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TITLE: Proposal to Perform Transfer Function Measurements of the PARKA Critical Facility Reactor at LASL by Cross-Correlation with a Pseudo-Random Input Signal

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MASTER

AUTHOR(S): J. F. Hafer, A. A. Wasserman, E. K. Honka
Control and Systems Analysis
Instrumentation and Control

APPROVED BY:

A A Wasserman _____ Supervisor, Control and Systems Analysis

H S Kirschbaum _____ Manager, Instrumentation and Control

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Westinghouse Electric Corporation

Astronuclear Laboratory
Box 10864, Pittsburgh, Pa. 15236
Telephone: 892-5600

June 24, 1964

*Mr. R. W. Schroeder
Space Nuclear Propulsion Office
NASA Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio

Subject: WANL-TME-793, "Proposal to Perform Transfer Function Measurement of the PARKA Critical Facility Reactor at LASL by Cross-Correlation with a Pseudo-Random Input Signal," dated May 21, 1964

Dear Mr. Schroeder:

Transmitted herewith are three (3) copies of the subject report. This report is transmitted for your information.

Respectfully,

H. F. Faught

H. F. Faught
Program Manager
NERVA Nuclear Subsystem

Enclosures - 3

cc: Mr. R. Wilke, SNPO-C Resident Office at WANL
Mr. G. O'Brien, SNPO-C Resident Office at WANL

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I. Objectives of Experiment

The purpose of this experiment is to: (1) check out the use of cross-correlation techniques with small-amplitude, binary input signals of predetermined statistical properties produced by a feedback-shift-register signal generator, to perform measurements of reactor transfer functions associated with drum reactivity perturbations; (2) perform an independent measurement of the low-power reactor transfer function in order to experimentally determine the reduced prompt-neutron generation time of a ROVER-type reactor for comparison with calculated values; (3) perform an independent measurement of the transfer function of an installed, hydraulic, ROVER-type control drum actuator for comparison with results obtained by sinusoidal oscillation techniques; (4) determine the relative advantages (i.e., measurement accuracy, frequency-band coverage, etc.) to be gained from applying the pseudo-random input signal outside the control loop (i.e., as a power-demand signal) as compared to applying the signal inside the control loop (i.e., as a drum-position-demand signal); and (5) gain hardware experience in the measurement of transfer functions by the cross-correlation technique using the WANL signal generator, in preparation for measurements of this type during the NRX-A2 tests[1].

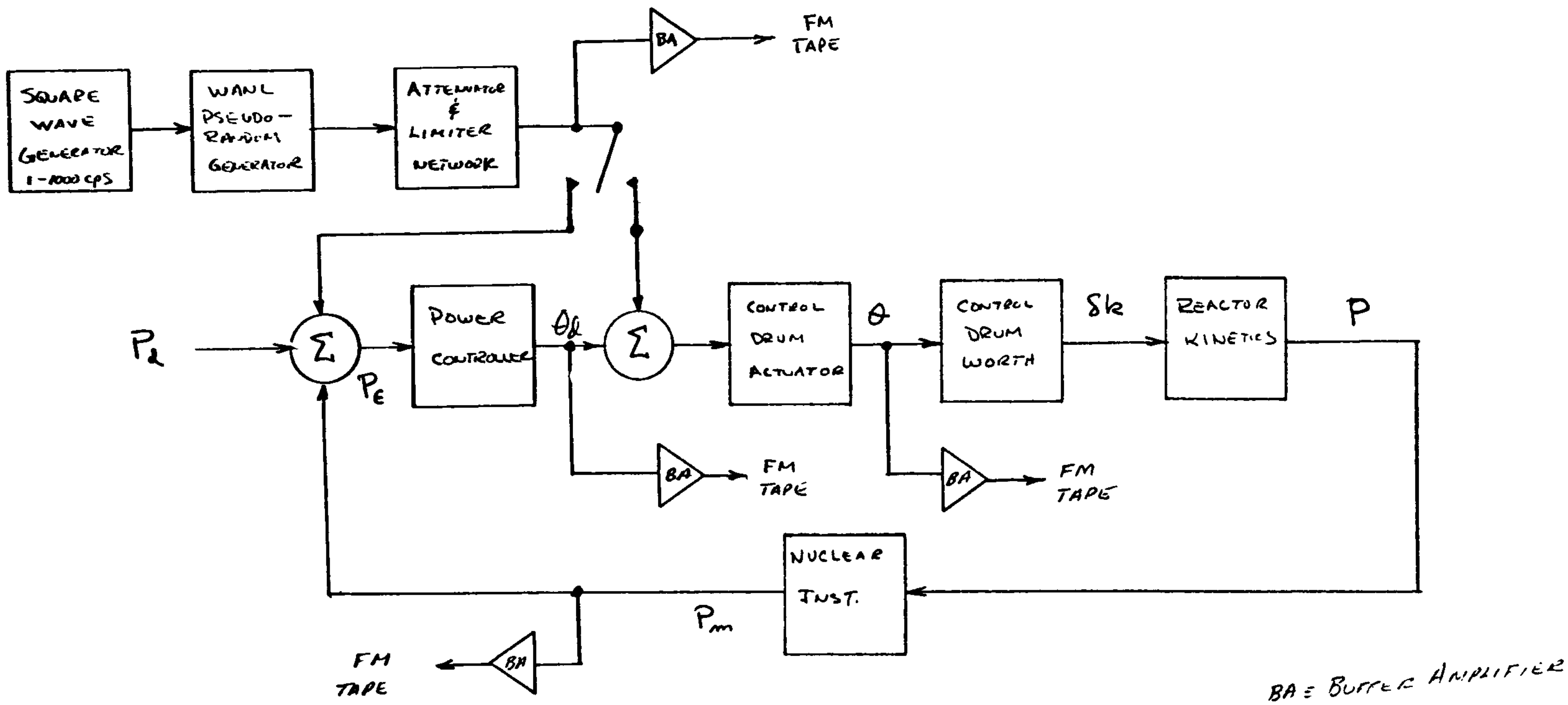
II. Nature of Experiment

A. General

The experiment with the PARKA reactor will consist in operating the reactor under automatic control at a predetermined steady-state power level with the addition of a small-amplitude, noise-like input signal from the WANL pseudo-random signal generator(2). A block diagram of the experimental setup is given in Figure 1.

It is planned to apply the attenuated generator output to the control-drum-actuator amplifier during a first series of tests and to the power-controller input during a second series of tests. The input signal, the perturbed-control-drum-position signal, the nuclear-instrumentation-output signal, and the power-controller-output signal will be recorded on FM tape, and the data will be processed off-line by cross-correlation using the digital system available at LASL. (To provide a cross-check of the LASL and WANL digital cross-correlation systems, the data will later be reprocessed using the WANL processing system at Large, Pennsylvania.

The power level to be used for these tests will be selected in consultation with LASL personnel so as to avoid (a) excessive buildup of induced radiation in the core and (b) the introduction of ambiguity in the results due to core heating effects, while providing (a) satisfactory discrimination against neutron-source effects, (b) an effective nuclear-instrumentation bandwidth of at least 100 cps, and (c) generally good signal-to-noise ratios. At least one



EXPERIMENT SETUP BLOCK DIAGRAM

FIGURE 1

measurement in the series outlined below will be repeated at a power level one to two decades higher than that selected for the main body of the measurements in order to check that the results are independent of power level in the range of powers considered.

B. Perturbation of the Control-Drum-Position Demand

For this series of tests, the generator output pulse train will be attenuated through a potentiometer or series input resistor, and applied at the input of the control-drum-actuator amplifier. The drum to be perturbed will be the same drum that is controlled by the power controller. The amplitude of the input signal will be adjusted such that the perturbation in the reactor power level is approximately $\pm$ 1% of the steady-state level. The unperturbed drums will be shimmed, prior to the test run, such that the perturbed drum position is approximately 90°.

In the different tests of this series, use will be made of sequences having different sequence lengths (L) and different numbers (N) of clock intervals of length Δt in the sequence length. The values of N and L have been chosen to cover the frequency range from approximately 0.015 cycles per second to 250 cycles per second. One set of values was selected to permit evaluation of the transfer functions over the entire frequency range, while the remaining sets were chosen to cover either the low or high frequency portions of the range, for comparison purposes. The following table gives the values chosen for each run.

TABLE 1

Run No.	Square-Wave Generator Frequency f(cps)	N (Bits/Sequence)	Sequence Length L(sec)	Clock Interval, Δt(sec/bit)	Approximate Frequency Range Covered Δf(cps)	Maximum Steady-State Run Time (min)
1	500	1023	2.046	0.002	0.5 - 250	1
2	500	32767	65.534	0.002	0.015 - 250	10
3	4	255	63.75	0.25	0.015 - 2	10
4	1	63	63	1.00	0.015 - 0.5	10

The maximum running time was chosen to cover about ten sequence lengths.

C. Power-Demand Perturbations

For this second series of tests, the generator output will be attenuated and applied at the input to the power controller as a power-demand signal. The amplitude of the input signal will again be adjusted such that the perturbation in the reactor power level is approximately $\pm$ 1% of the steady-state level. The perturbed drum will again be shimmed to the 90° position by initial adjustment of the unperturbed drums.

The tests to be run for this series have identical values of N, L, etc. as given in Table 1.

III. Implementation of Measurements

A. Pseudo-Random-Signal Generator

The input signals will be produced by means of a special, feedback-shift-register, pseudo-random-binary-signal generator, designed[2] by E. K. Honka of the WANL Control and Systems Analysis Section and built by WANL Instrumentation and Control personnel. A block diagram of the pseudo-random pulse generator is given in Figure 2, Dwg. 928F685. The following are some of the major hardware features of the WANL generator.

1. The signal generator is an all-solid-state device constructed of Harmon-Kardon digital modules with silicon semi-conductors.

2. It consists of two individual generator channels packed in a single portable steel box. Each channel has individual cycle-length adjustment and can be driven at different rates from different clock pulse sources.

3. The clock output is connected to the input of each shift-register-generator channel through an "and-gate" controlled by a manual switch.

4. The output of each generator channel can be disconnected individually and completely from the system being studied by de-energizing a relay provided for each output.

5. A double (parallel-connected) indicator light indicates when the "and-gate" connecting the clock to each generator channel has been switched "on"(permitting clock pulses to drive the generator).

6. A double indicator light indicates when each generator channel is in operation (i.e., generating output pulses).

7. A double indicator light indicates when the contacts of each output relay are closed.

8. A double indicator light indicates when the pulse train from each generator channel is passing through the output relay to the system being studied.

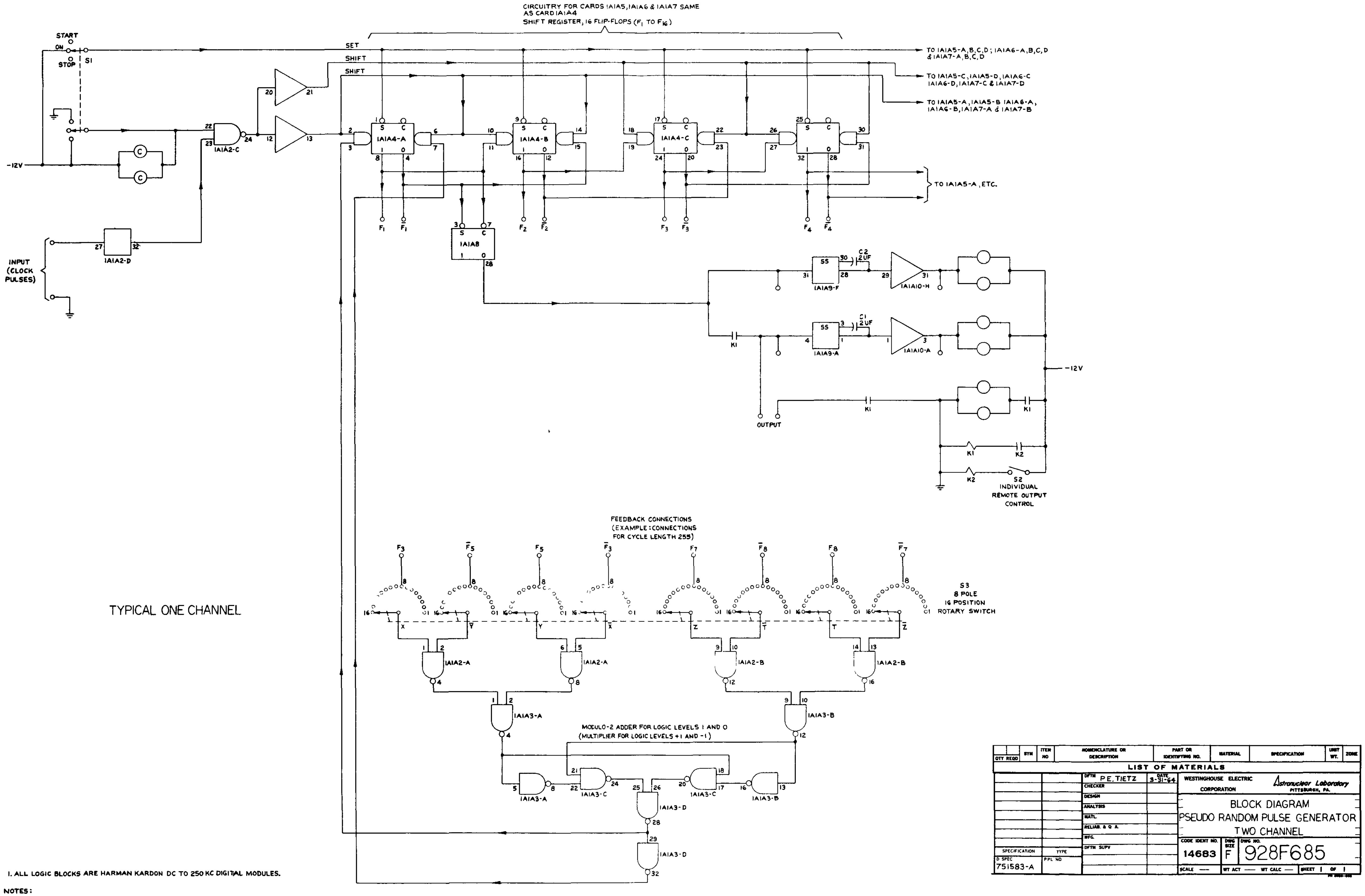

CIRCUITRY FOR CARDS 1A1A5, 1A1A6 & 1A1A7 SAME AS CARD 1A1A4
SHIFT REGISTER, 16 FLIP-FLOPS (F1 TO F16)
START
ON
STOP
S1
-12V
INPUT (CLOCK PULSES)
1A1A2-D
1A1A2-C
SET
SHIFT
SHIFT
1A1A4-A
1A1A4-B
1A1A4-C
1A1A8
TO 1A1A5-A,B,C,D; 1A1A6-A,B,C,D & 1A1A7-A,B,C,D
TO 1A1A5-C, 1A1A5-D, 1A1A6-C 1A1A6-D, 1A1A7-C & 1A1A7-D
TO 1A1A5-A, 1A1A5-B 1A1A6-A, 1A1A6-B, 1A1A7-A & 1A1A7-B
TO 1A1A5-A, ETC.
1A1A9-F
1A1A10-H
1A1A9-A
1A1A10-A
C2 2UF
C1 2UF
K1
K2
OUTPUT
S2 INDIVIDUAL REMOTE OUTPUT CONTROL
FEEDBACK CONNECTIONS (EXAMPLE: CONNECTIONS FOR CYCLE LENGTH 255)
S3 8 POLE 16 POSITION ROTARY SWITCH
TYPICAL ONE CHANNEL
1A1A2-A
1A1A2-B
1A1A3-A
1A1A3-B
MODULO-2 ADDER FOR LOGIC LEVELS 1 AND 0 (MULTIPLIER FOR LOGIC LEVELS +1 AND -1)
1A1A3-C
1A1A3-D
1. ALL LOGIC BLOCKS ARE HARMAN KARDON DC TO 250 KC DIGITAL MODULES.
NOTES:
LIST OF MATERIALS
P.E. TIETZ
3-31-64
WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory PITTSBURGH, PA.
BLOCK DIAGRAM
PSEUDO RANDOM PULSE GENERATOR
TWO CHANNEL
14683
F
928F685
751583-A

FIGURE 2

9. The output voltage of each signal generator channel switches between about +8 and -8 volts and is limited to this range by Zener diodes. These levels are fairly close to the +12 and -12 volt power-supply voltages so that, in the event of malfunction in the signal generator, the output signal level cannot change by a large amount.

10. The generator outputs are to be connected to operational amplifiers in the control circuits via fixed resistors having a resistance of 100 K or greater so that the gain of the control amplifiers will be insensitive to changes in the output impedance of the generator.

The signal generator will be driven by a square-wave generator (Hewlett-Packard or equivalent). The square-wave requirements are $\pm$ 10 V peak-to-peak output with a frequency range of 1 cps to 1000 cps.

Additional limiting of the generator output signal will be accomplished with Zener or normal diodes at the output of the attenuation network. For the tests with the generated output applied to the power controller, the attenuation must be approximately 250 to 1000. The input voltages to the power controller will be in the range of 0.0065 volts to 0.035 volts. Using a normal diode as a Zener would provide a limit at 0.3 volts. Hence, any malfunction in the attenuator would provide an input step of 0.3 volt into the power controller, demanding a power increase of no more than a factor of three above the operating power level.

B. Signal Recording

The signals to be recorded during the tests are the input signal, the controlled-drum position, the reactor power level, and the power-controller output. Each of these signals will be fed to the FM tape units through buffer amplifiers to isolate the control system from the data system.

IV. Data Processing

The processing of the data will be performed at LASL. The signals that have been recorded on FM tape will be digitized by means of a multiplexing unit and then processed by the VAST and VAC digital codes at LASL to perform the cross-correlation and the evaluation of the magnitudes and phases of the pertinent system transfer functions.

The FM tape records will also be made available to WANL personnel for performing the cross-correlations at WANL with the Huntsville code.

V. Results of Analog-Computer Simulations

Analog-computer runs were performed by Control and Systems Analysis personnel at WANL for each of the proposed tests. The computer simulation consisted of the PARKA power controller, the reactivity worth of one controlled drum, a six delayed-neutron-group linear kinetics simulation, the static characteristics of the PARKA nuclear instrumentation, and an actual hydraulic actuator located in the WANL Actuator Laboratory (with trunk lines to the analog computer). The actuator used was a "large-volume", hydraulic actuator identical to the actuators that will be used for the NRX-A2 tests. The actuator velocity limits were set at +45°/sec and -300°/sec by hydraulic orificing.

Tables 2 and 3 give a summary of input and output information obtained from the analog simulations of the proposed experiments. Table 2 is for the first series of tests with the generator input applied to the control drum amplifier, while Table 3 is for the second series of tests with the generator input applied to the power controller. For each run, the power-level perturbation was ± 1% of the steady-state value.

The actual analog-computer traces are given in Figures 3 to 10. The non-pulse-like character of the recorded input for the fast runs is due to the 50 cps bandwidth of the recorder. (The values given for the input amplitudes in the tables were measured from an oscilloscope display.)

TABLE 2

Analog-Computer Results : Input Signal to Control Drum Amplifier

Test Run	N(bits/sec)	θ(input)	$\dot{\theta}$(max)(°/sec)	Power Controller Output (volts)
1	1023	± 3°	45	± 0.35
2	32767	± 3°	45	± 0.50
3	255	± 1°	29	± 0.50
4	63	± 1°	40	± 0.50

TABLE 3

Analog-Computer Results : Input Signal to Power Controller

Test Run	N(bits/sec)	P(input)volts	$\dot{\theta}$(max)(°/sec)	Power Controller Output (volts)
1	1023	± 0.035	32	± 0.63
2	32767	± 0.035	30	± 0.70
3	255	± 0.0065	23	± 0.50
4	63	± 0.0065	23	± 0.60

The small limit cycles seen in Figures 3 to 10 on the traces for the control-drum position, the power level, and the controller output were caused by the hydraulic-actuator-backlash characteristics. The frequency of the limit cycles is approximately 2 cps with an amplitude of 0.1% of the steady-state power level. The drum oscillation amplitudes associated with the limit cycle is approximately ± 0.1°. It is not expected that such a small limit cycle would have a significant effect on the safety or accuracy of the transfer function measurements.

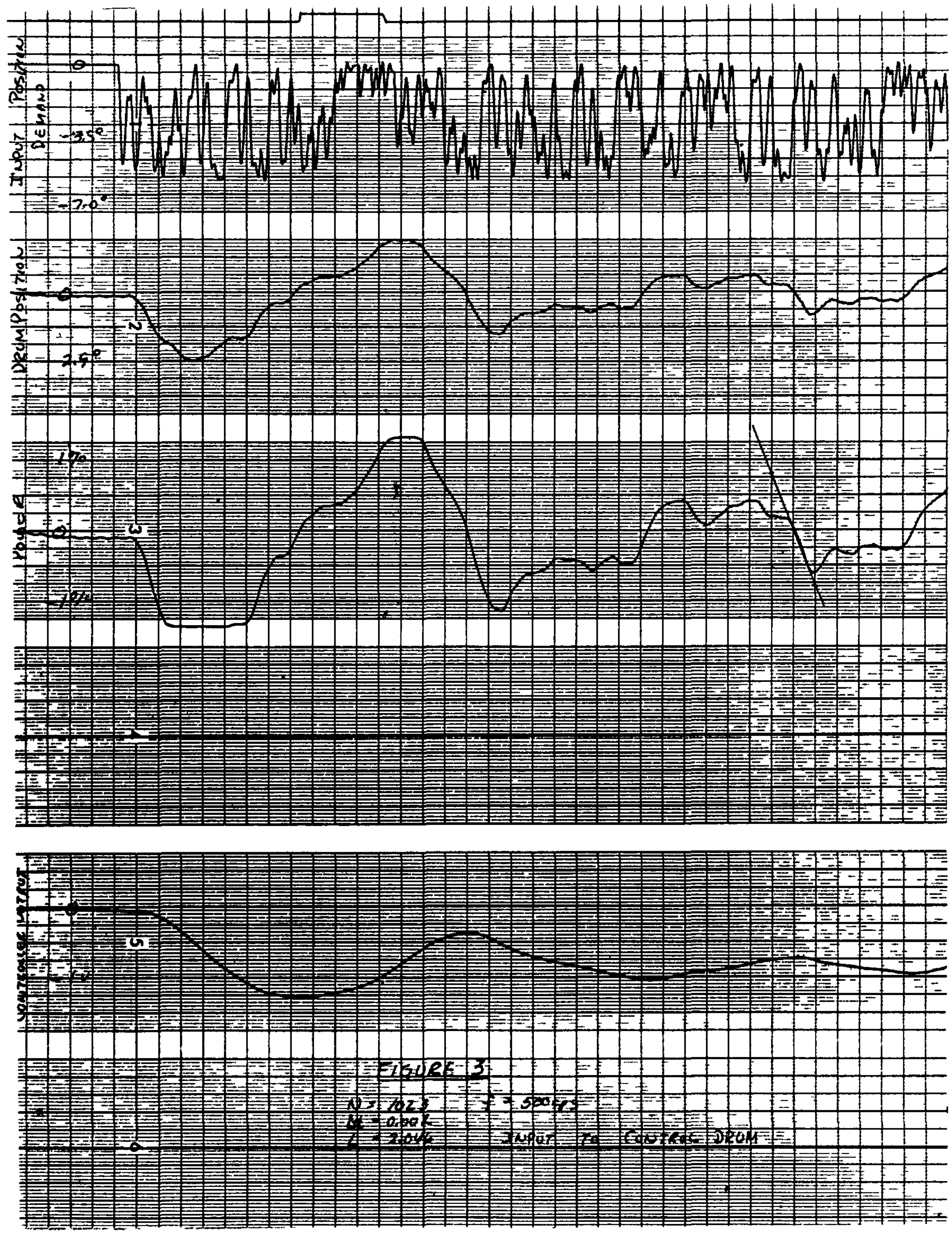


FIGURE 3

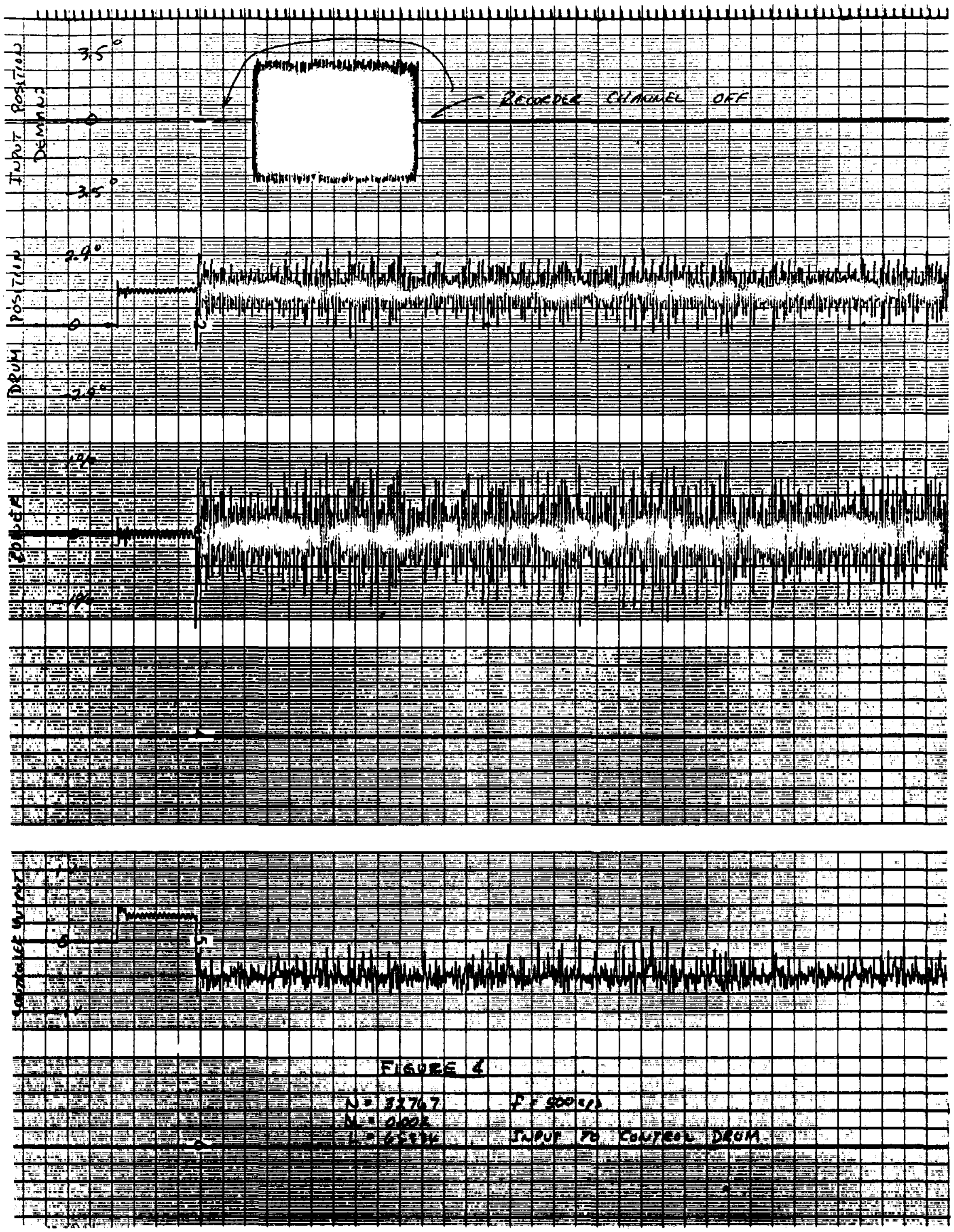

INPUT POSITION DEMAND
RECORDER CHANNEL OFF
DRUM POSITION
FIGURE 4
INPUT TO CONTROL DRUM

FIGURE 4

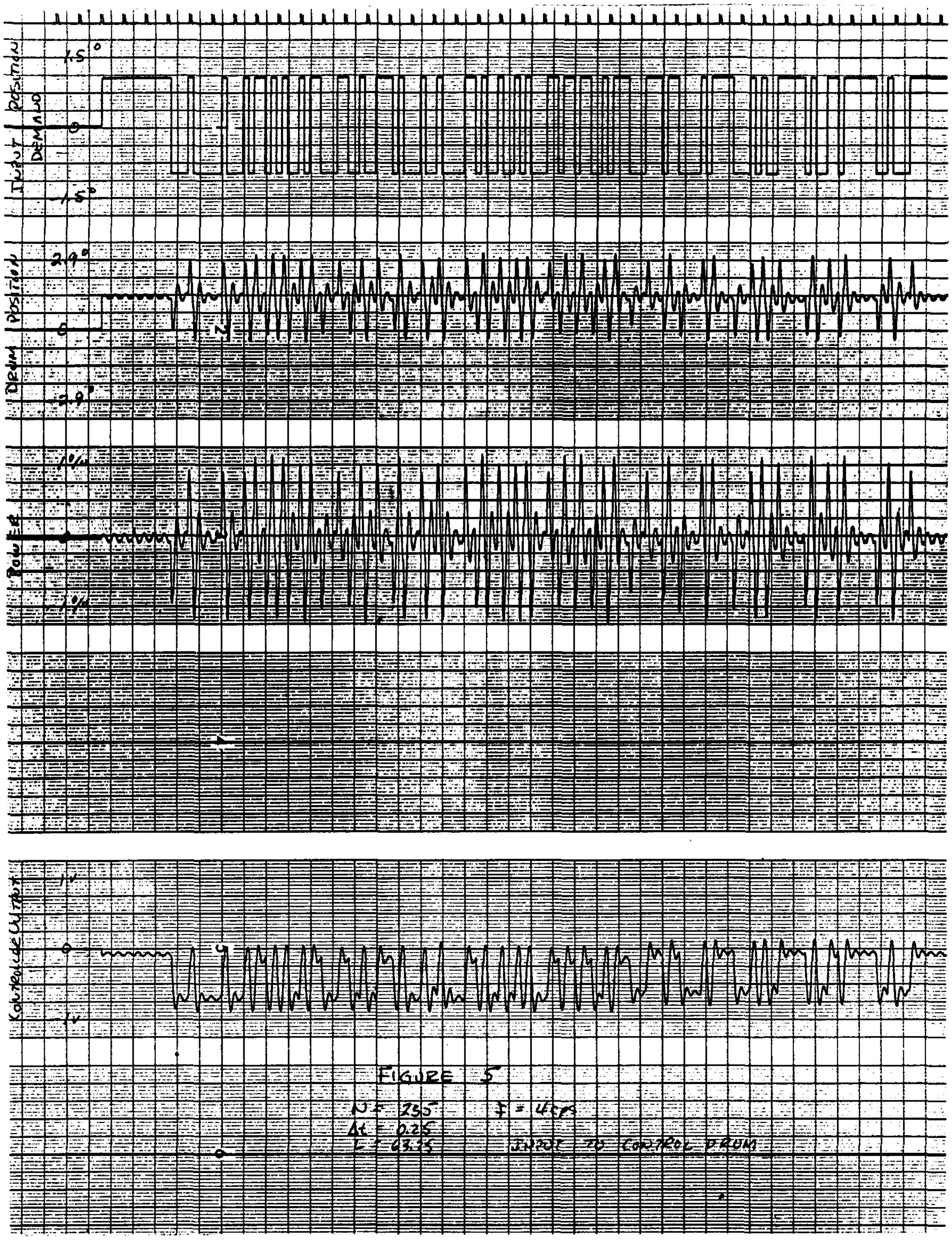

1.5°
0
-1.5°
INPUT POSITION DEMAND
2.9°
-2.9°
DRUM POSITION
1%
-1%
POWER
1v
-1v
FIGURE 5
N = 255
f = 4 cps
INPUT TO CONTROL DRUM

FIGURE 5

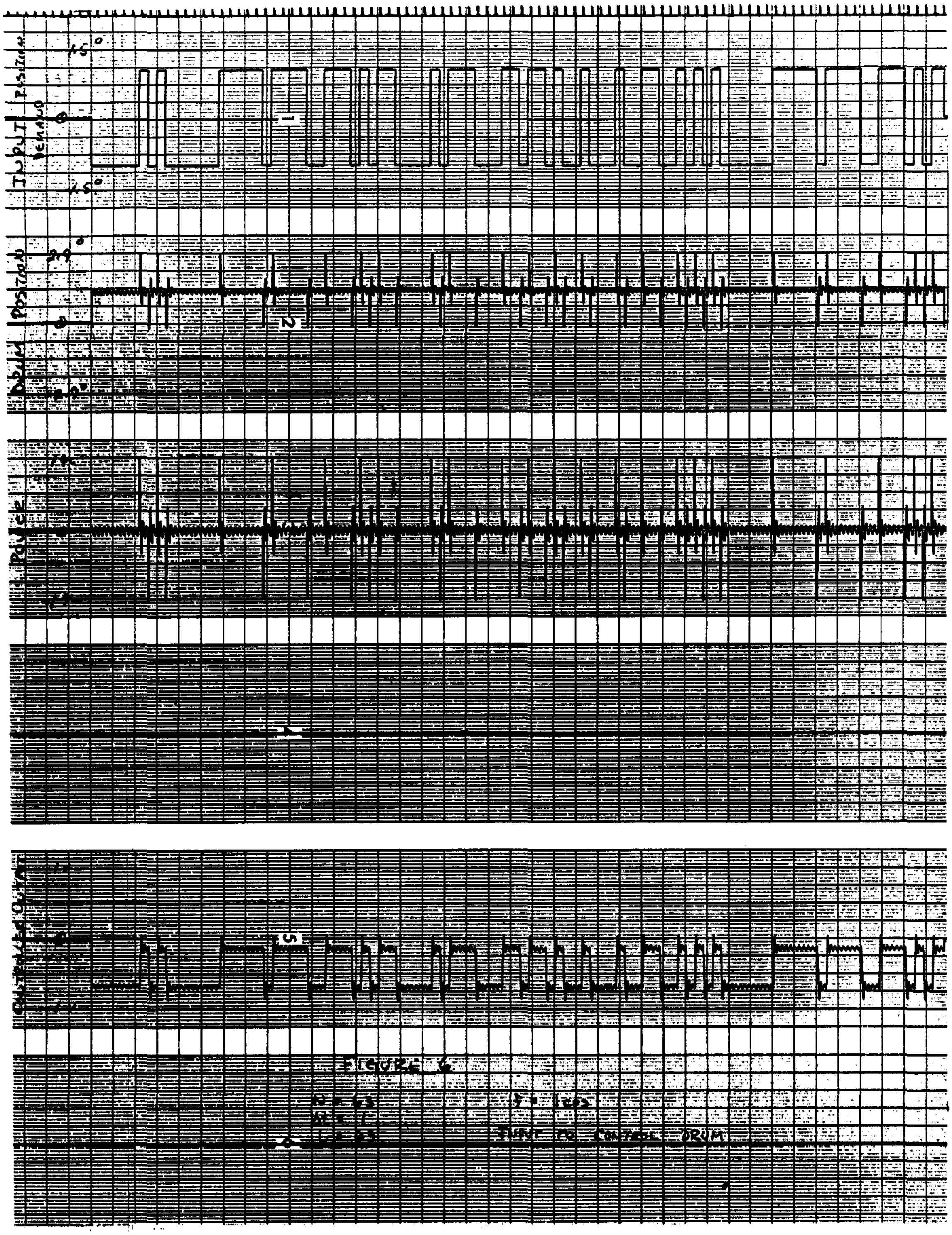


FIGURE 6

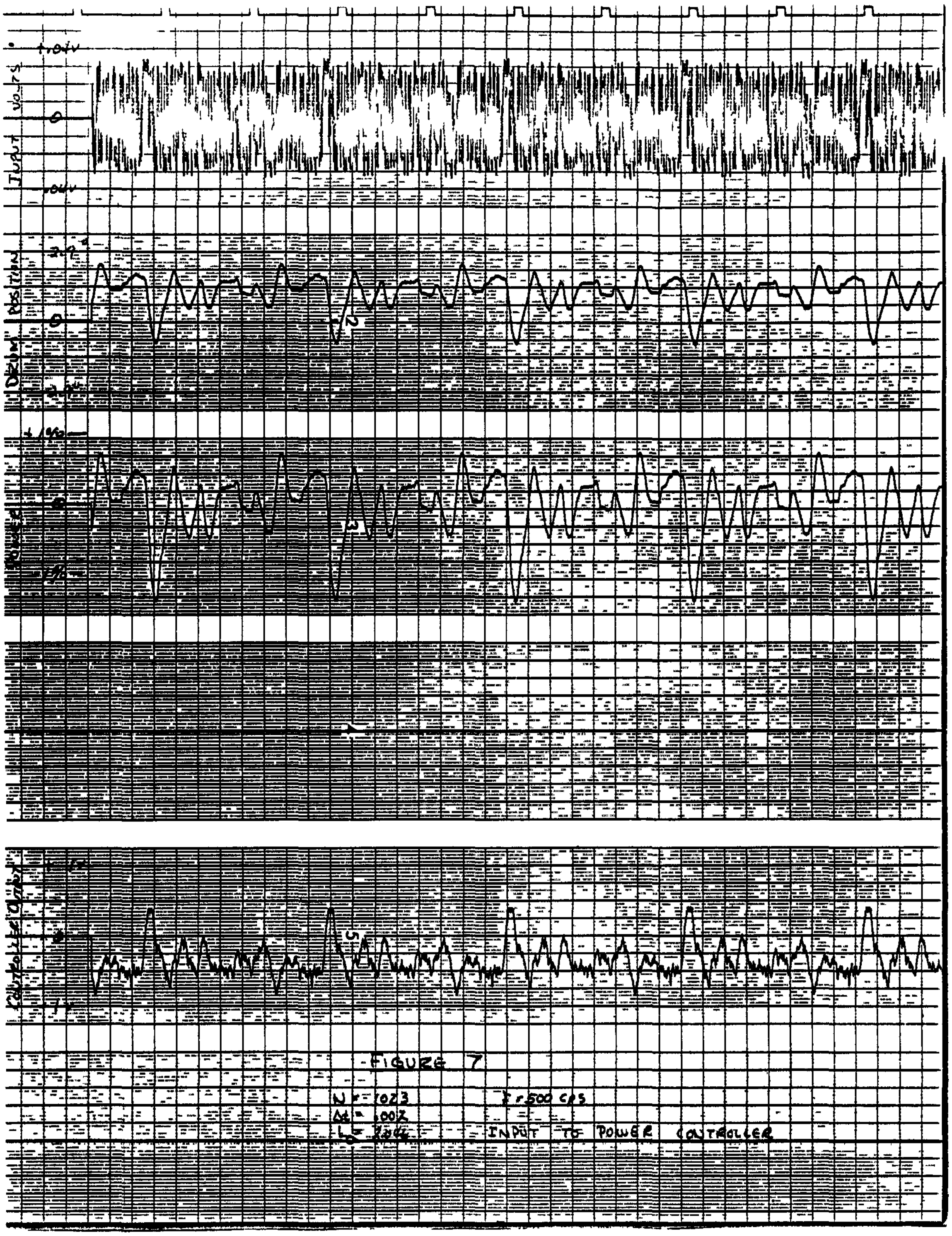

INPUT VO.75
DRUM POSITION
POWER
FIGURE 7
INPUT TO POWER CONTROLLER

FIGURE 7

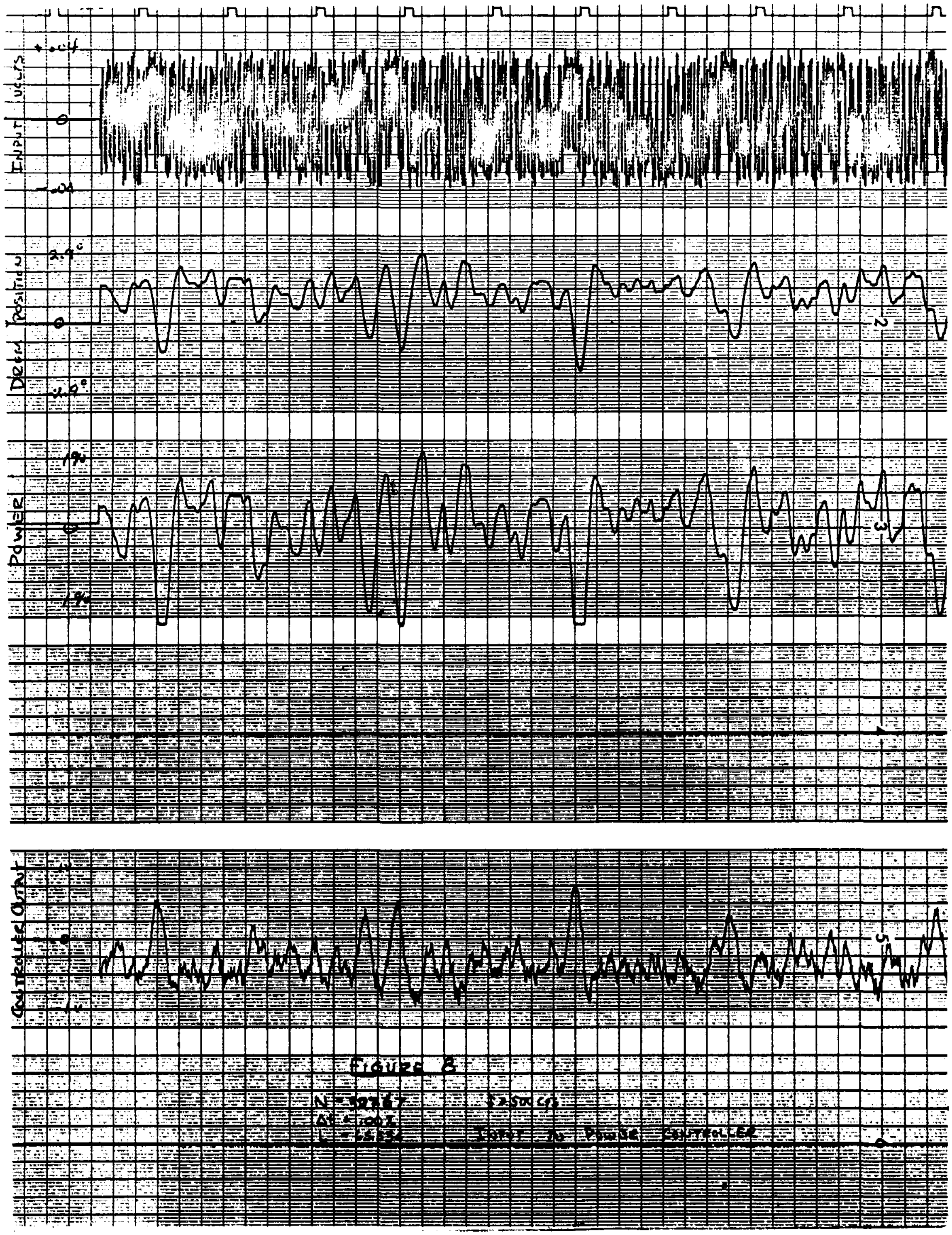


FIGURE 8

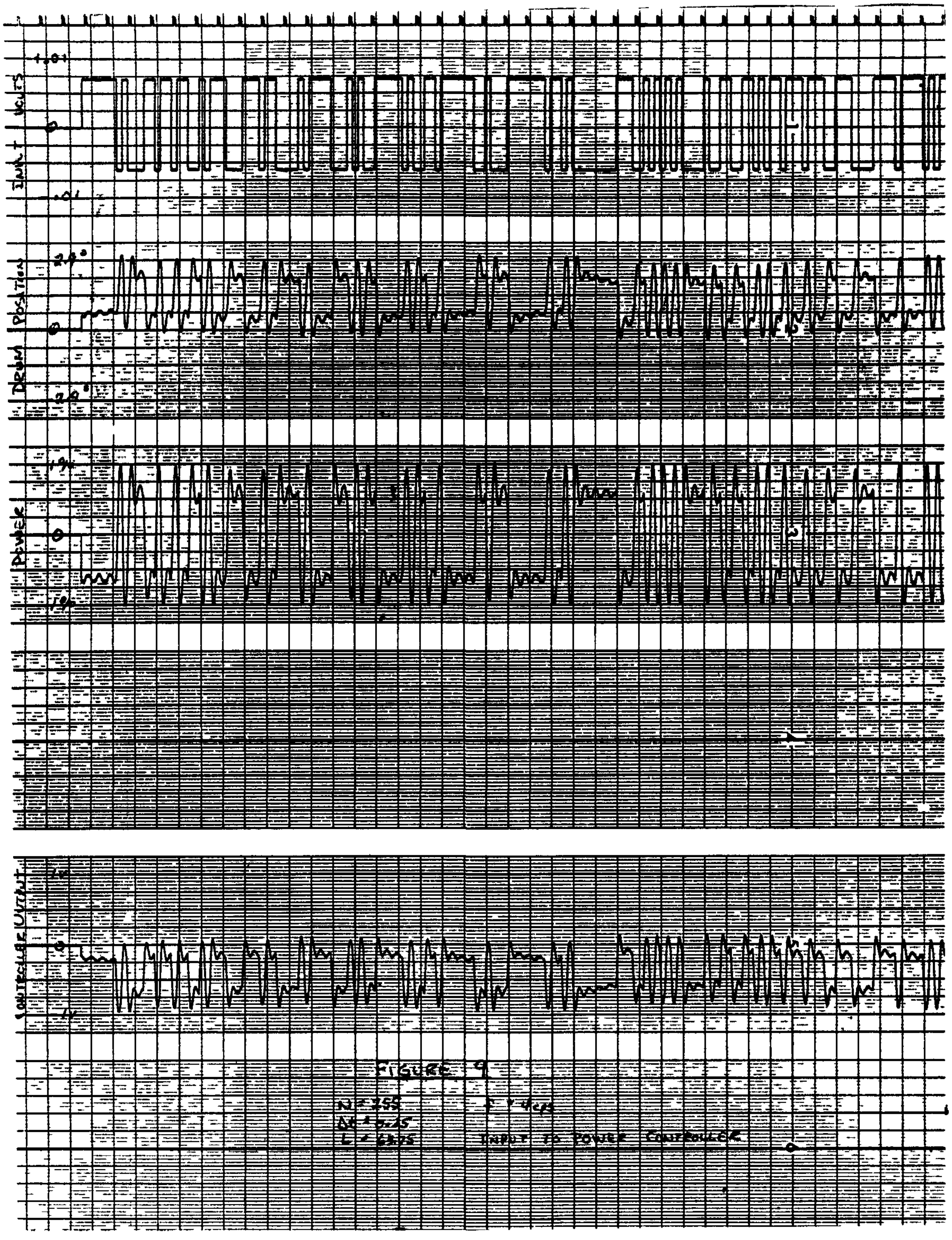

INPUT VOLTS
DRUM POSITION
POWER
CONTROLLER OUTPUT
FIGURE 9
N = 255
f = 4 cps
INPUT TO POWER CONTROLLER

FIGURE 9

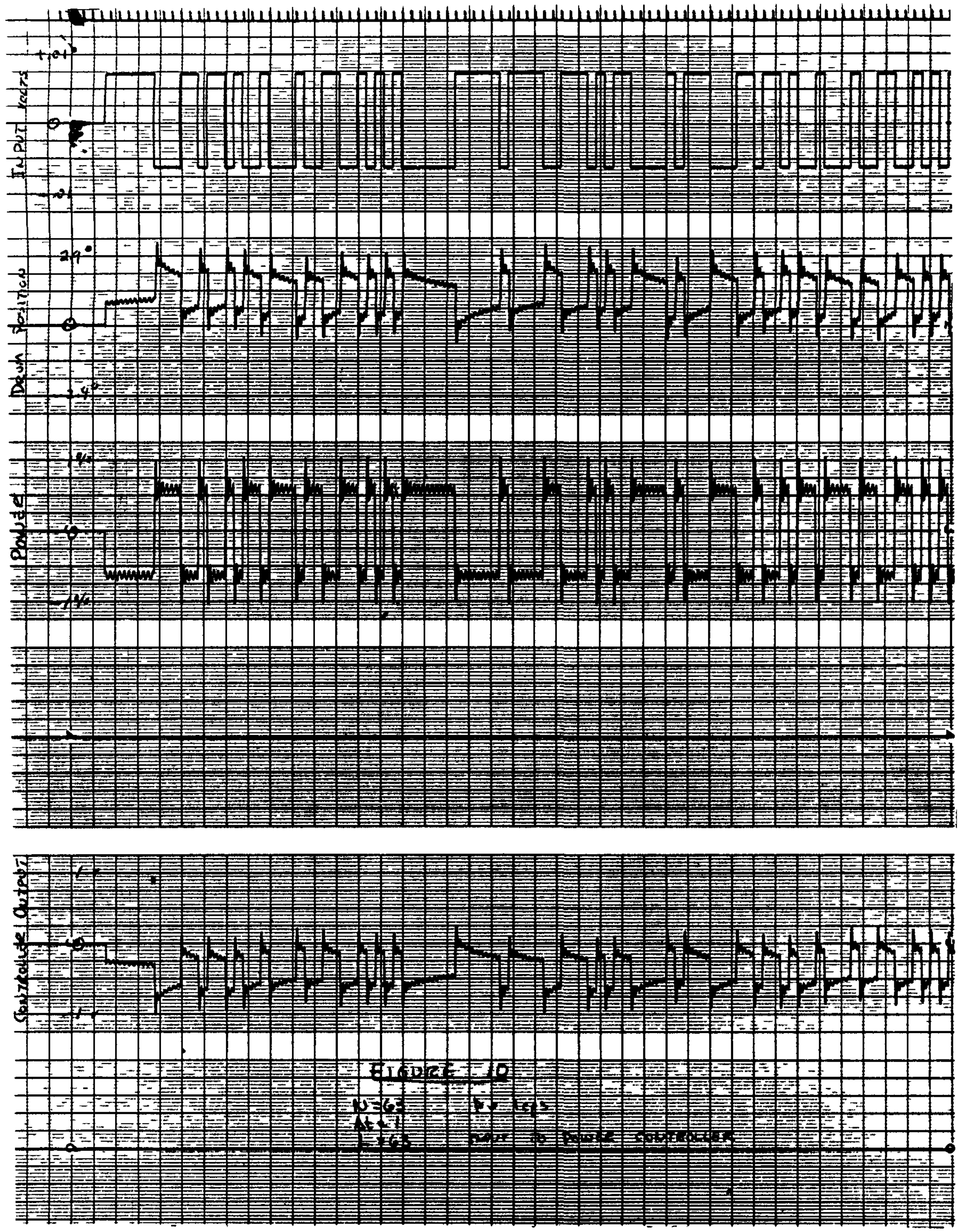


FIGURE 10

The analog computer studies show that in achieving a $\pm$ 1% power perturbation, the input signals to the control drum and the power controller will be relatively small. Ample protection against equipment malfunctions will be provided through the use of diodes to assure that no large excursions will be introduced. The reactivity perturbations from the controlled drum during the signal application will be $\pm$ 2¢ or less.

The controlled drum will reach velocities of 45°/sec during the transients. However, these high velocities exist for very short periods of time. It is felt that the velocity limits at 45°/sec provided by orifices in the hydraulic system would not introduce appreciable non-linearities into the transfer function measurements in the planned tests.

It is felt that the proposed series of tests can be accomplished in a manner that will not compromise the safety of the reactor and operating personnel, and will provide valuable experience in the use of the pseudo-random generator for the measurement of reactor transfer functions.

VI. References

1. A. A. Wasserman, E. K. Honka, G. H. Steiner, "Proposal for Measurement of NRX-A2 Reactor and Facility Transfer Functions by Cross-Correlation With Pseudo-Random Binary Input Signals", WANL-TME-757, (April 20, 1964), (U).

2. E. K. Honka, "Design of a Feedback-Shift-Register, Pseudo-Random-Binary Signal Generator for Transfer Function Measurements", (WANL report in preparation).