuits. A selector switch on the front panel of the charger connects the current meter into each of the three circuits to provide a means of monitoring the charging rate. The three potentiometers are used to adjust the charging current of each of the three circuits. The normal 16-hour charging rate for the 5 volt battery circuit is 220 milliamperes. The charging rate for the +12 volt supply is 45 milliamperes and for the -12 volt circuit, is 90 milliamperes. Fully charged batteries will provide continuous operation of the instrument for an eight-hour period.

APPENDIX 3

Computer Analysis

```
                74/74    OPT=1                          FTN 4.6+446       31/07/79  09.49.17       PAGE     1

      PROGRAM RTSPEC (INPUT,OUTPUT,TAPE5=INPUT)
C
C
C
C    ********************************************************************
C    *                                                                  *
C    *                                                                  *
C    *   SPECTROMETRIC ANALYSIS                                         *
C    *                                                                  *
C    *                                                                  *
C    *   ANALYSIS OF THE DATA FROM THREE CHANNELS BY THE                *
C    *             SPECTROMETRIC METHOD                                 *
C    *                                                                  *
C    *                                                                  *
C    *   COUNTING SCHEME                                                *
C    *                                                                  *
C    *        CHANNEL 1           CHANNEL 2           CHANNEL 3         *
C    *          (RA A)             (RA C')             (TH C')          *
C    *                                                                  *
C    *          COUNT 1                                                 *
C    *                             COUNT 2                              *
C    *                             COUNT 3                              *
C    *                                                 COUNT 4          *
C    *                                                 COUNT 5          *
C    *                                                                  *
C    *                                                                  *
C    ********************************************************************
C
C
      IMPLICIT REAL (A-Z)
      INTEGER NOM(20),I,J,K,AI,CONT1(10)
      DIMENSION L(5),T(10),COUNT(10),E(5)
      COMMON/FILTRE/NFRA,NFRB,NFRC,NFTB,NFTC
      COMMON/LAMBDA/L
      DATA L/.2272,.02586,.03519,.001086,.01146/
      AI=4HSTOP
C
C
 100  READ(5,105)NOM
C
      IF(NOM(1).EQ.AI)      STOP
C
      READ(5,*) VOL, EVOL, TECH, G, EG
C
C             VOL = SAMPLING RATE IN LITERS/MIN
C            EVOL = % ERROR IN VOL
C            TECH = SAMPLING TIME IN MIN
C               G = SAMPLING EFFICIENCY
C              EG = % ERROR IN G
C
      READ(5,*)OL1,OL2,OL3,OL4
      READ(5,*)(T(2*I-1),T(2*I),CONT1(I),I=1,5)
C
      PRINT 121,NOM
      PRINT 122 ,VOL, EVOL, TECH, G, EG
      PRINT126,OL1,OL2,OL3,OL4
      PRINT 123
```

```
      PRINT 124,(T(2*I-1),T(2*I),CONT1(I),I=1,5)
  105 FORMAT (20A4)
  121 FORMAT("1"/ /" ",T40,"SPECTROMETRIC ANALYSIS "///" ",T20,
     + "SAMPLE :     ",T35,20A4//)
  122 FORMAT (" ",T10,"SAMPLING CHARACTERISTICS  "//
     1 " ",T20,"SAMPLING RATE                    ",T48,F8.2,"   @",F5.2,
     2 " %  LITERS/MINUTE "/" ",T20,"SAMPLING TIME"T50,F6.2
     3  T69"MINUTES"/T20 "COUNTING EFFICIENCY"T50,F6.2"   @"F5.2" %"/ )
  123 FORMAT(" "T10"COUNTS  (T IS THE TIME FROM START OF SAMPLING)"//T10
     + "T(START)",T22,"T(END)",T45,"CHANNEL(1)"T65"CHANNEL(2)"T85
     + "CHANNEL(3)"/T46"(RA A)"T66"(RA C')"T86"(TH C')"//)
  124 FORMAT (" ",T7,2F10.2,T45,I8  /2(" ",T7,2F10.2,T65,I8  /)
     + 2(" ",T7,2F10.2,T85,I8  /)/ /)
  125 FORMAT(" "10X"OVERLAP FACTORS"//15X"C1 IN C2"F9.3
     */15X"C2 IN C1"F9.3/,15X"C2 IN C3"F9.3/15X"C3 IN C2"F9.3//)
C
      DO 444 I=1,10
      COUNT(I)=CONT1(I)
  444 T(I)=T(I)-TECH
C
C
      TRA=0
      TRB=0
      TRC=0
      TTB=0
      TTC=0
      COUNT1=COUNT(1)
      COUNT2=COUNT(2)
      COUNT3=COUNT(3)
      COUNT4=COUNT(4)
      COUNT5=COUNT(5)
      J=0
  300 NFRA=COUNT(1)/(EXP(-L(1)*T(1))-EXP(-L(1)*T(2)))
      ENFRA=NFRA/COUNT(1)**0.5
      ECC2=EXP(-L(3)*T(3))-EXP(-L(3)*T(4))
      ECC3=EXP(-L(3)*T(5))-EXP(-L(3)*T(6))
      EBC2B=L(3)*(EXP(-L(2)*T(3))-EXP(-L(2)*T(4)))/(L(3)-L(2))
      EBC2C=L(2)*(EXP(-L(3)*T(3))-EXP(-L(3)*T(4)))/(L(2)-L(3))
      EBC2=EBC2B+EBC2C
      EBC3B=L(3)*(EXP(-L(2)*T(5))-EXP(-L(2)*T(6)))/(L(3)-L(2))
      EBC3C=L(2)*(EXP(-L(3)*T(5))-EXP(-L(3)*T(6)))/(L(2)-L(3))
      EBC3=EBC3B+EBC3C
C
      CA2=(EXP(-L(1)*T(3))-EXP(-L(1)*T(4)))/((L(2)-L(1))*(L(3)-L(1)) )
      CA2=CA2*L(2)*L(3)+EBC2B*L(1)/(L(1)-L(2))+EBC2C*L(1)/(L(1)-L(3))
      CA2=NFRA*CA2
      CA3=(EXP(-L(1)*T(5))-EXP(-L(1)*T(6)))/((L(2)-L(1))*(L(3)-L(1)))
      CA3=CA3*L(2)*L(3)+EBC3B*L(1)/(L(1)-L(2))+EBC3C*L(1)/(L(1)-L(3))
      CA3=NFRA*CA3
      C2=COUNT(2)-CA2
      C3=COUNT(3)-CA3
      EC2=(   COUNT(2)           +(CA2*ENFRA/NFRA)**2)**.5
      EC3=(   COUNT(3)           +(CA3*ENFRA/NFRA)**2)**.5
C
      NFRB=(C3-C2*ECC3/ECC2)/(EBC3-ECC3/ECC2*EBC2)
      NFRC=(C2-NFRB*EBC2)/ECC2
      ENFRB=(EC3*EC3+EC2*EC2*(ECC3/ECC2)**2)**.5
```

```
      ENFRB=ENFRB/(EBC3-EBC2*ECC3/ECC2)
      ENFRC=(EC2*EC2+(ENFRB*EBC2)**2)**.5/ECC2
C
      ECC4=EXP(-L(5)*T(7 ))-EXP(-L(5)*T(8))
      ECC5=EXP(-L(5)*T(9 ))-EXP(-L(5)*T(10))
      EBC4=(EXP(-L(4)*T(7))-EXP(-T(8)*L(4)))/(L(5)-L(4))*L(5)
      EBC4=(EXP(-L(5)*T(7))-EXP(-T(8)*L(5)))/(L(4)-L(5))*L(4)+EBC4
      EBC5=(EXP(-L(4)*T(9))-EXP(-T(10)*L(4)))/(L(5)-L(4))*L(5)
      EBC5=(EXP(-L(5)*T(9))-EXP(-T(10)*L(5)))/(L(4)-L(5))*L(4 )+EBC5
      NFTB=(COUNT(5)-COUNT(4)*ECC5/ECC4)/(EBC5-EBC4*ECC5/ECC4)/.64
      NFTC=(COUNT(4)/.64-NFTB*EBC4)/ECC4
      ENFTB=(   COUNT(5)+ECC5*ECC5/ECC4/ECC4*COUNT(4))**.5/.64
      ENFTB=ENFTB/(EBC5-ECC5/ECC4*EBC4)
      ENFTC=(   COUNT(4)/.64**2+(ENFTB*EBC4)**2)**.5/ECC4
C
C
C
      TESTA=ABS((NFRA-TRA) /NFRA    )
      TESTB=ABS((NFRB-TRB )/NFRB            )
      TESTC=ABS((NFRC-TRC)/NFRC            )
      TESTD=ABS((NFTB-TTB)/NFTB    )
      TESTE=ABS((NFTC-TTC)/NFTC      )
      TEST=TESTA+TESTB+TESTC+TESTD+TESTE
      IF (TEST.LT.0.001) GO TO 399
C
      J=J+1
C
      TRA=NFRA
      TRB=NFRB
      TRC=NFRC
      TTB=NFTB
      TTC=NFTC
      COUNT(1)=COUNT1*(1.0+OL1)-OLAPM(T(1).T(2))*OL2
      COUNT(2)=COUNT2*(1.0+OL2+OL3)-OLAPG(T(3),T(4))*OL1
      COUNT(2)=COUNT(2)-OLAPD(T(3),T(4))*(OL1*.36+OL4*.64)
      COUNT(3)=COUNT3*(1.0+OL2+OL3)-OLAPG(T(5),T(6))*OL1
      COUNT(3)=COUNT(3)-OLAPD(T(5).T(6))*(OL1*.36+OL4*.64)
      COUNT(4)=COUNT4*(1+OL4)-OLAPM(T(7).T(8))*OL3
      COUNT(5)=COUNT5*(1+OL4)-OLAPM(T(9),T(10))*OL3
      IF (COUNT(4).LT.0.0)   PRINT*,"*****OVER-LAP IS TOO LARGE***"
      IF (COUNT(4).LT.0.0) GO TO 399
C
      GO TO 300
C
  399 INTER=(EVOL/100)**2+(EG/100)**2
      ENFRA=((ENFRA/NFRA)**2+INTER)**.5*NFRA/VOL/G
      ENFRB=((ENFRB/NFRB)**2+INTER)**.5*NFRB/VOL/G
      ENFRC=((ENFRC/NFRC)**2+INTER)**.5*NFRC/VOL/G
      ENFTB=((ENFTB/NFTB)**2+INTER)**.5*NFTB/VOL/G
      ENFTC=((ENFTC/NFTC)**2+INTER)**.5*NFTC/VOL/G
      NFRA=NFRA/VOL/G
      NFRB=NFRB/VOL/G
      NFRC=NFRC/VOL/G
      NFTB=NFTB/VOL/G
      NFTC=NFTC/VOL/G
      DO 1001 I=1,5
 1001 E(I)=EXP(-L(I)*TECH)
```

```
      C
              NARA=NFRA*L(1)/(1-E(1))
              NARBB=L(2)/(1-E(2))
              NARBA=(1/NARBB)+(E(2)-E(1))/(L(2)-L(1))
              NARB=NARBB*(NFRB-NARA*NARBA)
              NARCC=L(3)/(1-E(3))
              NARCB=1/NARCC+(E(3)-E(2))/(L(3)-L(2))
              NARCA=NARCB+L(2)*(E(3)-E(2))/(L(3)-L(2))/(L(1)-L(2))
              NARCA=NARCA+L(2)*(E(3)-E(1))/(L(2)-L(1))/(L(3)-L(1))
              NARC=NARCC*(NFRC-NARB*NARCB-NARA*NARCA)
              NATB=NFTB*L(4)/(1-E(4))
              NATCC=L(5)/(1-E(5))
              NATCB=1/NATCC+(E(5)-E(4))/(L(5)-L(4))
              NATC=NATCC*(NFTC-NATB*NATCB)
              ENARA=ENFRA*NARA/NFRA
              ENARB=(ENFRB*ENFRB+(ENARA*NARBA)**2)**.5*NARBB
              ENARC=(ENFRC*ENFRC+(ENARB*NARCB)**2+(ENARA*NARCA)**2)**.5*NARCC
              ENATB=ENFTB*NATB/NFTB
              ENATC=(ENFTC*ENFTC+(ENATB*NATCB)**2)**.5*NATCC
      C
              DARA=NARA*L(1)/2.22
              DARB=NARB*L(2)/2.22
              DARC=NARC*L(3)/2.22
              DATB=NATB*L(4)/2.22
              DATC=NATC*L(5)/2.22
              ARRA=1.0
              ARRB=DARB/DARA
              ARRC=DARC/DARA
              ARTB=1.0
              ARTC=DATC/DATB
              WLR=(NARA*13.69+NARB*7.69+NARC*7.69)/(1.3*100000)
              WLT=7.8*(NATB+NATC)/(1.3*100000)
              EWLT=(ENATB*ENATB+ENATC*ENATC)**.5*7.80/(1.3*100000)
              EWLR=(ENARA*ENARA*13.69*13.69+7.69*7.69*(ENARB*ENARB+ENARC*ENARC))
              EWLR=EWLR**.5/(1.3*100000)
              ENARA=ENARA/NARA *100.0
              ENARB=ENARB/NARB *100.0
              ENARC=ENARC/NARC*100.0
              ENATB=ENATB/NATB*100.0
              ENATC=ENATC/NATC*100.0
              EWLR=EWLR/WLR*100.0
              EWLT=EWLT/WLT*100.0
      C
              PRINT224,J
              PRINT 221
              RAA=4HRA-A
              RAB=4HRA-B
              RAC=4HRA-C
              THB=4HTH-B
              THC=4HTH-C
              PRINT222,RAA,NARA,DARA,ENARA,ARRA
              PRINT222,RAB,NARB,DARB,ENARB,ARRB
              PRINT222,RAC,NARC,DARC,ENARC,ARRC
              IF(CONTI(4).LT.11)  GO TO 200
              PRINT222,THB,NATB,DATB,ENATB,ARTB
              PRINT222,THC,NATC,DATC,ENATC,ARTC
              PRINT223,WLR,EWLR,WLT,EWLT,WLR+WLT
```

```
              GO TO 211
        200   PRINT 223,WLR,EWLR .
        211   CONTINUE
         221  FORMAT(" "///
             +T5"DAUGHTER ",T20,"CONCENTRATION",T43,"ACTIVITY",T61,"ERROR  ",
             + T80,"RELATIVE          "/" ",T20,"(ATOMS/LITER)",T44,"(PCI/L)  "
             + T61"(IN %)"T80"ACTIVITY"//)
         222  FORMAT(" ",T5,A4,T20,F10.2,T40,F10.4,T60,F6.2,T80,F6.3)
         223  FORMAT (" "///T20"WORKING LEVEL"T36
             +,F6.3," @",F6.2," %  RADON" /" ",T36,F6.3," @",
             + F6.2," %  THORON"/" ",T35,"---------"/" ",T20
             + "TOTAL ",T36,F6.3)
         224  FORMAT(10X"SAMPLES WITH OVERLAP ARE CALCULATED USING THE SUCCESSIV
             *E APPROXIMATION METHOD."/11X"THERE WERE"I3" PASSES TO ACHIEVE AN E
             *RROR OF LESS THAN 0.1 %"//)
              GO TO 100
              END
```

```
      FUNCTION OLAPG(TO,TF)
      IMPLICIT REAL(A-Z)
      COMMON/LAMBDA/   LRA,LRB,LRC,LTB,LTC
      COMMON/FILTRE/RA,RB,RC,TB,TC
      OLAPG=RA*(EXP(-LRA*TO)-EXP(-LRA*TF))
      RETURN
      END
```

```
FUNCTION OLAPM      74/74   OPT=1                        FTN 4.6+446        31/07/79  09.49.17         PAGE      1

      FUNCTION OLAPM(TO,TF)
      IMPLICIT REAL(A-Z)
      COMMON/LAMBDA/   LRA,LRB,LRC,LTB,LTC
      COMMON/FILTRE/RA,RB,RC,TB,TC
      EA=EXP(-LRA*TO)-EXP(-LRA*TF)
      EB=EXP(-LRB*TO)-EXP(-LRB*TF)
      EC=EXP(-LRC*TO)-EXP(-LRC*TF)
      NFC=RC*EC
      NFB=RB*(EB/(LRC-LRB)*LRC+EC/(LRB-LRC)*LRB)
      EA=EA*LRB*LRC/((LRB-LRA)*(LRC-LRA))
      EB=EB*LRA*LRC/((LRA-LRB)*(LRC-LRB))
      EC=EC*LRA*LRB/((LRA-LRC)*(LRB-LRC))
      NFA=RA*(EA+EB+EC)
      OLAPM=NFC+NFB+NFA
      RETURN
      END
```

```
      FUNCTION OLAPD(TO,TF)
      IMPLICIT REAL(A-Z)
      COMMON/LAMBDA/   LRA,LRB,LRC,LTB,LTC
      COMMON/FILTRE/RA,RB,RC,TB,TC
      EB=EXP(-LTB*TO)-EXP(-LTB*TF)
      EC=EXP(-LTC*TO)-EXP(-LTC*TF)
      OLAPD=TC*EC+TB*(EB/(LTC-LTB)*LTC+EC/(LTB-LTC)*LTB)
      RETURN
      END
```

```
                              SPECTROMETRIC ANALYSIS

          SAMPLE :              TEST ROOM  18/05/79

   SAMPLING CHARACTERISTICS

          SAMPLING RATE                    11.00   @10.00 %  LITERS/MINUTE
          SAMPLING TIME                    10.00             MINUTES
          COUNTING EFFICIENCY                .27   @ 2.00 %

    OVERLAP FACTORS

        C1 IN C2     0.000
        C2 IN C1     0.000
        C2 IN C3     0.000
        C3 IN C2     0.000

   COUNTS  (T IS THE TIME FROM START OF SAMPLING)

   T(START)    T(END)                  CHANNEL(1)         CHANNEL(2)         CHANNEL(3)
                                        (RA A)             (RA C')            (TH C')

    11.00       20.00                     997
    11.00       20.00                                         897
    40.00       70.00                                        2373
    11.00       20.00                                                              50
    40.00       70.00                                                             238

   SAMPLES WITH OVERLAP ARE CALCULATED USING THE SUCCESSIVE APPROXIMATION METHOD.
    THERE WERE  1 PASSES TO ACHIEVE AN ERROR OF LESS THAN 0.1 %

DAUGHTER       CONCENTRATION          ACTIVITY          ERROR             RELATIVE
               (ATOMS/LITER)           (PCI/L)          (IN %)            ACTIVITY

RA-A               122.59             12.5463           10.68               1.000
RA-B                85.24               .9930           23.47                .079
RA-C                90.90              1.4410           13.60                .115
TH-B               609.14               .2980           19.30               1.000
TH-C                21.47               .1108           22.70                .372

               WORKING LEVEL       .023 @  8.39 %  RADON
                                   .038 @ 18.66 %  THORON
                                 --------
               TOTAL               .061
```

```
      PROGRAM KUS (INPUT,OUTPUT)
*
*        CALCULATION OF THE WORKING LEVEL BY
*        THE KUSNETZ METHOD. USES SUBROUTINES KMEK,
*        KMEL, DNABC, SCOOP AND GEN.
*
*        INPUT TOTAL COUNTS FROM 2 OR 3
*        ACCURACY WILL BE DEGRADED.
*        COUNT PERIODS. IF 2 COUNT PERIODS USED
*
*         COUNT 1  RADON
*         COUNT 2         RADON + THORON
*         COUNT 3                          THORON ONLY
*
*
      IMPLICIT REAL (A-Z)
      INTEGER I, AI, NOM(20)
C
      COMMON/CKMEK/KMEL,DKMEL,KRAD,DKRAD,KTHO,DKTHO
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
C
      DATA LAN,LAA,LAB,LAC/.001,.002,.003,.004/
      DATA LRN,LRA,LRB,LRC/.00012589,.2272,.02586,.03519/
      DATA LTN,LTA,LTB,LTC/.7629,263.165,.001086,.01146/
      AI=4HSTOP
C
C
1     READ 100, NOM
*
      IF(NOM(1).EQ.AI)  STOP
*
      READ*, TECH, V, EV, G, EG
*
*
*        TECH = SAMPLING TIME IN MIN
*           V = SAMPLING RATE IN LITERS/MIN
*          EV = % ERROR IN V
*           G = COUNTING EFFICIENCY
*          EG = % ERROR IN G
*
*
*     READ THE COUNTS. TS, TE ARE THE
*     TIMES FROM THE START OF SAMPLING.
*
      READ*,TS1,TE1,CONTE1
      READ*,TS2,TE2,CONTE2
      READ*,TS3,TE3,CONTE3
C
      TO1=TS1-TECH
      TF1=TE1-TECH
      TO2=TS2-TECH
      TF2=TE2-TECH
      TO3=TS3-TECH
      TF3=TE3-TECH
*
*
```

```
      PRINT110,NOM
 100  FORMAT(20A4)
  110 FORMAT("1"," ",T30,"KUSNETZ ANALYSIS   "//"  SAMPLE :    ",20A4//)
      PRINT 122, V, EV, TECH, G, EG
  122 FORMAT (" ",T10,"SAMPLING CHARACTERISTICS  "//
     1 " ",T20,"SAMPLING RATE                    ",T48,F8.2,"   @",F5.2,
     2 " %  LITERS/MINUTE "/" ",T20,"SAMPLING TIME"T50,F6.2
     3  T69"MINUTES"/T20 "COUNTING EFFICIENCY"T50,F6.2"   @"F5.2" %"/ )
*
      PRINT 113
*
 113  FORMAT(10X"COUNTS  (TO AND TF ARE THE COUNTS FROM THE START OF SAM
     *PLING)"//)
*
      PRINT114,TS1,TE1,CONTE1
     +         ,TS2,TE2,CONTE2
     +         ,TS3,TE3,CONTE3
  114 FORMAT("  COUNT(1):"/" ",T22,"TO = ",F9.2," MIN"/" ",T22,"TF = ",
     + F9.2," MIN"/
     + " ", T18," COUNT = ",F8.1//
     +      "  COUNT(2):"/" ",T23,"TO= ",F9.2/" ",T23,"TF= ",F9.2/
     + " ", T18," COUNT = ",F8.1//
     +      "  COUNT(3):"/" ",T23,"TO= ",F9.2/" ",T23,"TF= ",F9.2/
     + " ", T18," COUNT = ",F8.1// )
C
C     IL FAUT RAMENER LE COMPTE A 1 LITRE, EFFFICACITE=1
C
      IF ( TF1.NE.TO1 )
     +CONTE1=CONTE1/TECH/(TF1-TO1)/V/G
      IF ( TF2.NE.TO2 )
     +CONTE2=CONTE2/TECH/(TF2-TO2)/V/G
      IF ( TF3.NE.TO3 )
     +CONTE3=CONTE3/TECH/(TF3-TO3)/V/G
      I=0
      TEST=-55.0
      DRST=1.0
      WLRAD=0.
          WLTHO=0.
      IF  (CONTE1.LE.0.) GO TO 3000
      IF (CONTE2.LE.0.) GO TO 2000
      IF (CONTE3.LE.0.) GO TO 1111
C
C
C      ON FAIT LE CAS A 33333333 (TROIS   )   COMPTES
C
C
      CALL KMEK(DRST,TECH,TO2,TF2-TO2)
      EKMEL=DKMEL
      KTOTAL=KMEL
      WLMEL=CONTE2/KMEL
      DWLMEL=EKMEL+EV+EG+100.0/SQRT(CONTE2*V*G*TECH*(TF2-TO2) )
      CALL KMEK(DRST,TECH,TO1,TF1-TO1)
      EKRAD=DKRAD
      KRADON=KRAD
      KCIT=KTHO
      WLRAD=(CONTE1-WLTHO*KTHO)/KRAD
      DWLRAD=EKRAD+EV+EG+100.0/SQRT(CONTE1*TECH*(TF1-TO1)*V*G)
```

```
      CALL KMEK (DRST,TECH,T03,TF3-T03)
      EKTHO=DKTHO
      KTHORO=KTHO
      KC3R=KRAD
      CONTE3=CONTE3-KRAD*WLRAD
      WLTHO=CONTE3/KTHO
      DWLTHO=EKTHO+EV+EG+100.0/SQRT(CONTE3*TECH*(TF3-T03)*V*G)
      GO TO 300
C
C
C     POUR LE CAS RADON   RADON-THORON
C
C
C     CALCUL DU W.L. TOTAL
 1111 CALL KMEK(DRST,TECH,T02,TF2-T02)
      EKMEL=DKMEL
      KTOTAL=KMEL
      WLMEL=CONTE2/KMEL
C     CALCUL DU W.L. RADON
      CALL KMEK(DRST,TECH,T01,TF1-T01)
      EKRAD=DKRAD
      KRADON=KRAD
      WLRAD=(CONTE1-WLTHO*KTHO)/KRAD
C     CALCUL DU W.L. THORON
      WLTHO=WLMEL-WLRAD
      DRST=WLRAD/WLTHO
      IF(DRST.LE.0.0) DRST=1.0
C     IL FAUT INCLURE CE LOOP POUR OBTENIR LE BON FACTEUR DE KUSNETZ TOTAL
      DWLRAD=EKRAD+EV+EG+100.0/SQRT(CONTE1*TECH*(TF1-T01)*V*G)
      DWLMEL=EKMEL+EV+EG+100.0/SQRT(CONTE2*V*G*TECH*(TF2-T02) )
      DWLTHO=(DWLRAD*WLRAD+DWLMEL*WLMEL)/WLTHO
      KTHORO=0.
      EKTHO=0.
      IF(ABS((TEST-WLTHO)/WLTHO).LT..001) GO TO 1112
      TEST=WLTHO
      I=I+1
      IF(I.GT.5) GO TO 1112
      GO TO 1111
C
C
C     POUR LE CAS RADON     THORON
C
C
 2000 CALL KMEK (DRST,TECH,T01,TF1-T01)
      KTOTAL=0.
      EKMEL=0.
      EKRAD=DKRAD
      KRADON=KRAD
      WLRAD=(CONTE1-WLTHO*KTHO)/KRAD
      DWLRAD=EKRAD+EV+EG+100.0/SQRT(CONTE1*TECH*(TF1-T01)*V*G)
      CALL KMEK (DRST,TECH,T03,TF3-T03)
      EKTHO=DKTHO
      KTHORO=KTHO
      CONTE3=CONTE3-KRAD*WLRAD
      WLTHO=CONTE3/KTHO
      DWLTHO=EKTHO+EV+EG+100.0/SQRT(CONTE3*TECH*(TF3-T03)*V*G)
      WLMEL=WLRAD+WLTHO
```

```
      DWLMEL=(DWLRAD*WLRAD+DWLTHO*WLTHO)/WLMEL
      GO TO1112
C
C
C
C
C
C      CAS        RADON-THORON      THORON
C
C
 3000 CALL KMEK (DRST,TECH,T02,TF2-T02)
      EKMEL=DKMEL
      KTOTAL=KMEL
      WLMEL=CONTE2/KMEL
      CALL KMEK (DRST,TECH,T03,TF3-T03)
      EKTHO=DKTHO
      KTHORO=KTHO
      WLTHO = (CONTE3-KRAD*WLRAD) / KTHORO
      WLRAD=WLMEL-WLTHO
      KRADON=0.
      EKRAD=0.
      DRST=WLRAD/WLTHO
      DWLMEL=EKMEL+EV+EG+100.0/SQRT(CONTE2*V*G*TECH*(TF2-T02) )
      DWLTHO=EKTHO+EV+EG+100.0/SQRT(CONTE3*TECH*(TF3-T03)*V*G)
      DWLRAD=(DWLTHO*WLTHO+DWLMEL*WLMEL)/WLRAD
      IF (DRST.LT.0.) DRST=1.0
      IF ( ABS( (TEST-WLRAD)/WLRAD).LT.0.001 ) GO TO 1112
      TEST =WLRAD
      I=I+1
      IF (I.GT.5 ) GO TO 1112
      GO TO 3000
C
C
C     ON IMPRIME FINALEMENT LE RESULTAT.
C
C
 1112 PRINT*," RESULTS  : "
 300  CONTINUE
*
C
      PRINT302,KRADON,EKRAD,KTHORO,EKTHO,KTOTAL,EKMEL
 302  FORMAT(//" THE KUSNETZ FACTORS USED WERE:"//
     + " K(RADON)= ",F7.2," @ ",F5.2," % "/
     + " K(THOR.)= ",F7.2," @ ",F5.2," % "/
     + " K(TOTAL)= ",F7.2," @ ",F5.2," % "/    //  /)
      PRINT210,WLRAD,DWLRAD,WLTHO,DWLTHO,WLMEL,DWLMEL
  210 FORMAT(" ",T20,"W.L.(RADON ) = ",F6.4," @ ",F4.1," %"/ /
     + " ",T15,"    +"/
     +        " ",T20,"W.L.(THORON) = ",F6.4," @ ",F4.1," %"/
     +  " ",T20,"-------------------------"/
     + /      " ",T20,"W.L.(TOTAL ) - ",F6.4," @ ",F4.1," %"/  )
      GO TO 1
      END
```

```
      SUBROUTINE KMEK (DRST,TECH,TATT,TMES)
      IMPLICIT REAL (A-Z)
      INTEGER I,J
      COMMON/CKMEL/KR,KT,KA,KM
      COMMON/CKMEK/KMOY,DK,KRAD,DKR,KTHO,DKT
      KMIN=1000.0
      KMAX=-55.0
      KRMIN=1000.0
      KRMAX=-55.0
      KTMIN=1000.0
      KTMAX=-55.0
      DO 999 I=1,100
      MAT=FLOAT(I*10)-9
      CALL KMELC(0.0,DRST*200.0,0.0,1.0,MAT,TECH,TATT,TMES)
      IF(KM.GT.KMAX) KMAX=KM
      IF(KM.LT.KMIN) KMIN=KM
      IF(KR.GT.KRMAX) KRMAX=KR
      IF(KR.LT.KRMIN) KRMIN=KR
      IF(KT.GT.KTMAX) KTMAX=KT
      IF(KT.LT.KTMIN) KTMIN=KT
  999 CONTINUE
      KMOY=(KMIN+KMAX)/2.0
      DK=(KMAX-KMOY)/KMOY*100.0
      KRAD=(KRMAX+KRMIN)/2.0
      KTHO=(KTMIN+KTMAX)/2.0
      DKR=(KRMAX-KRAD)*100.0/KRAD
      DKT=(KTMAX-KTHO)*100.0/KTHO
      RETURN
      END
```

```
      SUBROUTINE SCOOPR(NA,NB,NC,T,V,G)
      IMPLICIT REAL(A-Z)
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/LAMACT/LAN,LAA,LAB,LAC
      COMMON/CSCOOP/A,B,C
      LA=LRA
      LB=LRB
      LC=LRC
      GO TO 1
      ENTRY SCOOPT
      LA=LTA
      LB=LTB
      LC=LTC
      GO TO 1
      ENTRY SCOOPA
      LA=LAA
      LB=LAB
      LC=LAC
      GO TO 1
    1 EA=0.0
      IF((LA*T).LT.200) EA=EXP(-LA*T)
      EB=EXP(-LB*T)
      EC=EXP(-LC*T)
      A=V*G/LA*(1.0-EA)*NA
      B=V*G*NA*((1.0-EB)/LB+(EB-EA)/(LB-LA))+V*G*NB*(1.0-EB)/LB
      C=(EC-EB)/((LC-LB)*(LB-LA))-(EC-EA)/((LC-LA)*(LB-LA))
      C=-LB*C+(EC-EB)/(LC-LB)+(1.0-EC)/LC
      C=C*V*G*NA+V*G*NB*((1.0-EC)/LC+(EC-EB)/(LC-LB))+V*G*NC*(1.0-EC)/LC
      RETURN
      END
```

```
      FUNCTION GENCR1(NO,TO,TF)
      IMPLICIT REAL (A-Z)
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/LAMACT/LAN,LAA,LAB,LAC
      LA=LRA
      GO TO 1
      ENTRY GENCT1
      LA=LTB
      GO TO 1
      ENTRY GENCA1
      LA=LAB
      GO TO 1
    1 EO=0.0
      IF(LA*TO.LT.100.) EO=EXP(-LA*TO)
      EF=0.0
      IF(LA*TF.LT.100.) EF=EXP(-LA*TF)
      GENCR1=NO*(EO-EF)
      RETURN
      END
```

```
FUNCTION GENCR2     74/74    OPT=1                  FTN 4.6+446        31/07/79  14.40.28        PAGE     1

      FUNCTION GENCR2(B,C,TO,TF)
      IMPLICIT REAL (A-Z).
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/LAMACT/LAN,LAA,LAB,LAC
      LB=LRA
      LC=LRB
      GO TO 1
      ENTRY GENBT2
      LB=LTA
      LC=LTB
      GO TO 1
      ENTRY GENCT2
      LB=LTB
      LC=LTC
      GO TO 1
      ENTRY GENCA2
      LB=LAB
      LC=LAC
    1 EB=EXP(-LB*TO)-EXP(-LB*TF)
      EC=EXP(-LC*TO)-EXP(-LC*TF)
      GENCR2=C*EC+B*(EB/(LC-LB)*LC+EC/(LB-LC)*LB)
      RETURN
      END
```

```
      FUNCTION GENCR3(RA,RB,RC,TO,TF)
      IMPLICIT REAL (A-Z)
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/LAMACT/LAN,LAA,LAB,LAC
      LA=LRA
      LB=LRB
      LC=LRC
      GO TO 1
      ENTRY GENCT3
      LA=LTA
      LB=LTB
      LC=LTC
      GO TO 1
    1 EA=EXP(-LA *TO)-EXP(-LA *TF)
      EB=EXP(-LB *TO)-EXP(- LB*TF)
      EC=EXP(- LC*TO)-EXP(- LC*TF)
      NFC=RC*EC
      NFB=RB*(EB/( LC- LB)* LC+EC/( LB- LC)* LB)
      EA=EA* LB*LC /(( LB- LA)*( LC- LA))
      EB=EB* LA* LC/(( LA- LB)*( LC- LB))
      EC=EC* LA* LB/(( LA- LC)*( LB- LC))
      NFA=RA*(EA+EB+EC)
      GENCR3=NFA+NFB+NFC
      RETURN
      END
```

```
      SUBROUTINE KMELC(NR,DR,NT,DT,TMAT,TECH,TATT,TMES)
      IMPLICIT REAL (A-Z)
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/CCOUNT/COUNTR,COUNTT,COUNTM
      COMMON/CSCOOP/SA,SB,SC
      COMMON/CDNABC/DN,DA,DB,DC
      COMMON/WLEVEL/WLR,WLT,WLA,WLM
      COMMON /CKMEL/KR,KT,KA,KM
      V=1.0
      G=1.0
      CALL DNABCR(NR,DR,TMAT)
      CALL SCOOPR (DA,DB,DC,TECH,V,G         )
      SA=SA/TECH
      SB=SB/TECH
      SC=SC/TECH
      WLR=DA*13.69+DB*7.69+DC*7.69
      WLR=WLR/(1.3*100000.0)
      COUNTR=GENCR1(SA,TATT,TATT+TMES)/TMES+GENCR3(SA,SB,SC,TATT,TATT+
     + TMES)      /TMES
      CALL DNABCT (  NT,DT,TMAT)
      CALL SCOOPT (DA,DB,DC,TECH,V,G)
      SA=SA/TECH
      SB=SB/TECH
      SC=SC/TECH
      WLT=DA*14.58+DB*7.8+DC*7.8
      WLT=WLT/(1.3*100000.0)
      COUNTT=GENCT2(SB,SC,TATT,TATT+TMES)/TMES
      WLA=0.0
      COUNTA=0.0
      KA=-55.0
      KR=-55.0
      KT=-55.0
      IF(WLT.NE.0.0) KT=COUNTT/WLT
      IF(WLR.NE.0.0) KR=COUNTR/WLR
      IF(WLA.NE.0.0) KA=COUNTA/WLA
      RST=(NR+DR)/(NT+DT)/200.0
      KM=(COUNTT+COUNTR+COUNTA)/(WLR+WLT+WLA)
      WLM=WLR+WLT+WLA
      COUNTM=COUNTR+COUNTT
      RETURN
      END
```

```
      SUBROUTINE DNABCR (NO,D,T)
C
      IMPLICIT REAL (A-Z)
      COMMON/CDNABC/NN,NA,NB,NC
      COMMON/LAMRAD/LRN,LRA,LRB,LRC
      COMMON/LAMTHO/LTN,LTA,LTB,LTC
      COMMON/LAMACT/LAN,LAA,LAB,LAC
      LN=LRN
      LA=LRA
      LB=LRB
      LC=LRC
      GO TO 902
      ENTRY DNABCT
      LN=LTN
      LA=LTA
      LB=LTB
      LC=LTC
      GO TO 902
      ENTRY DNABCA
      LN=LAN
      LA=LAA
      LB=LAB
      LC=LAC
      GO TO 902
C
  902 EN=0
      IF((LN*T).LT.100) EN=EXP(-LN*T)
      EA=0.
      IF ((LA*T).LT.100.) EA=EXP(-LA*T)
      EB=EXP(-LB*T)
      EC=EXP(-LC*T)
C
      NN=D*(1-EN)/LN+NO*EN
C
      NA=D*(1-LA*EN/(LA-LN)-LN*EA/(LN-LA))/LA+LN*NO*(EN-EA)/(LA-LN)
C
      NBN=EN/((LA-LN)*(LB-LN))
      NBA=EA/((LN-LA)*(LB-LA))
      NBB=EB/((LN-LB)*(LA-LB))
      NBNN=NBN*LA*LB
      NBAA=NBA*LN*LB
      NBBB=NBB*LN*LA
      NB=D*(1-NBNN-NBAA-NBBB)/LB+LA*LN*NO*(NBN+NBA+NBB)
C
      NCCC=1-EC
      NCN=(EN-EC)/((LA-LN)*(LB-LN)*(LC-LN))
      NCA=(EA-EC)/((LN-LA)*(LB-LA)*(LC-LA))
      NCB=(EB-EC)/((LN-LB)*(LA-LB)*(LC-LB))
      NCNN=NCN*LA*LB*LC
      NCAA=NCA*LN*LB*LC
      NCBB=NCB*LN*LA*LC
      NC=D*(NCCC-NCNN-NCAA-NCBB)/LC+LB*LA*LN*NO*(NCN+NCA+NCB)
C
      RETURN
      END
```

```
                         KUSNETZ ANALYSIS

  SAMPLE :          TEST ROOM  18/05/79

        SAMPLING CHARACTERISTICS

              SAMPLING RATE                 11.00   ±10.00 %  LITERS/MINUTE
              SAMPLING TIME                 10.00             MINUTES
              COUNTING EFFICIENCY             .27   ± 2.00 %

         COUNTS  (TO AND TF ARE THE COUNTS FROM THE START OF SAMPLING)


  COUNT(1):
                    TO =     11.00 MIN
                    TF =     26.00 MIN
                 COUNT =   3093.0

  COUNT(2):
                    TO=    165.00
                    TF=    180.00
                 COUNT =   507.0

  COUNT(3):
                    TO=    245.00
                    TF=    260.00
                 COUNT =   356.0



 THE KUSNETZ FACTORS USED WERE:

 K(RADON)=  221.67 ±  9.68 %
 K(THOR.)=   13.98 ±   .78 %
 K(TOTAL)=   12.83 ±  6.85 %



              W.L.(RADON ) =  .0313 ± 23.5 %

              W.L.(THORON) =  .0534 ± 18.3 %
              --------------------------

              W.L.(TOTAL ) =  .0887 ± 23.3 %
```

APPENDIX 4

Results and Discussion

The optimum counting scheme for the determination of the working levels of both radon and thoron by the spectrometric method is illustrated as follows:

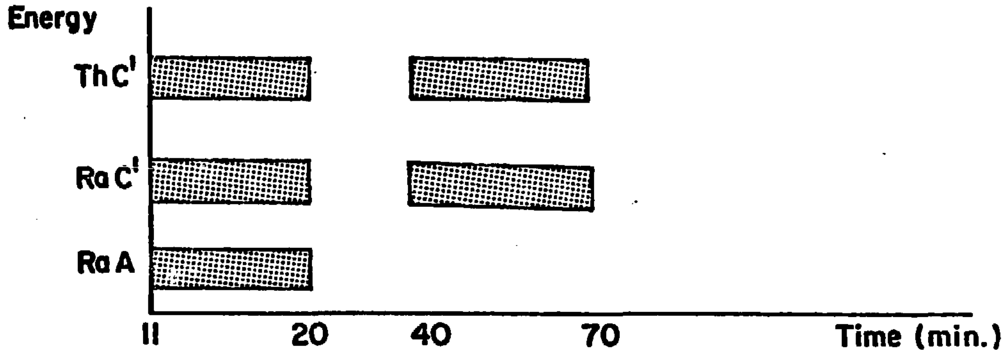


Figure 3. Optimum Counting Scheme, Spectrometric Method

The optimum counting scheme for the modified Kusnetz method is illustrated below:

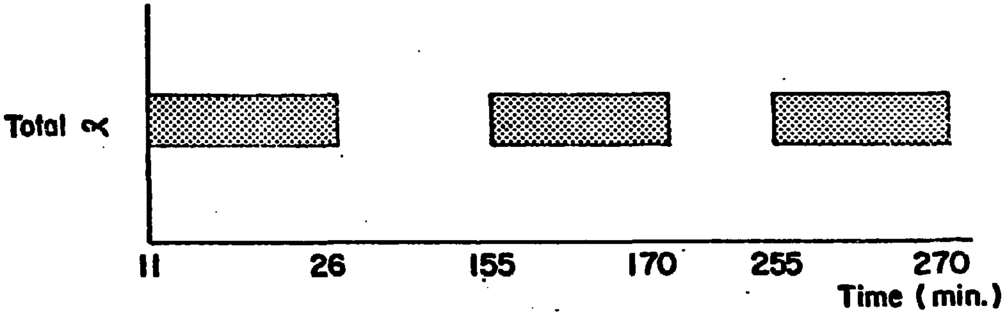


Figure 4. Optimum Counting Scheme, Kusnetz Method

In both cases the times indicated are from the start of sampling.

A number of air samples were taken in a radioactive ore storage room of the Geological Survey of Canada. The working levels of radon and thoron were determined by both the alpha spectrometric and modified Kusnetz methods on each of the filters using the optimum counting procedures. The results are presented in Table 1.

Since the optimum counting scheme for the spectrometric method requires overlapping count periods for both radon and thoron daughters, a third major modification of the instrument was required.

Along with flexible count periods and sampling and counting systems housed in the same case, the new instrument* (CANALPH-3A) will contain circuitry to output the values of the working levels of both radon and thoron from either method (alpha-spectrometric or Kusnetz). This will eliminate the need for external computer analysis.

---

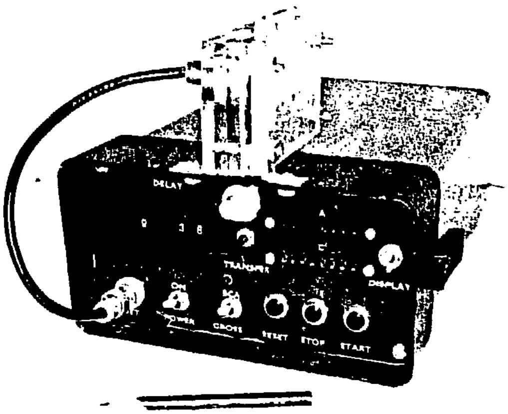
*This new instrument (CANALPH-3A) will be developed, on contract, by a private firm.

TABLE 3

Results from Radioactive Ore Storage Room (G48-A)
Geological Survey of Canada

SAMPLE	WORKING LEVEL					
	SPECTROSCOPY			KUSNETZ		
	Radon	Thoron	Total	Radon	Thoron	Total
15/5/79(1)	0.030	0.041	0.071	--	--	--
15/5/79(2)	0.030	0.039	0.069	--	--	--
15/5/79(3)	0.032	0.037	0.069	--	--	--
18/5/79	0.023	0.038	0.061	0.031	0.053	0.088
23/5/79	0.027	0.049	0.076	0.031	0.051	0.081
24/5/79	0.027	0.040	0.066	0.031	0.048	0.081
29/5/79	0.027	0.049	0.077	0.032	0.052	0.081

PHOTOGRAPH 1
Overall View of CANALPH-3



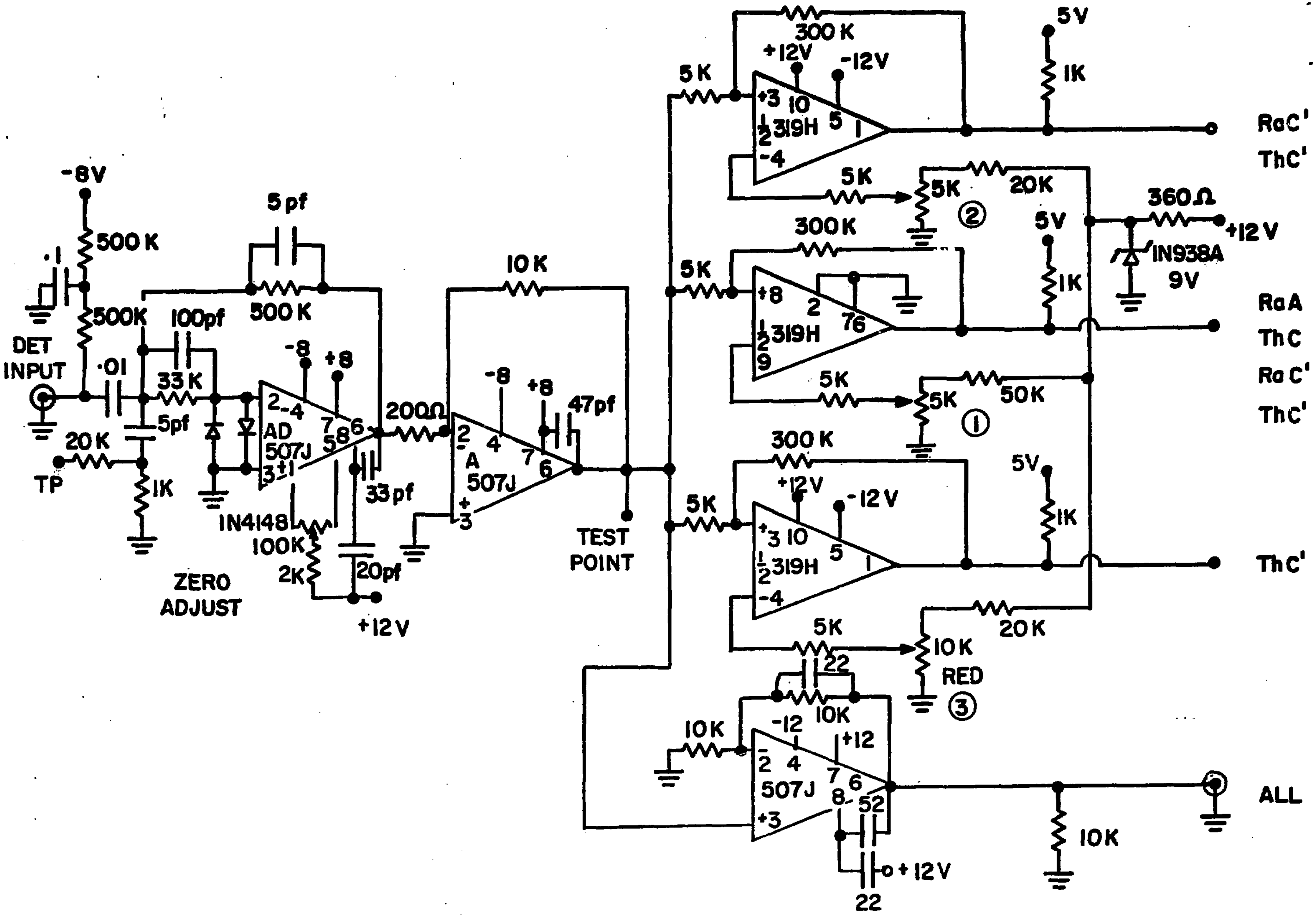


Figure 5. Detector/Amplifier and Discriminator Circuitry

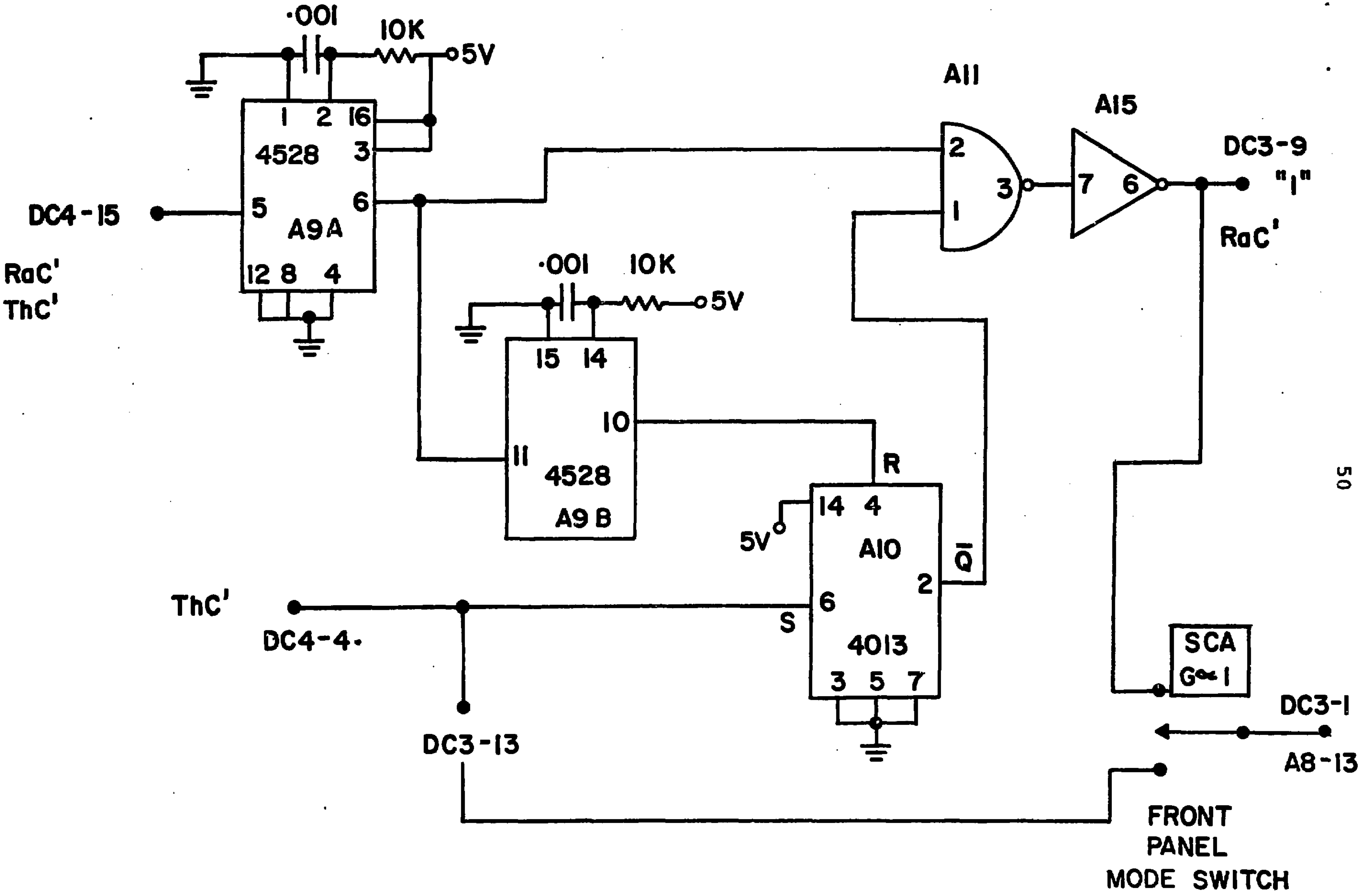


Figure 6a. Subtract Circuitry

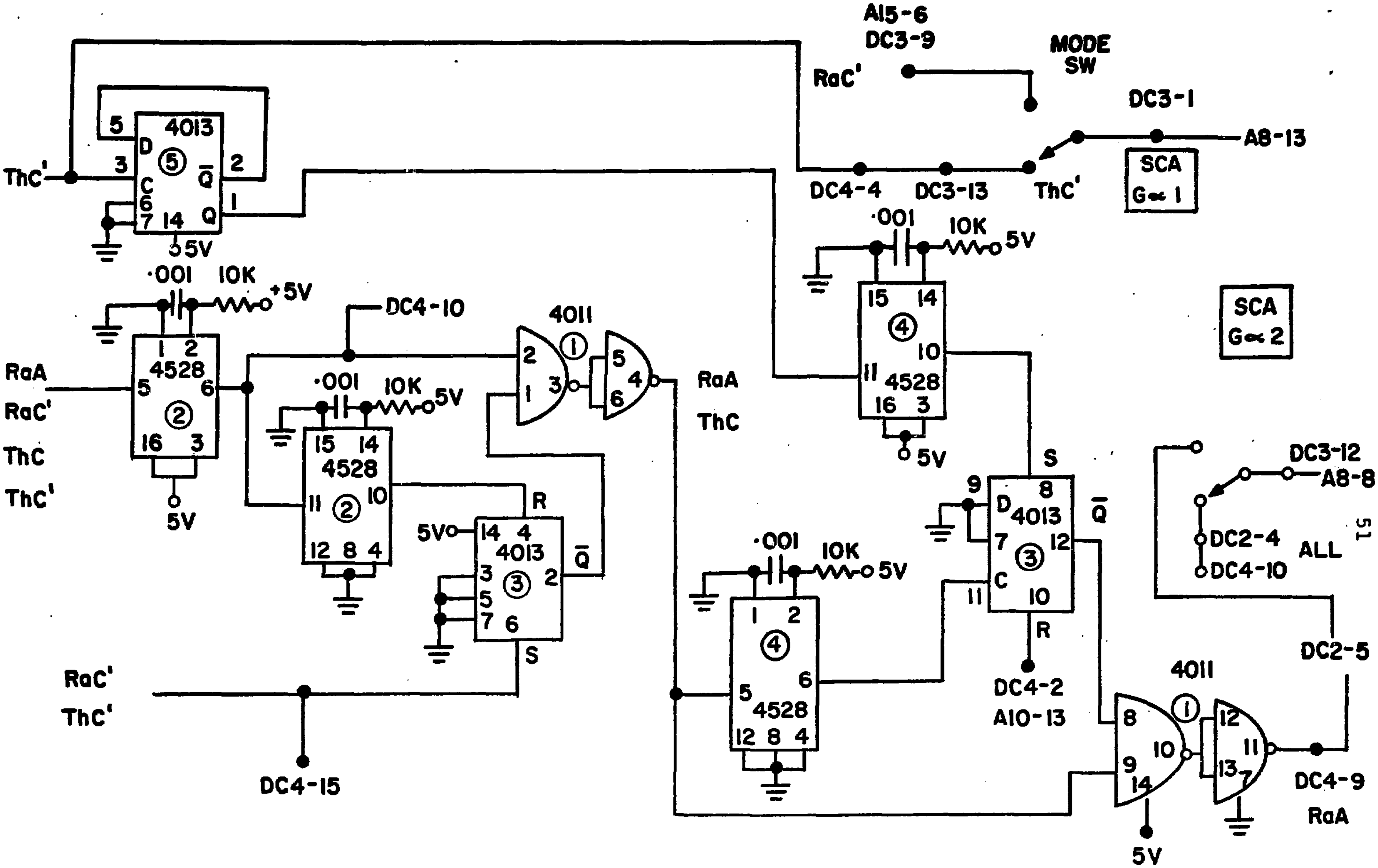


Figure 6b. Subtract Cicruitry

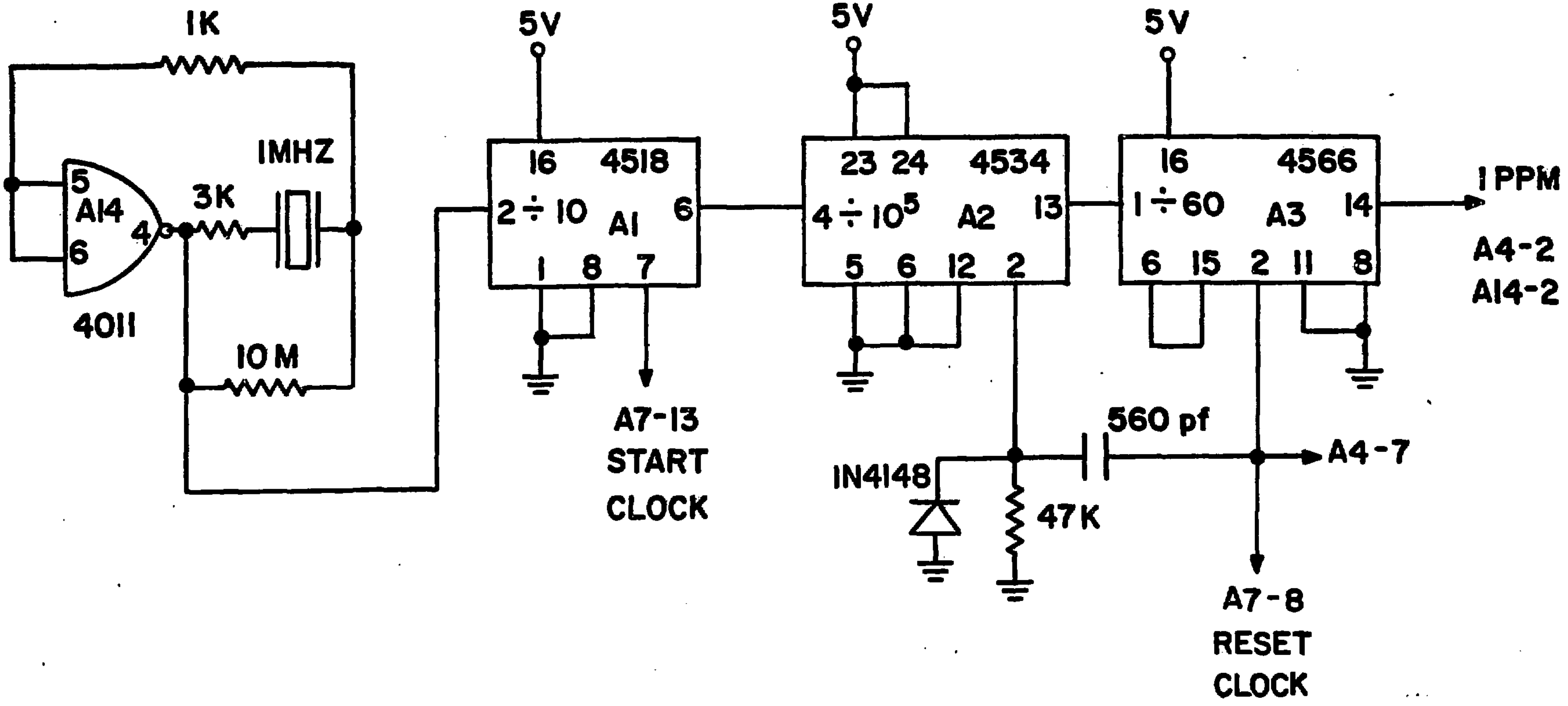


Figure 7a. Clock Circuit

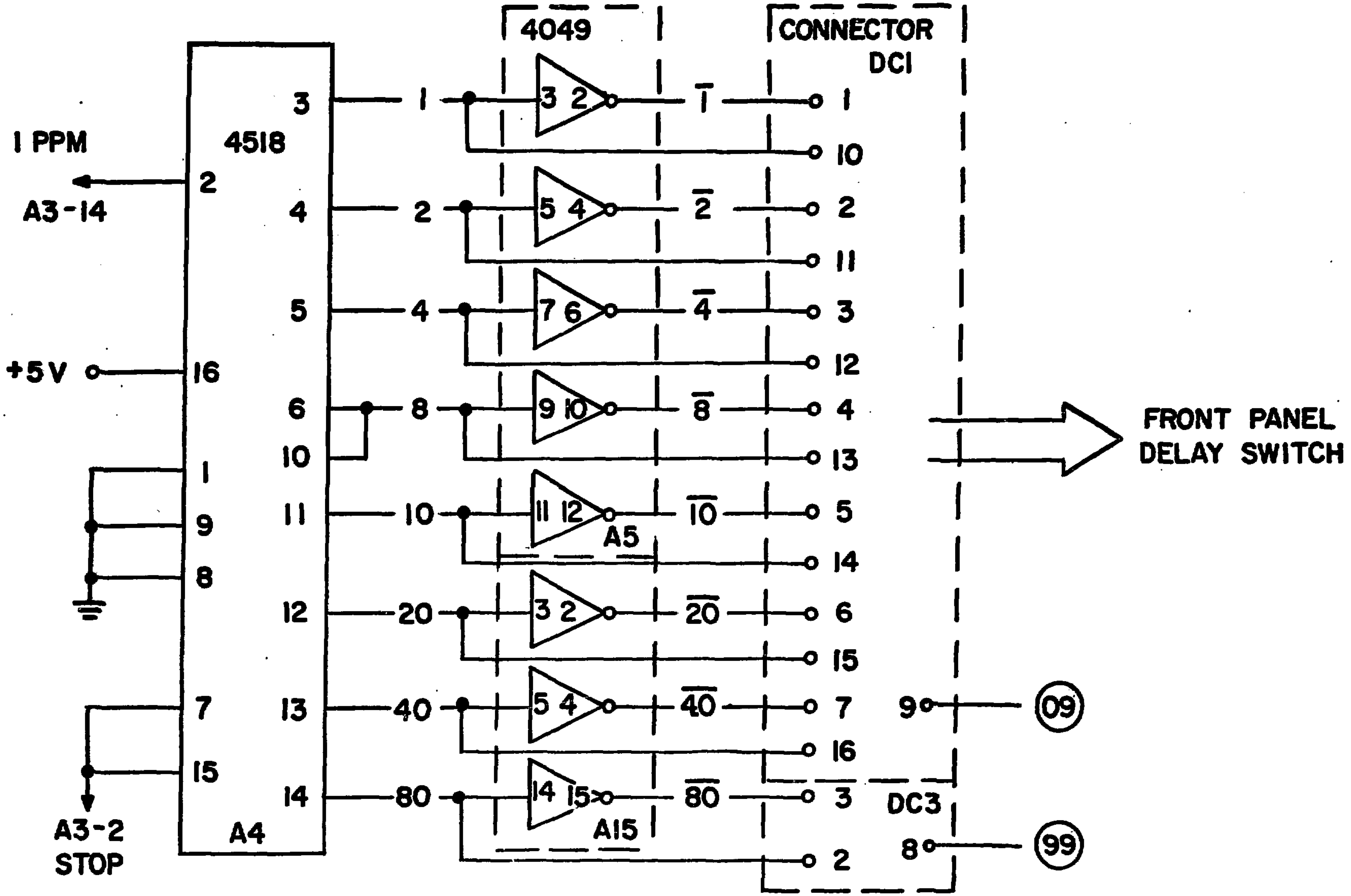


Figure 7b. Clock Circuit

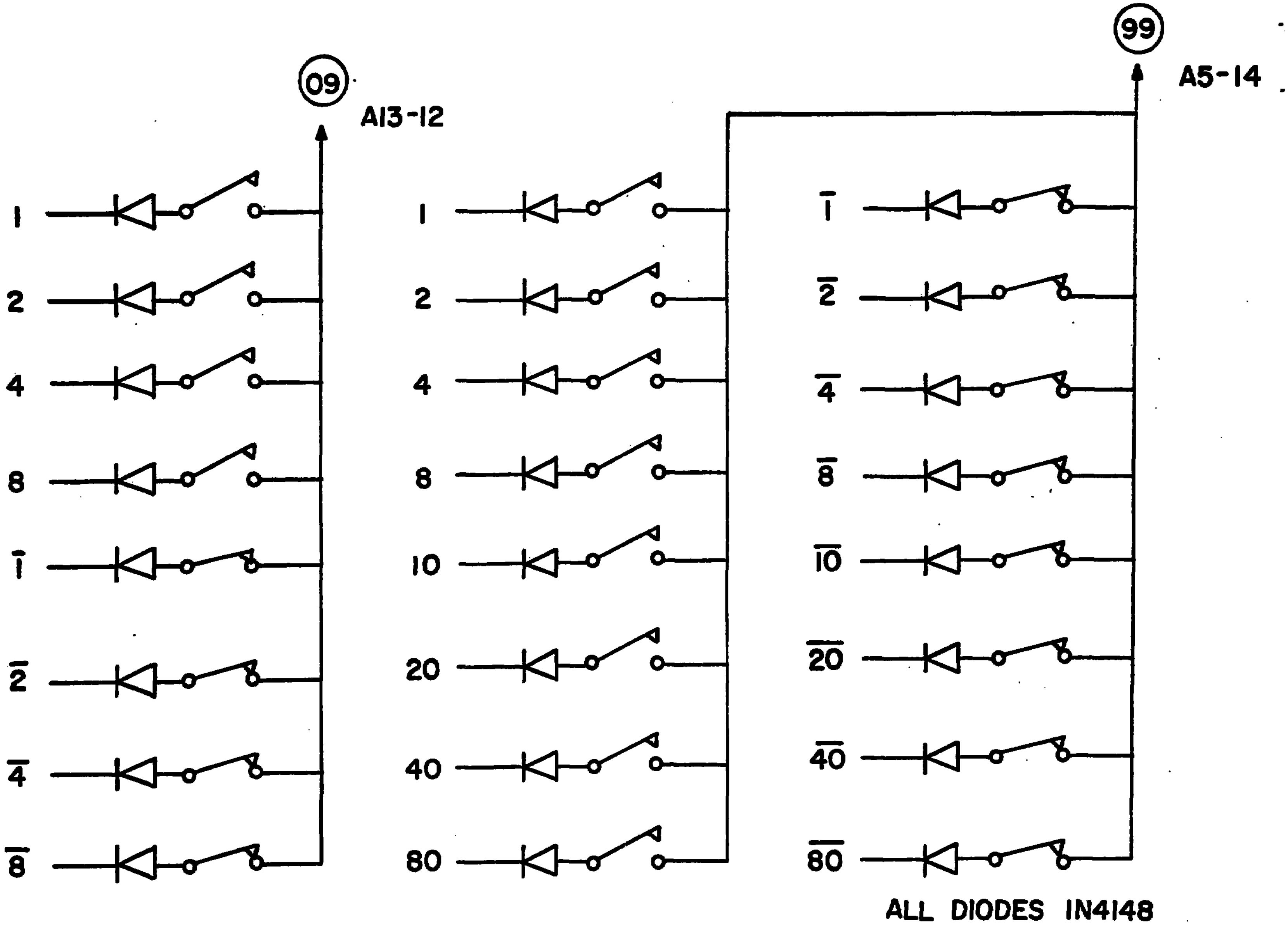


Figure 8a. Timer Switch Circuitry

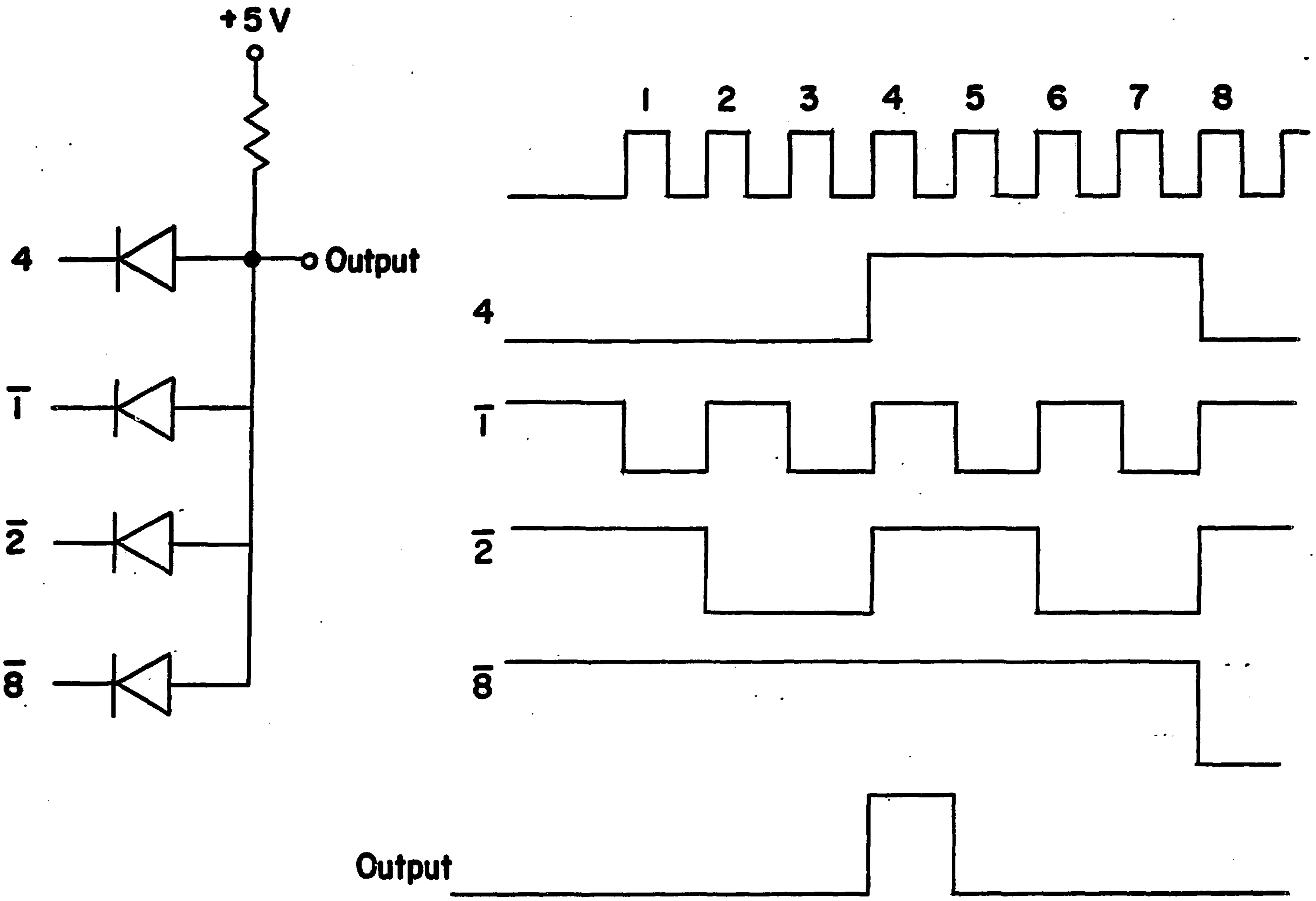


Figure 8b. Timer Switch Circuitry

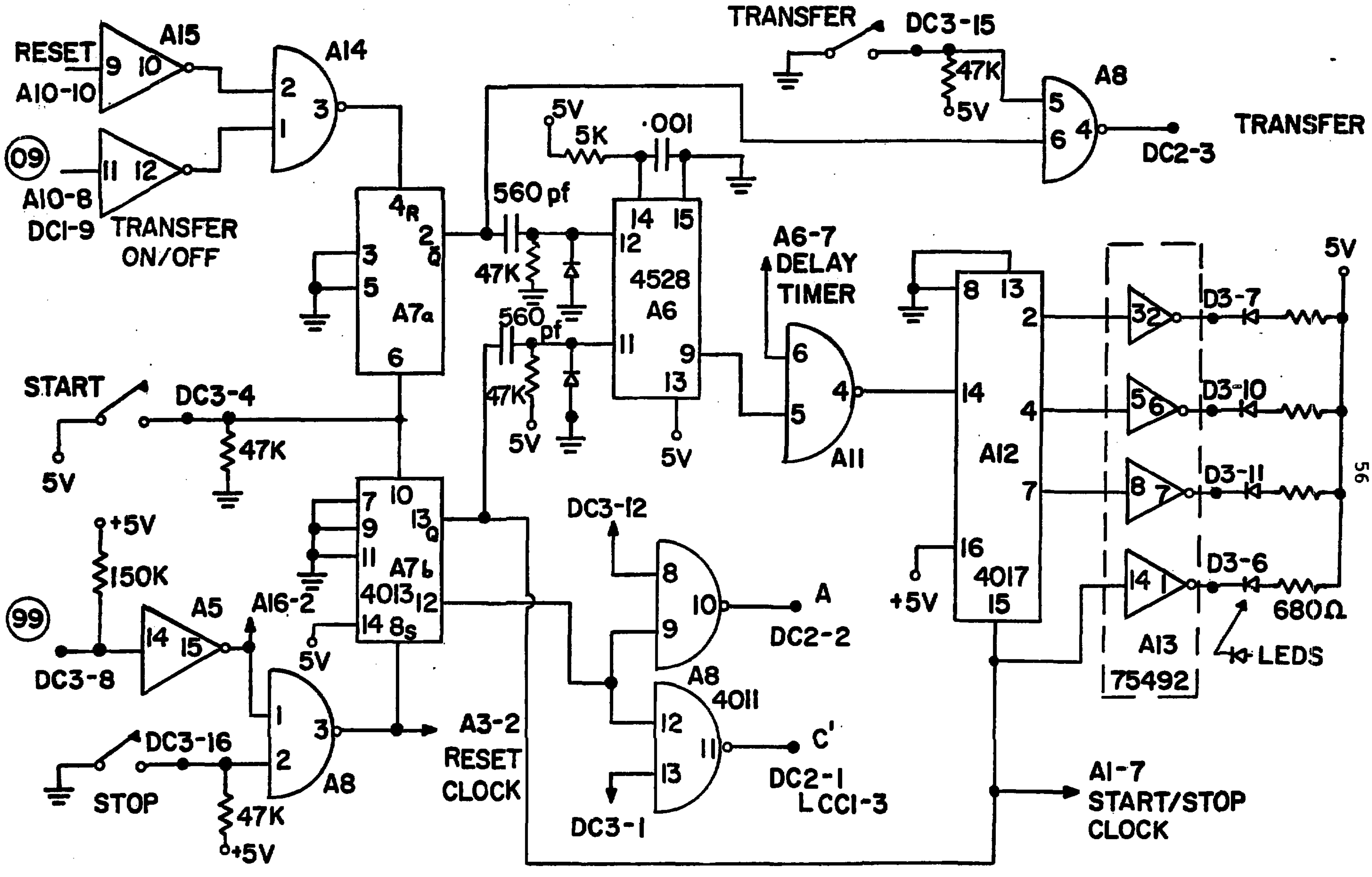


Figure 9. Main Control Circuit

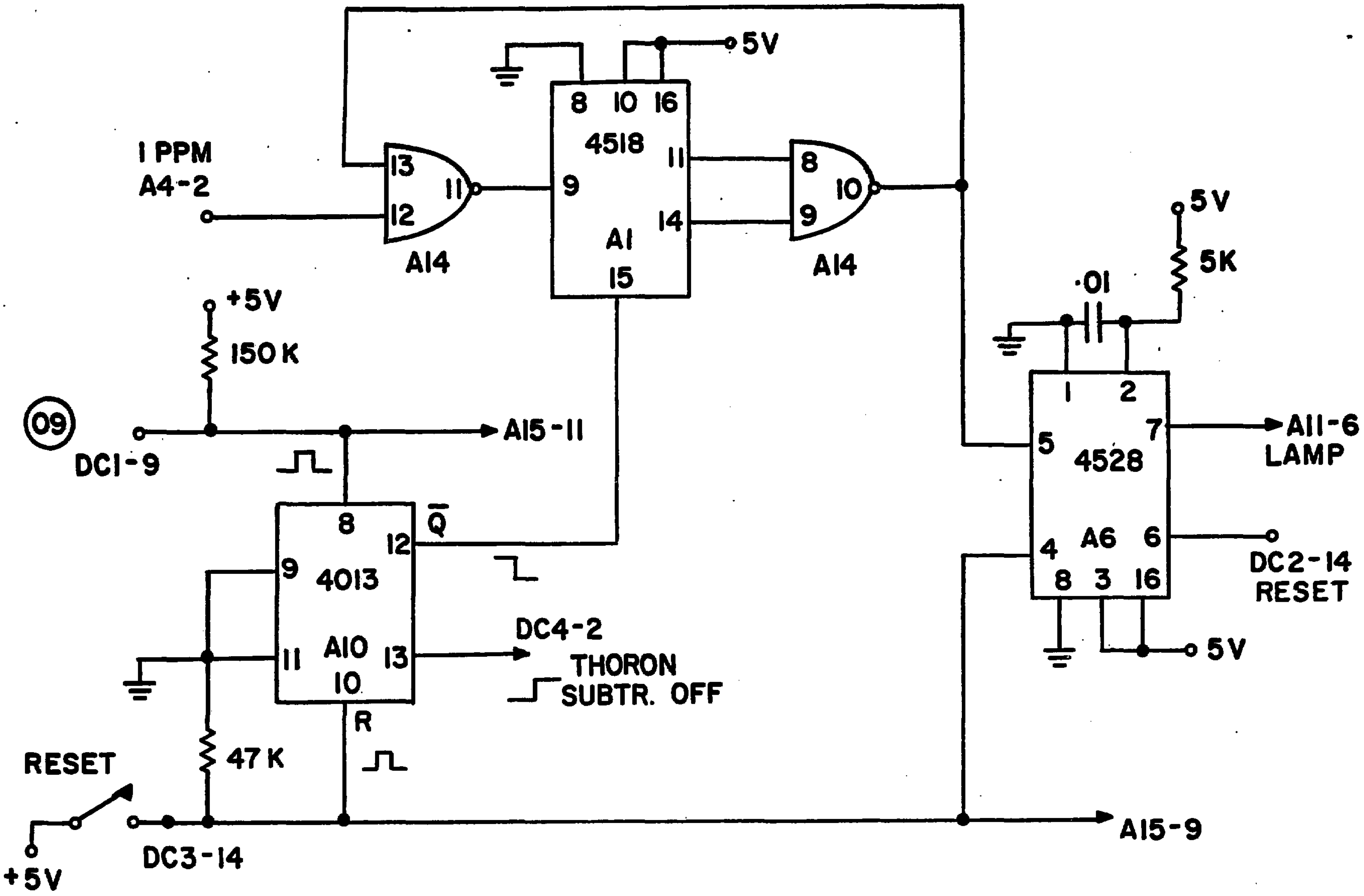


Figure 10. Delay Timer Circuit

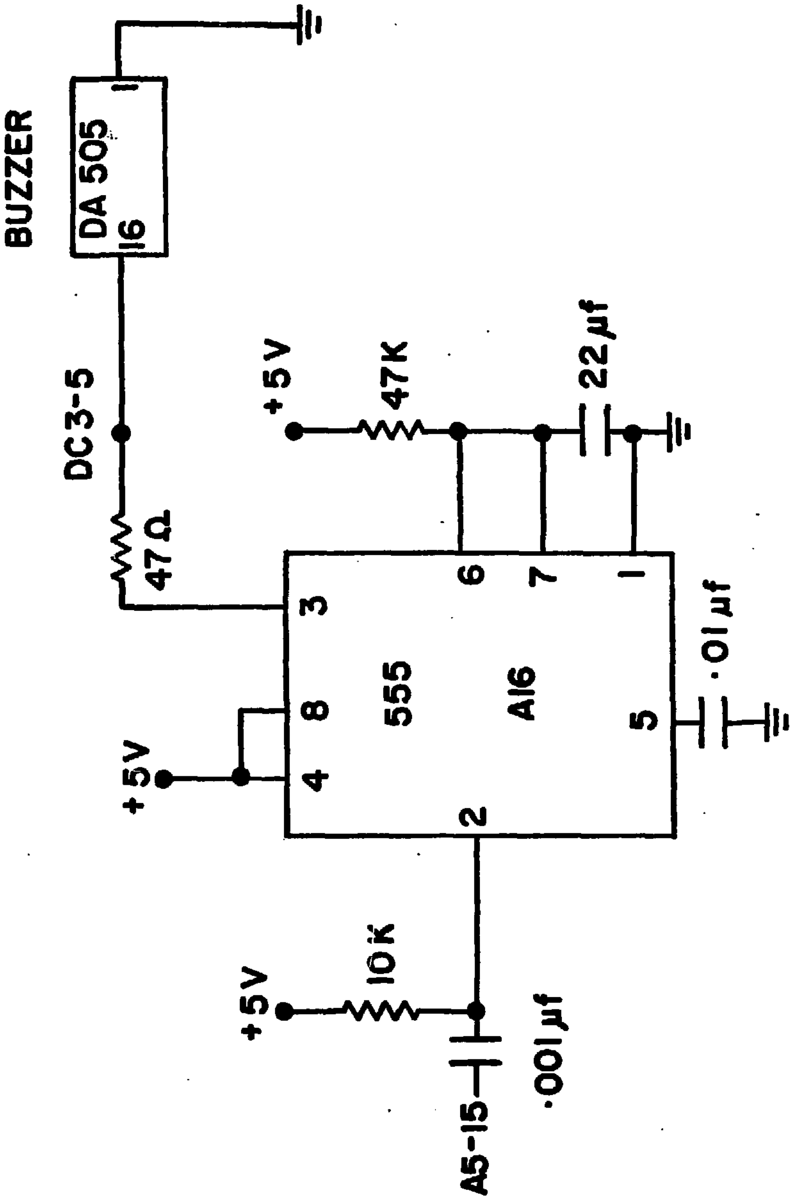


Figure 11. Alarm Circuit

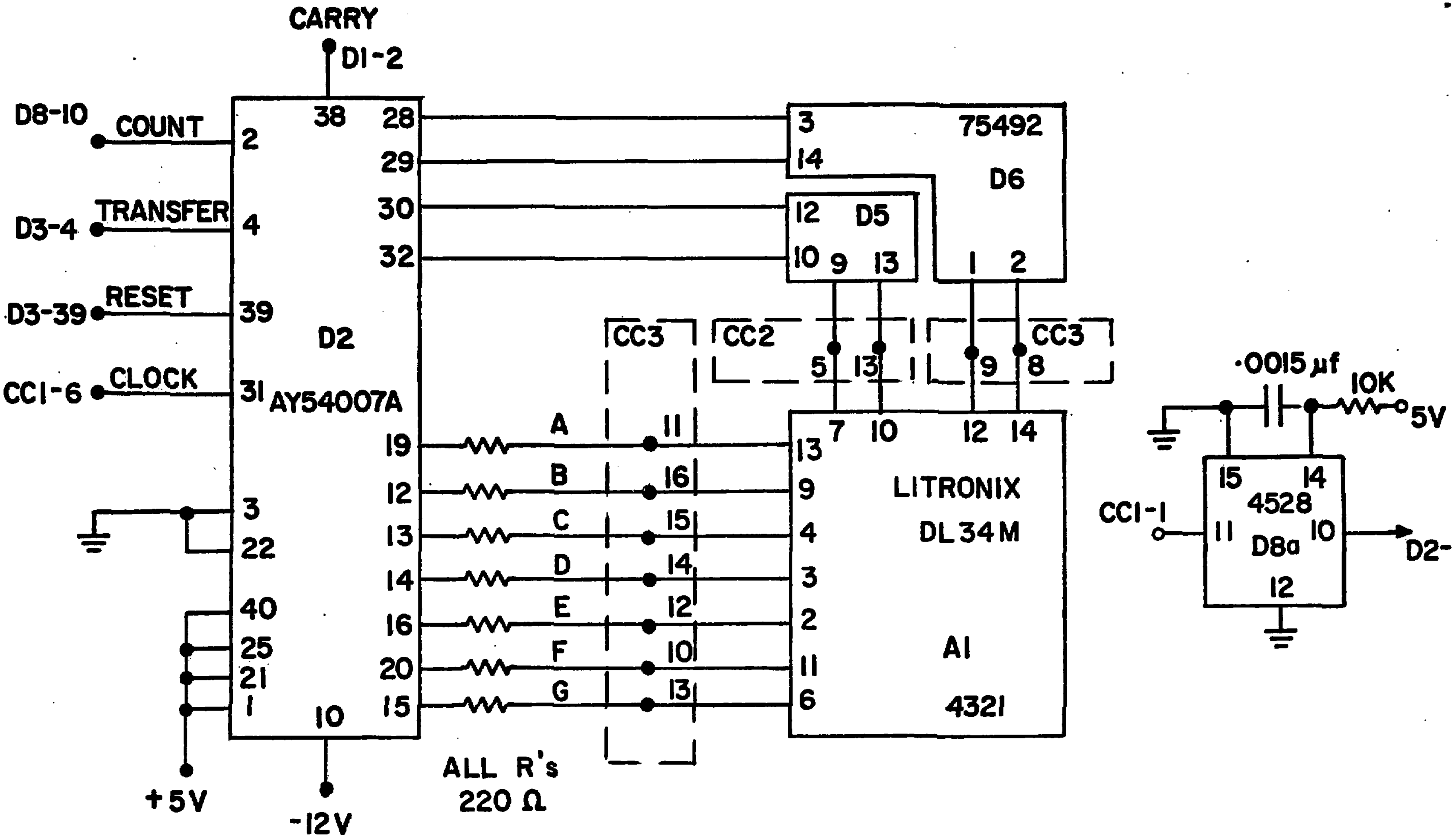


Figure 12a. Counter/Display Circuit

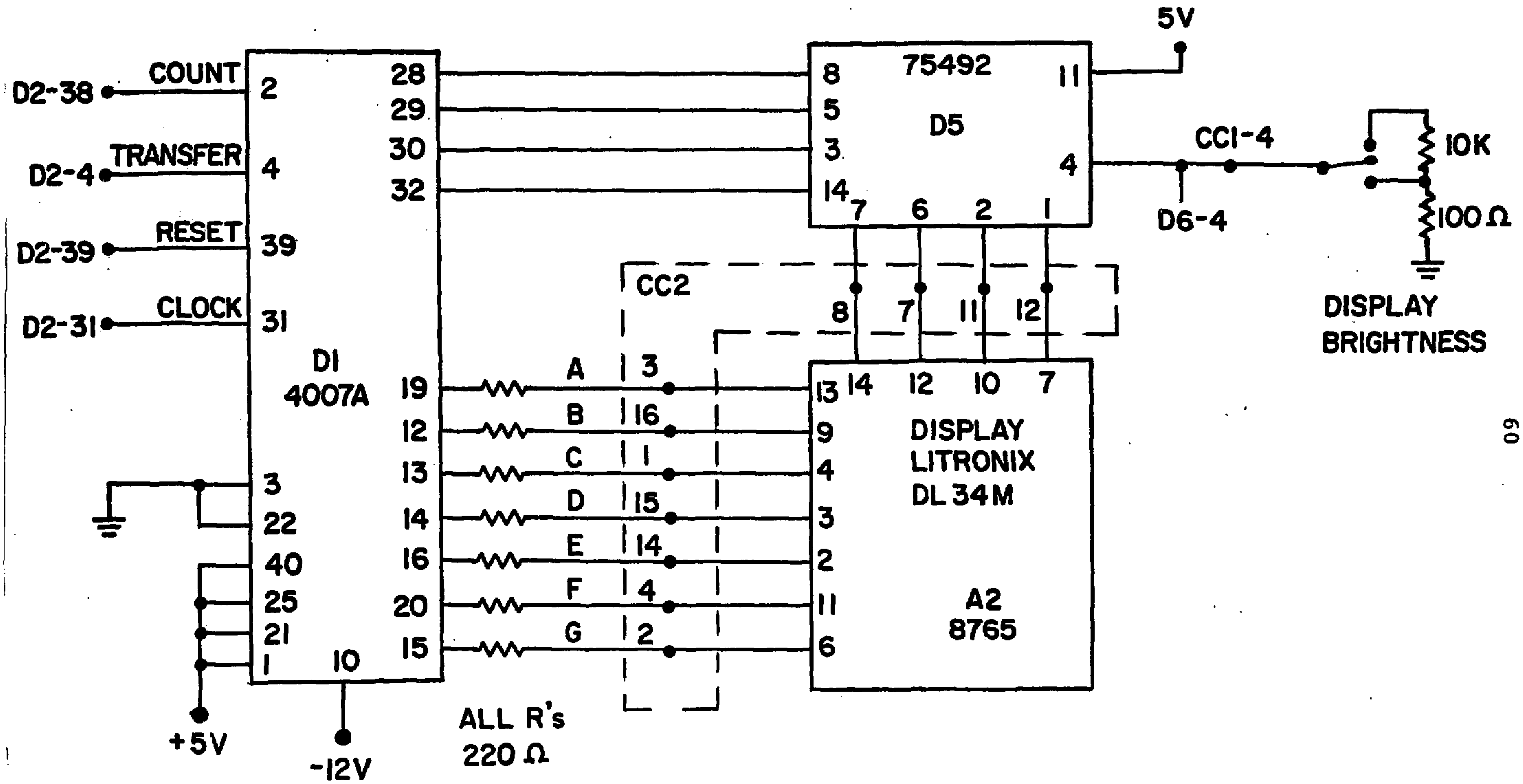


Figure 12b. Counter/Display Circuit

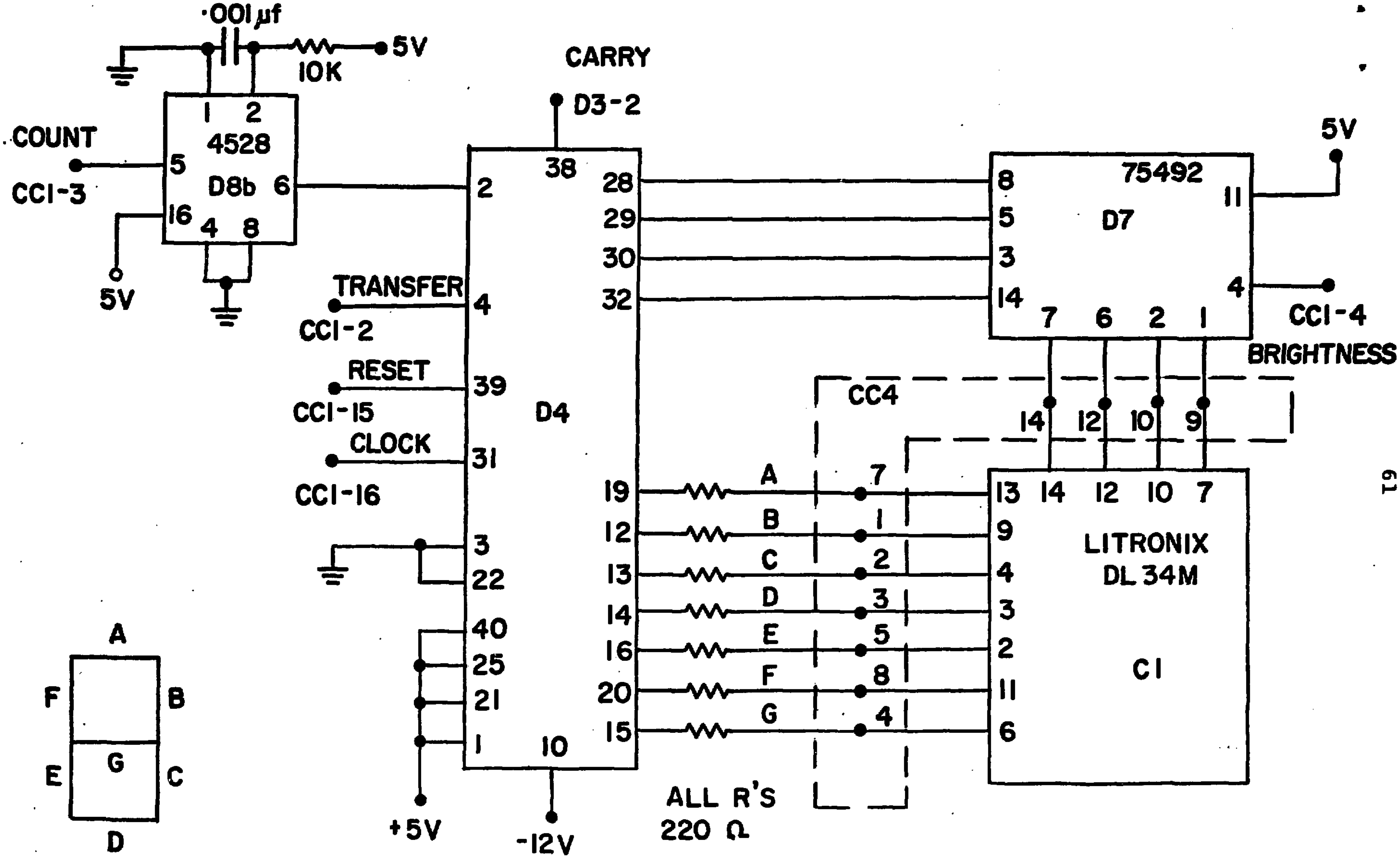


Figure 12c. Counter/Display Circuit

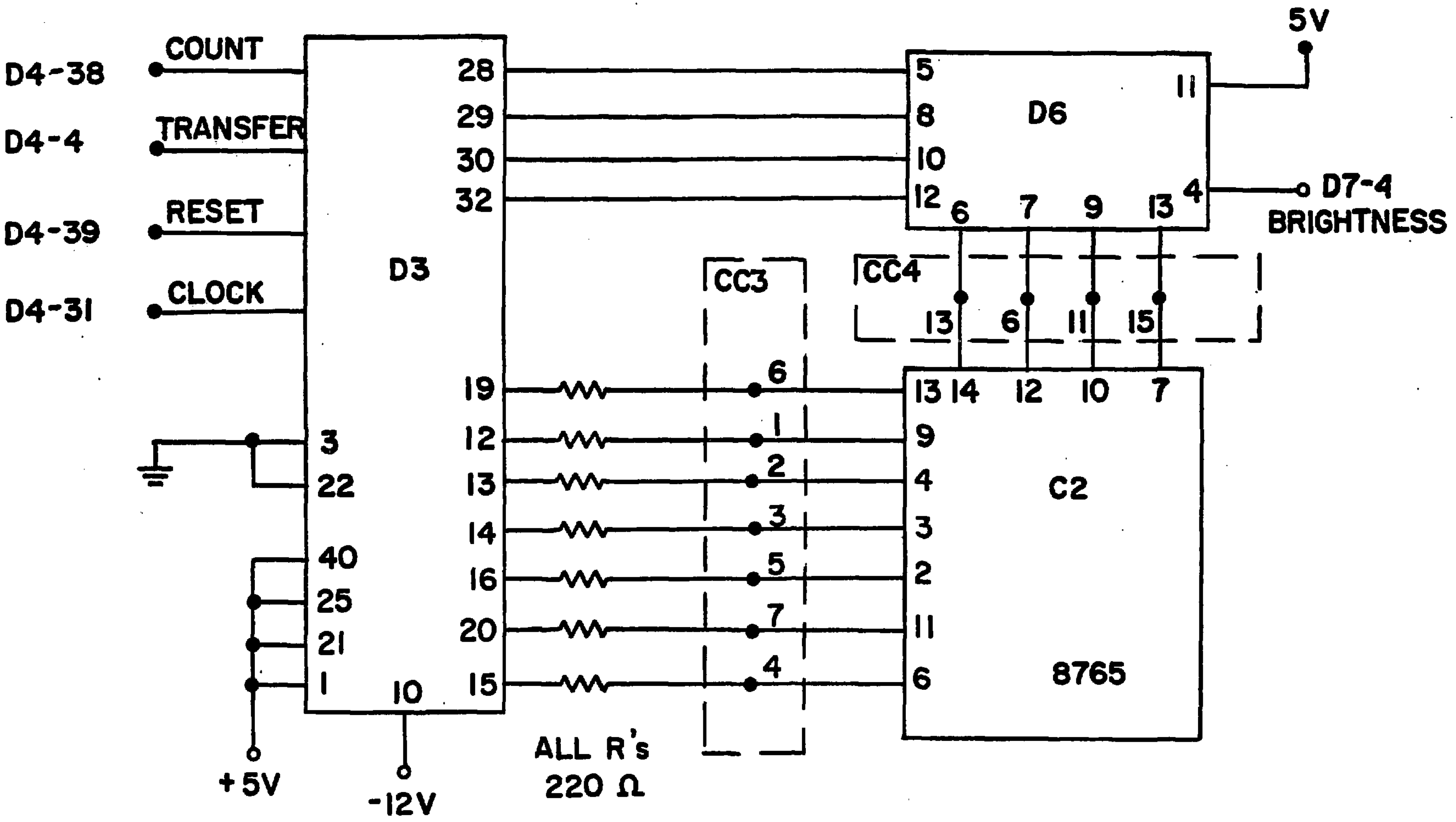


Figure 12d. Counter/Display Circuit

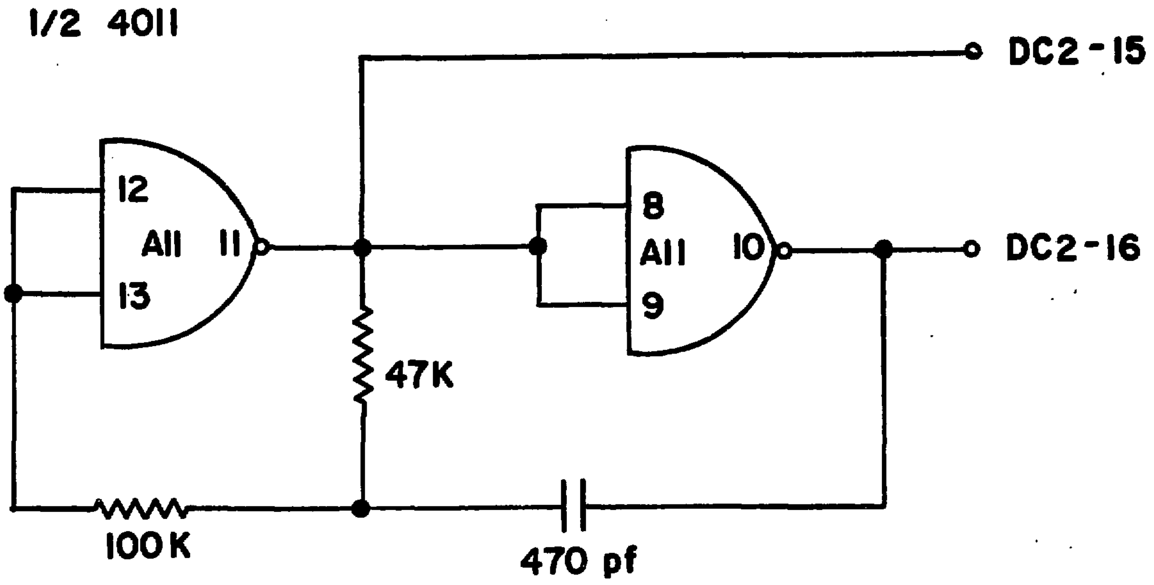


Figure 13. Digit Select Clock

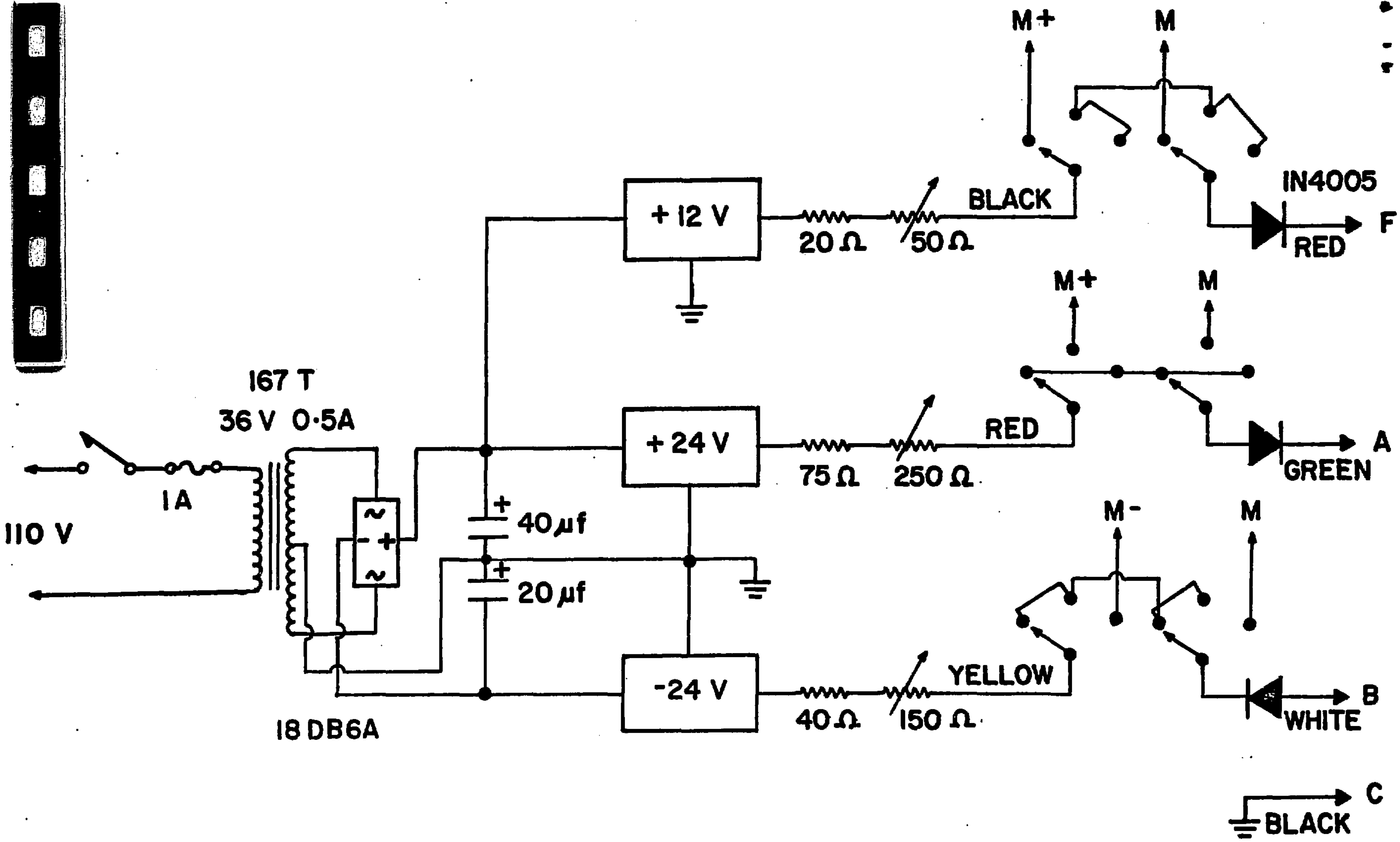


Figure 14. Battery Charger