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A Radio-Telemetered Data-Acquisition System For Self-Potential Measurements

by

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INTRODUCTION

The U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) has designed and built a data-acquisition and control system to remotely monitor Self-Potential (SP). Ground voltages,(Self-Potentials), "are related to subsurface localization of heat" (Zablocki, 1980,p.1) These voltages are of interest to the Hawaiian Volcano Observatory in that SP changes may be used to monitor subsurface changes in magma storage or movement. Measurement of SP is usually done using 2 electrodes and a high impedance voltmeter. Voltage readings are taken in a leap-frog fashion across a desired profile. The profiles are repeated then compared in time to determine the magnitudes and polarities of the SP changes. This procedure requires re-occupying the line with a team periodically to chart the changes of the SP. This acquisition system eliminates the need to have people re-occupy the profile. Electrodes are permanently installed across the desired profile and the SP readings are regularly transmitted back to the Observatory.

The concept of telemetering SP measurements is straight-forward. Suitable electrodes are installed across a desired profile, and the acquiared date is stored by a commercially-available acquisition system. After a complete series of measurements are made the data is radio telemetered to the HVO. The radio transmitter is turned on only after all the readings have been taken so that noise generated by the radio does not interfere with the SP voltage measurements.

This report describes the measurement and telemetry equipment that has been designed and implemented to remotely monitor SP. The initial profile for this experiment is located across recent basaltic lava flows in the Hawaii Volcanoes National Park approximately 8 Km. east of HVO.

OVERVIEW OF THE SP DATA ACQUISITION SYSTEM

This section gives an overview of the SP data acquisition system, which is shown in the diagram D1. The diagram shows in block form the major components of this system; the horizontal line through the diagram separates circuitry at the field site at the Escape Road from the circuitry at the receiving site at the Hawaiian Volcano Observatory (HVO). Diagrams D2 and D3 show detailed wiring information.

The acquisition system, excluding electrodes, is designed to meet the following requirements:

1) Operated solely from 12 volts dc (air cell batteries for year).
   a) Current draw at a constant 105 mA not including the transceiver. (65 mA for acquisition system, 40mA for HK-21 Terminal Node Controller (TNC).)
2) Uses radio telemetry to transfer data and programs between the HVO and the remote field site.

3) Capable of monitoring 8 electrodes.
4) Capable of selecting any combination of the 8 electrodes for measurement and reversing their inputs to the amplifier.
5) Capable of inserting a load resistor in parallel across the selected electrodes.
6) Uses a 16 bit analog to digital(A/D) converter with a resolution of 76.2939 uVolts.
7) Digitizes and stores all electrode and inserted resistor voltages in the field acquisition system for later radio transmission back to the HVO.
8) Overall system noise below +/- 0.5mV (after correcting for temperature drift of the isolation amplifier).

A maximum of 8 electrodes can be accessed by the acquisition system. Combinations of electrodes are selected via the RELAYS AND DRIVE BOARD. These signals pass to the BURR BROWN isolation amplifier, part number 3652, before being converted to equivalent digital values by the 16 bit A/D. The RS-232 output of the A/D are changed to 0-5 volt CMOS levels in order to communicate with the Tattletale model 4A using the POWER CONVERTER AND LEVEL SHIFTER BOARD. The data from the A/D are stored in the Model 4A for later output to the POCKET PACKET HK-21. The HK-21 receives the serial output from the Model 4A and "packetizes" these data and sends these packets to the RR-155 transceiver for transmission.

The signals transmitted from the field are received in the HVO's "Crisis Tower". Radio signals from the field are received by a second RR-155 transceiver. The received signals are demodulated by the radio to produce the packetized signals. These signals are sent to a second Pocket Packet HK-21 where they get "unpacketized" These signals are sent to the Leading Edge computer (PC-XT clone) which captures these data using BITCOM terminal emulation software and it's terminal session logging option.

BLOCK DIAGRAM OF SP DATA ACQUISITION SYSTEM FIELD UNIT

Block diagram D4 shows the data acquisition system field unit designed to collect data from SP electrodes.

Starting on the left are the lines depicted as 'ELECTRODES' that connect the SP electrodes to the acquisition system. A maximum of eight electrodes can be accessed with this system. The voltage between any two electrodes can be measured. The two measured electodes are selected with the 'LINE SELECT RELAYS' indicated by relays 1 through 16. A load resistor is inserted periodically to monitor any changes in the contact resistances of the electrodes. Refer to the section 'CONTACT RESISTANCE AND 'W' CALCULATIONS' for details. The value of the load resistor RP is set at 20K ohm which is approximately equal to the contact resistances of any two electrodes. 'LOAD SELECT RELAY' #17 inserts the resistor into the circuit. The 'POLARITY RELAY' reverses the electrode signals going to the 'ISOLATION AMPLIFIER'. Polarity reversal allows monitoring of any drifts or offsets associated with the isolation amplifier. Relays #18 and #19 control the polarity of the signals going to the isolation amplifier. The detailed circuit description of the relay drive circuit is in the "SP DATA ACQUISITION RELAY DRIVE SCHEMATIC" section.

The isolation amplifier is a Burr Brown 3652 optically isolated amplifier. Isolation is required to eliminate the ground loop that causes drifts in the SP data.

The analog signals from the isolation amplifier go to the 16 bit A/D Crystal Semiconductor (CDB5501). The digitized signals are stored in the Tattletale model 4A for later radio transmission to the HVO.

The Tattletale model 4A is a data logger with 8 analog inputs and 16 digital I/O ports. The I/O ports are used to control the switch drivers which activate the line select relays. The analog inputs are not used in our application. The 4A also has a 'software' UART to accept and store the digital data from the CDB5501 A/D. The stored data is transmitted to the HVO through the 'POCKET PACKET MODEL HK-21', and the 'TRANSCEIVER, MODEL RT-155'. The Pocket Packet is the link between the Tattletale Model 4A and the transceiver. The HK-21 packetizes the digital signal into discrete groups, then sends the packet to the radio for transmission. The receiving station's HK-21 checks for errors in the packet before accepting. If an error is detected by the HVO's HK-21 it asks for retransmission. The HK-21 also has built-in 1200 Baud modem. The HK-21 has the control outputs necessary to activate a standard voice grade transceiver.

SP DATA ACQUISITION SYSTEM
RELAYS AND DRIVE

The relay drive circuit is used to supply the necessary voltage and current levels to operate the various relays in the S-P Data Acquisition System. The digital I/O ports from the Tattletale Model 4A provide signals either directly or through other circuits to the Relay Drive board. These signals are used to control the sequencing of the relays. Diagram D5 shows the 'SP DATA ACQUISITION SYSTEM RELAY DRIVE SCHEMATIC'. To simplify the drawing, the relays are shown with the coils separated from the contacts. The numbers on the left side of the coils are the relay identification numbers. The corresponding contacts have the same number attached to them. The number on the right of the coils is the relay model number.

Several factors lead to choosing reed relays in the input multiplexer section.

1) Survivability from high voltage electrical disturbances mainly lightning induced.
2) Needed high interchannel isolation (low leakage) to reduce signal contamination from adjacent channel signals.

The reed relays initially used were general purpose switching types which proved too noisy. COTO reed relays, part number 3501-12-911 and 3502-12-911 were selected because of their ultra low thermal EMF and leakage characteristics.

The signals that control relays #1 through #16 come from the outputs of two 4028s located on another board. These signals are used to turn on HEXFET Q1 through Q16 which in turn, control relays 1 through 16. Relays 1 through 16 are the 'ELECTRODE SELECT RELAYS' which go to 8-dual screw terminals connected to the analog input BNC connectors; only two electrodes are compared at a time. Each analog input is connected to 2 single-pole single-throw low thermal EMF reed relays.

The potential difference between each selected electrode pair is measured in the following four modes:

1. Direct without load resistor, V1
2. Reverse Polarity without load resistor, V2
3. Direct with load resistor, V3
4. Reverse Polarity with load resistor, V4

Relays 18 and 19 reverse the polarity of the signal from the selected electrode pair to two dual-screw terminal strips which are wired to the Isolation Amplifier. Any offsets introduced by the Amplifier will be evident in certain combinations of these four measurement modes. If V is the true voltage and VO is the offset introduced by the Isolation Amplifier, then:

$$V1 = V + VO$$
$$V2 = -V + VO$$

therefore,

$$V = (V1 - V2)/2$$
$$VO = (V1 + V2)/2$$

Relay #17 is the Load Select Relay that inserts a 'load' resistor of 20k ohms across the selected electrode pair. The ratio of voltage with resistor to voltage without the resistor will give an indication of changes in the contact resistance of the electrode pair. The section "CONTACT RESISTANCE AND 'W' CALCULATIONS" provides furthur details. A large contact resistance may indicate problems with one of the electrodes and not real changes in signal.

All of the relays are controlled by identical electronic components and circuitry. The active component in each case is an International Rectifier N-Channel HEXFET IRFD123. This HEXFET has a 1 watt capacity and is mounted in a 4-pin dual in-line plastic package. The 110K ohm resistor on the gate is used to provide a low impedance path to ground to stop oscillation. The 'Control Input Signals' are from two 4028s and the Tattletale Model 4A located on the 'I/O Expander Board'. These signals are 5 volt CMOS compatible levels that activate HEXFETS 1 through 20 and relays 1 through 19 (there is no relay #20). A 50 pin ribbon cable connector is used to get the control signals on board.

The Relay Drive Board serves as a level shifter current booster to activate the relays in the electrode and mode select parts of the acquisition system. The 5 volt input level is 'shifted' to control the 12 volt relays and the I/O drive current capability is 'boosted' from about 2 mA to approximately 500 mA safely.

TATTLETALE MODEL 4A I/O DETAILS

This section describes the interconnections depicted in drawing D6 'TATTLETALE MODEL 4A I/O DETAILS'. This diagram shows the circuitry and connections between the circuit boards within the 'Yellow box'. The 'Yellow Box' is a small suitcase sized plastic container that houses the field unit acquisition electronics.
The radio telemetry, consisting of the transceiver and the 'pocket packet' Model HK-21, is connected and operated as described in their appropriate manufacturers guides. We will focus here on the basic acquisition hardware interconnections, as seen on the drawing, which consists of the following:

1) Tattletale Model 4A
2) I/O Expander board
3) Relays and Drive board
4) Power Converter and Level shifter Board
5) CDB5501 16 Bit A/D
6) Isolation Amplifier

The heart of the acquisition system is the Tattletale Model 4A data logger manufactured by ONSET Computer Corp, Falmouth, MA. The Tattletale is used to accomplish the following tasks.

1) Control relays that select the electrode pairs and the modes of their measurement.
2) Store digitized data from the outboard A/D.
3) Calibrate the outboard 16 bit A/D.
4) Provide time of day and temperature for each electrode measurement.
5) Supply the radio telemetry with compatible signals for transmission.

The box for the TATTLETALE MODEL 4A is on the lower left corner of the diagram. There are two connectors that are shown on the board. The long one on the right is a single in-line connector with 32 pins at .1 inch centers. The second one labelled "MODULAR JACK is an RJ-11 telephone jack that is used to send signals to the TNC-Transceiver radio telemetry section.

The 32 Pin In-Line Connector

The 32 pin connector is used as the analog and digital I/O port for the Model 4A. The following table summarizes the pin assignments and functions for the 32-pin connector on the Tattletale.

#'s	PIN	Function
1	ADGND	A/D's digital ground
2	V-	Negative supply (or ground)
3	ANGND	A-D's analog ground
4	COM	Common
5	A7	Analog channel 7;tied to thermistor
6	A6	Analog channel 6

#	PIN	Function
7	A5	Analog channel 5
8	A4	Analog channel 4
9	A3	Analog channel 3
10	A2	Analog channel 2
11	A1	Analog channel 1
12	A0	Analog channel 0
13	ANRF+	Analog reference
14	Vsw	Sw. ana. supply
15	I/O pin 14	4028A-10 (A)
16	I/O pin 15	4028A-13 (B)
17	I/O pin 0	4028A-12 (C)
18	I/O pin 1	SLEEP wakeup
19	I/O pin 2	4028A-11 (D)
20	I/O pin 3	4028B-10 (A)
21	I/O pin 4	has pull up resistor
22	I/O pin 5	4028B-13 (B)
23	I/O pin 6	4028B-12 (C)
24	I/O pin 7	UGET input(From Level shifter board)
25	I/O pin 8 A/D CAL	USEND output(To calibrate CDB5501)
26	I/O pin 9	SDI data line
27	I/O pin 10	4028B-11 (D)
28	I/O pin 11	resistor in/out
29	I/O pin 12	direct relay
30	I/O pin 13	reverse relay
31	Reg 5v	regulated 5 volts
32	Ground	Digital ground

The first four pins are shorted together to provide proper grounding. Pins #6 through #14 are not hooked to any external circuits since another A/D is used. Pin #5 is used to measure temperature with the Tattletale's on-board thermistor.

Pins #15 through #30 are the digital I/O connections for the Model 4A. The model 4A has 16 digital I/O ports available for use and the SP application requires 20. The board labelled I/O expander creates the additional I/O necessary. Two 4028 BCD to decimal decoders are used to convert 8 model 4A outputs to a maximum of 20 outputs. The 8 model 4A outputs used in the I/O expander board are indicated in the third column by the numbers "4028X-YY (Z)" where the X indicates which 4028 either A or B is used, the YY's indicate the 4028's pin and the Z indicates the input weighted code for that 4028. The outputs of the 4028's go to the 'RELAYS & DRIVE BOARD'. Pin #24 and #25 go to the 'POWER CONVERTER AND LEVEL SHIFTER BOARD'; before going on to the 'CDB5501 16 BIT A/D'. Pin #24 is the model 4A's software UART and accepts serial data from the CDB5501 A/D. Pin #25 is used to send a calibration pulse to the A/D. Five other lines go to the I/O expander board; two are for power (#31,#32) and the other three (#28,#29,#30) pass through and are used on the 'RELAYS & DRIVE BOARD' for controlling the different modes. Of the remaining three digital I/O ports (#18,#21,#26) only #26 is really available for general use. The other two might be used for their intended "Special function" and create a problem if used as an output. Pin #18 can be used to wake up the Tattletale from it's low power mode. If the model 4 is put into the low power mode all I/O lines except Pin #21 revert to inputs and are held at CMOS low levels with pull-down resistors. Pin #21 is pull-up high in the low power mode. It can be used to turn off power to external circuitry through a p-channel MOSFET.

All of the digital I/O outputs are CMOS compatible and capable of driving 1 TTL load (about 2.6mA).

The Modular Jack

The other connector shown in the TATTLETALE MODEL 4A block is labelled "Modular Jack". This is an RJ-11 type telephone jack which provides the output signal from the Tattletale to the packet controller model HK-21 of the radio telemetry section. The serial out signal from this jack is 0 to 5 volt CMOS logic signal, inverted from standard RS-232 signals. It is not suitable for driving a standard RS-232 cable directly.

The Onset TC-4 interface cable which is connected to this port has a driver built into it that converts the 0/5 volt inverted signals to approximately +/-10 volts(RS-232), non-inverted. One end of the TC-4 has the modular RJ-11 plug and the other end has a DB-25 female connector which connects directly to the Packet radio controller.

I/O EXPANDER BOARD

This board, as shown on the diagram, is connected between the Tattletale and the "RELAYS & DRIVE BOARD"(Fig. D5). The function of the I/O expander board is to take some of the thirteen I/O ports from the Tattletale and create a total of 21 ports to the RELAYS & DRIVE BOARD.

The two 4028 IC's take 8 digital I/O's from the Tattletale and create 20 outputs. Seventeen of the possible 20 are actually used and sent to the "RELAYS & DRIVE BOARD". Although 17 outputs are available, only 2 outputs, one from each 4028, can be energized at any given time and poses no problem as only two electrodes are selected at any given time.

In addition, 3 outputs from the Tattletale go directly to the Relays & Drive Board without modification. These 3 lines control the different mode-select relays. With the ground connection, there are a total of 21 connections which go by a 50 conductor ribbon cable between the I/O expander and Relays and drive boards. The output labelled Q0 for both 4028's are unused to provide a means of clearing all outputs to a zero or low level which clears all of the relays. When the input code for output Q0 is selected all of the other outputs revert to low levels and no lines are active. This clears all of the used outputs to zero and de-energizes all electrode select relays. Details of the Relay & Drive Board are presented in the section and the associated schematic labelled "SP DATA ACQUISITION SYSTEM RELAY DRIVE

SCHEMATIC". The following chart summarizes the codes of the relays, 4028s and the Tattletale commands which control them.

The Qs are the outputs of the appropriate 4028 AND the 0s and 1s associated with the Qs are the bit pattern necessary to activate that output. The 8,4,2,1 and D,C,B,A are the weighted BCD codes. The 2,0,15,14 are the corresponding Tattletale model 4A "I/O pin #" weighted pins. The column heading "TATTLETALE COMMANDS AND I/O PIN #" show the PSET and PCLR commands to activate the relay by selecting the proper 4028 output. Example: If relay #1 needs to be activated PSET 14, PCLR 2,0,15 will send the bit pattern 0001 to component 4028A, selecting output Q1 which activates relay #1.

The ODD-NUMBERED relays are controlled by 4028A and the EVEN-NUMBERED relays are controlled by 4028B. The operation of both 4028s are identical; the only difference is as shown on the charts below where the ODD numbered relays are controlled by PSET/PCLR of 2,0,15,14 while the EVEN numbered relays are controlled by PSET/PCLR of 10,6,5,3.

The letters A,B,C,D correspond to the 4028 inputs A1,B1,C1,D1 which also have the corresponding binary coded decimal weights 8,4,2,1.

4028A(CONTROLS ODD NUMBERED RELAYS)

	8 D 2	4 C 0	2 B 15	1 A (A is the LSB) 14	TATTLETALE COMMANDS AND I/O PIN #		RELAY#
Q1	0	0	0	1	PSET 14	PCLR 2,0,15	1
Q2	0	0	1	0	PSET 15	PCLR 2,0,14	3
Q3	0	0	1	1	PSET 15,14	PCLR 2,0	5
Q4	0	1	0	0	PSET 0	PCLR 2,15,14	7
Q5	0	1	0	1	PSET 0,14	PCLR 2,15	9
Q6	0	1	1	0	PSET 0,15	PCLR 2,14	11
Q7	0	1	1	1	PSET 0,15,14	PCLR 2	13
Q8	1	0	0	0	PSET 2	PCLR 0,15,14	15

4028B(CONTROLS EVEN NUMBERED RELAYS)

	8 D 10	4 C 6	2 B 5	1 A (A is the LSB) 3	TATTLETALE COMMANDS AND I/O PIN #		RELAY#
Q1	0	0	0	1	PSET 3	PCLR 10,6,5	2
Q2	0	0	1	0	PSET 5	PCLR 10,6,3	4
Q3	0	0	1	1	PSET 5,3	PCLR 10,6	6
Q4	0	1	0	0	PSET 6	PCLR 10,5,3	8
Q5	0	1	0	1	PSET 6,3	PCLR 10,5	10
Q6	0	1	1	0	PSET 6,5	PCLR 10,3	12
Q7	0	1	1	1	PSET 6,5,3	PCLR 10	14
Q8	1	0	0	0	PSET 10	PCLR 6,5,3	16
Q9	1	0	0	1	PSET 10,3	PCLR 6,5	SPARE, NO RELAY

The following summarizes the Tattletale commands that control the signals that go directly from the Tattletale I/O through the I/O expander board to the relays and drive board. These lines are directly controlled by the Tattletale so any on/ off combination is possible.

FUNCTION	TATTLETALE COMMANDS AND I/O PIN #	RELAY#
INSERT RESISTOR	PSET 11	17
DIRECT CONNECT	PSET 12	18
REVERSE CONNECT	PSET 13	19

Power for the I/O Expander Board comes from the Tattletale Model 4A's board and is indicated by +5V TT (Fig. D6).

POWER CONVERTER AND LEVEL SHIFTER BOARD

This board has two main functions: 1) Convert the +12 volt input voltage to +8V and 5V. 2) Change the signal from the CDB5501 16 bit A/D to an acceptable signal level for use by the Tattletale Model 4A.

The upper left of diagram D6, in the box labelled POWER CONVERTER AND LEVEL SHIFTER BOARD, shows that the power converter section consists of the two LM340s, the 7660 and associated capacitors. The two LM340s are 3-terminal positive voltage regulators. One regulates 8 volts and the other regulates 5 volts. The LM340's are in TO-220 packages. The 7660 is a CMOS Voltage Converter in an 8 pin DIP package which takes a positive input voltage and creates an equal negative output voltage. The LM340s are connected to the 12v external power source and both have the same 1.5A output current rating. The +5 volts output goes directly to provide the +5 volts out and to the input of the 7660 which produces the -5 volts output. The +5 volts output has a conservative rating of 1 amp of which we are drawing less than 20 mA. However, on the -5 volts output we are already drawing about 10 mA (power for the CDB5501) which drops the voltage from the 7660 to about -4.5 volts. The voltage output of the 7660 drops off linearly from -4.5 volts at 1volt/20 ma. To maintain a value of -4.0 volts the maximum additional current capability of the 7660 is 10 ma. The 8 volt regulator powers the transceiver and has a conservative rating of 1 amp.

The other use of this board is as a "Level shifter" which uses the MAX232 IC. This IC is a dual RS-232 receiver/transmitter with 4 voltage level translators. Two of the translators convert 0 to +5 volts TTL/CMOS levels to plus and minus 9 volts RS232 compatible outputs. The other two are RS232 receivers that convert RS232 inputs and convert them to 5 Volts TTL/CMOS compatible signals. Only one of the RS232 to CMOS/TTL converters is used and is connected to the serial output of the CDB5501 16 BIT A/D. The signal is converted to 0 to +5 volts level before going to the Tattletale UGET software UART input.

CDB5501 16 BIT A/D

The CDB5501 manufactured by Crystal Semiconductor Corporation (Austin, Texas) is an evaluation board designed to give users experience with the capabilities of the CS5501 16 bit A/D. This board has everything onboard required for our application, including a good layout to control noise so the board is used "as is" in our acquisition system. The evaluation board comes complete with documentation that details of it's operation (Crystal

Semiconductor Corporation 1989) will not be discussed. The following are hardware switch and jumper settings that we use to make the CDB5501 compatible with the Tattletale.

P1	INT	Uses ON-Board 4.9152 MHz Osc.
P2	0	CLKIN Rate us 4.9152 MHz.
P3	12	1.2KHz Baud rate
P4	10	Counts 2048 not DRDY pulses before not CS is enabled.
P5	AC	Asynchronous Communications Mode for data output.
P8	---	No connections
P9	DC	Use Decimation Counter
P10	---	No connections
P11	BC	Internal Baud Clock Used

The SW1 SWITCH

The switch labelled SW1 settings

SW1	1	2	3	4
ON	X	X	-	-
OFF	-	-	X	X

The SW1 switches are set as shown above, positions 1 and 2 are on and 3 and 4 are off. Positions 1 and 2 control the type of calibration that is initiated when the cal line is taken low. In our case, we have the CDB5501 set up to do a "self-cal". Switch SW1 position 3 is set for bipolar analog inputs. Switch SW1 position 4 is set for the "awake" mode.

Drawing D6, "TATTLETALE MODEL 4A I/O DETAILS", shows the upper middle box labelled CDB5501 16 BIT A/D which represents the CDB5501 and all of the inter-board connections. The analog signals come on board through a BNC female connector(ANALOG INPUT BNC). The CDB5501 accepts inputs of +/- 2.5VDC. and has a 16 bit A/D converter. The general dynamic range is as follows: -2.5vdc=000000 counts

+2.5vdc=65,536 counts
0.0vdc=32,768 counts
.0763mv= 1 count

These values are used to calculate the actual analog input voltages.

ISOLATION AMPLIFIER FOR SP DATA ACQUISITION FIELD UNIT

This section describes the Isolation Amplifier that is used as the buffer/ground isolator in the SP Data Acquisition Field unit as shown in drawing D7 "ISOLATION AMPLIFIER FOR SP DATA ACQUISITION FIELD UNIT".

SP measurements use non-polarizing lead-lead chloride electrodes as the probes that contact the earth at selected points. When these electrodes are selected during the measurement sequences one of the electrodes becomes a ground point to the acquisition system. The acquisition system also has a finite resistance to the ground either through the antenna system or through other leakages like the batteries and housing hardware. These different grounds can and do cause unwanted offsets and drifts to the actual small millivolt changes in SP readings. To alleviate this problem an isolation amplifier is used between the "electrode and mode select relays" and the acquisition system A/D. This amplifier provides adequate isolation to eliminate the different grounds from interacting with each other and thereby reduce their affects on the data.

The isolation amplifier is a Burr Brown model 3652 powered by a Burr Brown model 722 dual isolated DC/DC converter. The isolation amplifier is optically isolated and the overall gain is .96. The input impedance is set to 30 Mohm by the two 15 Mohm resistors to input common. These resistors are installed to improve the stability of the amplifier. The 500 Kohm resistors between pin# 8 and 11 and pin# 9 and 10 are used to set the gain of the 3652 to 0.96. The other two 500Kohm resistors in combination with the 1 microfarad capacitor form a single-pole RC filter with the 3 db point at 1 Hz. The purpose of this filter is to remove high frequency "noise" from the input signals. The error associated with the combination of 1 Mohm filter resistance and the 30 Mohm input impedance is given by the ratio 30/31. The input to the Isolation amplifier is lower than the actual value before the filter by this amount (.9677). By using the inverse of this value the actual value can be calculated. The 10K pot on the output balance pins is used to zero the output stage of the 3652.

The drift characteristics of the 3652 include a field drift expected to be well above the specified drift level of +-.5mV so it is necessary to correct for this thermal drift. One of the measurement combinations results in a shorted input to the 3652 and we use these data to remove the thermal drift from the data before analyzing for real SP changes.

The 3652 is powered via the 722 Dual Isolated DC-DC converter which isolates the input circuit power supply from the output circuit power supply and thus helps retain the isolation characteristics of the 3652. The power for this board comes from the 12 VDC system power supply.

CONTACT RESISTANCE AND "W" CALCULATIONS

The only electrode parameter that we are able to interactively measure is the contact resistance. The contact resistance of an electrode is the equivalent DC resistance between any electrode and the ground with which it is in contact. Our technique for measuring this parameter provides us with a quantitative way of gauging the condition of the electrodes and their interface with the ground. The sum of ground resistances plus contact resistances of each electrode is deduced by inserting a resistor in parallel across the electrodes and comparing that reading to that taken when no resistor is across the electrodes. The ratio of the voltage-with-resistor over voltage-without-resistor is given the arbitrary designation 'W' and is related to contact resistance assuming that ground resistance is negligible. The following is a more detailed discussion of this process.

Diagram D8, "EQUIVALENT CIRCUITS", shows a simple circuit model for the task of determining contact resistance of the electrodes (not a model for the mechanism of SP generation). We treat the SP source as an ideal voltage source with electrode-to-ground resistances labeled RC1 and RC2; both of these resistances are combined to form the equivalent resistance RC=RC1+RC2. The electrodes have very low internal DC resistances; the electrode internal dc resistances are much less than RC,RF,RIN defined below.

The upper diagram shows the case when no resistor is used across the electrodes or, in other words, the electrodes are directly hooked up to the pre-amp circuitry. The resistors RF1 and RF2 are part of the input filter. The filter's 1 microfarad capacitor is not shown and it's impedance assumed infinite when measurement is being made. These two resistors are combined to form the equivalent filter resistor RF. The value of RIN is set by 4 resistors to 31 Mohms (see D7). The; 3652 has a differential input impedance of well over 10^{10} ohms. The voltage input as seen by the "Ideal Preamp" is the voltage that appears across RIN. This voltage labeled VINDIR (voltage input direct mode) is given by the formula:

#1) VINDIR=(RIN SP)/(RIN+RF+RC)

Here, the value of SP represents the voltage of the ideal voltage source. This parameter will disappear in the calculations.

The lower diagram is the circuit with the resistor RP in parallel with the two electrodes. RF and RIN are the same as before. Here again the voltage of interest is the voltage appearing at the input of the Ideal Preamp. This voltage is represented by VINRES (voltage input with the parallel resistor inserted). The representative value of VINRES is given by the following formula:

#2) VINRES=(SP1 RIN)/(RF+RIN)

Where:
SP1={SP[RP(RF+RIN)/(RP+RF+RIN)]}/{RC+[RP(RF+RIN)/(RP+RF+RIN)]}

This formula again assumes a value of SP as the voltage of an ideal voltage source.

The measured values of analog voltages are used to calculate the following ratio:

W=VINRES/VINDIR.

In terms of the circuit resistances this ratio is:
#3) W=[RP(RC+RF+RIN)]/[RC(RF+RIN+RP)+RP(RF+RIN)]

Substituting the known values into the formula and solving #3:

RP=20,000 OHMS RF=1,000,000 OHMS RIN=30,000,000 OHMS

and solving equation #3 we get:

#4) W=(RC+31,000,000)/[(1551 RC)+31,000,000]

Solving for RC, the contact resistance, we get:

#5) RC={48,050,000,000/[1551(1551 (W-1))]} - (31,000,000/1551)

Formula #5 gives the solution for deriving the contact resistance (RC) for the given values of RP,RF,RIN.

The general solution for RC is:

#6 RC=[RP(1-W)(RF+RIN)]/[(RF W)+(RIN W)+RP(W-1)]

Typical values of W and RC measured during the first few months of operation are W=.6 RC=13.3k ohms.

SOFTWARE NOTES

The Tattletale model 4A data logger uses a version of BASIC called TTBASIC. This interpreted language is loaded in an on-board ROM. Programs and data are stored in the Tattletale RAM. The programs can either be written on the Tattletale or on any word processor capable of generic ASCII files. The files created are then downloaded to the Tattletale using a terminal emulator over an RS232 connection. Programs for this applications were created using the utility called Tattletools-PC (Onset Computer Corporation 1989) that combines an editor and a terminal emulator and works interactively with the Tattletale.

The program listing that follows is called 'COLLECT2.SP'. It's purpose is to collect Self-Potential(SP) data using this Data Acquisition System. Also refer to diagram D9 and D10 for the flow diagram for this program. The collected data is sent by VHF radio telemetry using Packet radio technology.

```
REM************************COLLECT2.SP***********************
REM**Used as a program for the Tattletale Model 4A data logger.
This REM**program collects Self-Potential (S.P.) data temporarily
stores REM**the data , then sends the data out of the Model 4A's
hardware REM**RS-232 port.  This data is packetized in the HK-21
Packet Radio REM**Controller and sent to the observatory via radio
transmitter.
REM**Each electrode combination is measured in four different
REM**"modes"and is described as follows:
```

```
  REM**PSET 11 CONTROLS RESISTOR INSERTING RELAY (ACTIVATES RELAY
  REM**#17)**
  REM**PSET 12 CONTROLS DIRECT CONNECT RELAY (ACTIVATES RELAY #18)
  REM**PSET 13 CONTROLS REVERSE CONNECT RELAY (ACTIVATES RELAY #19)
REM**MODE 0, M=0 DIRECT NO RESISTOR
REM**MODE 1, M=1 REVERSE NO RESISTOR
REM**MODE 2, M=2 DIRECT WITH 20K OHM PARALLEL RESISTOR INSTALLED
REM**MODE 3, M=3 REVERSE WITH 20K OHM PARALLEL RESISTOR INSTALLED

REM**The sequence of measurements is as follows:
REM**DIRECT MODE NO RESISTOR
REM**REVERSE MODE NO RESISTOR
REM**DIRECT WITH RESISTOR
REM**REVERSE WITH RESISTOR
REM**IF 2 ELECTRODES ARE SELECTED, THE SEQUENCE WOULD BE AS FOLLOWS
REM**ELECTRODE 1,1 DIRECT NO RESISTOR (11D0)
REM**    "     1,2   "    "     "      (12D0)
REM**    "     2,1   "    "     "      (21D0)
REM**    "     2,2   "    "     "      (22D0)
REM**    "     1,1 REVERSE NO RESISTOR (11R0)
REM**    "     1,2    "     "     "     (12R0)
REM**    "     2,1    "     "     "     (21R0)
REM**    "     2,2    "     "     "     (22R0)
REM**    "     1,1 DIRECT WITH RESISTOR (11DR)
REM**    "     1,2   "      "      "    (12DR)
REM**    "     2,1   "      "      "    (21DR)
REM**    "     2,2   "      "      "    (22DR)
REM**    "     1,1 REVERSE WITH RESISTOR (11RR)
REM**    "     1,2    "      "      "    (12RR)
REM**    "     2,1    "      "      "    (21RR)
REM**    "     2,2    "      "      "    (22RR)

REM**IF MORE ELECTRODES ARE USED THERE WOULD BE THAT MANY MORE
REM**COMBINATIONS TO MEASURE FOR THE ELECTRODE DATA.
REM**HOWEVER THE CALIBRATION MEASUREMENTS WOULD ONLY BE ON
REM**ELECTRODE CHANNELS 7,AND 8 AND ONLY CONTAIN THE COMBINATIONS
REM**AS ILLUSTRATED ABOVE BUT INSTEAD OF 1'S AND 2'S, THERE WOULD
REM**BE 7 AND 8'S.

REM*****************************************************************
REM**************START MAIN BODY OF THE PROGRAM*****************
REM*****************************************************************
  REM**SET BAUD RATE TO 1200**
60 ASM 16,DB 6

REM**PRINT CURRENT TIME AND ASK IF NEW TIME NEEDS TO BE ENTERED
61 RTIME
62 PRINT 'THE CURRENT TIME IS ',?(2),':',?(1),' ',?(0)
63 PRINT 'THE CURRENT DATE IS ',?(4),'/',?(3),'/',?(5)
64 PRINT:INPUT 'Do you want to enter a new date and time(Y/N) :' T
65 IF T = N GOTO 92
66 IF T = Y GOTO 68
```

```
67 GOTO 64
68 INPUT 'THE YEAR IS (0 TO 99)     ' ?(5)
69 INPUT 'THE MONTH IS (1 TO 12)    ' ?(4)
70 INPUT 'THE DAY IS (1 TO 31)      ' ?(3)
71 INPUT 'THE HOUR IS (0 TO 23)     ' ?(2)
72 INPUT 'THE MINUTE IS (0 TO 59)   ' ?(1)
73 INPUT 'THE SECOND IS (0 TO 59)   ' ?(0)
74 STIME
76 PRINT : PRINT 'THE NEW TIME IS ',?(2),':',?(1),' ',?(0)
77 PRINT 'THE NEW DATE IS ',?(4),'/',?(3),'/',?(5)
78 PRINT:INPUT 'PRESS "C" TO CONTINUE OR "R" TO REDO TIME AND DATE:
'T
79 IF T = C GOTO 92
80 IF T = R GOTO 68


REM** ENTER NUMBER OF ELECTRODES TO TRIGGER NUMBER OF RELAYS
REM**LINE 93 AND 94 SETS THE RANGE FOR VALID ELECTRODE INPUT
REM**NUMBERS.
REM**YOU NEED AT LEAST 2 ELECTRODES TO DO A COMPARISON.  WHAT WOULD
REM**NORMALLY HAVE BEEN ELECTRODE INPUTS 7 AND 8 ARE USED FOR
REM**CALIBRATION SIGNALS.

92 INPUT 'ENTER THE AMOUNT OF ELECTRODES :' R
93 IF R<2 GOTO 92
94 IF R>6 GOTO 92
95 E=R

REM**CLEAR ANY ACCIDENTALLY SET RELAYS*******
200 PCLR 2,3,15,14,10,6,5,0,11,12,13

REM**START COLLECTING DATA FROM THE SELECTED ELECTRODES AND
REM**TRANSMIT TO HVO.
REM**SELECTING MODES & ELECTRODES TO READ DATA FROM.
210 FOR M=0 TO 3
220     FOR A=1 TO R
230         FOR B=1 TO R

                REM**GOSUB 7000 IS SHORT CAPACITOR SECTION.
240             IF A><B GOSUB 7000

                REM**GOSUB 6000 IS SELECT MODE RELAY/S SECTION.
250             GOSUB 6000

                REM**GOSUB 2230 IS SELECT INPUT ELECTRODE RELAYS
                REM**SECTION.
260             GOSUB 2230

                REM**GOSUB 3100 IS WAIT:CAL:COMPARE:STORE DATA
                REM**SECTION.
270             GOSUB 3100
```

```
                REM**CLEAR ALL RELAYS BEFORE SELECTING NEXT
                REM**ELECTRODE/MODE COMBINATION.
280             PCLR 0,2,3,5,6,10,11,12,13,14,15

290         NEXT B
300     NEXT A
310 NEXT M

    REM**GOSUB 4460 IS TRANSMIT DATA BACK TO OBSERVATORY SECTION
320 GOSUB 4460

REM**END ELECTRODE DATA COLLECTION AND TRANSMIT BACK TO HVO
REM**SECTION START COLLECTING DATA FROM CALIBRATION INPUTS CHANNELS
RME**7 & 8
REM**SELECTING MODES & CALIBRATION CHANNEL INPUTS TO READ DATA
REM**FROM.
400 FOR M=0 TO 3
410     FOR A=7 TO 8
420         FOR B=7 TO 8

                REM**GOSUB 7000 IS SHORT CAPACITOR SECTION.
430             IF A><B GOSUB 7000

                REM**GOSUB 6000 IS SELECT MODE RELAY/S SECTION.
440             GOSUB 6000

                REM**GOSUB 2230 IS SELECT INPUT ELECTRODE RELAYS
                REM**SECTION.
450             GOSUB 2230

                REM**GOSUB 3100 IS WAIT:CAL:COMPARE:STORE DATA
                REM**SECTION.
460             GOSUB 3100

                REM**CLEAR ALL RELAYS BEFORE SELECTING NEXT
                REM**ELECTRODE/MODE COMBINATION.
470             PCLR 0,2,3,5,6,10,11,12,13,14,15

480         NEXT B
490     NEXT A
500 NEXT M

    REM**R=8 USED IN LINE 4475 TO GET CALIBRATION DATA OUT OF
    REM**DATAFILE
510 R=8

    REM**GOSUB 4460 IS TRANSMIT DATA BACK TO OBSERVATORY SECTION
520 GOSUB 4460

REM**SET "R" BACK TO THE ORIGINAL VALUE AFTER SETTING TO R=8 IN
REM**LINE 510. THE ORIGINAL VALUE IS DETERMINED BY LINE 92 AND
REM**ASSIGNED TO "E" IN LINE 95. NOW WE ASSIGN "R" BACK TO "E"
```

```
REM**SO THAT THE NUMBER OF ELECTRODES SELECTED ARE CORRECT WHEN
REM**STARTING TO COLLECT DATA ON THE NEXT ROUND(GOTO LINE 200).
530 R=E

     REM**THIS SECTION RESERVED TO INSTALL DELAY IF NEEDED BEFORE
     REM**COLLECTING ANOTHER ROUND OF ELECTRODE AND CALIBRATION
     REM**DATA.
     REM**THIS LOOP IS SET UP TO WAIT 1 HOUR BEFORE STARTING AGAIN,
     REM**ANY TIME SPAN CAN BE PROGRAMMED.
     REM**30000=300 SECONDS(5 MIN.) WE LOOP THROUGH THIS 12 TIMES
     REM**TO GET 1 HR.
     REM**THIS SECTION IS REMARKED OUT BECAUSE THE TIME FOR 1 ROUND
     REM**IS ALREADY GREATER THAN AN HOUR, HOWEVER THE LINES ARE
     REM**INSERTED HERE IF PROGRAM CHANGES DICTATE A DELAY BETWEEN
     REM**MEASUREMENTS.
REM**540 FOR S=1 TO 12
REM**550     SLEEP 0
REM**560     SLEEP 30000
REM**570 NEXT S

     REM**GO BACK TO START ANOTHER SET OF ELECTRODE AND CAL
     REM**READINGS,STORE AND TRANSMIT BACK TO THE OBSERVATORY.
590 GOTO 200

REM**************************************************************
REM*****************END OF MAIN BODY OF PROGRAM******************
REM**************************************************************
REM**************************************************************
REM**************************************************************
REM*****************START SUBROUTINE SECTION*********************
REM**************************************************************


REM******************START GOSUB 2230****************************
REM***************SELECT INPUT ELECTRODE RELAYS SECTION**********

REM**LINES 2230-2390 SET THE CODES TO THE INPUT OF THE 4028'S**
REM**THE A SIGNIFYS 4028A,THE B FOR 4028B**
REM**THE PSET #'S SET THOSE I/O,S TO OUTPUTS THEN SETS THEM TO
REM**HIGH(+5V)**
REM**THE PCLR #'S SET THOSE I/O'S TO OUTPUTS THEN SETS THEM TO
REM**LOW(0V)**

2230 IF A=1 PSET 14:PCLR 2,0,15
2240 IF A=2 PSET 15:PCLR 2,0,14
2250 IF A=3 PSET 15,14:PCLR 2,0
2260 IF A=4 PSET 0:PCLR 2,15,14
2270 IF A=5 PSET 0,14:PCLR 2,15
2280 IF A=6 PSET 0,15:PCLR 2,14
2290 IF A=7 PSET 0,15,14:PCLR 2
2300 IF A=8 PSET 2:PCLR 0,15,14
2310 IF B=1 PSET 3:PCLR 10,6,5
```

```
2320 IF B=2 PSET 5:PCLR 10,6,3
2330 IF B=3 PSET 5,3:PCLR 10,6
2335 IF B=4 PSET 6:PCLR 10,5,3
2350 IF B=5 PSET 6,3:PCLR 10,5
2360 IF B=6 PSET 6,5:PCLR 10,3
2370 IF B=7 PSET 6,5,3:PCLR 10
2380 IF B=8 PSET 10:PCLR 6,5,3
2390 IF B=9 PSET 10,3:PCLR 6,5
2400 RETURN

REM******END GOSUB 2230 SELECT INPUT ELECTRODE RELAYS SECTION****
REM*************************************************************
REM*************************************************************
REM*************START GOSUB 3100******************************
REM****WAIT:CAL:COMPARE:STORE DATA SECTION***********************
REM**WAIT 1 MINUTE TO ALLOW RISETIME CURVE TO STABILIZE BEFORE
REM**GETTING
REM**READINGS(3100,3105) . THEN SEND SELFCAL PULSE AND START
REM**READING DATA.
REM**CALIBRATE (PSET/PCLR 8),GET DATA FROM A/D AND STORE (UGET).
REM**PSET AND PCLR TOGGLES I/O #8 TO CAUSE THE CDB5501 TO DO A
REM**SELFCAL.
REM**THE UGET COMMAND GETS AND STORES 2 BYTES OF DATA FROM THE
REM**CDB5501.
REM**2 BYTES ARE REQUIRED TO GET 1 16 BIT DATA POINT FROM THE
REM**CD5501. THE 5501 IS A 16 BIT A/D BUT THE OUTPUT IS PACKETIZED
REM**INTO 2-8BIT UART COMPATIBLE WORDS SO IT TAKES 2 BYTES TO MAKE
REM**1 DATA WORD. "RETURN"TO CHANGE MEASUREMENT CONFIGURATION
REM**EITHER DIRECT/REVERSE OR RESISTOR/NO RESISTOR **

3100 SLEEP 0
3105 SLEEP 6000
3110 PSET 8
3120 SLEEP 0
3130 SLEEP 100
3135 PCLR 8

REM** LOOKING AT THE DATA FOR STABILIZATION LINE 3220 GIVES THE
REM**TOLERANCE FOR DATA STABILITY AT 1 BIT. LINES 3240,3250 SETS
REM**SAMPLING INTERVAL AT 15 SEC. IF THE LAST TWO POINTS AGREE TO
REM**1 BIT, THE LAST POINT IS STORED**
REM**STORE DATA ROUTINE STARTS AT LINE 3280;SEE LINE 3220.
REM**L IS USED TO PROVIDE EXIT FROM THE COMPARISON LOOP IF THE
REM**ELECTRODE OR SIGNAL LINES ARE CREATING RANDOM NOISE SO THAT
REM**THE DATA DOESN'T STABILIZE TO WITHIN 1 BIT. LINES 3225,3226
REM**SET THE COUNT TO 12, ANYTHING GREATER OR EQUAL TO 12 WILL
REM**AUTOMATICALLY SAVE THE LAST VALUE FOR X EVEN IF THE DATA IS NO
REM**GOOD OR NOISY. THIS WILL ALLOW THE ACQUISITION TO CONTINUE
REM**EVEN THOUGH THERE IS A BAD ELECTRODE.

3140 T=0:L=0
3150 UGET 1200,2,T,800
```

```
3155 T=0
3160 Y=GET(T,#2)
3170 SLEEP 0
3180 SLEEP 100
3190 T=0
3200 UGET 1200,2,T,800
3205 T=0
3210 Z=GET(T,#2)
3220 IF ABS(Y-Z)<1 GOTO 3280
3225 L=L+1
3226 IF L>=12 GOTO 3280
3230 Y=Z
3240 SLEEP 0
3250 SLEEP 1500
3260 GOTO 3190

REM**STORE DATA**
REM**X=POINTER VARIABLE FOR X DATAFILE. EACH DATA POINT HAS A
REM**DISCRETE LOCATION IN THE DATAFILE. THIS LOCATION IS
REM**DETERMINED BY LINE 3280 WHICH MUST TAKE INTO ACCOUNT ELECTRODE
REM**COMBINATION AND MODE OF MEASUREMENT: DIRECT,REVERSE,DIRECT
REM**WITH RESISTOR, REVERSE WITH RESISTOR P=COUNTS THE AMOUNT OF
REM**DATA IN THE DATA FILE. EACH TIME LINE 3310 RUNS, 16 BYTES ARE
REM**USED UP IN THE DATAFILE SINCE EACH NUMBER IS STORED AS 2
REM**BYTES(16BITS)

3280 X=(16+((B-1)*64))+(M*16)+((A-1)*512)
3300 RTIME
 REM**STORE DD,MM,YY,HH,MM,SS,TEMP,D INTO THE DATAFILE**
3310 STORE X,#2,?(3),?(4),?(5),?(2),?(1),?(0),TEMP(CHAN(7)),Z
3305 P=X
3320 RETURN

REM*****END GOSUB 3100 WAIT:CAL:COMPARE:STORE DATA SECTION*******
REM**************************************************************

REM*****************START GOSUB 4460****************************
REM********TRANSMIT DATA BACK TO MAIN COMPUTER SECTION**********
4470 XSHAKE 1000
4475 IF R=8 GOTO 5000
4480 FOR A = 1 TO R
4490    FOR B = 1 TO R
4500     FOR M = 0 TO 3
4510 X = (16+((B-1)*64))+(M*16)+((A-1)*512)
4520   FOR I = 1 TO 8
4530     IF I = 7 GOTO 4560
4540     IF I = 8 GOTO 4570
4550     PRINT #2,GET(X,#2)," "; : GOTO 4580
4560     PRINT #4,GET(X,#2)," "; : GOTO 4580
4570     PRINT #5,GET(X,#2)
4580   NEXT I
4590       NEXT M
```

```
4600      NEXT B
4610     NEXT A
4620 RETURN

REM**START GOTO 5000 WHICH SETS THE A AND B VARIABLES TO 7 AND 8 IN
REM**PLACE OF LINES 4480 AND 4490.  THIS SETS THE DATA POINTER X TO
REM**GET THE CALIBRATION DATA FROM THE DATAFILE.
5000    FOR A = 7 TO 8
5010        FOR B =7 TO 8
5020        GOTO 4500

REM**********END GOSUB 4460 TRANSMIT DATA SECTION*****************
REM**************************************************************
REM**********************START GOSUB 6000************************
REM**SELECT THE PROPER RELAYS FOR THE DIFFERENT MODE MEASUREMENTS**
REM**THE FOLLOWING ARE RELAY SELECT CODES(ALSO CALLED MODE SELECT**
REM**RELAYS)
REM**PSET 11 CONTROLS RESISTOR INSERTING RELAY (ACTIVATES RELAY
REM**#17)
REM**PSET 12 CONTROLS DIRECT CONNECT RELAY (ACTIVATES RELAY #18)
REM**PSET 13 CONTROLS REVERSE CONNECT RELAY (ACTIVATES RELAY 19)
REM**MODE 0, M=0 DIRECT NO RESISTOR
REM**MODE 1, M=1 REVERSE NO RESISTOR
REM**MODE 2, M=2 DIRECT WITH 20K OHM PARALLEL RESISTOR INSTALLED
REM**MODE 3, M=3 REVERSE WITH 20K OHM PARALLEL RESISTOR INSTALLED

 REM**FIRST CLEAR ALL MODE RELAYS
6000 PCLR 11,12,13

 REM**THEN CHECK THE VALUE OF M AND SET THE APPROPRIATE RELAY/S
6010 IF M=0 PSET 12
6020 IF M=1 PSET 13
6030 IF M=2 PSET 11,12
6040 IF M=3 PSET 11,13

 REM**RETURN
6050 RETURN

REM******************END GOSUB 6000*****************************
REM**SELECT THE PROPER RELAYS FOR THE DIFFERENT MODE MEASUREMENTS**
REM**************************************************************


REM***********************START GOSUB 7000***********************
REM*****************SHORT CHARGED CAPACITOR SECTION***************
REM*THIS SUBROUTINE SHORTS THE INPUT OF THE PREAMP BY SELECTING THE
REM*TWO INPUT RELAYS FOR THE SAME ELECTRODE. THE REASON FOR THIS IS
REM*TO AVOID HAVING THE CHARGED INPUT CAPACITOR DISCHARGE THROUGH
REM*THE ELECTRODES AND POLARIZING THEM. THE RELAYS ARE CLOSED FOR
REM*1 MINUTE TO ALLOW THE 1 uFARAD FILTER CAPACITOR TO DISCHARGE
REM**THROUGH THE 1 MEG OHM FILTER RESISTANCES (2-500K RESISTORS).
REM**EITHER THE DIRECT OR REVERSE SELECT
```

```
REM**RELAYS MUST BE ACTIVATED OTHERWISE THE CAPACITOR WILL NOT BE
REM**HOOKED TO THE INPUT SELECT RELAYS WHICH DO THE SHORTING. THE
REM**RESISTOR INSERTING RELAY DOESN'T EFFECT THE SHORTING PROCESS.
REM**THE FOLLOWING RELAY SELECT CODES(ALSO CALLED MODE SELECT
REM**RELAYS)
REM**ARE AS FOLLOWS:
REM**PSET 11 CONTROLS RESISTOR INSERTING RELAY (ACTIVATES RELAY
REM**#17)**
REM**PSET 12 CONTROLS DIRECT CONNECT RELAY (ACTIVATES RELAY #18 )
REM**PSET 13 CONTROLS REVERSE CONNECT RELAY (ACTIVATES RELAY #19)

REM**FIRST CLEAR MODE SELECT RELAYS 17,18,19
7000 PCLR 11,12,13

 REM**NEXT CLEAR ALL ELECTRODE SELECT RELAYS TO DISCONNECT ANY
     REM**ELECTRODES FROM THE CHARGED CAPACITOR
7010 PCLR 0,2,3,5,6,10,14,15

 REM**SELECT DIRECT CONNECT RELAY (THIS HOOKS UP THE RESISTOR AND
     REM**CAPACITOR FILTER TO THE ELECTRODE SELECT RELAYS).
7120 PSET 12

REM**SELECT TWO RELAYS FOR THE SAME ELECTRODE TO SHORT AND
REM**DISCHARGE CAPACITOR THROUGH 1 MEG OHM FILTER RESISTOR. IN THIS
REM**CASE ELECTRODE #6 IS SELECTED.
7130 PSET 0,15:PCLR 2,14
7140 PSET 6,5 :PCLR 10,3

 REM**DISCHARGE CAPACITOR FOR 1 MINUTE.
7150 SLEEP 0
7160 SLEEP 6000

 REM**CLEAR ALL RELAYS AND RETURN
7170 PCLR 0,2,3,5,6,10,11,12,13,14,15
7180 RETURN

REM*************END GOSUB 7000*************************************
REM**SHORT CHARGED CAPACITOR SECTION*******************************
REM***************************************************************
REM***************************************************************
REM***************END SUBROUTINE SECTION*************************
REM***************************************************************
```

DATA STORAGE AND TRANSMISSION FORMAT

The sequence of data acquisition is different than the sequence of data transmission to the Observatory. The following describes these differences.

The electrode data are collected and saved in the following sequence.

ELECTRODE	1,1	DIRECT	NO	RESISTOR
"	1,2	"	"	"
"	1,3	"	"	"
"	1,4	"	"	"
"	1,5	"	"	"
"	2,1	"	"	"
"	2,2	"	"	"
"	2,3	"	"	"
"	2,4	"	"	"
"	2,5	"	"	"
"	3,1	"	"	"
"	3,2	"	"	"
"	3,3	"	"	"
"	3,4	"	"	"
"	3,5	"	"	"

If more electrodes are involved this pattern continues. The other modes have the identical electrode sequencing pattern as above. The other 3 modes are sequenced in the following order.

REVERSE NO RESISTOR
DIRECT WITH RESISTOR
REVERSE WITH RESISTOR

The following are the sequence of data transmission out of the datafile of the Tattletale. These data are transmitted via the Packet TNC and RR-155 transceiver.

ELECTRODE	1,1	DIRECT NO RESISTOR
"	"	REVERSE NO RESISTOR
"	"	DIRECT WITH RESISTOR
"	"	REVERSE WITH RESISTOR
ELECTRODE	1,2	DIRECT NO RESISTOR
"	"	REVERSE NO RESISTOR
"	"	DIRECT WITH RESISTOR
"	"	REVERSE WITH RESISTOR
ELECTRODE	1,3	DIRECT NO RESISTOR
"	"	REVERSE NO RESISTOR
"	"	DIRECT WITH RESISTOR
"	"	REVERSE WITH RESISTOR

Pattern continues for more electrodes....

ELECTRODE	2,1	DIRECT NO RESISTOR
"	"	REVERSE NO RESISTOR
"	"	DIRECT WITH RESISTOR
"	"	REVERSE WITH RESISTOR
ELECTRODE	2,2	DIRECT NO RESISTOR
"	"	REVERSE NO RESISTOR
"	"	DIRECT WITH RESISTOR
"	"	REVERSE WITH RESISTOR

......Continue until the data for the last electrode combination are transmitted.

As can be seen, the sequence of data acquisition differs from the sequence of data transmission to the HVO. This is important to keep in mind during data processing. The program can be modified if needed to keep the sequences the same.

The data that are transmitted to the observatory are received on a Leading Edge IBM-compatible computer. A terminal emulator program running in the session logging mode is used to capture the received data. The stored data is removed from the Leading Edge then sorted and plotted on another PC.

PACKET RADIO CONTROLLER NOTES

This data acquisition system uses "Packet Radio Technology". The type that we use is the HK-21 by the Heath Company (Heath,1988). This equipment is also called a terminal node controller (TNC).

The TNC uses a system that considerably reduces errors in the radio transmitted data. The digital signals from the acquisition system are grouped into discrete packets. These packets are sent via a radio to the receiving TNC which checks for any errors in the data group and sends a confirming signal. If the originating TNC does not receive a confirming signal it will automatically resend the same packet of data. The signals are either confirmed or the connection is terminated. The TNC also serves as the controller for the transceiver by controlling the push to talk line (PTT).

Both TNCs must be in "transparent" mode when communicating with each other. Otherwise the TNC and TATTLETALE will get into and endless loop talking nonsense to each other. The TNC on the computer end needs to be able to transmit control characters to the field TNC and this is only possible with the TNCs in the "transparent" mode. The above is best accomplished by setting CONMODE TO TRANS on both TNCs.

The field TNC is called HVO01 and the observatory receiving TNC is called HVO02.

There are two baud rates that need to be set for each tnc. One controls the baud rate between the TNC and the radio. This is called HBAUD. The other baud rate is called ABAUD for the speed of data transmission between the TNC and either the Leading Edge computer or the Tattletale model 4A depending on which unit is being set.

Presently the baud rates are set as follows:

FIELD:HBAUD=1200	ABAUD=1200
OBSERVATORY:HBAUD=1200	ABAUD=9600

The HBAUD must be set for 1200 for both TNCs because of the transmitter audio bandwidth limitation. 1200 is the maximum baud rate the RR155 transceivers can send. ABAUD is set at 1200 for the field and 9600 for Observatory receive TNC. ABAUD was originally set at 1200 for both TNCs to match the baud rate at which the radio was transmitting and, in this way, try to reduce any timing problems when transmitting large amounts of data from the field to the Observatory. The ABAUD for the Observatory was changed to 9600 as an experiment to see if any problems would be created; none have surfaced so far. The ABAUD for the field site could be changed to 9600 as well. Changing the ABAUD to 9600 would make it easier to re-establish contact with the TNCs in the event of a power failure or glitch because the default value of ABAUD is 9600.

The various TNC operating settings are default setting that are initiated during power up. Settings that need to be changed are sent via the RS-232 port. All settings are stored in battery backed-up RAM of the TNC.

All of the following except those marked with the asterisk are default settings. The default settings are listed next to the asterisk.

The following are settings that are used with the terminal node controller located at the FIELD UNIT data acquisition site. The call sign for this controller is HV001.

8BITCONV	OFF	
AX25L2V2	ON	
ABAUD	1200	*9600
ASYRXOVR	0	
AUTOLF	ON	
AWLEN	8	*7
AXDELAY	0	
AXHANG	0	
BEACON	EVERY 0	
BBFAILED	0	
BKONDEL	ON	
BTEXT		
BUDLIST	OFF	
Link state is: DISCONNECTED		
CBELL	OFF	
CONPERM	OFF	
CHECK	30	
CLKADJ	8	
CMDTIME	10	*1
CMSG	OFF	
CMSGDISC	OFF	
CPACTIME	OFF	
CR	ON	
CTEXT		
CANLINE	$18	
COMMAND	$03	
CANPAC	$19	
CONOK	ON	
CONMODE	TRANS	*CONVERSE
CONSTAMP	OFF	
DAYUSA	ON	
DELETE	OFF	

DWAIT	32	
DIGIPEAT	ON	
DIGISENT	0	
ECHO	ON	
ESCAPE	OFF	
FLOW	ON	
FRACK	3	
FULLDUP	OFF	
HBAUD	1200	
HEADERLN	OFF	
HEALLED	OFF	
HID	OFF	
HOVRERR	0	
HUNDRERR	0	
LCOK	ON	
LFADD	ON	*OFF
LFIGNORE	OFF	
LCALLS		
LCSTREAM	ON	
MONITOR	ON	
MBOD	ON	*OFF
MALL	ON	
MCON	OFF	
MFILTER	$00	
MRPT	ON	
MSTAMP	OFF	
MYCALL	HVO01	
MYALIAS		
MYMCALL	HVB01	
MAXFRAME	2	
MCOM	OFF	
NEWMODE	ON	*OFF
NOMODE	OFF	
NUCR	OFF	
NULF	OFF	
NULLS	0	
PACLEN	255	*96
PARITY	0	
PASS	$16	
PASSALL	OFF	
PACTIME	AFTER 10	
PERSIST	127	
PPERSIST	OFF	
RCVDFRMR	0	
RCVDIFRA	36	
RCVDREJ	0	
RCVDSABM	1	
RETRY	10	
REDISPLA	$12	
RESPTIME	5	
RXBLOCK	OFF	
RXCOUNT	96	

```
RXERRORS 34
SCREENLN 0
SENDPAC  $0D
SENTFRMR 0
SENTIFRA 19
SENTREJ  0
SLOTTIME 1
START    $11
STOP     $13
STREAMSW $7C
STREAMCA OFF
STREAMDB OFF
TRFLOW   OFF
TRIES    0
TRACE    OFF
TXCOUNT  96
TXDELAY  50          *30
TXFLOW   ON          *OFF
TXQOVFLW 0
UNPROTO  CQ
USERS    1
XFLOW    ON
XMITOK   ON
XOFF     $13
XON      $11
```

The following are settings for the CONTROL UNIT terminal node controller located at the Observatory. This controller works with the Leading Edge computer via COM1 to interface and control the transceiver that communicates with the Escape Road Data Acquisition Unit. The call sign for this controller is HVO02

```
8BITCONV OFF
AX25L2V2 ON
ABAUD    1200
ASYRXOVR 0
AUTOLF   OFF         *ON
AWLEN    8           *7
AXDELAY  0
AXHANG   0
BEACON   EVERY 0
BBFAILED 0
BKONDEL  ON
BTEXT
BUDLIST  OFF
Link state is: DISCONNECTED
CBELL    OFF
CONPERM  OFF
CHECK    30
CLKADJ   8
CMDTIME  10          *1
```

CMSG	OFF	
CMSGDISC	OFF	
CPACTIME	OFF	
CR	ON	
CTEXT		
CANLINE	$18	
COMMAND	$03	
CANPAC	$19	
CONOK	ON	
CONMODE	TRANS	*CONVERSE
CONSTAMP	OFF	
DAYUSA	ON	
DELETE	OFF	
DWAIT	32	
DIGIPEAT	ON	
DIGISENT	0	
ECHO	OFF	*ON
ESCAPE	OFF	
FLOW	ON	
FRACK	3	
FULLDUP	OFF	
HBAUD	1200	
HEADERLN	OFF	
HEALLED	OFF	
HID	OFF	
HOVRERR	0	
HUNDRERR	0	
LCOK	ON	
LFADD	OFF	
LFIGNORE	OFF	
LCALLS		
LCSTREAM	ON	
MONITOR	ON	
MBOD	OFF	
MALL	ON	
MCON	OFF	
MFILTER	$00	
MRPT	ON	
MSTAMP	OFF	
MYCALL	HV002	
MYALIAS		
MYMCALL		
MAXFRAME	2	
MCOM	OFF	
NEWMODE	OFF	
NOMODE	OFF	
NUCR	OFF	
NULF	OFF	
NULLS	0	
PACLEN	96	
PARITY	0	
PASS	$16	

PASSALL	OFF
PACTIME	AFTER 10
PERSIST	127
PPERSIST	OFF
RCVDFRMR	0
RCVDIFRA	0
RCVDREJ	0
RCVDSABM	0
RETRY	10
REDISPLA	$12
RESPTIME	5
RXBLOCK	OFF
RXCOUNT	0
RXERRORS	0
SCREENLN	0
SENDPAC	$0D
SENTFRMR	0
SENTIFRA	0
SENTREJ	0
SLOTTIME	1
START	$11
STOP	$13
STREAMSW	$7C
STREAMCA	OFF
STREAMDB	OFF
TRFLOW	OFF
TRIES	0
TRACE	OFF
TXCOUNT	0
TXDELAY	50 *30
TXFLOW	OFF
TXQOVFLW	0
UNPROTO	CQ
USERS	1
XFLOW	ON
XMITOK	ON
XOFF	$13
XON	$11

SP DATA REDUCTION

The SP data that are received on the controlling computer at HVO must be checked for file size, edited if not the right size, and then sorted before further reduction and display by PC program BOB (Murray,1990).

Specifically, the data are stored by using a terminal emulation program BITCOM (BIT software Inc., 1987) with the log-session-to disk option activated, running on a Leading Edge PC-XT compatible computer. The resulting log file must be closed manually at the appropriate time to insure that only complete cycles of data are included in the data file. The data are recorded on 5.25" diskette and taken to another computer for processing.

The datafile is first checked for missing data by counting the number of lines in the file using the Quick Basic (Microsoft Ver.4.5) program "COUNT.EXE". Data are reported as one line per measurement. The value returned by Count.bas is divided by the number of measurements in a complete electrode measurement cycle; if this division returns zero for a remainder then it is assumed that there are no missing data lines in the file. If a non-zero remainder is returned the datafile is manually edited to remove the partial measurement cycles so that the file can be properly sorted. At this time a complete electrode measurement cycle for our application of seven electrodes (5 SP electrodes and 2 calibration inputs) contains 116 data lines which takes approximately 4 hrs to complete. Each 116 lines of the datafile are in the following sequence and comprise one complete measurement cycle; there are many cycles in the real datafile. The format for each line is: DAY MONTH YEAR HOUR MIN SEC TEMPERATURE SP-DATA. The following lists each of the 116 lines that comprise a complete data acquisition cycle. The FILENAME column indicates to what file that particular measurement is stored into during data sorting.

LINE #	ELECTRODE MEASURED	MODE	FILENAME
1	1,1	DIRECT NO RESISTOR	11SO.DAT
2	1,1	REVERSE NO RESISTOR	11IO.DAT
3	1,1	DIRECT WITH RESISTOR	11SR.DAT
4	1,1	REVERSE WITH RESISTOR	11IR.DAT
5	1,2	DIRECT NO RESISTOR	12SO.DAT
6	1,2	REVERSE NO RESISTOR	12IO.DAT
7	1,2	DIRECT WITH RESISTOR	12SR.DAT
8	1,2	REVERSE WITH RESISTOR	12IR.DAT
9	1,3	DIRECT NO RESISTOR	13SO.DAT
10	1,3	REVERSE NO RESISTOR	13IR.DAT
11	1,3	DIRECT WITH RESISTOR	13SR.DAT
12	1,3	REVERSE WITH RESISTOR	13IR.DAT
13	1,4	DIRECT NO RESISTOR	14SO.DAT
14	1,4	REVERSE NO RESISTOR	14IO.DAT
15	1,4	DIRECT WITH RESISTOR	14SR.DAT
16	1,4	REVERSE WITH RESISTOR	14IR.DAT
17	1,5	DIRECT NO RESISTOR	15SO.DAT
18	1,5	REVERSE NO RESISTOR	15IO.DAT
19	1,5	DIRECT WITH RESISTOR	15SR.DAT
20	1,5	REVERSE WITH RESISTOR	15IR.DAT
21	2,1	DIRECT NO RESISTOR	21SO.DAT
22	2,1	REVERSE NO RESISTOR	21IO.DAT
23	2,1	DIRECT WITH RESISTOR	21SR.DAT
24	2,1	REVERSE WITH RESISTOR	21IR.DAT
25	2,2	DIRECT NO RESISTOR	22SO.DAT
26	2,2	REVERSE NO RESISTOR	22IO.DAT

27	2,2	DIRECT WITH RESISTOR	22SR.DAT
28	2,2	REVERSE WITH RESISTOR	22IR.DAT
29	2,3	DIRECT NO RESISTOR	23S0.DAT
30	2,3	REVERSE NO RESISTOR	23I0.DAT
31	2,3	DIRECT WITH RESISTOR	23SR.DAT
32	2,3	REVERSE WITH RESISTOR	23IR.DAT
33	2,4	DIRECT NO RESISTOR	24S0.DAT
34	2,4	REVERSE NO RESISTOR	24I0.DAT
35	2,4	DIRECT WITH RESISTOR	24SR.DAT
36	2,4	REVERSE WITH RESISTOR	24IR.DAT
37	2,5	DIRECT NO RESISTOR	25S0.DAT
38	2,5	REVERSE NO RESISTOR	25I0.DAT
39	2,5	DIRECT WITH RESISTOR	25SR.DAT
40	2,5	REVERSE WITH RESISTOR	25IR.DAT
41	3,1	DIRECT NO RESISTOR	31S0.DAT
42	3,1	REVERSE NO RESISTOR	31I0.DAT
43	3,1	DIRECT WITH RESISTOR	31SR.DAT
44	3,1	REVERSE WITH RESISTOR	31IR.DAT
45	3,2	DIRECT NO RESISTOR	32SR.DAT
46	3,2	REVERSE NO RESISTOR	32I0.DAT
47	3,2	DIRECT WITH RESISTOR	32SR.DAT
48	3,2	REVERSE WITH RESISTOR	32IR.DAT
49	3,3	DIRECT NO RESISTOR	33S0.DAT
50	3,3	REVERSE NO RESISTOR	33I0.DAT
51	3,3	DIRECT WITH RESISTOR	33SR.DAT
52	3,3	REVERSE WITH RESISTOR	33IR.DAT
53	3,4	DIRECT NO RESISTOR	34S0.DAT
54	3,4	REVERSE NO RESISTOR	34I0.DAT
55	3,4	DIRECT WITH RESISTOR	34SR.DAT
56	3,4	REVERSE WITH RESISTOR	34IR.DAT
57	3,5	DIRECT NO RESISTOR	35S0.DAT
58	3,5	REVERSE NO RESISTOR	35I0.DAT
59	3,5	DIRECT WITH RESISTOR	35SR.DAT
60	3,5	REVERSE WITH RESISTOR	35IR.DAT
61	4,1	DIRECT NO RESISTOR	41S0.DAT
62	4,1	REVERSE NO RESISTOR	41I0.DAT
63	4,1	DIRECT WITH RESISTOR	41SR.DAT
64	4,1	REVERSE WITH RESISTOR	41IR.DAT
65	4,2	DIRECT NO RESISTOR	42S0.DAT
66	4,2	REVERSE NO RESISTOR	42I0.DAT
67	4,2	DIRECT WITH RESISTOR	42SR.DAT
68	4,2	REVERSE WITH RESISTOR	42IR.DAT
69	4,3	DIRECT NO RESISTOR	43S0.DAT
70	4,3	REVERSE NO RESISTOR	43I0.DAT
71	4,3	DIRECT WITH RESISTOR	43SR.DAT
72	4,3	REVERSE WITH RESISTOR	43IR.DAT
73	4,4	DIRECT NO RESISTOR	44S0.DAT
74	4,4	REVERSE NO RESISTOR	44I0.DAT
75	4,4	DIRECT WITH RESISTOR	44SR.DAT
76	4,4	REVERSE WITH RESISTOR	44IR.DAT
77	4,5	DIRECT NO RESISTOR	45S0.DAT
78	4,5	REVERSE NO RESISTOR	45I0.DAT

79	4,5	DIRECT WITH RESISTOR	45SR.DAT
80	4,5	REVERSE WITH RESISTOR	45IR.DAT
81	5,1	DIRECT NO RESISTOR	51S0.DAT
82	5,1	REVERSE NO RESISTOR	51I0.DAT
83	5,1	DIRECT WITH RESISTOR	51SR.DAT
84	5,1	REVERSE WITH RESISTOR	51IR.DAT
85	5,2	DIRECT NO RESISTOR	52S0.DAT
86	5,2	REVERSE NO RESISTOR	52I0.DAT
87	5,2	DIRECT WITH RESISTOR	52SR.DAT
88	5,2	REVERSE WITH RESISTOR	52IR.DAT
89	5,3	DIRECT NO RESISTOR	53S0.DAT
90	5,3	REVERSE NO RESISTOR	53I0.DAT
91	5,3	DIRECT WITH RESISTOR	53SR.DAT
92	5,3	REVERSE WITH RESISTOR	53IR.DAT
93	5,4	DIRECT NO RESISTOR	54S0.DAT
94	5,4	REVERSE NO RESISTOR	54I0.DAT
95	5,4	DIRECT WITH RESISTOR	54SR.DAT
96	5,4	REVERSE WITH RESISTOR	54IR.DAT
97	5,5	DIRECT NO RESISTOR	55S0.DAT
98	5,5	REVERSE NO RESISTOR	55I0.DAT
99	5,5	DIRECT WITH RESISTOR	55SR.DAT
100	5,5	REVERSE WITH RESISTOR	55IR.DAT
101	7,7	DIRECT NO RESISTOR	77S0.DAT
102	7,7	REVERSE NO RESISTOR	77I0.DAT
103	7,7	DIRECT WITH RESISTOR	77SR.DAT
104	7,7	REVERSE WITH RESISTOR	77IR.DAT
105	7,8	DIRECT NO RESISTOR	78S0.DAT
106	7,8	REVERSE NO RESISTOR	78I0.DAT
107	7,8	DIRECT WITH RESISTOR	78SR.DAT
108	7,8	REVERSE WITH RESISTOR	78IR.DAT
109	8,7	DIRECT NO RESISTOR	87S0.DAT
110	8,7	REVERSE NO RESISTOR	87I0.DAT
111	8,7	DIRECT WITH RESISTOR	87SR.DAT
112	8,7	REVERSE WITH RESISTOR	87IR.DAT
113	8,8	DIRECT NO RESISTOR	88S0.DAT
114	8,8	REVERSE NO RESISTOR	88I0.DAT
115	8,8	DIRECT WITH RESISTOR	88SR.DAT
116	8,8	REVERSE WITH RESISTOR	88IR.DAT

The Quick Basic (Microsoft Ver.4.5) program 'TTSOCON6.EXE' sorts the single edited data file into 116 individual files and replaces the 2 digit numerical month with a 3 letter month compatible with "BOB" format. Lines 1,117,233...etc. are in the file 11S091.dat, lines 2,118,233...etc. are in the file 11I091.dat etc... for a total of 116 different data files. These files are then ready to be used with the PC program 'BOB' (Murray,1990) a time series data-management and plotting program.

The file name contains the measured electrode combination , the mode and the year followed by the .dat extension. The first two numbers indicate what two electrode inputs are being measured and can be any combination of 1,1 to 8,8. The next two characters indicate the measurement mode:

SO = direct with no parallel resistor
IO = reversed polarity at input to preamp with no parallel resistor
SR = direct with parallel resistor
IR = reversed polarity at input to preamp with parallel resistor

These data files are referenced by the 'BOB' program using four characters. The first two are the electrode combinations measured followed by two characters that indicate the mode. However because BOB's file referencing scheme does not allow the actual file name and the channel identification to be the same (Murray,1990), the mode characters in the channel ID were changed to the following:
DO = direct with no parallel resistor
RO= reversed polarity at input to preamp with no parallel resistor
DR = direct with parallel resistor
RR = reversed polarity at input to preamp with parallel resistor

In other words the BOB channel identification (CHID) 11DO accesses the real file labelled 11SOyy.dat where the yy is the date for the year that was specified by a BOB command.

Once the data is in the proper BOB files, and format, the analog SP voltages are back-calculated using BOB commands.

Where:

1. Direct without load resistor, V1
2. Reverse Polarity without load resistor, V2
3. Direct with load resistor, V3
4. Reverse Polarity with load resistor, V4

If V is the true SP voltage and VO is the offset introduced by the Isolation Amplifier, then:

$$V1 = V + VO$$
$$V2 = -V + VO$$

therefore,

$$V = (V1 - V2)/2$$
$$VO = (V1 + V2)/2$$

Finally taking into account the Isolation Amplifier gain of 0.928992. The Self-Potential(SP) = V(1.076). The formula used for any two electrodes is therefore:

$$SP = ((V1 - V2)/2)*1.076$$

MICROSOFT QUICKBASIC 4.5 SOURCE CODE FOR
COUNT.BAS & TTSOCON5.BAS

```
'**********************COUNT.BAS****************************
'This program counts the amount of lines in the datafile collected
```

```
'by the IBM XT computer used for collecting Self Potential (SP)
'data.

CLS

PRINT "THIS PROGRAM COUNTS THE AMOUNT OF LINES IN THE SELECTED"
PRINT "FILES"
PRINT "IF THIS NUMBER IS NOT EVENLY DIVISIBLE BY THE AMOUNT OF"
PRINT "LINES"
PRINT "IN A COMPLETE ACQUISITION CYCLE THEN THE FILE MUST BE:"
PRINT "CORRECTED FOR ERRORS."
PRINT
PRINT "For 7 electrodes (5 for SP electrode and 2 for "
PRINT " calibrations)"
PRINT "116 data lines are in a complete acquisition cycle."
PRINT
INPUT "Datafilename.dat to be counted ", filename$
OPEN filename$ FOR INPUT AS #1

INPUT "NUMBER OF LINES IN A COMPLETE ACQUISITION CYCLE ",NUMBER$
NUMBER% = VAL(NUMBER$)

DO UNTIL EOF(1)
     LINE INPUT #1, data$
     n = n + 1
     IF n = 1 then CLS
     LOCATE 10, 20
     PRINT "COUNTING THE AMOUNT OF LINES IN THE FILE"
LOOP
CLS
LOCATE 12, 20
PRINT "THERE ARE "; n; " LINES OF DATA IN THIS FILE:
LOCATE 14, 20
PRINT data$ + " IS THE LAST LINE IN THE FILE"

LOCATE 13,20
PRINT "WITH "; (n / NUMBER%); " COMPLETE ACQUISITION CYCLES."

CLOSE
BEEP: BEEP: BEEP: BEEP
END




'************************TTSOCON6.BAS*****************************
'Program to sort and convert SP measurements to analog voltages
'this program assumes 1 reading for each electrode combination, in
'other words, for each electrode pair 16 readings will result.  The
'combinations are as follows starting with the first two
'electrodes:
```

```
'1) 11DIR0 Elect. 1&1 chosen Direct connect to preamp no resistor.
'2) 11REV0 Elect. 1&1 chosen Reverse connect to preamp no resistor.
'3) 11DIRR Elect. 1&1 chosen Direct connect to preamp with
'resistor.
'4) 11REVR Elect. 1&1 chosen Reverse connect to preamp with
'resistor.
'5) 12DIR0 Elect. 1&2 chosen Direct connect to preamp no resistor.
'6) 12REV0 Elect. 1&2 chosen Reverse connect to preamp no resistor.
'7) 12DIRR Elect. 1&2 chosen Direct connect to preamp with
'resistor.
'8) 12REVR Elect. 1&2 chosen Reverse connect to preamp with
'resistor.
'9) 21DIR0 Elect. 2&1 chosen Direct connect to preamp no resistor.
'10)21REV0 Elect. 2&1 chosen Reverse connect to preamp no resistor.
'11)21DIRR Elect. 2&1 chosen Direct connect to preamp with
'resistor.
'12)21REVR Elect. 2&1 chosen Reverse connect to preamp with
'resistor.
'13)22DIR0 Elect. 2&2 chosen Direct connect to preamp no resistor.
'14)22REV0 Elect. 2&2 chosen Reverse connect to preamp no resistor.
'15)22DIRR Elect. 2&2 chosen Direct connect to preamp with
'resistor.
'16)22REVR Elect. 2&2 chosen Reverse connect to preamp with
'resistor.

'The main purpose of this program is to sort and create data files
'that are useable in "BOB".
'This program differs from TTSOCON4.BAS in that it does NOT create
'a separate file for temp.dat. BOB uses 11S0yy for the temperature
'data.
'This was done because of the added step that would be required to
'create the temperature file.  If it becomes necessary to have all
' of the temperature points.  TTSOCON4.BAS can be modified to
'accomplish this.  With the present configuration of BOB only
'hourly temperature points (the same as data points) are plotted.
'This program differs from TTSOCON5.BAS in that there are more
'indicators printed to the screen to show the status of the sorting
'process.
'The first set of data to be sorted are the electrode readings,
'then the calibration readings are sorted.
'This program also changes the numeric month to the equivalent
'alphabet month.


DECLARE SUB mode (mod$, i)
DECLARE SUB CONVERT (filebuffer$)
DECLARE SUB CHANGEMONTH (filebuffer$)

'DEFINITIONS AND DECLARATIONS

TYPE spvar
```

```
     rawdata AS STRING * 5
     rawdat AS SINGLE
     elecnum AS INTEGER
     elect AS STRING * 4
     i AS INTEGER
     label AS STRING * 8
     dataname AS STRING * 12
END TYPE

CLS
PRINT "This program used to sort Tattletale model 4A data into"
PRINT "their"
PRINT "appropriate files.  These files are then accessed by BOB"
PRINT "for plotting."
PRINT "The month column is changed from numeric to 3 letter"
PRINT "alphabet"
PRINT "before storing into the datafile."
PRINT "Please make sure that the selected datafile has had the"
PRINT "changedate program run on it to avoid missing data points "
PRINT "from being generated when using the different measurements"
PRINT "for corrections."
PRINT : PRINT : PRINT

INPUT "Datafilename .dat to be sorted ", filename$
OPEN filename$ FOR INPUT AS #1

DO
     INPUT "NUMBER OF ELECTRODES ", elecnum%
     SELECT CASE elecnum%
     CASE 2 TO 6   '7 and 8 ar the calibration inputs
          EXIT DO
     CASE ELSE
          PRINT "Number of electrodes must be 2 through 6"
LOOP
LOCATE 13, 20
PRINT " THE NUMBER OF ELECTRODES TO SORT = "; elecnum%

CYCLES = 0

'****START SORTING THE FILE FOR SP DATA AND PUT  IN PROPER FILES
'The label$ consists of the elec$ and the mod$.  The mod$
'identifies
'the measurement mode.  the mode is cycled through as follows:
'         S0=Straight no resistor
'         I0=Inverted no resistor
'         SR=Straight with parallel resistor
'         IR=Inverted with parallel resistor
'These mode abbreviations are sued to indicate the same modes as:
'         D0=Direct no resistor
'         R0=Reverse no resistor
'         DR=Direct with parallel resistor
'         RR=Reverse with parallel resistor
```

```
LOCATE 12, 20
PRINT "STARTING TO CREATE DATA AND CALIBRATION FILES FOR USE IN
PRINT "BOB"
DO UNTIL EOF(1)  'Read data file until end is reached (EOF)=-1
     FOR combo1=1 TO elecnum%  'Setting up for labelling the files
        FOR combo2=1 TO elecnum% 'Dependent on the number of elect.
         elec$=(LTRIM$(STR$(COMBO1))+(LTRIM$(STR$(COMBO2))))
          FOR i=1 to 8 STEP 2
               CALL mode(mod$,i)
               label$=elec$ + mod$
               LOCATE 15, 20
               PRINT "****APPENDING TO FILE "; label$; "*****"
               LOCATE 14, 20
               PRINT "THEN NUMBER OF COMPLETED DATA CYCLE =;CYCLES
               '**To change year extension, modify the next line
               '**to the appropriate year.("xx.dat)
              dataname$="E:\DATA\KILAUEA\ESCAPERD\"+label$+"91.dat"
               OPEN dataname$ FOR APPEND AS #2
               LINE INPUT #1, LINEBUFFER$
               ON ERROR GOTO clsfile
               'If there are not enough lines in the datafile goto
               'error handler clsfile
                    CALL CONVERT(LINEBUFFER$)
               PRINT #2, LINEBUFFER$
               CLOSE #2
          NEXT i
        NEXT combo2
     NEXT combo1

'**************END SP DATA SORTING SECTION***********************

'**********START CALIBRATION SORTING SECTION*********************
'****************************************************************
'Using the same sorting procedure as in the DATA sorting section
'except using the combo1 and combo2 values of 7 to 8 to limit the
'loop to just looking for channels 7 & 8 which contain the
'calibration information.

     FOR combo1=7 TO 8  'Setting up for labelling the files
         FOR combo2=7 TO 8 'Dependent on the number of elect.
         elec$=(LTRIM$(STR$(COMBO1))+(LTRIM$(STR$(COMBO2))))
          FOR i=1 to 8 STEP 2
               CALL mode(mod$,i)
               label$=elec$ + mod$
               LOCATE 15, 20
               PRINT "****APPENDING TO FILE "; label$; "*****"
               LOCATE 14, 20
               PRINT "THEN NUMBER OF COMPLETED DATA CYCLE =;CYCLES
               '**To change year extension, modify the next line
               '**to the appropriate year.("xx.dat)
              dataname$="E:\DATA\KILAUEA\ESCAPERD\"+label$+"91.dat"
```

```
                OPEN dataname$ FOR APPEND AS #2
                LINE INPUT #1, LINEBUFFER$
                ON ERROR GOTO clsfile
                'If there are not enough lines in the datafile goto
                'error handler clsfile
                     CALL CONVERT(LINEBUFFER$)
                PRINT #2, LINEBUFFER$
                CLOSE #2
           NEXT i
         NEXT combo2
      NEXT combo1
      CYCLES=CYCLES +1
      LOCATE 14, 20
      PRINT "THE NUMBER OF COMPLETED DATA CYCLES =;CYCLES

      LOOP
CLOSE
LOCALE 20,20
BEEP: BEEP: BEEP
PRINT "FINISHED CREATING 'BOB' FILES"
END
'ERROR HANDLER clsfile closes #2 then resumes program execution
clsfile:
      PRINT "ERROR, CLOSING FILE'
      PRINT "THE LAST FILE WAS ";label$
      CLOSE #2
      SEEK #1,1
      END

SUB CHANGEMONTH (change$)
      MONTH$ = MID$(change$,4,2)
      SELECT CASE MONTH$
           CASE " 1"
                MONTH$="JAN"
           CASE " 2"
                MONTH$="FEB"
           CASE " 3"
                MONTH$="MAR"
           CASE " 4"
                MONTH$="APR"
           CASE " 5"
                MONTH$="MAY"
           CASE " 6"
                MONTH$="JUN"
           CASE " 7"
                MONTH$="JUL"
           CASE " 8"
                MONTH$="AUG"
           CASE " 9"
                MONTH$="SEP"
           CASE "10"
                MONTH$="OCT"
```

```
          CASE "11"
               MONTH$="NOV"
          CASE "12"
               MONTH$="DEC"
          CASE ELSE
               PRINT "ERROR IN month$
               PRINT change$
               PRINT "MONTH$ = ",MONTH$
               STOP

     END SELECT
day$=LEFT$(change$,3)
filebuffer$=RTRIM$(change$)
rest$=RIGHT$(change$,23)
change$=day$ + MONTH$ + rest$


END SUB


SUB CONVERT (filebuffer$)

     CALL CHANGEMONTH(filebuffer$)
     rawdata$=MID$(filebuffer$, 25, 5)
     rawdat!=VAL(Rawdata$)
     'PRINT rawdat
     convertdat!=(rawdat!-3276) * 7.629395E-05
     'PRINT convertdat!;
     convertdat$=STR(convertdat!)
     'PRINT convertdat$
     filebuffer$=filebuffer$ + " " + convertdat$
     'PRINT filebuffer$
END SUB

SUB mode(mod$,i)
     txt$="SOIOSRIR"
          mod$=MID$(txt$,i,2)
          'PRINT mod$
END SUB
```

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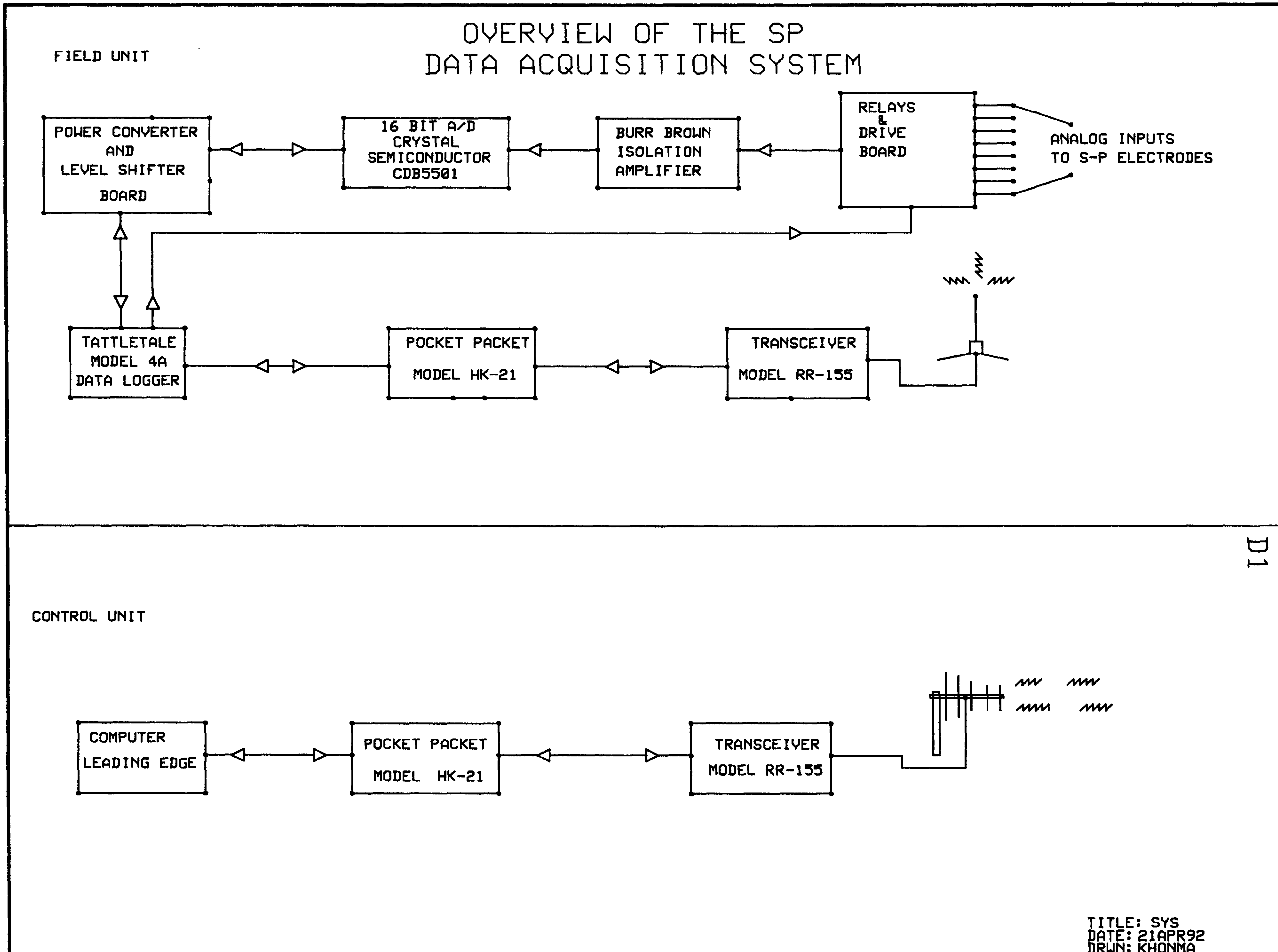
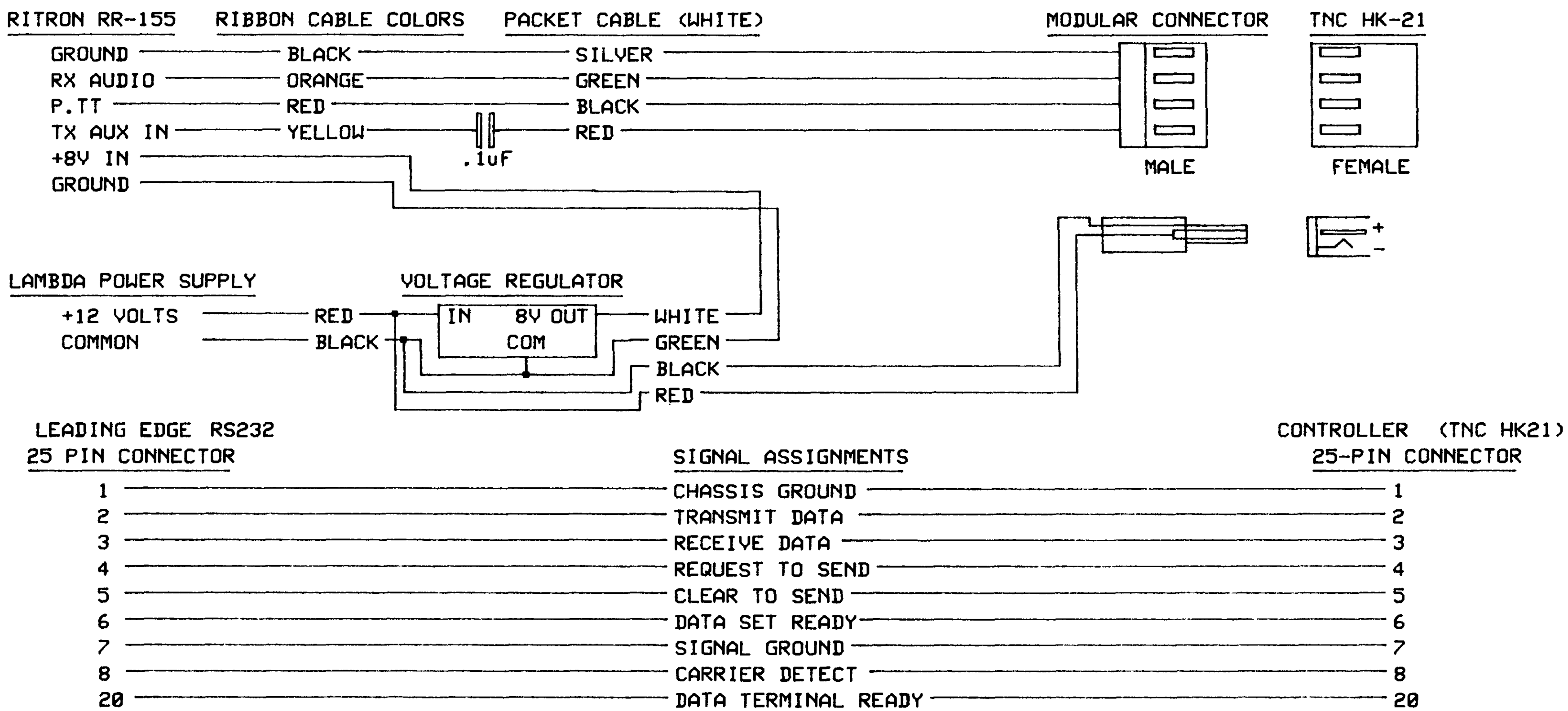


OVERVIEW OF THE SP
DATA ACQUISITION SYSTEM
FIELD UNIT
POWER CONVERTER AND LEVEL SHIFTER BOARD
16 BIT A/D CRYSTAL SEMICONDUCTOR CDB5501
BURR BROWN ISOLATION AMPLIFIER
RELAYS & DRIVE BOARD
ANALOG INPUTS TO S-P ELECTRODES
TATTLETALE MODEL 4A DATA LOGGER
POCKET PACKET MODEL HK-21
TRANSCEIVER MODEL RR-155
D1
CONTROL UNIT
COMPUTER LEADING EDGE
POCKET PACKET MODEL HK-21
TRANSCEIVER MODEL RR-155
TITLE: SYS
DATE: 21APR92
DRWN: KHONMA

TRANSCEIVER-PACKET-COMPUTER

WIRING DIAGRAM

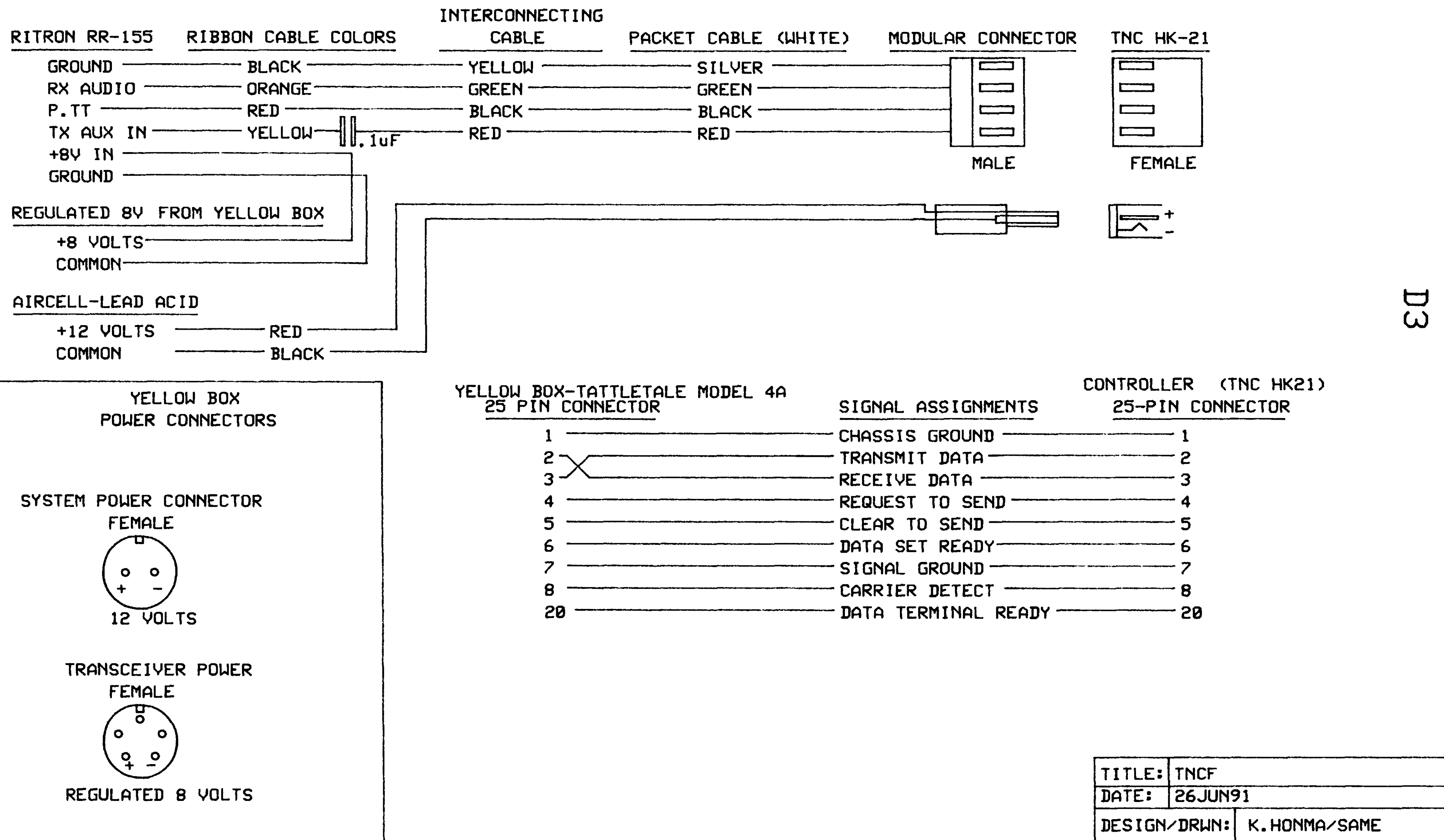
D2



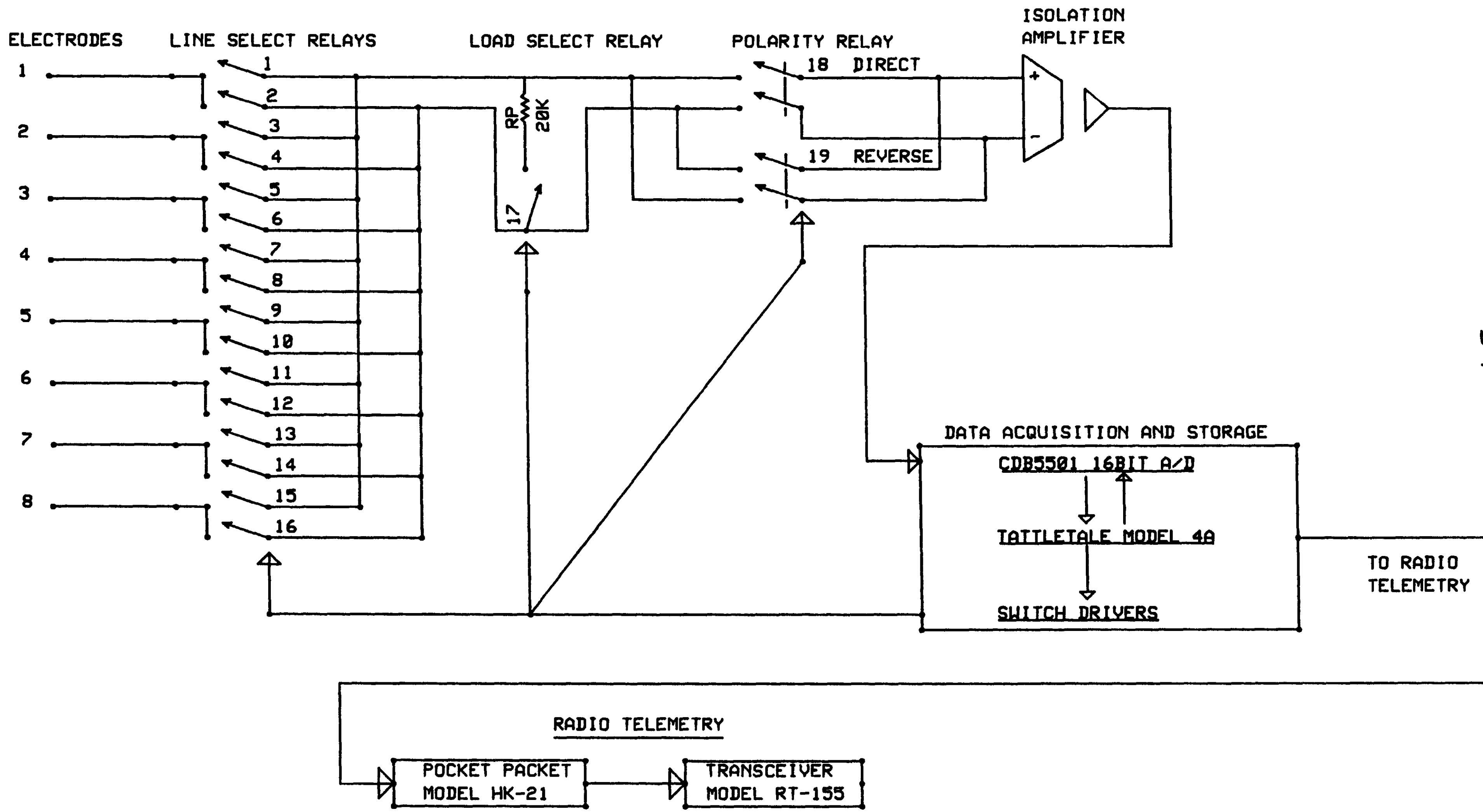
TITLE:	TNCO
DATE:	26JUN91
DESIGN/DRWN:	K.HONMA/SAME

TRANSCEIVER-PACKET-TATTLETALE

WIRING DIAGRAM



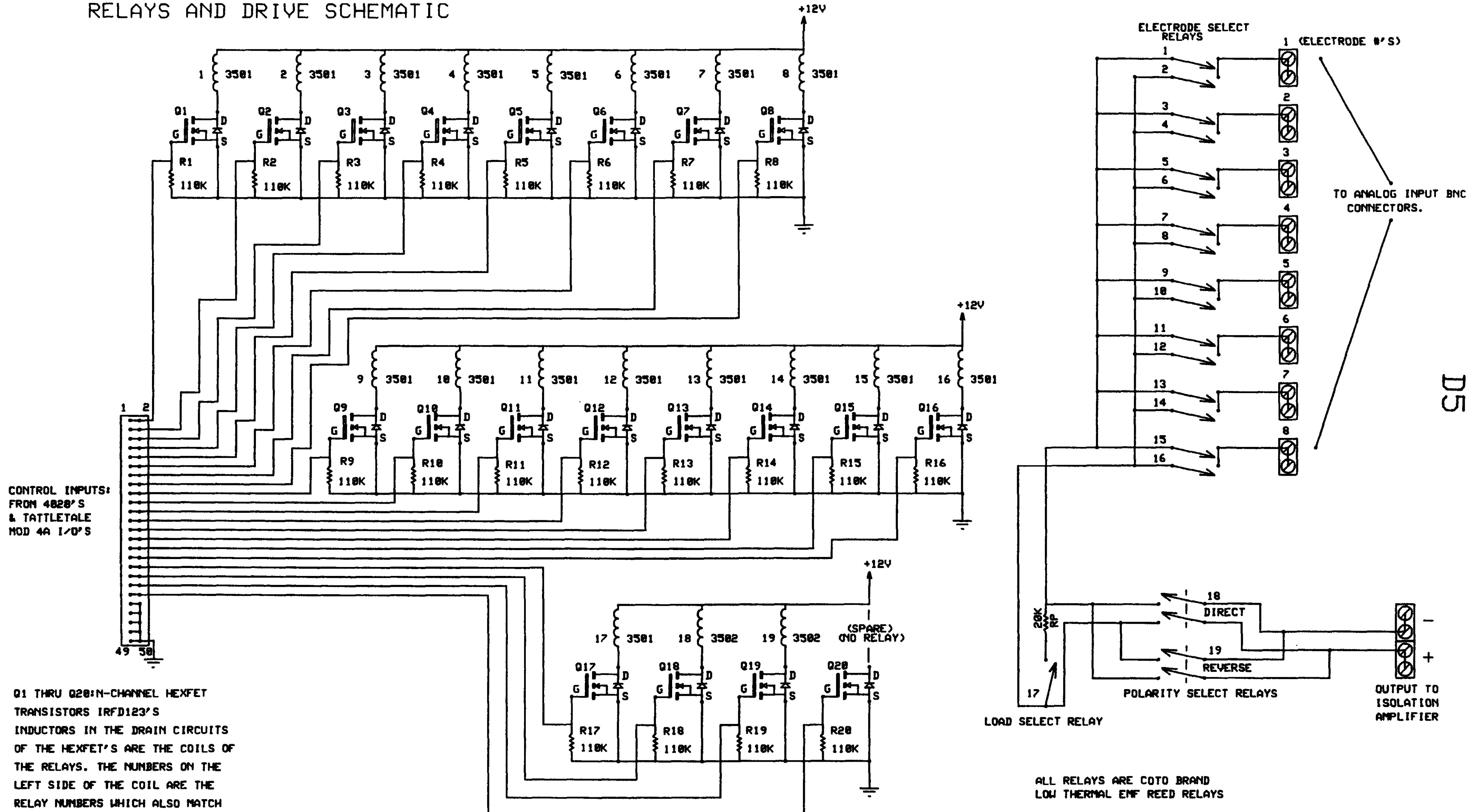
BLOCK DIAGRAM OF SP DATA ACQUISITION SYSTEM FIELD UNIT



D4

TITLE: SP
DATE: 21FEB92
NAME: K HONMA

SP DATA ACQUISITION SYSTEM
RELAYS AND DRIVE SCHEMATIC

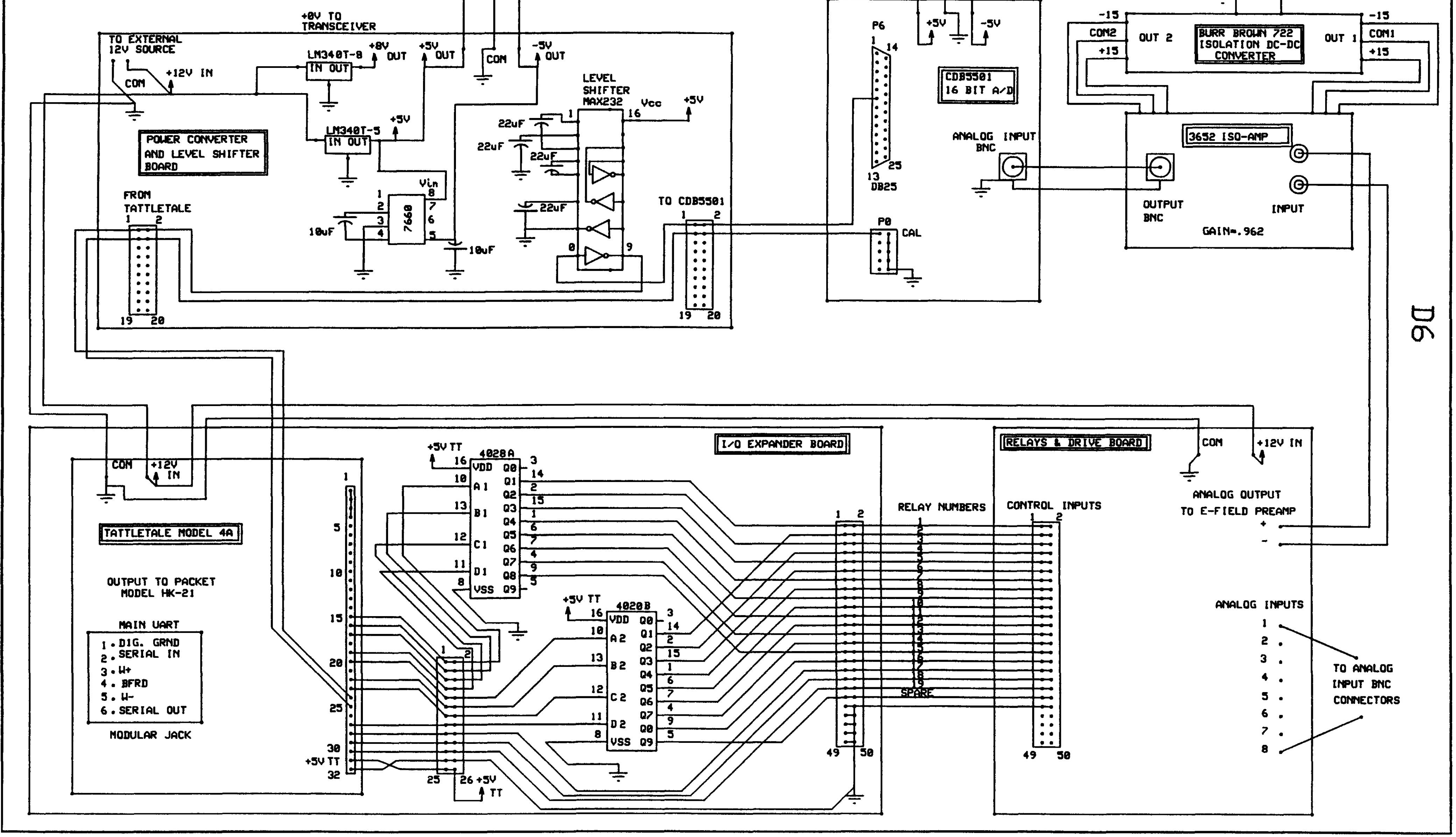


Q1 THRU Q20:N-CHANNEL HEXFET TRANSISTORS IRFD123'S
INDUCTORS IN THE DRAIN CIRCUITS OF THE HEXFET'S ARE THE COILS OF THE RELAYS. THE NUMBERS ON THE LEFT SIDE OF THE COIL ARE THE RELAY NUMBERS WHICH ALSO MATCH THE NUMBERS WITH THE CONTACTS.

ALL RELAYS ARE COTO BRAND LOW THERMAL EMF REED RELAYS

TITLE: RLDRV
DATE: 21FEB92
NAME: K HONMA

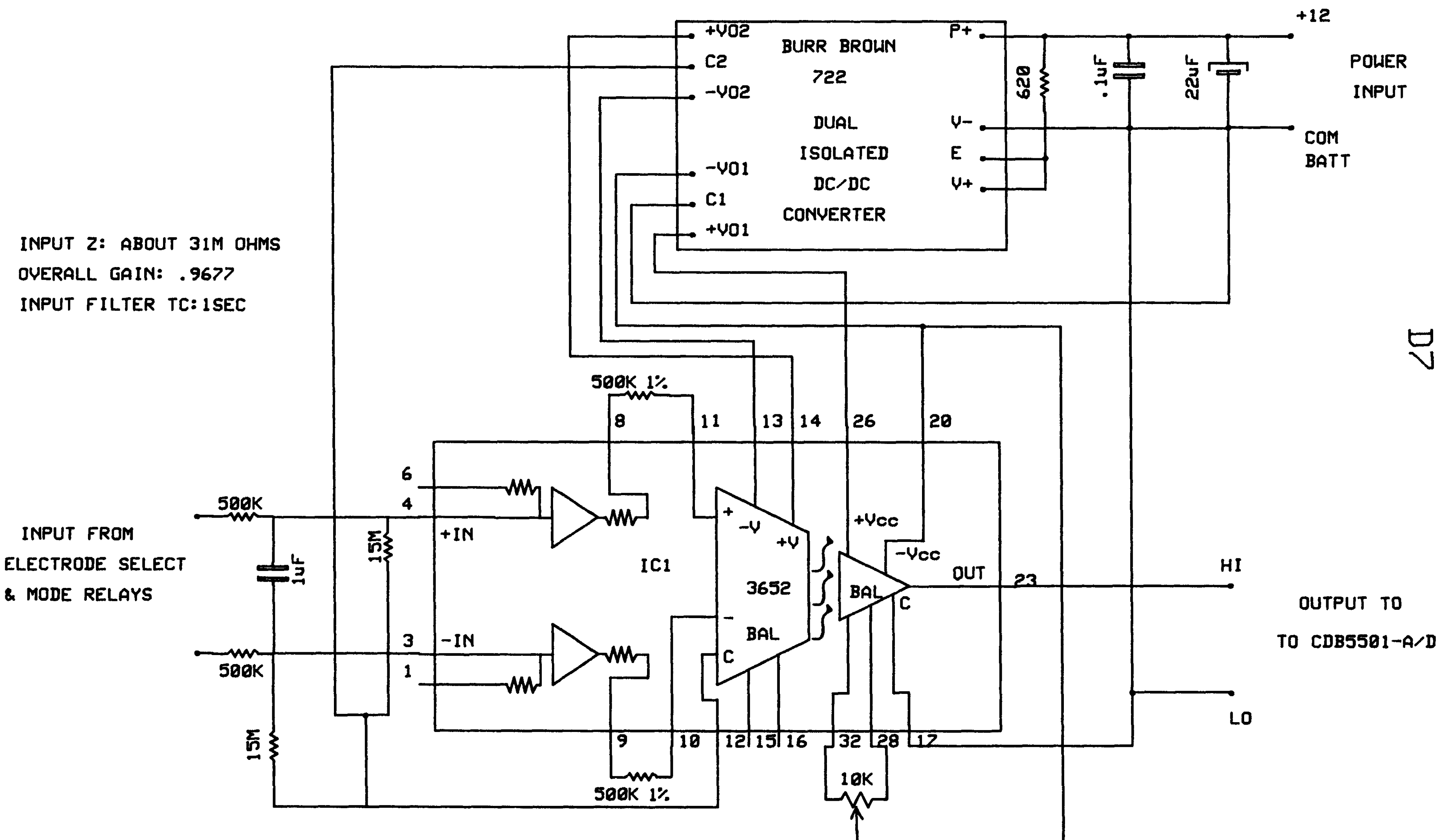
TATTLETALE MODEL 4A I/O DETAILS (TT1)



ISOLATION AMPLIFIER FOR SP DATA ACQUISITION FIELD UNIT

D7

INPUT Z: ABOUT 31M OHMS
OVERALL GAIN: .9677
INPUT FILTER TC:1SEC

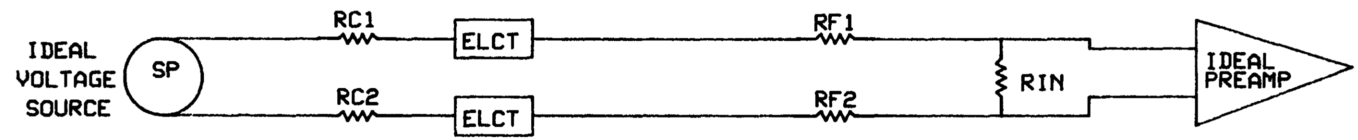


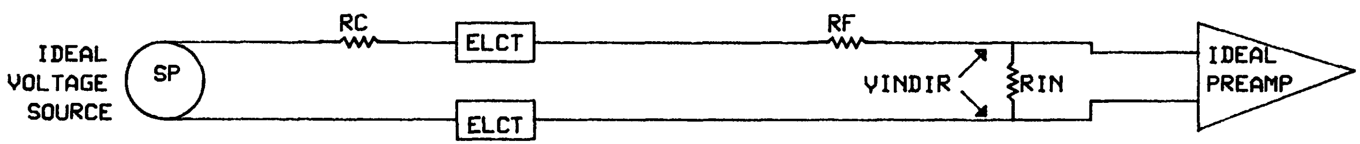
DATE: 8APR91
TITLE: ISOAMP
DESIGN\DRAWN: K.HONMA\SAME

D8

EQUIVALENT CIRCUITS

FOR RESPONSE CALCULATIONS ONLY





WHERE RC=RC1+RC2

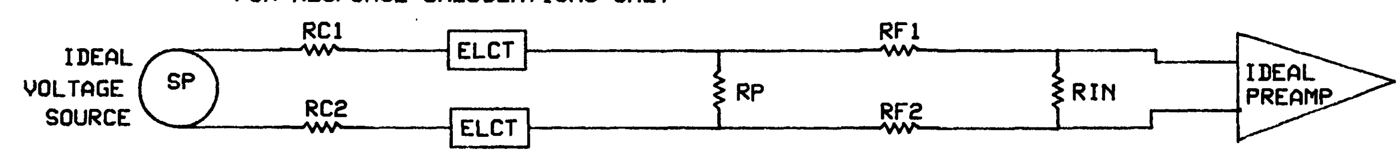
WHERE RF=RF1+RF2

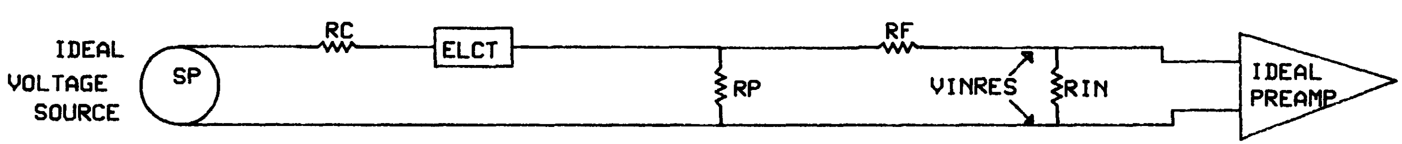
ELCT = SP ELECTRODES
DC RESISTANCE ASSUMED
<< RC,RF,RIN

$$VINDIR = \frac{RIN\ SP}{RIN+RF+RC}$$

EQUIVALENT CIRCUITS

FOR RESPONSE CALCULATIONS ONLY



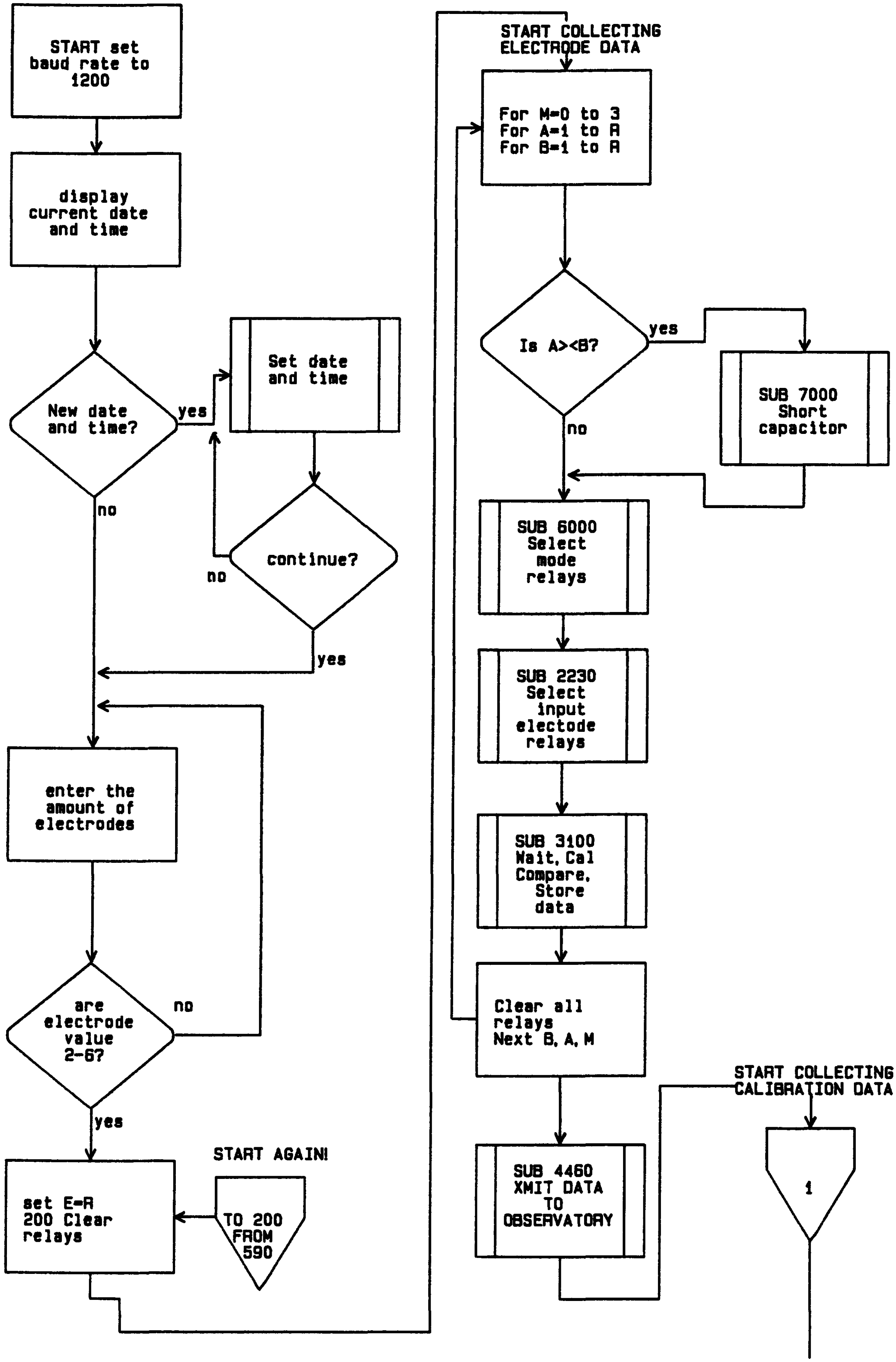


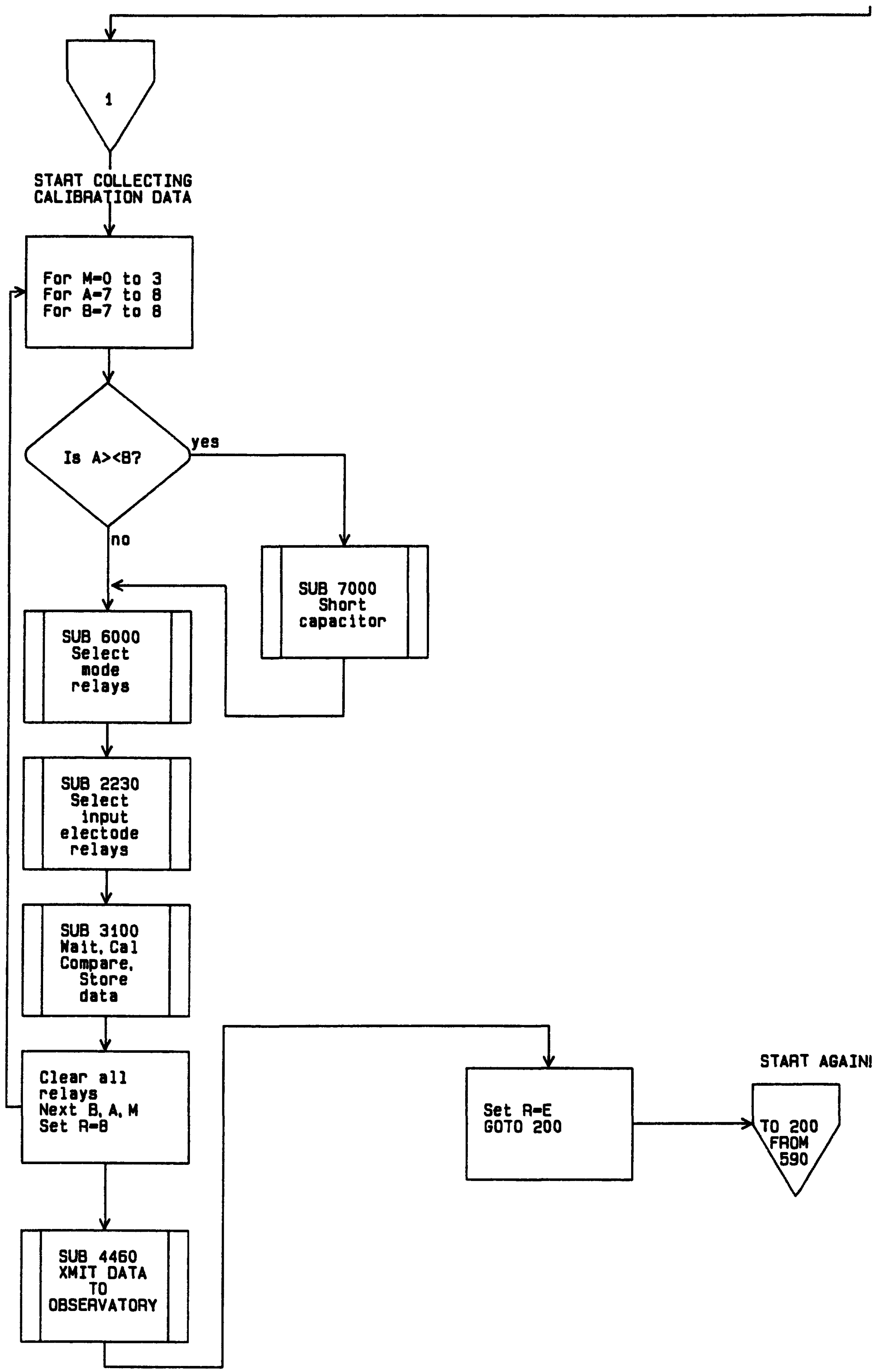
WHERE RC = RC1+RC2
RF = RF1+RF2

$$VINRES = \frac{\left[\dfrac{[SP]\,\dfrac{[RP[RF+RIN]]}{[RP+RF+RF]}}{RC + \dfrac{[RP[RF+RIN]]}{[RP+RF+RIN]}}\right][RIN]}{[RF+RIN]}$$

TITLE: WACQ
DATE: 21JUN91
DESIGN: K HONMA

TATTLETALE MODEL 4A ACQUISITION PROGRAM COLLECT2.SP




1
START COLLECTING
CALIBRATION DATA
For M=0 to 3
For A=7 to 8
For B=7 to 8
Is A><B?
yes
no
SUB 7000
Short
capacitor
SUB 6000
Select
mode
relays
SUB 2230
Select
input
electode
relays
SUB 3100
Wait, Cal
Compare,
Store
data
Clear all
relays
Next B, A, M
Set R=8
SUB 4460
XMIT DATA
TO
OBSERVATORY
Set R=E
GOTO 200
START AGAIN!
TO 200
FROM
590