27
6-6-77
25 to UT 15
SAND-77-0195

UNLIMITED RELEASE

3151

INSTRUMENTATION SYSTEM FOR MASSIVE HYDRAULIC FRACTURE MAPPING

L. J. KECK AND R. W. SEAVEY

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Energy Research
and Development Administration under Contract AT (29-1)-789

PRINTED APRIL 1977

Sandia Laboratories

SF 2900 Q(7-73)

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia Laboratories, operated for the United States Energy Research & Development Administration by Sandia Corporation.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

SF 1004-DF (3-75)

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$4.50; Microfiche \$3.00

PAGES 1 to 2
WERE INTENTIONALLY
LEFT BLANK

SAND-77-0195
Unlimited Release
Printed April 1977

INSTRUMENTATION SYSTEM FOR
MASSIVE HYDRAULIC FRACTURE MAPPING

L. J. Keck and R. W. Seavey
Sandia Laboratories
Albuquerque, New Mexico

Abstract

The measurement of induced surface potentials has been used in a research effort to map the orientation of fractures created by massive hydraulic fracturing. A first generation measurement system has been developed via field testing that has successfully mapped fracture orientation.

The design, layout, and operation of the instrumentation system used to generate, measure, and analyze surface potentials during a massive hydrofracture are described. The objective of this report is to aid the transfer of this technology to the private sector.

MASTER

Use of trade names or makes and models
of equipment is for information only
and does not constitute endorsement by
the Energy Research and Development
Administration (ERDA) or Sandia
Laboratories.

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	7
II. Induced Surface Potential Instrumentation System	8
III. Current Generator	14
1. Requirements	14
2. Design	14
3. Circuit Description	15
4. Operating Procedure	22
IV. Potential Measurement Box	26
1. Requirements	26
2. Circuit Description	28
3. Operating Procedure	38
V. Instrumentation Van	40
1. Data Recording System	40
References	46
Appendix A	47
Appendix B	51

I. Introduction

The measurement of induced surface potentials has been used in a research effort to map the orientation of fractures created by massive hydraulic fracturing (MHF). MHF is a natural gas production stimulation technique currently under development by many private companies for utilization in the tight gas sandstone reservoirs of the West and the Devonian shale formations of the East. Knowledge of the fracture system characteristics created by MHF is needed, during developmental testing, to assist in evaluating the effectiveness of the stimulation treatment and, during commercial utilization, to optimize well placement location.

A first generation measurement system has been successfully developed via field testing that can map the orientation of the fracture system created by MHF. In anticipation that such a capability will find commercial applications as the utilization of MHF becomes more widely employed, this design manual report has been prepared that describes the design, layout, and operation of the developed instrumentation system. Sandia Laboratories will also provide technical consulting assistance to implement the utilization of this instrumentation system as appropriate.

Further inquiries should be directed at C. L. Schuster, Supervisor, Instrumentation Systems Division 5733, Sandia Laboratories - 505-264-9142.

II. Induced Surface Potential Instrumentation System

Measurements are taken by recording the potentials at 24 circumferential locations around the well before, during, and after the fracture. The potentials measured are created by injecting current into the fracture and the surrounding earth through the casing of the fracture well. The casing of a well remotely located is used for the current return. Changes in the potential field should provide information on the orientation of the fracture.

Figure 1 shows a typical layout for surface potential measurements. Each potential measurement location consists of a pair of potential probes driven into the earth and a potential measurement box (PMB). The probes are stainless steel stakes approximately two feet long. A wire from each probe is fed to a PMB usually located adjacent to the inner potential probe. The output from twelve PMB's are frequency multiplexed onto one coax cable. The coax cable feeds power from the instrumentation van to each PMB and feeds data via the frequency multiplex from each PMB to the instrumentation van. Two coax cables thus feed the potential data from all 24 locations to the instrumentation van for processing and recording. Figure 2 is a block diagram of this system.

LAYOUT FOR SURFACE POTENTIAL INSTRUMENTATION

FIG. 1

BLOCK DIAGRAM - INSTRUMENTATION SYSTEM

FIG. 2

The distances from the fracture well to the inner and outer probes are dependent on the well depth and the predicted fracture length. A computer model has been developed which aids in the selection of probe spacings.¹

As noted previously, the surface potentials of interest are generated by injecting current into the earth through two widely spaced well casings.

The bipolar current pulse used and a typical response observed at a PMB is shown in Figure 3. The equipment used to generate this pulse is detailed in the following section.

The sequence of events used to make a measurement is as follows:

1. A positive current flow is initiated.
2. A one-second delay is used to allow all transients associated with the step current pulse to subside.
3. Potentials are measured and the values recorded.
4. The current is turned off.
5. A two-second delay is used to allow all transients to subside.
6. A negative current flow is initiated.

The surface potentials are the differences between the values recorded for the positive pulse and the values recorded for the negative pulse.

The voltage and current used to generate the potential field are measured in the same manner.

EQUIPMENT LAYOUT AND TYPICAL CURRENT AND POTENTIAL WAVEFORMS

FIG. 3

The potential readings can be divided by the current to obtain normalized potentials or "resistance" readings for each location.

This system has been successfully employed on several massive hydrofractures by AMOCO in the Wattenberg field.²

III. Current Generator

1. Requirements

The current generator was designed to provide up to 600 volts and 50 amperes into a load of eight ohms or more with the capability of providing bipolar pulses. The current generator was to be controlled either manually or by the PDP-11 computer. Monitoring circuits were to be provided to measure the applied voltage and current and supply an output compatible with the PDP-11.

The most critical requirement for the current generator is that at no time shall the source of energy that provides the current come into contact with the earth at any place except the driving points. In this case, these points are the fracture well and the return well.

2. Design

The design of the current generator utilizes batteries for a voltage source. The batteries are connected to the drive wells through relays and the current pulse is initiated via the firing of a silicon controlled rectifier (SCR). In order to provide the bipolar pulse, the SCR is turned off after the desired pulse width has been obtained, relays reverse the load connections and the SCR is fired again. Isolation amplifiers provide the voltage and current

monitoring. Interlock circuits provide a means of removing high voltages when access to the circuitry is required for maintenance or adjustments. Means of charging the batteries are also provided.

3. Circuit Description

Figure 4 is a schematic of the current generator and a complete parts list is given in Appendix A. Batteries E1 through E7 consist of twelve lead acid batteries with a voltage of 6.75 volts each and a capacity of 7.5 ampere-hours. Batteries used in this generator are Globe Union Gell Cells, GC-680-1B. The desired voltage is selected by means of switches S1 through S7 in steps of 81 volts (6.75 volts x 12 batteries). Any combination of batteries may be selected. Voltage selection is made by operating initially with just one set of batteries and monitoring the current. The desired current can then be obtained by adding an appropriate number of batteries. The current and voltage may be locally observed with meters M1 and M2.

Relay K1 connects the batteries to relays K2 and K3 and is energized through the interlocking relays K10 and K9 and switches S11 through S15. The interlocks will be described later. Relays K2 and K3 are controlled by switch S9. In the position shown (CHARGE) S9 connects the batteries to the charging power supply PS3 through K2 and K3. In the REMOTE position S9 allows the PDP-11 to operate K2 and K3. In the LOCAL position S9 energizes

CURRENT GENERATOR SCHEMATIC
FIG. 4

K2 and K3 and connects the batteries to the output lines and Q3 through relays K4 and K5. Relays K4 and K5 provide reversal of the output lines and are controlled by switch S10. In the position shown (LOCAL +) S10 leaves K4 and K5 de-energized and these relays connect the positive battery terminal to J4 and the negative terminal to J5. In the LOCAL position S10 energizes K4 and K5 and the output lines are reversed. The REMOTE position of S10 allows control of K4 and K5 by the PDP-11. Note that both S9 and S10 must be in the REMOTE position before the PDP-11 can control the current generator. With J1 connected to the PDP-11 and switches S9 and S10 in REMOTE, operation is performed by applying 28 V to the READY line of J1 through a relay contact (2 ampere rating). Line reversal is accomplished by connecting the 28 V line of J1 to the REVERSE line of J1 through a second relay with the same contact rating. The START/STOP line of J1 is connected to the PDP-11 TTL output logic. Logic "0" is approximately + 5 V and logic "1" is nearly ground (< 0.2 V).

The sequence of operation from the remote location is as follows:

1. Close ready relay -- applies 28 V to K2 and K3 which connects the batteries to the output lines.
2. Apply logic "1" to the START/STOP line after a one second delay -- fires the SCR which applies a current pulse to the output lines. A description

of the firing circuits will follow. The one second delay is to allow relays to fully close. The time is somewhat arbitrary but should be long enough to allow contact bounce to settle down.

3. Return START-STOP line to logic "0" after approximately a two second time delay -- turns off the SCR. A two second time delay is used in order to allow sufficient time for reduction of transients and data accumulation.
4. Close reverse relay after a one second delay -- reverses output lines. The delay is necessary in order for the SCR to be completely turned off. Any length of time greater than 0.1 seconds should be sufficient. Greater times were used to allow all other voltage transients in the earth to subside.
5. Apply logic "1" to the START-STOP line after a one second delay -- fires the SCR again. This provides the opposite polarity pulse. The time delay is again to avoid contact bounce.
6. Return START-STOP line to logic "0" after approximately a two second time delay -- turns off the SCR. The time delay is for reasons stated in 3 above.
7. Return REVERSE line to zero voltage after a one second time delay -- releases the reversing relays. The delay is again to allow voltage transients to subside.

8. Return READY line to zero voltage after a one second time delay -- returns batteries to the charging circuits.

Application of a logic "1" level to the START-STOP line initiates the current pulse. In the LOCAL position of S9 and S10 closing S8 will initiate the current pulse. Relays K6, K7 and K8 are normally open, Q1 is off, Q2 is on and C2 is charged to the battery voltage E8. The battery voltage should be between 18 and 30 volts and consists of four Gell-Cell batteries in this generator. A "1" level on the START-STOP lines (or closing S8) turns off Q1, turns on Q2 and closes K8 and K6. Closing K6 discharges C2 into the gate of the SCR (Q3) through R6 and turns the SCR on and allows current to flow through the load connected to J4 and J5. Relay K7 is also closed and connects C1 to the power supply PS4 and is charged to the power supply level through R7. Power supply PS4 should be set to approximately the output voltage level but not less than 200 volts. When the START-STOP line is returned to the "0" level (or S8 is opened) Q1, Q2, K6, K7 and K8 are returned to their original status. Capacitor C2 is again charged to the E8 voltage level and C2 is connected to Q3 anode and cathode applying a negative voltage to the anode. This negative voltage turns off the SCR providing the time constant of C1 and the load resistance is large enough to hold the SCR anode voltage at a negative value longer than the turn off

time of the SCR. This turn off time is typically 100 microseconds for the C152P. In this design, a minimum time constant of six times this value is used to insure turn off.

Note that relay K6 should be a mercury relay to avoid contact bounce. Contact bounce could reduce the energy stored in C2 enough to prevent the SCR from firing. Capacitor C1 should be charged to full power supply voltage prior to termination of the pulse. With 75 microfarads for C1 and 464 ohms for R7 and to charge C1 from + V to - V this time is approximately 0.35 seconds. Therefore, the minimum pulse width that should be applied is 0.35 seconds.

A pulse width of approximately two seconds is used to allow voltage transients to subside. Data accumulation requires 0.25 seconds (10 samples at 25 ms spacing). Therefore, the minimum width of 0.35 seconds is considerably less than any width that should be used in the type of experiment.

Voltage and current are monitored by A1 and A2 respectively. The amplifiers A1 and A2 are Burr-Brown 3451 "Iso-Op-Amps" with selectable gains by means of switches S16 and S17. In this design gains of 10 and 20.5 are used for A1 and 7.9 and 15.4 for A2. Filters FL1 and FL2 are TTE J830 low-pass filters to reduce high frequency noise and have a 10% insertion loss at D.C. Resistors R9, R10, R11 provide a 1000 to 1 reduction in input voltage to A1. Overall gain in the voltage monitoring circuit is then 0.009

(R9-R11 attenuation of 0.001 times A1 gain of 10 times the attenuation of FL1 of 0.9) or 0.018 when A1 gain is 20.5.

Resistor R12 is a current viewing resistor made up of ten 0.1 ohm resistors in parallel for a total resistance of 0.01 ohms and thus producing a voltage drop of 0.01 volts per ampere. Thus an output from A2 of approximately .07 volts per ampere (voltage drop of R12 x A1 gain x FL2 attenuation) is obtained in the low gain position and 0.139 volts per ampere in the high gain position. These gains are only design figures and are not accurate enough for data reduction purposes. Overall gains of the monitoring circuits should be measured with the highest degree of accuracy prior to any test. The outputs from the monitors are connected to the PDP-11 for data accumulation and storage and should be kept at a level of 5 volts or less.

The trim pots R21, R17 and R31; R27 are used to adjust the amplifiers to a zero output voltage with no signal present. This adjustment procedure is given in the Burr-Brown data sheets and will not be presented here.

The interlock circuitry consists of switches S11 through S15 and relays K10 through K12. Switches S12 through S15 are door and drawer interlock switches mounted on the two back doors, the drawer containing the battery switches, F1, K1, M1 and M2, and the drawer containing Q3 and K2 through K8. Switch S11 is an ON-OFF switch. Opening of switches S11 through S15 will remove the battery voltage from all circuits except the battery switches and will turn

off PS3 and PS4. Power supply PS2 provides power for all relays except K1 which is operated from 110 VAC and K9 which is energized by PS4.

Power supply PS3 provides battery charging voltage and PS4 provides the SCR turn off voltage. Relay K9 is operated from the PS4 voltage and must be approximately 200 volts or more before K9 can be energized because of the dropping resistor R8. Zener diode D10 prevents the voltage on the relay to exceed about 28 volts. Relay K9 in turn operates relay K10 and subsequently K1. This interlock is to remove the battery voltage from the SCR unless sufficient voltage is present to turn the SCR off. Without this precaution the SCR could be locked in the conducting state. Manually operating the ON-OFF switch (S11) will turn off all high voltage circuits if the SCR somehow did get locked in the conduction state. This could be done by attempting to terminate the output pulse before C1 is sufficiently charged. Relays K11 and K12 turn on the two power supplies PS3 and PS4.

4. Operating Procedure

The following is a step-by-step operating procedure for the current generator. With all switches as shown in Fig. 4:

1. Insert correct value of protecting fuse, F1. The value of this fuse should be approximately three-quarters of the desired output current. These fuses are rectifier fuses and are intended for

semi-conductor application and, therefore, have considerably different characteristics than ordinary fuses encountered. The fuses may take several minutes to open at their rated current. As an example, a 30 ampere fuse will pass 45 amperes for two seconds and 120 amperes for 0.2 seconds.

Therefore, the fuse used should be rated at a lower value than the desired current in order to properly protect the generator.

2. Connect J1, J2 and J3 to the PDP-11.
3. Connect J4 and J5 to the driving wells.
4. Connect J6 to a source of 110 VAC.
5. Close all doors and drawers -- closes interlock switches S12 through S15.
6. Close switch S18 -- applies AC power to PS1 to provide ± 15 V to A1 and A2.
7. Turn on PS2 and adjust to 28 volts.
8. Close switch S11 -- operates relay K11 and K12.
9. Turn on PS3 and set to 567 volts and set the current limit between 1.1 and 1.5 amperes. The current limit can be set by shorting the output terminals with a very low output voltage.
10. Turn on PS4 and set to 600 volts and set the current limit to 1.5 amperes as in step 8. When PS4 exceeds approximately 200 volts, relay K9, K10 and K1 will operate and PS3 will begin to charge the batteries.

11. Adjust the balance and offset potentiometers on A1 and A2 following the procedures in the Burr-Brown data sheet.
12. Leave the current generator in this condition until all batteries are fully charged as indicated by a current of approximately 20 milliamperes from PS3. This may take 10 hours or so if the batteries are very low.
13. When the batteries are fully charged reduce PS3 voltage to 81 volts.
14. Select one set of batteries by turning off six of the switches S1 through S7. CAUTION: Make sure that PS3 has been reduced before the battery voltage is reduced. PS3 should never be set higher than 86.4 volts times the number of batteries to be selected.
15. Reduce PS4 to about 250 volts.
16. Set S9 and S10 to the LOCAL position.
17. Close switch S8 and observe the current indication on meter M1.
18. Open switch S8 after about one second.
19. Select the number of batteries to produce the desired current based on the observed current in 17. i.e., if 10 amperes are desired and 2 amperes were observed in 17, select five sets of batteries by turning on five of the switches S1 through S7.
20. Set PS4 to the voltage selected by S1 through S7 (81 x 5 or 405 volts in the example cited).

21. Set PS3 to the voltage selected. (405 volts in the example)
22. Set the gain of A1 to high if the voltage selected is less than 250 volts and to low if the selected voltage is over 250 volts.
23. Set the gain of A2 to high if the current desired is less than 30 amperes and to low if over 30 amperes.
24. Close S8 and observe current on M1 to verify that the desired current is obtained.
25. Open S8 after about one second.
26. Place switches S9 and S10 in the REMOTE position.
27. The current generator is ready to be operated from the PDP-11.

IV. Potential Measurement Box

1. Requirements

The electronics system in each PMB used to make potential measurements is shown in Figure 5. The potential measurements are made in the presence of natural and man-made noise. These noise currents consist of telluric currents, currents that originate from industrial sources, and natural local currents. Telluric currents flow in uniform sheets and cover large areas of the earth. This is caused by lightning storms and by changes in the magnetic field. Their period can vary from less than a second to several days. Industrial currents are generally associated with power lines and broadcast radio stations. Natural local currents are produced by electrochemical reaction in the earth. Local thunderstorms generate noise currents which can also be large enough to cause damage to the instrumentation system. From these sources DC electrical potential differences of up to 750 mV have been observed and AC potential differences of 1 to 2 V peak-to-peak have been observed (as broad-band noise) on an oscilloscope. These measurements were observed in the Wattenburg field approximately 30 miles northeast of Denver, Colorado, with probe spacings of 1000 feet.

BLOCK DIAGRAM -- POTENTIAL MEASUREMENT BOX

FIG. 5

2. Circuit Description

The PMB must be capable of amplifying the desired potential and rejecting the potentials caused by noise currents. Following is an item-by-item description of how the system was designed to reduce noise, provide gain, and transmit the measurement to the instrumentation van.

- A. RFI/EMI Filtering -- The signal lines from the potential probes are fed through two Erie Model 9051-100 RFI/EMI filters as they initially enter the chassis of the PMB. These filters provide 15 db of attenuation at 15 kHz, 28 db attenuation at 150 kHz and 33 db attenuation or greater at frequencies above 300 kHz. The chassis is a weather-proof aluminum instrument case purchased from Zero Manufacturing.
- B. Lightning Protection -- The lightning protection is not intended to protect against direct hits on the instrument case or the signal lines. It is intended to protect the input amplifier from input voltages in excess of ± 15 V caused by static buildup during local thunderstorms or by lightning strikes in the vicinity. The protection consists of a pair of closed contacts on relay K1 during periods of non-operation and by surge protection diode CR1 during periods of operation. CR1 will clamp the input to a maximum of 5 V and dissipate 1000 W for 1 ms.

C. 60 Hz Rejection -- Power line currents and DC tellurics are generally the largest noise currents. To reduce the power line noise, a 60 Hz band reject filter is placed before the first amplifier stage. The filter is a model B83 and was obtained from TT Electronics. Its input impedance is 100K Ω and thus it provides negligible loading on the potential probes. Impedance between probes is generally less than 5K Ω . The filter provides 50 db rejection at 60 Hz. Its 3 db points are at 46 Hz and 78 Hz.

D. Isolation Amplifier -- A Burr-Brown Model 3450/16 Isolation Amplifier is used to provide electrical isolation between pairs of potential probes and also to provide DC blocking of telluric currents. Figure 6 shows a schematic of this amplifier and notes how it was modified for this application. The amplifier has a fixed gain of two in this configuration.

The input circuit has a time constant of seven seconds and a 3 db point at .023 Hz. This appears to be sufficient to block DC tellurics but permit measurements of the pulsed DC induced potentials.

E. Low-Pass Filter -- A 10 Hz low-pass filter follows the isolation amplifier. This filter in conjunction with the input network in the isolation amplifier limits the frequency response of the system from

FIG. 6

.023 Hz to 10 Hz. This filter provides 3 db attenuation at 10 Hz and 58 db minimum attenuation at frequencies above 60 Hz.

- F. Variable Gain Amplifier -- A Burr-Brown Model 3640/16 Instrumentation Amplifier is used to provide variable gain for the system. Calibrated gains of 1, 3, 10, 30, 100, 300 and 1000 can be selected. An uncalibrated vernier can multiply these gains from 1 to 4. The gain required is dependent on well geometry, probe spacing and injection current.

Figure 7 shows a schematic of this amplifier and notes how it was modified for this application. The resistors on the input are to provide proper loading for the low-pass filter and to balance the source impedances for the amplifier inputs.

- G. Multiplex Module -- The multiplex module allows 12 PMB's to be connected to the instrumentation van via one coax cable. DC power is provided to all the systems in parallel from the van. An FM multiplex signal is sequentially collected and amplified by each system along the cable and fed back to the instrumentation van. Figure 8 is a schematic of this module.

DC power from the instrumentation van comes into the module on Pin D and out on Pin L. Inductors L1 and L2 and capacitor C1 form a DC path for the current flow.

P.O. BOX 11400 TUCSON, ARIZONA 85705, U.S.A.

7-2-75

BURR-BROWN		MODEL 3640	
P.O. BOX 11400 TUCSON, ARIZONA 85705, U.S.A.		P.O. BOX 11400 TUCSON, ARIZONA 85705, U.S.A.	
TITLE: INSTRUMENTATION AMPLIFIER - RACK MOUNT		SUBJECT: CIRCUIT DIAGRAM	
ENC. 1	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 2	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 3	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 4	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 5	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 6	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 7	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 8	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 9	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 10	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 11	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 12	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 13	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 14	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 15	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 16	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 17	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 18	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 19	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 20	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 21	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 22	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 23	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 24	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 25	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 26	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 27	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 28	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 29	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 30	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 31	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 32	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 33	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 34	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 35	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 36	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 37	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 38	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 39	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 40	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 41	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 42	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 43	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 44	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 45	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 46	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 47	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 48	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 49	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 50	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 51	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 52	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 53	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 54	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 55	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 56	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 57	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 58	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 59	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 60	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 61	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 62	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 63	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 64	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 65	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 66	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 67	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 68	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 69	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 70	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 71	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 72	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 73	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 74	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 75	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 76	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 77	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 78	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 79	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 80	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 81	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 82	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 83	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 84	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 85	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 86	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 87	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 88	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 89	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 90	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 91	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 92	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 93	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 94	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 95	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 96	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 97	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 98	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 99	DATE 11/2/72	SM. OF 1	NO. 8
ENC. 100	DATE 11/2/72	SM. OF 1	NO. 8

R6 CHANGED TO 100K

C4 CHANGED TO 0.22 MICRO-FARAD

SMI NOT USED

BURR-BROWN 3640 AMPLIFIER
FIG. 7

20D7415 REV B

MULTIPLEX MODULE

FIG. 8.

The output of the variable gain amplifier is fed into the multiplex module on Pine J and to the input of a constant bandwidth voltage controlled oscillator. Thus, the potential measured between the probes is converted into a frequency proportional to that potential.

One or more carrier frequencies from systems upstream on the coax cable are fed into the module on Pine L. Resistors R1, R2 and R3 form a network for mixing the local subcarrier with those coming in. Capacitor C2 blocks the power supply voltage from the mixing network and 741S amplifier input. R4 is the bias resistor for the 741S amplifier. Resistor R1 allows the level of the local carrier to be adjusted to be equal to the level of incoming carriers. Resistor R6 allows the gain of the 741S amplifier to be adjusted to compensate for mixing losses and cable losses. The LH0002 is a unity gain, low output impedance amplifier used to drive the long coax cable lengths between systems. Capacitor C5 blocks the DC power supply voltage from damaging the LH0002.

Pins D, L and C (common) are connected to the coax cable through isolated BNC connectors. This is to prevent any local currents from being generated in the earth and thus degrade the potential measurements.

Table 1 lists the carrier frequencies used in each PMB. The highest frequencies were located nearest the instrumentation van to reduce cable attenuation losses.

- H. Regulated Power Supply -- All active circuits in the PMB's are powered from a regulated DC/DC converter. The input to the converter is protected by a series resistor (R_s) and a 30 volt zener diode. The value of the series resistor is dependent on the length and resistance of coax cable used between the PMB's. Table 1 lists some typical values for R_s . The zener diode and resistor permits a wide range of supply voltage and cable lengths to be used without damaging the DC/DC converter.

The DC/DC converter used was purchased from Semiconductor Circuits, Inc., and is a model 30C24-15D100Q.

Current drain for each PMB is 120 mA.

- I. Power Supplies -- Two 150 volt, 1.5 ampere supplies in the instrumentation van are used to provide power to the two lines of PMB's. Figure 9 shows a schematic of the filter used to separate DC power and multiplexed carriers. The multiplexed carriers are fed to two banks of 12 FM discriminators.

TABLE 1

<u>PMB A & B</u>	<u>VCO Freq. & Deviation</u>	<u>Rs 200 ft (1)</u>	<u>Rs 500 ft (1)</u>
1	16 ± 2 kHz	425	200
2	24 ± 2 kHz	425	200
3	32 ± 2 kHz	425	220
4	40 ± 2 kHz	470	250
5	48 ± 2 kHz	470	270
6	56 ± 2 kHz	470	300
7	64 ± 2 kHz	560	350
8	72 ± 2 kHz	560	425
9	80 ± 2 kHz	620	470
10	88 ± 2 kHz	620	560
11	96 ± 2 kHz	700	620
12	104 ± 2 kHz	700	700

(1) Calculated for this length of RG 58 coax between each PMB and 110 VDC power supply setting.

POWER-MULTIPLEX FILTER

FIG. 9

3. Operating Procedure

Before the PMB's are connected in a system configuration each PMB should be setup and tested individually.

The following procedure will generally be required only after initial fabrication of the PMB's.

1. Connect DC power to an individual PMB through a filter as shown in Fig. 9. Connect a frequency counter, oscilloscope and FM discriminator bank to the FM discriminator connection.
2. Adjust the supply voltage so that 28 VDC is applied to the input of the DC/DC converter. Current drain should be approximately 120 ma. Test for ± 15 volts out of the converter.
3. Adjust the balance and offset potentiometers following the procedures on the Burr-Brown data sheets.
4. Short the signal input lines. Adjust R6 to mid-range. Adjust R1 to obtain a one volt peak-to-peak carrier on the oscilloscope. The frequency meter should read approximately center frequency for the carrier being used.
5. Apply a 1 mv, 5 Hz signal to the input lines. Check for proper output voltage from the appropriate FM discriminator based on the gain settings for the 3640 amplifier and the FM discriminator. Do not forget the fixed gain of two in the 3450 amplifier.

After all the PMB's have been tested individually the following procedure may be used for system set-up.

1. Connect PMB 1A to the power supply as described above and connect a Telemetering Spectrum Analyzer to the FM discriminator connection. Use the same coax cables in this procedure that are going to be used in the field installation.
2. Apply DC power and monitor the spectrum analyzer for a "clean" spectrum. The DC power voltage will have to be adjusted as PMB's are added to the system.
3. Insert PMB 2A into the system. Adjust R6 on PMB 1A until the two carriers are of equal amplitude.
4. Insert PMB 3A into the system. Adjust R6 on PMB 2A until the three carriers are of equal amplitude. This procedure adjusts the gain of the 741S amplifier to compensate for losses in the cables and mixing networks.
5. Repeat the above procedure until all twelve PMB's are connected into the system.
6. Repeat for string B PMB's.

V. Instrumentation Van

The instrumentation van contains power supplies for the PMB's, the data recording system and the current generator for creating the potential field.

1. Data Recording System

The data recording system performs the following functions:

- A. Control the current generator during the periods when measurements are being made. A detailed description of the current generator and the control sequence from the PDP 11/10 has already been given.
- B. Demultiplex and measure the potentials present at all 24 locations simultaneously.
- C. Measure the voltage and current levels produced by the current generator simultaneously with the potential measurements.
- D. Store the above data on permanent records for post-test analysis.
- E. Provide a hard copy output for quick look of test results.

Figure 10 is a block diagram of the system and some associated monitoring and test equipment.

INSTRUMENTATION VAN

FIG. 10

The heart of the data recording system is a PDP-11/10 minicomputer. Peripherals included with the PDP-11/10 are a Lab Peripheral System (LPS11), a printer terminal (LA36), a mass storage disk (RK11), and a cassette tape unit (TA11). The PDP-11/10 operates under the RT11 operating system. All application programs have been written in BASIC. Appendix B includes some sample programs.

The other major component of the system is the 24 FM discriminators.

As shown previously, the potential data are fed into the instrumentation van via frequency multiplex on two coax cables. These are referred to as String A and String B. Each string is fed into a bank of FM discriminators. The outputs of the FM discriminators are proportional to the analog voltages measured between probe pairs.

The outputs of the discriminators and the voltage and current monitors from the current generator are fed into the LPS11. The LPS11 contains an analog multiplexer and a 12 bit A/D converter. Table 2 shows the channel assignments for the LPS11. Each input is digitized and the result stored in the RK11.

In addition to storing the data on the RK11, simple calculations are performed and the results are printed out on the LA36 for quick visual monitoring of test results. Figure 11 shows a typical printout. The "resistance" readings are scaled values of the potential measurements divided by the current used to create that potential.

Cassette tapes are used as backup storage for test data and programs.

TABLE 2

<u>LPS11</u> <u>CHANNEL</u>	<u>DATA</u>
0	Voltage Monitor
1	Current Monitor
2	PMB 1A
3	PMB 2A
4	PMB 3A
5	PMB 4A
6	PMB 5A
7	PMB 6A
8	PMB 7A
9	PMB 8A
10	PMB 9A
11	PMB 10A
12	PMB 11A
13	PMB 12A
14	PMB 1B
15	PMB 2B
16	PMB 3B
17	PMB 4B
18	PMB 5B
19	PMB 6B
20	PMB 7B
21	PMB 8B
22	PMB 9B
23	PMB 10B
24	PMB 11B
25	PMB 12B

TEST NO: 1 TIME: 9:36:00
 VOLTS = 332.572 AMPS = 27.6503 RESISTANCE = 12.0278
 VOLTS = -331.83 AMPS = -27.6669 RESISTANCE = 11.9938
 POTENTIAL - MILLIVOLTS (A1>A12 & B12>B1)
 8.15609 8.14957 8.14367 8.15242 8.15242 8.15425
 8.14326 8.14204 8.16036 8.1626 8.16443 8.1571
 8.15486 8.14937 8.17094 8.15039 8.14713 8.14754
 8.14734 8.14672 8.15283 8.15812 8.1394 8.16748

TEST NO: 2 TIME: 9:36:30
 VOLTS = 332.698 AMPS = 27.6488 RESISTANCE = 12.033
 VOLTS = -331.884 AMPS = -27.6669 RESISTANCE = 11.9957
 POTENTIAL - MILLIVOLTS (A1>A12 & B12>B1)
 8.15568 8.15018 8.14571 8.15425 8.15324 8.1569
 8.14367 8.14347 8.16138 8.16341 8.16707 8.15873
 8.15344 8.1512 8.17094 8.15059 8.14876 8.14795
 8.14876 8.14774 8.15344 8.15812 8.14001 8.16829

TEST NO: 3 TIME: 9:37:00
 VOLTS = 332.517 AMPS = 27.6609 RESISTANCE = 12.0212
 VOLTS = -332.119 AMPS = -27.6654 RESISTANCE = 12.0049
 POTENTIAL - MILLIVOLTS (A1>A12 & B12>B1)
 8.15609 8.15079 8.14469 8.15364 8.15324 8.15446
 8.14449 8.14347 8.16097 8.16239 8.16504 8.15873
 8.15486 8.14998 8.17114 8.15079 8.14876 8.14876
 8.14774 8.14713 8.15344 8.15873 8.13981 8.1685

TEST NO: 4 TIME: 9:37:30
 VOLTS = 332.354 AMPS = 27.6593 RESISTANCE = 12.016
 VOLTS = -331.992 AMPS = -27.6609 RESISTANCE = 12.0023
 POTENTIAL - MILLIVOLTS (A1>A12 & B12>B1)
 8.15547 8.14896 8.1451 8.15364 8.15303 8.15364
 8.14286 8.14388 8.16138 8.163 8.16565 8.15751
 8.15446 8.15039 8.17114 8.151 8.14795 8.14815
 8.14835 8.14734 8.15283 8.15853 8.13919 8.1685

TEST NO: 5 TIME: 9:38:00
 VOLTS = 332.644 AMPS = 27.6639 RESISTANCE = 12.0245
 VOLTS = -331.92 AMPS = -27.6593 RESISTANCE = 12.0003
 POTENTIAL - MILLIVOLTS (A1>A12 & B12>B1)
 8.15527 8.14998 8.1451 8.15385 8.15303 8.15629
 8.14347 8.14306 8.16219 8.16321 8.16585 8.15832
 8.15527 8.15018 8.17155 8.14957 8.14774 8.14734
 8.14856 8.14713 8.15344 8.15771 8.13858 8.16789

DATA PRINTOUT

FIG. 11

REFERENCES

1. L. C. Bartel, L. J. Keck and R. P. McCann, "Use of Potential Gradients in Massive Hydraulic Fracture Mapping and Characterization," SPE 6090, presented at the SPE 51st Annual Fall Meeting in New Orleans, Louisiana, October 4-6, 1976.
2. R. P. McCann, L. C. Bartel and L. J. Keck, "Massive Fracture Mapping and Characterization Program: Surface Potential Data for Wattenberg '75 - '76 Experiments," SAND-77-0396, Sandia Laboratories, 1977.
3. R. G. Hay, D. V. Power, C. L. Schuster and Twombly, Jr., "Detection of Hydraulic Fracture Orientation and Dimension in Cased Wells," SPE 5626, presented at the SPE 50th Annual Fall Meeting, Dallas, Texas, September 28-October 1, 1976.
4. L. J. Keck and R. P. McCann, "Massive Hydraulic Fracture Mapping and Characterization Program: Surface Potential Data for Pinedale '75 Experiments," SAND-76-0375, Sandia Laboratories, August, 1976.

Appendix A

Current Generator Parts List

E1-E7	12 each Lead Acid Batteries, Globe Union Gel-Cell, GC-680-1B
E8	4 each, TRI-34-R Mercury Batteries or 4 each GC-680-1B
S1-S7	Switch, Ross Eng. Co. R-30-2P-2T-30 Modified to 4" x 4" x 8" and 12 KV Rating
S8	Switch, SPST, Toggle
S9	Switch, DPDT, Toggle Center Position Off
S10	Switch, SPDT, Toggle Center Position Off
S11	Switch, SPST, Toggle
S12-S15	Switch, Door Interlock Control Switch No. MS-16106-2
S16-S17	Switch, DPDT, Toggle
S18	Switch, DPST, Toggle
K1	Relay, Ross Eng. Co. E-40-NO
K2-K5	Relay, ITT RF10B
K6	Relay, Mercury Wetted Babcock BW5-1007J
K7	Relay, ITT RGD5-2C02-0018, 12 volt coil
K8,K9	Relay, Filtors BRJV20P3PGAS-1
K10-K12	Relay ITT RB2A
F1	Fuse, Bussman KAC
M1	Ammeter 50-0-50 amps. Simpson No. 1327 Cat. No. 2810
M2	Voltmeter 0-750 volts Simpson No. 1327 Cat. No. 9850
Q1	Transistor, 2N2484
Q2	Transistor, 2N2222A
Q3	SCR, C152P

D1-D4	
D7-D9	Diode, IN914
D11	
D5	Diode, IN1190
D6	Diode, R350
D10	Diode, Zener, IN3030B
C1	5 each Capacitors 15MF, 1000V Sprague No. 271B59
C2	Capacitor, 0.47MF, 600V T.R.W. No. 663F47496W
C3, C5	Capacitor, 6800PF, 500V Dura-Mica Series
C4, C6	Capacitor, 3900PF, 500V Dura-Mica Series
R1	Resistor, 100K, 1/8 W C. C.
R2	Resistor, 2.7K, 1/8 W C. C.
R3	Resistor, 1K, 1/8 W C. C.
R4	Resistor, 2 x 68 5 W W.
R5	Resistor, 180, 1/4 W C. C.
R6	Resistor, 51, 1/4 W C. C.
R7	Resistor, 464, 5W W.W.
R8	Resistor, 39K, 1/4 W C. C.
R9, R11	Resistor, 1M, 1/4 W, MF 1%
R10	Resistor, 2.05K, 1/4 W, MF 1%
R12	Resistor, 10 each, 0.1 Ω 3 W, WW 1%
R13, R14	Resistor, 48.7K, 1/4 W, MF 1%
R15	Resistor, 383K, 1/4 W, MF 1%
R16	Resistor, 750K, 1/4 W, MF 1%
R17	Resistor, Variable, 100K Trimpot
R18	Resistor, 750K, 1/4 W, C. C.
R19	Resistor, 383K, 1/4 W, MF 1%

R20 Resistor, 750K, 1/4 W, MF 1%
 R21 Resistor, Variable 100K Trimpot
 R22 Resistor, 10M, 1/4 W, C. C.
 R23, R24 Resistor, 48.7K, 1/4 W, MF 1%
 R25 Resistor, 48.7K, 1/4 W, MF 1%
 R26 Resistor, 1M, 1/4 W, MF 1%
 R27 Resistor, Variable 100K Trimpot
 R28 Resistor, 750K, 1/4 W, C. C.
 R29 Resistor, 487K, 1/4 W, MF 1%
 R30 Resistor, 1M, 1/4 W, MF 1%
 R31 Resistor, Variable 100K Trimpot
 R32 Resistor, 10M, 1/4 W, C. C.
 R33, R34 Resistor, 15K, 1/4 W, C. C.
 A1, A2 Amplifier, Burr-Brown "ISO-OP-AMP" 3451
 PS1 Power Supply, Analog Devices AD902
 PS2 Power Supply, 28V, 5A LAMBDA LA 50-03B
 PS3, PS4 Power Supply, 600V, 1.5A HP6448B
 FL1, FL2 Filter, TT Electronics Model J 830, 15K Impedance

Appendix B

```

10 REM - PROGRAM TO SAMPLE AND STORE RESISTIVITY DATA
20 REM - D IS THE DELAY TIME BEFORE SAMPLING STARTS
30 REM - N IS THE NUMBER OF SAMPLES TAKEN PER CHANNEL
40 REM - R IS THE TIME BETWEEN SAMPLES IN MILLISECONDS
50 DATA 1,10,25
60 READ D,N,R
70 PRINT "TULSA-AMOCO DATA"
80 PRINT
85 PRINT
90 PRINT "DELAY TIME = 'D'SECONDS"
110 PRINT "TIME BETWEEN SAMPLES = 'R'MILLISECONDS"
130 PRINT "NUMBER OF SAMPLES = 'N'PER CHANNEL"
150 F2$="TULSAA.DAT"
160 PRINT "DATA FILE: "F2$
180 PRINT "VOLTAGE MONITOR GAIN HI OR LO ";
190 INPUT G3$
210 IF G3$="HI"GO TO 240
220 IF G3$="LO"GO TO 260
230 GO TO 180
240 G3=5.53282
250 GO TO 270
260 G3=2.76671
270 PRINT "CURRENT MONITOR GAIN HI OR LO ";
280 INPUT G2$
300 IF G2$="HI"GO TO 330
310 IF G2$="LO"GO TO 350
320 GO TO 270
330 G2=65.7161
340 GO TO 360
350 G2=32.8581
360 OPEN "TESTNO.DAT" AS FILE VF1
370 TO=VF1(1)-1
380 PRINT "LAST TEST NUMBER = ";TO
400 PRINT "NEXT TEST NUMBER = ";\INPUT T1
410 VF1(1)=T1
415 CLOSE VF1
430 PRINT "START TIME = ";\INPUT T2
450 PRINT "TIME BETWEEN TESTS = ";\INPUT T4
460 PRINT
470 PRINT "NOTE: ";
490 INPUT Z$
495 PRINT
500 PRINT "READY TO BEGIN TESTS ";\INPUT Y$
505 PRINT
510 IF Y$="Y"GO TO 540
520 RESTORE
530 GO TO 10
540 DIM A9(5),A(145),B(145),P1(29),N1(29),R(26),C(290),D(290)
550 CALL "TICK"(U)
560 D9=5.18400E+06
570 FOR I=1 TO 5
580 A9(I)=INT(U/D9)
590 U0=(U/D9-INT(U/D9))*D9
600 D9=60^(4-I)
610 U=U0
620 NEXT I
630 H$=STR$(A9(2))
640 T8$="10"
650 IF A9(2)>=10 THEN 670
660 H$=SEG$("10"&H$,2,3)
670 M$=STR$(A9(3))
680 IF A9(3)>=10 THEN 700
690 M$=SEG$("10"&M$,2,3)
700 A9$=H$&M$

```

```

710 T3=VAL(A9$)
720 IF T3<T260 TO 550
730 CALL "REL"(1,1)
740 CALL "SETC"(4,1)
750 CALL "WAIT"(0)
760 I0=0\E0=0
770 FOR I=1 TO N
780 CALL "ADC"(0,V0)
790 E0=E0+V0
800 CALL "ADC"(1,J0)
810 I0=I0+J0
820 NEXT I
830 U=2038\V=2058
840 CALL "DOR"(0,BIN"1",0)
850 CALL "ADC"(1,T)
860 CALL "LED"(T)
870 IF T>UGO TO 850
880 PRINT CHR$(7);
890 CALL "SETC"(4,D)
900 CALL "WAIT"(0)
910 CALL "USE"(A)
920 CALL "SETR"(4,1,R)
930 CALL "RTS"(A,0,29,N,2)
940 FOR I=0 TO (N*29)-1
950 CALL "RDB"(A,Z)
960 IF Z<OGO TO 950
970 C(I)=Z
980 NEXT I
990 CALL "DOR"(1,BIN"1",0)
1000 PRINT CHR$(7);
1010 CALL "SETC"(4,2)
1020 CALL "WAIT"(0)
1030 CALL "REL"(2,1)
1040 CALL "SETC"(4,2)
1050 CALL "WAIT"(0)
1060 I1=0\E1=0
1070 FOR I=1 TO N
1080 CALL "ADC"(0,V1)
1090 E1=E1+V1
1100 CALL "ADC"(1,J1)
1110 I1=I1+J1
1120 NEXT I
1130 CALL "DOR"(0,BIN"1",0)
1140 CALL "ADC"(1,T)
1150 CALL "LED"(T)
1160 IF T<VGO TO 1140
1170 PRINT CHR$(7);
1180 CALL "SETC"(4,D)
1190 CALL "WAIT"(0)
1200 CALL "USE"(B)
1210 CALL "SETR"(4,1,R)
1220 CALL "RTS"(B,0,29,N,2)
1230 FOR I=0 TO (N*29)-1
1240 CALL "RDB"(B,Z)
1250 IF Z<OGO TO 1240
1260 D(I)=Z
1270 NEXT I
1280 CALL "DOR"(1,BIN"1",0)
1290 PRINT CHR$(7);
1300 CALL "SETC"(4,1)
1310 CALL "WAIT"(0)
1320 CALL "REL"(2,0)
1330 CALL "SETC"(4,1)
1340 CALL "WAIT"(0)
1350 CALL "REL"(1,0)
1360 FOR I=0 TO 28

```

```

1370 P1(I)=0\N1(I)=0
1380 NEXT I
1390 FOR J=0 TO 28
1400 FOR K=0 TO (N-1)*29 STEP 29
1410 P1(J)=P1(J)+C(J+K)
1420 N1(J)=N1(J)+D(J+K)
1430 NEXT K
1440 NEXT J
1450 OPEN F2$ AS FILE VF2
1460 K=(T1-1)*64
1470 VF2(26+K)=T3
1480 VF2(27+K)=T1
1490 VF2(28+K)=E0
1500 VF2(29+K)=I0
1510 VF2(30+K)=E1
1520 VF2(31+K)=I1
1521 VF2(58+K)=P1(26)
1522 VF2(59+K)=P1(27)
1523 VF2(60+K)=P1(28)
1524 VF2(61+K)=N1(26)
1525 VF2(62+K)=N1(27)
1526 VF2(63+K)=N1(28)
1530 FOR I=0 TO 25
1540 VF2(I+K)=P1(I)
1550 VF2(32+I+K)=N1(I)
1560 NEXT I
1565 CLOSE VF2
1570 PRINT DAT$
1580 PRINT
1590 PRINT "TEST NO:   "T1
1600 PRINT
1610 PRINT "TIME:   "T3
1620 PRINT
1630 M1=(P1(0)-E0)/(N*G3)
1640 M1=-M1
1650 M2=(P1(1)-I0)/(N*G2)
1660 M2=-M2
1670 R1=M1/M2
1680 PRINT "POSITIVE PULSE"
1690 PRINT "VOLTS = ";M1;TAB(20);"AMPS = ";M2;TAB(40);"RESISTANCE = ";R1
1710 M1=(N1(0)-E1)/(N*G3)
1720 M1=-M1
1730 M2=(N1(1)-I1)/(N*G2)
1740 M2=-M2
1750 R2=M1/M2
1760 PRINT "NEGATIVE PULSE"
1770 PRINT "VOLTS = ";M1;TAB(20);"AMPS = ";M2;TAB(40);"RESISTANCE = ";R2
1780 FOR I=0 TO 25
1790 Q1=P1(I)
1800 IF Q1<(2*N)GO TO 1840
1810 IF Q1>(N*4095-2*N)GO TO 1840
1820 NEXT I
1830 GO TO 1860
1840 PRINT "BAD DATA AT P1 -- ";I
1850 GO TO 1820
1860 FOR I=0 TO 25
1870 Q2=N1(I)
1880 IF Q2<(2*N)GO TO 1920
1890 IF Q2>(N*4095-2*N)GO TO 1920
1900 NEXT I
1910 GO TO 1940
1920 PRINT "BAD DATA AT N1 -- ";I
1930 GO TO 1900
1940 PRINT
1950 PRINT "RESISTANCE TABLE"
1960 FOR I=2 TO 26

```

```
1970 R(I)=(P1(I)-N1(I))/(P1(1)-N1(1))
1980 NEXT I
1990 FOR J=2 TO 22 STEP 4
2000 PRINT R(J),R(J+1),R(J+2),R(J+3)
2010 NEXT J
2020 PRINT
2025 PRINT P1(26),P1(27),P1(28)
2030 T1=T1+1
2040 T2=T3+T4
2045 OPEN "TESTNO.DAT" AS FILE VF1
2050 VF1(1)=T1
2060 CLOSE VF1
2070 PRINT
2080 PRINT
2085 GO TO 540
2090 END
```

```

100 REM - PROGRAM TO PLOT TULSA AMOCO DATA
105 F1$="TULSAA.DAT"
110 PRINT "TULSA AMOCO DATA"
120 PRINT
130 PRINT "FIRST TEST FOR PLOT:  ";
140 INPUT K1
145 M1=K1
160 PRINT "LAST TEST FOR PLOT:  ";
170 INPUT K2
190 PRINT "RADIAL:  ";
200 INPUT R$
202 DIM P1(26),N1(26),S(26),R(26)
204 T5=(K2-K1)+1
205 GO TO 240
206 OPEN F1$ FOR INPUT AS FILE VF1
208 K=(K1-1)*64
210 I=N2+1
212 P1(I)=VF1(I+K)
214 N1(I)=VF1(I+K+32)
220 R(I)=P1(I)-N1(I)
222 S(I)=S(I)+R(I)
226 K1=K1+1
228 IF K1<=K2 GO TO 208
230 CLOSE VF1
234 S(I)=S(I)/T5
235 GO TO 390
240 L1=LEN(R$)
250 A$=SEG$(R$,0,1)
260 IF A$="A" GO TO 280
270 IF A$="B" GO TO 300
280 N1=1
290 GO TO 310
300 N1=13
310 IF L1=360 TO 350
320 B$=SEG$(R$,2,2)
330 N2=VAL(B$)
340 GO TO 370
350 B$=SEG$(R$,2,3)
360 N2=VAL(B$)
370 X1=N1+N2
380 X2=X1+32
305 GO TO 204
390 K=(M1-1)*64
394 D1=S(I)
395 PRINT "AVERAGE VALUE = ";-D1/10
396 D3=-2*(D1/1000)
400 FOR I=1 TO 72
410 PRINT "-";
420 NEXT I
430 PRINT
440 OPEN F1$ FOR INPUT AS FILE VF1
450 P1=VF1(X1+K)
460 N1=VF1(X2+K)
490 T3=VF1(26+K)
500 T1=VF1(27+K)
510 R1=P1-N1
520 C1=((R1-D1)*100)/D1
530 D2=INT(D3+C1+.5)
540 IF D2>0 GO TO 560
550 D2=0
560 PRINT T1;TAB(6);T3;TAB(D2);"D"
570 K=K+64
580 IF K>=K2*64 GO TO 600
590 GO TO 450
600 CLOSE VF1

```



```
610 FOR I=1 TO 27  
620 PRINT  
630 NEXT I  
640 END
```

```

100 PRINT "PROGRAM TO AVERAGE AND COMPARE TWO SERIES OF TESTS"
105 PRINT
110 DIM P1(26),N1(26),S(26),Z(26)
115 DIM R(26),D(26),C(26)
120 PRINT "INPUT DATA FILE: ";INPUT F$
130 PRINT
140 PRINT "FIRST SERIES"
160 PRINT "FIRST TEST ";INPUT T1
170 PRINT "LAST TEST ";INPUT T2
180 PRINT
190 PRINT "SECOND SERIES"
200 PRINT "FIRST TEST ";INPUT T3
210 PRINT "LAST TEST ";INPUT T4
220 PRINT
225 T5=(T2-T1)+1\T6=(T4-T3)+1
230 OPEN F$ FOR INPUT AS FILE VF1
245 K=(T1-1)*64
250 FOR I=0 TO 25
260 P1(I)=VF1(I+K)
270 N1(I)=VF1(I+K+32)
280 NEXT I
290 FOR I=2 TO 26
300 R(I)=(P1(I)-N1(I))/(P1(1)-N1(1))
330 S(I)=S(I)+R(I)
340 NEXT I
350 T1=T1+1
360 IF T1<=T2GO TO 245
365 M=(T3-1)*64
370 FOR I=0 TO 25
380 P1(I)=VF1(I+M)
390 N1(I)=VF1(I+M+32)
400 NEXT I
410 FOR I=2 TO 26
420 R(I)=(P1(I)-N1(I))/(P1(1)-N1(1))
430 Z(I)=Z(I)+R(I)
440 NEXT I
450 T3=T3+1
460 IF T3<=T4GO TO 365
470 CLOSE VF1
480 FOR I=2 TO 25
490 S(I)=S(I)/T5
500 Z(I)=Z(I)/T6
505 D(I)=(Z(I)-S(I))*100
507 C(I)=D(I)/S(I)
510 NEXT I
520 PRINT
530 PRINT "FIRST AVERAGE"
540 PRINT
700 FOR J=2 TO 22 STEP 4
710 PRINT S(J),S(J+1),C(J+2),S(J+3)
720 NEXT J
722 PRINT
724 PRINT
730 PRINT
732 PRINT "SECOND AVERAGE"
734 PRINT
740 FOR J=2 TO 22 STEP 4
750 PRINT Z(J),Z(J+1),Z(J+2),Z(J+3)
760 NEXT J
762 PRINT
764 PRINT
766 PRINT
770 PRINT "RESISTANCE CHANGE X 100"
780 PRINT

```

```
790 FOR I=2 TO 22 STEP 4
800 PRINT D(I),D(I+1),D(I+2),D(I+3)
810 NEXT I
820 PRINT
830 PRINT
840 PRINT
850 PRINT
860 PRINT "PERCENT CHANGE"
870 PRINT
880 FOR I=2 TO 22 STEP 4
890 PRINT C(I),C(I+1),C(I+2),C(I+3)
900 NEXT I
910 FOR J=1 TO 5
920 PRINT
930 NEXT J
940 END
```

DISTRIBUTION:

Charles H. Atkinson
Bartlesville Energy Research
Center
U. S. ERDA
Bartlesville, OK 74003

J. S. Ball
Bartlesville Energy Research
Center
U. S. ERDA
Bartlesville, OK 74003

Alex Crawley (10)
U. S. ERDA Fossil Energy
20 Massachusetts Avenue NW
Washington, DC 20545

Dresser Atlas
Region Office
P. O. Drawer 2610
Midland, TX 79701

Dresser Atlas
Hobbs District
Attn: Roger Slaughterbeck
P. O. Box 1858
Hobbs, NM 88240

Energy Products
Attn: Glenn Weatherford
5900 South Homphill
P. O. Box 6500
Fort Worth, TX 76115

C. R. Fast
Amoco Production Company
P. O. Box 591
Tulsa, OK 74102

Fenix & Scisson, Inc.
5805 E. 15th Street
Tulsa, OK 74112

Gearhart Owens Industries
Attn: Cecil Alan
P. O. Box 1936
Fort Worth, Texas 76115

Hugh D. Guthrie, Director
Division of Oil, Gas and Shale
Technology
U. S. ERDA Fossil Energy
20 Massachusetts Avenue NW
Washington, DC 20545

Dr. J. D. Ham, Assistant Director
Division for Petroleum and Natural
Gas
U. S. ERDA Fossil Energy
20 Massachusetts Avenue NW
Washington, DC 20545

Halliburton Services
Wellex Division
P. O. Box 2687
Houston, TX 77001

Dr. Merle Hanson
Lawrence Livermore Laboratory
Livermore, CA 94550

D. K. Nowlin, Director
Special Programs Division
U. S. ERDA
Albuquerque, NM 87115

Patso Company, Inc.
Attn: John Reeves, Jr.
P. O. Box 18271
Houston, TX 77023

A. A. Pitrolo, Director
Morgantown Energy Research Center
U. S. ERDA
Morgantown, WV 26505

Schlumberger
P. O. Box 2175
Houston, TX 77001

Seismopgraph Service Corp.
Birdwell Division
P. O. Box 1590
Tulsa, OK

SIE, Inc.
Attn: M. Marion Hawthorne
Rt. 5, Box 214
Fort Worth, TX 76126

Dr. M. C. Smith, Q22
Los Alamos Scientific Labs
Los Alamos, New Mexico

Dr. L. Z. Shuck
Morgantown Energy Research Center
U. S. ERDA
Morgantown, WV 26505

Sperry-Sun, Inc.
Regional Office
Attn: Ted Ashby
Denver Club Bldg., Suite 260-L
516 Seventeenth Street
Denver, CO 80202

Sperry-Sun, Inc.
P. O. Box 36363
Houston, TX 77036

Don Ward, Chief
Natural Gas Branch
U. S. ERDA Fossil Energy
Washington, DC 20545

Western Geophysical Co. of America
B. B. Thigpen, V.P.
Instrumentation & Field Service
Houston, TX 77001

Dr. Phillip C. White
Assistant Administrator
U. S. ERDA Fossil Energy
20 Massachusetts Avenue NW
Washington, DC 20545

1100 C. D. Broyles
1110 J. D. Kennedy
1120 G. E. Hansche
Attn: B. C. Benjamin, 1123
1130 H. E. Viney
Attn: R. D. Statler, 1133
5163 D. E. Munson
5700 J. H. Scott
5710 G. E. Brandvold
5730 H. M. Stoller
5732 D. A. Northrop
5733 L. J. Keck (15)
5733 C. L. Schuster
5733 R. W. Seavey (15)
9420 T. L. Pace
9422 J. L. Rogers
8266 A. A. Aas (2)
3141 C. A. Pepmuller (5)
3151 W. L. Garner (3)
for ERDA/TIC (25)
Attn: R. P. Campbell, 3171-1