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ANALOG MODEL AND EVALUATION OF THE FOUNTAIN VALLEY RATE-OF-FLOW CONTROL STATION

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16. ABSTRACT

The Fountain Valley Conduit is a 45-mile pipeline constructed by the Bureau of Reclamation to deliver water from Pueblo Dam near Pueblo, Colorado north to the cities of Colorado Springs, Stratmoor Hills, Fountain, and Widefield, Colorado. A computer based supervisory control system will control 5 pumping plants along the pipeline and a RFCS (rate-of-flow control station) to regulate waterflow. An analog computer model was designed to represent the RFCS and evaluated to determine system performance. This report details the conduit system, the analog model, and control performance criteria.

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October 1981

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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INTRODUCTION

Delivery of domestic water supplies from reservoirs to municipal consumers demands a system of pipes, valves, and tanks comparable to the plumbing found in each user's residence. Just as there must be a faucet to control tap water flow, there must also be valves in the reservoir conduit delivery network to regulate water supply. Similarly, water tanks and conduits are necessary to regulate and transport water through the system for consumer use.

This report studied the reaction of the water delivery system to changes in flow introduced by regulating valves. The Fountain Valley area southeast of Colorado Springs, Colorado receives domestic water through a 3-mile long, 24-inch diameter pipe known as the Fountain Valley Lateral. Water from the Lateral serves consumer needs in the Fountain Valley and adjoining areas. To effectively regulate water supply using computer-controlled valves is an important engineering inquiry related to the construction of the Fountain Valley water supply system.

The work described originates from a request to evaluate the performance characteristics of a RFCS (rate-of-flow control station) located in the Fountain Valley Lateral, Municipal Water System, Fryingpan-Arkansas Project, Colorado. The general location of the system's components are identified on figure 1. Details of the project are found in the Physical Description of the Fountain Valley System section.

The remote control of pipe valves was studied to ensure the system's operation would not rupture the pipes. If the valves close too fast, the resulting rise in pressure would burst the pipe. This water-hammer limitation places difficult requirements on the valve controllers. Because the storage tank cannot hold all the water in the pipe, the controller must ensure the tank will not overflow. These requirements occasionally require conflicting control functions. Therefore, a thorough study of the control was made. The valve control system should be stable. Additionally, speed of response should be reasonably fast without excessive response error or pressure surge. This study was made to ensure the method of water flow control meets all control requirements.

The primary objective was to identify the restrictions in behavior of a sequential, dual valve, tank-level regulating, subsystem specified for the Fountain Valley Lateral. The method of evaluation was an analog computer model. The model simulates terminal tank level, watered conduit, microprocessor control, external valve controllers, and valve behavior characteristics. The level control system modeled represents the design approach for regulation of water levels at the Fountain and Widefield terminal tanks with source water from the Widefield regulating tank.

CONCLUSIONS

1. The specified method of regulating terminal tank level, using a remote terminal unit actuated RFCS is expected to perform adequately.

2. System response to transient pipe behavior is slow and substantially attenuated by large system energy transfer capacities.

3. Proportional-integral values are critical to flow-path-control stability. Recommended ranges and initial values are indicated below:

Variable	Range	Initial value
K_p	0.0 to 1.0	0.5
K_i	0.0 to 0.1	0.01

4. The model evaluation provides a simulated approximation of actual physical behavior of the RFCS. Variations in system components or operational failures were not considered in this study. Any change in equipment or firmware or failure therein is beyond the study limitations.

PHYSICAL DESCRIPTION OF THE FOUNTAIN VALLEY SYSTEM

The Fountain Valley system studied is shown on figure 2 and shows the operational diagrams for the Widefield regulating tank, Fountain-Widefield RFCS, Fountain terminal tank, and Widefield terminal tanks. Figure 2 also describes the Fountain-Widefield RFCS and the Widefield regulating tank.

The symmetry of the Fountain and Widefield tank level controls invites selection of one of the

two systems for modeling purposes. The flow from the Widefield regulating tank to Fountain terminal tank stream was chosen to evaluate valve control characteristics. Indicated on figure 2 are the valve sizes, water level modulation ranges and set points, flow capacities, and elevation differences from which the dynamic flow of the system may be determined. A diagram of the simplified tank level regulating system adopted for the analog computer simulation is depicted on figure 3.

The 24-inch pipe from the Widefield regulating tank and the RFCS valve manifold are depicted on figure 4. The selected valve manifold system for the model is the lower manifold section which contains 6- and 8-inch motor-operated butterfly valves. Flow in and out of the model system manifold is evaluated for a 12-inch conduit.

The site layout for the Widefield regulating tank, the RFCS, and the Fountain terminal tank are shown on figure 5. In subsequent velocity and flow computations, the distance across the RFCS was neglected and assumed small in comparison with total distances from the regulating tank to the terminal tank.

Dimensions of Fountain Valley terminal tank and Widefield regulating tank are shown on figures 6 and 7, respectively. The Widefield regulating tank supplies water to the Fountain terminal tank through the RFCS valve manifold.

MODEL DESCRIPTION

The valve control flow diagram depicted on figure 8 was the specified method of performing control of the valves at the RFCS. A tank level span is determined through which each valve (6-inch designated small valve and 8-inch designated medium valve) is opened and closed sequentially to maintain tank level. The water level modulation ranges for both the small and medium valves are shown on figure 2.

The final number of controlled valves was two. Figure 8, prepared prior to Solicitation DS-7422, anticipated that three valves might be employed in the RFCS. The model study considered contains the two-valve system which retains the small and medium vlave designations, and excludes the large third valve.

Valve positions are controlled by a microprocessor-based RTU (remote terminal unit) which receives and compares the valve flow and tank level status. The RTU sends valve request positions to the valve controller corresponding to the flow requirements of the terminal tank.

A second block diagram developed for the valve control system is depicted on figure 9. Represented in the diagram is a system analog to the expected microprocessor control. Model variables and control parameters are specified on the diagram.

The model employs two alternating valve control signals which change valve position and consequent flow into the terminal tank. In the control loop, present valve position is compared with resulting valve flow, and the smaller signal establishes the valve request position for the valve controllers.

Control variables are defined on the righthand side of figure 9. Those variables which may be assumed to have negligible variance with respect to time are assigned constant values. Value assignment is based on computations which appear in the section on Control Parameters.

Implementation of the model system on the analog computer is given on figure 10. Depicted are counterpart, interactive models for both valves. These contributions are labeled S (small) and M (medium) throughout the model.

Valve control resulting from comparator selected request position appears on the lower section of the diagram. Position of the valve is translated to static flow by function generators and proportioned by the fractional contribution of the valve to total flow. A closed pipe water model transfers static flow to a conduit-simulated flow into the terminal tank.

Both valve position and flow control loop signals indicated at the top and center of figure 10 are a function of relative tank flow. In the position loop, the difference between flow in and out of the tank is integrated to produce a simulated tank level capacity. The time variant tank level is summed with the valve range center level and multiplied by the position-to-level difference ratio. The resulting signal is the individual valve span indicated on figure 9. Valve span is

summed with the center position of the valve and the valve position signal transferred to its respective control loop comparator. The flow loop translates water into the tank to a dynamic flow for each valve. Dynamic flow is summed with maximum desired flow contribution for each valve (setpoint) producing the actuating error signal for a P-I (proportional plus integral) flow transfer. Output for the P-I control is proportional to the sum of the dynamic flow error and the integral of the flow error with respect to time. As the flow error becomes small, sufficient integration time provides enough controller output to drive the flow loop to the setpoint.

The dual-valve RFCS model performs a sequential alternation of flow versus position control of the valves as tank level is changed by downstream flow demand. Tank fill operations simulated initially open the small valve, and if flow demand exceeds the capacity of the small valve, open the medium valve until the required tank level is stabilized. For decreased flow out of the tank, the process is reversed and medium valve closure responds to decreased demand with small valve closure following as flow out of the tank decreases.

Given that the simulated tank is full and that some constant flow out step response is introduced to the system, both valves will demand flow control until each one reaches its flow capacity for a given request position. At flow per position capacity, a new position request is initiated based on contribution requirements of the valve toward meeting dynamic tank level needs. Flow increases or decreases corresponding to valve position requested.

The complete model is scaled to a one pu (per unit) magnitude for all signals and a rate of operation of 1000 times the real time event sequence rate. The time scaling magnitude is mandated to expedite testing and data collection since the modeled terminal tank has a physical time constant of about 32 hours.

CONTROL PHILOSOPHY

The control implementation seems complex when studied by flowchart or modeling diagram. The complexity created by the presence of two control systems in parallel must not override the simplicity of the concept itself. The requirement is to maintain a level in a tank without overflowing the tank or producing pressure surges in the pipe. Further, the valves should have a maximum flow somewhat less than at full open.

The tank level is controlled by a zone controller where each valve is assigned a zone of levels in the tank. As the tank fills, the smaller valve is saved for control at the top of the tank, and pressure surges are minimized. The control is integral in nature and the tank volume acts as the integrator. There is no need for proportional or differential control because of the large volume of the tank and the resultant low gain.

The control then transfers to flow control when the level control requests maximum flow. The control chosen is P-I in nature. The derivative was not needed because the valves have position control included as a separate control loop. This P-I controller does have the possibility of instability, and therefore, K_p and K_i should be kept within stable ranges.

CONTROL PARAMETERS

Computation of model variables prescribed by the control block diagram (fig. 9) and implemented in the analog computer diagram (fig. 10) are developed from the reference drawings (figs. 2 through 7).

Time constant T_{tank} is the time required in seconds to fill the empty tank to the overflow weir at El. 5930.00 with no flow out and total maximum flow in. Tank height H_t was 44 feet from base to overflow weir, and D_t (tank diameter) was 100 feet. Tank volume (V_t) is the product $\pi \left(\frac{D_t}{2}\right)^2 H_t$ and equal to 345,575 ft³.

The flow Q for the small valve and medium valve equals 1.04 and 2.00 ft³/s respectively, resulting in a total maximum flow Q_{max} of 3.04 ft³/s. T-Tank (T_{tank}) equals total tank volume V_t divided by Q_{max} (maximum flow) into the tank and is 113,676 seconds or about 32 hours.

Time constant T_w, representing the modeled lag in the closed pipe, is the ratio of the product of L (pipe length) from the last regulating tank and V

(water velocity) to the product of (g) gravity acceleration) and the system H (head) from the last regulating tank, or

$$T_w = \frac{LV}{gH}$$

Figure 5 indicates pipe length (excluding distance across the RFCS) to be 265.38 feet. Velocity is constrained to a 12-inch diameter pipe with a 55.00-foot head between the outlet of the regulating tank and the inlet of the terminal tank. The flow for the 12-inch diameter pipe is 47 ft^3/s, and the velocity of the water is 59.8 ft/s. With a gravity acceleration of 32.2 ft/sec^2, the water flow time lag, T_w is 8.95 seconds.

The small and medium butterfly valves, when driven at maximum speed T_{vs} and T_{vm} respectively, are to close/open in 60 seconds (see fig. 2).

Water level modulation ranges designated on figures 9 and 10 as span are specified on figure 2. The Fountain terminal tank with associated valve control and alarm levels is shown on figure 11. The figure shows a 1-foot span for both the small and medium valve. There is a 35.5-foot threshold capacity from the bottom of medium span to the low-tank-level alarm. To expedite time relationships in the model, a compressed valve span-to-tank capacity ratio was employed. Tank threshold capacity below the valve spans was taken to be a zero reference. Medium valve span center was referenced at base plus one-third and small valve span center was referenced at base plus two-thirds. Full tank model capacity was thus zero base plus one.

Maximum flows for the small and medium valves are 0.33 and 0.66 ft^3/s on a per unit base, since total flow from both valves is 3.04 ft^3/s with the valves contributing 1.04 and 2.00 ft^3/s respectively.

A static valve characteristic is generated in the valve controller simulation. A function generator receives per unit position from the controller and transfers from a typical butterfly valve performance curve the position to equivalent static flow. The per unit position-to-flow transfer is depicted on figure 12 and indicates incremental values. Since valve position in the model is constrained to zero base with an upper limit of 1, valve flow below zero is made zero and valve flow transfer exceeding 1 per unit was equated to 1 per unit. Graphical model test data (see app. A) give evidence to the upper-lower limit discontinuity in those chart recordings which indicate the flow into the terminal tank. To the model, the end point change from one valve to another appears as a time delay between the sequential opening and closing of the valves. No significant effects were observed in system behavior due to the simulation discontinuity. It is suspected that the actual system may exhibit a similar characteristic.

MODEL TEST DATA

No values were specified for the P-I controller coefficients in the section on control parameters. The range of values assigned to both the proportional and integral coefficients is a function of complete system response. Although it was not obvious at the outset of model construction and testing, only the P-I coefficients readily contribute to any system instability. Because the system is composed of relatively large energy transfer capacities, introduction of any perturbations of a magnitude much less than those capacities does not produce any significant effects in the complete model system.

Total pipe flow from both valves (3.04 ft^3/s) is at any instant of time about 0.000868 percent of the total terminal tank capacity. Thus, any transient flow in or out of the tank resulting only from a rapid change in conduit flow produces negligible effects on system performance.

System component response times are relatively large so that introduction of fast transient changes in pipe flow is reflected negligibly in system response. Again, the large system capacity attenuates the transient amplitude before system components can reflect a relatively slow reaction to the change.

System Frequency Response

Graphical data (fig. A1, app. A), which detail the sequence of system responses as a sine wave of increasing frequency, is introduced representing flow out of the tank.

Time scaled or indicated frequency is in the range 0.001 to 2.00 Hz. The indicated frequency is 1000 times the real-time system, and

thus, the actual frequency response is made over the range 0.000001 to 0.002 Hz.

System frequency response is taken by restricting closed-loop transfer to position feedback only. This restriction assures that the variable of primary interest, tank level, stays in the loop.

With sinusoidal variation of flow out of the system; tank level, static medium valve flow, static small valve flow, and flow into the tank are displayed on three successive pages (fig. A1) for the test frequency range. Numerical data corresponding to the charted results indicate a 3 dB frequency (real time) at about 0.000001 Hz, 20 dB attenuation in tank level response at 0.0002 Hz, and 40 dB attenuation at 0.002 Hz. The electrical behavior of the model simulates a low frequency, single-pole, low-pass filter. With only 90 electrical degrees of phase shift resulting from the equivalent transfer function, the restricted system is always minimum phase and is inherently stable.

K_p Range Step Response

As previously indicated, instability can only be detected when position path control is disabled, and flow path control only enabled with comparator switching inactive.

P-I coefficient K_i is set at its nominal (0.01) initial value and remains constant in this test. The graphical data (fig. A2, app. A) proceed from the variation of coefficient K_p throughout its range (0.0 to 1.0) while introducing a low frequency square wave (0.00015 Hz) step variation in valve setpoint indicated as maximum desired flow on the analog diagram (fig. 10).

Charted is the setpoint step perturbation and system responses in small valve dynamic flow, medium valve dynamic flow, and flow into the tank. When control stability is measured in terms of the usual step response parameters (peak overshoot, rise time, etc.), it is observed that system damping is proportional to the value of K_p. Coefficient K_p cannot be increased beyond its recommend value without (as expected) increasing the delay, rise, and settling time accordingly. Below the initial value of K_p, peak overshoot increases appreciably causing oscillatory behavior as K_p approaches zero.

K_i Range Step Response

System responses with K_p set at its initial value of 0.5 and K_i varied in a range from near its zero lower limit to the upper recommended value (0.01) were similarly recorded (fig. A3, app. A). Coefficient K_i was increased in decade steps to increments both above and below the nominal value.

Behavior of the system, again with only the flow path enabled, was recorded for a low frequency (0.00015 Hz) square wave variation in valve flow setpoint. Responses are charted for dynamic small valve flow, dynamic medium valve flow, and flow into the tank.

Integral response is deficient for K_i substantially below the nominal value 0.01. At K_i equal to 0.01, flow exhibits a small overshoot and performance is that of a slightly underdamped system. At values of K_i exceeding the recommended initial value (0.01), signals indicated become increasingly oscillatory toward the upper limit of the range.

System Step Response

Graphical data (fig. A4, app. A) detail system response with both position and flow control paths enabled and comparator switching active. A step response is evoked by introducing a low frequency square wave (0.00002 Hz) variation in valve flow setpoint located in the flow control path. Charted data were taken for resulting tank level, dynamic small valve flow, dynamic medium valve flow, and flow into the tank.

P-I control coefficient K_p is constant at its initial value of 0.5 and coefficient K_i is varied from slightly above its initial nominal value to values exceeding its recommended range. The only incurred result is to drive the P-I control into saturation, forcing perpetual position path feedback since flow is (in error) always at a maximum. The system remains unconditionally stable if not useful.

REFERENCES

This report relies on project specification and design data from the following reference documents:

- Solicitation No. DS-7422, Supervisory Control System, Fountain Valley Conduit, Bureau of Reclamation, 1980.

- Specification 7D-C7446, Fountain Valley Lateral, Fryingpan Arkansas Project, Colorado, Bureau of Reclamation, 1980.

Drawings and design data were taken from the above documents and used to evaluate the performance of rate-of-flow control valves associated with the project.

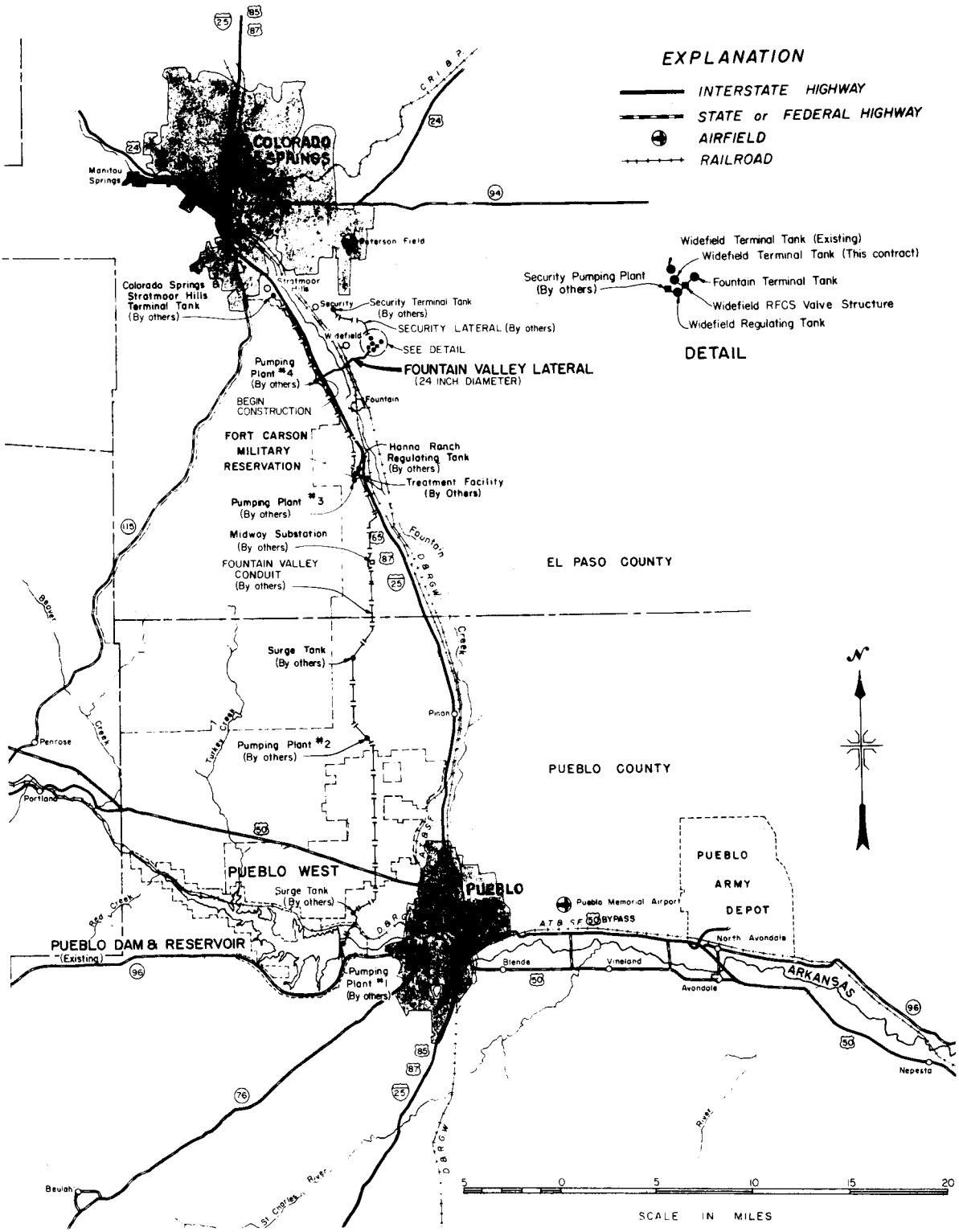
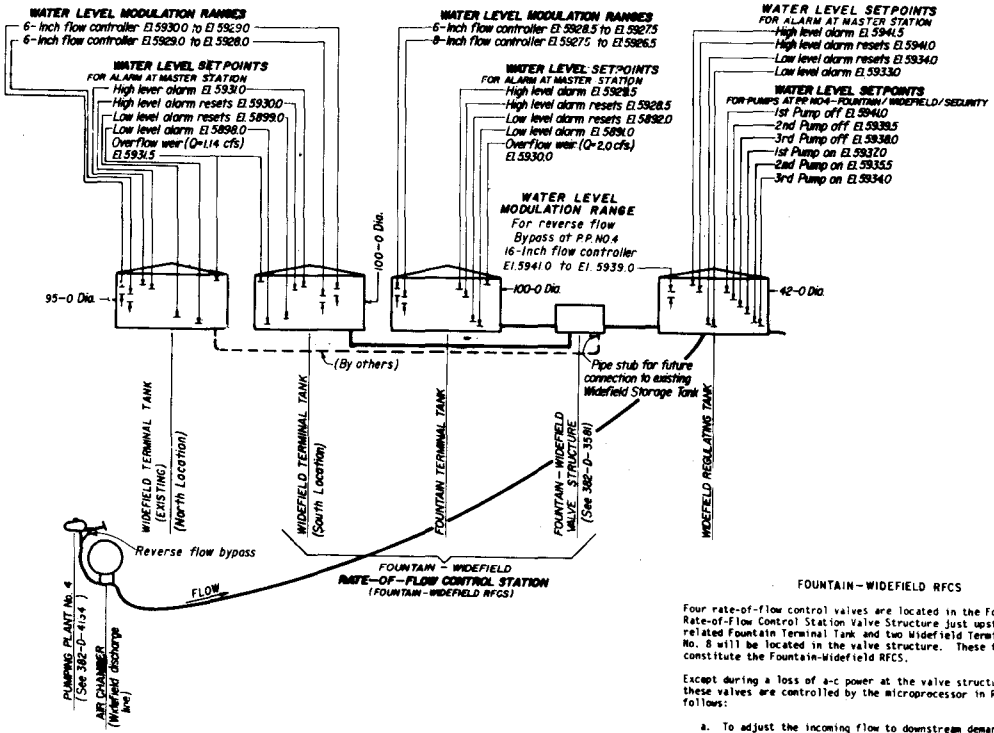


Figure 1.—General location map.



WIDEFIELD REGULATING TANK

Two ultrasonic water-level measuring devices will be provided in the Widefield Regulating Tank. Each of the two water level devices will operate into the RTU and also into dedicated telemetering equipment to provide redundant signal paths for the water level information. The RTU will transmit the water level signals to the MS where the two levels will be displayed and recorded. The MS will retransmit the signals to RTU No. 6 at Pumping Plant No. 4 for local indication only. The water level signals that operate into the dedicated telemetering equipment will be transmitted directly from the tank to the programmable controller at Pumping Plant No. 4 for automatic control of the Widefield pumping units. The programmable controller at Pumping Plant No. 4 will use one of the water-level device inputs to provide signals for normal Start-Stop operation of Widefield discharge manifold units at Pumping Plant No. 4. The water-level signal will also be used by RTU No. 6 for water-level modulation when Pumping Plant No. 4 is in the BYPASS mode. Each level signal will be limit checked for abnormal high and low levels. Abnormal high water level (elevation 5941.5) or low water level (elevation 5933.0) at the Widefield Regulating Tank will initiate shutdown of all of the Widefield manifold units at Pumping Plant No. 4 and activate an alarm at the MS. The low water level (elevation 5933.0) will also initiate closure of motor-operated butterfly valves 6BF-1, 8BF-2, 6BF-3, and 6BF-4 in the Widefield Rate-of-flow Control Station Valve Structure, shut down the unit in the Security Pumping Plant, and activate an alarm at the MS. The four butterfly valves will open automatically when the Widefield Regulating Tank water level rises to reset elevation 5934.0 The high water-level function must be reset by the MS operator. The low water-level function will reset at elevation 5934.0 following manual operation of one unit as described in the Notes and under Pumping Plant No. 4.

FOUNTAIN-WIDEFIELD RFCS

Four rate-of-flow control valves are located in the Fountain-Widefield Rate-of-Flow Control Station Valve Structure just upstream from its related Fountain Terminal Tank and two Widefield Terminal Tanks. RTU No. 8 will be located in the valve structure. These four structures constitute the Fountain-Widefield RFCS.

Except during a loss of a-c power at the valve structure (see Notes), these valves are controlled by the microprocessor in RTU No. 8 as follows:

a. To adjust the incoming flow to downstream demand at flows less than their maximum set-rates, the valves are controlled by the rise or fall of the water levels in the Fountain Terminal Tank and in either one of the two Widefield Terminal Tanks (as selected).

b. At flows equal to their maximum set-rates, the valves are controlled by their Venturi meter sections.

The water-level modulation ranges in the Fountain Terminal Tank control the operation of one 6-inch and one 8-inch controller; those in either one of the two Widefield Terminal Tanks control the operation of two 6-inch controllers. A selection feature will be provided to transfer control from the North Widefield to the South Widefield Terminal Tank or vice versa.

These two pairs of flow controllers are installed in parallel but operate in sequence. The RTU No. 8 microprocessor will be set to limit maximum flows through each rate-of-flow controller as follows:

FOUNTAIN	6-inch - Q max. = 1.04 ft^3/s	(6RFAV-1)
	8-inch - Q max. = 2.00 ft^3/s	(8RFAV-2)
WIDEFIELD	6-inch - Q max. = 1.14 ft^3/s	(6RFAV-3)
	6-inch - Q max. = 1.14 ft^3/s	(6RFAV-4)

For each rate-of-flow controller (6RFAV-1, 8RFAV-2, 6RFAV-3, 6RFAV-4) the microprocessor in the RTU will display the instantaneous flow passing through the unit locally and will transmit the flow to the MS. The instantaneous flow in cubic feet per second passing through each pair of units will be summed and each total will be indicated locally and transmitted to the MS for indication and recording. Also, the accumulated total in millions of gallons passing through each pair of units will be summed and indicated locally and at the MS.

Upon receiving a low water-level (elevation 5933.0) signal from the Widefield Regulating Tank (via the RTU), the motors of motorized butterfly valves (6BF-1, 8BF-2, 6BF-3, 6BF-4) located immediately upstream from the rate-of-flow controllers will be activated to fully close their respective valves in 60 seconds.

When the water level at the Widefield Regulating Tank has recovered to elevation 5934.0, the RTU will activate the motors of the motorized butterfly valves to fully reopen together in 60 seconds.

These valves act as an emergency device to prevent unwatering the intervening pipeline when a low water condition occurs in the Widefield Regulating Tank. However, if an emergency demand arises when the valves are closed, they can be opened individually by manual operation (at their correct time rate). For safety reasons, the control panel breaker in the valve structure should be set to the "OFF" position before manual operation is attempted.

Two ultrasonic water-level measuring devices will be provided in each of the Fountain and the two Widefield Terminal Tanks. Each water-level measuring device will operate into the RTU to provide a water-level signal for local indication, and indication and recording at the MS. The Widefield and Fountain water-level signals will also be used for modulation of their associated rate-of-flow controllers (6RFAV-1 and 8RFAV-2 or 6RFAV-3 and 6RFAV-4).

Each level signal will be limit checked by the RTU for abnormal high and low levels. Abnormal high water level (elevation 5929.5 in the Fountain Terminal Tank and elevation 5931.0 in the selected Widefield Terminal Tank) will activate an alarm at the MS. These alarm functions will reset automatically when the levels fall to elevation 5928.5 in the Fountain Terminal Tank and elevation 5930.0 in the selected Widefield Terminal Tank. Abnormal low water level (elevation 5891.0 in the Fountain Terminal Tank and elevation 5898.0 in the selected Widefield Terminal Tank) will activate an alarm at the MS. These alarm functions will automatically reset when the levels rise to elevation 5892.0 in the Fountain Terminal Tank and elevation 5899.0 in the selected Widefield Terminal Tank.

Figure 2.—Schematic diagram for operation of Fountain Valley Conduit and Lateral.

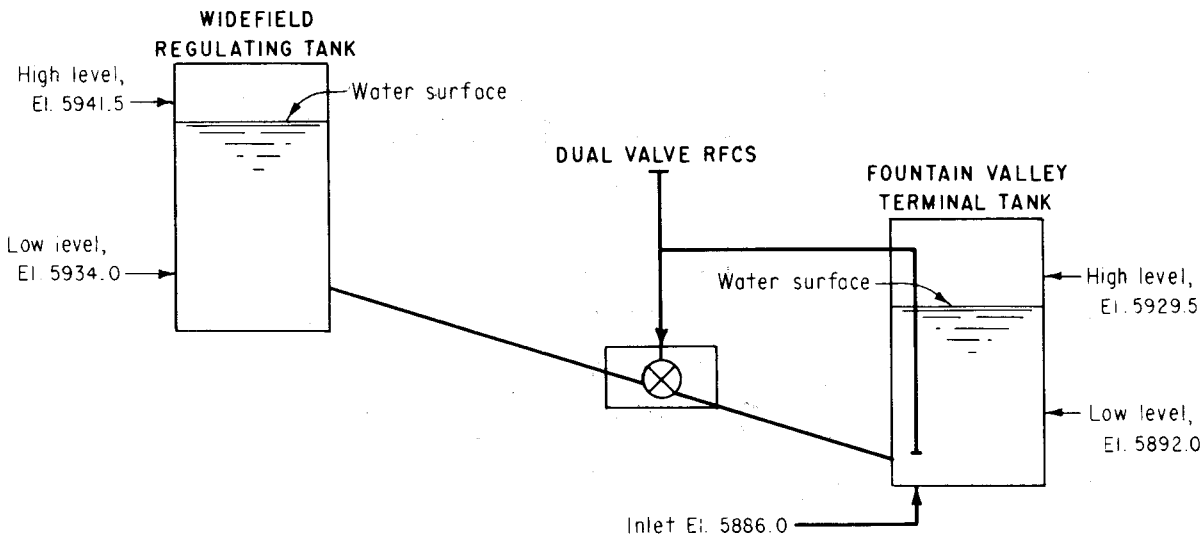


Figure 3.—Simplified diagram of the tank level regulating system.

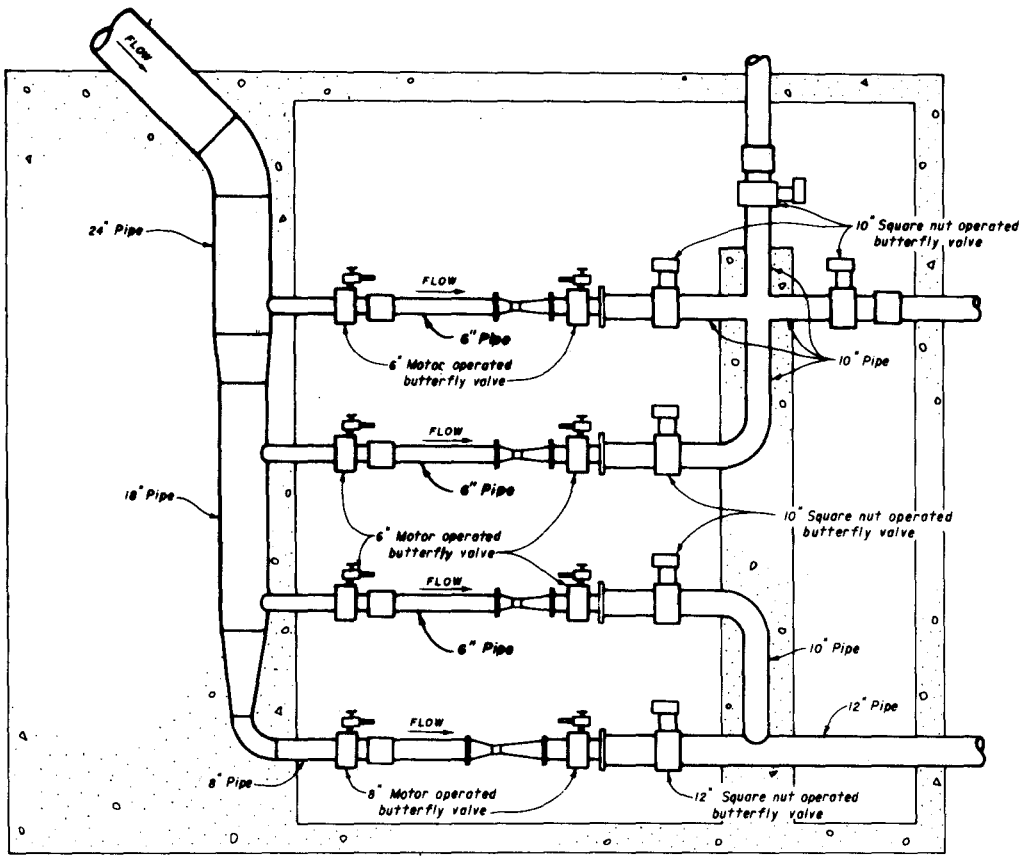


Figure 4.—Modeled valve manifold system.

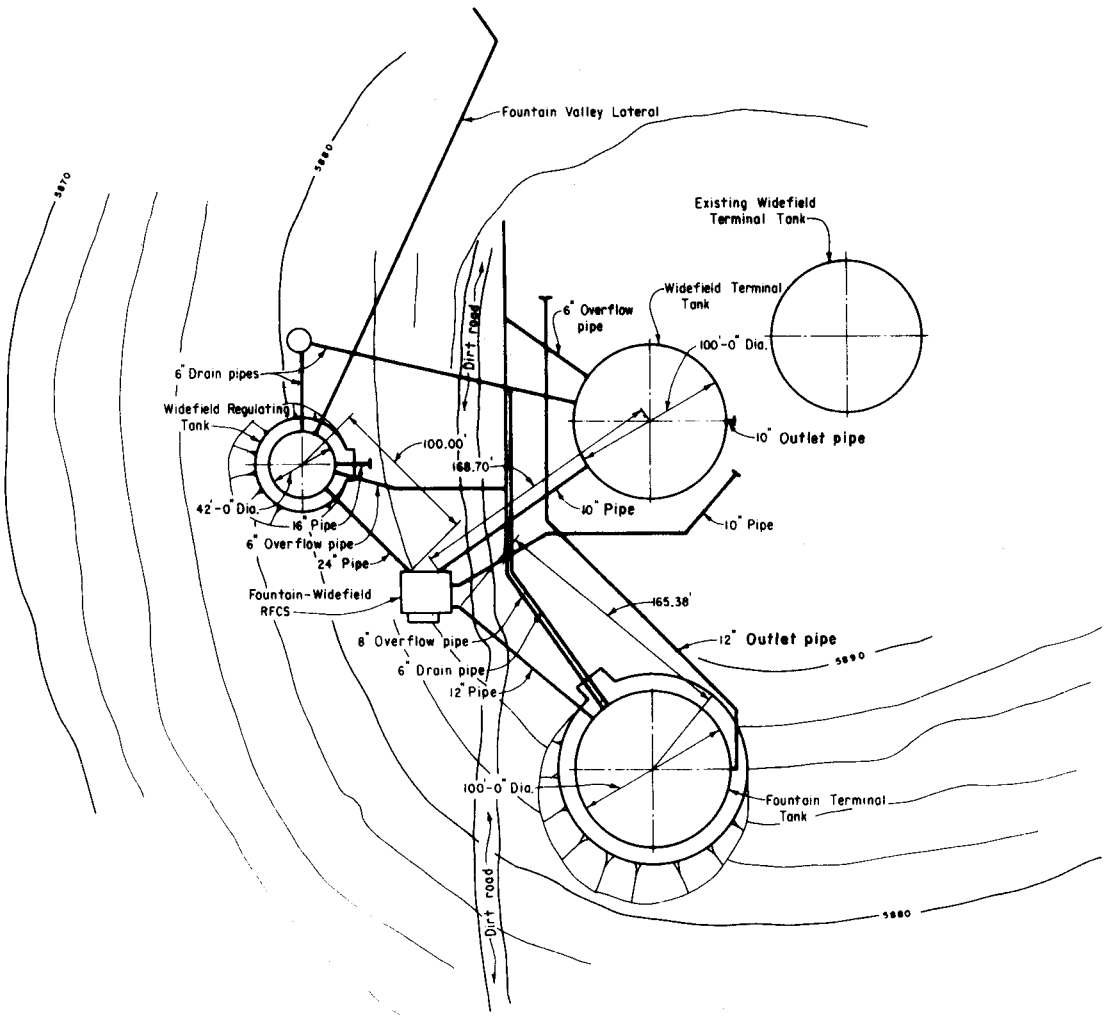


Figure 5.—Site layout.

FOUNTAIN TERMINAL TANK

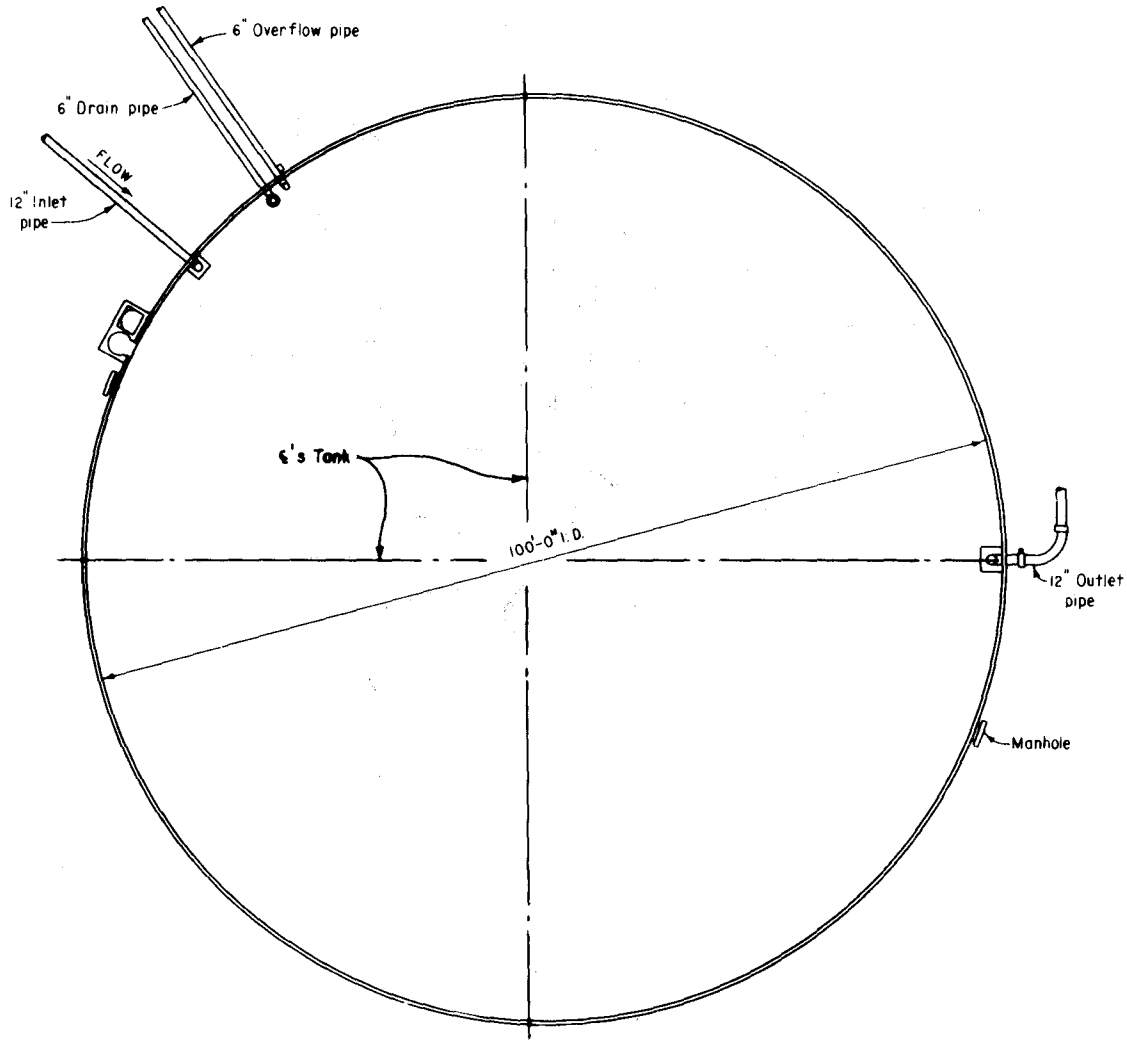


Figure 6.—Details of the Fountain terminal tank.

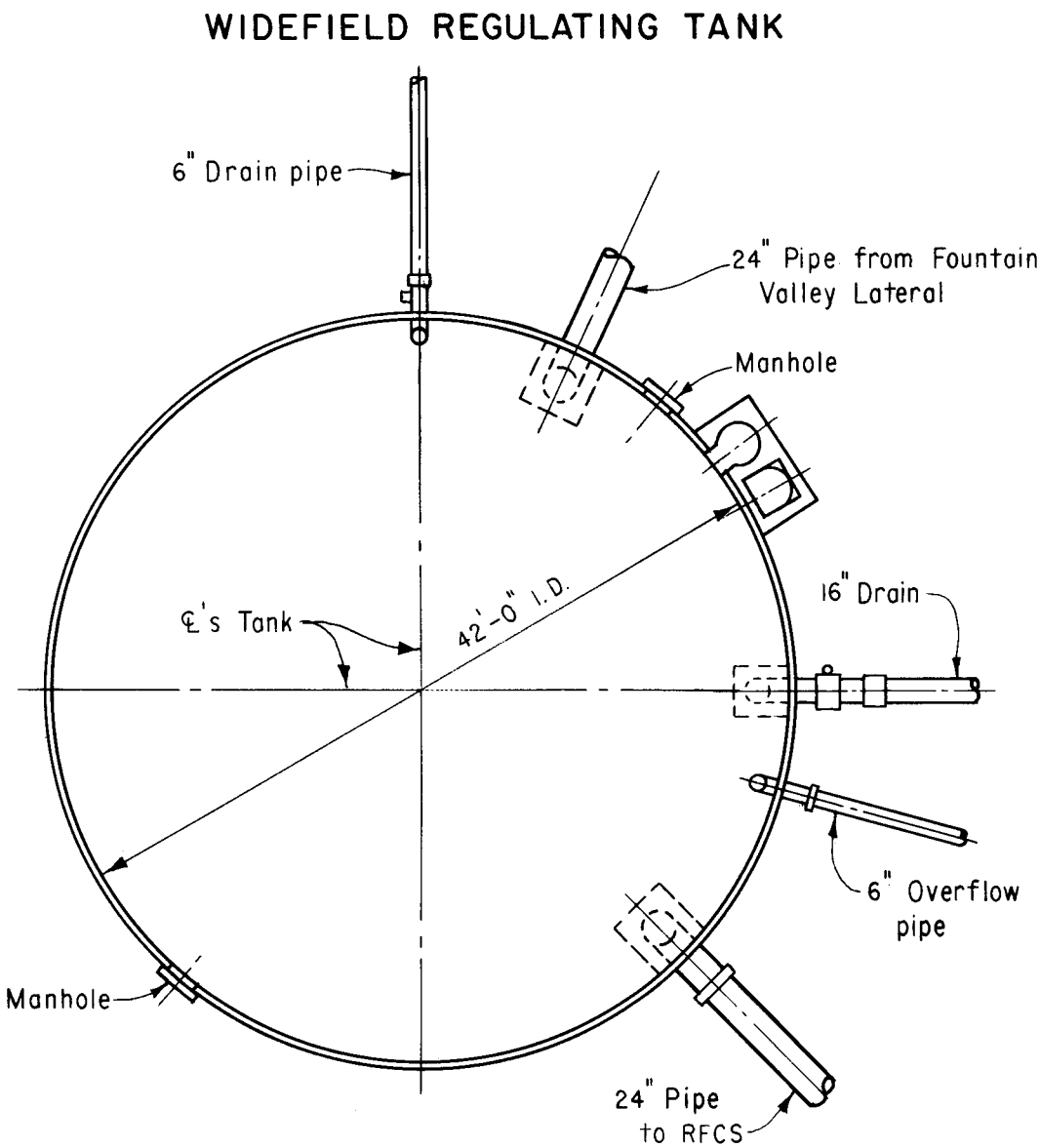
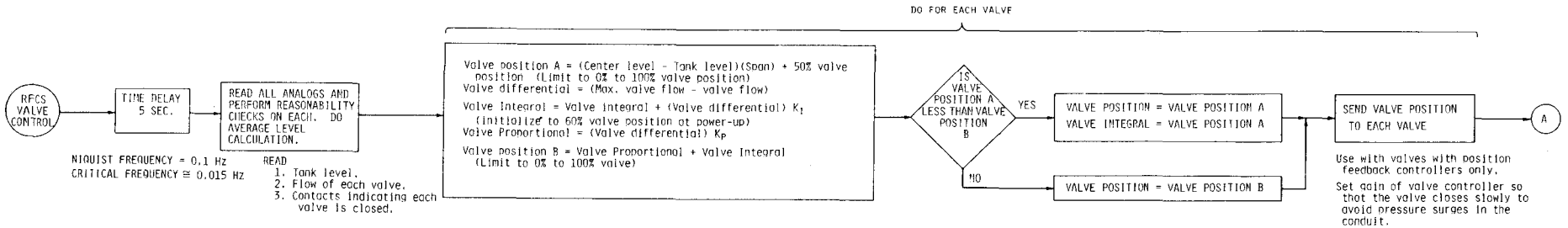
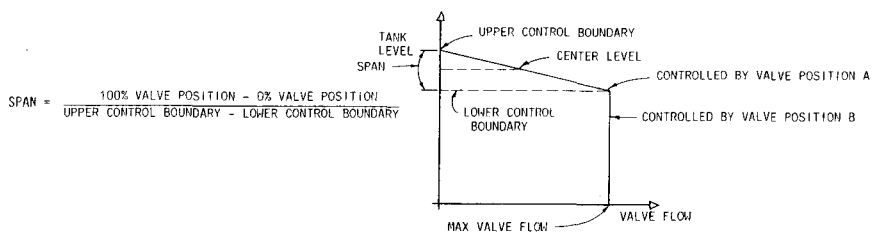


Figure 7.—Details of the Widefield regulating tank.

TYPICAL VALVE CONTROL ROUTINES FOR A MICROPROCESSOR-BASED CONTROL SYSTEM AT A RFCS





$$\text{SPAN} = \frac{\text{100\% VALVE POSITION} - \text{0\% VALVE POSITION}}{\text{UPPER CONTROL BOUNDARY} - \text{LOWER CONTROL BOUNDARY}}$$

Time to fill volume between lower control boundary and upper control boundary at max. valve flow must be at least 3 times the time required to close the valve from 100% to 0% valve position.

ERROR FLAG MESSAGES

No. 1 - at Tank No.__ level is above range but all valves are indicated as closed.

No. 2 - at Tank No.___ level is below range but all valves are indicated as at maximum set flow.

No. 3 - at Tank No.___ analog input for ___ is reading outside of reasonability limits. Is override acceptable?

No. 4 - at Tank No.___ analog input for ____ has an excessive rate of change. Is override acceptable?

No. 5 - at Tank No.__ both level readings are outside of reasonability limits. Should last valid reading be used?

No. 6 - at Tank No.___ difference between level readings is out of limits. Highest will be used for control.

No. 7 - at Tank No.___ emergency high level. Upstream Butterfly valves closure initiated.

No. 8 - at Tank No. _ emergency low level.

No. 9 - at Tank No. _ Valves do not indicate complete closure with level above control range.

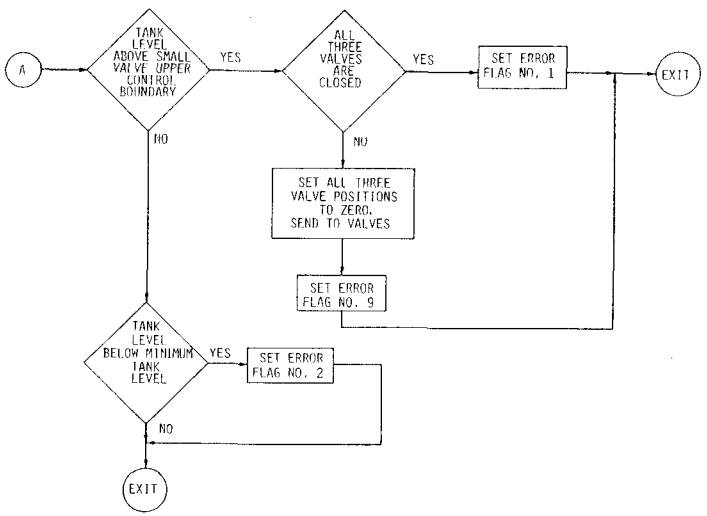
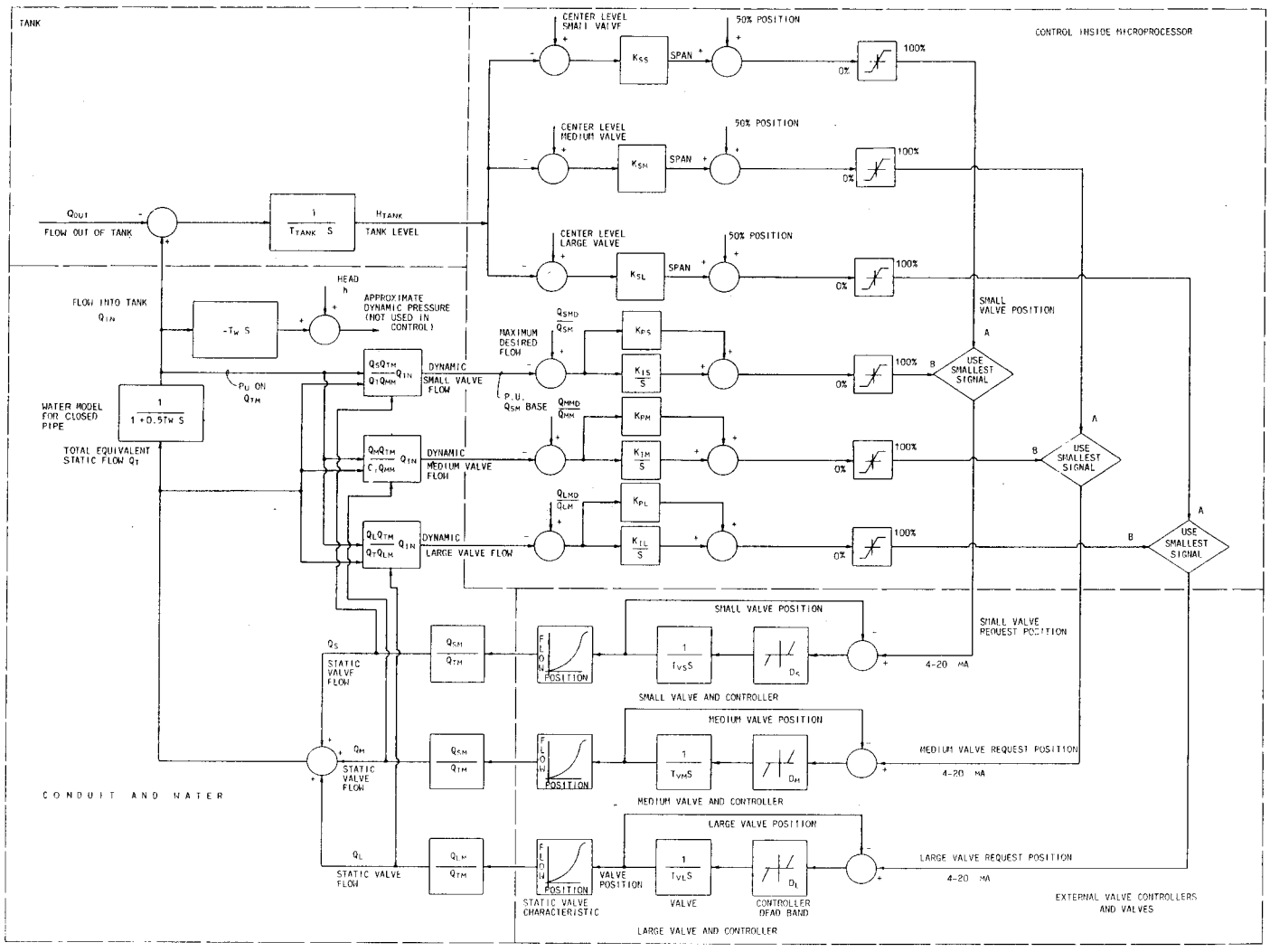


Figure 8.—Valve control flow diagram.

TYPICAL VALVE CONTROL BLOCK DIAGRAMS FOR A MICROPROCESSOR-BASED CONTROL SYSTEM AT A RFCS



T_{TANK} = time in seconds to fill the empty tank to overflow wier with no flow out and total desired maximum flow in.

$T_W = \frac{lv}{gh}$ where l = length of conduit from last regulating tank
v = velocity of water in conduit which is flow divided by cross sectional area of conduit.
h = head of system from last regulating tank.
g = acceleration of gravity

Note: T_W changes with flow.

Q_{TM} = Sum of Q_{SM}, Q_{MM} and Q_{LM}, the total desired maximum flow.

Q_{SM} = Maximum flow for small valve. cfs.

Q_{MM} = Maximum flow for medium valve. cfs.

Q_{LM} = Maximum flow for large valve. cfs.

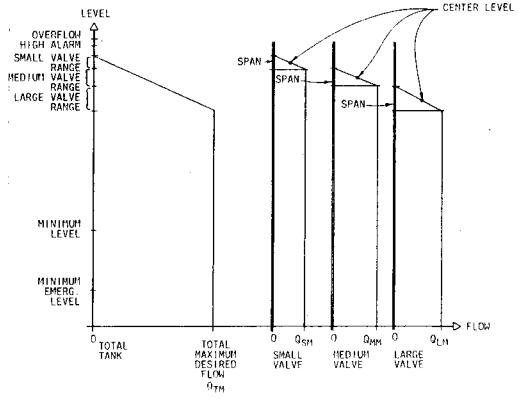
T_{VS} = Time for valve to close from full open when closing at maximum speed - small valve.

T_{VM} = Time for valve to close - medium valve.

T_{VL} = Time for valve to close - large valve.

Q_{SMD}, Q_{MMD}, Q_{LMD} = Desired flow in small, medium and large valve

TANK FLOW AND LEVEL CHART



$$\left.\begin{matrix} K_{SS} \\ \text{OR} \\ K_{SM} \\ \text{OR} \\ K_{SL} \end{matrix}\right\} = \frac{\text{0\% - 100\% valve position}}{\text{Upper range level - Lower range level}}$$

Figure 9.—Valve control block diagrams.

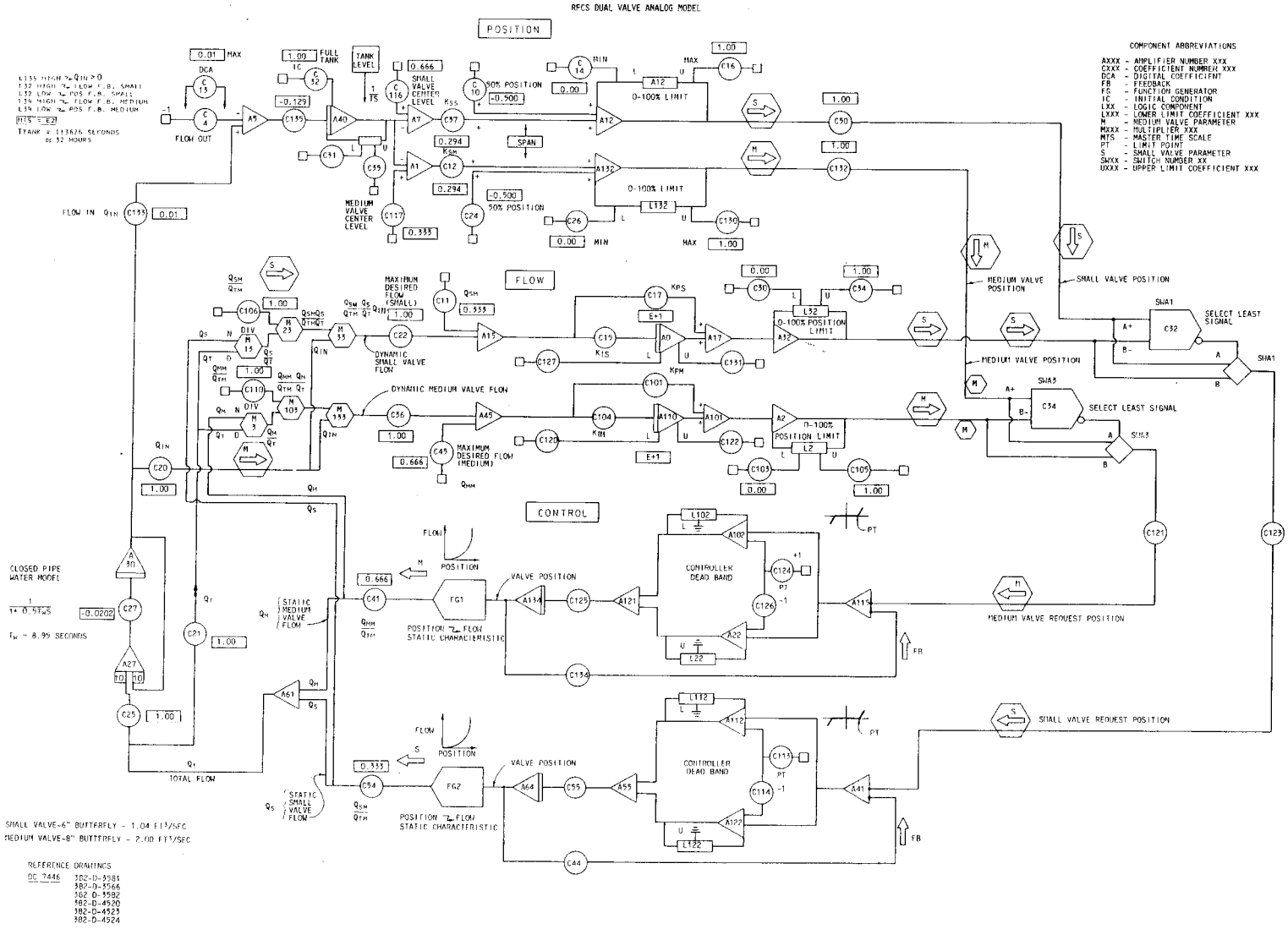


Figure 10. – RFCS dual valve analog model.

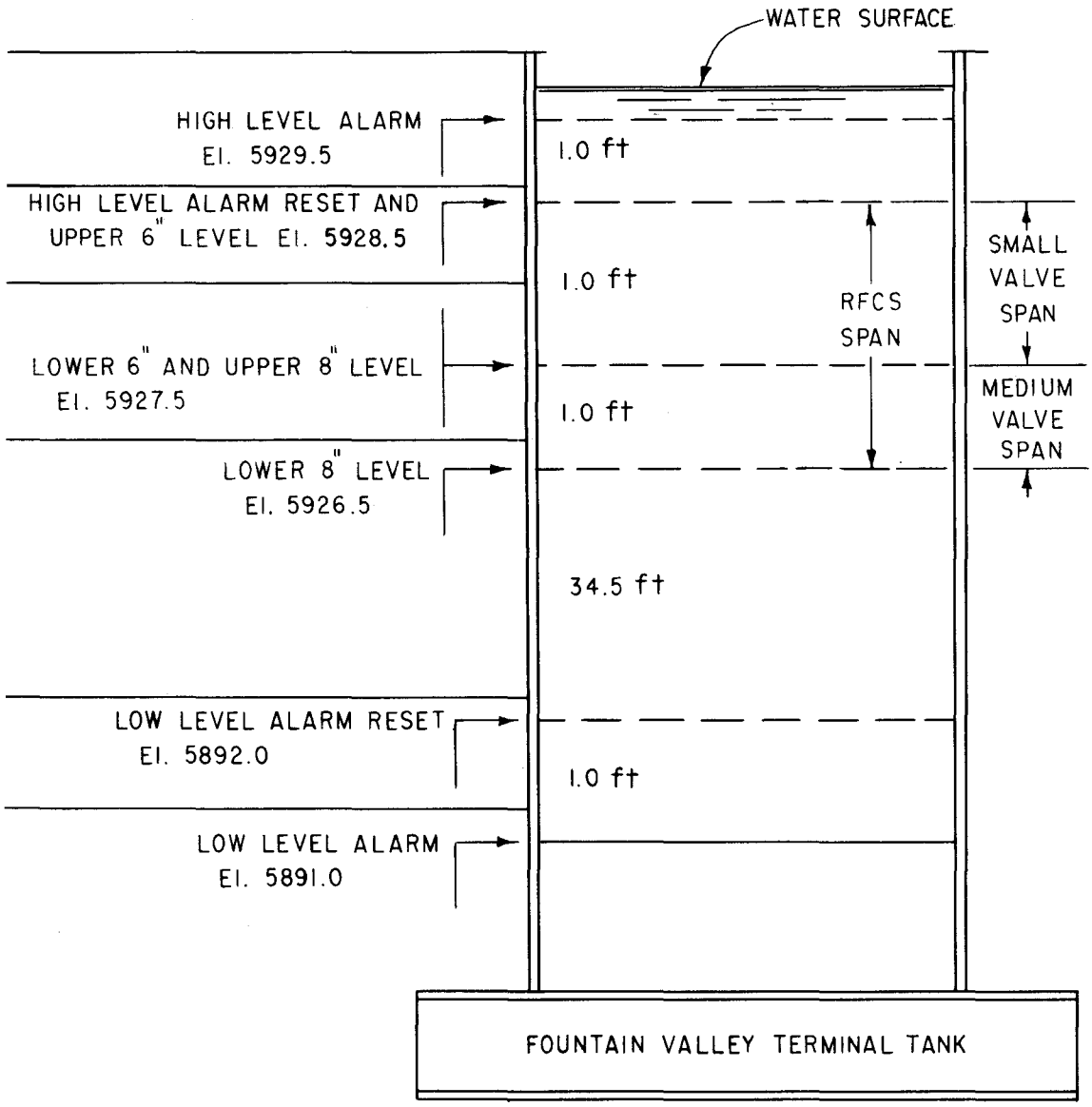


Figure 11.—Valve control span and alarm levels.

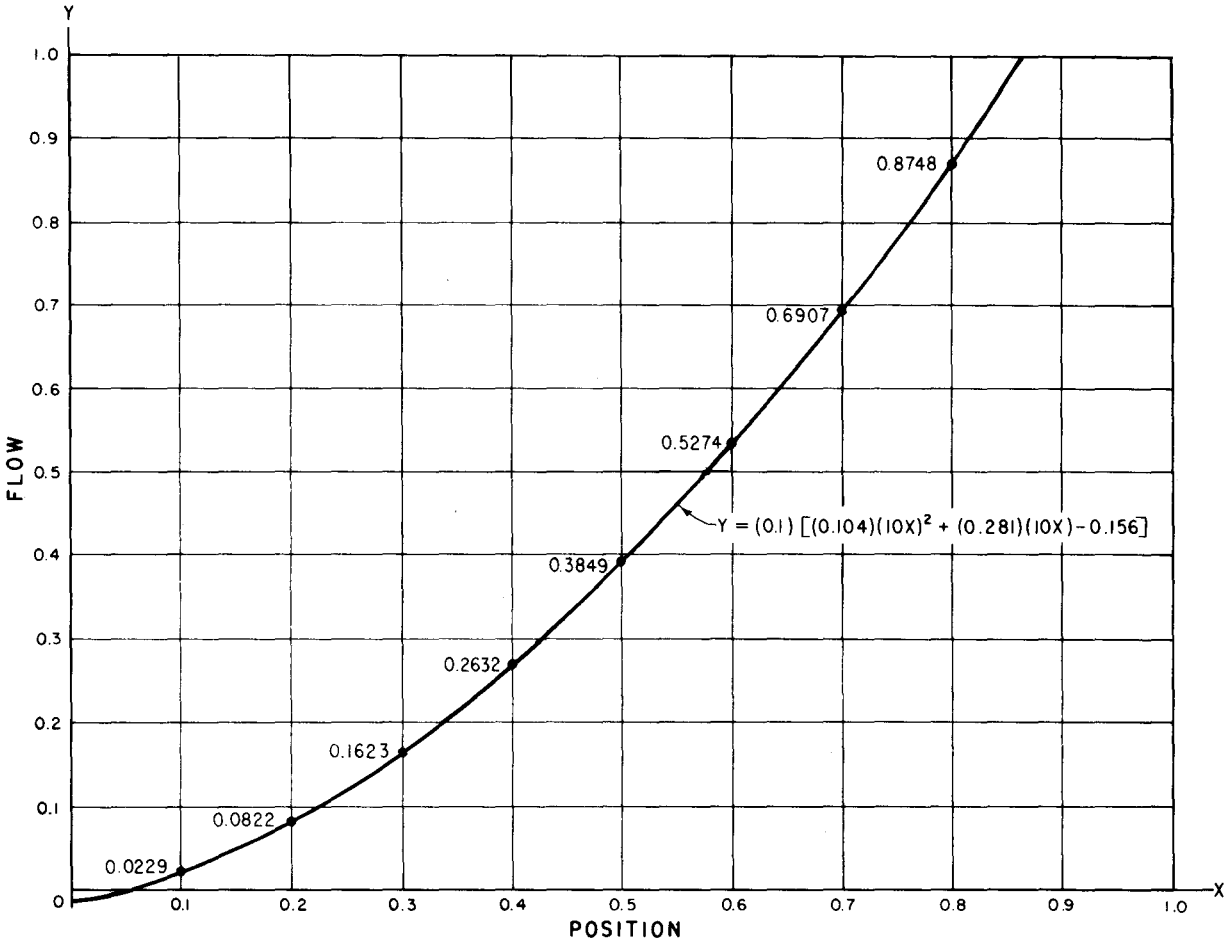


Figure 12.—Position-to-flow transfer.

APPENDIXES

ABBREVIATIONS FOR APPENDIXES A AND B
(found on figures A1, A2, A3, and A4)

C_s = Chart speed (mm/s)

E = Integrator rate

E = 10^1 Reference integrator rate

$E2$ = 1 (10^2) Integrator rate

FB = Feedback

$FTNVLY$ = Fountain Valley

I_o = Integrator zero

I_{110} = Integrator 110

IND = Indicated

K_i = Integral control constant

K_p = Proportional control constant

MTS = Master integrator time scale

Q_{in} = Flow into tank

Q_{out} = Flow out of tank

APPENDIX A

MODEL TEST DATA

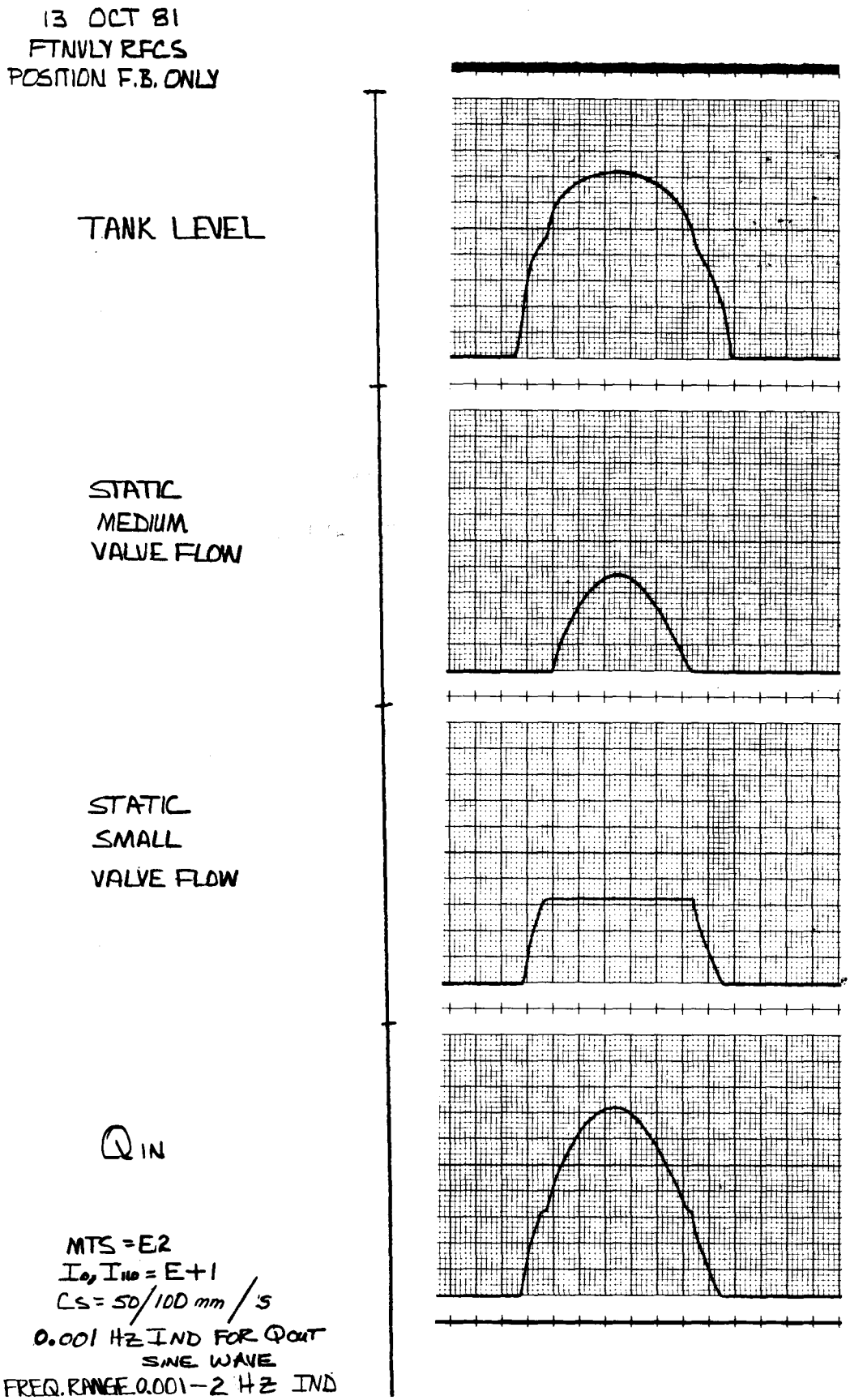


Figure A1.—System frequency response — graphical data (1 of 3).

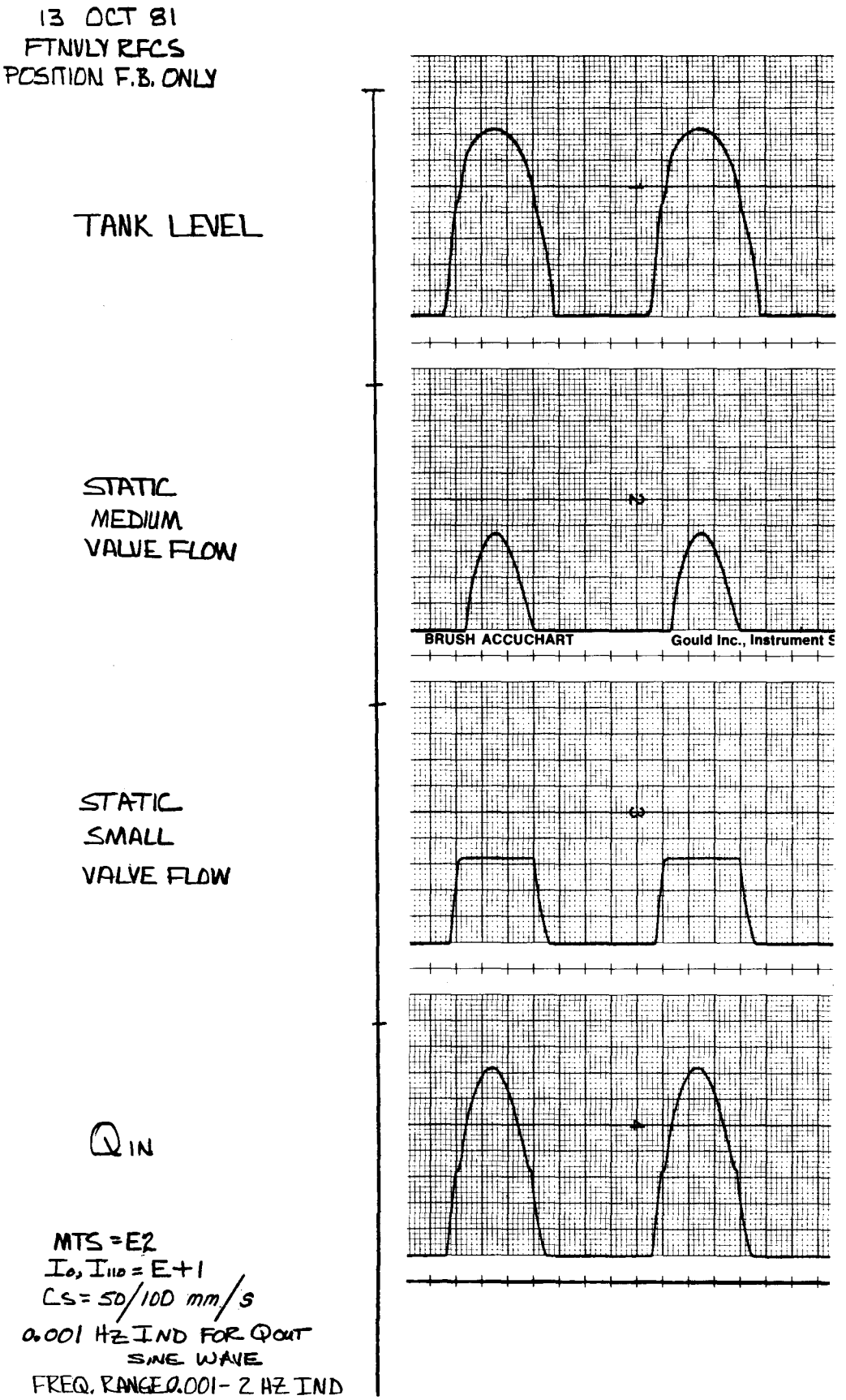


Figure A1.—System frequency response — graphical data (2 of 3).

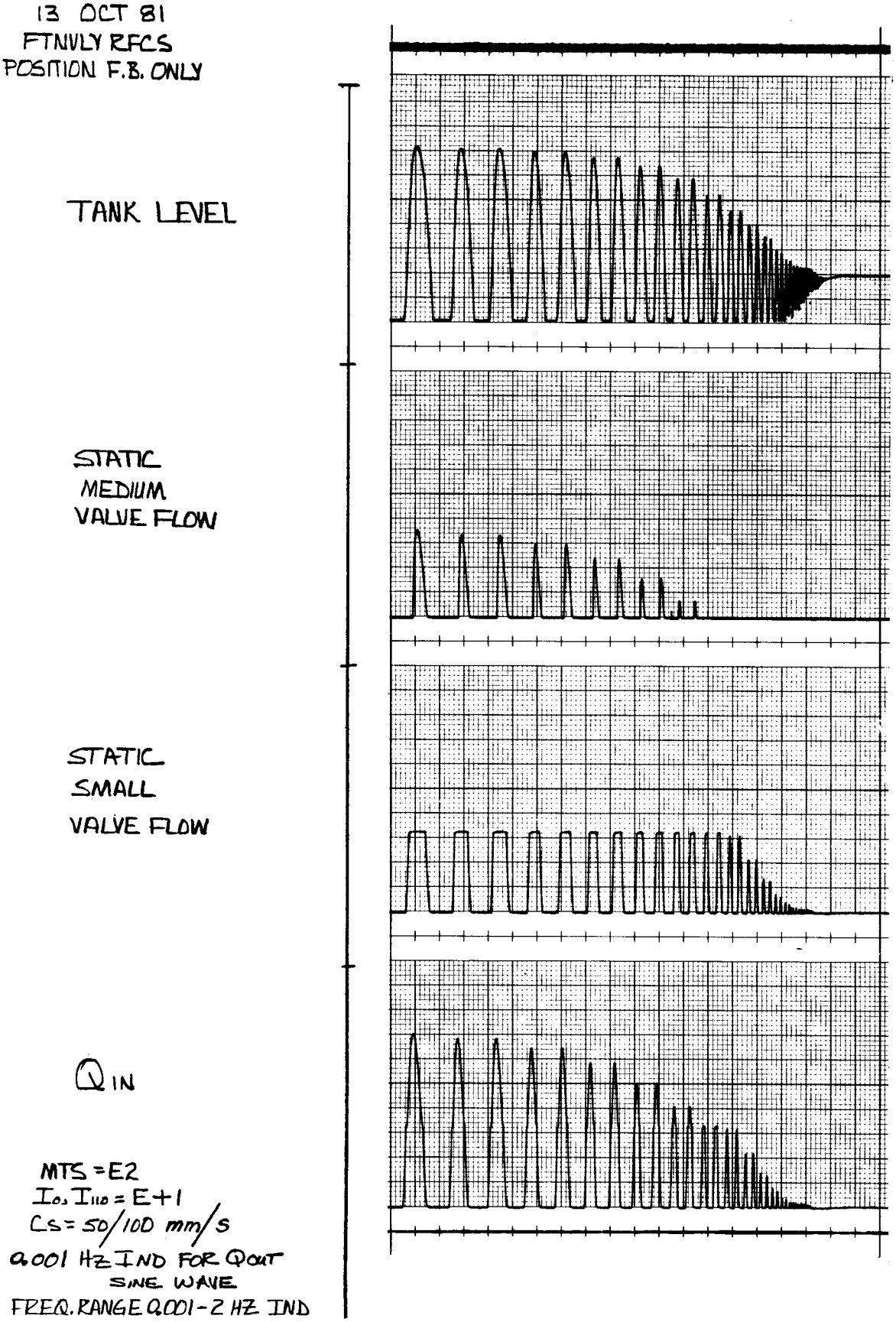


Figure A1.—System frequency response — graphical data (3 of 3).

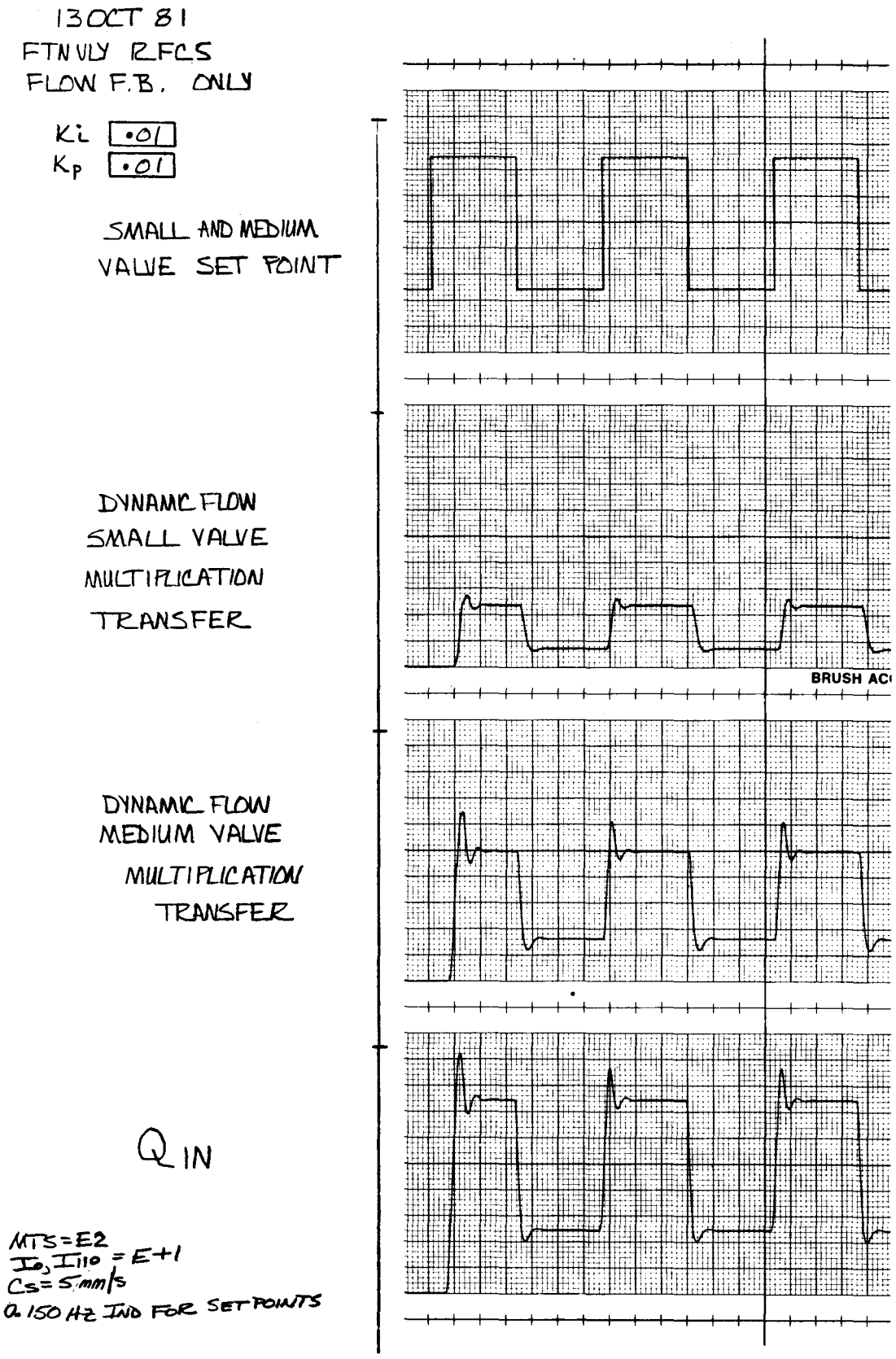


Figure A2.—K_p Range step response — graphical data (1 of 11).

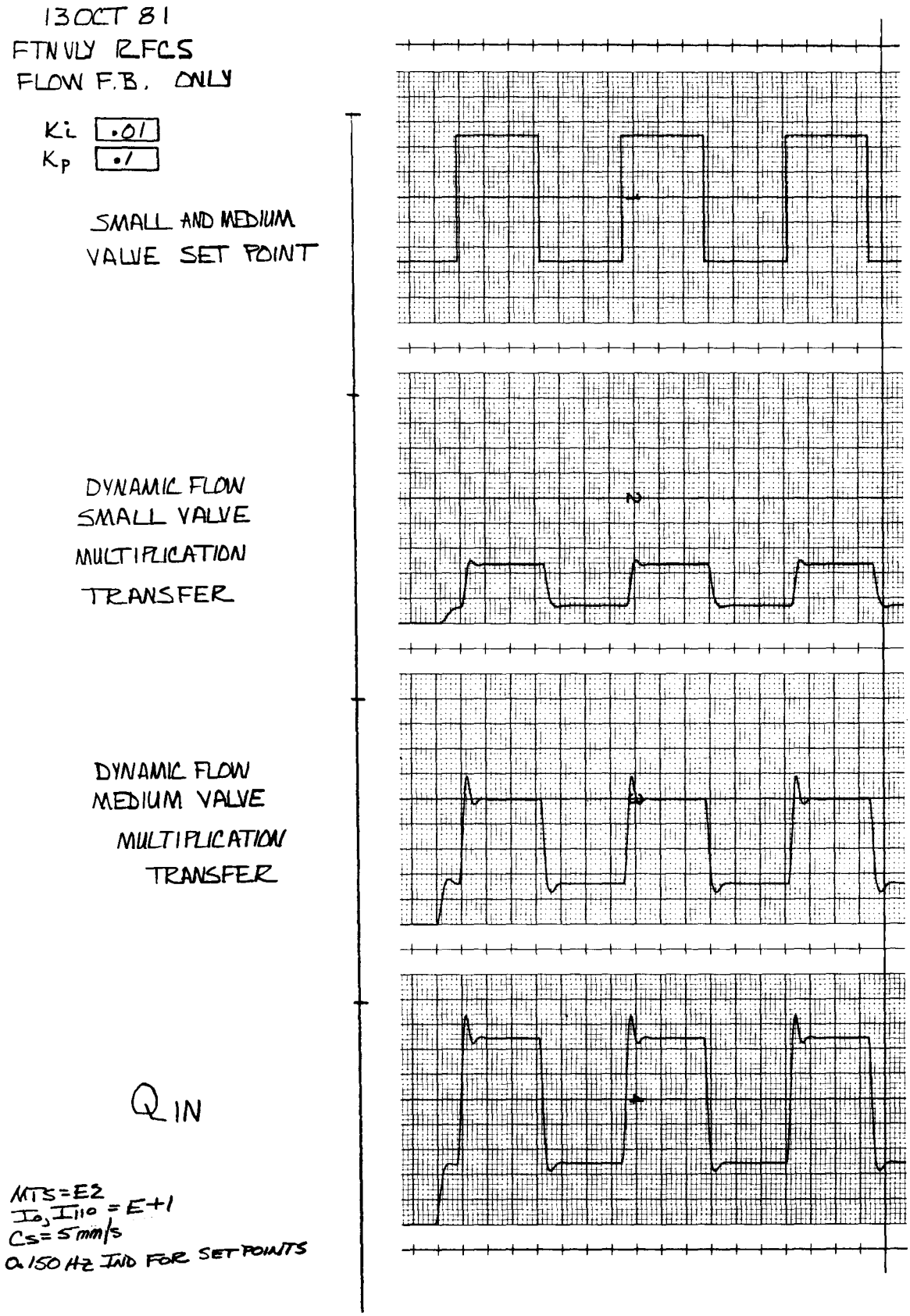


Figure A2.—K_p Range step response — graphical data (2 of 11).

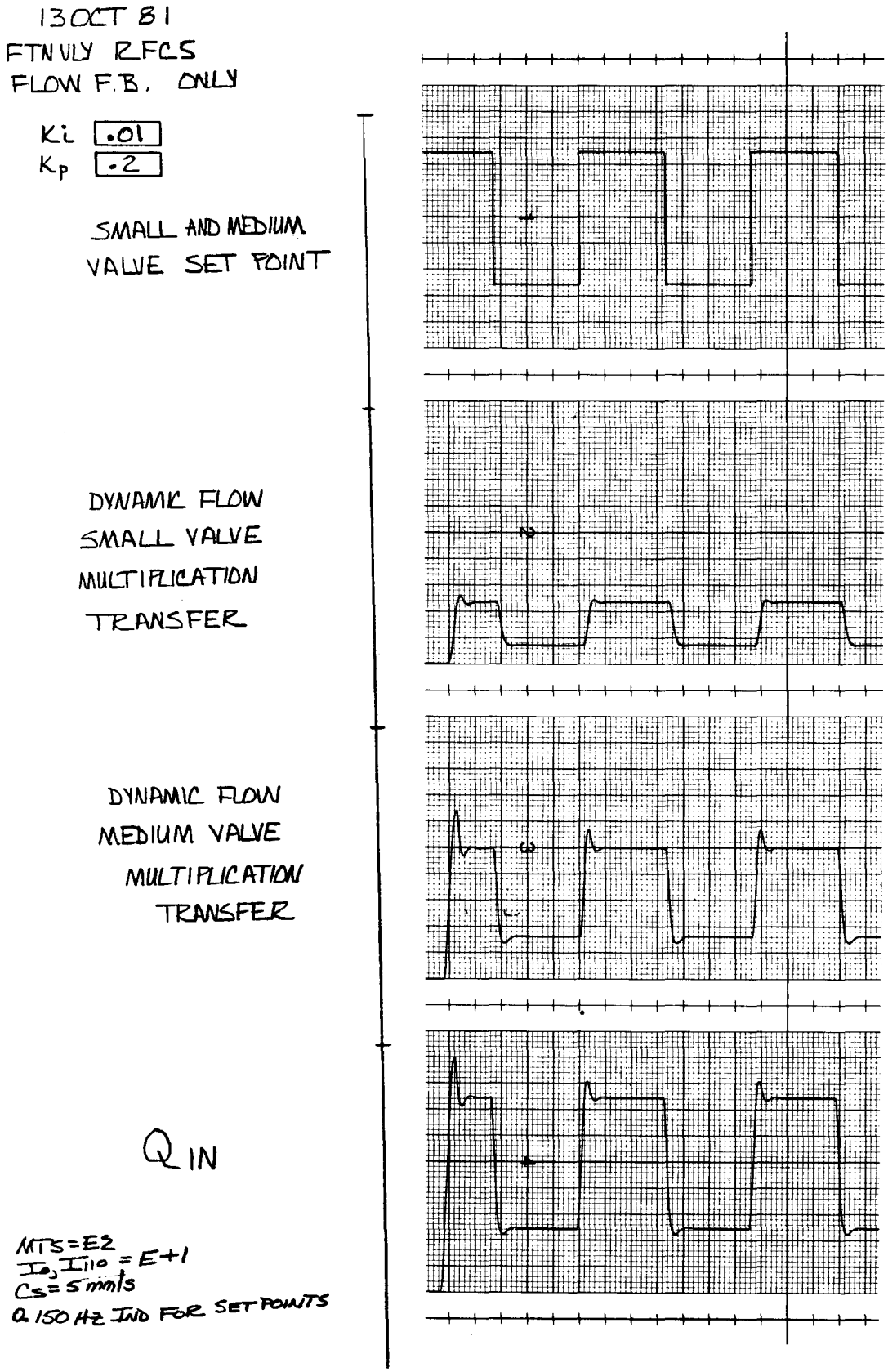


Figure A2.—K_p Range step response — graphical data (3 of 11).

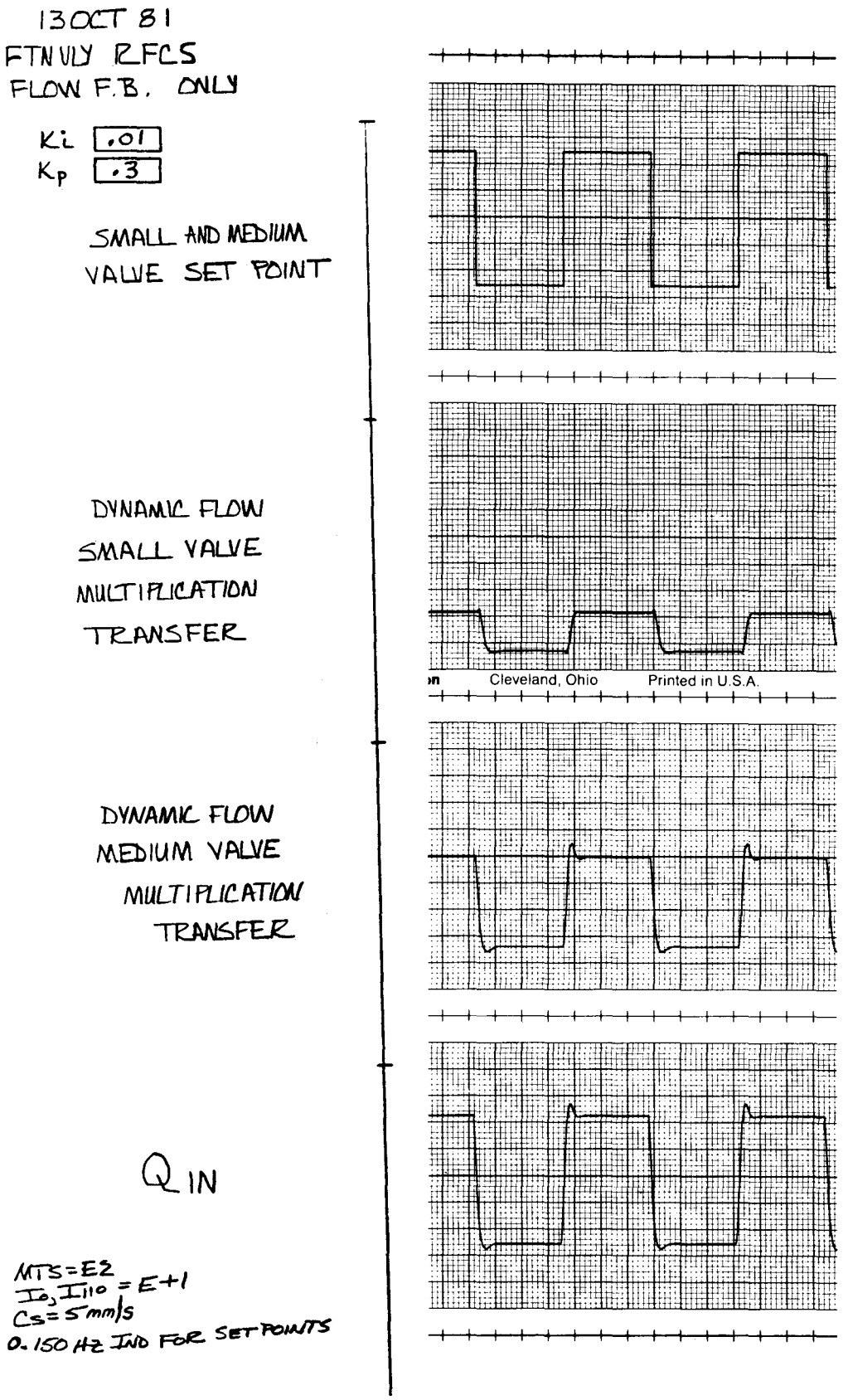


Figure A2.—K_p Range step response — graphical data (4 of 11).

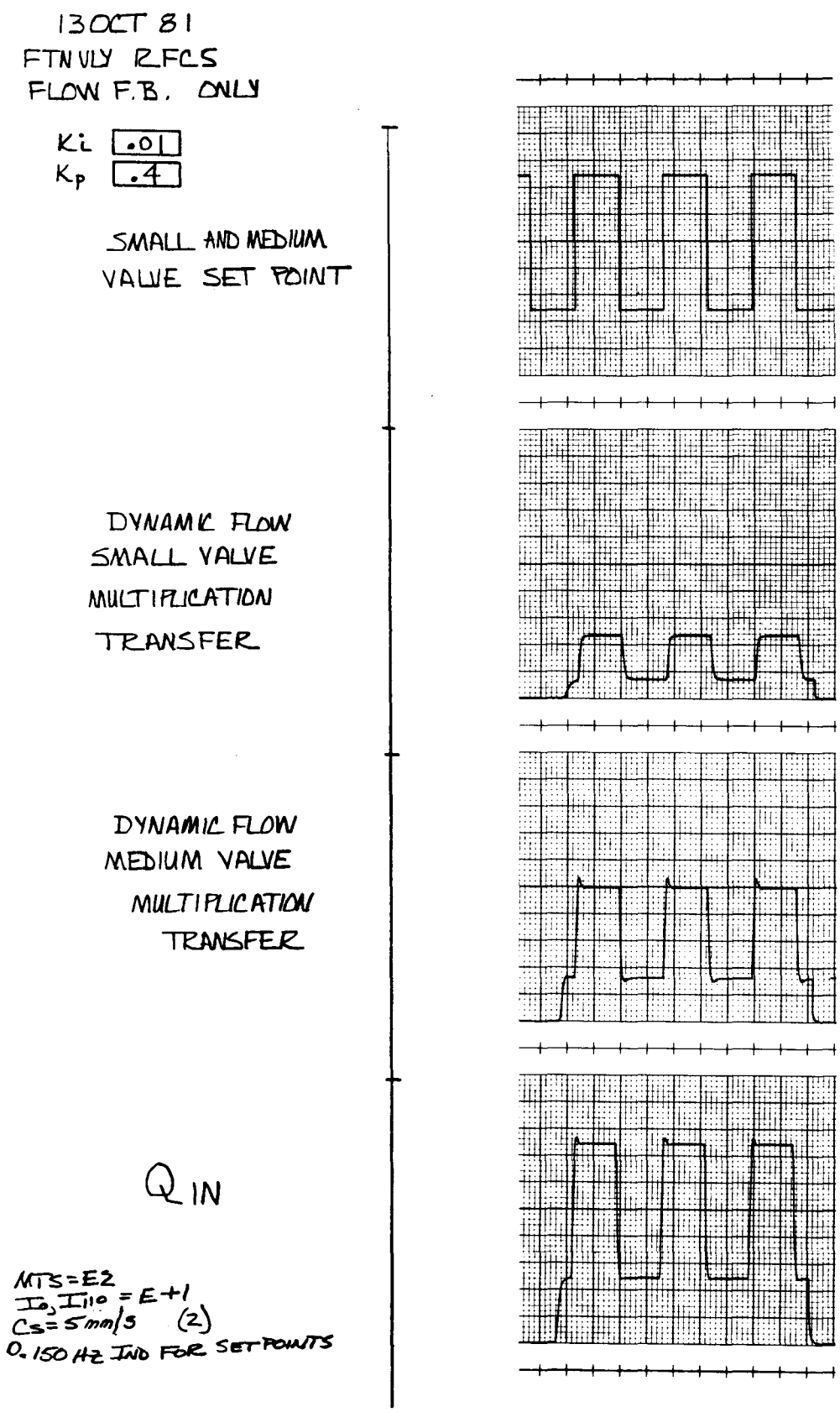


Figure A2.—K_p Range step response — graphical data (5 of 11).

13 OCT 81
FTNVLY RFCS
FLOW F.B. ONLY

K_i .01
K_p .5

SMALL AND MEDIUM
VALVE SET POINT

DYNAMIC FLOW
SMALL VALVE
MULTIPLICATION
TRANSFER

DYNAMIC FLOW
MEDIUM VALVE
MULTIPLICATION
TRANSFER

Q IN

MTS = E2
I_o, I_{110} = E+1
C_s = 5mm/s
0.150 Hz IND FOR SET POINTS

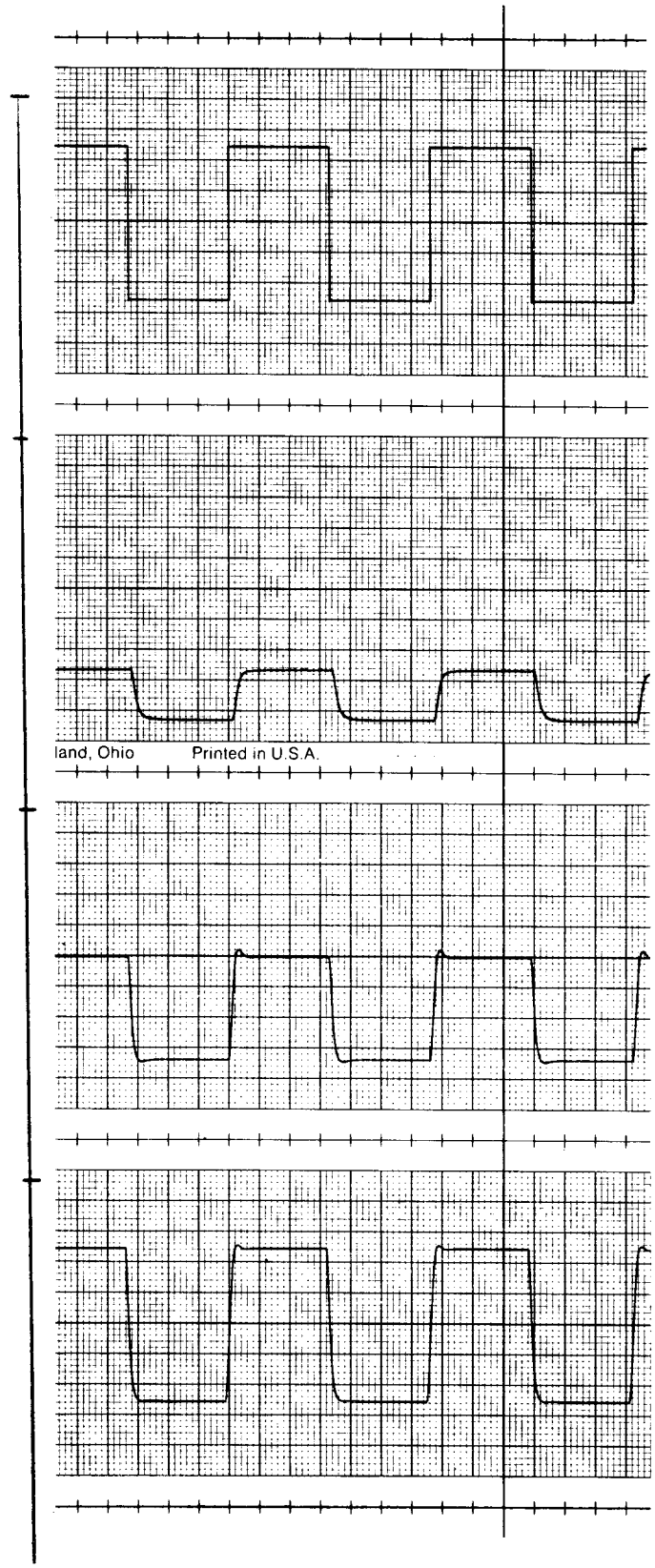


Figure A2.—K_p Range step response — graphical data (6 of 11).

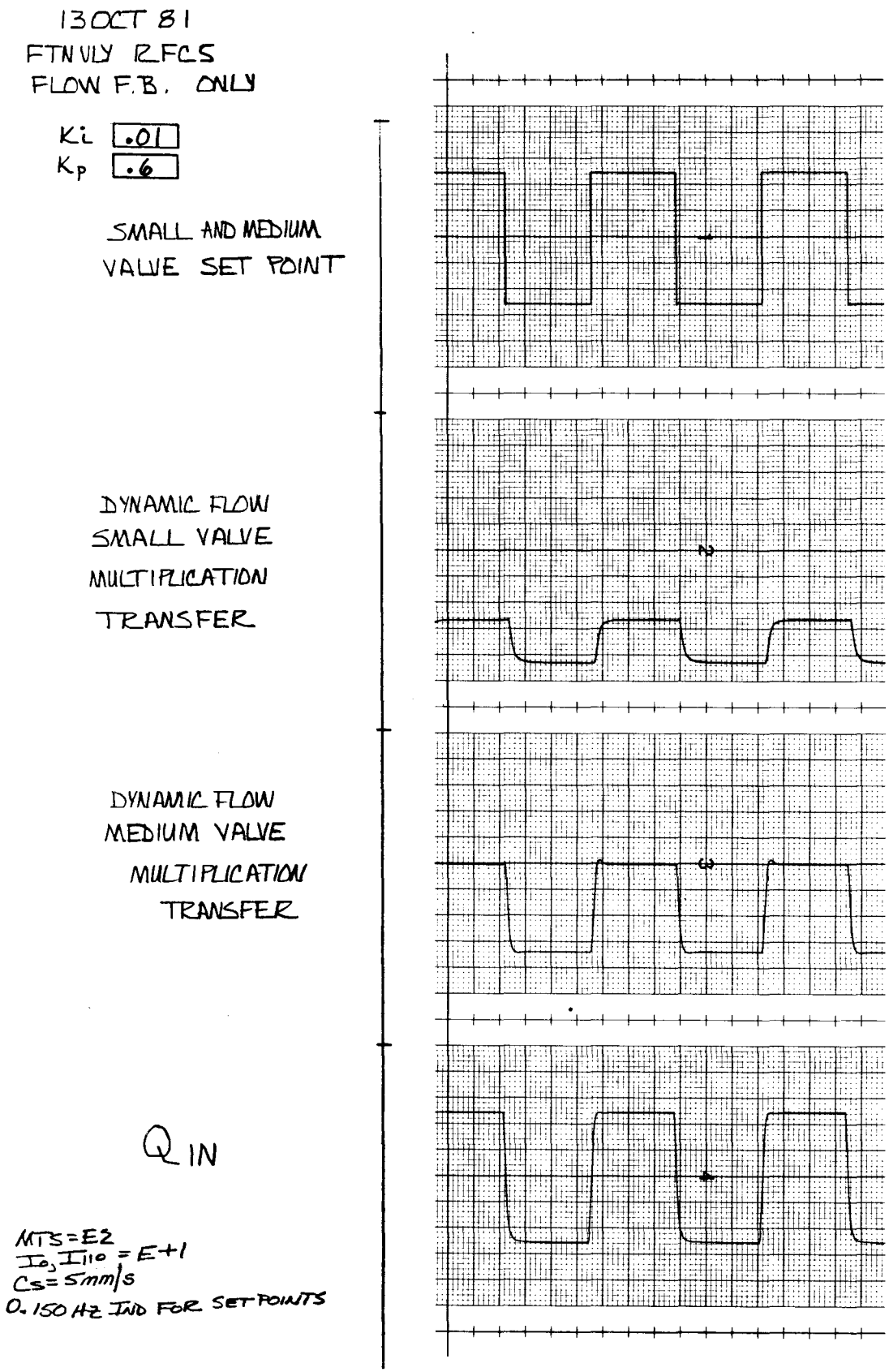


Figure A2. — K_p Range step response — graphical data (7 of 11).

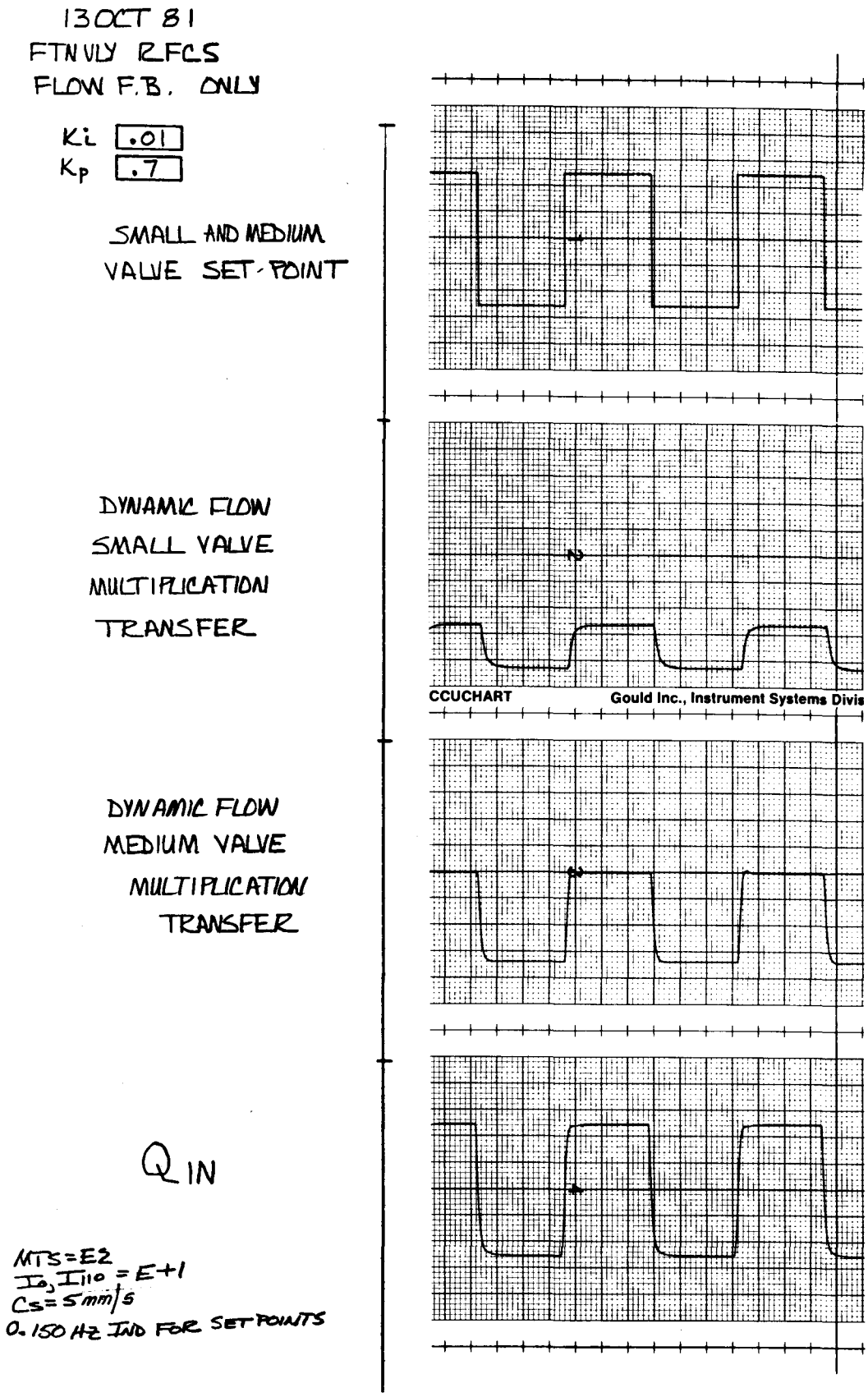


Figure A2.—K_p Range step response — graphical data (8 of 11).

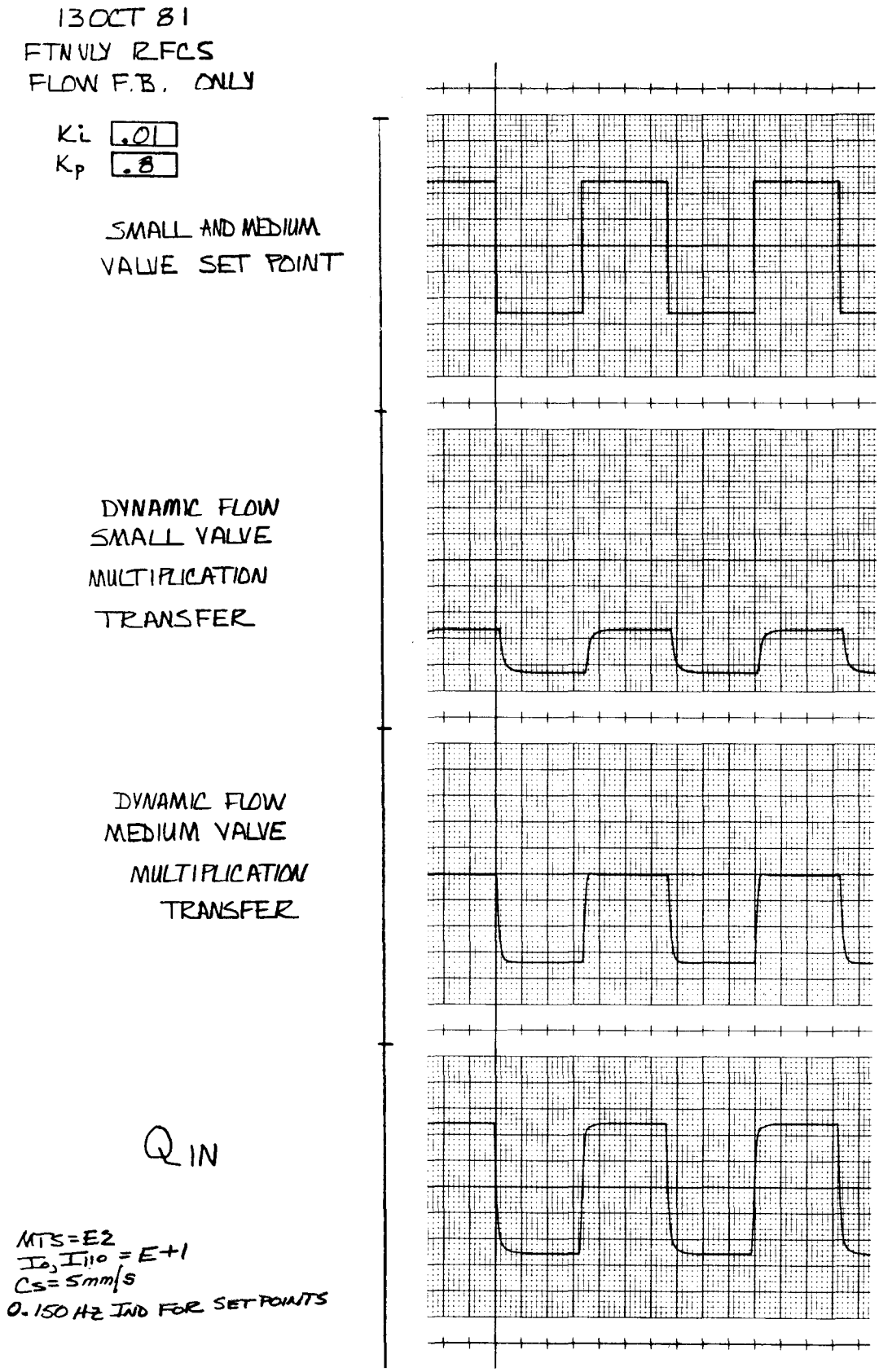


Figure A2.—K_p Range step response — graphical data (9 of 11).

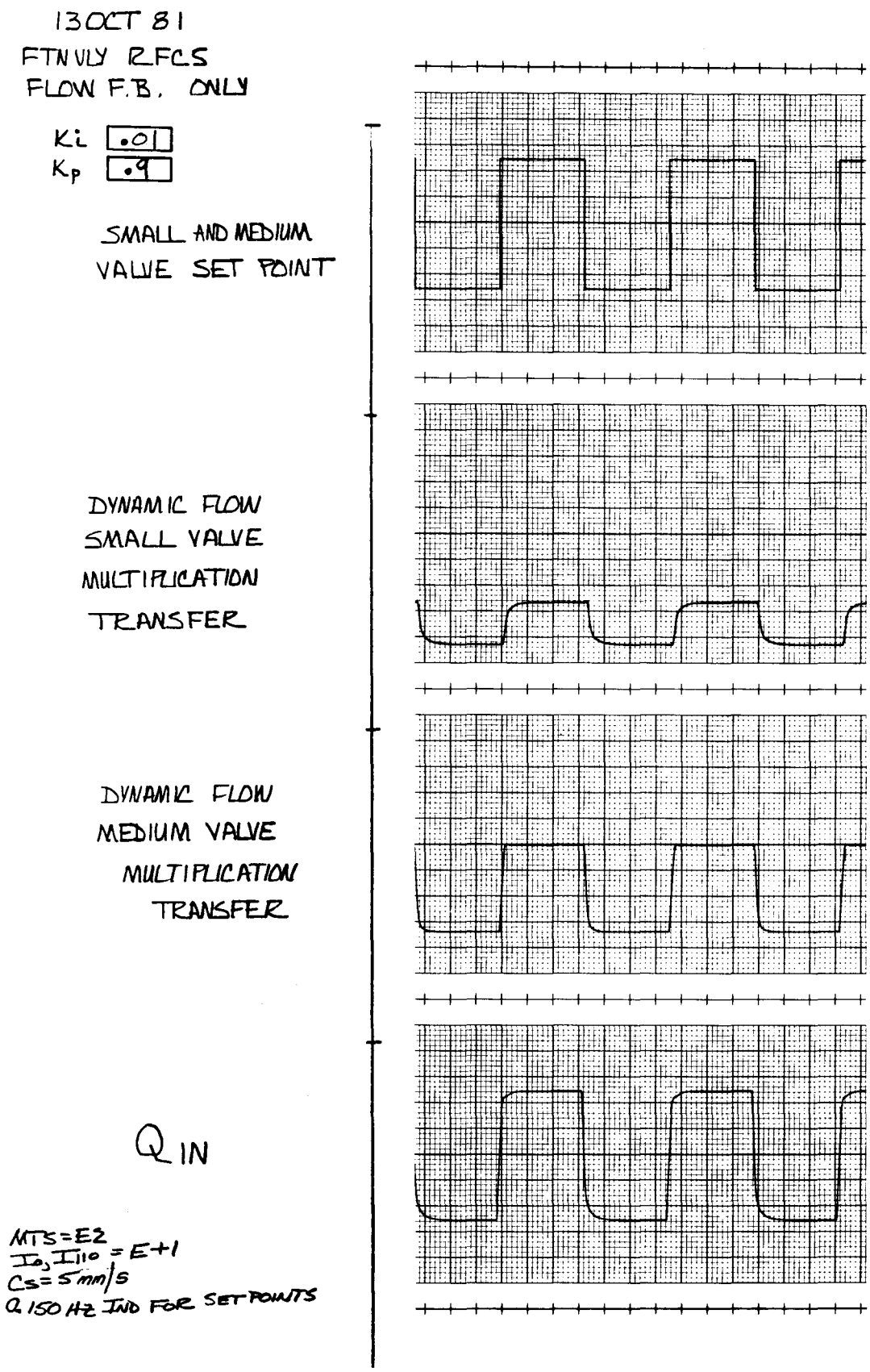


Figure A2.—K_p Range step response — graphical data (10 of 11).

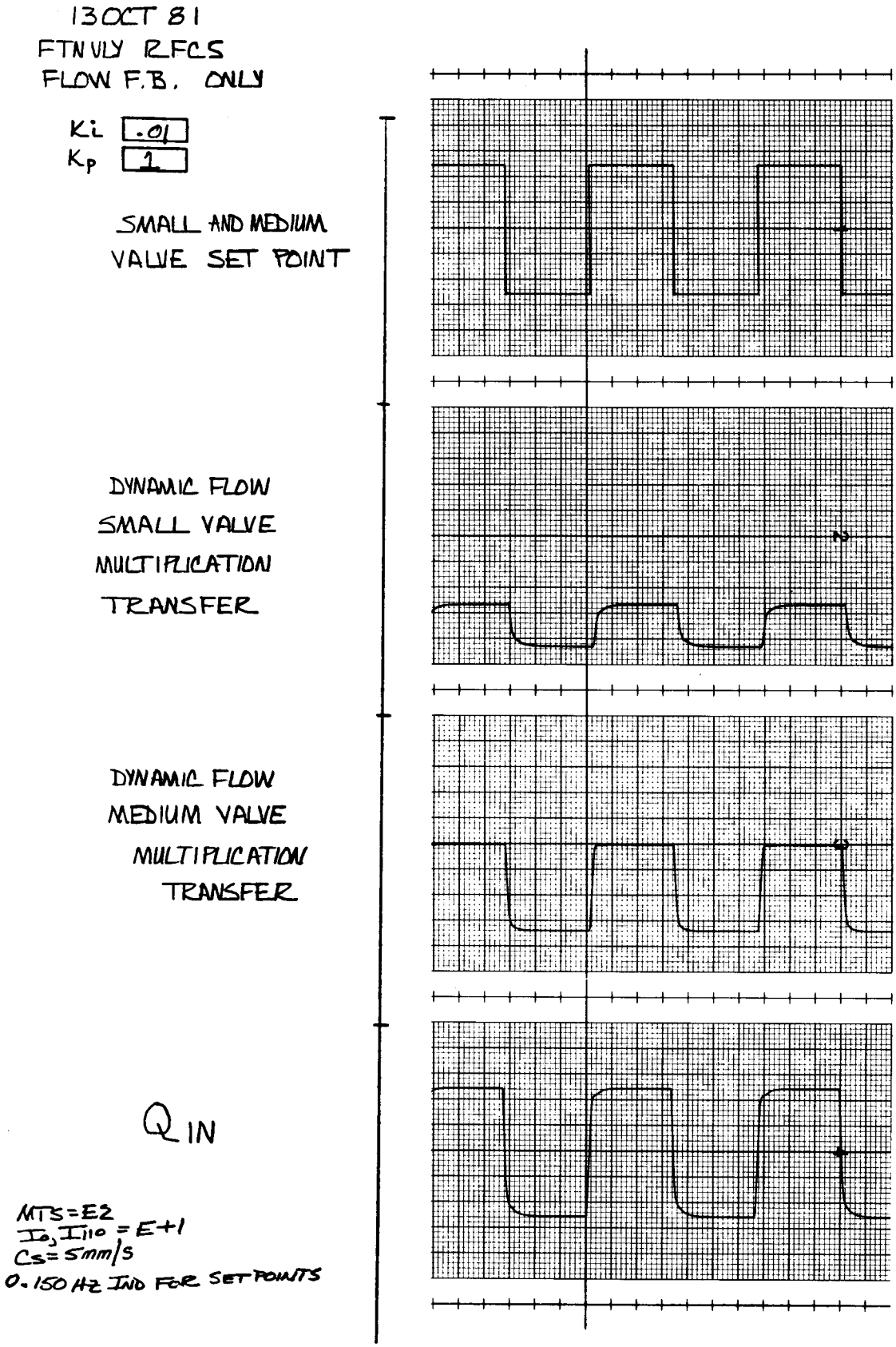


Figure A2.—K_p Range step response — graphical data (11 of 11).

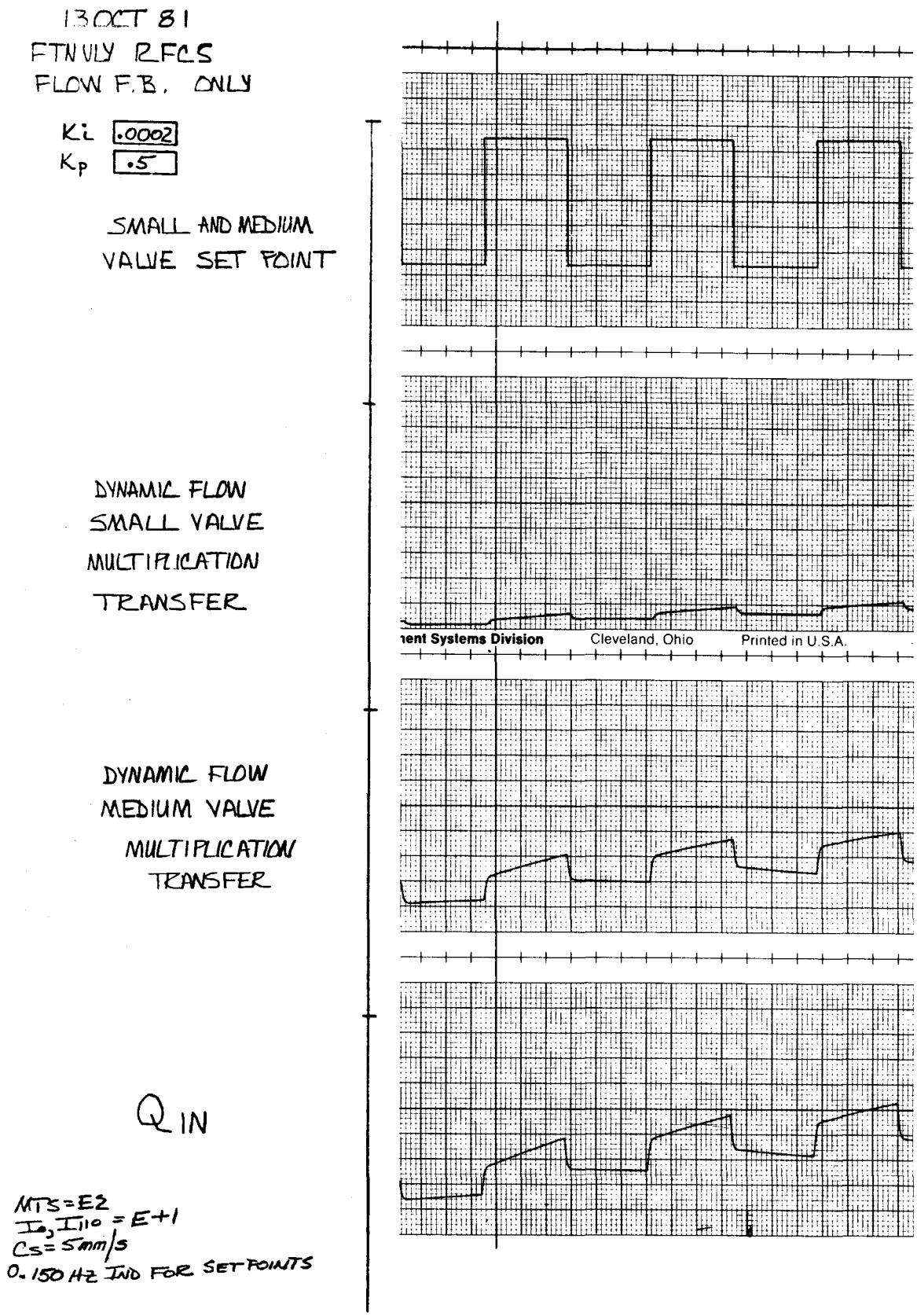


Figure A3.—K_i Range step response — graphical data (1 of 7).

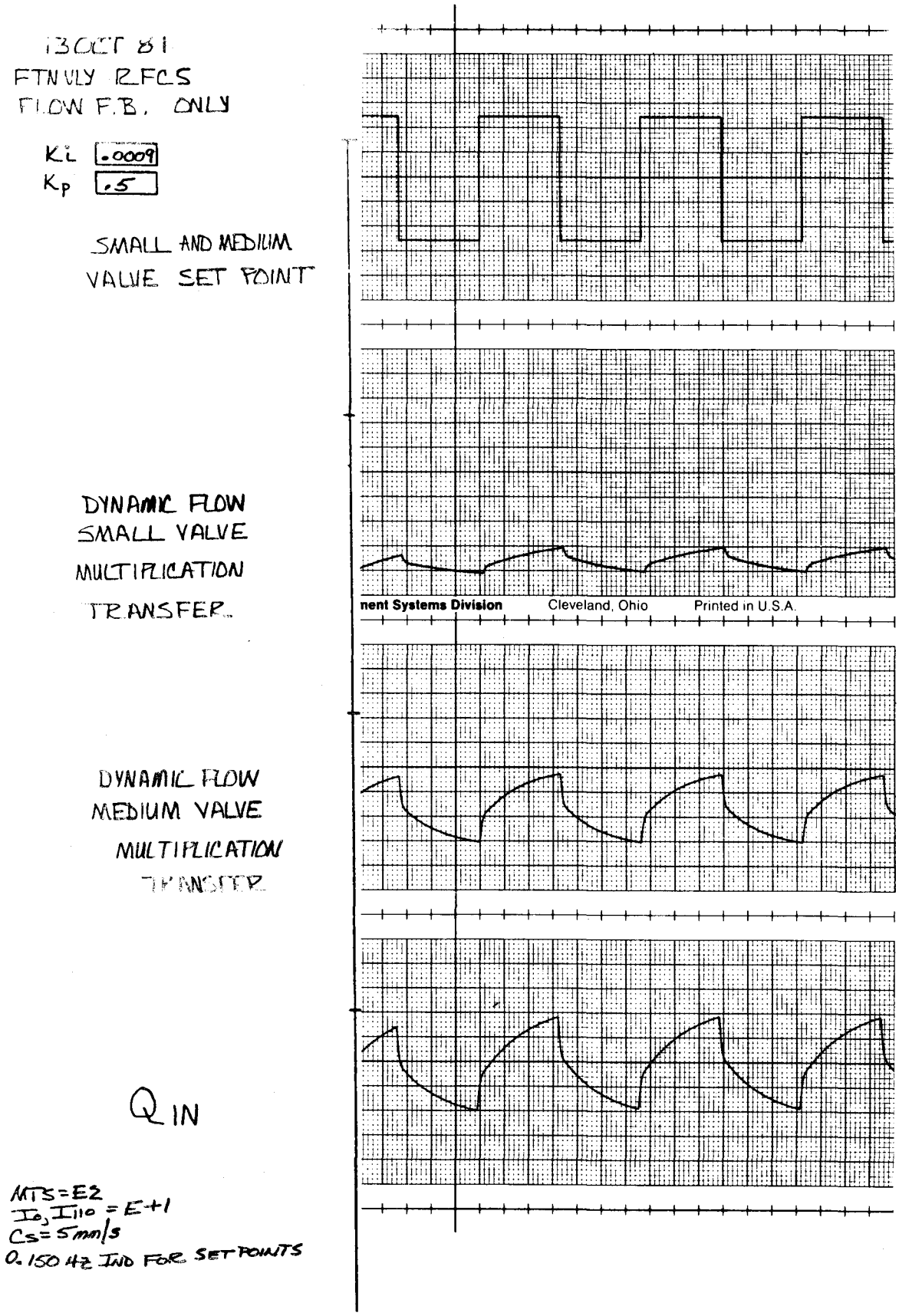


Figure A3.—K_i Range step response — graphical data (2 of 7).

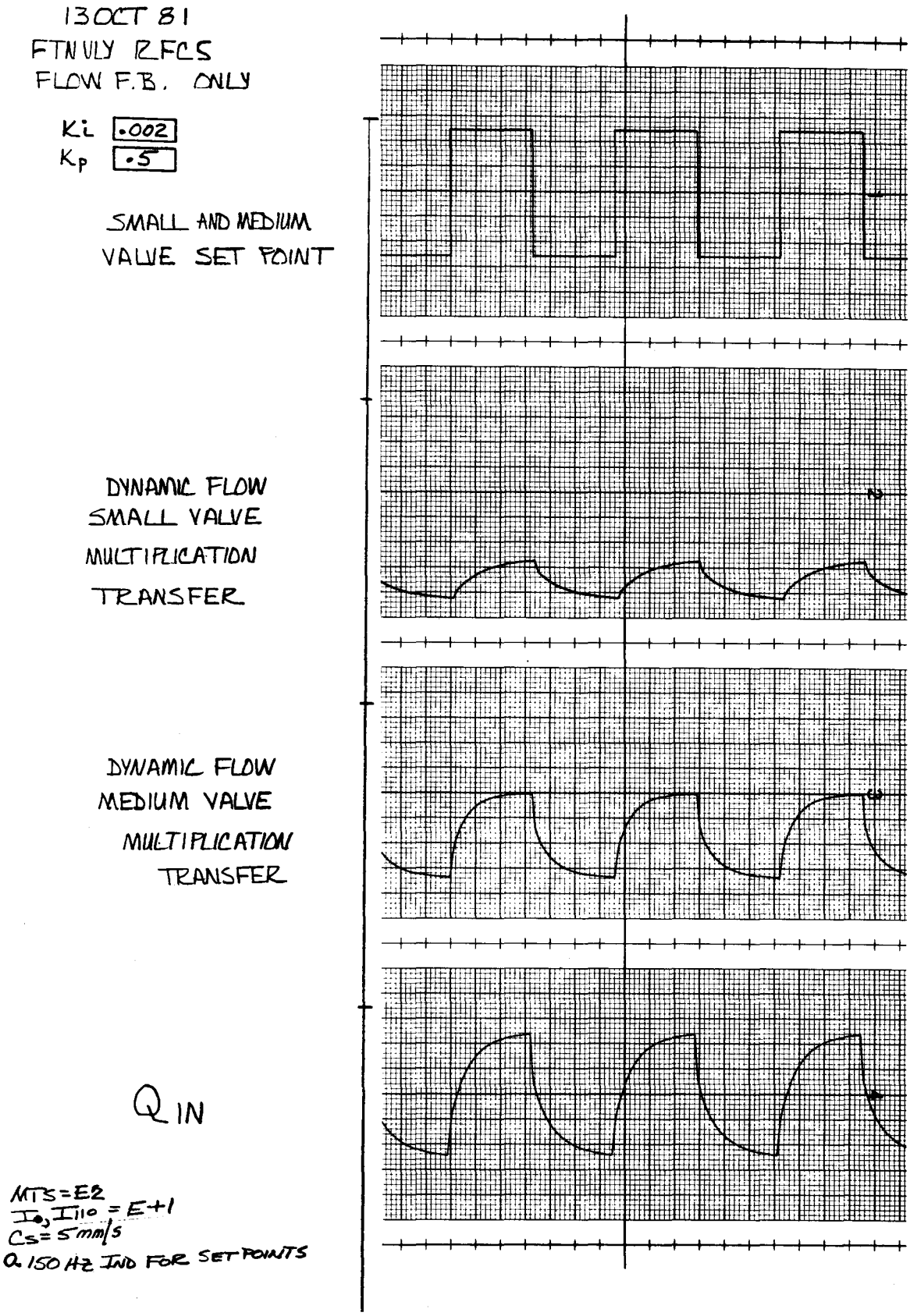


Figure A3.—K_i Range step response — graphical data (3 of 7).

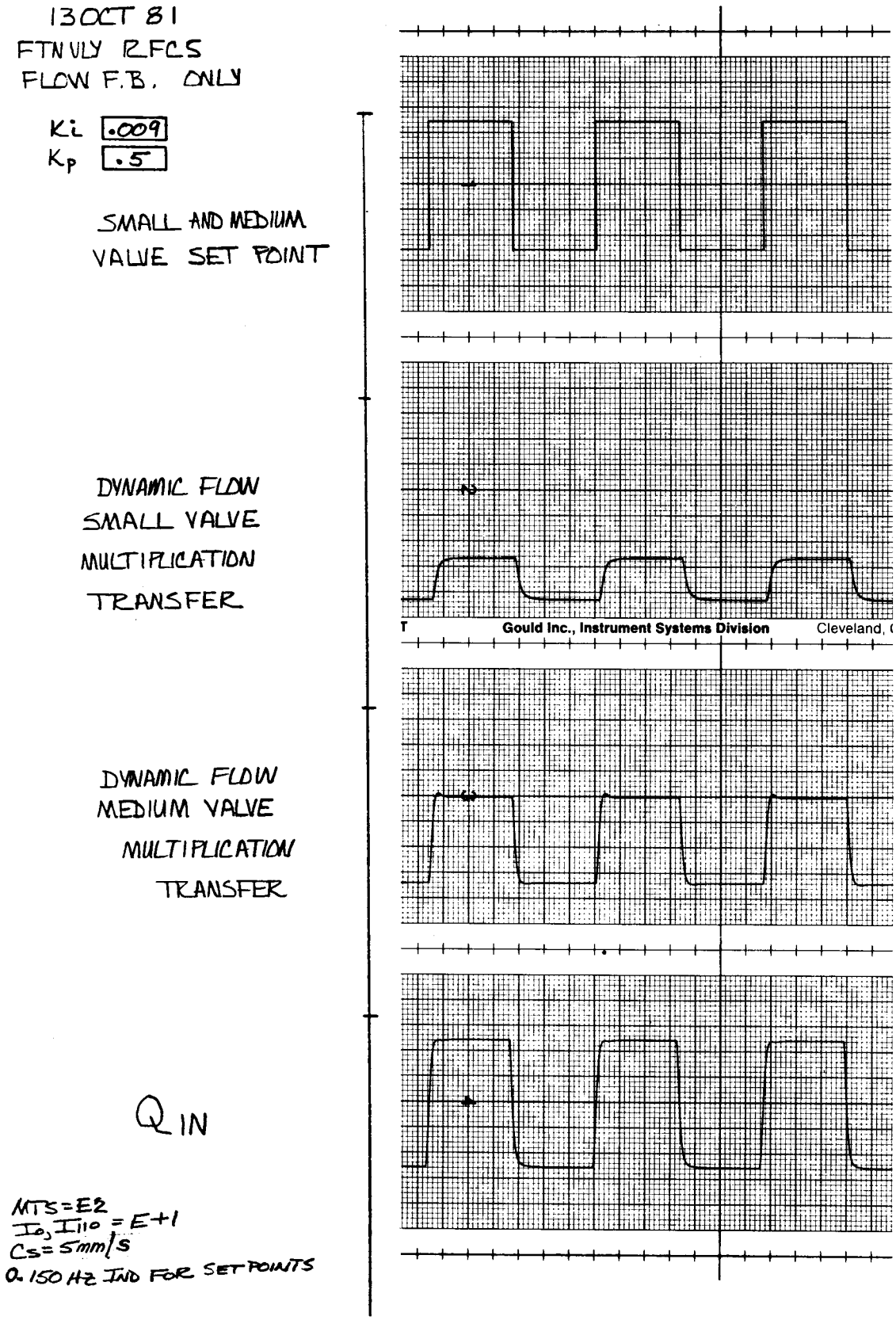


Figure A3.—K_i Range step response — graphical data (4 of 7).

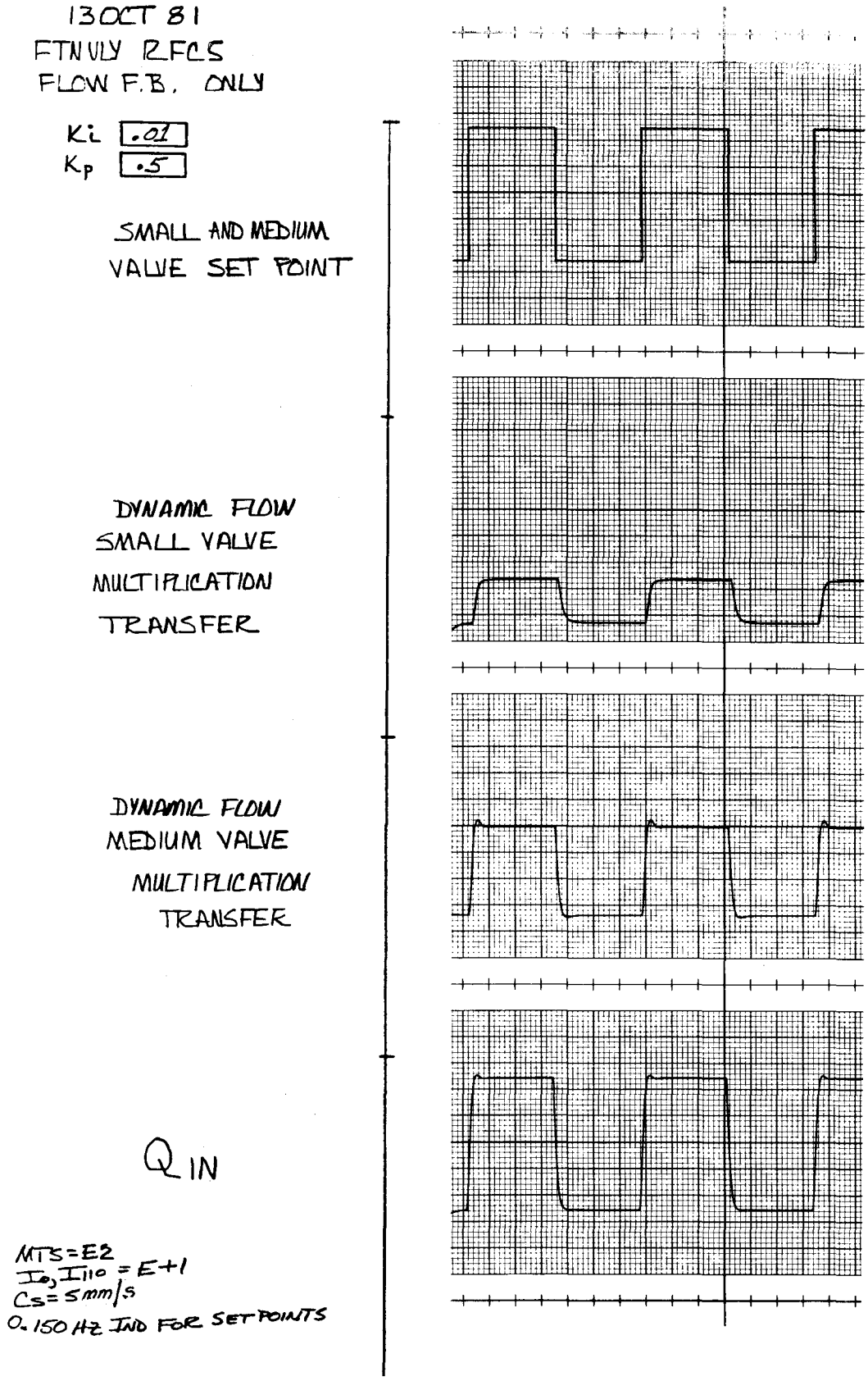


Figure A3.—K_i Range step response — graphical data (5 of 7).

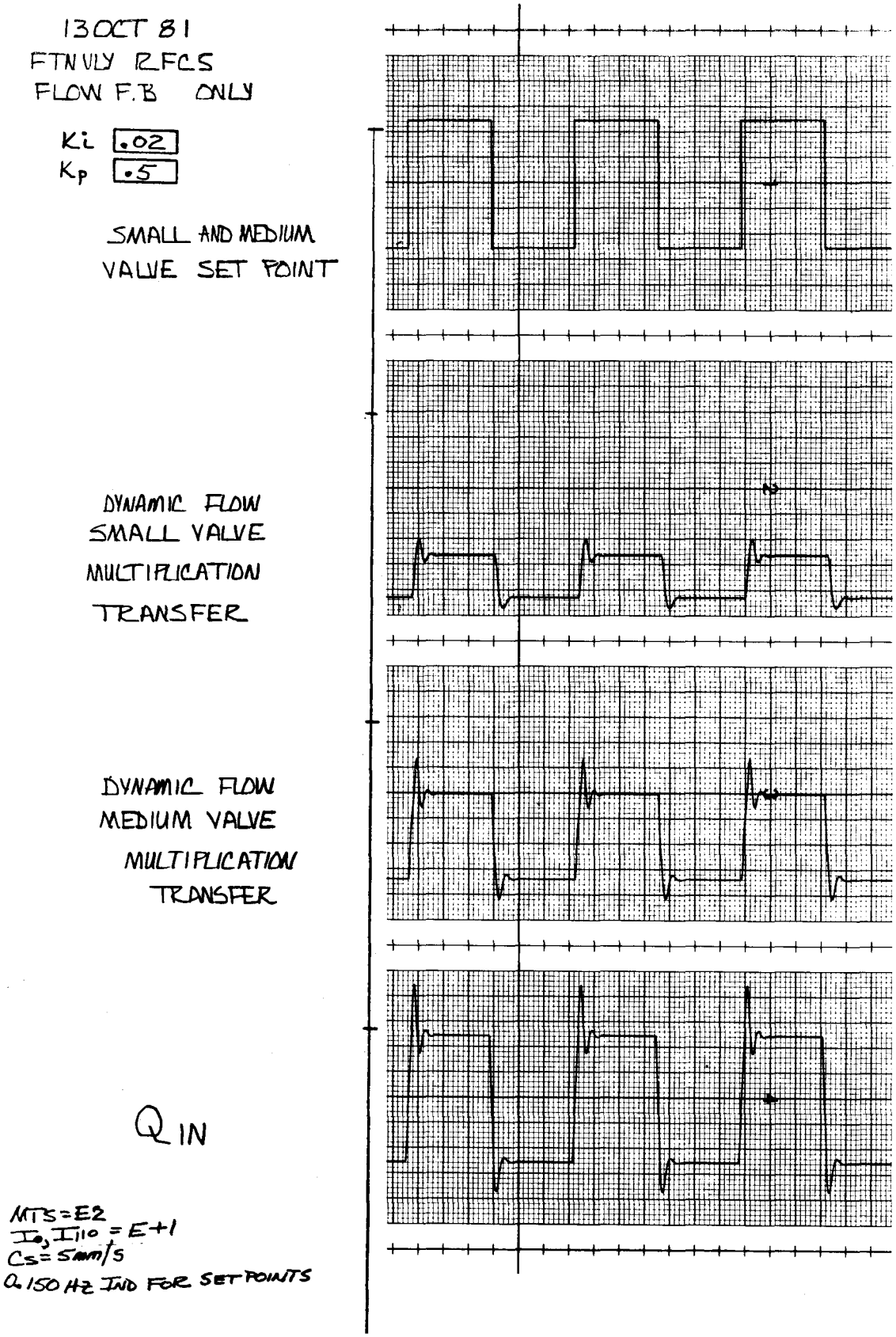


Figure A3.—K_i Range step response — graphical data (6 of 7).

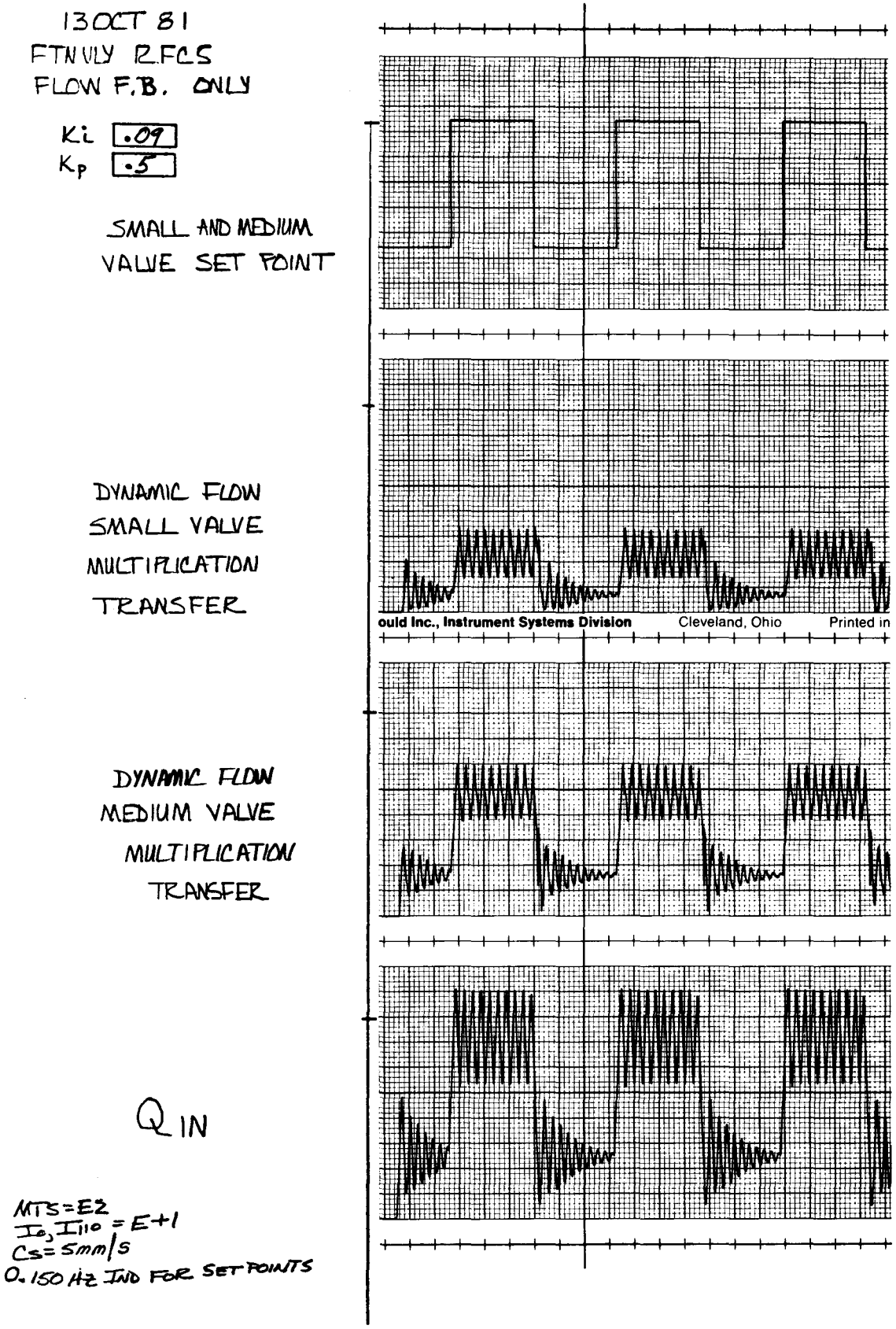


Figure A3.—K_i Range step response — graphical data (7 of 7).

13 OCT 81
FTN VLV RFCS
POSITION AND FLOW F.B.

Ki .02
Kp .5

TANK LEVEL

DYNAMIC FLOW
SMALL VALVE
MULTIPLICATION
TRANSFER

DYNAMIC FLOW
MEDIUM VALVE
MULTIPLICATION
TRANSFER

Q IN

MTS=E2
Io, I110 = E+/
Cs=.5MM/SEC (50/100 MM/SEC)
.02 HZ IND FOR SET POINTS
SQUARE WAVE INPUT

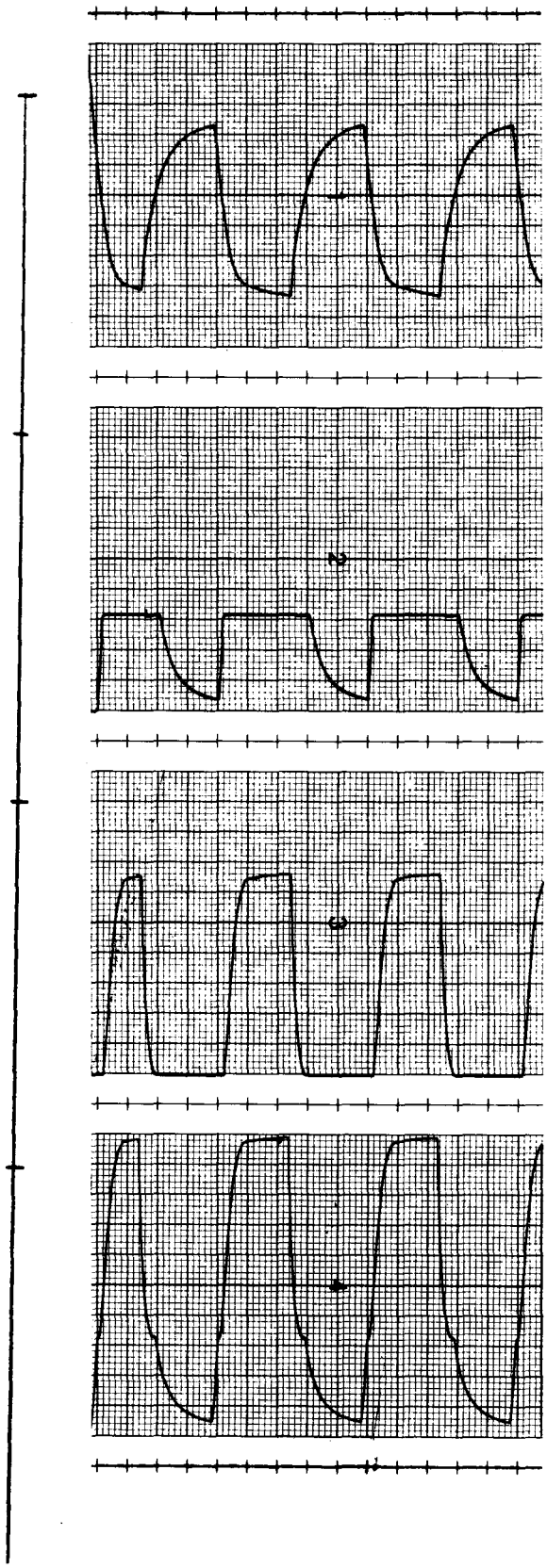


Figure A4.—System step response — graphical data (1 of 4).

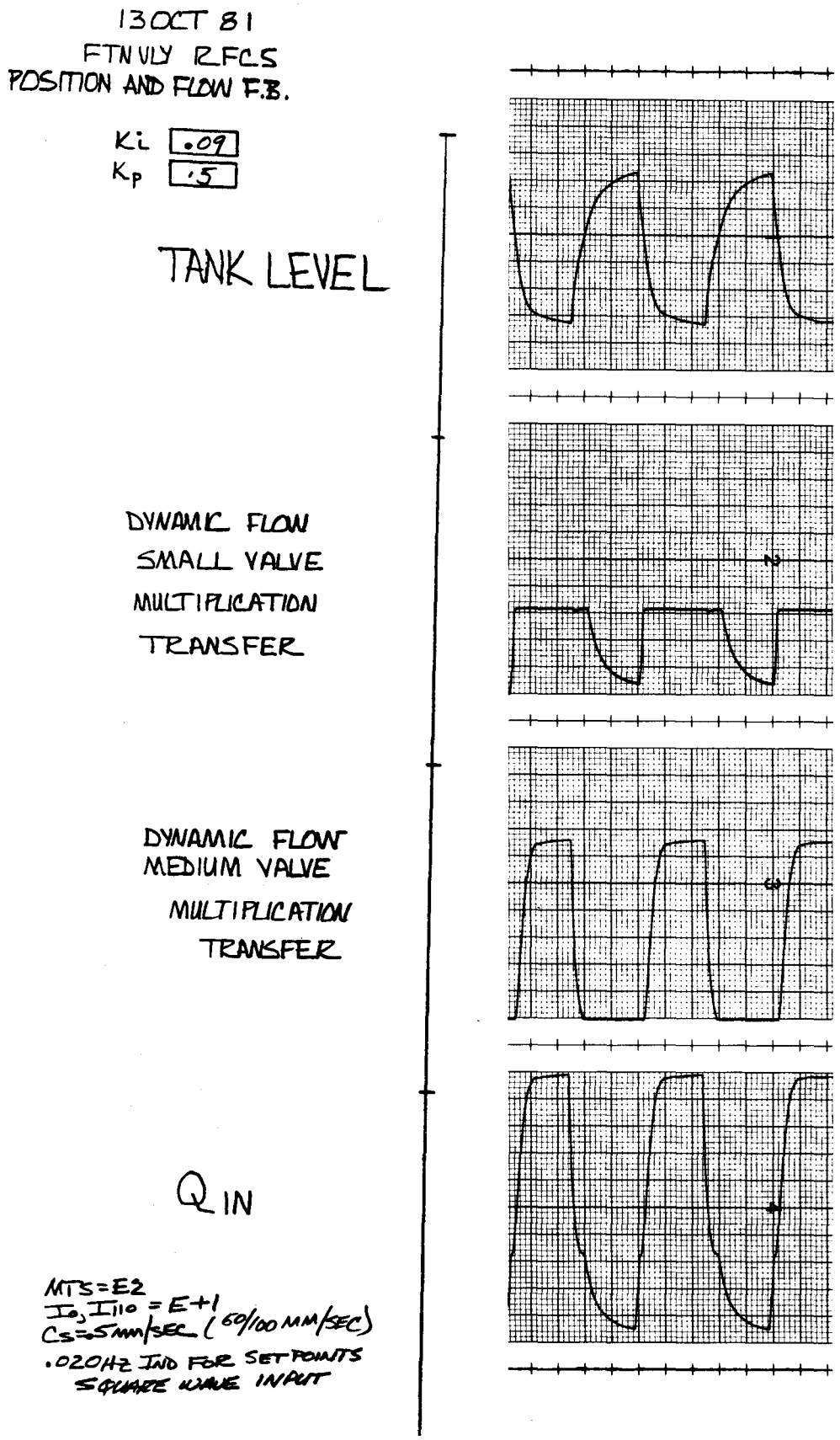


Figure A4.—System step response — graphical data (2 of 4).

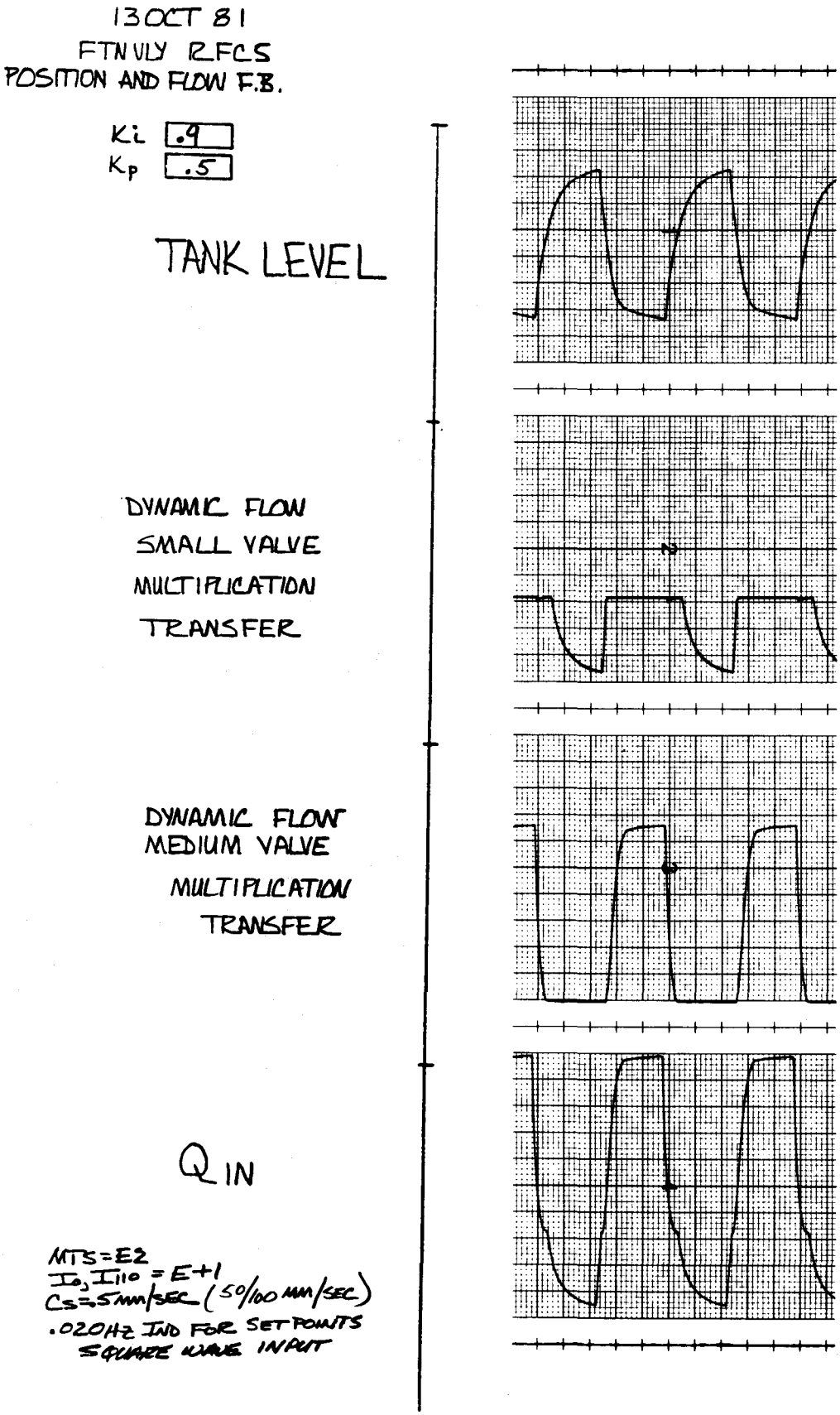


Figure A4.—System step response — graphical data (3 of 4).

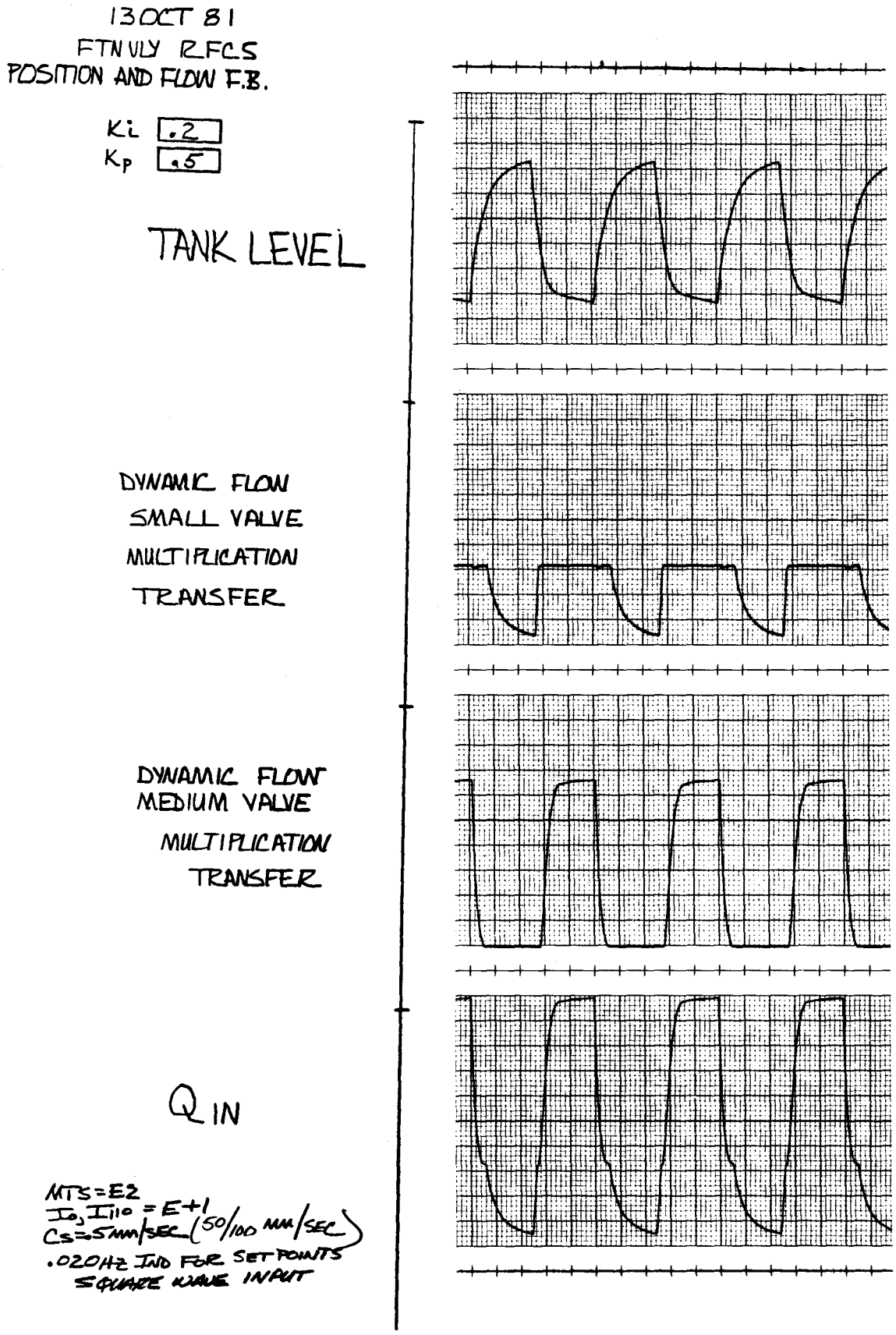


Figure A4.—System step response — graphical data (4 of 4).

APPENDIX B

SYSTEM ANALOG COEFFICIENT LISTING

FINVLY RFCS

13 OCT 81

REPORT DATA

1QT
1CL
1E2
1C000 = +0.2258
1C001 = +0.7635
1C002 = +0.9966
1C003 = +0.9967
1C004 = +0.0089
1C005 = +0.0729
1C006 = +0.9003
1C007 = +0.7503
1C010 = -0.5002
1C011 = +0.3331
1C012 = +0.2941
1C013 = -0.0103
1C014 = +0.0001
1C015 = +0.0200
1C016 = +0.9994
1C017 = -0.9999
1C020 = +0.9997
1C021 = +0.9999
1C022 = +0.9999
1C023 = +0.9989
1C024 = -0.4999
1C025 = +0.9994
1C026 = +0.0000
1C027 = -0.0202
1C030 = +0.0000
1C031 = -0.9997
1C032 = +0.9999
1C033 = -0.8745
1C034 = +0.9988
1C035 = +0.0000
1C036 = +0.9999
1C037 = +0.2937
1C040 = +0.5000
1C041 = +0.6660
1C044 = -0.9999
1C045 = +0.6660
1C050 = +0.9997
1C051 = +0.0000
1C054 = +0.3329
1C055 = +0.1600
1C060 = +0.1181
1C061 = +0.0009
1C064 = +0.0318
1C065 = -0.8759
1C070 = -0.0000
1C071 = -0.8754
1C074 = -0.0000
1C075 = +0.0050
1C100 = +0.9891
1C101 = -0.5000
1C102 = -0.9997
1C103 = -0.0000
1C104 = +0.0100
1C105 = +1.0000
1C106 = +0.9999
1C107 = +0.6663
1C110 = +0.9999
1C111 = -0.8758
1C112 = +0.1996
1C113 = +0.0000
1C114 = -0.9998
1C115 = +0.0109
1C116 = +0.6658
1C117 = +0.3330
1C120 = +0.0000
1C121 = +0.9999
1C122 = +0.9999
1C123 = +1.0000
1C124 = +0.0000
1C125 = +0.1600
1C126 = -0.9999
1C127 = -0.0000
1C130 = +0.9999
1C131 = +0.9999
1C132 = +1.0000
1C133 = +0.0099
1C134 = -0.9997
1C135 = -0.1290
1C136 = -0.0100
1C137 = -0.0100
1RV00=00000
1RV01=30672
1RV02=00000
1RV04=00000
1RV05=00000
1RV06=32624
1RV10=00000
1RV11=00000
1RV12=32760
1RT0=20000
1RT1=32000
1RT2=00000

```
1I000=E+1
1I004=E+0
1I010=E+0
1I014=E+0
1I016=E+0
1I020=E+0
1I024=E+0
1I030=E+0
1I034=E+0
1I036=E+0
1I040=E+0
1I044=E+0
1I050=E+0
1I054=E+0
1I060=E+0
1I064=E+0
1I070=E+0
1I074=E+0
1I100=E+0
1I104=E+0
1I110=E+1
1I114=E+0
1I120=E+0
1I124=E+0
1I130=E+0
1I134=E+0
1F01:
1B=41
1V01=+0.0000
1V02=+0.0000
1V03=+0.0000
1V04=+0.0000
1V05=+0.0000
1V06=+0.0000
1V07=+0.0000
1V08=+0.0000
1V09=+0.0000
1V10=+0.0000
1V11=+0.0000
1V12=+0.0000
1V13=+0.0000
1V14=+0.0000
1V15=+0.0000
1V16=+0.0000
1V17=+0.0000
1V18=+0.0000
1V19=+0.0000
1V20=+0.0000
1V21=+0.0000
1V22=+0.0011
1V23=+0.0229
1V24=+0.0500
1V25=+0.0822
1V26=+0.1197
1V27=+0.1623
1V28=+0.2102
1V29=+0.2632
1V30=+0.3215
1V31=+0.3849
1V32=+0.4535
1V33=+0.5274
1V34=+0.6065
1V35=+0.6907
1V36=+0.7802
1V37=+0.8748
1V38=+0.9747
1V39=+0.9900
1V40=+0.9990
1V41=+0.9999
1S;
1F02:
1B=41
1V01=+0.0000
1V02=+0.0000
1V03=+0.0000
1V04=+0.0000
1V05=+0.0000
1V06=+0.0000
1V07=+0.0000
1V08=+0.0000
1V09=+0.0000
1V10=+0.0000
1V11=+0.0000
1V12=+0.0000
1V13=+0.0000
1V14=+0.0000
1V15=+0.0000
1V16=+0.0000
1V17=+0.0000
1V18=+0.0000
1V19=+0.0000
1V20=+0.0000
1V21=+0.0000
1V22=+0.0011
1V23=+0.0229
1V24=+0.0500
1V25=+0.0822
1V26=+0.1197
1V27=+0.1623
1V28=+0.2102
1V29=+0.2632
1V30=+0.3215
```

```
1V31=+0.3849
1V32=+0.4535
1V33=+0.5274
1V34=+0.6065
1V35=+0.6907
1V36=+0.7802
1V37=+0.8748
1V38=+0.9747
1V39=+0.9900
1V40=+0.9990
1V41=+0.9999
1S;
```


GPO 837-212

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled, "Publications for Sale". It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.