UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Ampere-Hour Monitor for the Electrochemical Exploration Technique

by

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Open-File Report 89-356
1989

INTRODUCTION

Surveys for buried sulfide and precious metal deposits have been conducted by measuring the ions deposited on electrodes carrying direct current (dc) (Banerjee, 1989, Gao, 1988, Russ, 1978, and Shmakin, 1984). The amount of material oxidized or reduced at the electrode is proportional to the soil salt concentration and to the charge delivered, in coulombs. Ampere-hour monitoring is necessary to relate the soil salt concentration to the measured electrode deposit.

A survey is conducted by deploying many electrodes and driving them with a high-voltage dc source for several hours. Field data is the ampere hours for each electrode. The electrodes are then returned to the lab for disassembly and chemical analysis.

The electrodes use a microporous membrane to separate an electrode salt solution from the earth. The membrane forms the soil contact end of a cylinder containing the solution. Electrical contact to the voltage supply is made at the opposite end with a spectrographic carbon rod immersed in the salt solution. This electrode configuration allows a wide choice of salt solutions and facilitates chemical analysis by reducing contamination.

The survey system uses a control console, two remote units, generator, dc rectifier, and an electrode array (see Fig. 1). Two high-voltage, high-current cables connect the dc generator to the remote units where the electrode array is connected. Fiber-optic cables connect the remote units to the control console. This arrangement separates most high-voltage wiring from the operators. There is no earth reference; the remote unit and electrode potentials are determined by the electrode contact resistance. All measurement and control electronics are battery powered.

The power source is a 15 KW 3 phase 400 Hz alternating current Onan Generator driven by a 25 hp Diesel engine. Voltage control is done with a transformer which is tapped to provide selectable output voltages from 20V to 400V. The maximum current is 100 A. The generator output is diode rectified and low pass filtered by capacitors and an inductor. Output ripple is about 5% at 50 A.

CURRENT MEASUREMENT

As many as 32 electrode pairs are connected to the generator output wires through fuses and 1 ohm shunt resistors. The current measurement system employs a multiplexer to connect one shunt to the input of a voltage-to-frequency (V/F) convertor. This provides a low cost analog-to-digital conversion and a data format suitable for fiber-optic cables and subsequent processing.

The multiplexer is sequenced from the control console, which transmits an electrode number via a fiber-optic cable. Universal Asynchronous Receiver/Transmitter integrated circuits (IC) perform parallel to serial conversion for the electrode number data. The output pulse rate, proportional

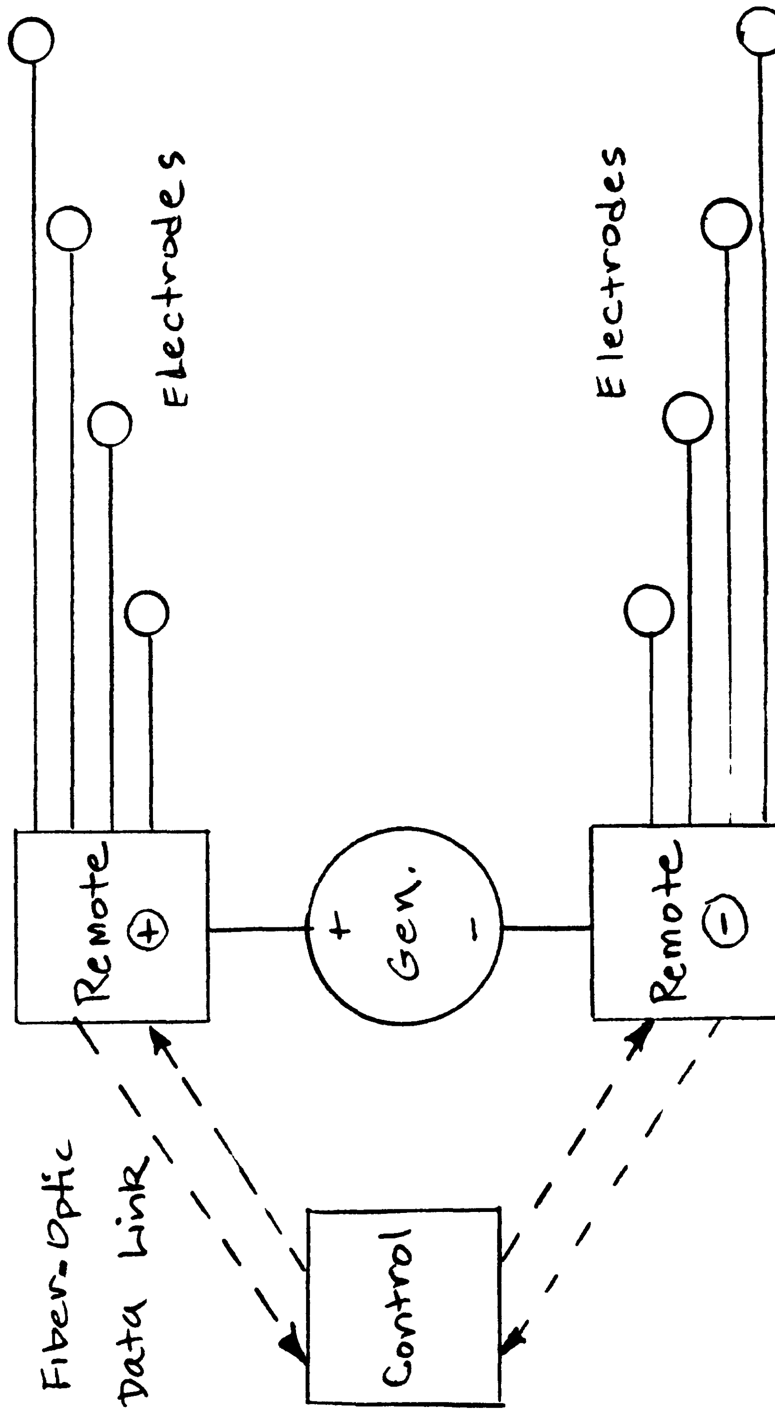


Figure 1 Block Diagram-Deployment

to current at 10 kHz/A, is sent to the control console via a second fiber optic cable. The pulses are counted to generate a sampled measurement for each electrode. We sample all 64 electrodes one hundred times per hour (see Fig. 2 for a block diagram). Both positive (+) and negative (-) electrodes are monitored because the current from one source electrode may be divided among several sink electrodes.

The V/F convertor must be able to generate a correct output pulse rate with time-varying input voltages because most dc generators have considerable ripple. The correct rate is proportional to the average dc level, not the root mean square level. Charge-balance and linear-current-source types of V/F convertors are both suitable and accurate even with unfiltered, full-wave-rectified sources (Burr-Brown, Inc., 1986). The sample period during which pulses are counted must contain an integral number of source ripples. We use 0.1 second, which provides compatibility with 50, 60, and 400 Hz generators.

CONTROL CONSOLE

The control console displays ampere-hours and number of samples. It generates sequential electrode selection commands and sums the received pulses. See figure 3 for a block diagram.

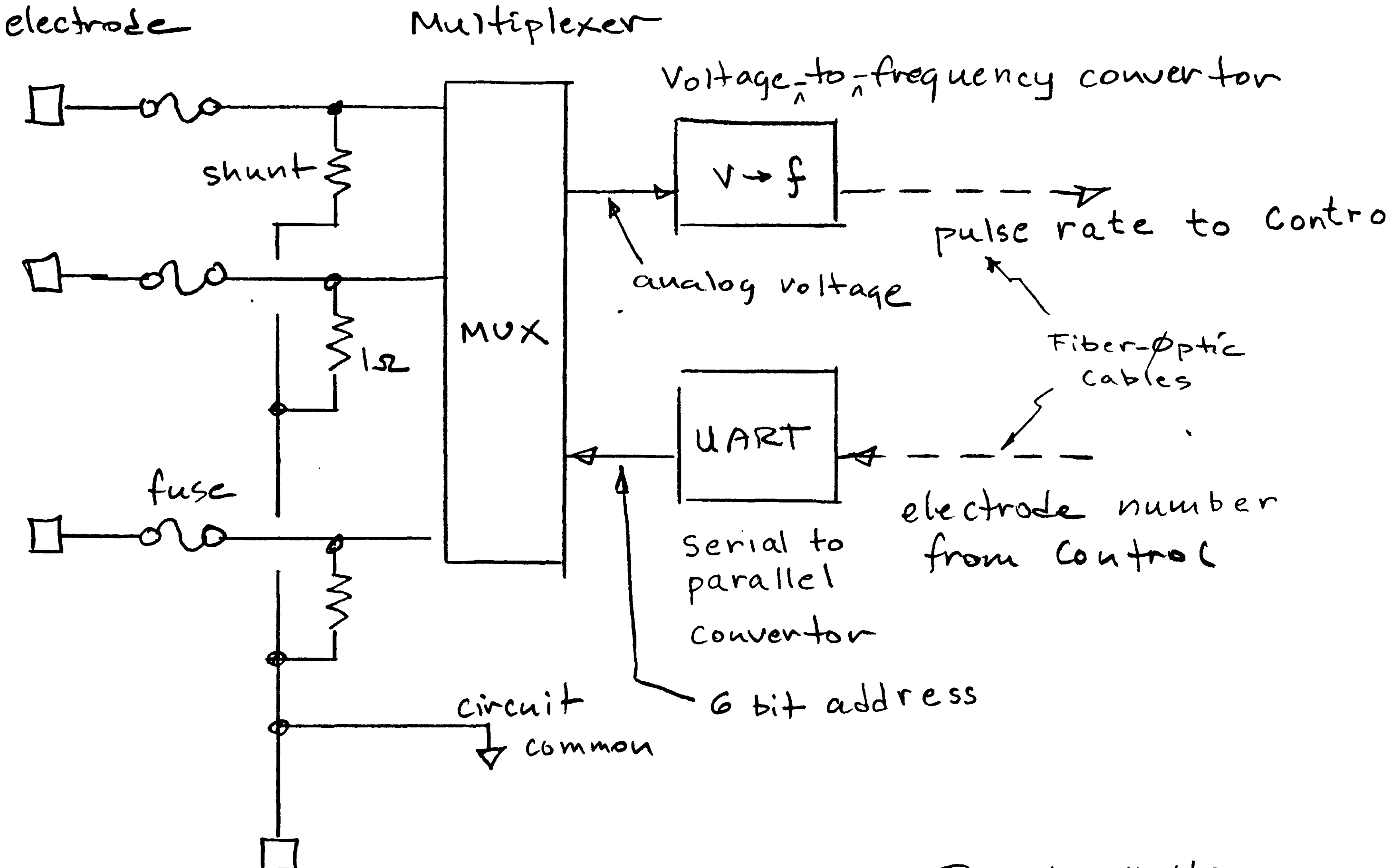
Summation is performed by a novel circuit using counting and memory-integrated circuits. The counter is preset with the old count total from the memory location for the selected electrode. It then counts upward from this value to sum the present sample to the total. Finally the new total is returned to the memory location, overwriting the previous total.

The detailed sequence of events begins with a clock pulse which advances the electrode number counter. The electrode number provides an address for the memory and is transmitted to the remote units. Next, the old total count for the electrode is read from memory and loaded into the counter. The counter counts upward for 0.1 second and the new total is then written into the memory. The operations sequence ends with an output to the display. The operator uses a thumbwheel switch to select an electrode number which displays an ampere-hour value. This electrode number is applied to the memory address and the electrode's count is latched to the display.

The power-up sequence clears the memory and uses the counter clear input to force zeros into all memory locations. The normal clock rate is momentarily increased to make the operation user transparent.

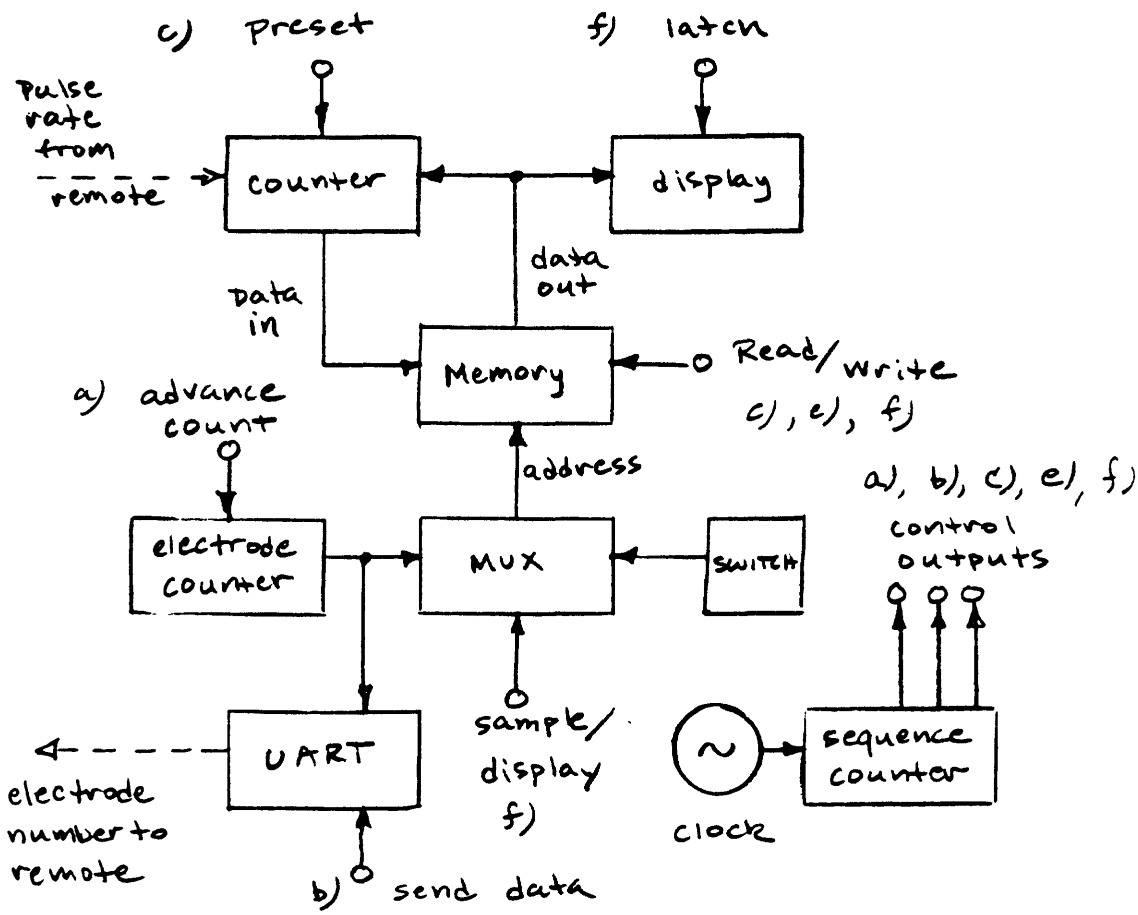
ACCURACY

The ampere-hour display has six digits, far in excess of its accuracy, to meet the dynamic range requirement. The operator needs to know if all electrodes have reasonable current flow after the first sample while the survey may require 10^4 samples. We can resolve 1 mA currents in one sample interval. The six-digit display can show 10 ampere-hours. The console has a divide-by-ten switch that allows up to 100 ampere-hours of sampling.



Block Diagram – Remote Units

Figure 2



Operations sequence

a) advance electrode number
b) transmit electrode number to remote
c) read memory to preset counter
d) count pulse rate for 0.1 second
e) write memory from counter
f) memory address = switch and load display

Figure 3 Block Diagram - Control Console

The absolute accuracy for the measurement is limited by the 1% tolerance resistors used as current shunts and by the 0.5% linearity of the voltage-to-frequency convertor. Other analog errors can be calibrated to zero relative to a voltage standard.

There are one count errors in the gating of pulses into the counter. These errors are only significant for small currents and the first few samples because the counter gating and the V/F convertor are not synchronized. For a generator with high ripple there are errors due to generator frequency drift, which results in sampling over a nonintegral number of ripple periods. These average to zero if the sample timing and generator ripple are asynchronous.

The units were tested with full wave and steady currents over the 10 mA to 2 A range using lab standards for comparison. All channels were accurate to within 2% when 10,000 counts were accumulated. Accuracy fell to 10% for 10 samples at 10 mA. High ripple at 60 Hz has no measureable effect on the V/F convertor. A 55 Hz ripple produces about 5% error in a single sample; however, the error decreased to less than 2% after 10 samples were accumulated.

CIRCUIT DESCRIPTION - REMOTE UNITS

Our schematic diagram (Fig. 4) shows the fuses, shunts and dc source output in the lower left corner. These compose the high-current paths. Note that circuit common is connected to the generator and only eight of a possible 32 electrodes are shown. For the remote unit connected to the dc source negative terminal, conventional current flow is from the electrode to the generator, and the 4051 multiplexer inputs are positive with respect to circuit common. The multiplexer connects one shunt to the AD537 V/F convertor. A 500 ohm pot provides a scale factor calibration, and the 0.01 microfarad capacitor sets the scale factor at 10 kHz/A of shunt current (10 kHz/V). The V/F output on pin 14 triggers a 10 microsecond one-shot, and its output drives a power MOSFET transistor. The transistor drives a light emitting diode (LED) coupled to a fiber-optic cable.

The selection of an electrode is controlled by a digital word transmitted from the control console via a second fiber-optic cable to an MFOD2404 photo diode + amplifier IC. The pulses are amplified 10 times by an operational amplifier, and 5 V pulses are generated by an LM311 comparator with a 200 mV threshold. The digital word is input to a 6402 Universal Asynchronous Receiver Transmitter (UART) chip. This IC recognizes stop, start and parity bits and places the 6 least significant bits of the word on its output pins 7-12. The chip is clocked at 32768 Hz by a crystal-controlled oscillator and one-shot buffer.

The most significant bit of the word selects the positive or negative remote unit by enabling a 4556 decoder at pin 1. The next two bits select one of four 4051 multiplexers by forcing one of four 4556 outputs low and enabling the 4051 at its pin 6. Finally, the three least significant bits chose one of eight switches in the multiplexer.

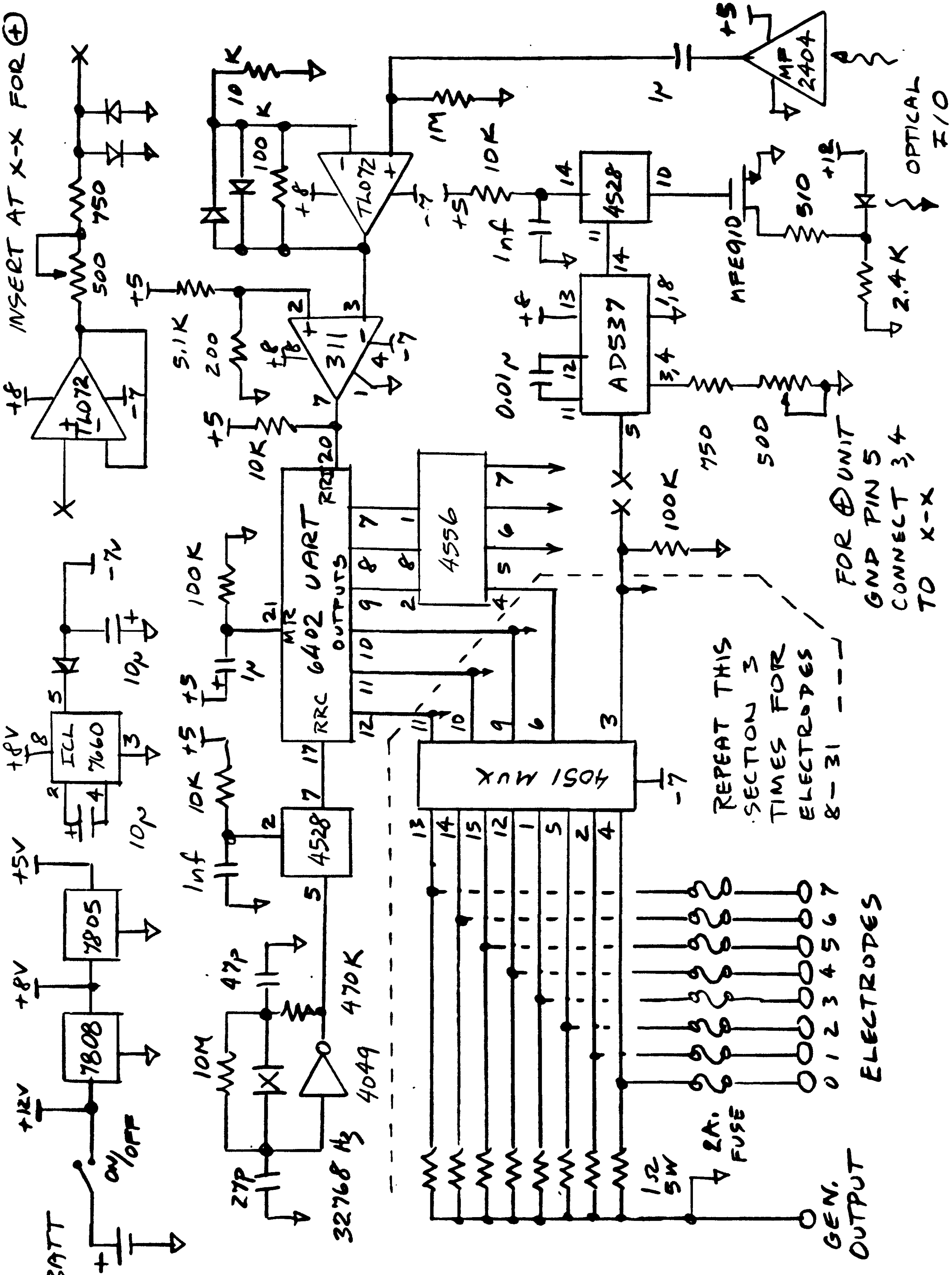


Figure 4 – SCHEMATIC – REMOTE UNITS

For the remote unit connected to the positive generator output, the multiplexer output is negative with respect to circuit common. A buffer amplifier is added to the circuit at X-X to sink about 1 mA from pins #3 and #4 of the V/F convertor, and pin 5 is grounded.

Power is from a 12 V, 1.9 ampere-hour battery with +8 V and +5 V regulators. A 7660 charge pump IC provides -7 volt power. Charge the battery to 14.7 V at the charge terminal and limit the current to 0.25 A. Battery drain is less than 15 mA.

CIRCUIT DESCRIPTION - CONTROL CONSOLE

A block diagram of the control console is given in Fig. 5. The fiber optic interface is a small board near the connectors and has two input amplifiers and two LED drivers. These amplifiers and drivers are similar to the circuits in the remote units. Note that the same digital word is sent to both remote units.

The second major subassembly counts the number of current samples summed in the ampere-hour display. It is detailed in Fig. 6 and provides four digits to count 100 hours at 100 samples per hour. The four 160 counters are cleared to zero when power is turned on and incremented every 36 seconds thereafter. The display is the number of complete 64 channel scans acquired. The 4543 decoders have outputs controlled by the backplane signal to drive liquid crystal displays.

Console power is similar to the remote units except for higher capacity to guarantee 100 hour operation. A zener-transistor circuit is used for low battery indication. This battery can be charged at 0.5 A.

The main assembly is the control board, and its circuitry is shown in Figures 7, 8 and 9. The heart of the system is the counter and random access memory (RAM) section of Fig. 7. This circuit sums an old ampere hour count in RAM with a new sample value and returns the sum to the same memory location. The operation begins by placing an electrode number on the RAM address buss with a 244 tristate buffer. The RAM then outputs the old ampere hour count to the preset inputs of the 160 counters. The count is loaded by pulsing the counter PRESET line. Then the counter is driven by the CLOCK line at a rate determined by the electrode current for 0.1 second. Finally, the count is stopped by taking the ENABLE line low, and the new total is written into RAM by pulsing the Read/Write line.

The next step is display. The RAM address is connected to a two digit hexadecimal thumbwheel switch by a second buffer driven by the SELECT line. The RAM outputs the count for the operator-selected electrode and it is latched to the 4543 display drivers by pulsing LATCH. This completes one electrode sample acquisition.

The six-digit display uses the Figure 7 circuit repeated six times. The low order counter has 'carry in' high, and successive digits are clocked by the previous digit's 'carry' output. They all share the same clock. The counters are set to zero by a pulse on the ZERO line. The RAM contents are set to zero by clocking through every address immediately after power goes on and executing the sampling sequence.

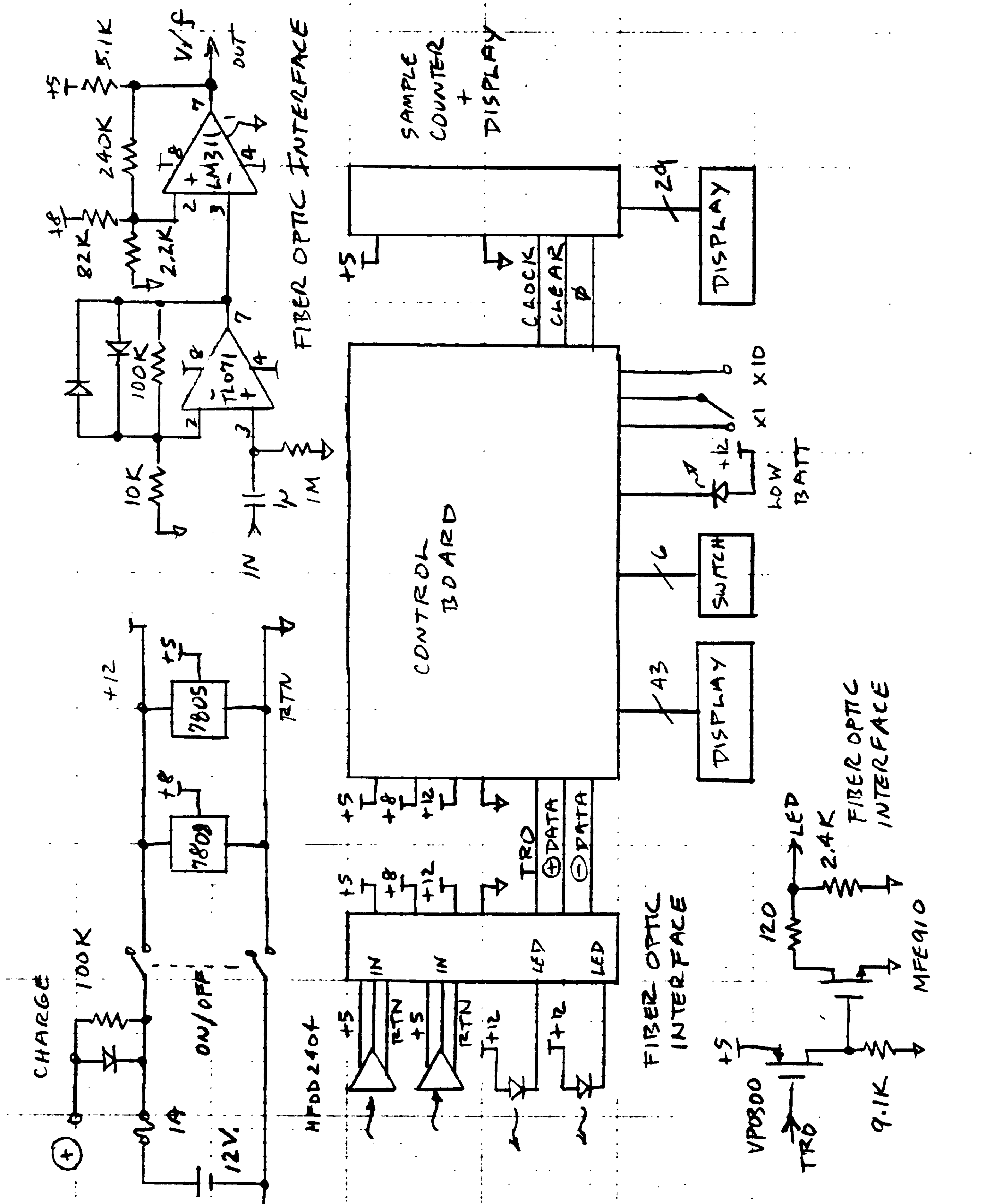


Figure 5 - SCHEMATIC - CHASSIS WIRING
CONTROL CONSOLE

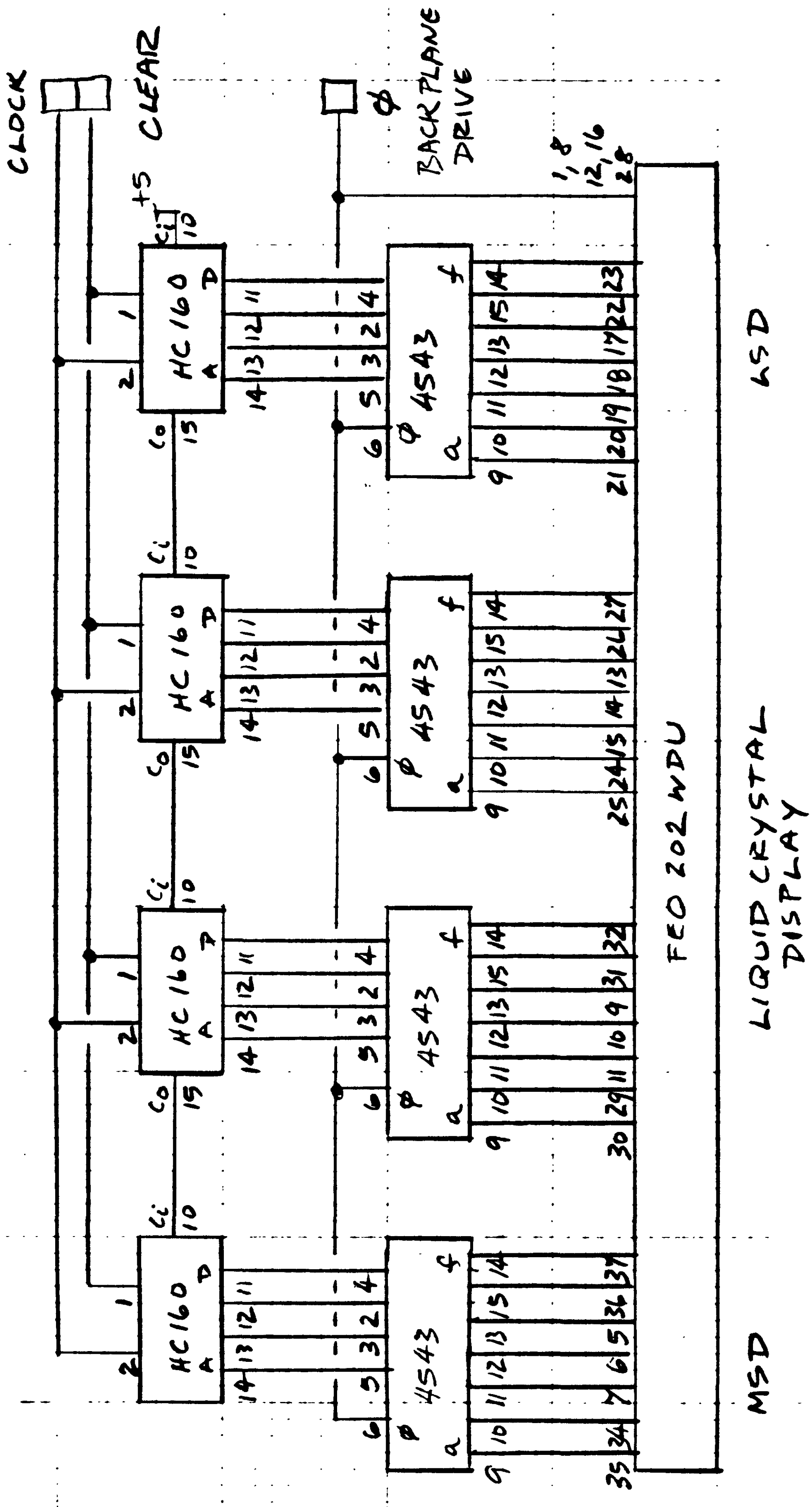
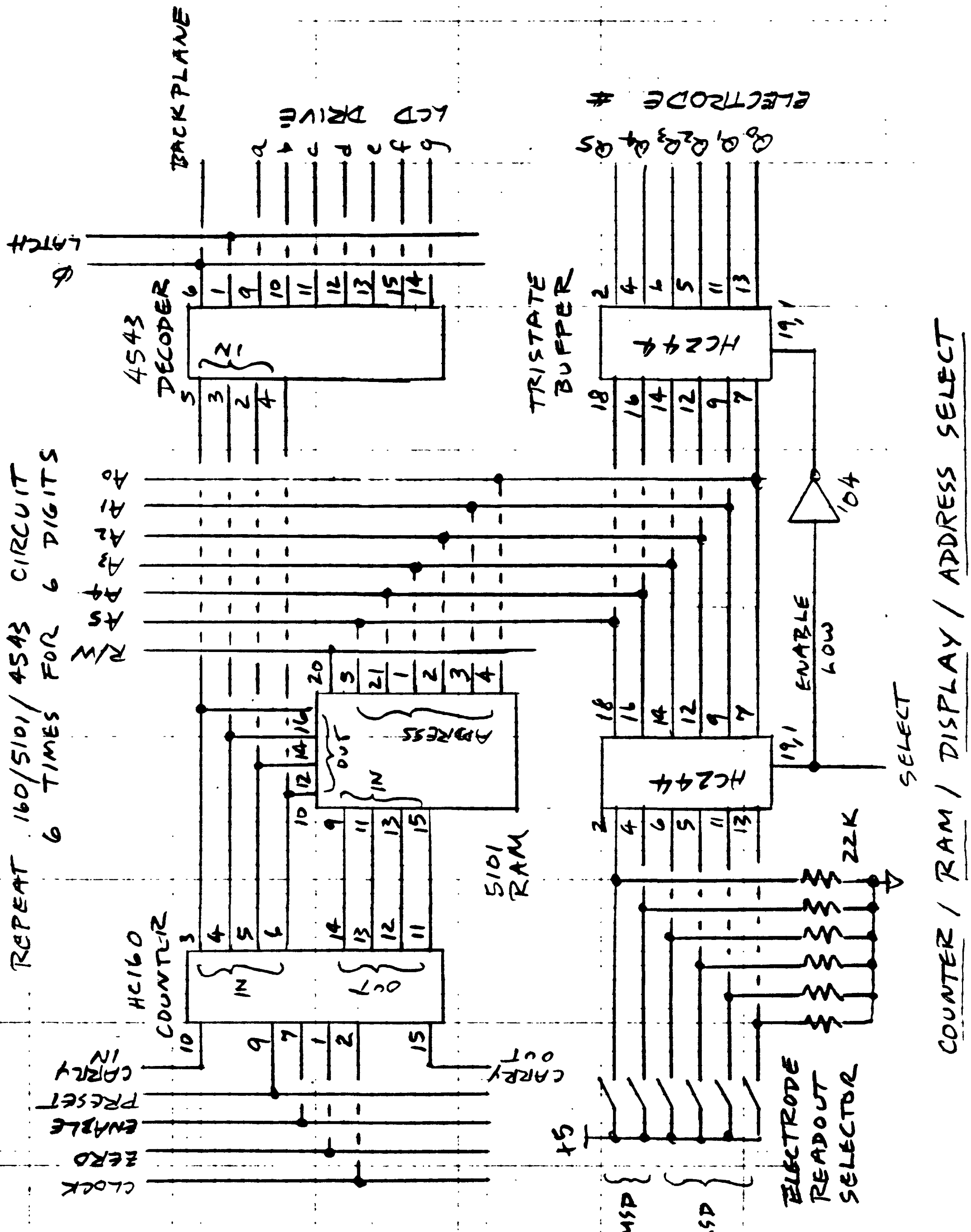
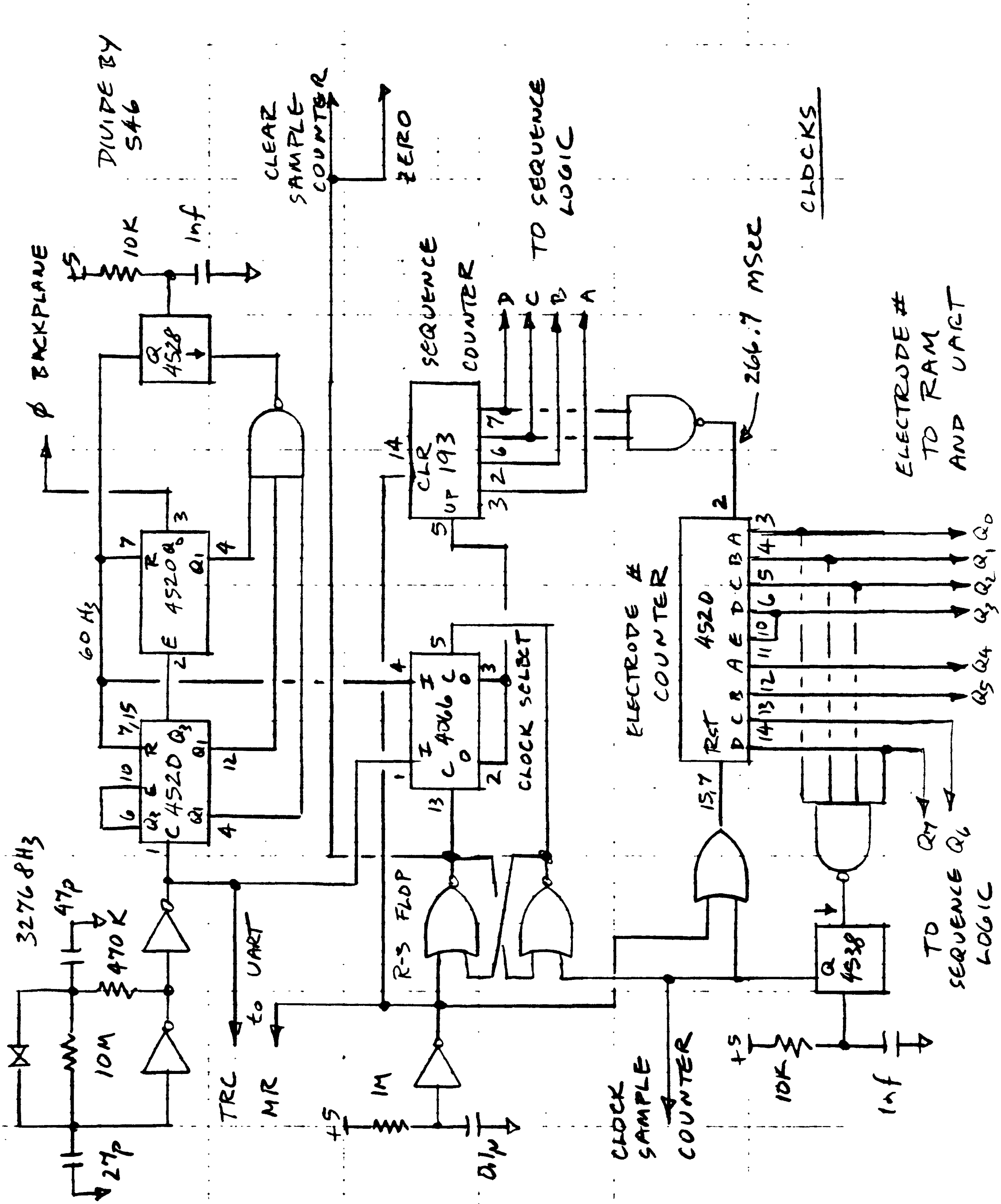


Figure 6 – SCHEMATIC – SAMPLE COUNTER



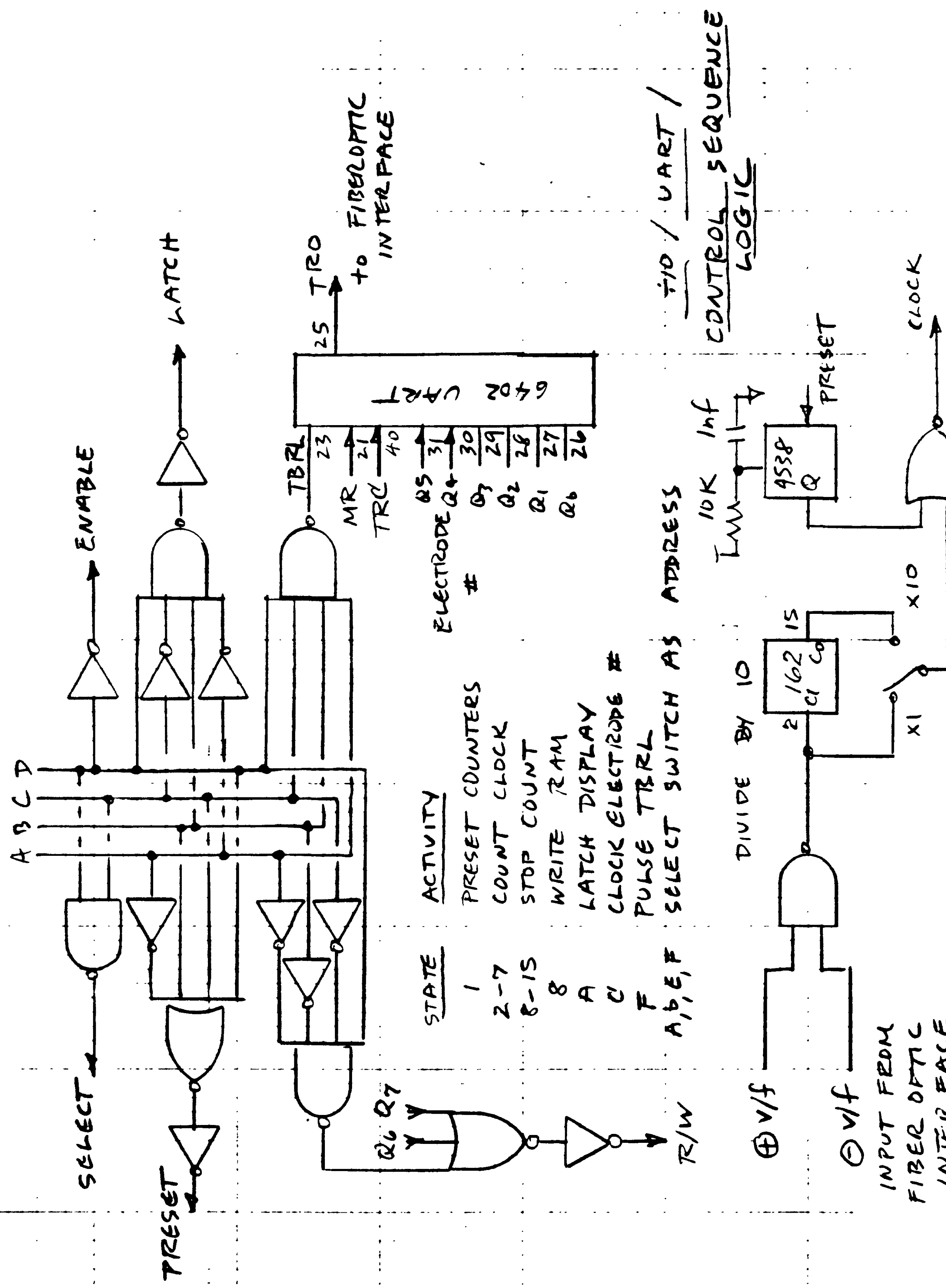
PARTIAL SCHEMATIC – CONTROL BOARD

Figure 7



PARTIAL SCHEMATIC – CONTROL BOARD

Figure 8



PARTIAL SCHEMATIC - CONTROL BOARD

Figure 9

The control board has two counters: the sequence counter goes from 0 to 15 to generate decoded states for the various pulses required for the sample summation and display; the electrode number counter counts from 0 to 135, and the first 64 counts are used as RAM addresses and electrode multiplexer addresses (Fig. 8).

We follow the count sequence starting when power is turned on when a flip-flop is set by a master reset pulse. This pulse loads control data to a UART and sets the sequence and electrode counters to zero. The flip-flop output clears the sample number display counter and asserts the ZERO line. Both flip-flop outputs are sent to a 4066 analog switch. During the start up cycle the 32768 Hz oscillator is used as the input to the 193 sequence counter. It in turn clocks the electrode counter at 2048 Hz. When the electrode number equals 135 (87 in hexidecimal), a gate triggers a one-shot which then resets the flip-flop and resets the electrode counter to zero and ends the cycle.

In normal operation, the 32768 Hz oscillator is divided by 546 (222 in hexadecimal) by two 4520 counters and a one-shot triggered by a gate. The 60 Hz one-shot output is selected by the 4066 and drives the sequence counter. Its 266.7 millisecond period output drives the electrode counter. After 36 seconds (0.2667x 135) the electrode counter is reset, the sample counter is clocked and one set of 64 samples has been collected.

For each electrode the sequence counter is clocked from 0 to 15. These states are decoded by gates shown in Fig. 9. The various outputs have been described previously but this diagram shows some new details. Note that the RAM read/write control is held in the read state when the electrode counter outputs Q6 or Q7 are high. This suppresses memory alteration when counting from 64 to 135. The CLOCK line is ORed with the PRESET leading edge to guarantee a clock pulse during preset for the synchronously preset 162 chips. The voltage-to-frequency convertor outputs are ORed together because only one remote unit is active at a time. The divide-by-10 switch selects a 162 counter input or output.

The UART which sends electrode numbers to the remote units is loaded by a Transmitter Buffer Register Load (TBRL) pulse. It is clocked by the 32768 Hz oscillator. The output is sent to both remote units simultaneously. Data output starts within two clock periods after TBRL is pulsed. The data word has a stop bit, a start bit and an odd parity bit. The two most significant bits are always zero.

CONCLUSION

This report has described an ampere-hour meter for monitoring multiple electrodes carrying direct current. It will be useful to someone repairing the instrument or to a designer building a similar instrument. The system provides portability, safety, dynamic range and low cost. Current monitoring can improve the interpretation of surveys using the electrochemical technique.

ACKNOWLEDGEMENTS

Don Hoover is the project manager. He initiated the work, reviewed the literature and provided translations of Russian and Chinese publications. The overall system design and project funding were the results of his work. Dave Smith is the analytical geochemist. Herb Pierce designed the electrodes.

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