WCAP-7819
Revision 1-A

WESTINGHOUSE CLASS 3

NUCLEAR INSTRUMENTATION SYSTEM ISOLATION AMPLIFIER

J. B. Lipchak
R. R. Bartholomew

April, 1975

APPROVED: C. Eicheldinger
C. Eicheldinger, Manager
Nuclear Safety Department

Work Sponsored by Projects Department

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear Energy Systems
P. O. Box 355
Pittsburgh, Pennsylvania 15230

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

SEP 0 3 1974

Mr. Romano Salvatori, Manager
Nuclear Safety Department
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, Pennsylvania 15230

Dear Mr. Salvatori:

The Regulatory staff has completed its review of Westinghouse Electric Corporation topical reports WCAP-7506-L (Proprietary) and WCAP-7819, Revision I (Nonproprietary) entitled "Nuclear Instrumentation System Isolation Amplifier." A summary of our evaluation is enclosed for your information.

As a result of our review we have concluded that the test results presented in the report demonstrate the functional adequacy of the isolation amplifier in Westinghouse Nuclear Instrumentation System equipment when adequate separation exists between the input (including power) and output wiring of the amplifier. As such WCAP-7506-L is acceptable for reference on license applications when used in support of isolation amplifiers with adequate wiring separation. However, additional testing and documentation (including the input-output wiring configuration) will be required to demonstrate the isolation capabilities of the amplifier if adequate separation does not exist. Also, use of this amplifier in other than the Nuclear Instrumentation System will require a reevaluation by the staff.

When WCAP-7506-L is used as a reference, the application which references it must also provide information demonstrating appropriate seismic and environmental qualifications of the isolation amplifier.

Topical report WCAP-7819, Revision 1 is considered an acceptable nonproprietary version of WCAP-7506-L. When either of these reports is used as a reference, both the proprietary report and the nonproprietary version must be referenced.

The staff does not intend to repeat its review of WCAP-7506-L and WCAP-7819, Revision I when they appear as references in a particular license application except to assure that the amplifier configuration is applicable to the specific plant involved.

Should Regulatory criteria or regulations change such that our conclusions concerning WCAP-7506-L and WCAP-7819, Revision I are invalidated, you will be notified and given the opportunity to revise and resubmit your topical report for review, should you so desire.

In accordance with established procedure, it is requested that Westinghouse issue revised versions of WCAP-7506-L and WCAP-7819, Revision I within three months of receipt of this letter, to include the AEC acceptance letter.

If you have any questions concerning our evaluation of WCAP-7506-L and WCAP-7819, Revision I, please contact us.

Sincerely,

DBVassallo

D. B. Vassallo, Chief
Light Water Reactors Project Branch 1-1
Directorate of Licensing

Enclosure:
Staff Evaluation of
WCAP-7506-L and WCAP-7819,
Revision I

TOPICAL REPORT EVALUATION

Report Identifications:	WCAP-7506-L (Proprietary) WCAP-7819, Revision 1 (Non-Proprietary)
Report Titles:	Test Report Nuclear Instrumentation System Isolation Amplifier
Report Dates:	WCAP-7506-L - February 1969 WCAP-7819, Revision 1 - January 1972
Originating Organization:	Westinghouse Electric Corporation
Reviewed By:	Electrical, Instrumentation and Control Systems Branch

Summary of Topical Reports

The subject reports provide a detailed description of the isolation amplifier and its uses in the nuclear instrumentation system. This includes a description of the testing performed to demonstrate the isolation capabilities of a prototype amplifier.

Summary of Regulatory Evaluation

Our evaluation consisted of a detailed review of the test methods and the test results to ascertain that (1) the test setup adequately simulated the in-circuit conditions of the isolation amplifier applications, (2) the faults applied to the amplifier output included all those that are deemed most probable in an actual installation, and (3) the test results adequately demonstrate the required isolation capabilities.

We conclude that the testing performed demonstrates that the amplifier will provide the required isolation, i.e., there is no effect on the input (protection) circuit when the output (non-protection) circuit is subjected to shorting, grounding, or the application of 120 VAC or ± 150 VDC.

It should be noted that the testing demonstrated the isolation capabilities of the amplifier only, i.e., it did not include the input-output wiring configuration of its actual applications. Additional testing should be performed to demonstrate the adequacy of the as-installed input-output wiring configuration.

SEP 03 1974

Regulatory Position

WCAP-7506-L is acceptable for reference when it is used to demonstrate the functional adequacy of the isolation amplifier in Westinghouse Nuclear Instrumentation System equipment when adequate separation exists between the input (including power) and output wiring of the amplifier. Additional testing and documentation will be required to demonstrate the isolation capabilities of the amplifier, to include the input-output wiring configuration, if adequate separation does not exist. Also, use of this amplifier in other than the Nuclear Instrumentation System will require a reevaluation by the staff.

When WCAP-7506-L is used as reference, the application which references it must also provide information demonstrating appropriate seismic and environmental qualification of the isolation amplifier.

WCAP-7819, Revision 1 is considered an acceptable nonproprietary version of WCAP-7506-L.

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SUMMARY

This report provides a description of the isolation amplifier used in the nuclear instrumentation system and includes the results of in-circuit testing of the isolation capabilities of the prototype amplifier. The test results demonstrate that the unit will provide the required isolation - there being no significant effect on the input (protection) circuit when the output (non-protection) circuit is subjected to shorts or the application of 120 VAC or ± 150 VDC.

SECTION 1

INTRODUCTION

The isolation amplifier used in the nuclear instrumentation system (NIS) consists of two cascaded operational amplifiers with an overall voltage gain of four. The input impedance is approximately 10^4 megohms and the output impedance is less than 0.1 ohm. Rated output is 0-10 VDC (positive polarity only) into a 200 ohm load. Accuracy is ± 0.25% of full scale. Military specifications were used as a guide in selecting components and all devices are derated to achieve high reliability and long-life. The amplifier is powered from the ± 25 VDC power supplies in the channel with which it is associated. No other power sources are required.

The output of the amplifier requires no filtering. The response time is fast and the unit is unconditionally stable under all environmental and operational conditions. Due to the high input impedance, this unit has essentially a zero circuit loading effect even on relatively high impedance signal sources.

Owing to the nature of nuclear detection systems (i.e., signal levels, noise susceptibility, circuit impedance, etc.) the input circuitry is referenced to ground rather than floating. In addition, external system requirements dictate the use of grounded output signals. Consequently, in this device, the input and output signals are referenced to a common ground.

Input/output isolation is achieved primarily by the output circuitry of the second amplifier stage. Added assurance of achieving and maintaining effective isolation is derived, in certain applications, by the relative impedance characteristics existing between the output of the first stage and the input of the second stage. The design basis for achieving the required isolation is that there shall be no detrimental effect on the input signal to the isolation amplifier (protection signal) when the output (non-protective signal) is short-circuited or subjected to the maximum voltage sources which could enter the racks containing the Nuclear Instrumentation System equipment. Specifically, the design basis encompasses the following fault conditions:

a. output short-circuited or grounded
b. output subjected to plus 150 VDC
c. output subjected to minus 150 VDC
d. output subjected to 120 VAC

SECTION 2

GENERAL CIRCUIT DESCRIPTION

The NIS isolation amplifier is packaged in a metal enclosure 7 inches long by 1.5 inches wide by 6 inches high. The input signal and power connections (protective) - are physically separated from the output connections (non-protective) - former being mounted on the bottom of the module (plug-in type) while the latter is mounted on one end. Test points and all adjustments are located on top of the module and include those used to set amplifier zero and gain and adjust the attenuated output signals to the various external loads.

The basic isolation amplifier is a two stage amplifier with an overall voltage gain of four. As shown in the elementary schematic of Figure 1, each of the two stages consists of an operational amplifier and each stage has its own feedback circuit, i.e., there is no overall feedback from the output of the second stage to the input of the first stage. The first stage is a voltage follower circuit with internal feedback. Each stage and therefore the overall amplifier is non-inverting (no polarity change between input and output).

The first stage is an integrated circuit amplifier used as a buffer. Although required only for high source impedance applications, it is functionally retained in low impedance applications as well. The second stage is a discrete component amplifier. Since there is no overall feedback around both stages, each stage operates independently of the other. This approach was taken since certain faults applied to the output of an amplifier may result in an unbalance between the feedback signal (resulting from the fault voltage) and the normal input signal. Under these conditions, the amplifier may be unable to maintain the normal balance between signal and feedback since control of the feedback may be lost during the fault condition. As a result, an error current would enter or leave the signal input terminal of the amplifier. The characteristics of the second stage of this isolation amplifier are such that the feedback error current is in the order of a few hundred microamps. Where the signal providing the input is developed from a high impedance or current source, this error current could alter the signal. However, if the signal source is a low impedance or voltage source with sufficient current capacity to handle the error currents, there will be a negligible effect on the signal voltage. For this reason, the first section of the isolation amplifier is introduced to buffer the signal source from the input terminal error current of the second stage when a fault voltage is applied to the output of the isolation amplifier. The output impedance of the buffer, being less than 2.5 ohm, allows the second stage error current to exist with no effect on the input of the first stage. This combination then eliminates the effect of faults on the output of the isolation amplifier from appearing at the input to the isolation amplifier.

If the signals being applied to all isolation amplifiers in the NIS were derived from low impedance sources, the first (buffer) stage would not be necessary. However, the NIS isolation amplifiers are also used to monitor high impedance current sources (Power Range detector signals) and this must be done without modifying the detector signal which is also monitored by other circuits in the channel.

The circuits which monitor the power range detector signals are designed to accept signals ranging from 100 microamps to 3.4 milliamps (corresponding to 100% full power) so that the total detector signal may be as low as one microamp per power unit. The signal voltage for the isolation amplifier is developed by the detector signal current through a resistance of 700 ohms to 20.8K ohm (again depending on the plant and full power neutron flux). The lowest sensitivity case utilizes 100 microamps thru 20.8K, providing a 2.08 volt signal for 100 power units. The power range summing amplifier, which amplifies the detector current signals, provides an output signal which is eventually applied to the Dropped Rod circuits. This circuit is a differentiator circuit and responds to rates of change of signal. It is important that no extraneous signals be induced in the detector signal circuit which may result in false operation of the Dropped Rod circuit. (NOTE: Harmonic voltages induced into the control windings of a magnetic type isolation amplifier, would be unacceptable in this application.)

A resistance network is included in the amplifier to provide four auxiliary low level output signals in addition to the main output. The main "Hi-Level" output is 0-10 VDC capable of driving 50 ma to a 200 ohm load. The four auxiliary output signals provide two 0-5 VDC outputs adjustable from 4.5 to 5.5 VDC into a high impedance load, one 0-50 mv output adjustable from 25 to 75 mv with a 50 ohm output impedance and one meter output adjustable to furnish 1 ma full scale to meters having coil resistances from 10 to 1000 ohms. Due to the circuit configuration and values of resistance required, some resistors in the output attenuator network may fail upon application of high voltage faults to these outputs. However, due to the normal failure mode of resistors (open circuit), the main output of the amplifier will recover to normal after removal of the fault even with failures in the resistor network.

SECTION 3

FAULT PROTECTION

The isolation amplifier has been designed to prevent destruction of the amplifier or any significant effect on its input signal when the following faults are applied to the 10 VDC (Hi-Level) output terminal or the attenuated outputs of the amplifier:

a. Short circuit (i.e., grounded output)
b. High positive voltage (+150 VDC)
c. High negative voltage (-150 VDC)
d. 120 VAC, 60 Hz

3.1 Short Circuit and Ground Fault Protection

A short circuit to ground on the Hi-Level output terminals of the amplifier will be sensed by the feedback circuit which will attempt to drive the output stage transistors to saturation so as to raise the output voltage. To prevent saturation from occuring and to limit the short circuit current, a current limiting circuit senses the collector current. If the current limit is exceeded this circuit produces a limiting signal which causes the output transistors to be driven toward cut-off. Thus the output short circuit current is limited to less than 100 ma.

3.2 High Positive Voltage (+150 VDC) Protection

The application of a positive voltage to the Hi-Level output terminal of the amplifier, will back bias a diode in the output circuit of the output stage transistors and block fault currents. The power supply is protected from the fault currents by current limiting resistors. The differential amplifi section of the second stage is protected from the fault entering through the feedback circuit by a diode clamp which limits the voltage to that set by a zener diode. The change in voltage will cause a forced unbalance in the differential amplifier input. However, the low output impedance of this buffer stage can easily handle this small error current with no significant effect at its input terminals.

3.3 High Voltage (-150 VDC) Protectio..

When a high negative voltage is applied to the Hi-Level output terminal of the amplifier, the power supply is again protected by current limiting resistors. The effect through the feedback circuit is also similar to that described for a positive fault voltage except the voltage is clamped by a different diode, zener diode combination.

The output stage is protected by a transistor at the base of the output stage transistors. The high negative voltage causes this transistor to saturate, clamping the bases of the output stage transistors and cutting them off. Although the full negative fault voltage plus the power supply voltage will appear from collector to emitter of the output stage transistors, little or no current flows through them. Practically all of the current is drawn from the power supply through a 15 watt resistor and the saturated transistor.

3.4 120 VAC, 60Hz Protection

The application of 120 VAC to the Hi-Level output terminal of the amplifier amounts to alternations of the high DC voltage faults. Protection for the high plus and minus DC voltage faults already described applies for alternate half cycles of the AC. Although the peak AC voltages will be greater than the DC fault voltages, the components are rated to withstand them. No reactive components are affected by the fault voltages.

SECTION 4

PROTOTYPE TESTING

Laboratory tests were made to determine the in-circuit isolation capabilities of the isolation amplifier used in the Nuclear Instrumentation System. Tests were performed at room ambient using a prototype model of the isolation amplifier and prototype equipment for the power range channel. The tests indicated that the effects on the input signal were negligible due to short circuit and high voltage faults applied to the output. An effect resulting from the switching transient during fault voltage application was detected in the output of the Dropped Rod Circuit. This effect was measured as a step change of 30 to 40 millivolts closer to the Dropped Rod Bistable trip point (corresponding to a 3% departure from the nominal 5PU or 1.275 volt trip point) setting.

Two sets of data were obtained corresponding to the two different circuit applications of the amplifier (Fig. 2). In the first test, fault data was taken with the input signal to the isolation amplifier derived from the sensing resistor R_c. The second set of fault data was obtained with the amplifier connected to the output of the power range linear amplifier. Note that this second application represents the identical circuit characteristics which would be employed in both the intermediate and source range channels, i.e., the low output impedance circuitry of all linear and log amplifiers which feed isolation amplifiers are derived through the same type operational amplifier and discrete component circuitry. Only the power range channel has a second and unique application, namely, the measurement of detector currents (high source impedance circuitry).

When monitoring the detector signal, the amplifier was connected to provide a voltage gain of four and the integrated amplifier was in the circuit to serve as a buffer. When monitoring the linear amplifier output, the amplifier was connected for a voltage gain of one with the integrated amplifier bypassed. The production units will actively use the integrated amplifier in all applications to take advantage of the additional buffer stage which is included on the standard isolation amplifier module.

In all cases, the detector signal simulation was accomplished with a KEPCO variable high voltage power supply and a fixed resistor Ra to simulate the detector. Signal variations were obtained by adjusting the high voltage. All data was recorded with the isolation amplifier output at 6.100 VDC rather than 10 VDC so as to maintain the 10 mv/division sensitivity of the recorder when measuring the dependent variables.

The detector signal current was measured by measuring the voltage developed across resistor Rb in series with the simulated detector (see Figure 2). The detector signal circuit was adjusted to provide a 2.500 VDC input to the Summing Amplifier and Isolation Amplifier with a 120 microamp detector current by adjusting the HVPS to obtain 1.200 VDC across resistor Rb and then adjusting control Rc to obtain a 2.500 VDC signal to the amplifiers. With the 2.500 VDC input, the gain of the Isolation Amplifier was adjusted to obtain 10.000 VDC at its output. There was no zero adjustment on the amplifier tested; however, production units will have this feature. The settings of detector signal control Rc and the Isolation Amplifier gain adjustment were not changed throughout the tests.

Initial test data was accumulated to determine the linearity of the gain-of-four amplifier. Output versus input is plotted in Figure 3, and percent error versus output is shown in Figure 4. Linearity was within 0.05% of full output.

Table I is a summary of the tests run for the various fault conditions and is an index of the recordings following it. Charts I through XII were obtained with the isolation amplifier connected in the gain-of-four configuration corresponding to the test setup of Figure 2. Charts XIII through XVI were obtained with the gain-of-one configuration wherein the buffer stage is bypassed. It should be noted that the dropped rod output was used as the measuring parameter for the majority of tests since the rate function corresponding to this parameter makes it more critical. In addition, any disturbance on the dropped rod circuit output is approximately three times as great as would be experienced on the level (linear) amplifier output since there is a gain-of-three associated with the dropped rod circuit. Chart XVII shows the output of the Dropped Rod circuit when a decreasing signal step change of one power unit is applied to the summing amplifier. The dropped rod circuit time constant was set for 15 seconds and the associated bistable trip adjustment set to just trip for a dropped rod output equivalent to the one P.U. decreasing step. The nominal settings for these parameters in normal plant operation is a time constant of five seconds and a trip level corresponding to a five P.U. decreasing power level, which is much less sensitive than the settings used.

Charts I and II respectively show the effect on the level amplifier output signal and the isolation amplifier input signal when the isolation amplifier output is shorted. No effect was detectable.

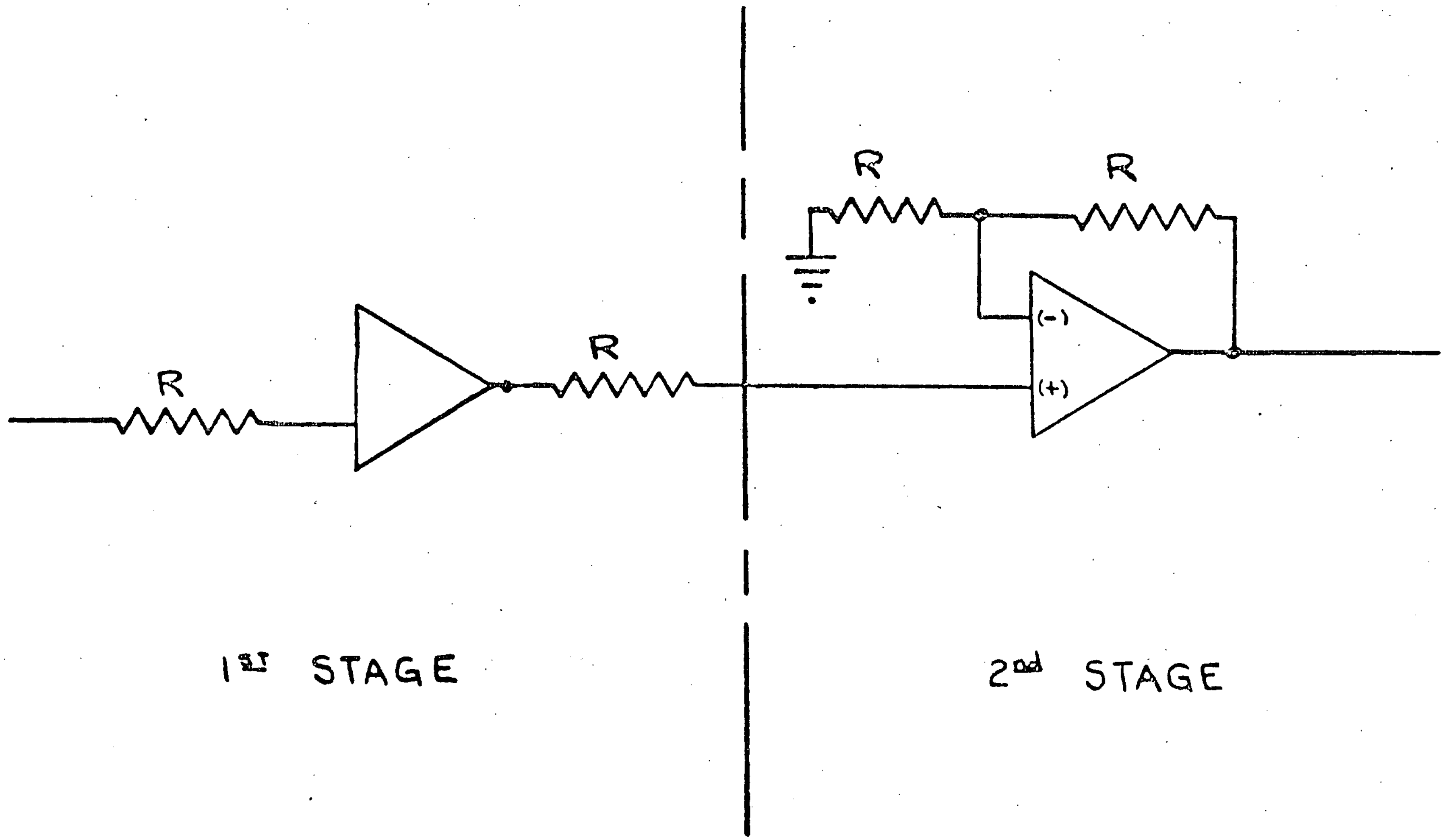
Charts III and IV show the effects on the same points when a 120 VAC fault was applied to the isolation amplifier output with a battery signal used to indicate when the fault was applied. There were no detectable effects with the 120 VAC fault application.

Charts V and VI indicate no effect on the same points associated with the application of a positive 150 VDC to the isolation amplifier output.

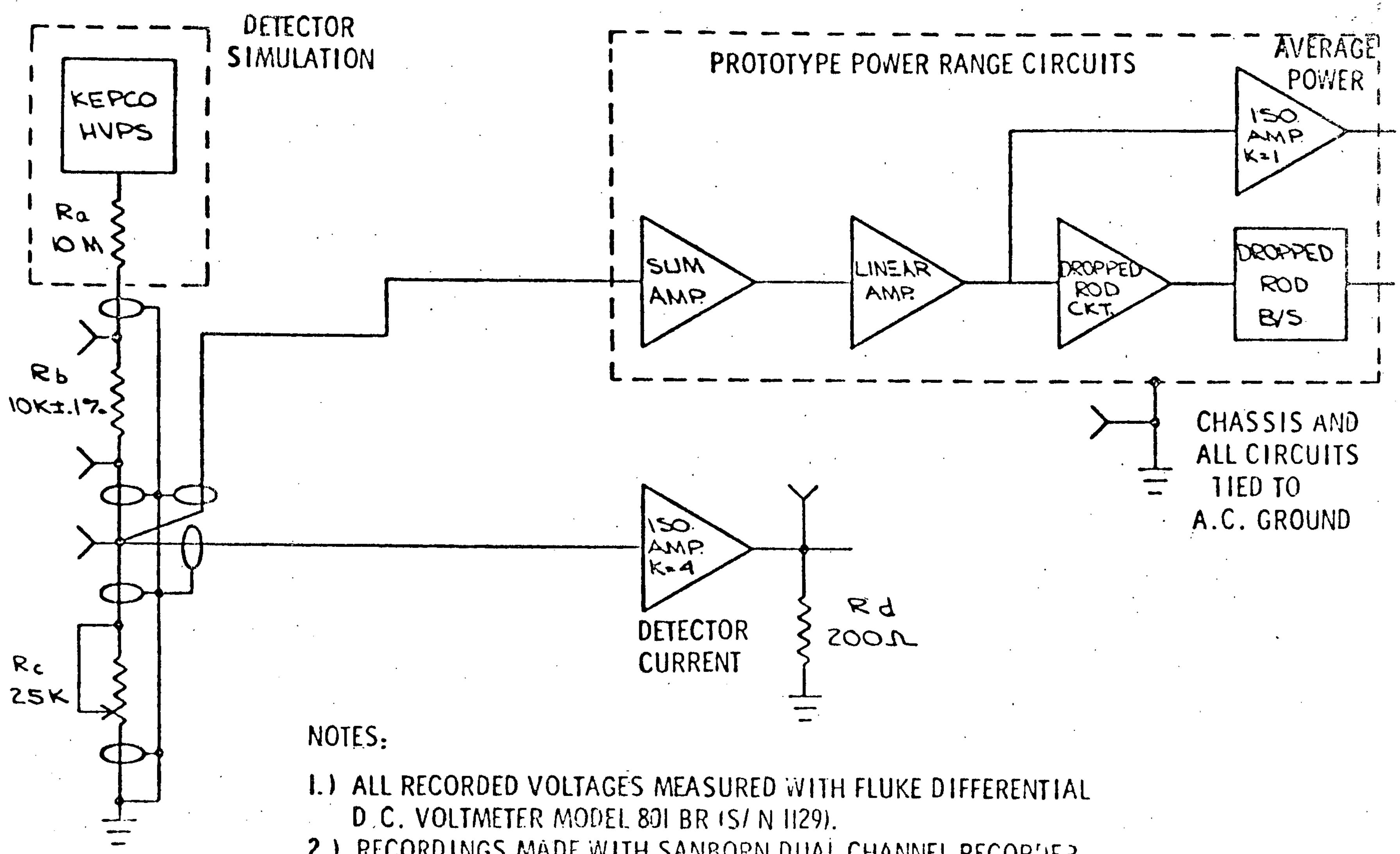
Charts VII and VIII are recordings of the level amplifier output and isolation amplifier input for a negative 150 VDC fault on the isolation amplifier output. Chart VII indicates no effect due to the fault application. Chart VIII, the isolation amplifier input, indicates a random 0.25 to 0.5 P.U. change.

Charts IX through XII indicate the effect on the dropped rod circuit output for a short circuit, -150 VDC, 120 VAC and +150 VDC fault condition respectively. The dropped rod bistable did not trip for any of the faults. There was no effect due to the short circuit fault or the +150 VDC fault condition. However, there was a random effect due to the 120 VAC fault and a definite effect due to the negative (-) 150 VDC fault application corresponding to a negative deflection of approximately 35 mv (equivalent to the effect of a 0.15 P.U. step change in detector signal). In addition, there was a transient effect which caused a slight negative shift in the dropped rod circuit output (about 10 to 20 mv equivalent to the effect of a 0.04 to 0.08 power unit positive step change [illegible]) and decayed exponentially to the nominal output with a [illegible] second time constant. A positive output from the dropped rod circuit is required for a bistable trip.

Charts XIII through XVI are the same as the previous four charts except the isolation amplifier was connected for a gain-of-one configuration wherein the buffer stage was bypassed and the isolation amplifier was driven from the level amplifier output as indicated on Figure 2. The results were essentially the same as for the previous setup except for a minor (20 mv) random spike for the +150 VDC fault condition.



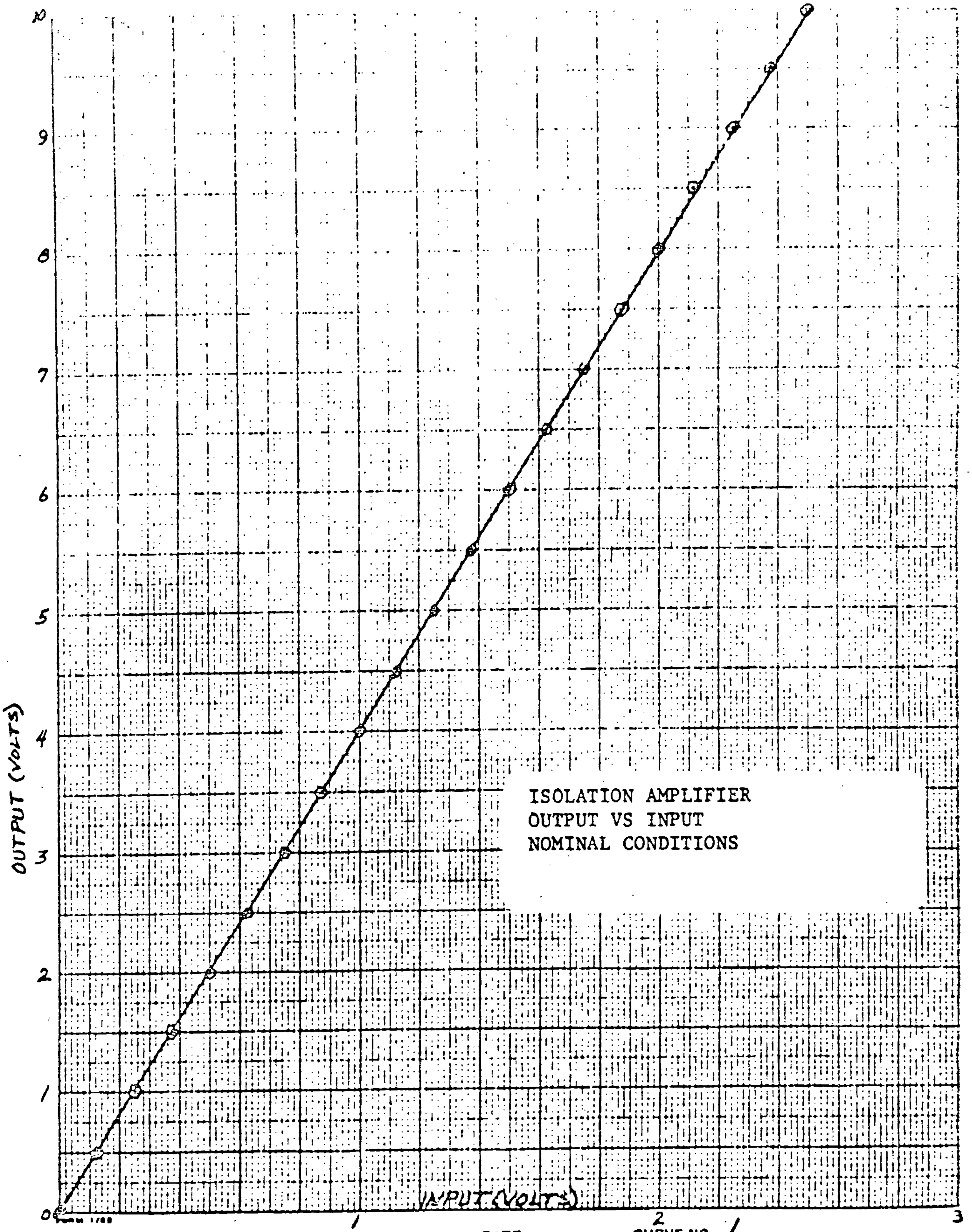
ELEMENTARY SCHEMATIC - ISOLATION AMPLIFIER



NOTES:

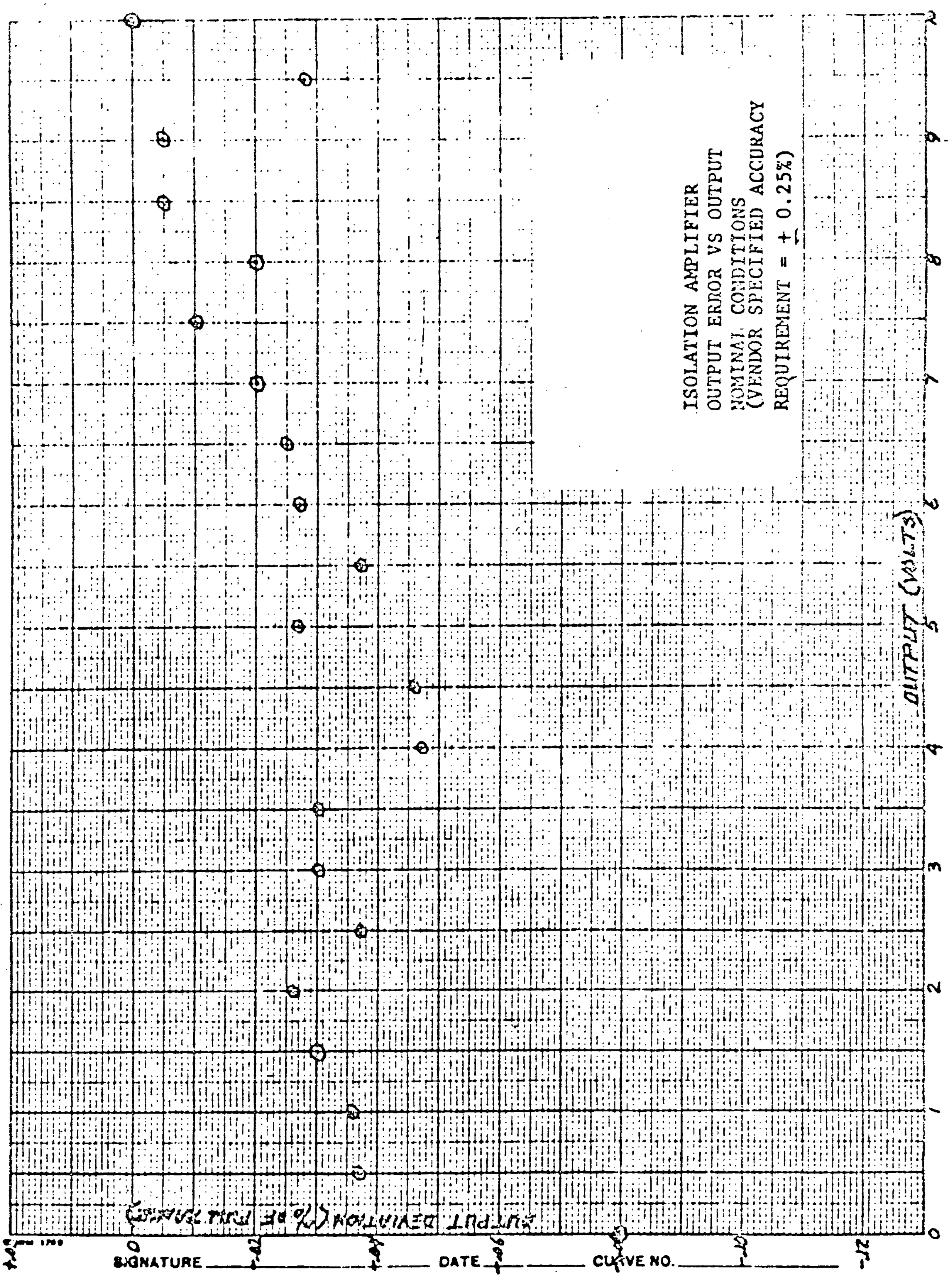
1.) ALL RECORDED VOLTAGES MEASURED WITH FLUKE DIFFERENTIAL D.C. VOLTMETER MODEL 801 BR (S/N 1129).
2.) RECORDINGS MADE WITH SANBORN DUAL CHANNEL RECORDER.
3.) FOR TESTS FOR EFFECTS ON DROPPED ROD CIRCUITS AND WITH ISOLATION AMPLIFIER FED FROM VOLTAGE SOURCE, ISOLATION AMPLIFIER INPUT WAS CONNECTED TO LINEAR AMPLIFIER OUTPUT

ISOLATION AMPLIFIER TEST SET-UP
FIGURE 2



SIGNATURE ______________ **DATE** __________ **CURVE NO.** 1

FIGURE 3



ISOLATION AMPLIFIER
OUTPUT ERROR VS OUTPUT
NOMINAL CONDITIONS
(VENDOR SPECIFIED ACCURACY
REQUIREMENT = ± 0.25%)

FIGURE 4

CHART NO.	ISOL. AMP. GAIN	ISOL. AMP. IN	LEVEL AMP. OUT	DROP ROD OUT	SHORT CIRCUIT	120 VAC	+150 VDC	-150 VDC
I	4		X		X			
II	4	X			X			
III	4		X			X		
IV	4	X				X		
V	4		X				X	
VI	4	X					X	
VII	4		X					X
VIII	4	X						X
IX	4			X	X			
X	4			X				X
XI	4			X		X		
XII	4			X			X	
XIII	1			X	X			
XIV	1			X				X
XV	1			X		X		
XVI	1			X			X	
XVII	4			X				

TABLE I

SUMMARY OF CHARTS

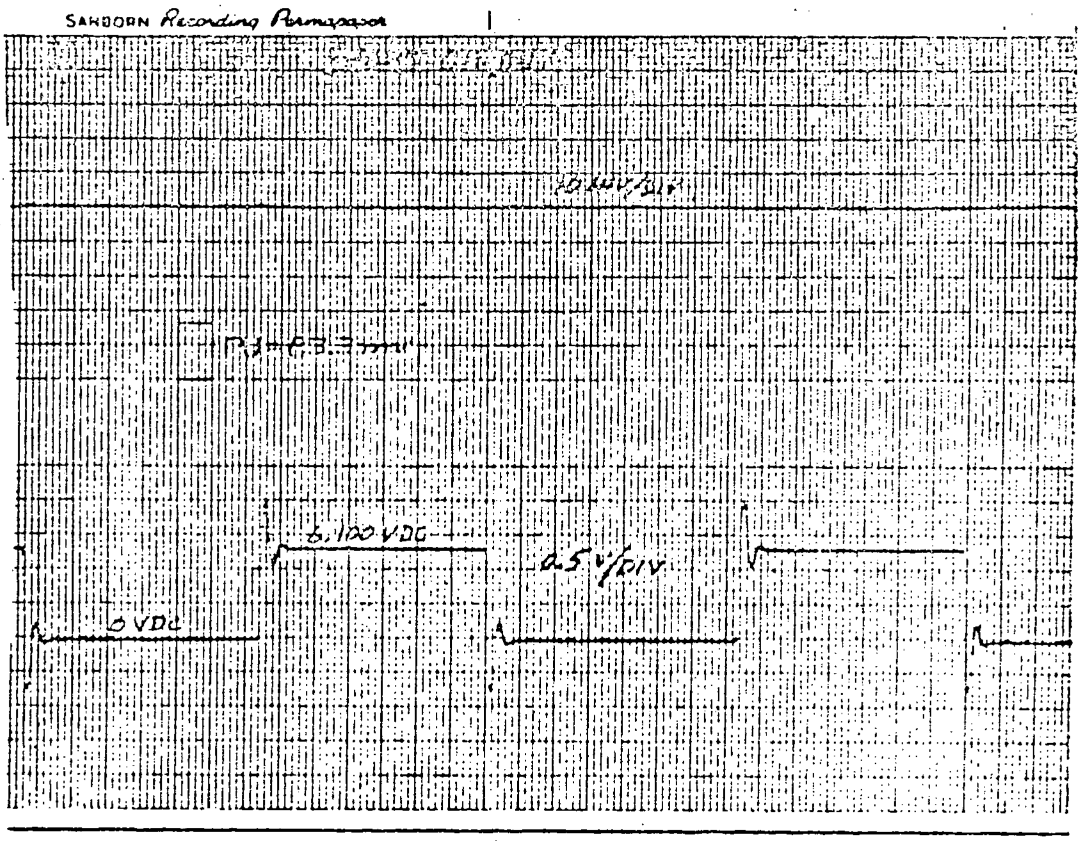


CHART I

CHARTS 100 mm/sec

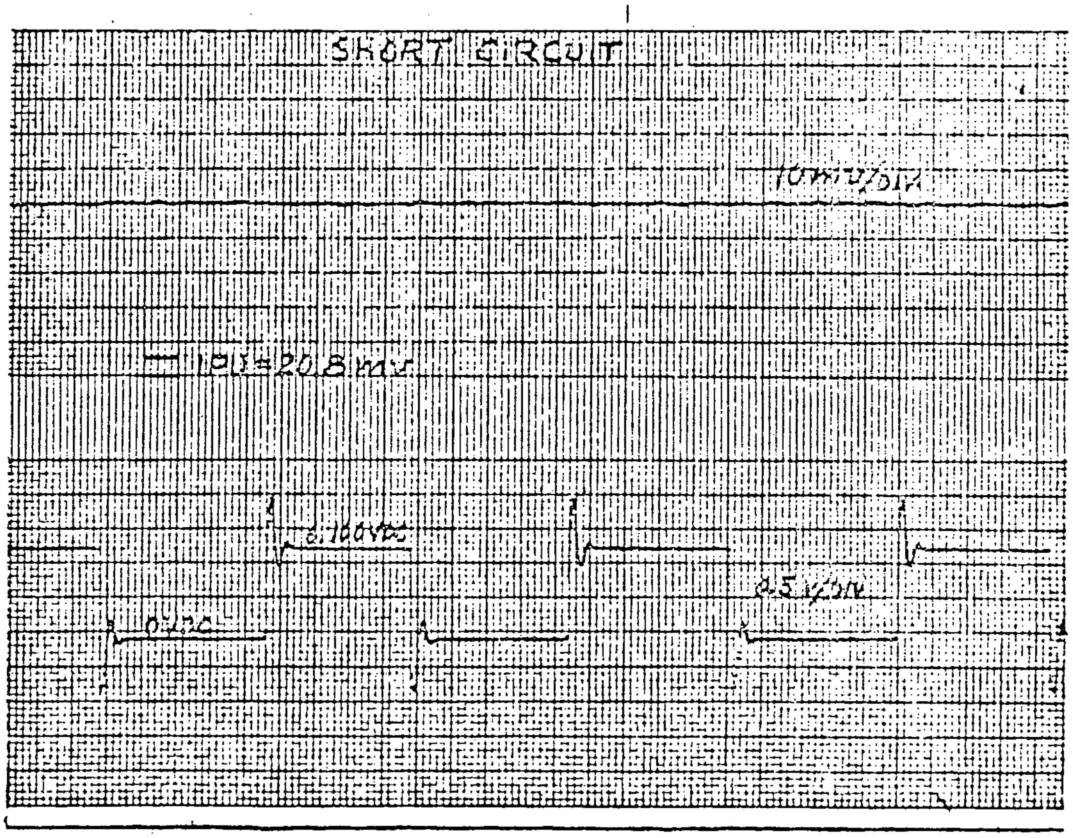


CHART II

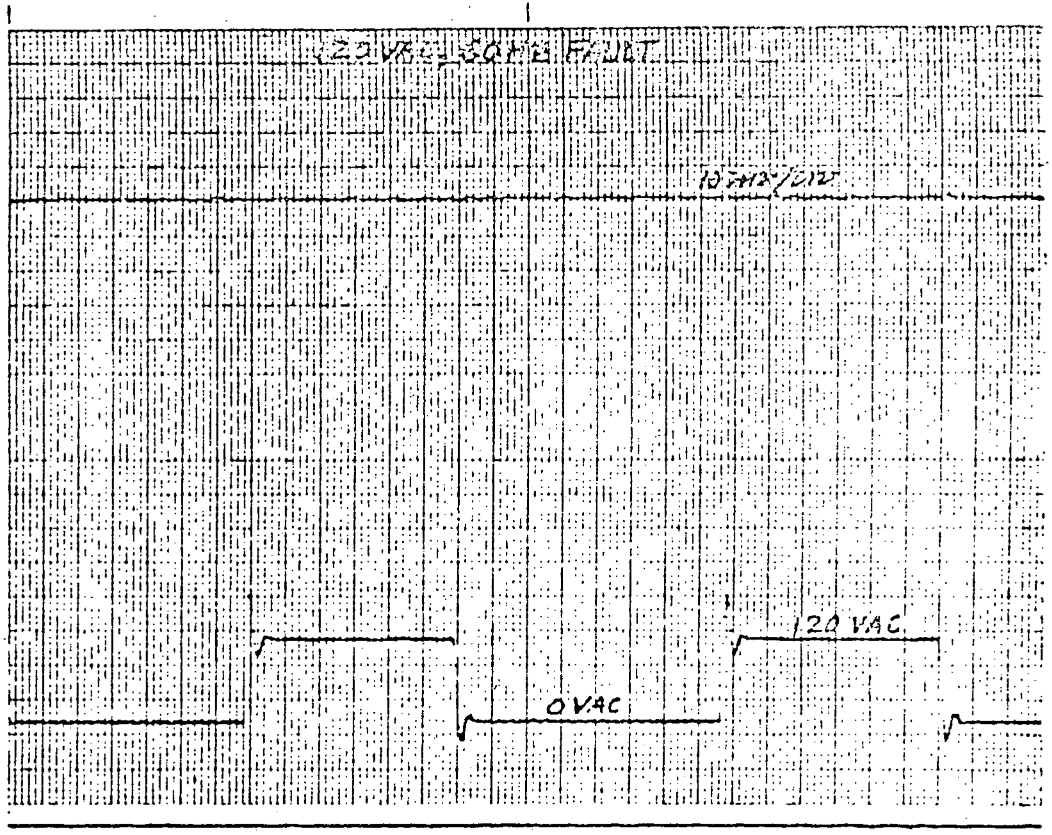


CHART III

CHART 100 mm/sec

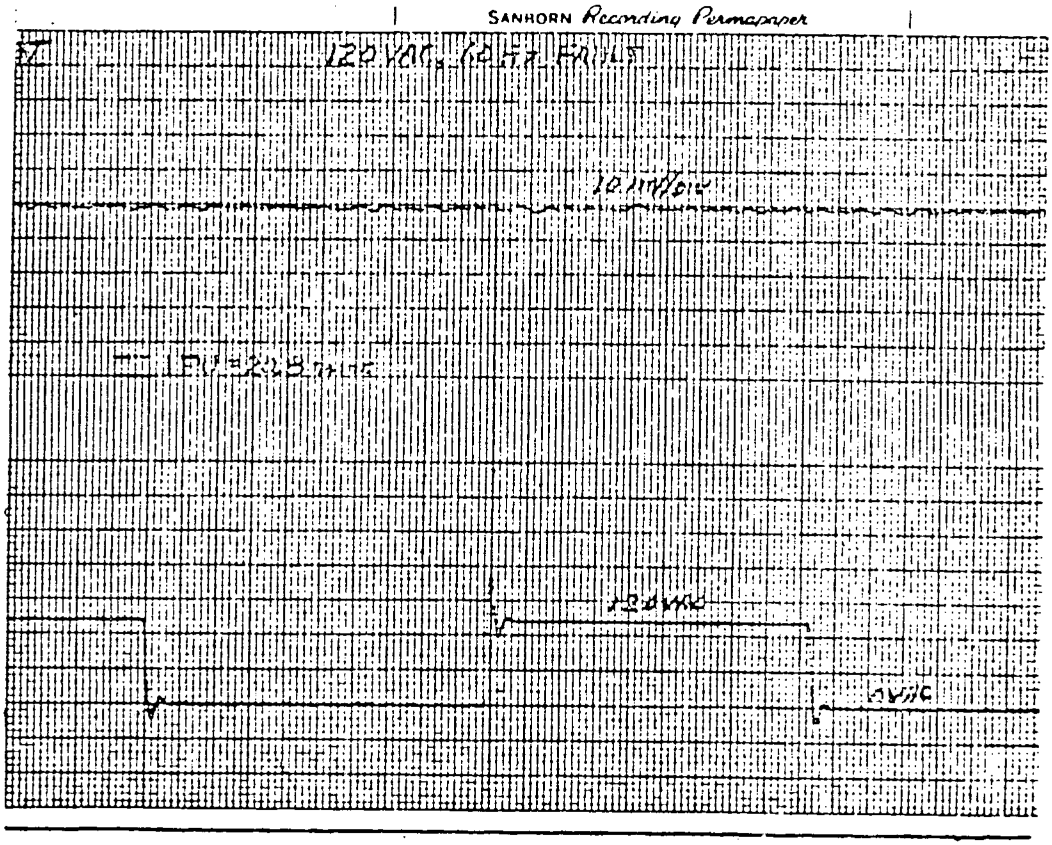


CHART IV

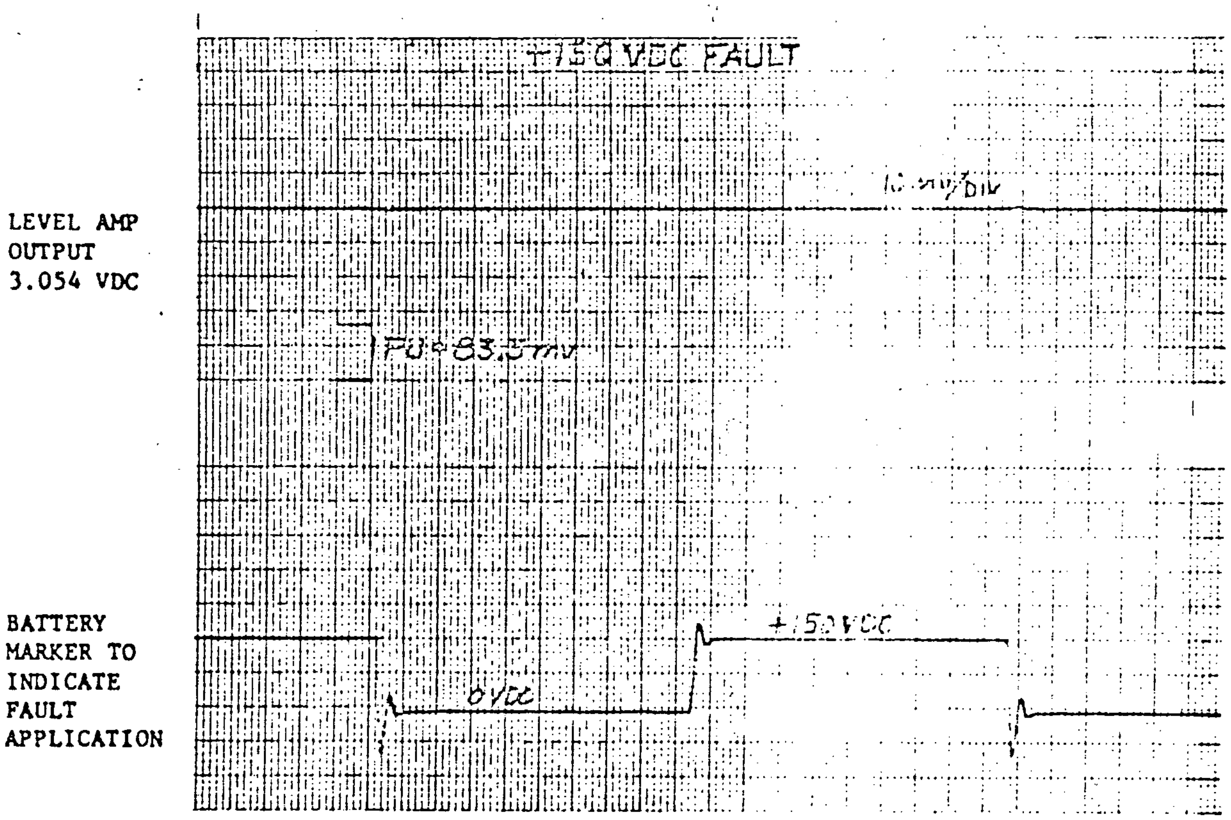


CHART V

CHARTS 100 mm/sec

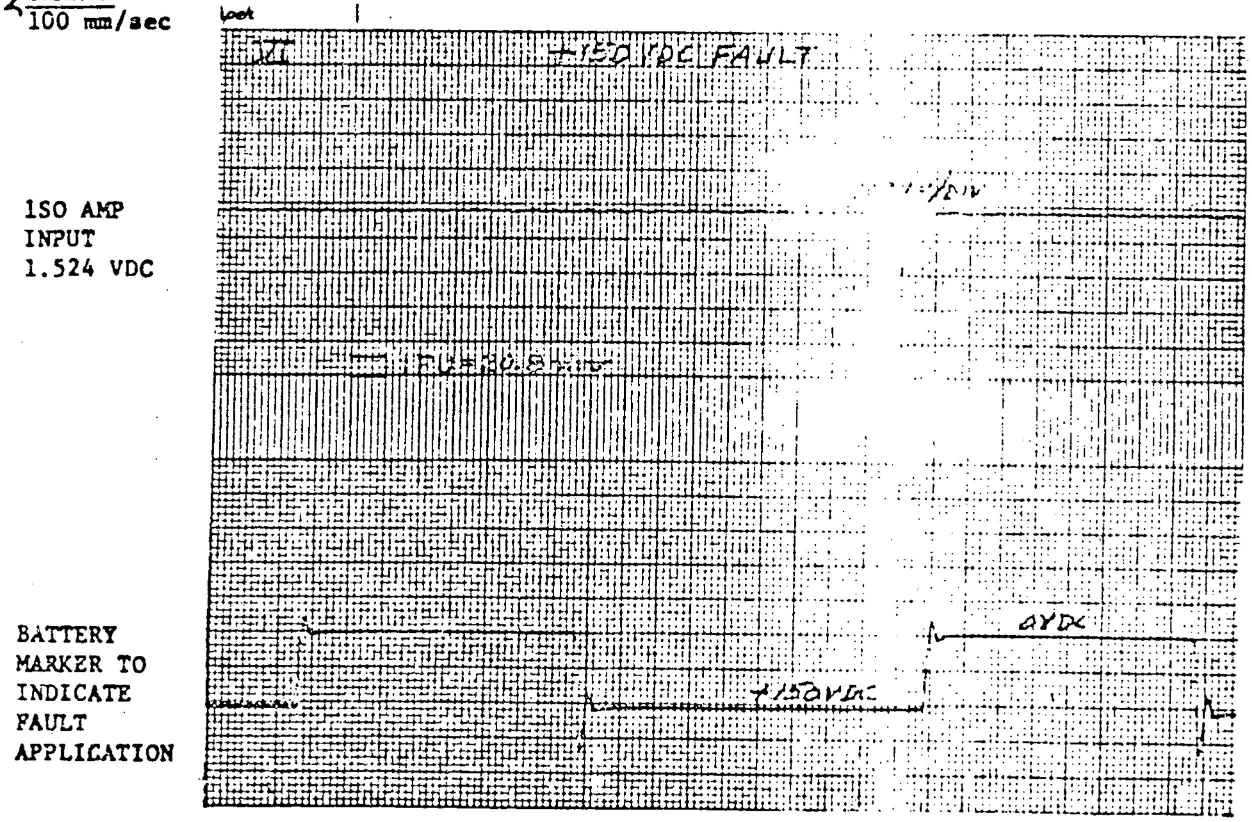


CHART VI

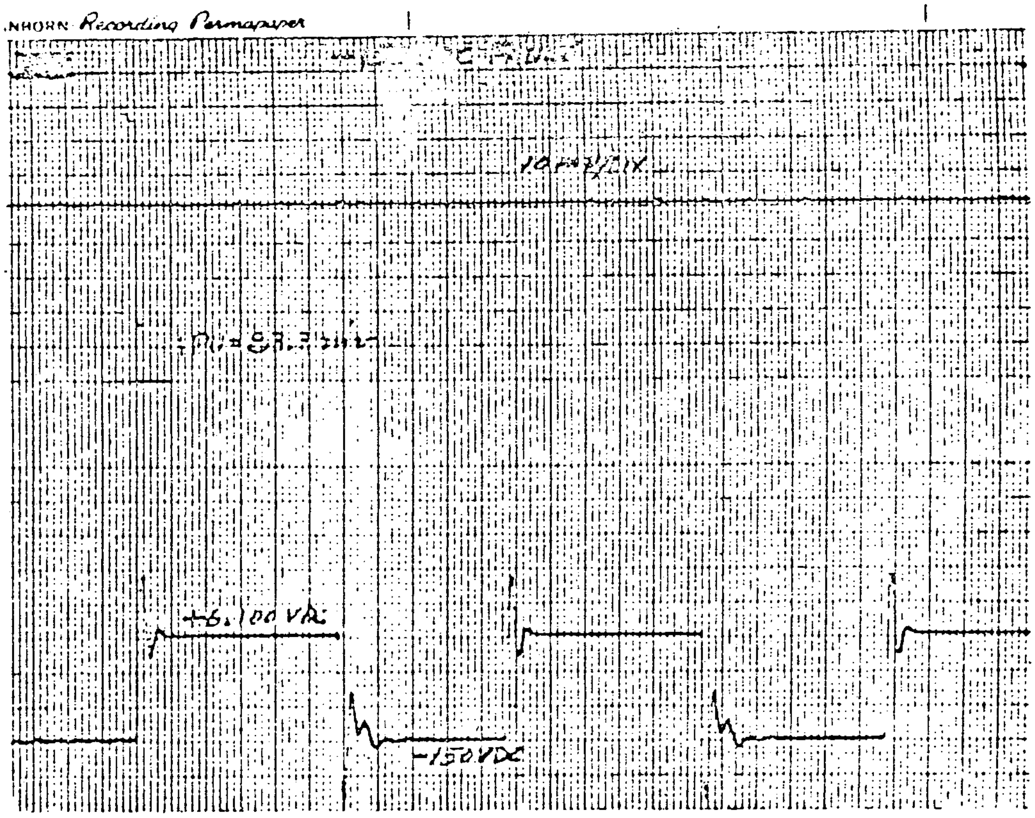


CHART VII

CHARTS
100 mm/sec

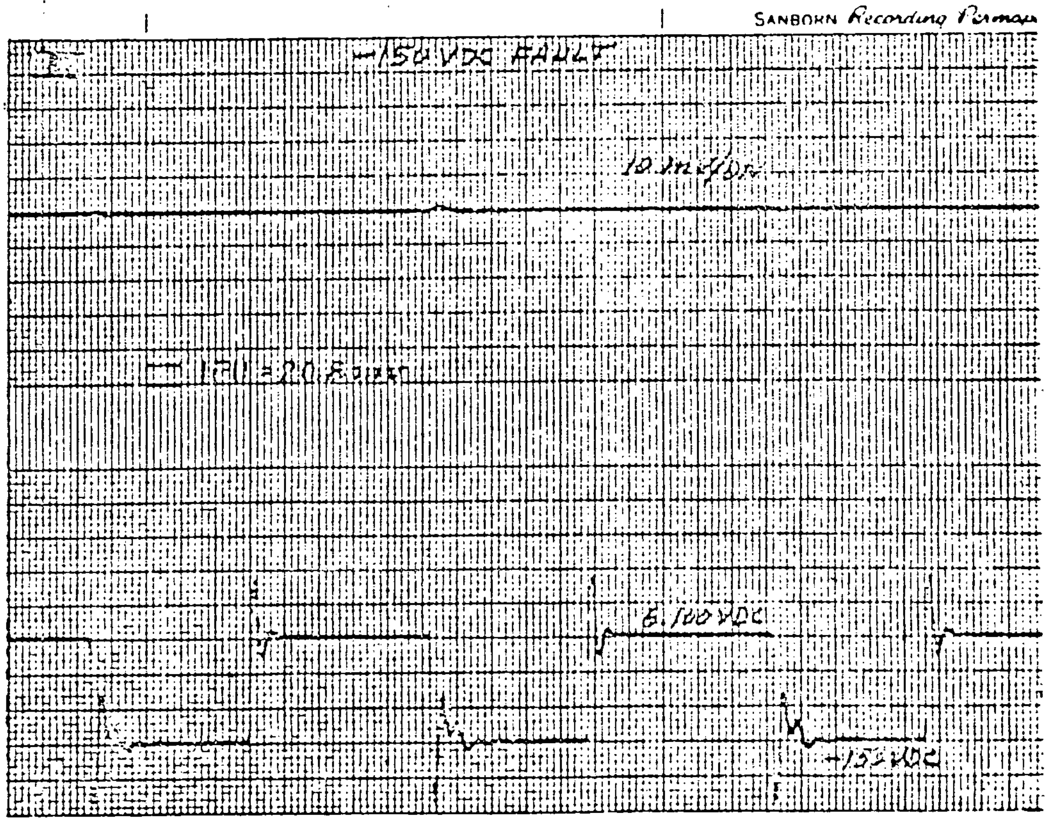


CHART VIII

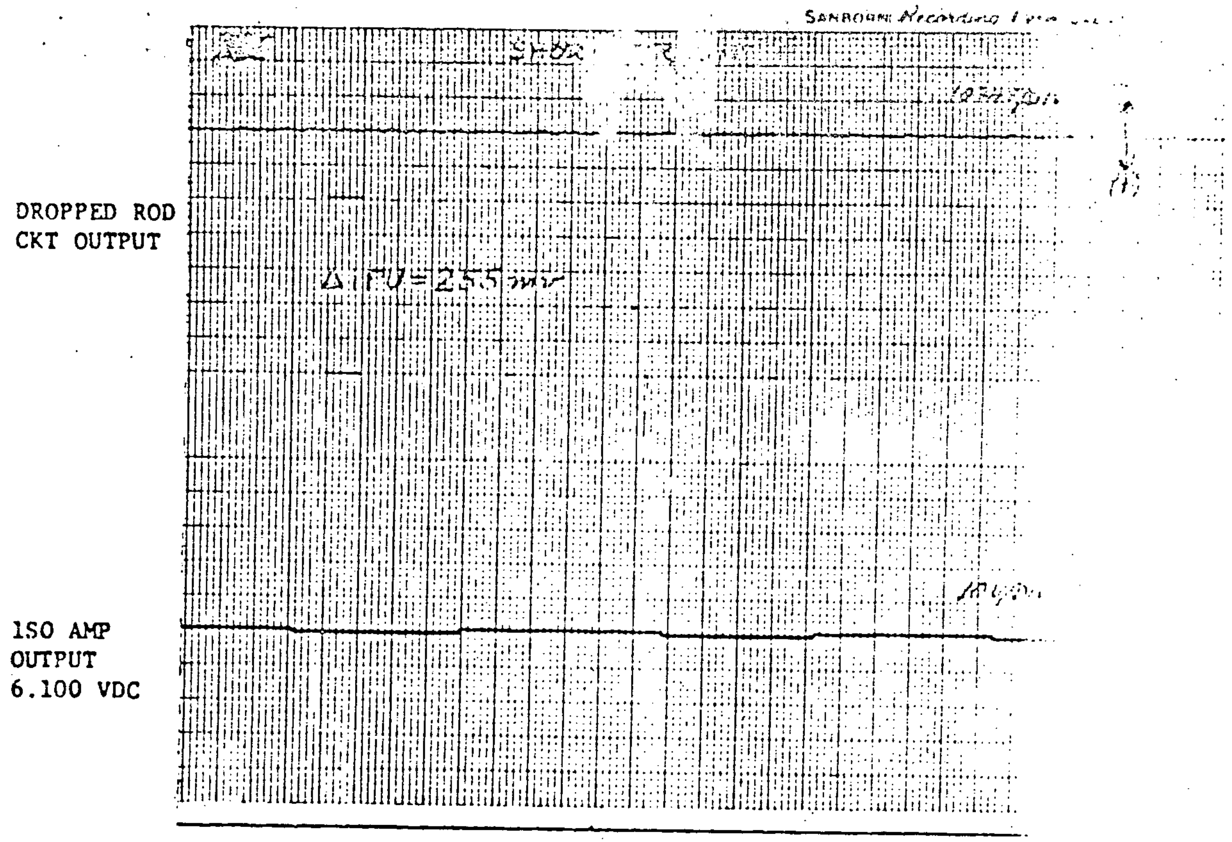


CHART IX

CHARTS
100 mm/sec

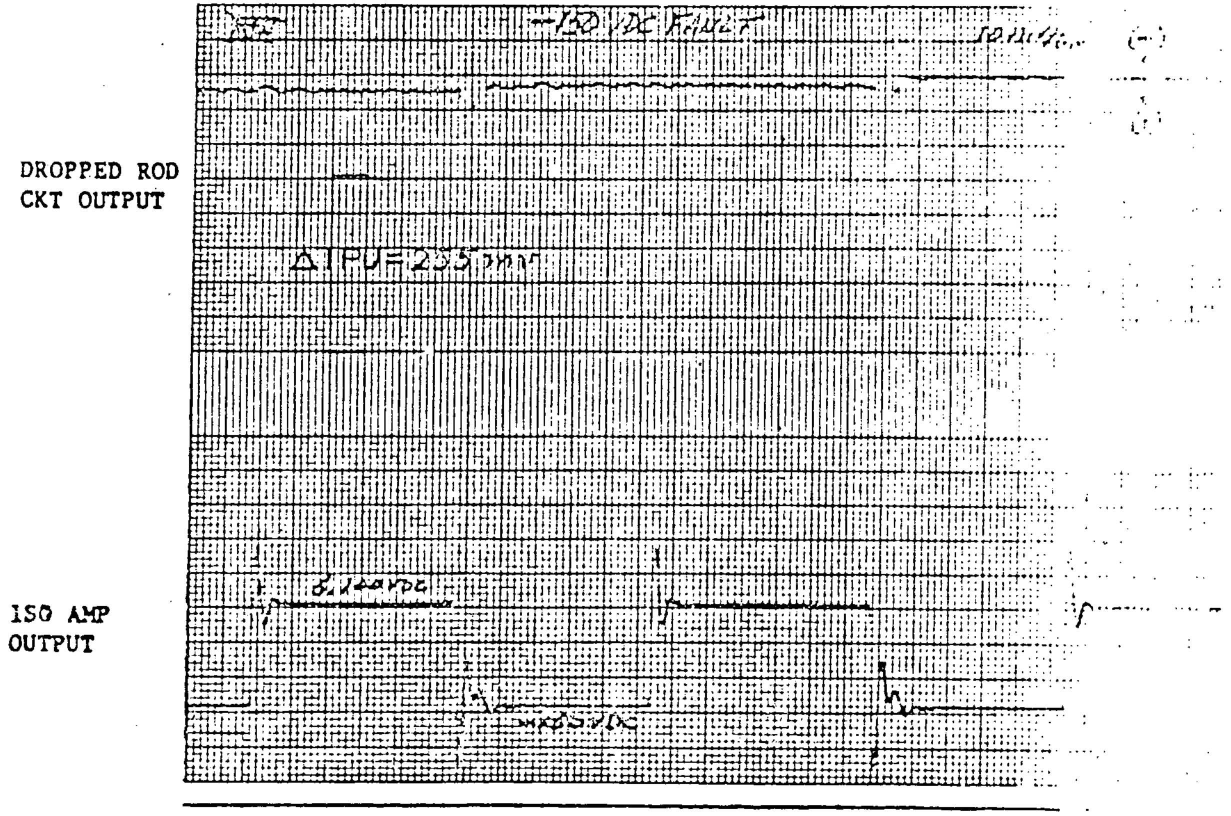
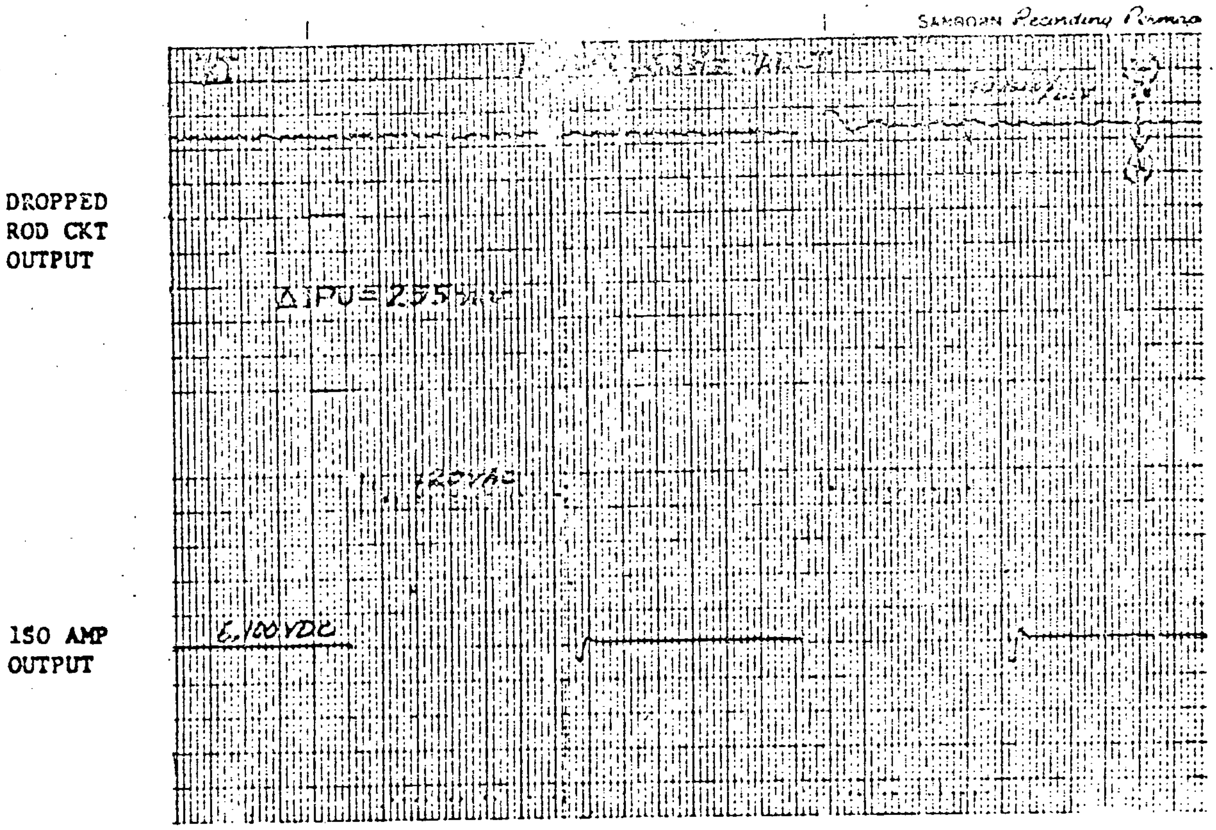
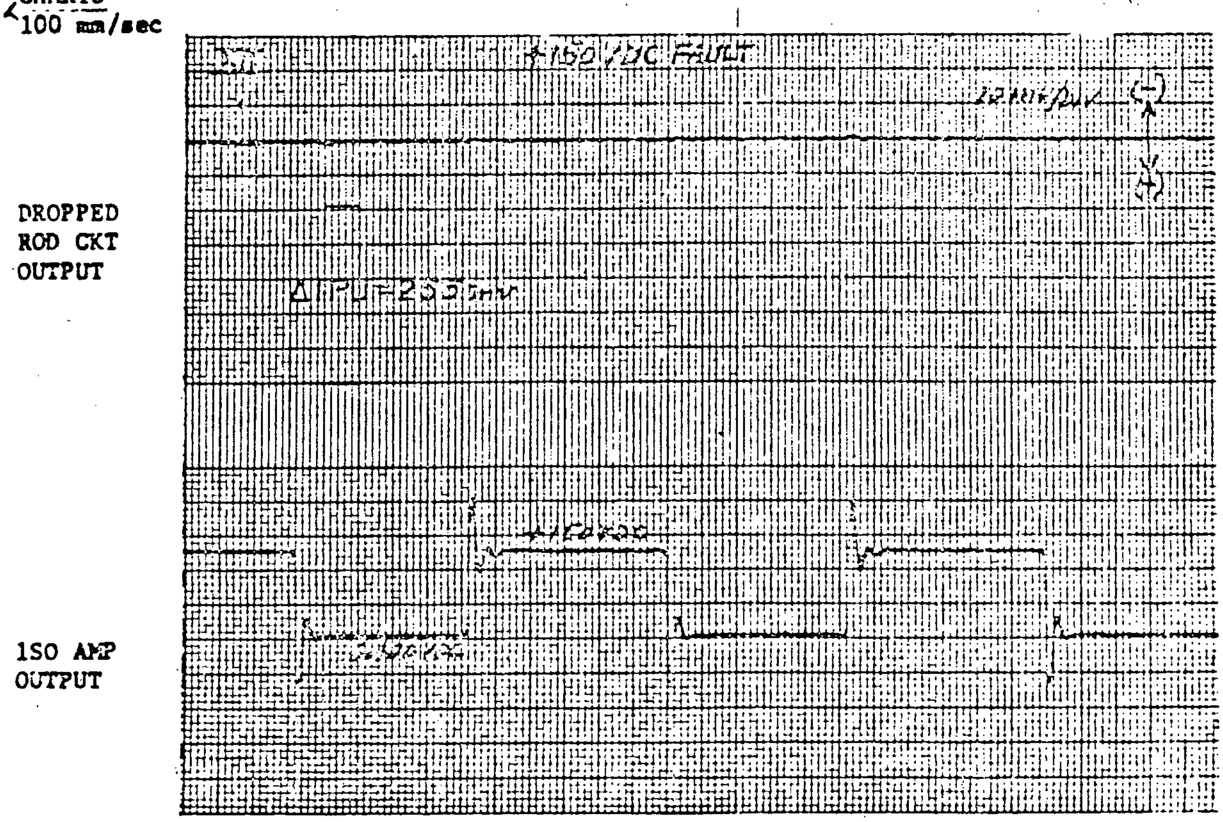


CHART X

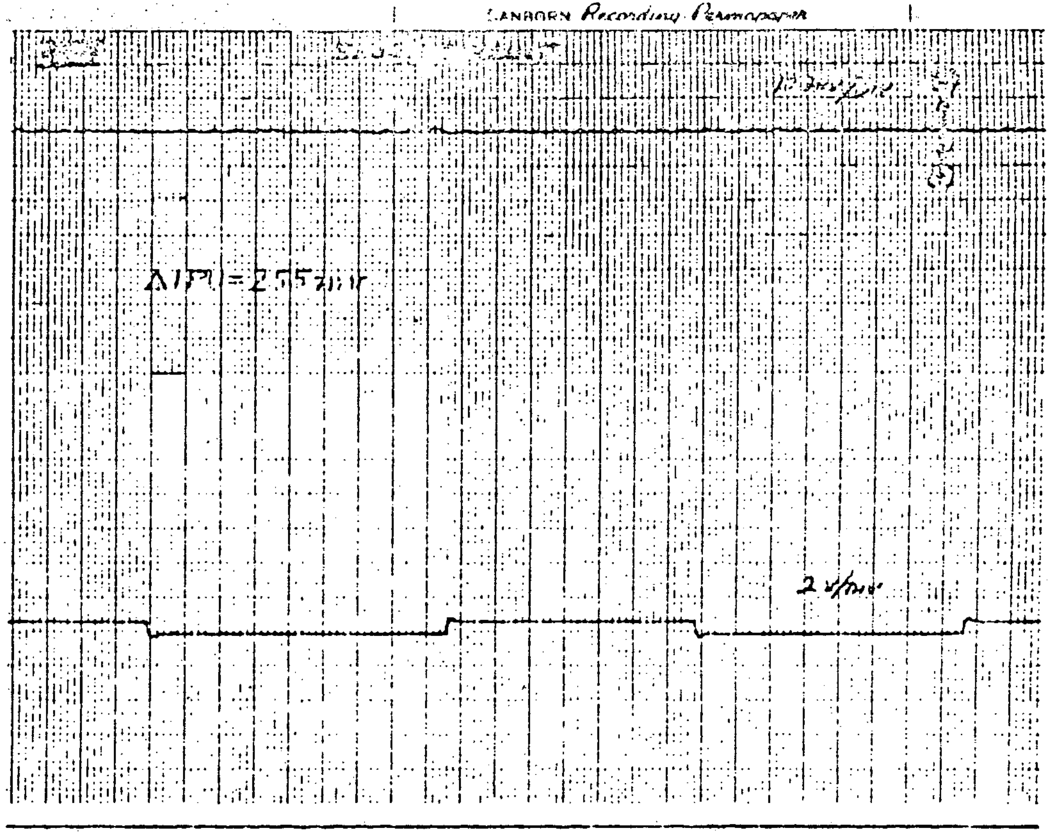


CHAPTER XI

CHARTS 100 mm/sec

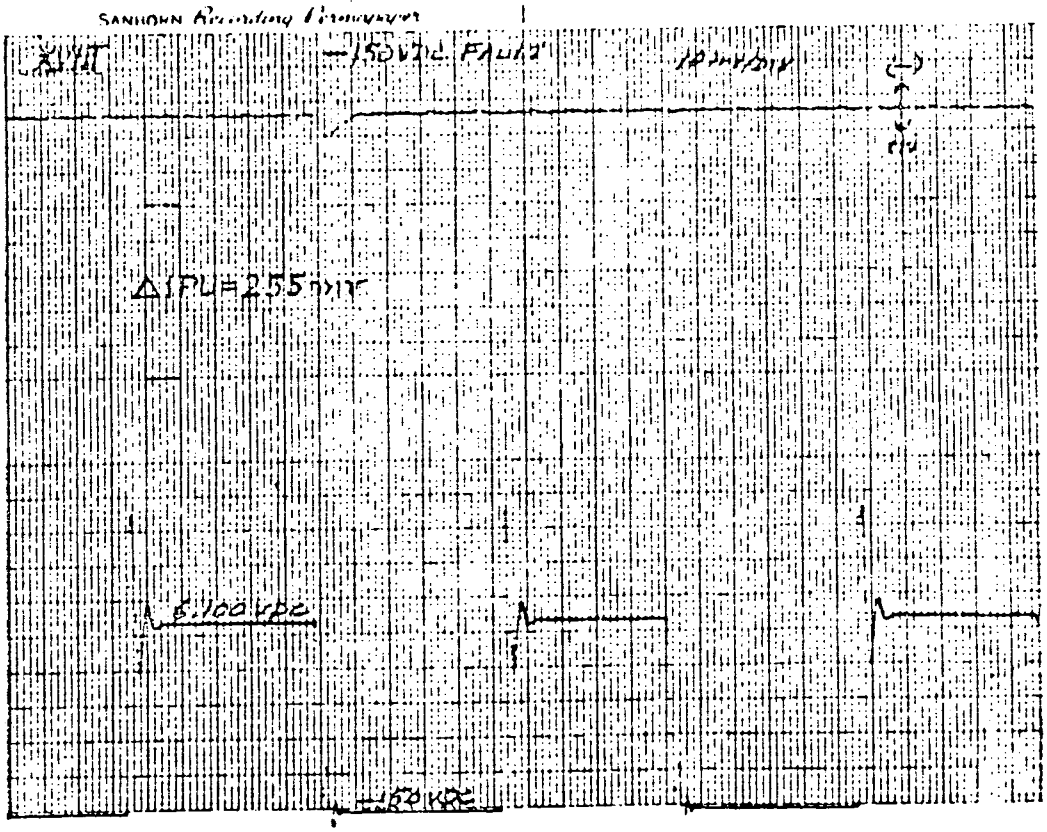


CHAPTER XII



CHAPTER XIII

CHARTS
100 mm/sec



CHAPTER XIV

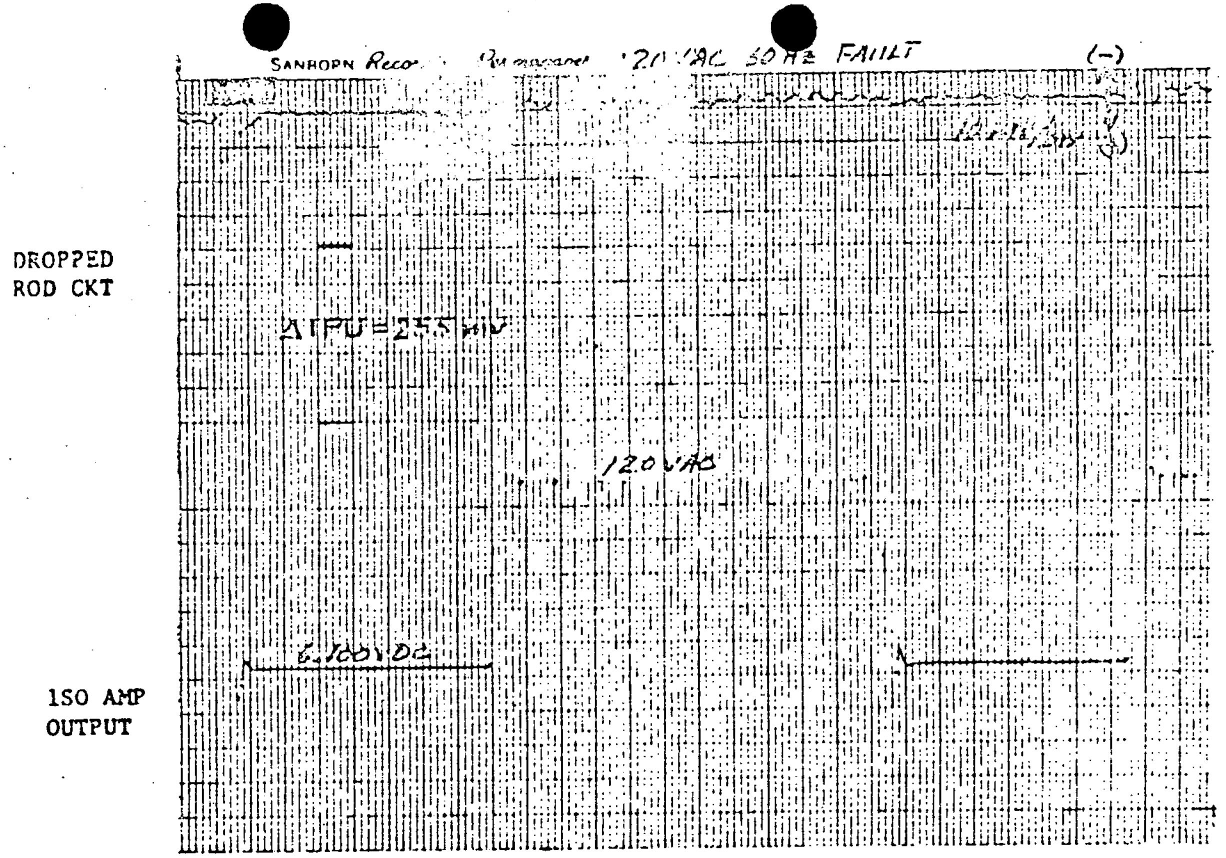


CHART XV

CHART
100 mm/sec

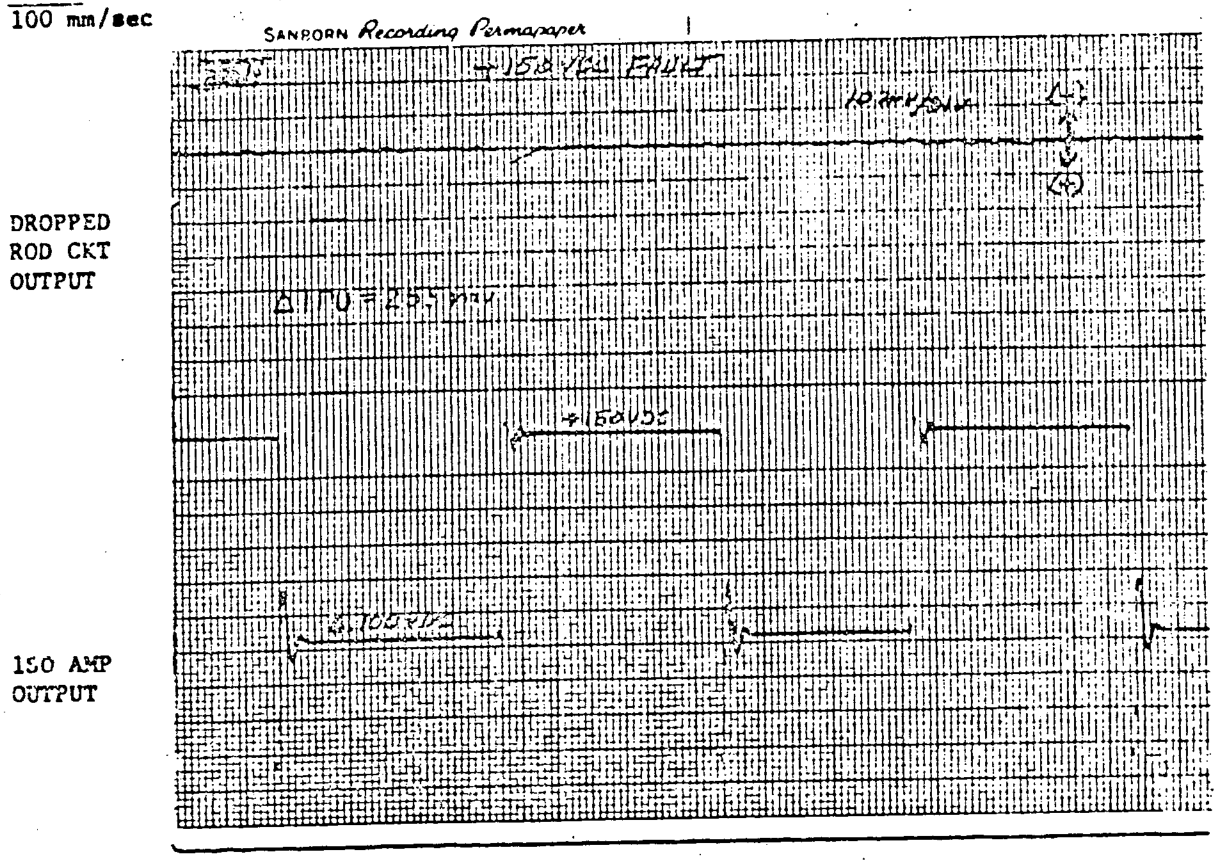
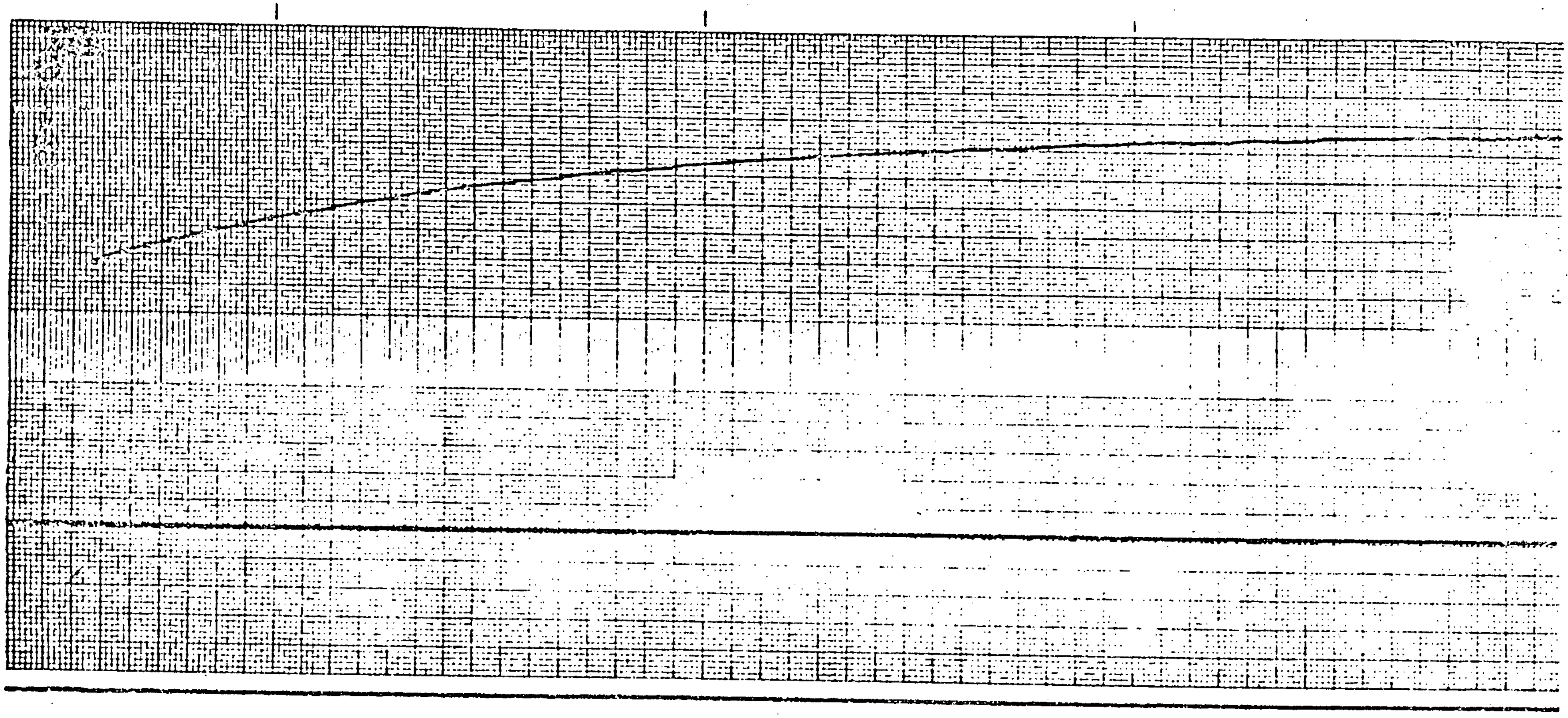


CHART XVI

5 mm/sec CHART SPEED



TOP CHANNEL-Output of Dropped Rod Circuit with one power unit step change (down) at the input to the summing amp. Dropped Rod Output step change from zero to +255 mv and decays to zero again on 15 second time constant. Dropped Rod Bistable set to just trip on this signal.

BOTTOM CHANNEL-ISO AMP output but recorder sensitivity set too low to see one power unit change.

CHART XVII

Appendix 3B

WESTINGHOUSE TEST REPORT

WCAP 7685