NISTIR 4595

Description of a Vibration Compensation System for the Small Scale Model Robot Crane Project

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ABSTRACT

This report describes the electronic hardware designed and developed for the Small Scale Model Robot Crane (SSMRC) Project sponsored by the Defense Advanced Research Projects Agency (DARPA). The purpose of this electronic hardware is to provide the necessary servo controls for the three axes of the SSMRC. The report begins with an introduction which explains the overall objectives of the project and describes the SSMRC system configuration. An electronic design section discusses each system component and describes the component from both a hardware and a system point of view. Test procedures and results, which give the troubleshooting methods and data needed for development of the system, are then presented. The report concludes with a brief summary and an appendix which provides electronic design schematics and descriptions of the parts used in the construction of the electronic hardware system.

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1. Introduction

Automation and the use of robotic systems are wide spread in manufacturing applications. Recent studies [1, 2] have indicated that there are potential applications of this technology to the heavy construction industry. The study documented in this report, being conducted by the National Institute of Standards and Technology (NIST) under the sponsorship of the Defense Advanced Research Projects Agency (DARPA), involved the investigation of construction cranes and how their operation could be improved by the use of robotics technology.

One of the principal operations of heavy construction industry involves handling, lifting, positioning, and assembling large components and machinery. These operations are not only labor intensive, but are dangerous and tiring for the laborer. If construction cranes could be operated like industrial robots, these operations would be completed more efficiently and safely.

As shown in Figure 1, ordinary construction cranes are stable only in the vertical direction. The load is free to rotate and to sway under the slightest side pressure like a pendulum. Under these conditions, it would be very difficult for the crane to perform any robotic-type operations due to the excessive compliance of its end-effector (in this case, the mechanism for hooking onto the load).

A new crane design utilizing six cables to suspend a load platform was proposed [2] as shown in Figure 2. Based on initial testing of several prototypes, this design results in a very stiff load platform [3, 4, 5]. This platform can be used in typical crane operations, or as a robot base, or a combination of both (Figure 3). This approach can be used on any of the various crane designs currently used in the construction industry as conceptually illustrated in Figures 4 a, b, and c.

The DARPA sponsored program on robot crane technology involved the design, development and testing of several prototypes to determine the performance characteristics of this proposed crane design. In the overall program, research was conducted on three different size models - large, intermediate and small. This report deals only with the small model and specifically with the electronics developed to control it. A description of the overall DARPA program and the results of this research are presented in [6].

The robot crane program utilized different size models in order to minimize the difficulties of working with very large, heavy structures. By using scaled models, it was possible to characterize design parameters and investigate system performance but with reduced effort and cost. This particular project involved working with the small model, which has been termed the Small Scale Model Robot Crane (SSMRC). The SSMRC is shown in the photograph in Figure 5.

2. Objective

The objective of this work was the design, development, and evaluation of a vibration compensation device for the SSMRC. The purpose of this device is to reduce vibration of the robot crane load platform which might result from the load shifting, contact between the load and

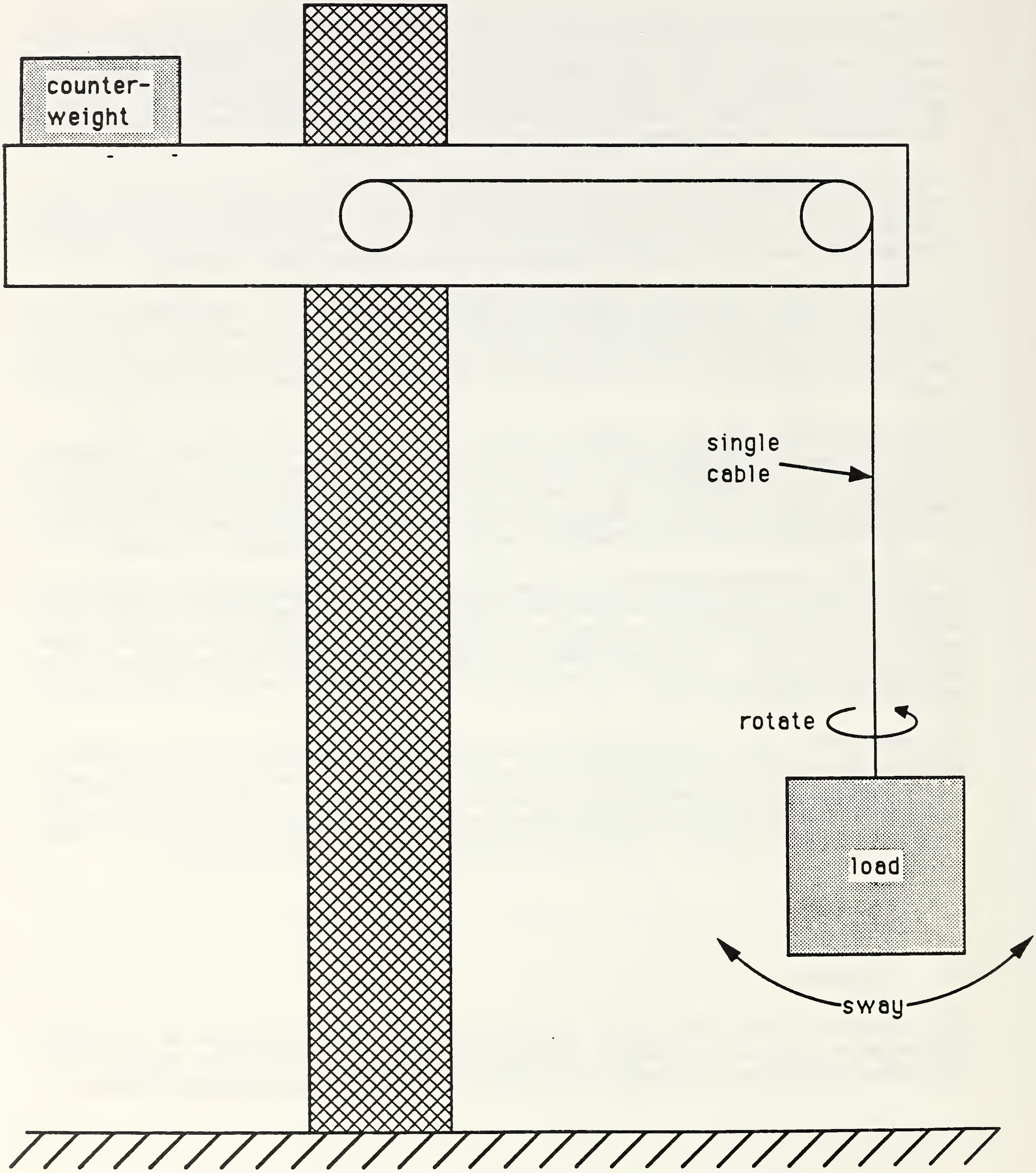


Figure 1. Typical Tower Crane Used for Building Construction

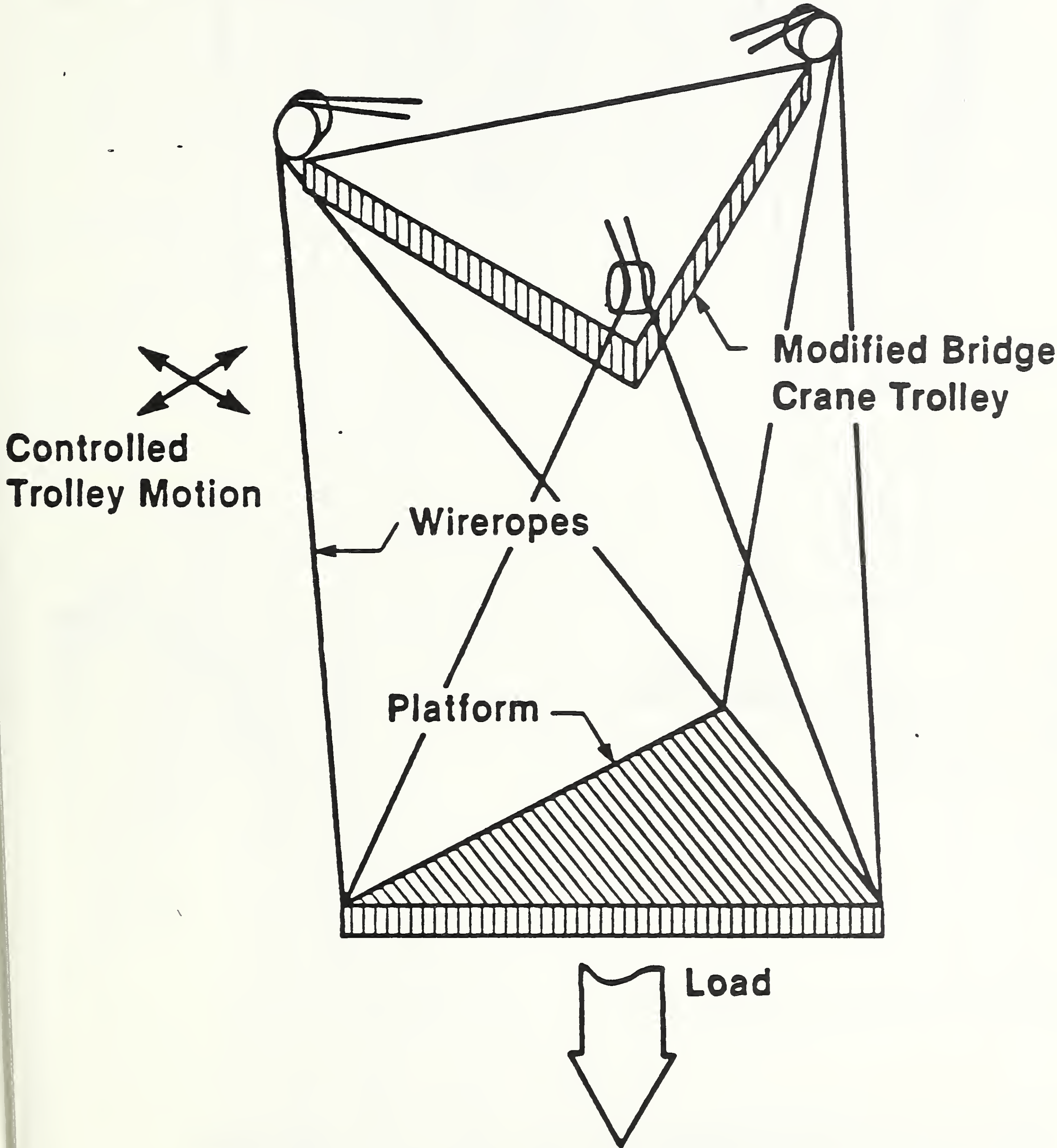


Figure 2. Design Concept for Improving Stiffness of Crane Suspension Mechanisms

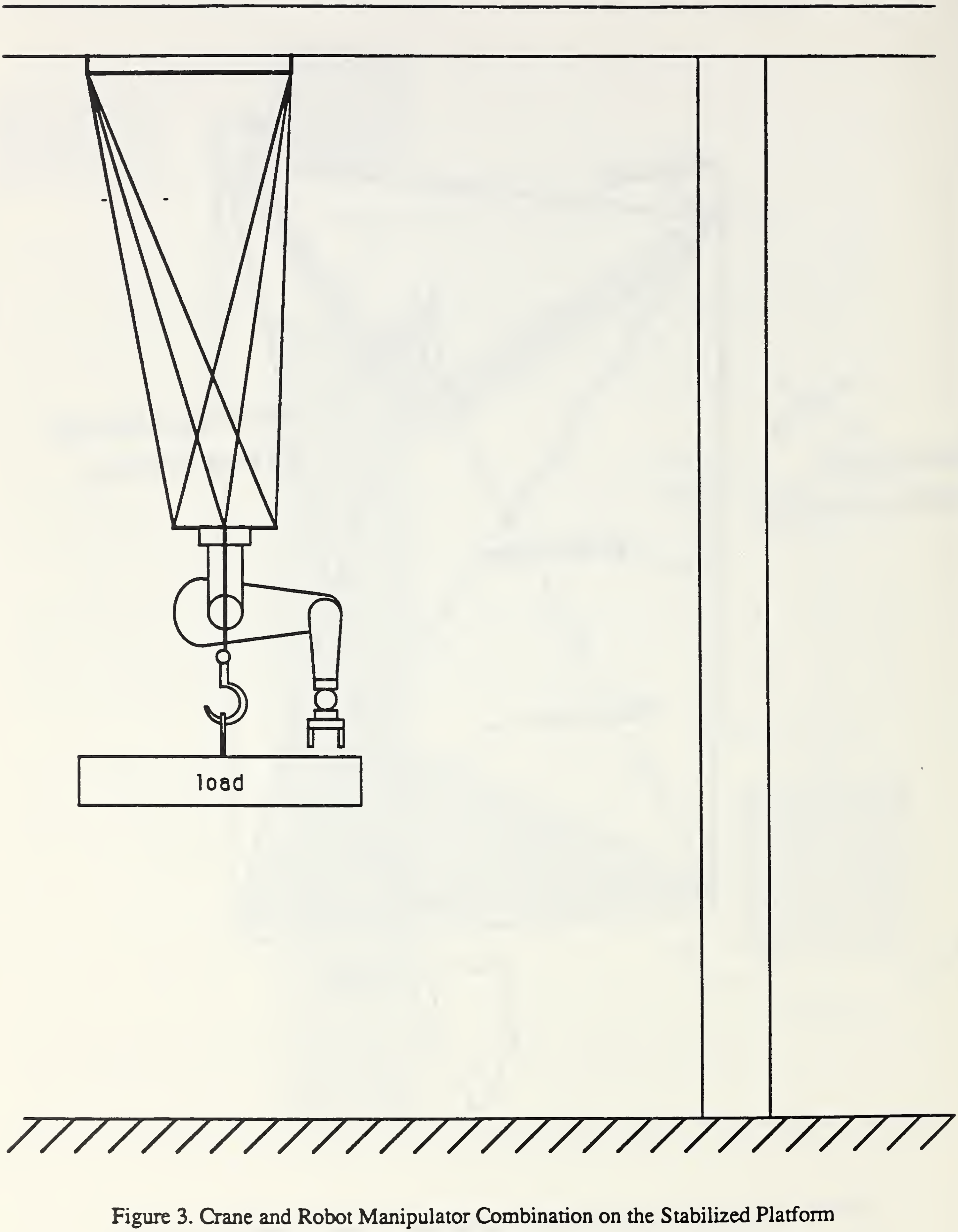
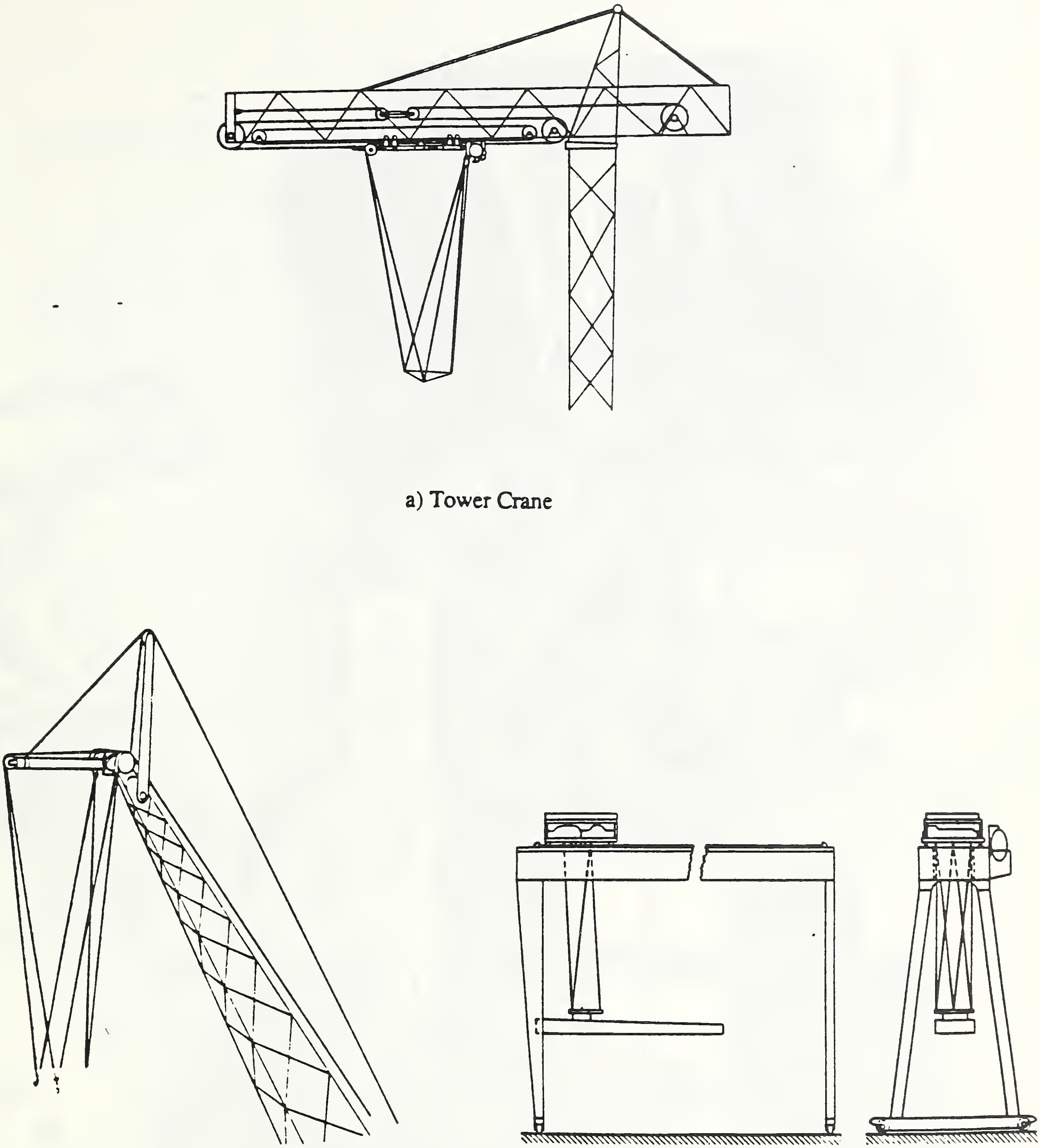


Figure 3. Crane and Robot Manipulator Combination on the Stabilized Platform



a) Tower Crane

b) Boom Crane

c) Gantry Bridge Crane (with extended reach)

Figure 4. Stabilized Platform Concept applied to Various Crane Designs

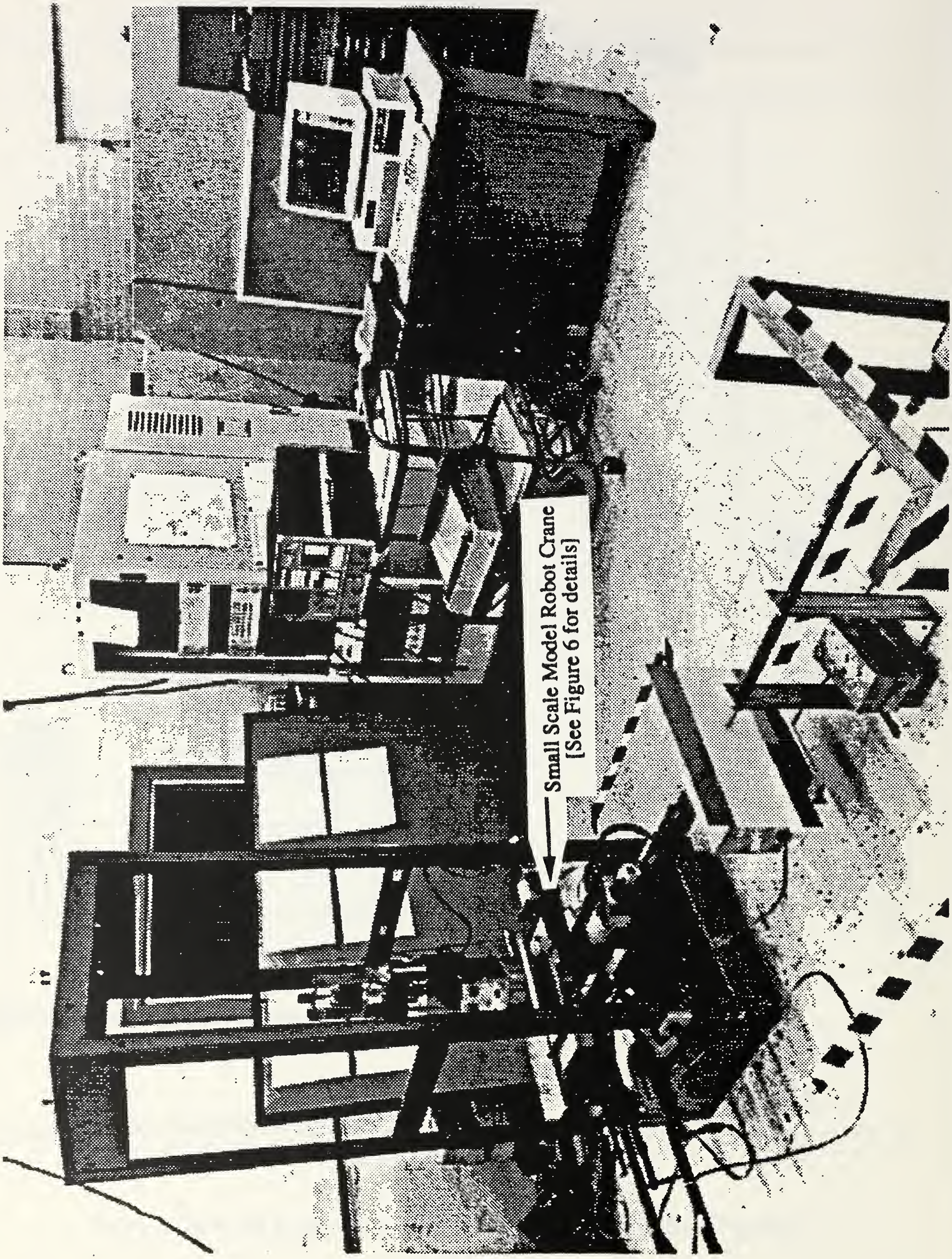


Figure 5. Small Scale Model Robot Crane

some external structure, or from wind loading. Reducing these vibrations will provide better stabilization of the platform and, therefore, better positioning control of the load.

3. Mechanical Design

The SSMRC is shown schematically in Figure 6. It consists of two equilateral triangular shaped platforms of the same size (11.43 cm). The upper platform is rigidly fixed to a supporting structure. The lower platform is suspended approximately 1.2 meters from the upper platform by six steel wire cables (0.1 cm diameter). Mounted beneath the lower platform is an X-Y precision positioning table, which provides translation along the X and Y axes. Mounted above the lower platform is a motor which is coupled to the X-Y positioning table and provides rotation about the Z axis. Mounted below the X-Y positioning table is a lateral translation end-loading subplatform structure. This subplatform structure consists of a 5 x 2.5 cm cross section, 1.8 meters long steel beam with two baskets suspended from its ends for the placement of lead bricks. The basket farthest from the platform simulates the payload and the nearest basket the counter weight.

The vibration compensation device consists of the X-Y positioning table, the rotary joint about the Z-axis, position and velocity feedback sensors and the servo controls for driving the motors. With this device it is possible to translate the payload on a plane parallel to that of the lower platform and to rotate it about an axis orthogonal to the same plane.

Attached to the drive screws of the X-Y table are two servo motors, one on the X-axis and one on the Y-axis, each driven by servo amplifiers. A higher torque motor assembly is attached to the beam via a bearing and located at the center of gravity of the system. Position and velocity sensors provide feedback to the amplifiers and are attached to the crane housing and to the motor shafts, respectively. Both relative and absolute position sensors are used for feedback.

Absolute position sensors are mounted to a rack assembly which houses the crane and are in contact with the crane. Two sensors are equal distance about the Z-axis and the third sensor is positioned at the payload end of the crane (see Figure 7). An IBM PC AT[1] computer is used to update the position of the crane via an Active Filter System and a Data Acquisition and Control System. Outputs from this system are amplified using a Voltage Amplifier System before sending signals to the servo amplifiers.

[1] Commercial equipment is identified in this report so that the electronic system and design procedures are adequately described. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that this equipment was necessarily the best available for these tasks.

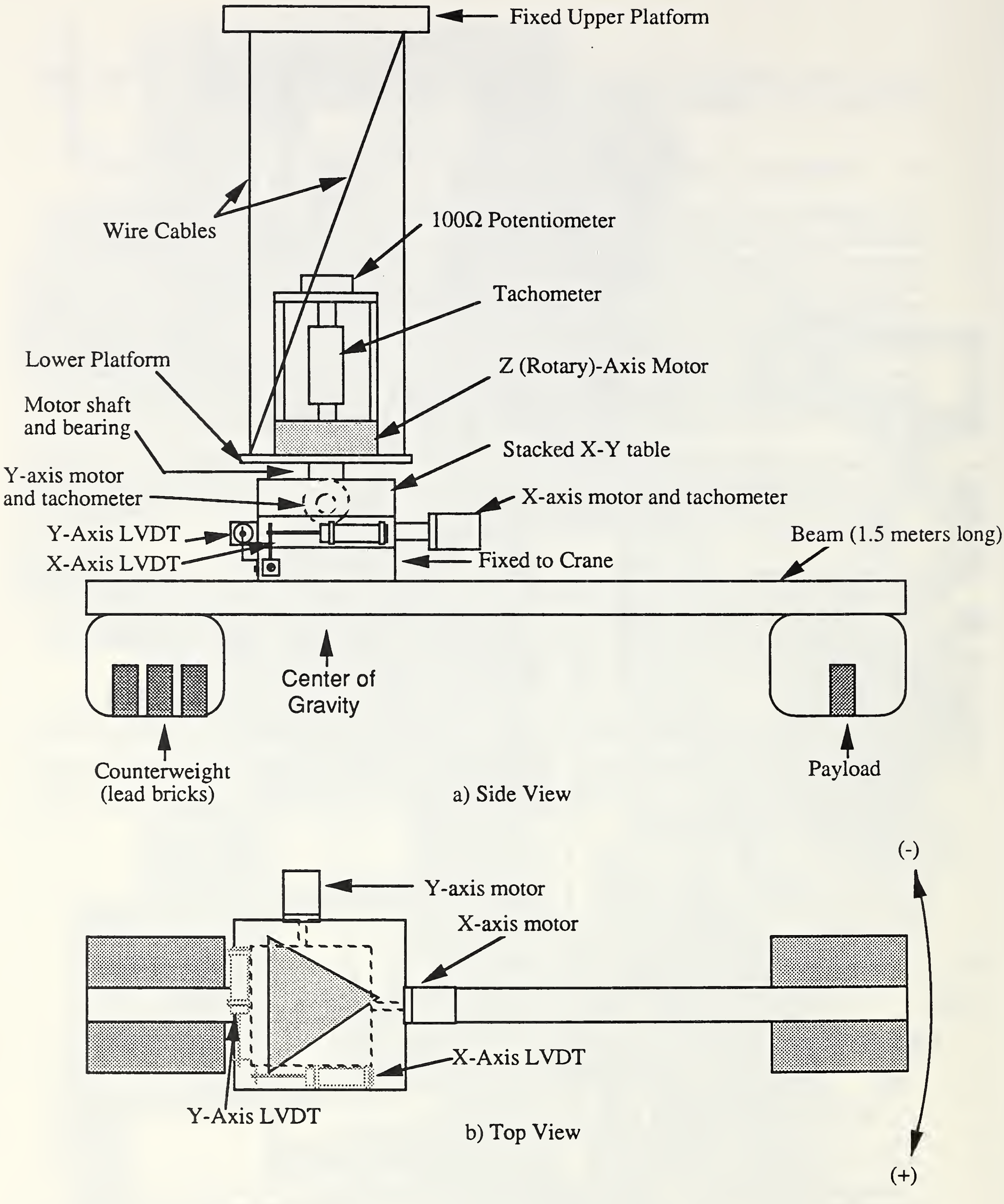


Figure 6. Side and Top Views of the Small Scale Model Robot Crane

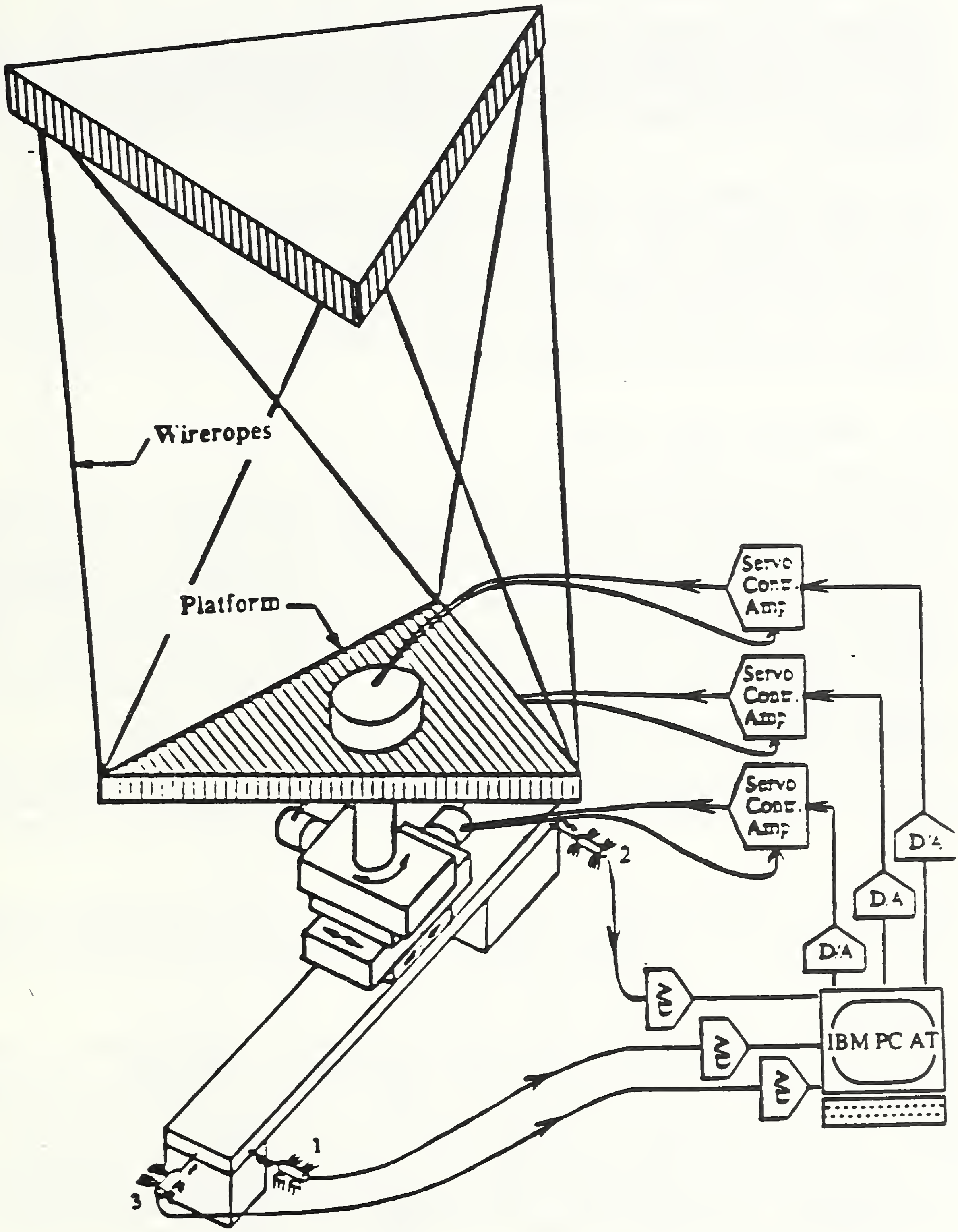


Figure 7.   Schematic of the Vibration Compensation System

4. Electronic System Design

The electronic system contains the following components: Three-Axis Servo Drive System which includes the relative position sensors, velocity sensors, motors, and amplifiers; Absolute position sensors; an Active Filter System; a Voltage Amplifier System; a Data Acquisition and Control System; and a Power Supply System (see Figure 8 and Appendix for detailed design and schematics).

The computer outputs data to the Data Acquisition and Control System which converts this data into a voltage. This voltage is sent through the Voltage Amplifier System and to the Three-Axis Servo Drive System to drive the crane. Feedback is sent from the absolute position sensors through the Active Filter System for low frequency filtering and back to the Data Acquisition and Control System to be converted into data that the computer can use. This data is then fed into the computer for an update of the crane's position. Each component of the electronic system is explained in more detail in the following sections.

4.1. Three-Axis Servo Drive

A Three-Axis Servo Drive System was designed to provide power to drive the three motors on the robot crane. This drive system has three 1000 watt pulse-width -modulated servo amplifiers with velocity-loop configuration manufactured by Inland Motor. Each amplifier uses +24 VDC and +90 VDC (maximum input voltage) and produces ±14 A (maximum) current that is adjustable to drive the majority of brush-type DC motors. The two motors currently being used are also from Inland Motor and are as follows: Rotary Joint, T-5144B Alnico Magnet motor with Imax = 3.75 A and Vmax = 85 V to provide 3.7 joules peak torque; and the X and Y Joints, QT-2606A Samarium Cobalt Magnet motor with Imax = 5.01 A and Vmax = 55 V to provide 2.0 joules peak torque.

The servo amplifiers can be configured for single-ended or double-ended use by providing one or two command inputs to the amplifiers. The double-ended configuration was chosen which takes an input from the computer and an input from the relative position sensor. This configuration makes the position sensor the reference point and the computer then, is the controller for the motor.

Feedback from a velocity sensor is necessary to provide the amplifier with a differentiated source synchronous with the motor shaft. To provide this, a tachometer is coupled to the shaft of the motor and the signal is fed into the velocity inputs of the servo amplifier (the labeling on the amplifier for these inputs are: TACH and TACH REF).

Besides the position and velocity information fed back into the amplifier, a series of adjustments are provided on the amplifier to provide the correct damping for system stability. The adjustments are as follows: system offset, command scaling, feedback scaling, AC gain, and current limit. The system offset is used to allow a ±0.2 V range of offset to add or subtract voltage to the command inputs. The command scaling and feedback scaling adjustments are used to provide a velocity adjustment and produce a percentage change (0% to 100%). The AC gain is a potentiometer to vary the velocity loop's summing-amplifier break frequency and is adjustable from 0.01 Hz to 1 kHz. The current limit is a start-up adjustment and is set for the current limit wanted to drive the motor.

An enable input is also provided on the amplifiers so that the power to the amplifiers can be on while the outputs to the motors can be enabled/disabled at will. If a current surge appears at the amplifier a fault light turns on and the output of the amplifier is disabled.

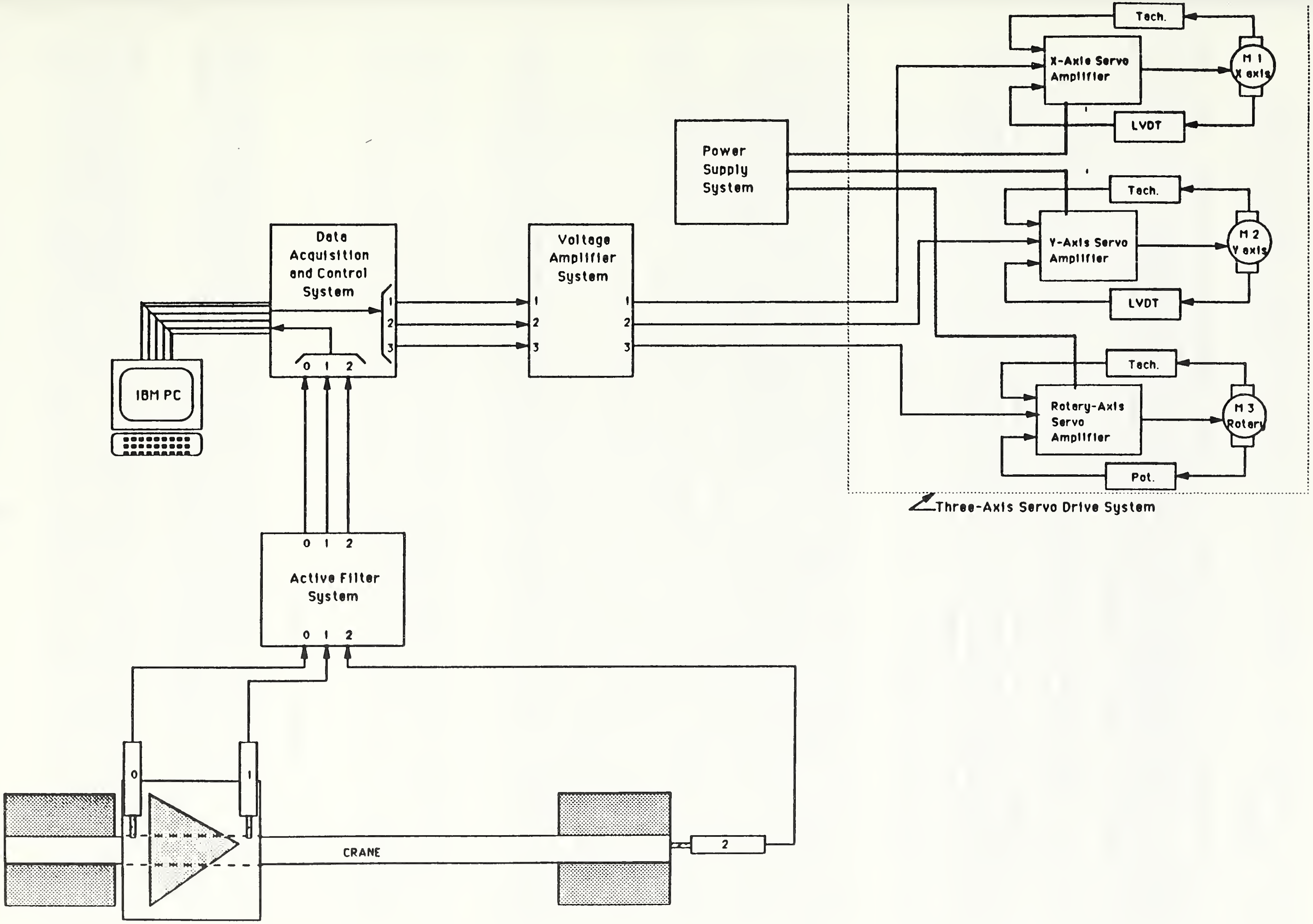


Figure 8. Electronics Diagram of the Small Scale Model Robot Crane Servo Control System

4.2. Sensors

As mentioned earlier, there are two types of position sensors used on the crane: relative and absolute. The relative position sensors for the X and Y axes are Linear Voltage Differential Transducers (LVDT) with ± 2.5 cm throw. A single-turn potentiometer is used on the rotary axis. Both sensors provide a voltage level output that is fed into the servo amplifiers to the + Command input (positive input side of the amplifier).

The absolute position sensors are spring-loaded LVDT's with a ± 5.0 cm throw. They provide a known position of the crane, based on the position of the LVDT's, to the computer. The spring is necessary to provide constant contact with the crane. The voltage level output from these sensors are fed into the Active Filter System and then to the Data Acquisition and Control System before being fed into the IBM computer. The input voltage levels are interpreted by the IBM computer to be the absolute position information.

4.3. Active Filter System

The Active Filter System is used to provide low-pass filtering for the output of the absolute position sensors while also providing signal amplification. The cut-off frequency can be adjusted from 0.1Hz to 25.6Hz from the front panel of the Active Filter System chassis. Each of the three channels are identical in circuitry and include an epoxy covered filter. There are eight digital inputs to the filter for selecting the cut-off frequency. As an input to the filter, the signal from the LVDT is fed through two operational amplifiers to provide gain to the signal without changing polarity.

The second operational amplifier has a reference potentiometer on the plus input and is used to offset this input for exact duplication of the signal from the Filter System. Therefore, the filtered signal will be a duplicate of the sensor signals, as close as possible.

4.4. Data Acquisition and Control System

The Data Acquisition and Control System consists of an Iomega interface board and an Iomega control board. The system is used to input and output data to and from the computer (IBM PC AT).

For data acquisition, the system takes an analog voltage from 0 VDC to +10 VDC and inputs it into the control board for analog-to-digital conversion. The control portion of the system uses a digital-to-analog conversion to send an analog voltage (0 VDC to +10 VDC) to the servo amplifiers via the voltage amplifier system. The voltage amplifier system is then used to scale the input to the servo amplifiers.

4.5. Voltage Amplifier System

The Voltage Amplifier System is used to scale the voltage from the Data Acquisition and Control System into a voltage that is usable by the servo amplifiers. A signal sent directly into the servo amplifier from the Data Acquisition and Control System would either not be sufficient to drive the crane or would drive the crane too far in one direction or the other.

The Voltage Amplifier System has two modes of operation: it can sum any or all of its eight channels or amplify single channels as needed. Three channels are necessary for this application of the crane and each channel has a maximum of ±13 V. Also, the Voltage Amplifier System is equipped with a reference voltage that can be used to apply a known voltage to the Servo Drive

System manually and without the use of the computer. This option is necessary for troubleshooting the system.

4.6. Power Requirements

Power for the SSMRC consists of servo amplifier power (two supplies for each amplifier), sensor power, and individual system power for the filter, voltage amplifier, and data acquisition and control systems. The individual system power supplies are ±12 VDC @ 1 A but are not explained in any further depth. However, an explanation of the servo amplifier and sensor power supplies is included, since they are important entities in the design of the overall system.

To completely isolate each joint from the others, it was found that the power supplied to each servo amplifier must be isolated. Therefore, a separate series of supplies was used to provide power to each joint. A power unit consisting of a 117 V to 68 V transformer and a supply that outputs +28 VDC and +90 VDC was used to drive the rotary joint. Since the current limit was set lower on the X and Y axis amplifiers, a lower rated power supply could be used for these two joints. Hence, a +28 VDC and a +24 VDC power supply was used for each joint and provided enough power to drive these two motors.

When applying 110 VAC to the rotary power supplies, it was found that it was necessary to delay the +90 VDC output by about one second from the +28 VDC output. This allowed the servo amplifier to be at a steady state when the one second passed and the +90 VDC could then be fed into the amplifier without causing damage. For shutdown, the reverse process was used. While the rotary supplies are equipped with a built-in delay, the X and Y joint servo amplifier supplies do not have a built-in delay and a start-up and shut-down procedure must be followed (see Section 5.0 TEST RESULTS). Switches for power to the X and Y joint amplifiers were needed for this procedure.

The sensor power consists of three ±12VDC @ 1A power supplies. One supply is used for the relative position LVDT's, one for the absolute position LVDT's and the third supply is used only for the rotary relative position potentiometer. It was found that isolation of power for the relative position LVDT's was not necessary since the LVDT's were differentially connected to the amplifier. The potentiometer supply was adjusted to ±10 VDC since the signal output fed into the data acquisition cannot exceed ±10 VDC. Also, since the crane is restricted to a ±30° motion, the potentiometer can never exceed ±10 VDC.

5. Electronic System Development

5.1. Troubleshooting Description

Preliminary checks were made on the electronic systems of the SSMRC, such as: servo amplifiers were configured for initial set-up, power was checked upon completion of the isolation wiring, and servo amplifiers were used to drive a motor without sensor feedback. Upon completion of preliminary checks, each servo amplifier was configured for single-ended operation (the minus command was used as the control input while the plus command was grounded).

With a single-ended configuration, all reference is made to the input ground. Therefore, only one drive is being used as a control device while being referenced to the common ground. With this in mind, an external variable power supply was used to input a command signal into the minus command of a servo amplifier while a tachometer was coupled to one end of the motor shaft and its signal fed into the tach inputs of the amplifier. By varying the voltage into the amplifier the speed of the motor could be controlled and coarse adjustments to the servo amplifier adjustment potentiometers could be made. Also, by feeding 0 VDC into the amplifer from the variable supply, a zero offset adjustment could be set. This procedure was done for all three servo amplifiers.

Next, a position sensor was connected as a control device to see if the sensor and amplifier were compatible. Since most LVDTs send out high frequency spikes, a test of this type was not unreasonable and was found that these sensors were indeed compatible with the amplifiers. Although, while testing a Linear Velocity Differential Transducer (LVel.DT) as a velocity feedback device instead of a tachometer, an unstable state occurred and could not be made stable by any adjustments or filtering. This, we feel, was due to the incompatablility of this particulat sensor with the servo amplifier. Also, since the LVel.DT was not coupled directly to the motor shaft, some delay was present between the sensor and the motor movement. The coupling used in this set-up was a precision X-Y table equipped with a worm-gear drive screw.

Once all position sensors and motor/tachometer combinations were adjusted coarsely, they were mounted on the robot crane and further testing proceeded. Beginning with the rotary joint, fine adjustments to the amplifier were made. Hence, by moving the joint, fine adjustment was made to the servo amplifier until a desirable movement was seen by the operator. This adjustment sequence involved fine adjustment of the command scaling, the ac gain, the dc offset, and the velocity feedback potentiometers. The tuning procedure was a very tedious process until reaching an operating range where there was a strong correlation between potentiometer adjustments and robot crane movement. The same procedure was used on all three joints and a finely tuned system evolved.

After the system was completely fine-tuned with ground as a reference and the position sensor as feedback, the computer was used as a controller and the position sensor used as its reference. This configuration of hardware connections is called double-ended and is used so that the computer does not have to drive the crane both to and from a location. A simple step input from the computer was fed into the servo-drive controllers and a tuning process of the amplifiers again took place. This included multiplying each displacement of the crane (vibration-compensator) with a constant and then sending it to the servo-drive controllers. The value of this constant was determined experimentally so that each axis had the fastest response possible to an impulse excitation and with no more than two oscillations before reaching steady state.

5.2. Start-up/Shut-down Procedures

As discussed earlier, a start-up and shut-down procedure was necessary in order that a stable state was reached before motor power-up and that all charge was dissipated from the amplifiers at power-down. The procedures are as follows:

To Turn Motors On:
Turn on Big Circuit Breaker on inside top/right of rack.
Turn on power switch to 28V Power Supply Chassis (bottom grey panel on the right side).
Turn on Voltage Amplifier System (grey panel with two digital meters on the front) {DO NOT TOUCH ANY OTHER KNOBS ON THIS CHASSIS!}.
Turn on X and Y 28V switches on the Power Supply Chassis.
Turn on X,Y, and R switches on bottom panel of rack.
Turn on Enable switches for X,Y, and R on the Servo Amplifier System. Motors should all be active now!

Power -Down Procedure for Motors:
Turn off X,Y and R switches on bottom panel of rack.
Turn off Enable switches after 60 seconds!!
Turn off X and Y 28V switches on Power Supply Chassis.
Turn off Big Circuit Breaker on inside top/right of rack.

To Power Big LVDT's:
Turn on Big Circuit Breaker on inside top/right of rack.
Turn on power switch to 28V Power Supply Chassis (bottom grey panel on the right side).
Turn on Active Filter System.

The previous sequence of events could be automated if so desired.

6. System Development Experiences

Testing of the electronics was a long process since many different problems were found. These problems evolved from: the sensor selection (velocity and absolute position sensors), grounding patterns and amplifier tuning methods.

As discussed in Section 4.1, the velocity sensors were changed from LVel.DT's to tachometers on the X- and Y- axis joints. Since a delay is present between the linear movement of the X-Y table and the rotary movement of the motor, the velocity feedback signal also is delayed and thus causes asynchronous timing of the motor and sensor. Therefore, a rotary velocity sensor was coupled to the motor shaft directly. This allowed the velocity feedback, from the velocity sensor (tachometer), to the servo amplifier to be completely synchronized with the motor. Stability of the system greatly improved due to this change.

Another sensor problem was due to the absolute position sensors. The LVDT's, being spring-loaded, provide a force on the crane at all times. Compensation must be provided for this force in order that the crane function as if it were free-standing. The compensation force was provided by the high torque of the motors on the X- and Y- axis joints. The rotary joint was unable to overcome the force from the LVDT's and additional torque was needed. This additional torque was provided by a gear box, with a ratio of 13 to 1, which did compensate for the force on the rotary joint. Sluggishness was still seen and, therefore, non-contact sensors are proposed in the future.

Many ground problems evolved during the troubleshooting process. The signal-to-noise ratio of the LVDT's is very low and, hence needs to be isolated from other electronic components. Also, the computer power line developed noise on the signal lines. Initially, the computer power line was plugged into an ordinary AC socket, as was the system electronics. But, the system electronics power was isolated from the line AC by using an isolation transformer built into its power supply system and thus, caused no noise problems. Therefore, an isolation transformer was also used on the computer power line.

Initial adjustment to the servo amplifiers was uncontrolled and did not cure instability. While velocity sensors were the main cause of instability, adjustment to the amplifiers was difficult since the manufacturer's literature did not explain details of these adjustments. A clearer description of the use and adjustment of these amplifiers by the manufacturer would have cut the adjustment time tremendously.

Once the velocity sensors were changed and fine adjustments on the joint were finished, no vibration was detected and the joint could be controlled using very small command signals with no hesitation or disturbances. Figures 9 through 14 show the response, without and with a digital controller input for each joint (X, Y, and Rotary) of the vibration compensation system. As can be seen from these test results, there is a significant improvement in the response of the robot crane model to impulse excitations to the X and Y axes. However, the rotary axis did not respond like the other axes and thus, increased gain to the digital controller was attempted. Oscillations in the rotary axis joint occurred and eventually the joint became unstable. A possible cure to the problem, that has not been attempted, is to use more sophisticated controller algorithms in this joint.

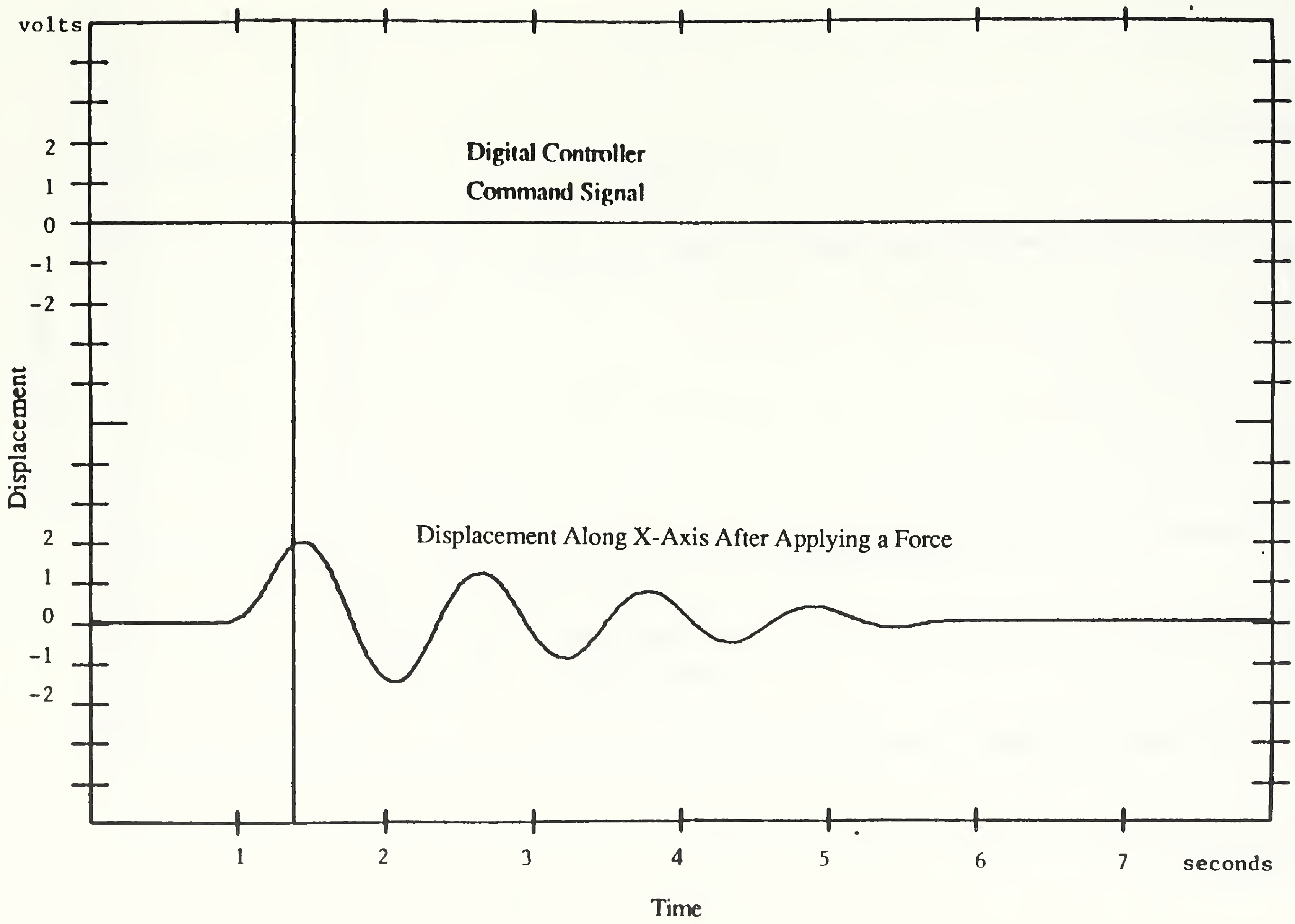


Figure 9. Uncompensated Output of the X-Axis Joint

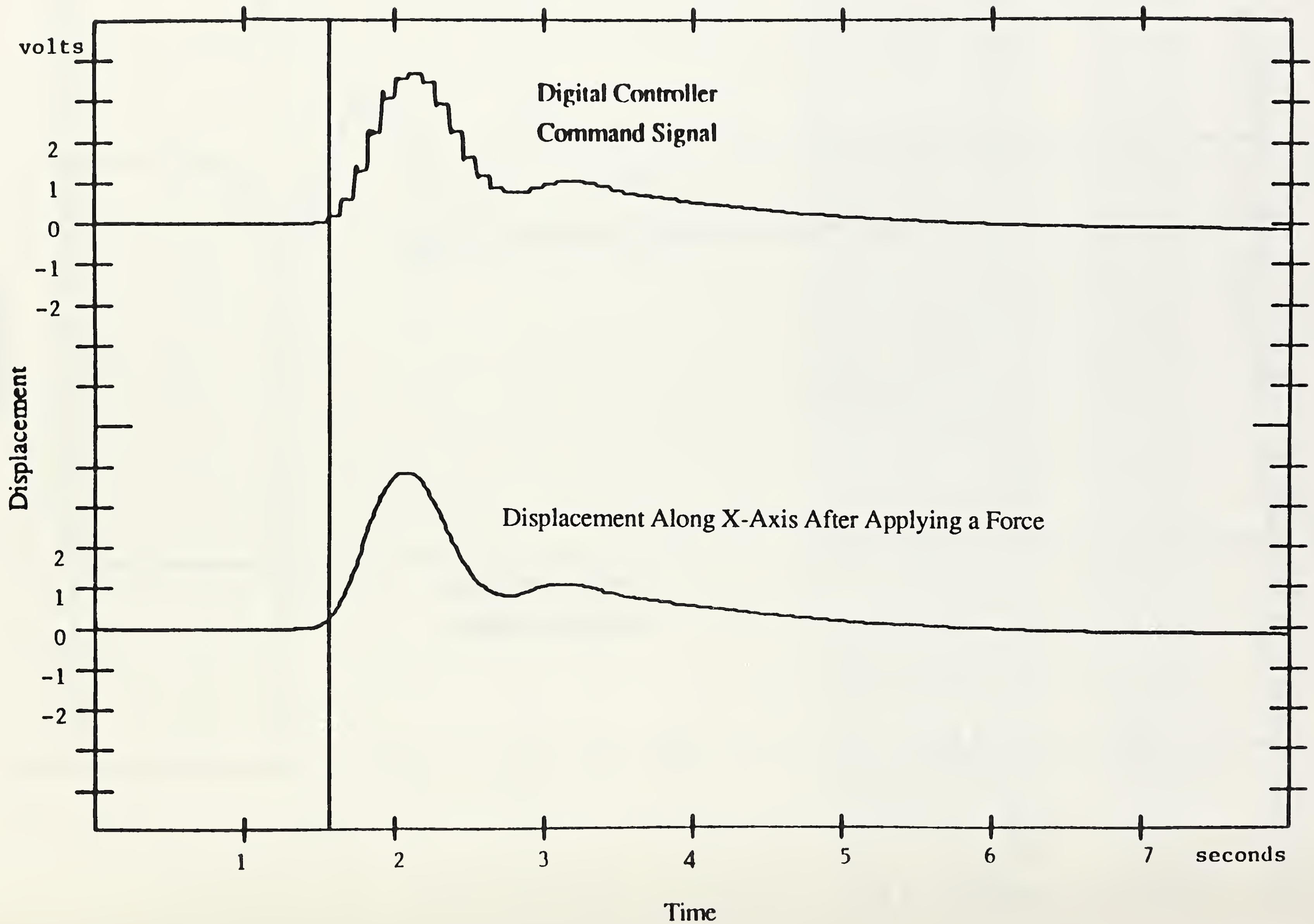


Figure 10. Compensated Output of the X-Axis Joint

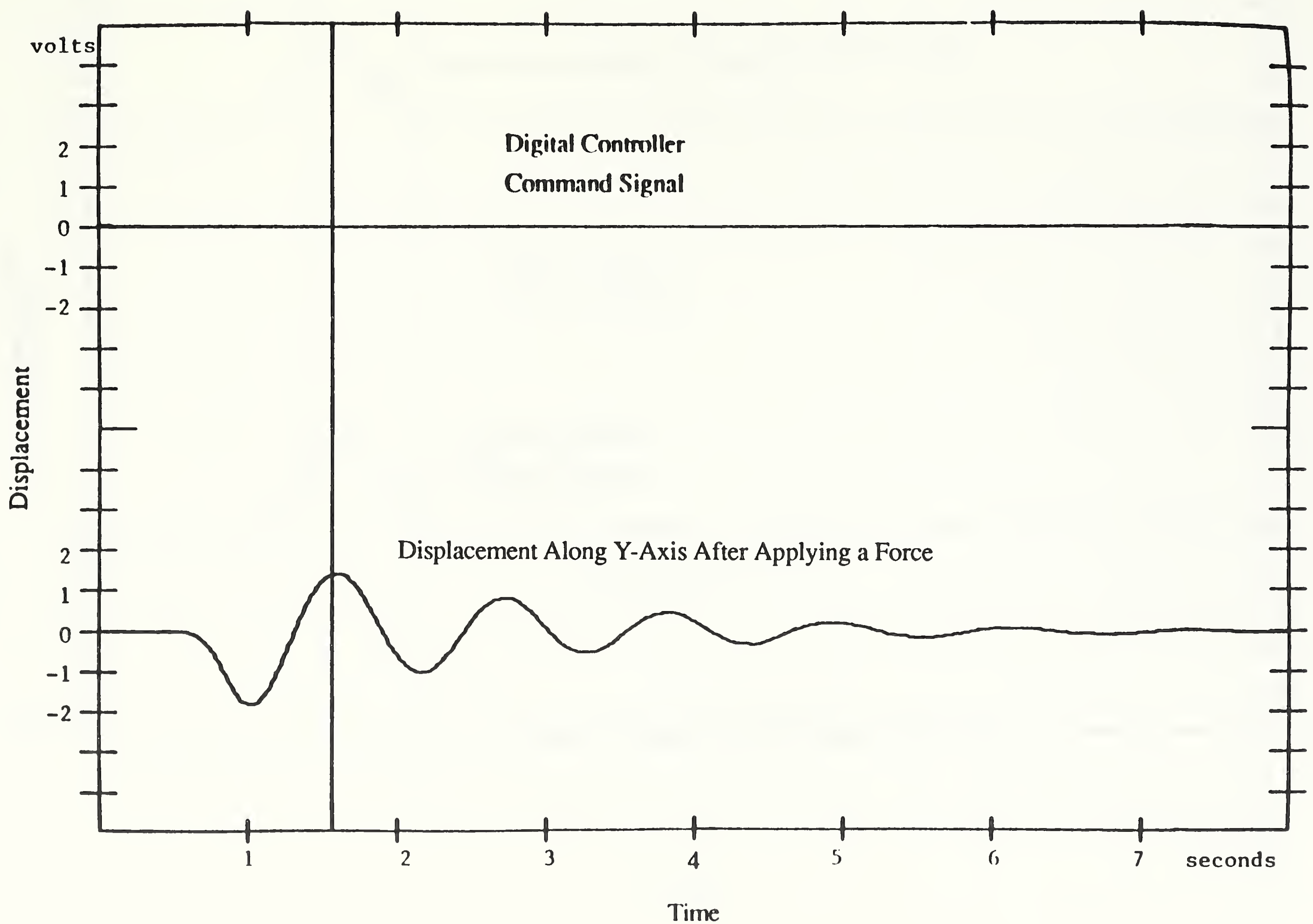


Figure 11. Uncompensated Output of the Y-Axis Joint

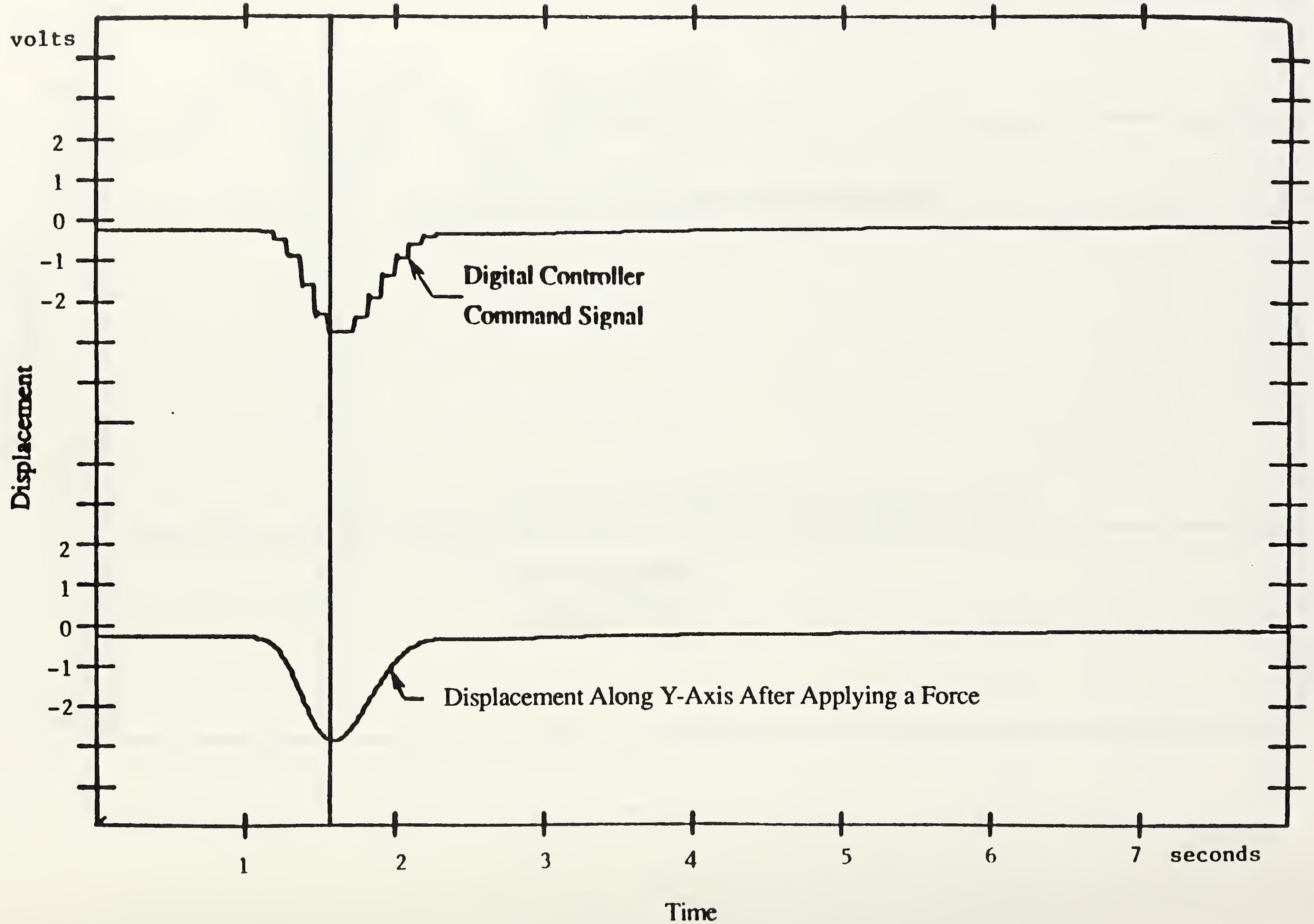


Figure 12. Compensated Output of the Y-Axis Joint

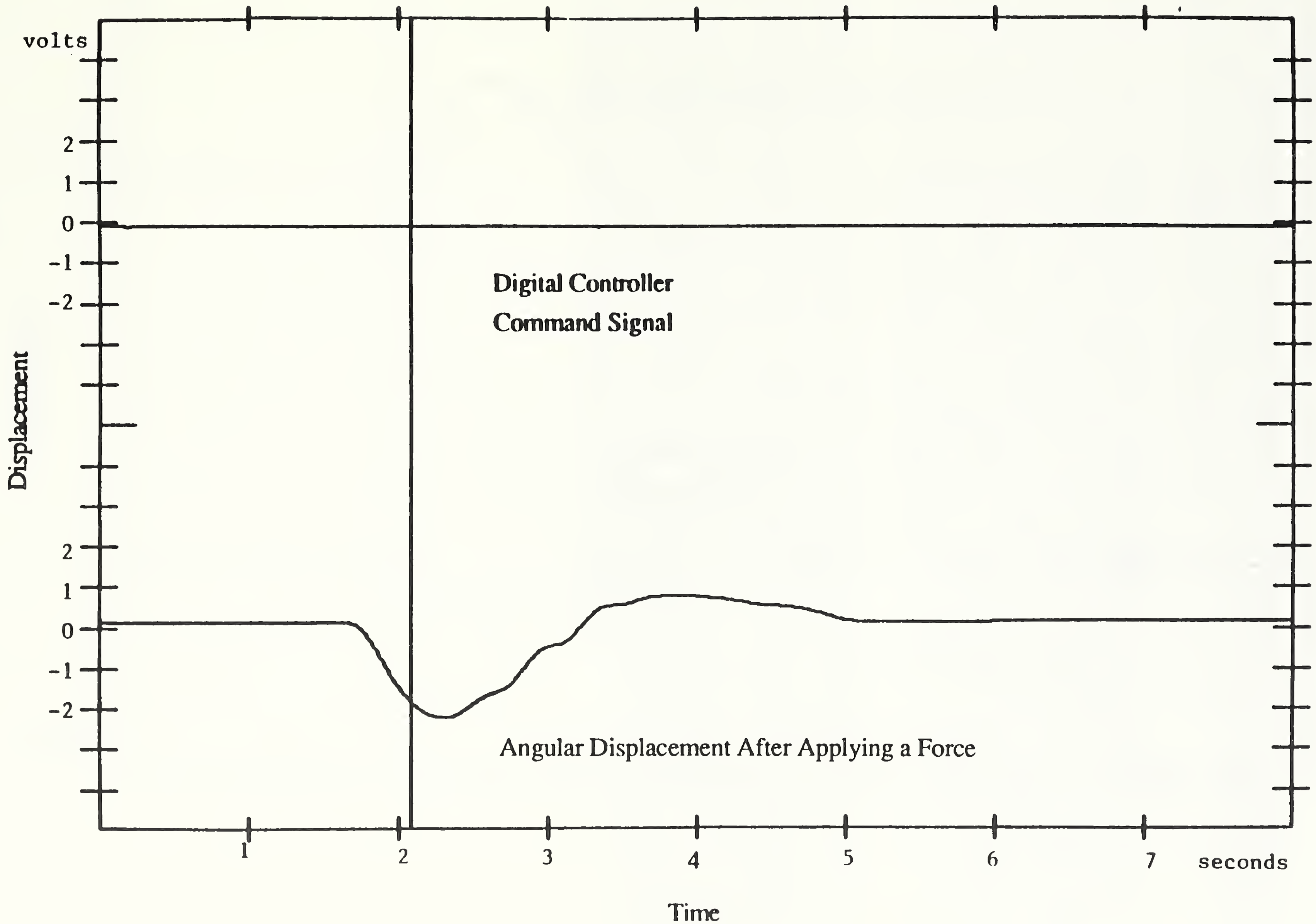


Figure 13. Uncompensated Output of the Rotary Joint

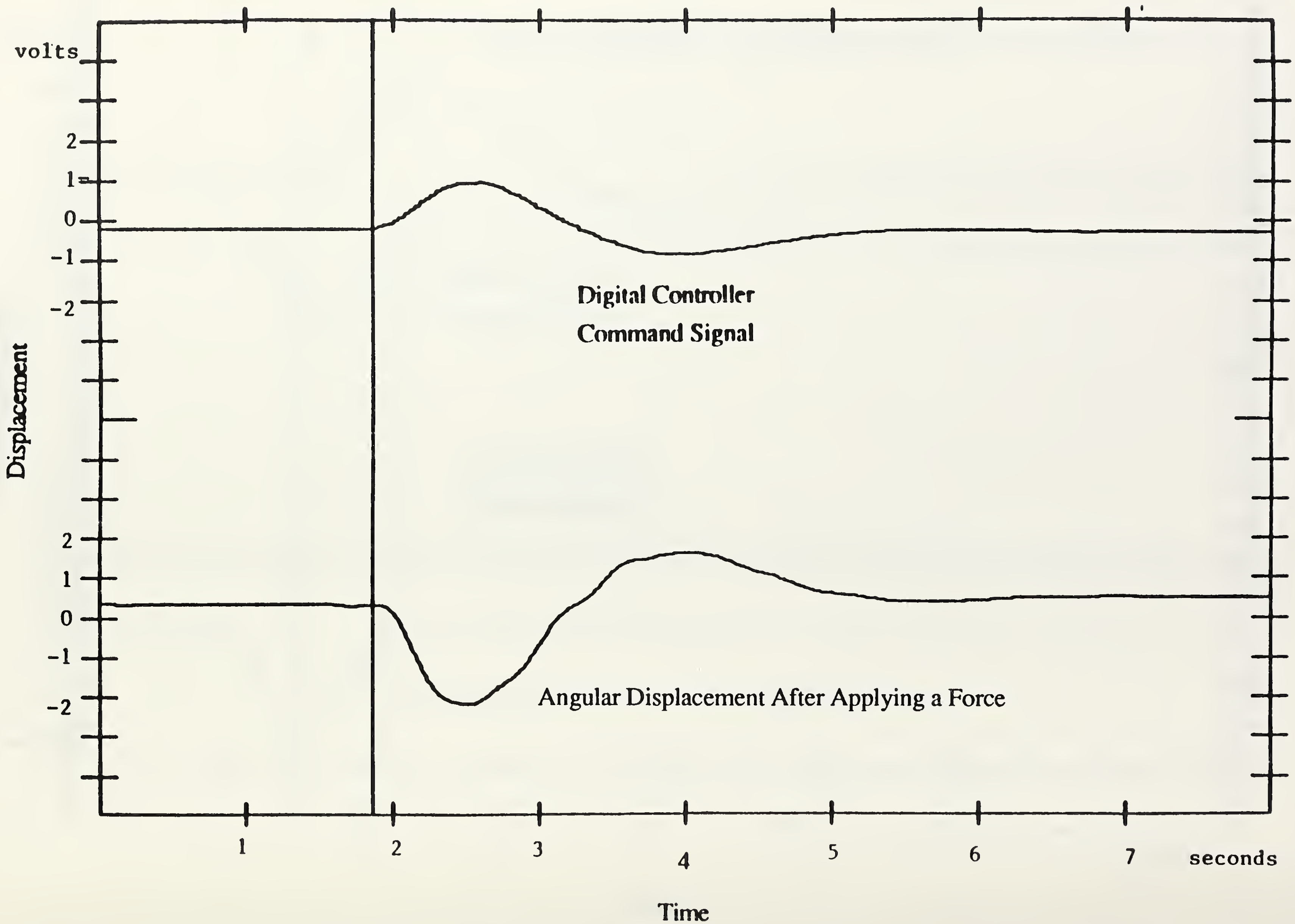


Figure 14. Compensated Output of the Rotary Joint

7. Summary

A vibration compensation system was designed, developed and evaluated for the SSMRC. The system reduced the vibration of the load platform caused by impulse excitations appearing at the load or at random points on the SSMRC. Also, the system can position the payload of the SSMRC to a location with the use of a digital controller.

The SSMRC project made use of many ideas in sensor design and motor control. Sensors used for the project were simple in theory and application, yet difficult to use in practice since noise was a large factor in many problems that arose. Also, the motors provided noise to the system which produced problems in sensor signals and, in turn, motor control. Since isolation of these noises were remedied, to the best of our knowledge, the sensors currently being used appear to work well with the system. The motors used are easily controlled with the servo amplifiers chosen. No reference material for the adjustment of the amplifier was provided which made the task of tuning the amplifiers very tedious. The overall housing of the crane is simply a standard 19" rack and does not allow 360° movement of the crane. This is a problem since only small movement (about 15°) of the rotary axis joint is available in this configuration.

Non-contact sensors, such as ultrasonic, inductive, capacitive, and vision sensors, could cure the problems caused by the currently used absolute positioning sensors. They are a good source of information to the computer and provide no external forces on the system (although these sensors have problems that accompany them as well). The motors used for all joints were modified to include tachometer coupling to the motor. This is unnecessary since many manufacturers include the tachometer and encoder in the housing of the motor. Also, as explained in Section 5, a more sophisticated algorithm for controlling the rotary axis should be tested and redesign of the rotary coupling between the motor and crane is necessary. If reconstruction of the rotary axis joint does take place in the future, reconstruction of the crane housing should also be done. The fixed upper platform (see Figure 6) should be mounted from a fixture which would allow for 360° movement of the crane for further micro-positioning research and development.

8. Acknowledgements

I would like to acknowledge the help of the following people: Mr. Nicholas Dagalakis for his support and efforts to complete the project on time. Mr. Azizolah Abrishamian for his help in design and implementation of the project. Mr. Wendell Wallace for the construction of electronic equipment. Mr. Mitch Tarica for the design and construction of the mechanical components necessary for the project. Mr. Roger Kilmer and Ms. Cheryl Hutchins for their additions to this paper. All of the above people worked long and hard for the completion of this fine tuned system in a short period of time. The robot crane technology program was funded by the Defense Advanced Research Projects Agency, Information Science and Technology Office, ARPA order 6380. Dr. Robert L. Rosenfeld was the project sponsor.

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[3] Dagalakis, N. G., Albus, J. S., Wang, B. L., Unger, J., and Lee, J. D., Stiffness Study of a Parallel Link Robot Crane for Shipbuilding Applications, Proceedings of the 7th International Conference on Offshore Mechanics and Arctic Engineering, Volume VI, Houston, TX, February 1988.

[4] Unger, J., and Dagalakis, N. G., Optimum Stiffness Study for a Parallel Link Robot Crane Under Horizontal Force, Proceedings of the Second International Symposium on Robotics and Manufacturing Research, Education and Applications, Albuquerque, NM, November 16-18, 1988.

[5] Dagalakis, N. G., Albus, J. S., Wang, B. L., Unger, J., and Lee, J. D., Stiffness Study of a Parallel Link Robot Crane for Shipbuilding Applications, accepted for publication in the ASME Transactions, Journal of Offshore Mechanics and Artic Engineering, 1989.

[6] Dagalakis, N. G., Albus, J. S., Goodwin, K. R., Lee, J. D., Tsai, T., Abrishamian, A., and Bostelman, R. V., Robot Crane Technology Program -- Final Report, NIST Technical Note 1267, National Institute of Standards and Technology, Gaithersburg, MD, July 1989.

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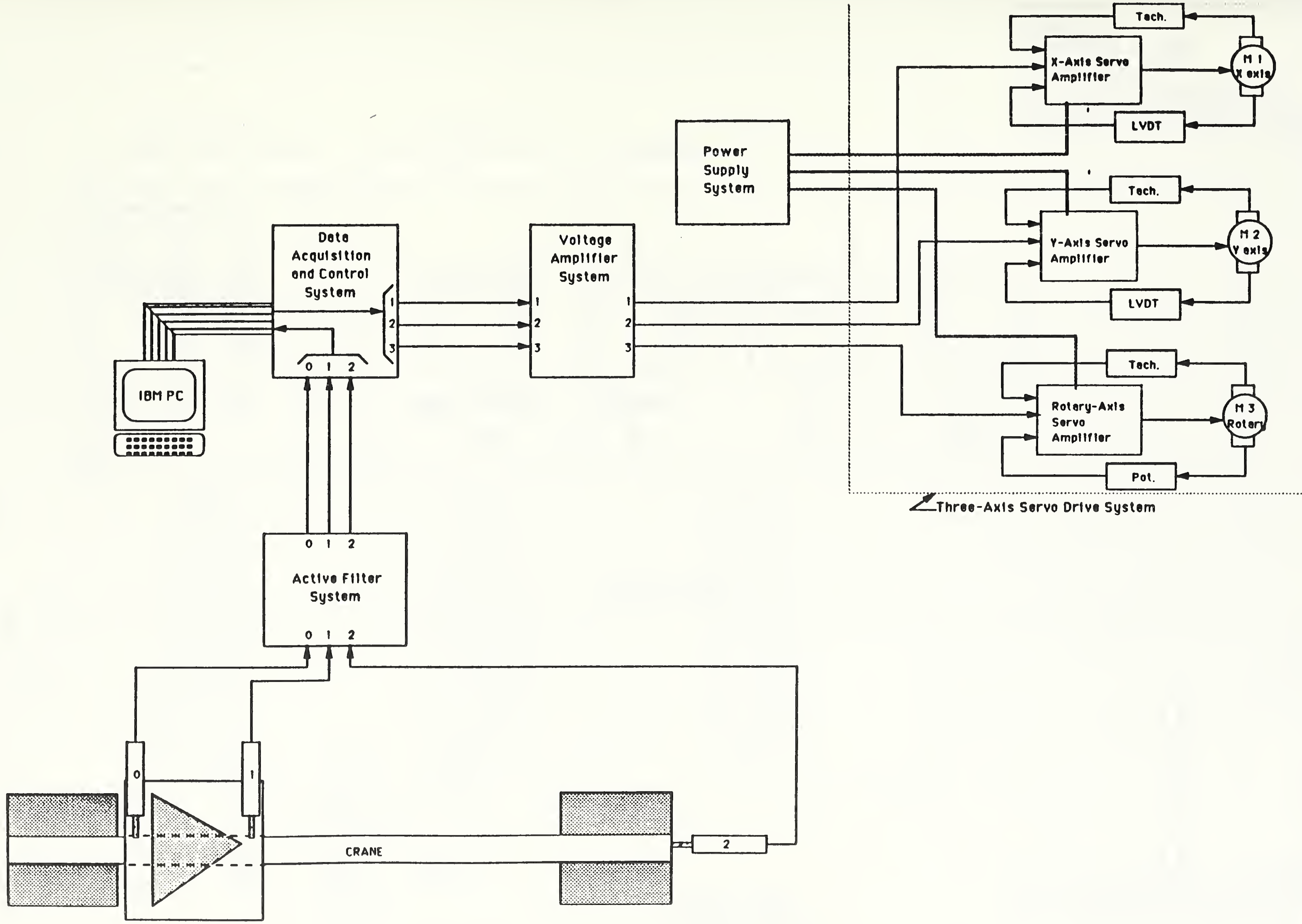
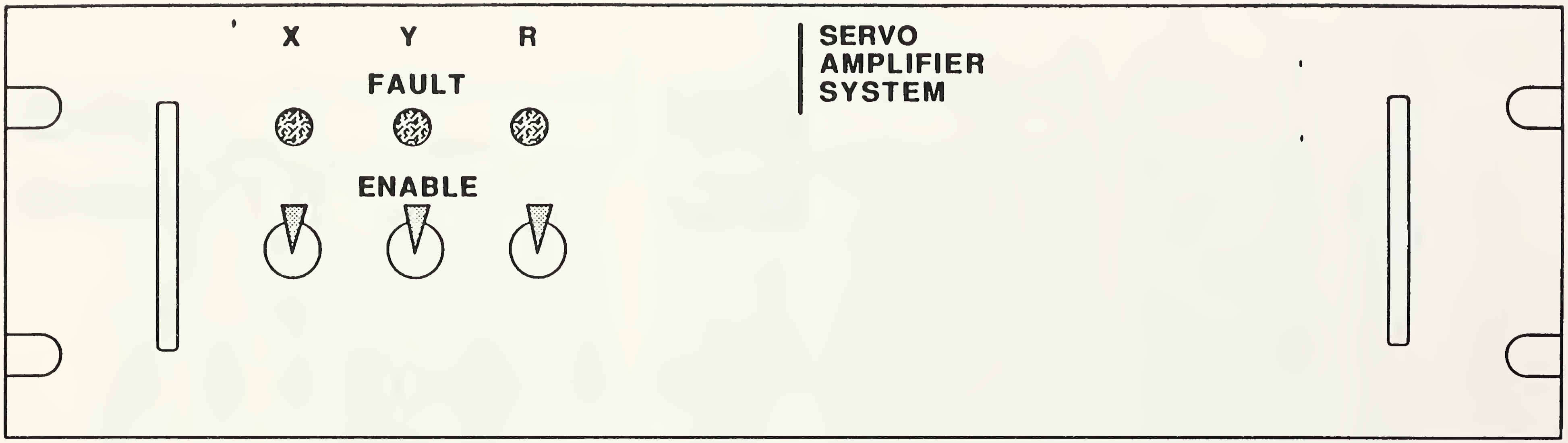
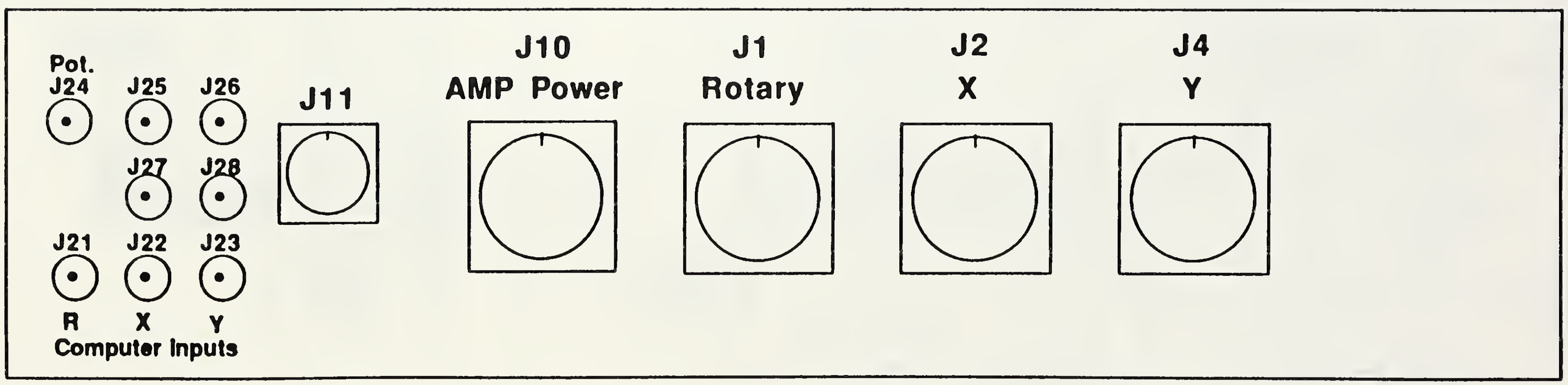


Electronics Diagram of the Small Scale Model Robot Crane Servo Control System

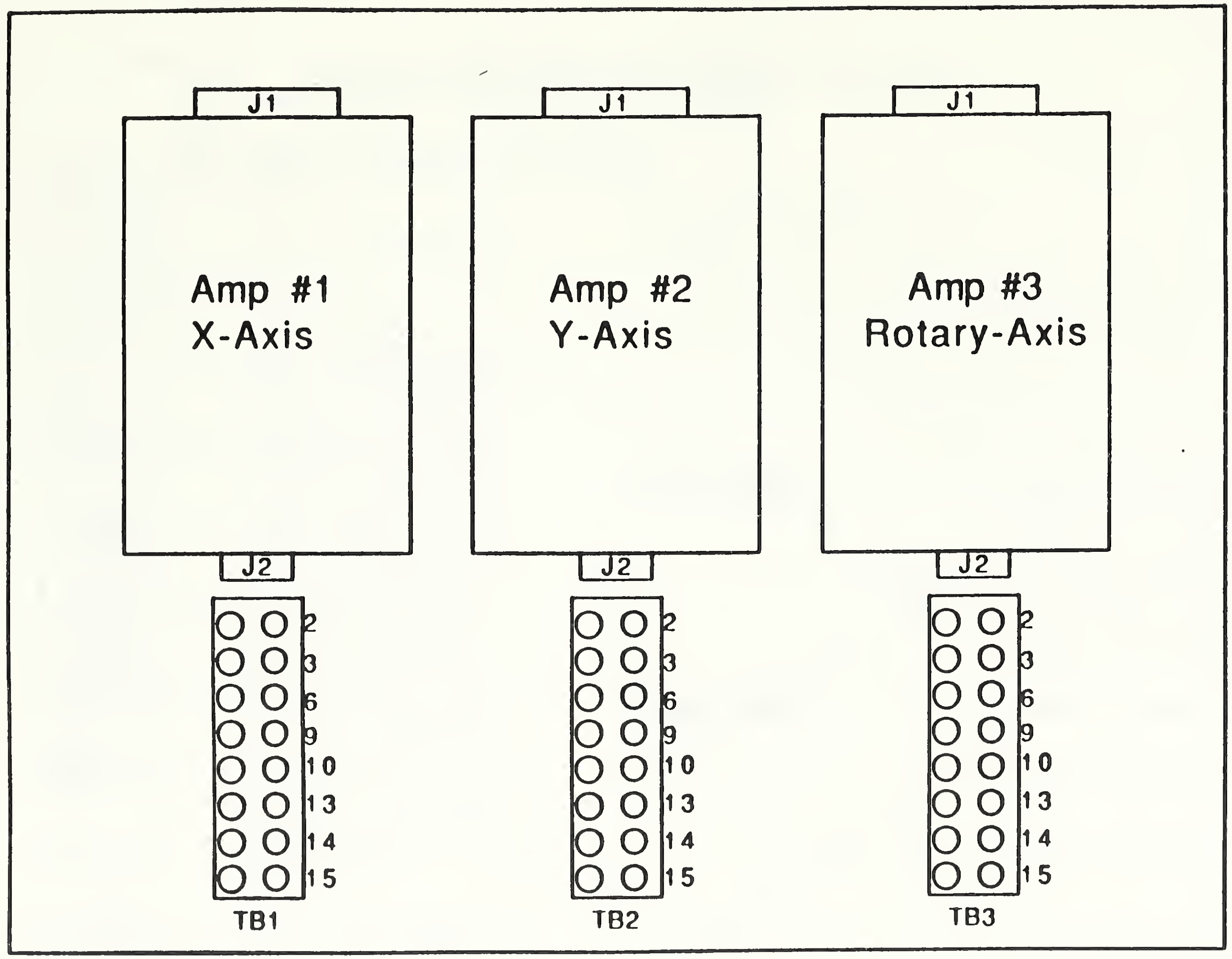


Front Panel



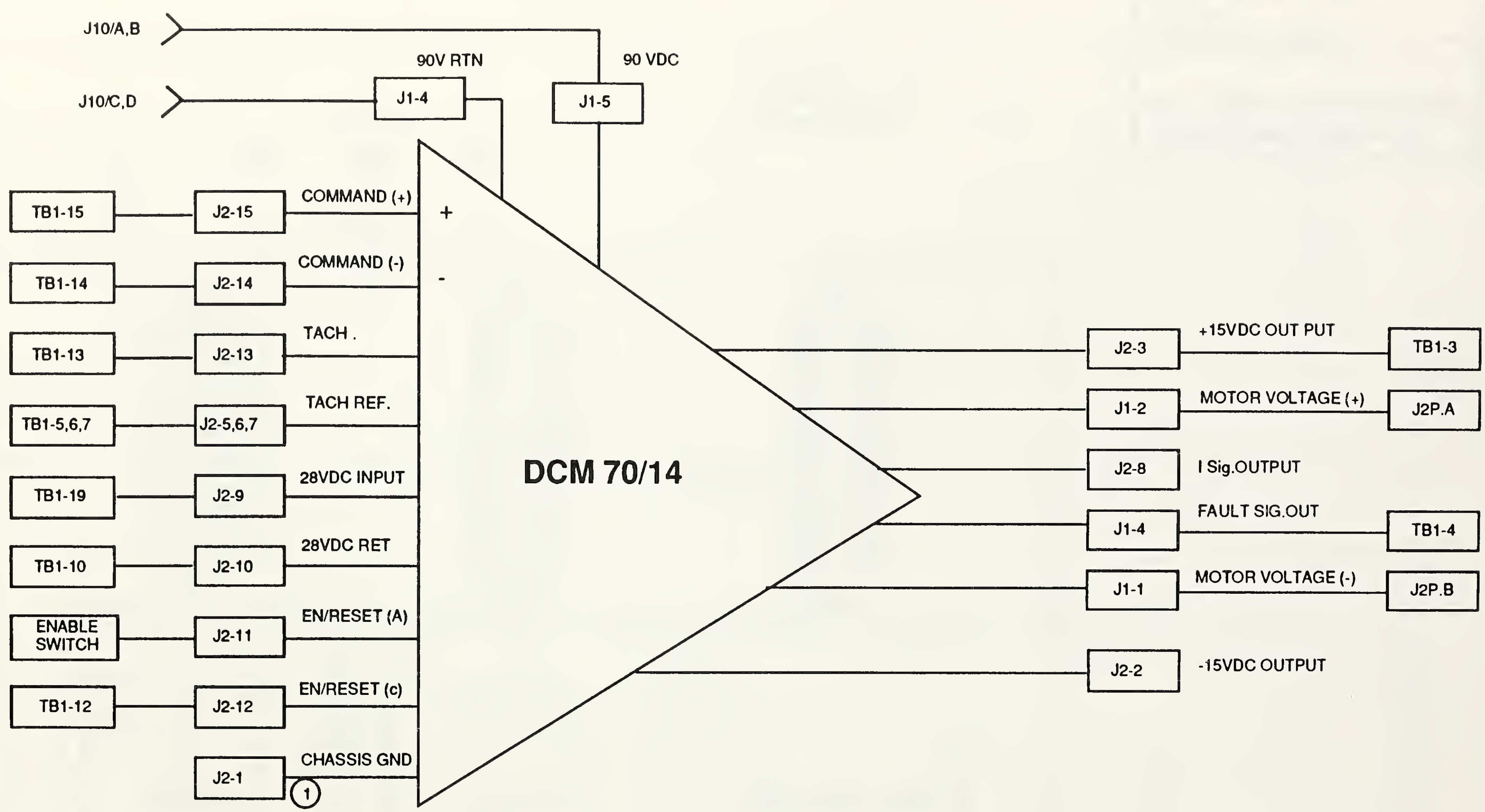
Back Panel

SERVO AMPLIFIER PANELS
for: 1/8 Scale Crane Model
Roger Bostelman
December 6, 1988
739.03



SERVO AMPLIFIER LAYOUT
for: 1/8th scale Model Crane

Roger Bostelman
739.03
December 6, 1988



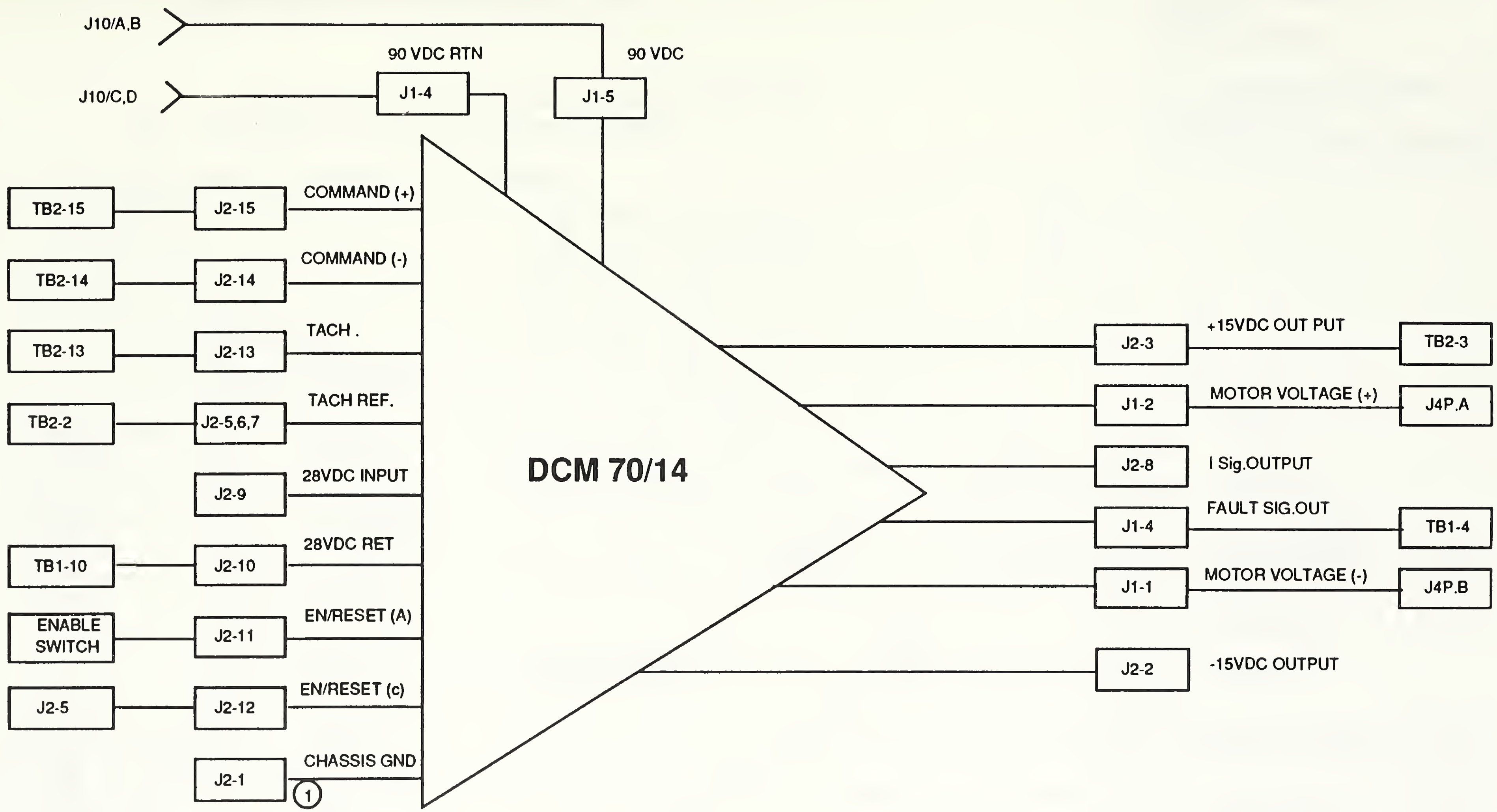
① Note: J2-1 connnects to J1-3 internally

② Note: J2-5,6,7 is common to +VDC internal supply.
J2-8 (I Sig. Output) return,and J2-4 (Fault sig. Output) return.

Reference: Inland Motor,"Operating Instructions", Figure 1

SERVO AMPLIFIER SCHEMATIC
for: X Axis
(1/8th Scale Crane Model)

Roger Bostelman
739.03
December 6, 1988



(1) Note: J2-1 connnects to J1-3 internally

(2) Note: J2-5,6,7 is common to +VDC internal supply.
J2-8 (I Sig. Output) return,and J2-4 (Fault sig. Output) return.

Reference: Inland Motor,"Operating Instructions",Figure 1

SERVO AMPLIFIER SCHEMATIC
for: Y Axis
(1/8th Scale Crane Model)

Roger Bostelman
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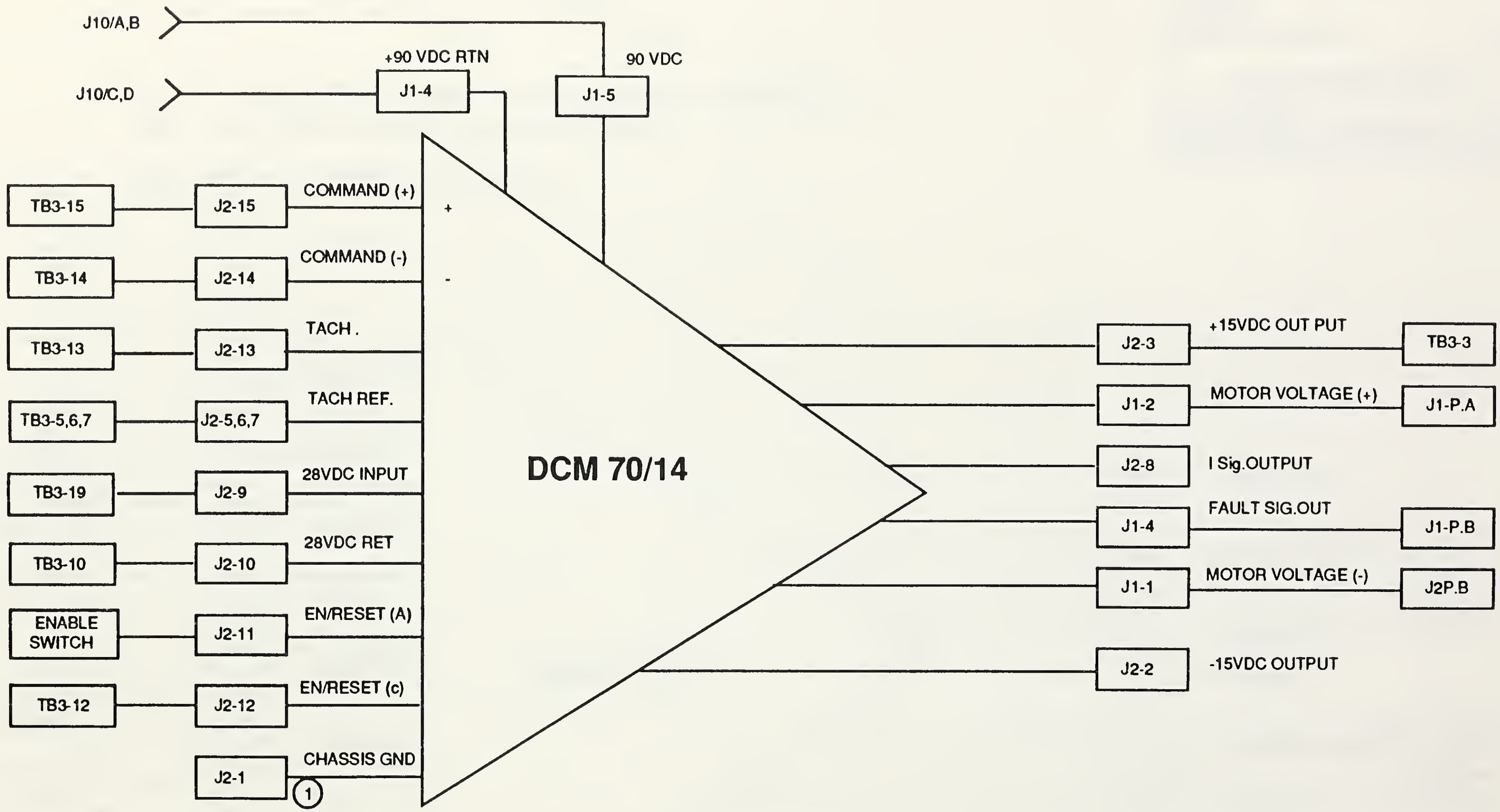
December 6, 1988



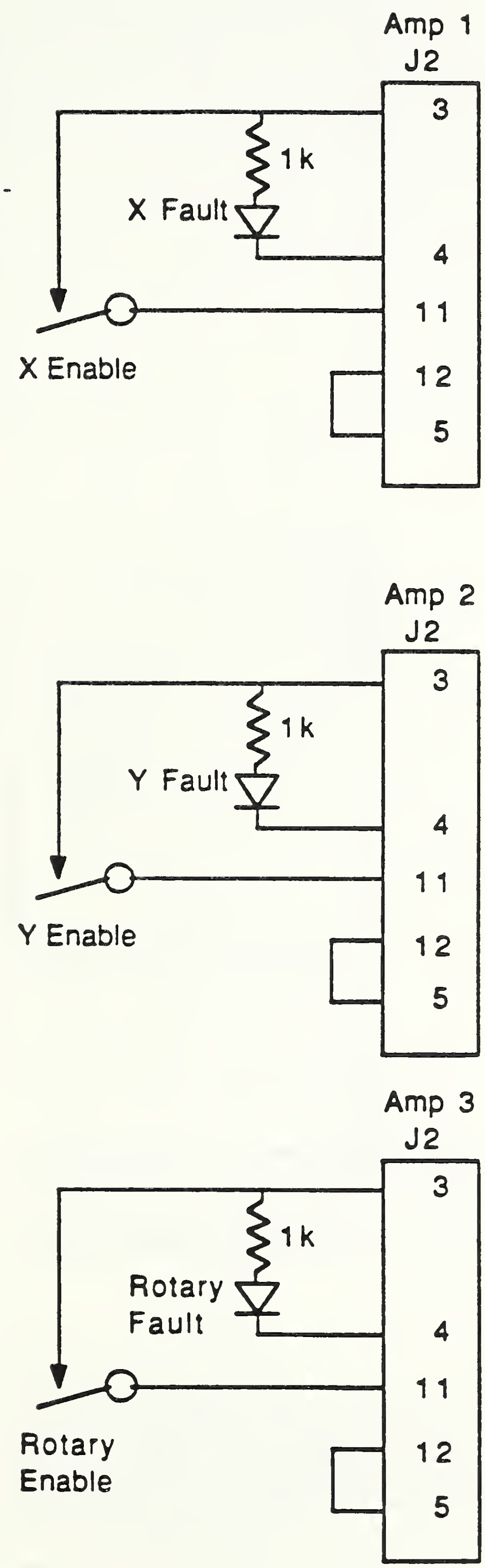
(1) Note: J2-1 connnects to J1-3 internally

(2) Note: J2-5,6,7 is common to +VDC internal supply.
J2-8 (I Sig. Output) return,and J2-4 (Fault sig. Output) return.

Reference: Inland Motor,"Operating Instructions", Figure 1

SERVO AMPLIFIER SCHEMATIC
for: Rotary Axis
(1/8th Scale Crane Model)

Roger Bostelman
739.03
December 6, 1988



FAULT AND ENABLE WIRING
for: 1/8th scale Model Crane

Roger Bostelman
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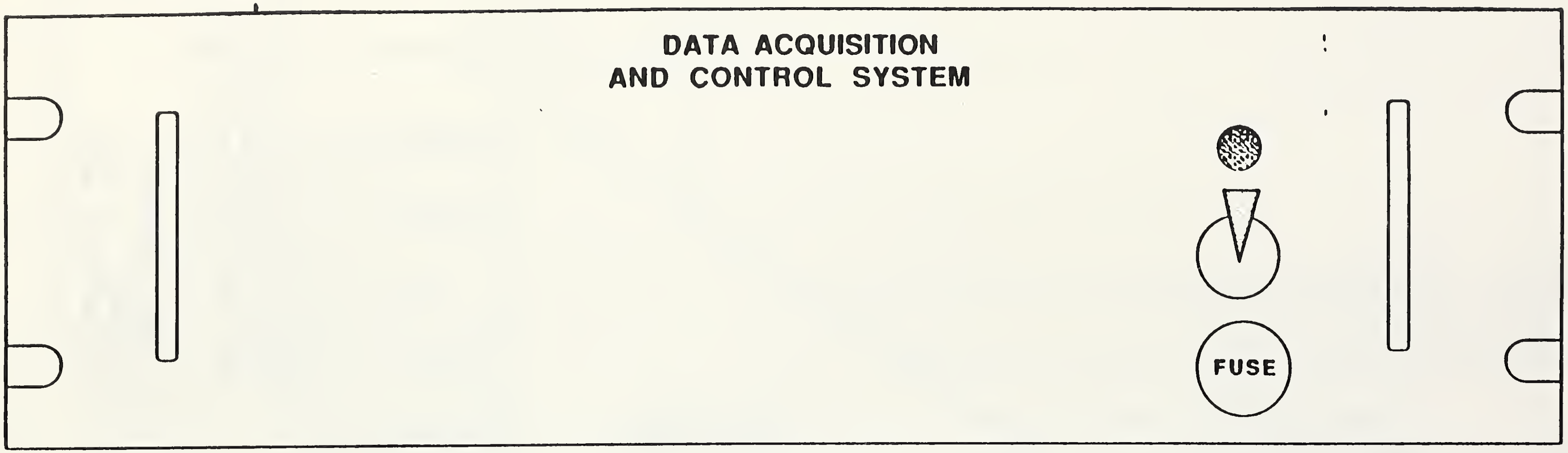
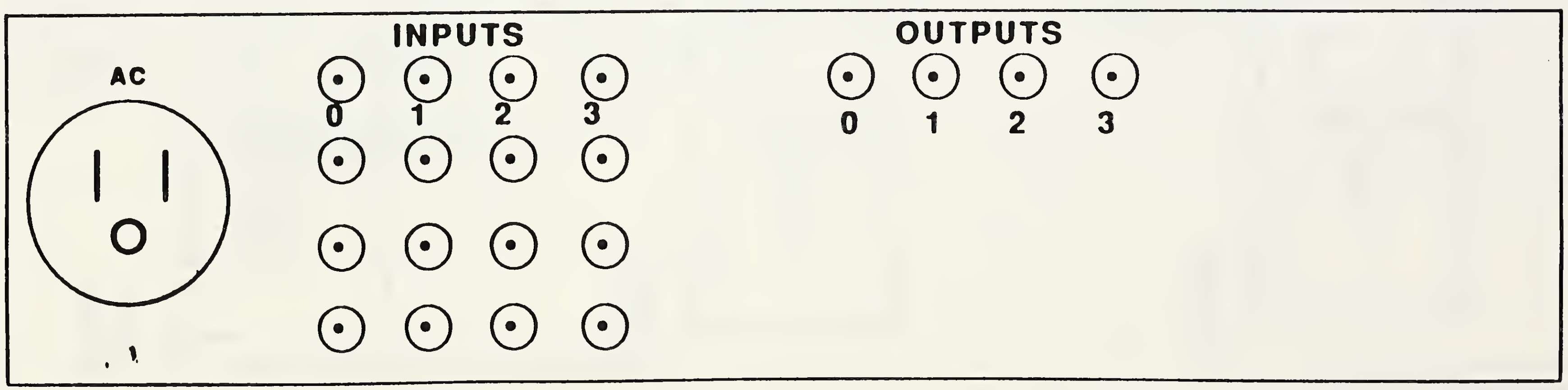
December 6, 1988

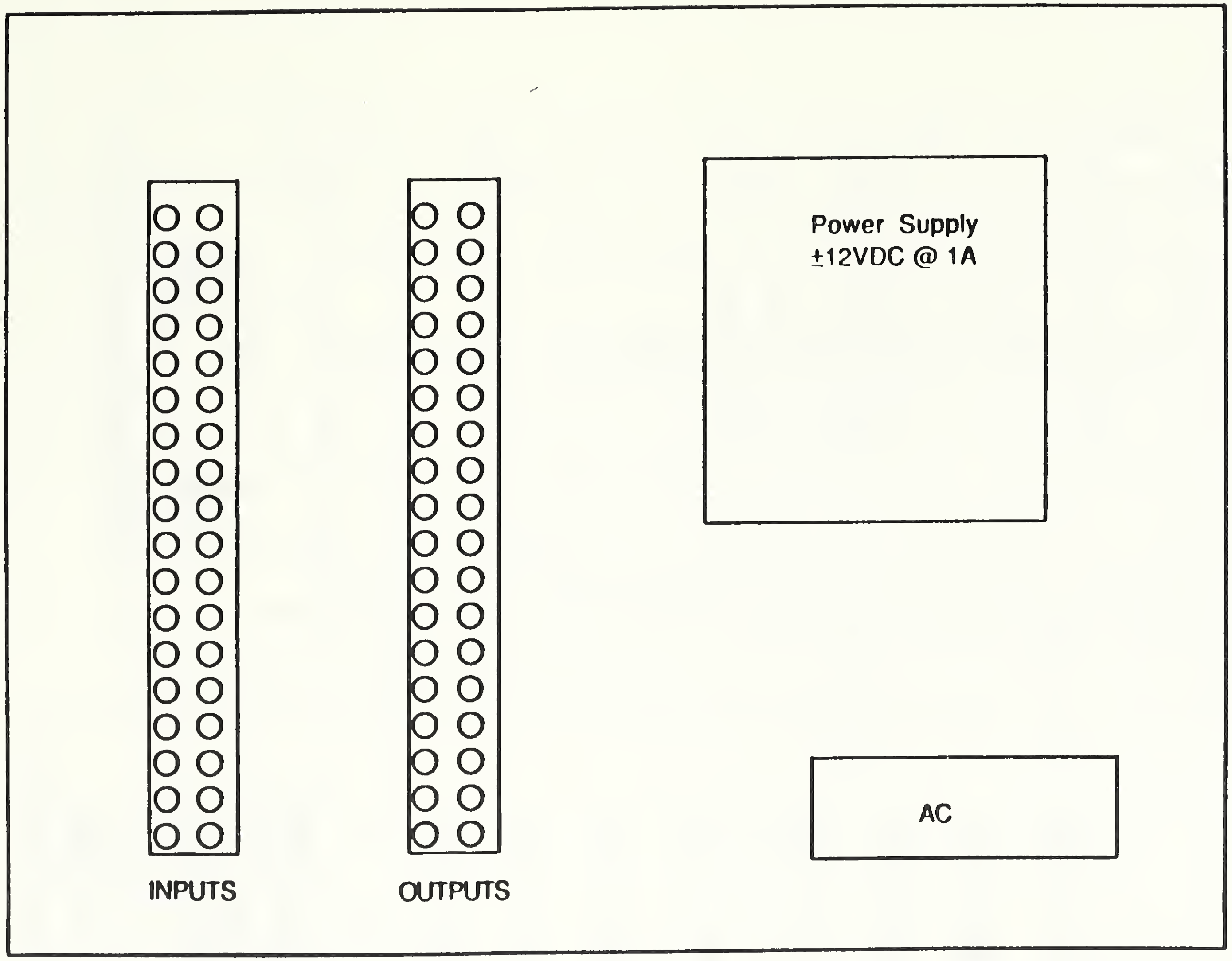


Front Panel

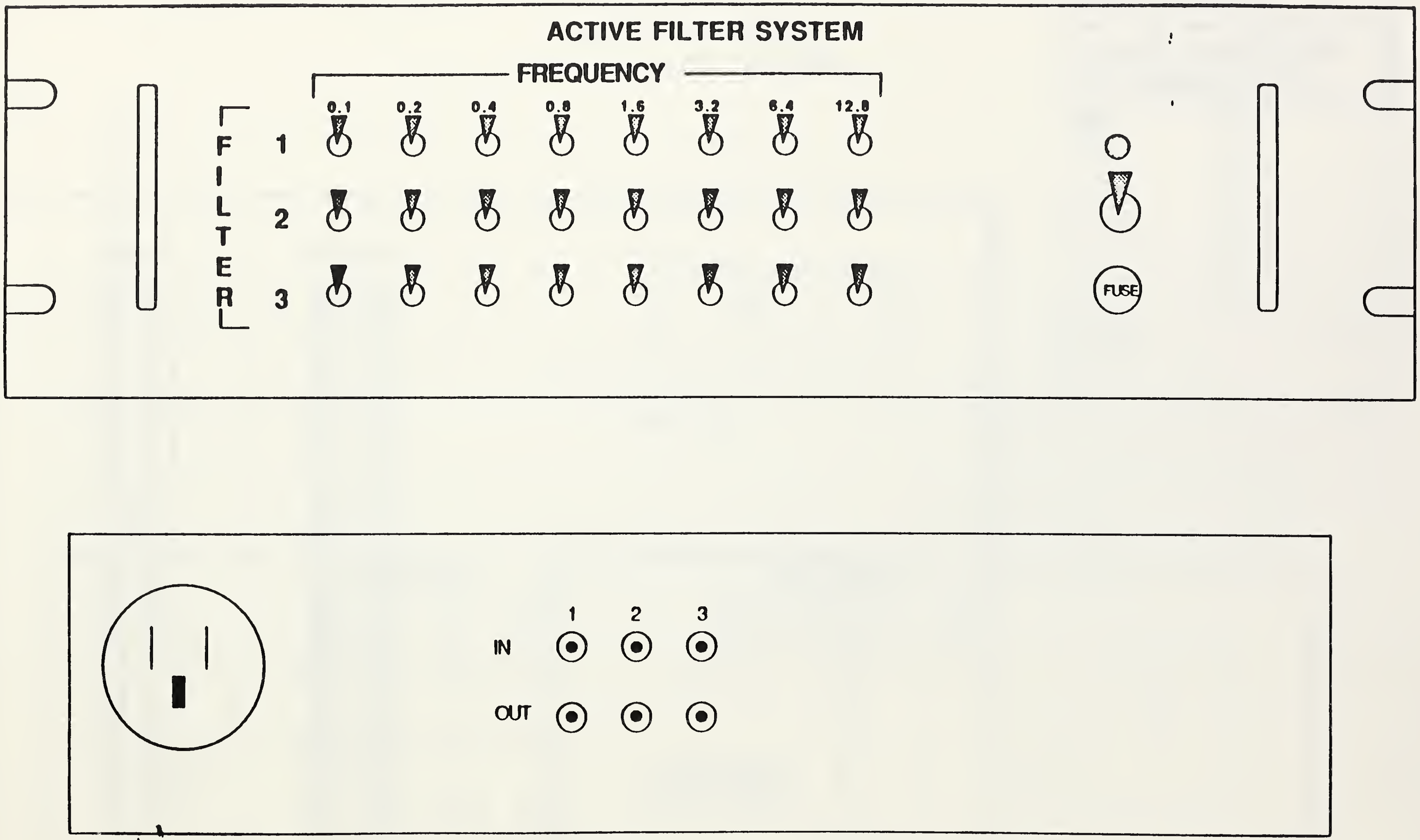


Back Panel

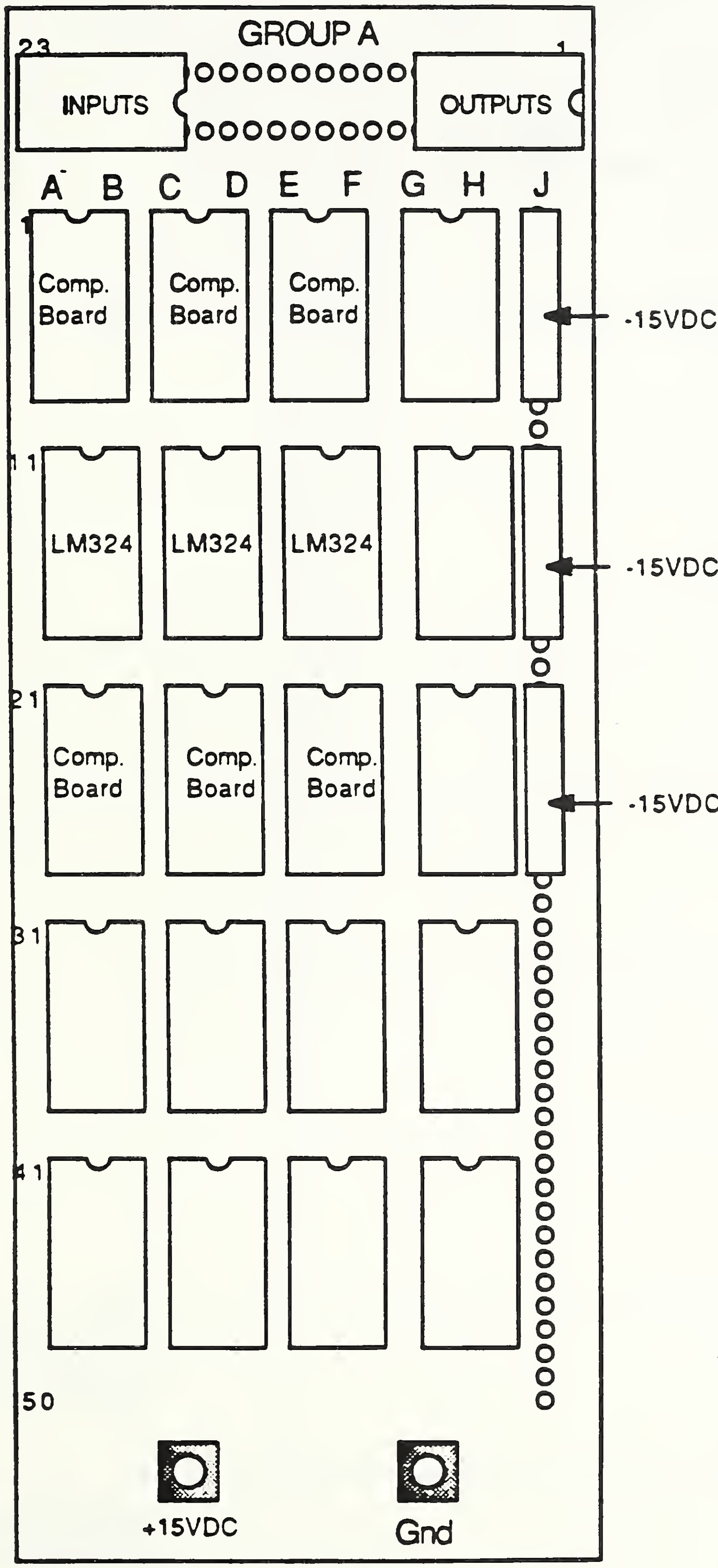
DATA ACQUISITION AND
CONTROL SYSTEM PANELS
for: 1/8 Scale Crane Model
Roger Bostelman
December 6, 1988
739.03



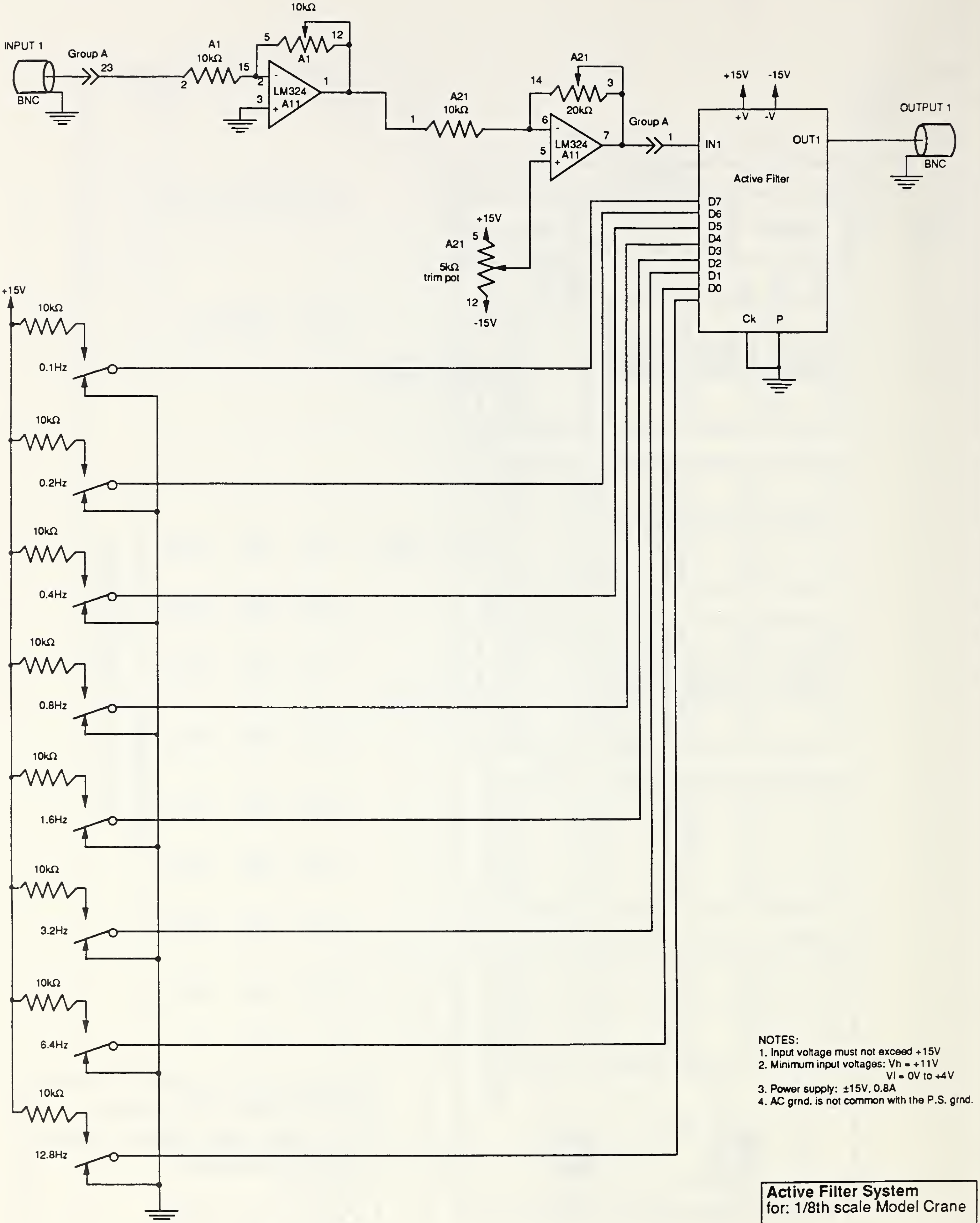
DATA ACQISITION AND
CONTROL SYSTEM LAYOUT
for: 1/8th scale Model Crane
Roger Bostelman
739.03
December 7, 1988



Front and Back Panels
for Active Filter System
(1/8th Scale Crane)
Roger Bostelman
739 03
October 4, 1988



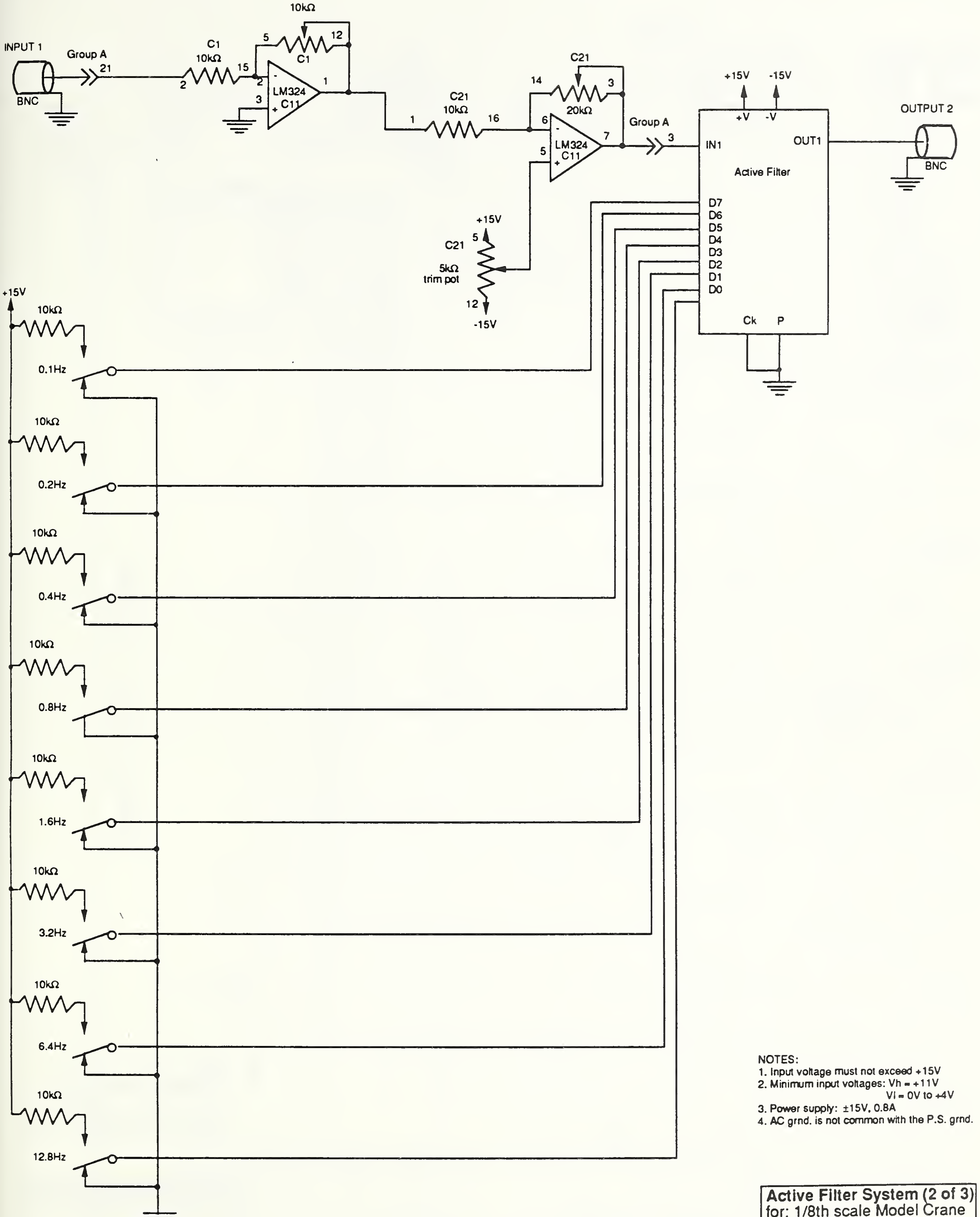
Active Filter IC Layout
for: 1/8th scale Model Crane
Roger Bostelman
739.03
October 12, 1988
Revised: Dec. 7, 1988



NOTES:
1. Input voltage must not exceed +15V
2. Minimum input voltages: Vh = +11V
Vl = 0V to +4V
3. Power supply: ±15V, 0.8A
4. AC grnd. is not common with the P.S. grnd.

Active Filter System
for: 1/8th scale Model Crane

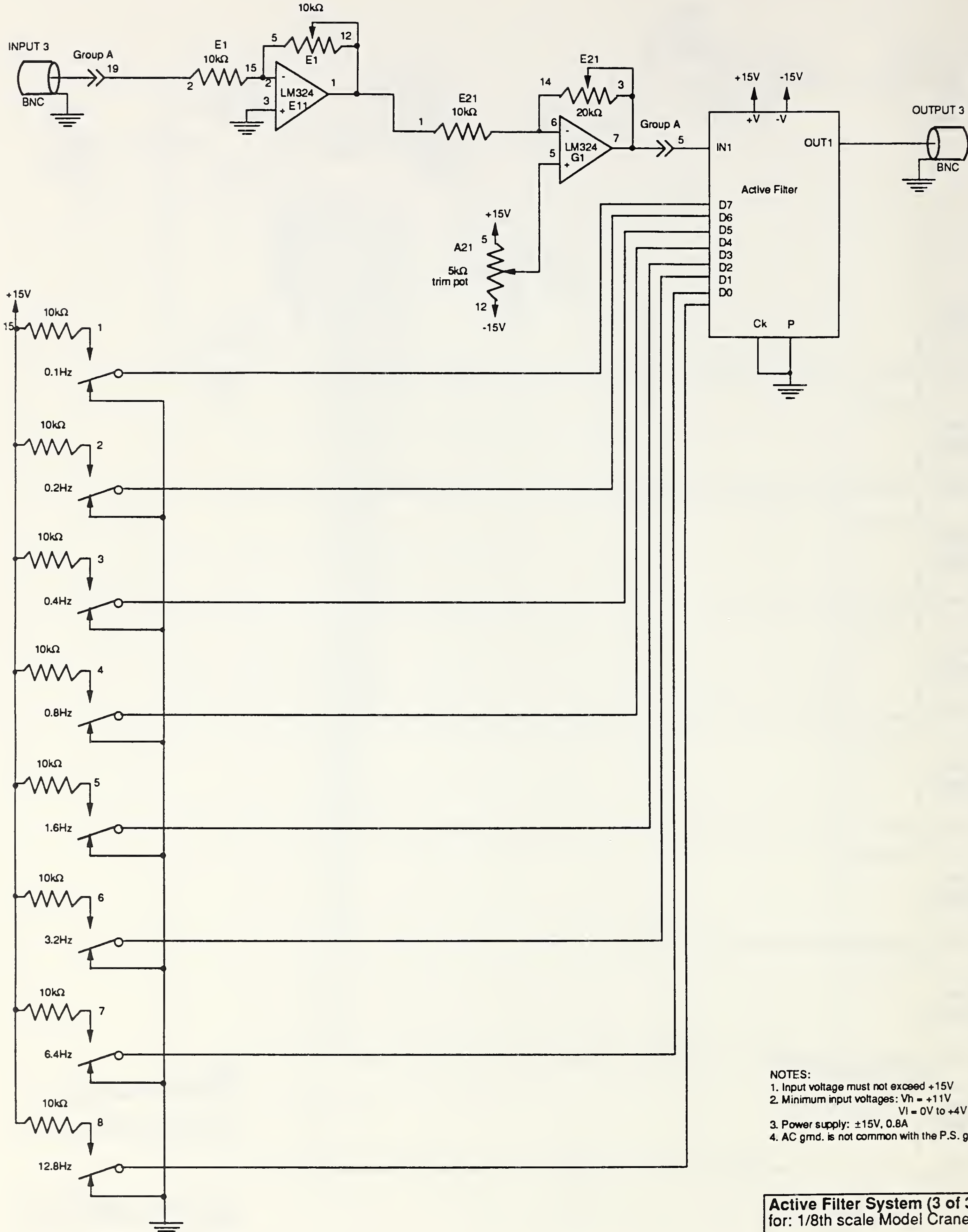
Roger Bostelman
739.03
October 11, 1988



NOTES:
1. Input voltage must not exceed +15V
2. Minimum input voltages: Vh = +11V
Vl = 0V to +4V
3. Power supply: ±15V, 0.8A
4. AC grnd. is not common with the P.S. grnd.

Active Filter System (2 of 3)
for: 1/8th scale Model Crane

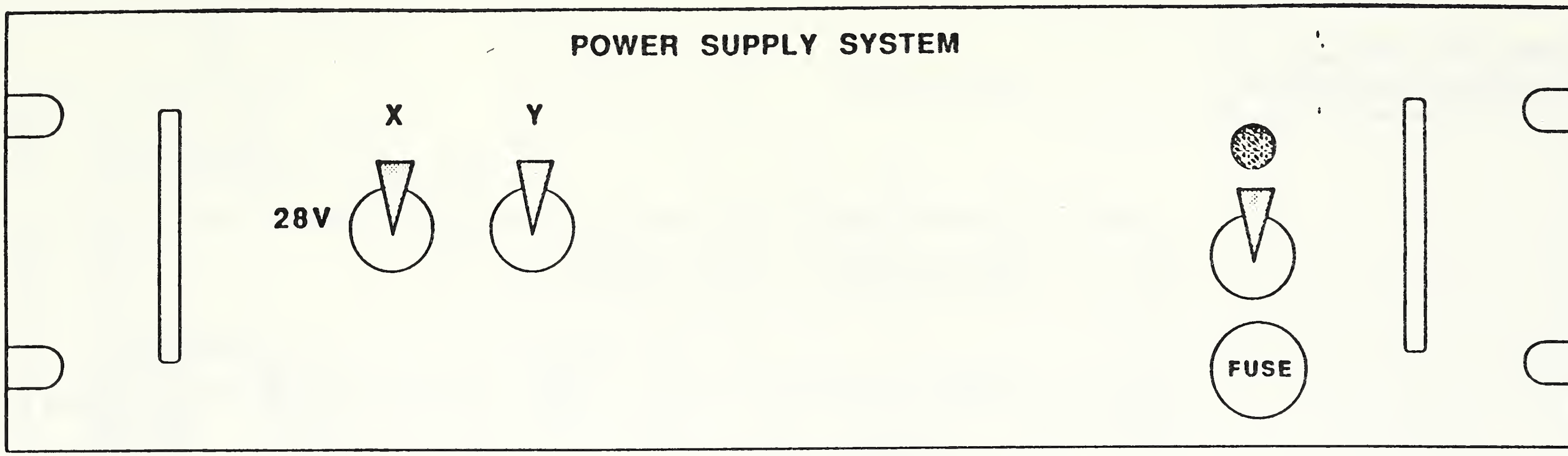
Roger Bostelman
739.03
October 11, 1988



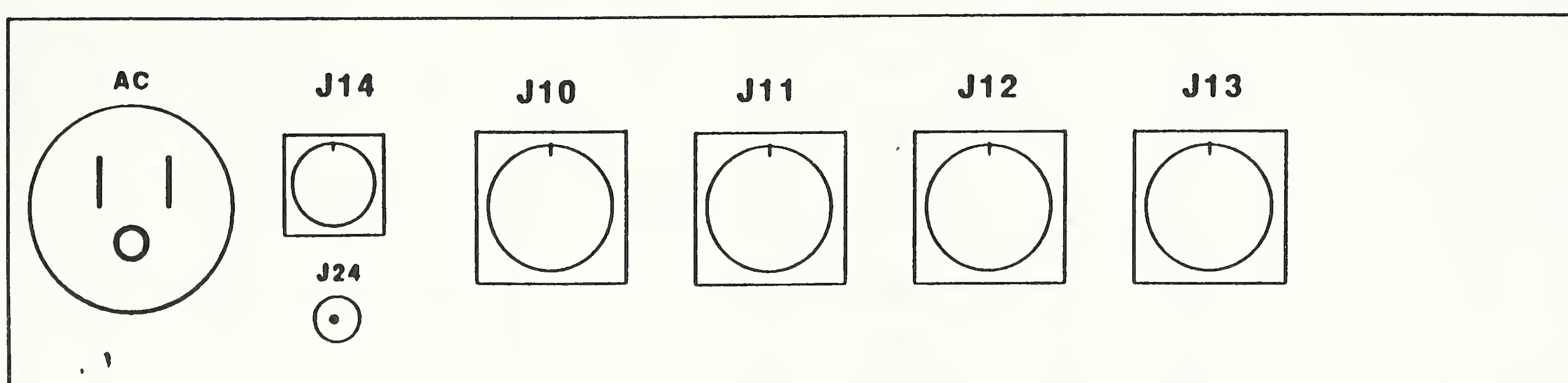
NOTES:
1. Input voltage must not exceed +15V
2. Minimum input voltages: Vh = +11V
Vl = 0V to +4V
3. Power supply: ±15V, 0.8A
4. AC grnd. is not common with the P.S. grnd.

Active Filter System (3 of 3)
for: 1/8th scale Model Crane

Roger Bostelman
739.03
October 11, 1988

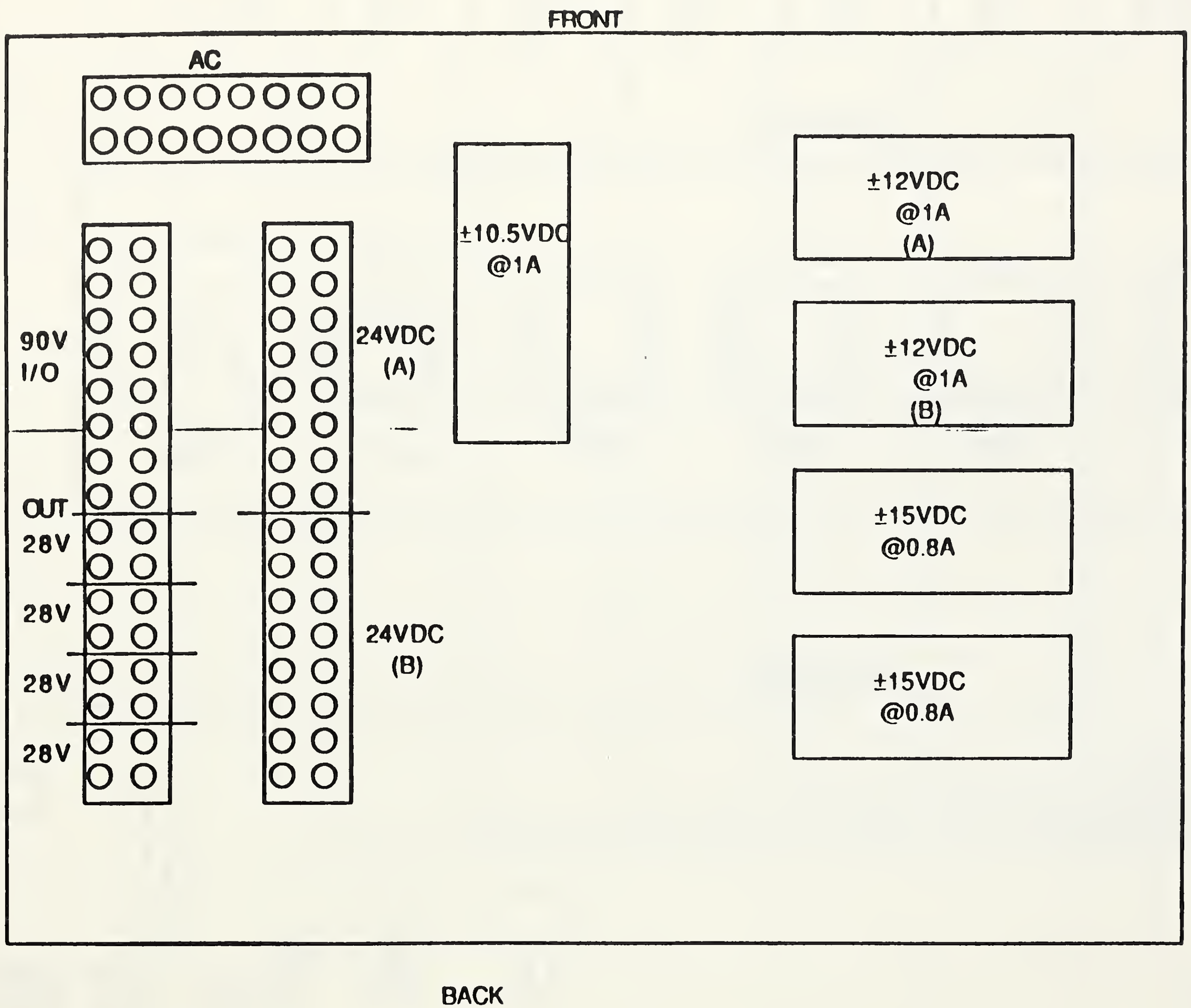


Front Panel



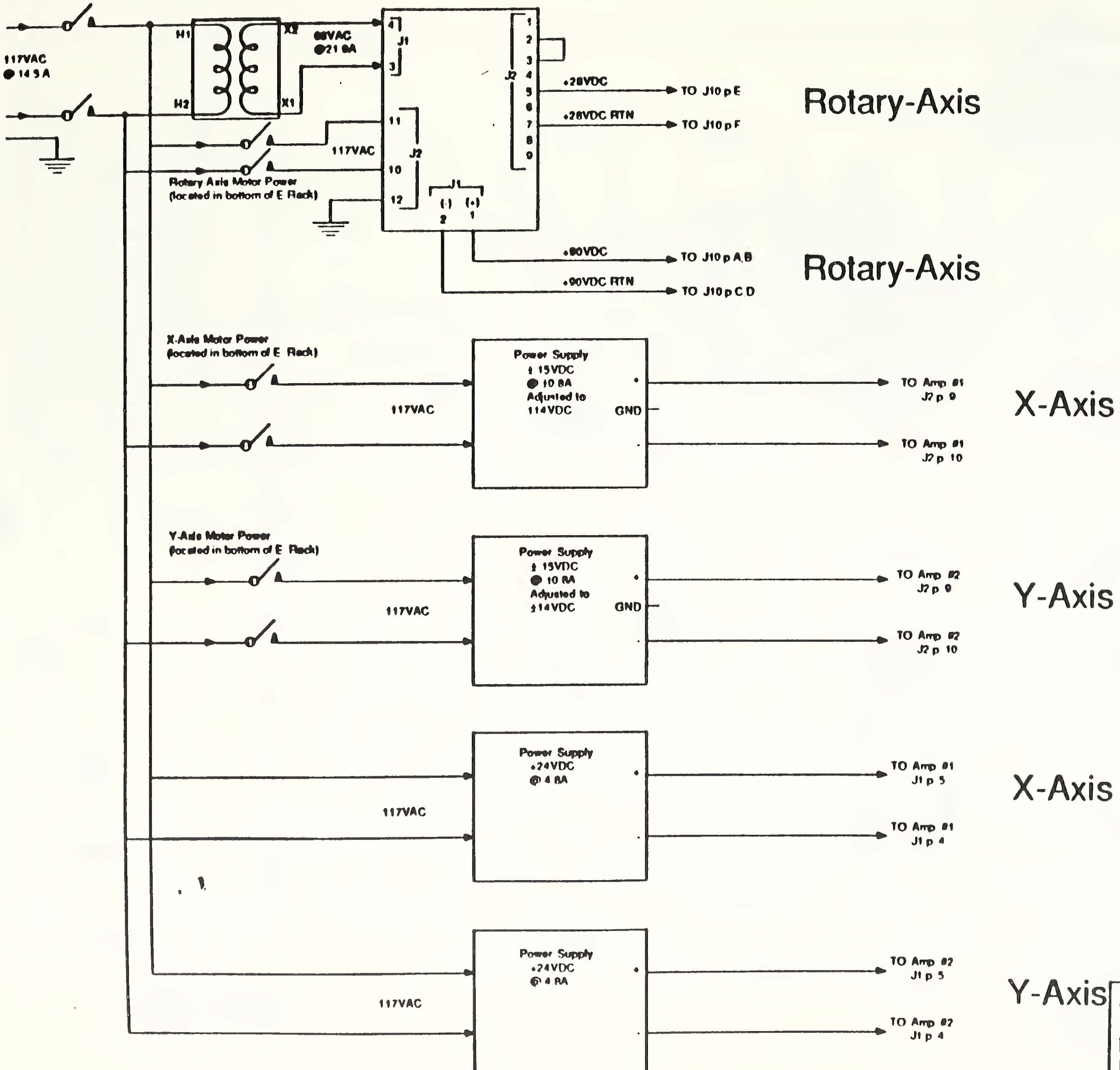
Back Panel

POWER SUPPLY SYSTEM PANELS
for: 1/8 Scale Crane Model
Roger Bostelman
December 6, 1988
739.03

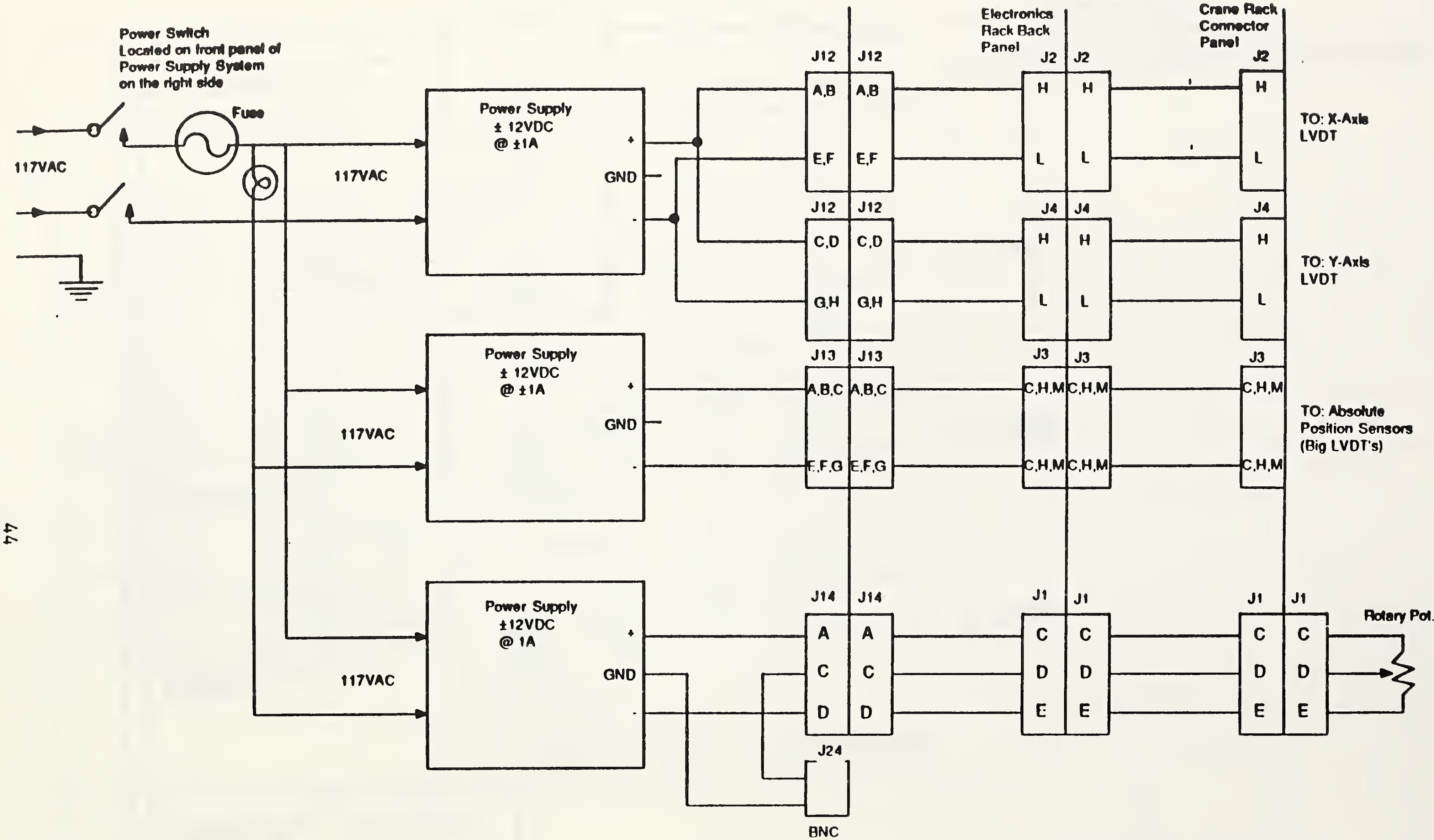


POWER SUPPLY SYSTEM LAYOUT
for: 1/8th scale Model Crane

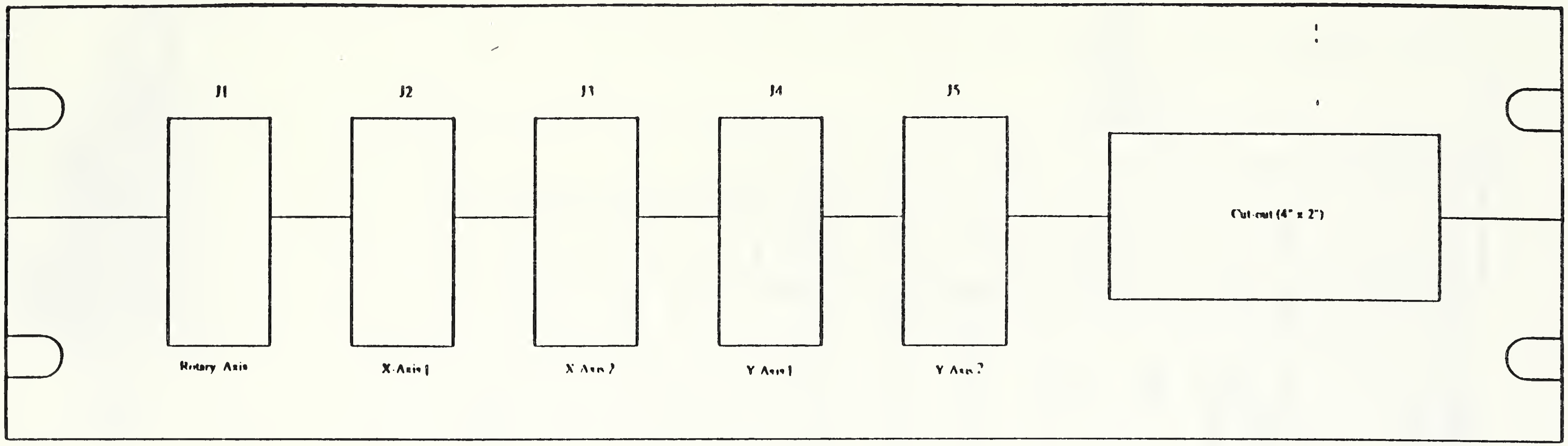
Roger Bostelman
739.03
December 7, 1988



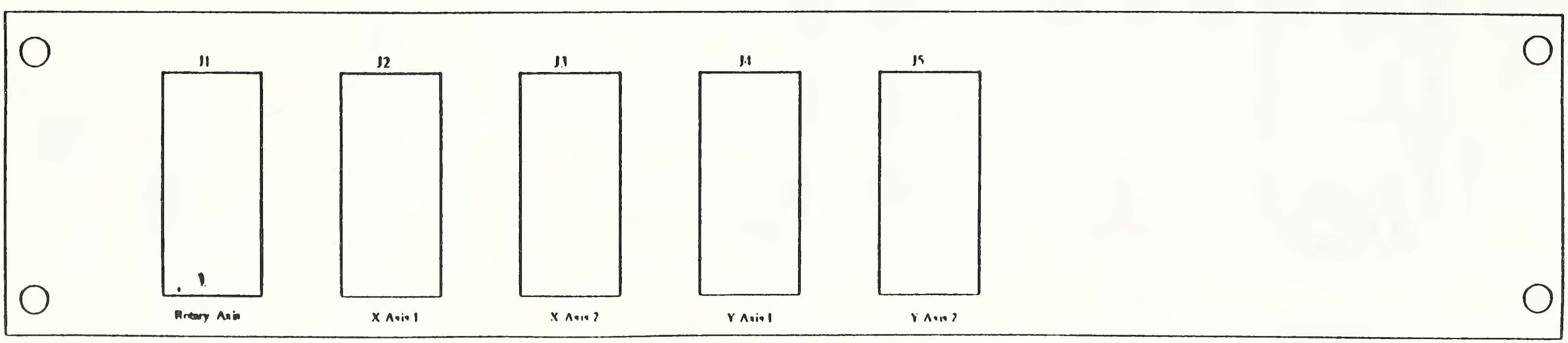
SERVO AMPLIFIER POWER SUPPLIES
for: 1/8 Scale Crane Model
Roger Bostelman
December 6, 1988
739.03



SENSOR POWER SUPPLIES
for: 1/8 Scale Crane Model
Roger Bostelman
December 6, 1988
739.03

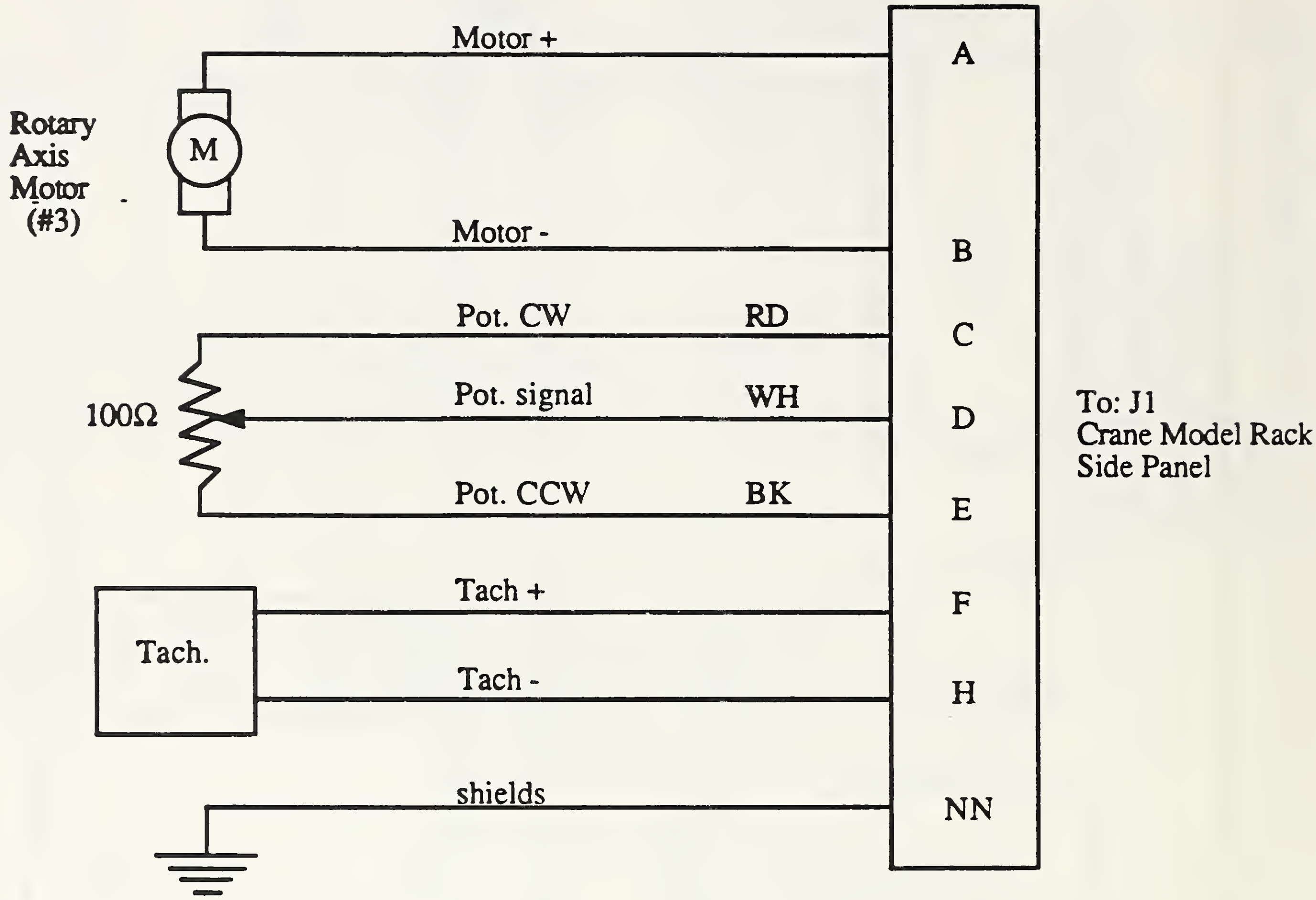


Electronic Rack Back Panel



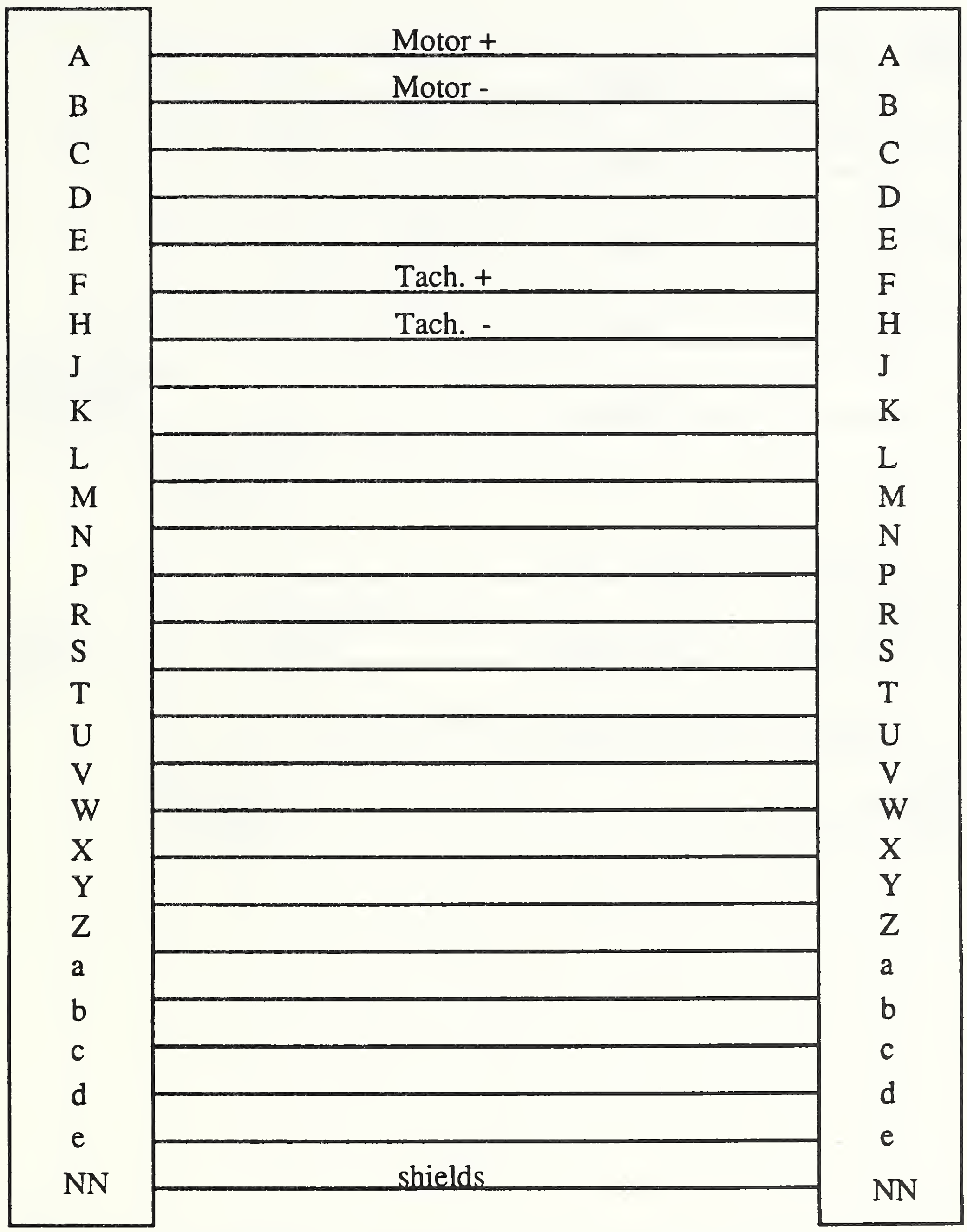
Crane Model Rack Side Panel

Connecter Panels
for 1/8 Scale Crane Model
Roger Bostelman
August 8, 1988



Notes:
1. Connectors: 56p. ELCO female
2. Keying: Top - 1, Bottom - 1

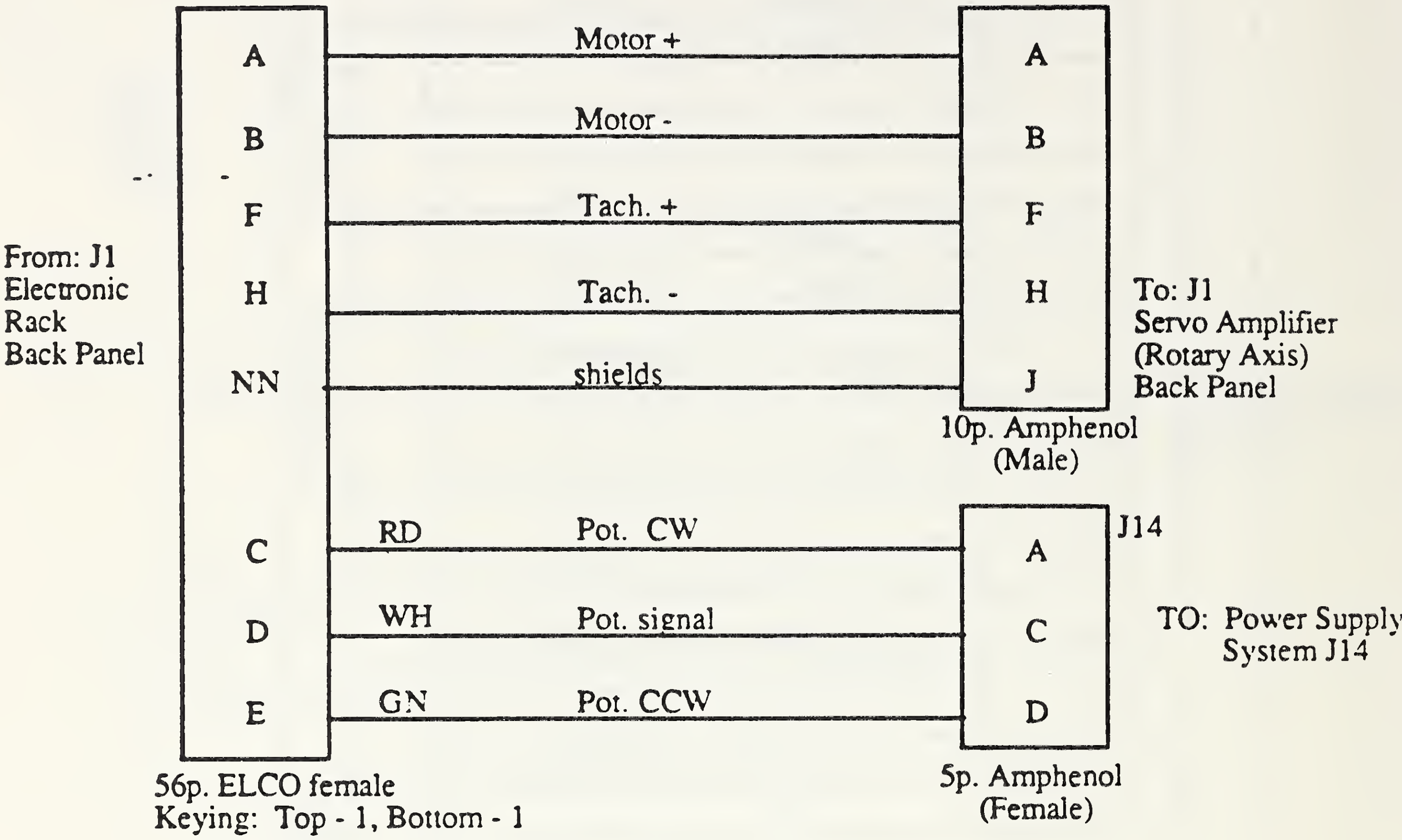
J1 Motor and Sensor Pinouts
for: Rotary Axis Motor and Sensors
(1/8 Scale Crane Model)
Roger Bostelman
August 9, 1988
739.01



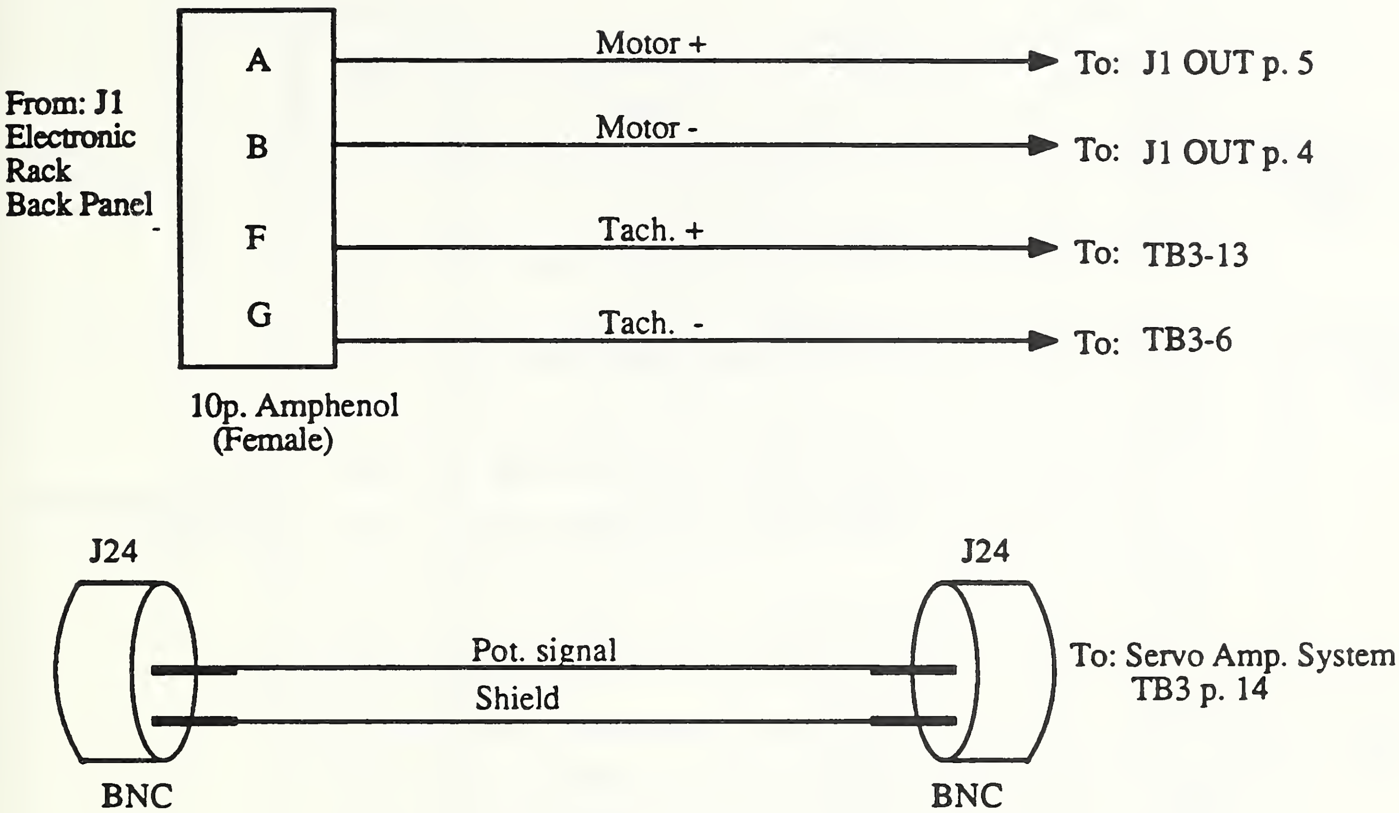
Notes:
1. Cable: 12Pair, shielded Belden
2. Connectors: 56p. ELCO female
3. Keying: Top - 1, Bottom - 1

J1 Cable drawing
for: Rotary Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
August 8, 1988
739.01

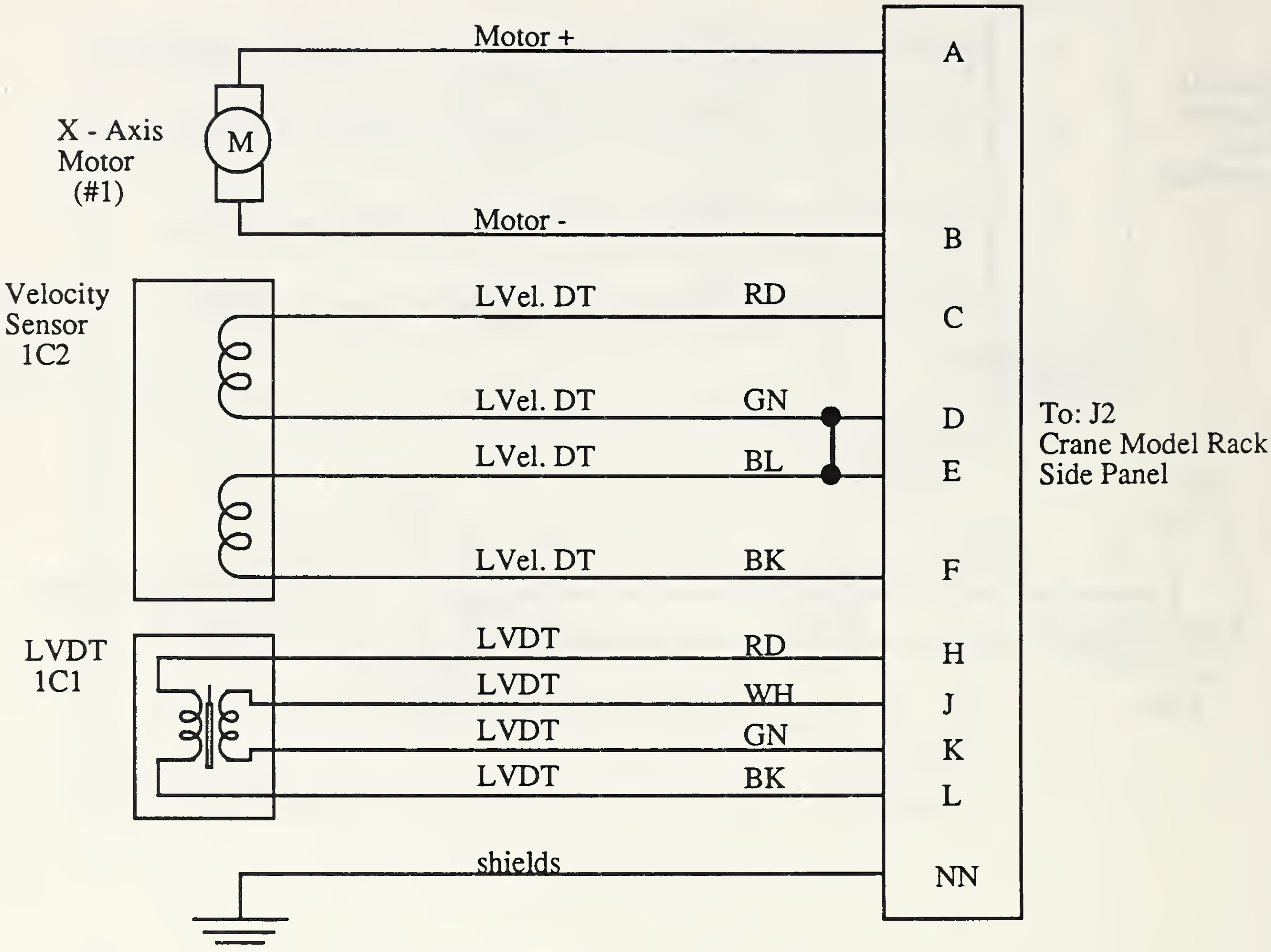


J1 Cable to Servo Amp.
for: Rotary Axis Motor and Sensors
(1/8 Scale Crane Model)
Roger Bostelman
October 19, 1988
Revised: Dec. 7, 1988
739.03



Notes:
1. Connections are made to the Amplifier System unless otherwise noted.
2. Pot. P. S., LVDT P. S. and computer all have ground connections tied together and are not common with the Servo Amplifiers.

J1 Rotary Connections to Electronics
for: Rotary Axis Motor and Sensors
(1/8 Scale Crane Model)
Roger Bostelman
August 8, 1988
739.01
(Revised Dec. 7, 1988)



Notes:
1. Connectors: 56p. ELCO female
2. Keying: Top - 1, Bottom - 2

J2 Motor and Sensor Pinouts
for: X - Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
August 9, 1988
739.01

From: J2
Crane Rack

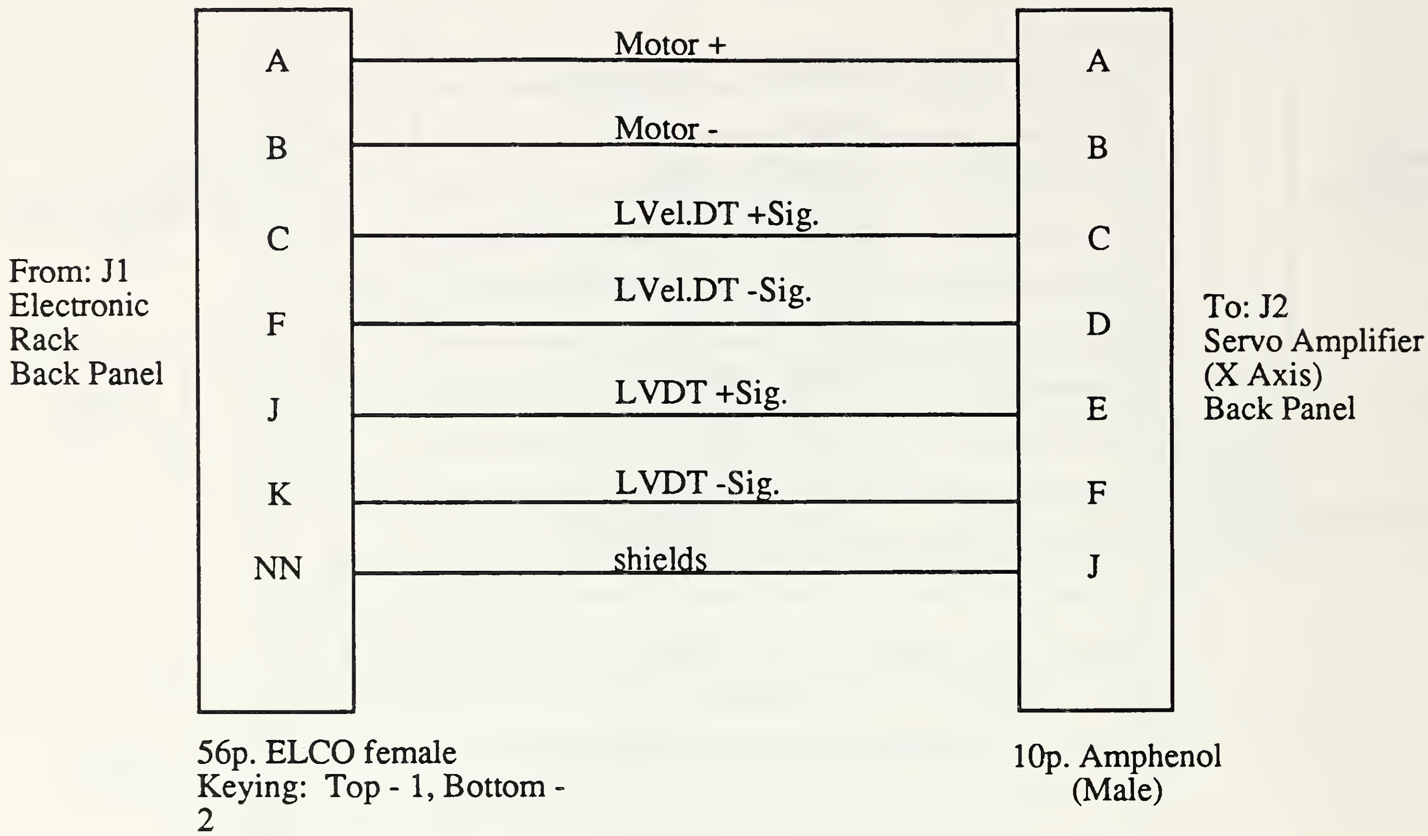
To: J2
Electronics Rack

From: J2 Crane Rack		To: J2 Electronics Rack
A	Motor +	A
B	Motor -	B
C	LVel. DT Sig. +	C
D	LVel. DT CT	D
E	LVel. DT CT	E
F	LVel. DT Sig. -	F
H	LVDT +24VDC	H
J	LVDT Sig. +	J
K	LVDT Sig. -	K
L	LVDT +24VDC RTN	L
M		M
N		N
P		P
R		R
S		S
T		T
U		U
V		V
W		W
X		X
Y		Y
Z		Z
a		a
b		b
c		c
d		d
e		e
NN	shields	NN

Notes:
1. Cable: 12Pair, shielded Belden
2. Connectors: 56p. ELCO female
3. Keying: Top - 1, Bottom - 2

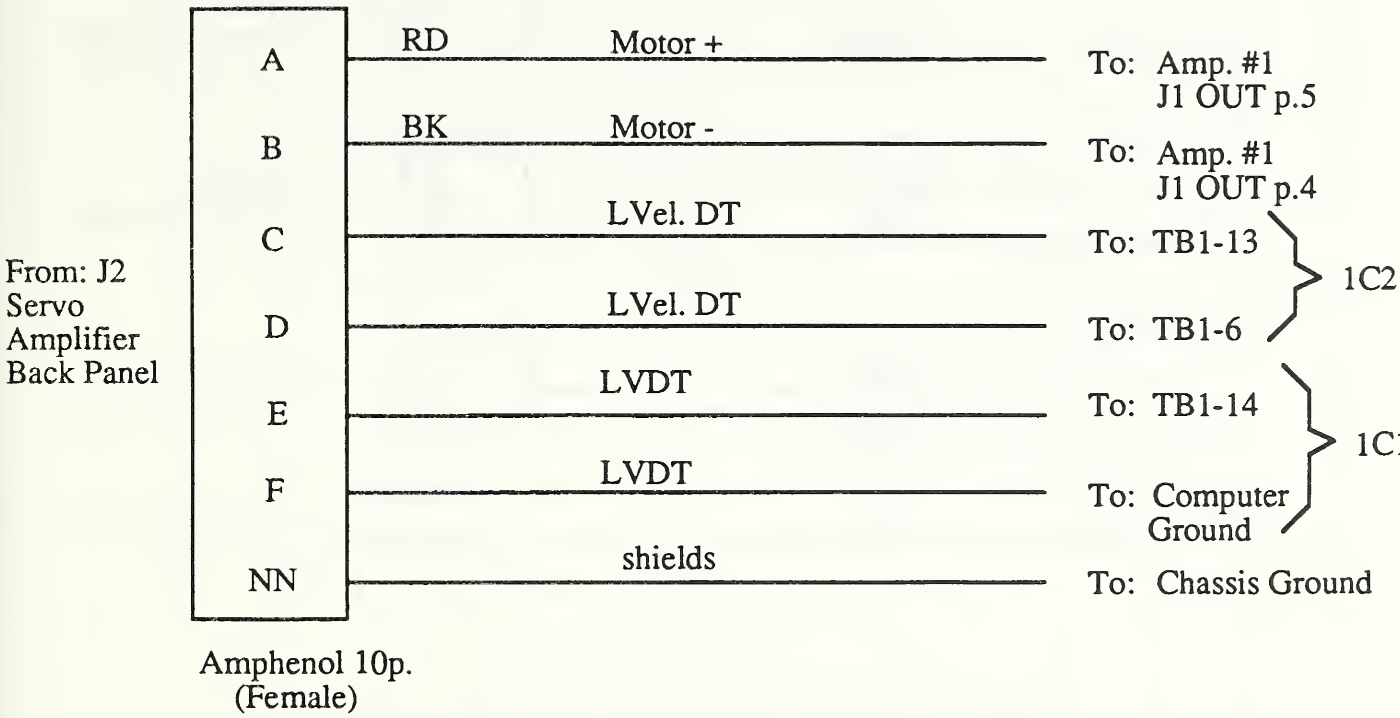
J2 Cable drawing
for: X - Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
August 8, 1988
739.01



J2 Servo Amplifier Cable
for: X Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
October 20, 1988
Revised: Dec. 7, 1988
739.03



Notes:
1. X-Axis corresponds to Amplifier 1.

J2 X-Axis Connections to Electronics
for: X - Axis Motor and Sensors
(1/8 Scale Crane Model)

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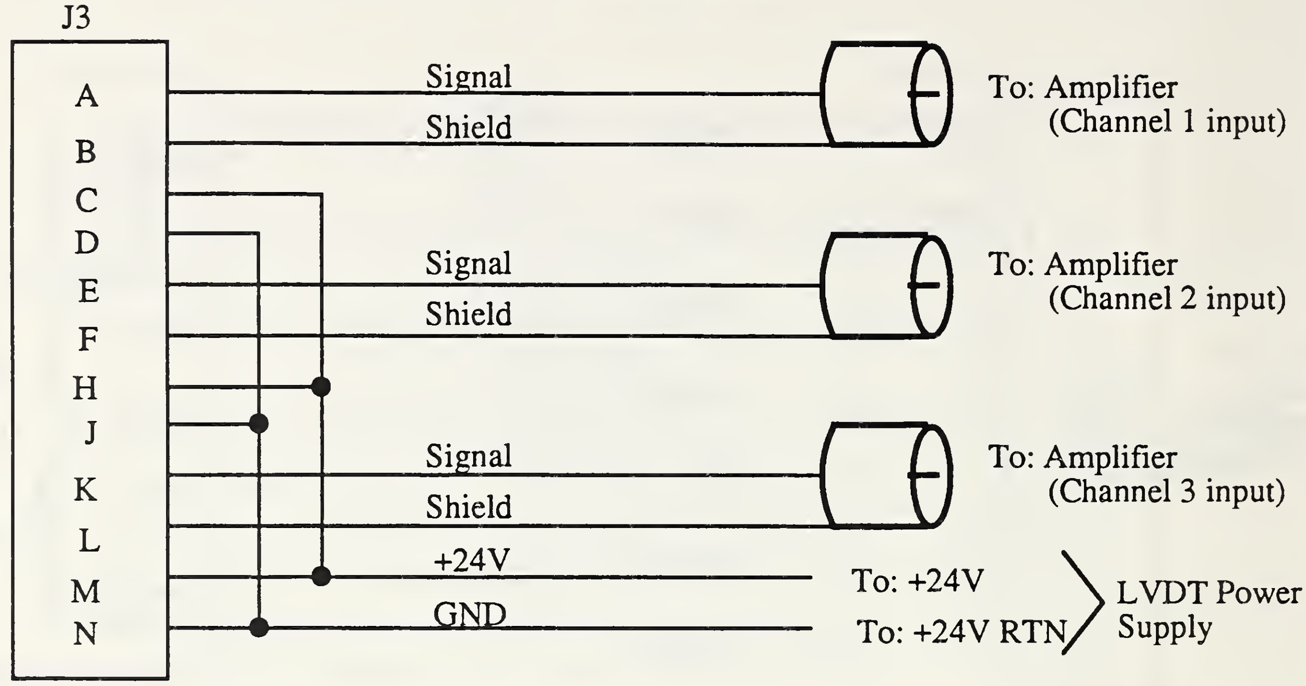
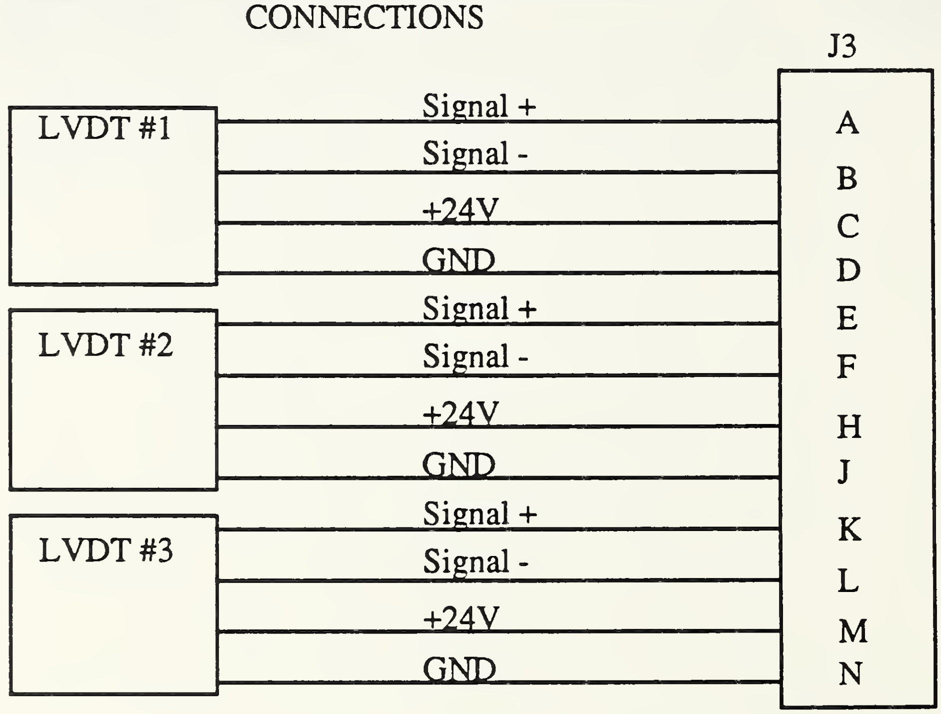
August 8, 1988
Revised: Dec. 7, 1988
739.01

ELECTRONIC RACK CONNECTIONS

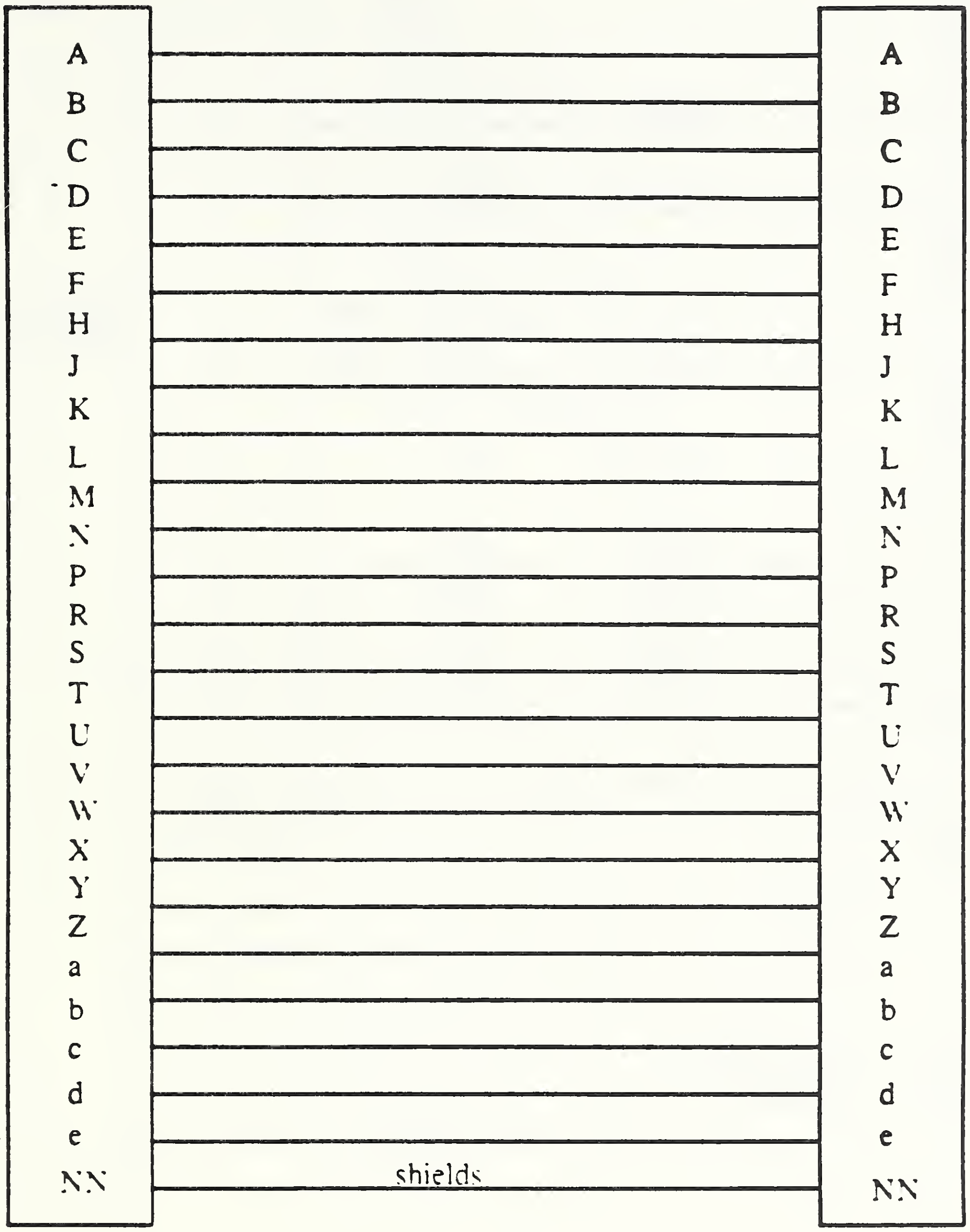


CRANE ELECTRONIC PANEL CONNECTIONS



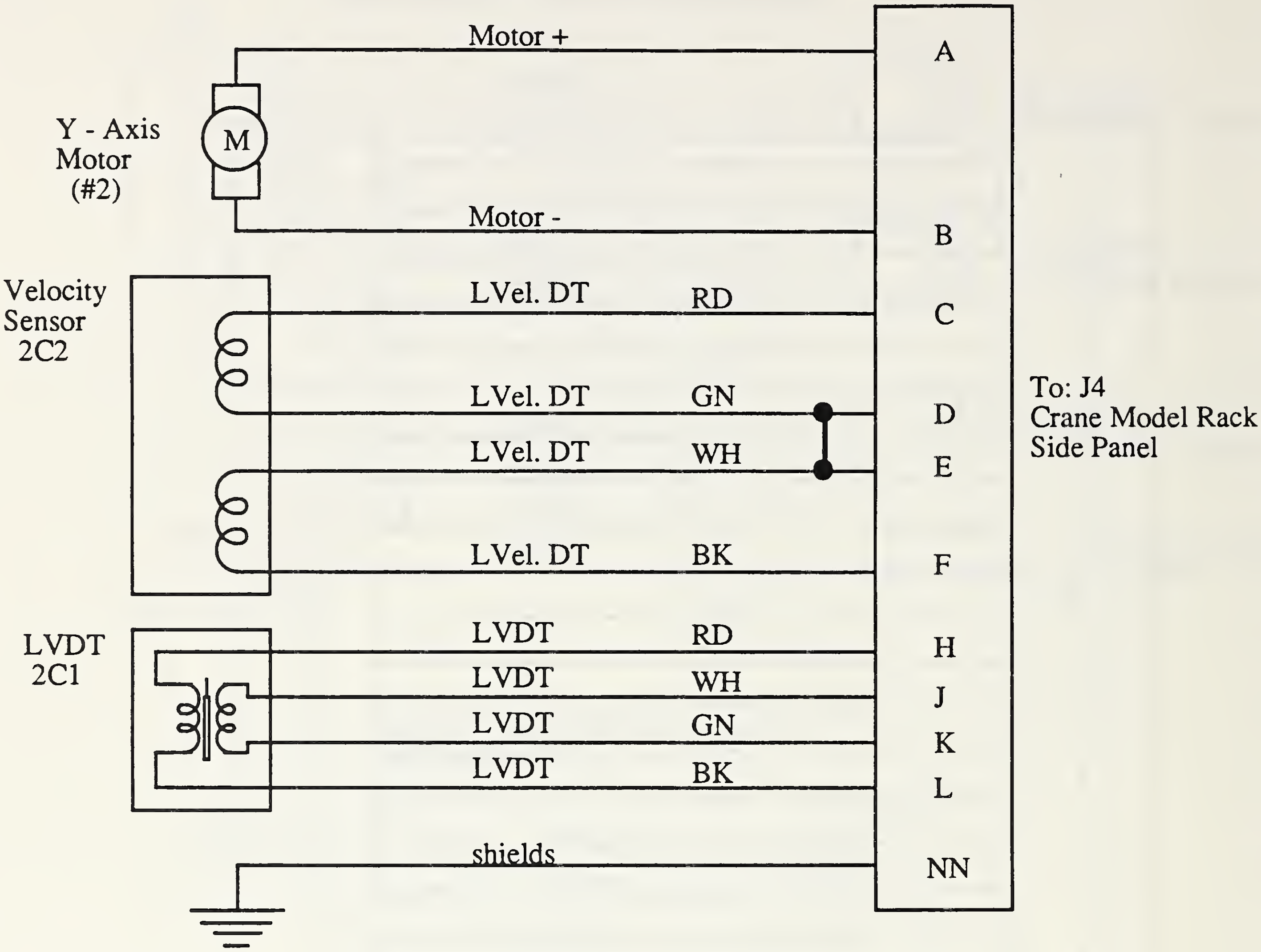
Notes:
1. J3 Connectors are 56 pin ELCO male connectors.
2. Keying: Top 1
   Bottom 3
3. LVDT's are mounted on the side and front of the crane.

J3 Cabling for: 1/8th Scale Model Crane Roger Bostelman 739.03 October 6, 1988



Notes:
1. Cable: 12Pair, sheilded Belden
2. Connectors: 56p. ELCO female
3. Keying: Top - 1, Bottom - 3

J3 Cable drawing
for: X - Axis Sensors
(1/8 Scale Crane Model)
Roger Bostelman
August 8, 1988
739.01



Notes:
1. Connectors: 56p. ELCO female
2. Keying: Top - 1, Bottom - 4

J4 Motor and Sensor Pinouts
for: Y - Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
August 9, 1988
739.01

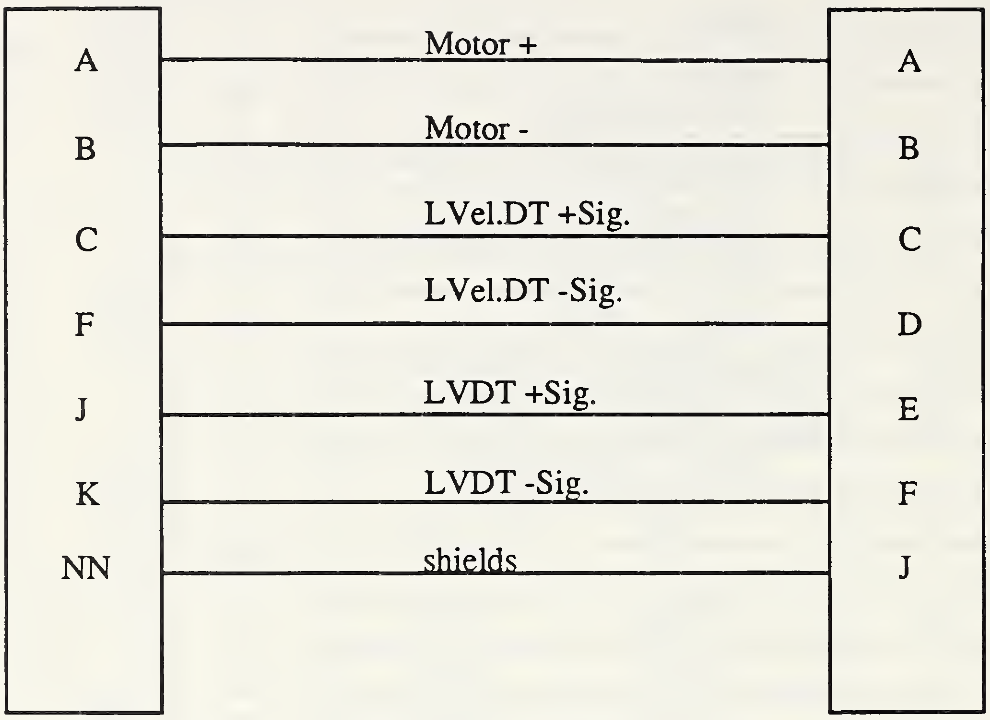
A	Motor +	A
B	Motor -	B
C	LVel. DT Sig. +	C
D	LVel. DT CT	D
E	LVel. DT CT	E
F	LVel. DT Sig. -	F
H	LVDT +24VDC	H
J	LVDT Sig. +	J
K	LVDT Sig. -	K
L	LVDT +24VDC RTN	L
M		M
N		N
P		P
R		R
S		S
T		T
U		U
V		V
W		W
X		X
Y		Y
Z		Z
a		a
b		b
c		c
d		d
e		e
NN	shields	NN

Notes:
1. Cable: 12Pair, shielded Belden
2. Connectors: 56p. ELCO female
3. Keying: Top - 1, Bottom - 4

J4 Cable drawing
for: Y - Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
August 8, 1988
Revised: Dec. 7, 1988
739.01

From: J1
Electronic
Rack
Back Panel



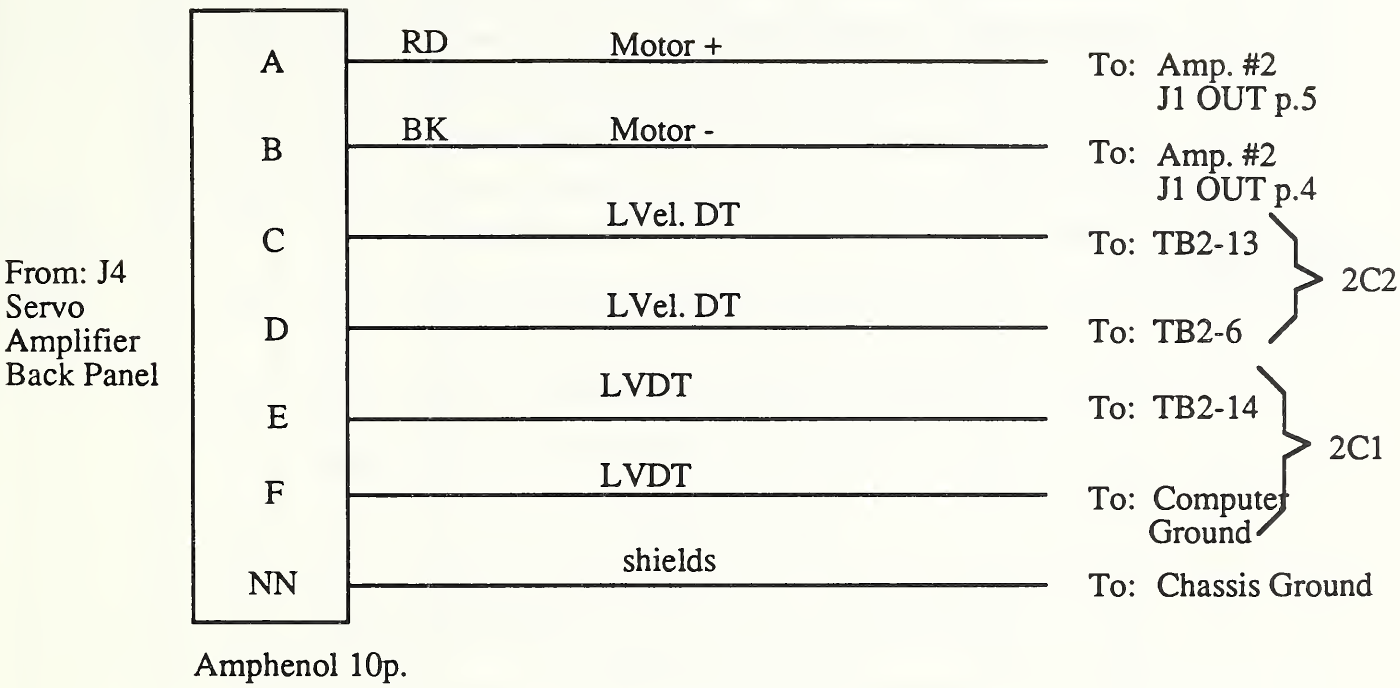
To: J4
Servo Amplifier
(Y Axis)
Back Panel

56p. ELCO female
Keying: Top - 1, Bottom - 4

10p. Amphenol
(Male)

J4 Cable to Servo Amp.
for: Y Axis Motor and Sensors
(1/8 Scale Crane Model)

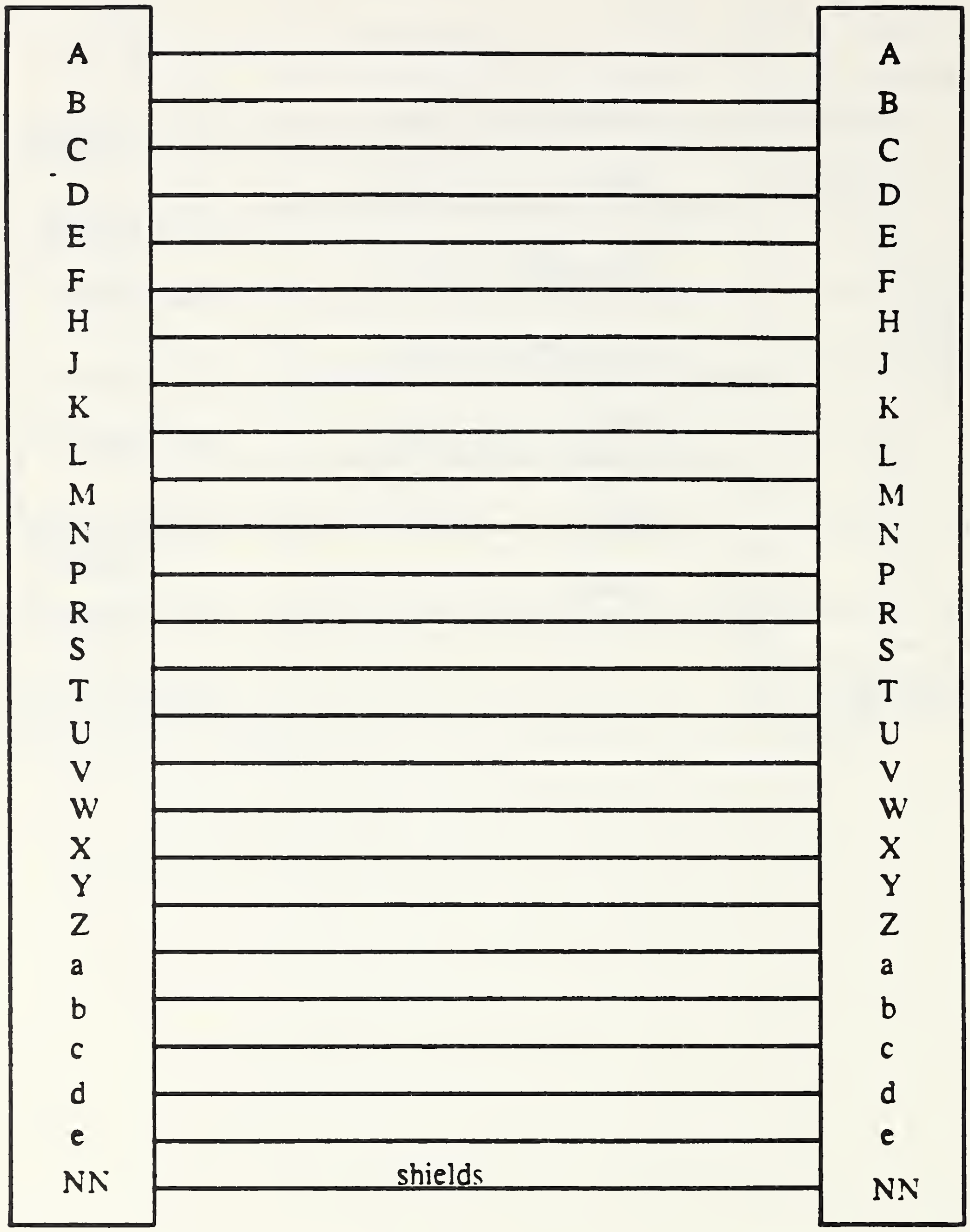
Roger Bostelman
October 20, 1988
Revised: Dec. 7, 1988
739.03



Notes:
1. Y-Axis corresponds to Amplifier 2.

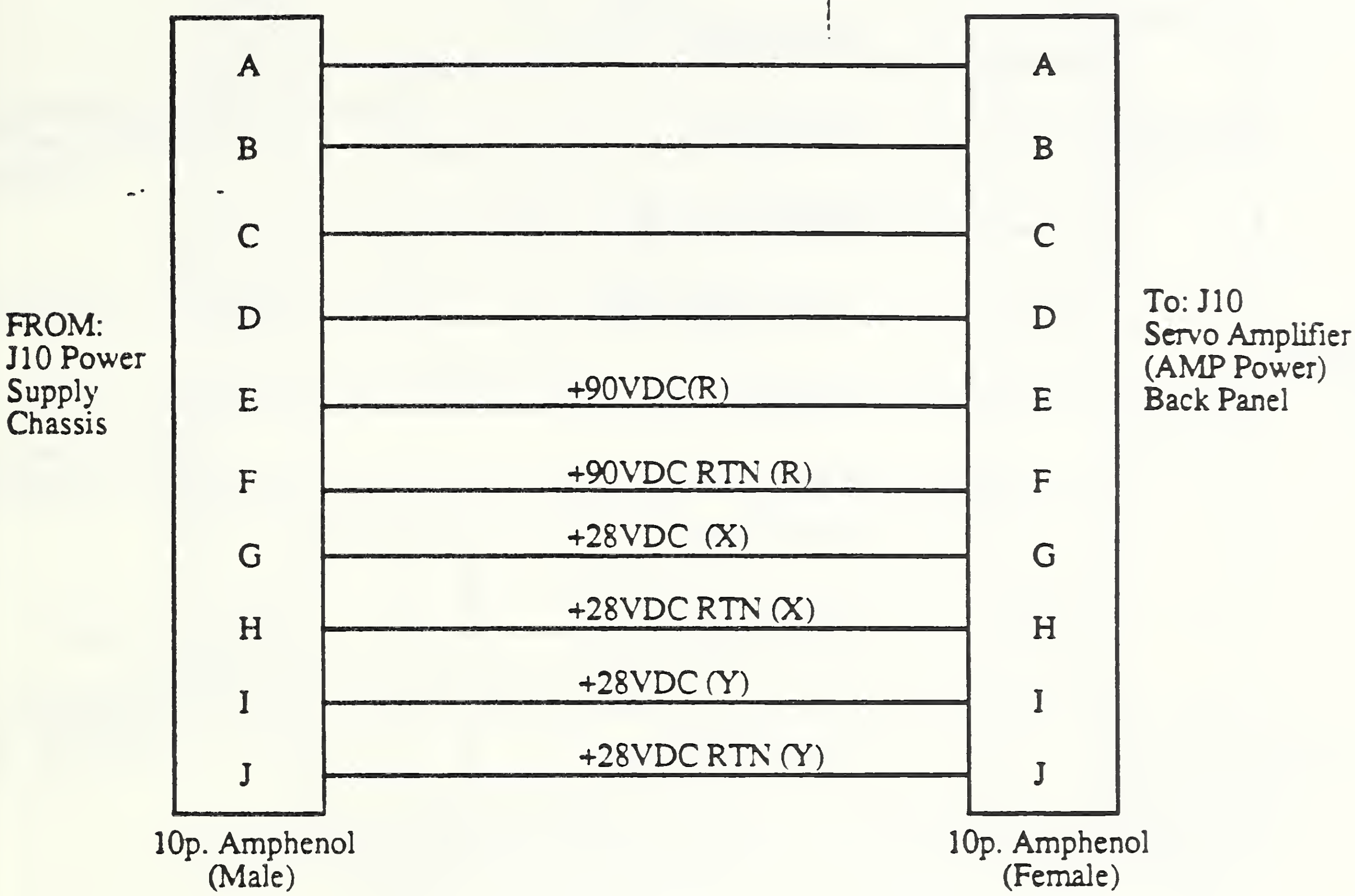
J4 Y-Axis Connections to Electronics
for: Y - Axis Motor and Sensors
(1/8 Scale Crane Model)

Roger Bostelman
October 20, 1988
739.03

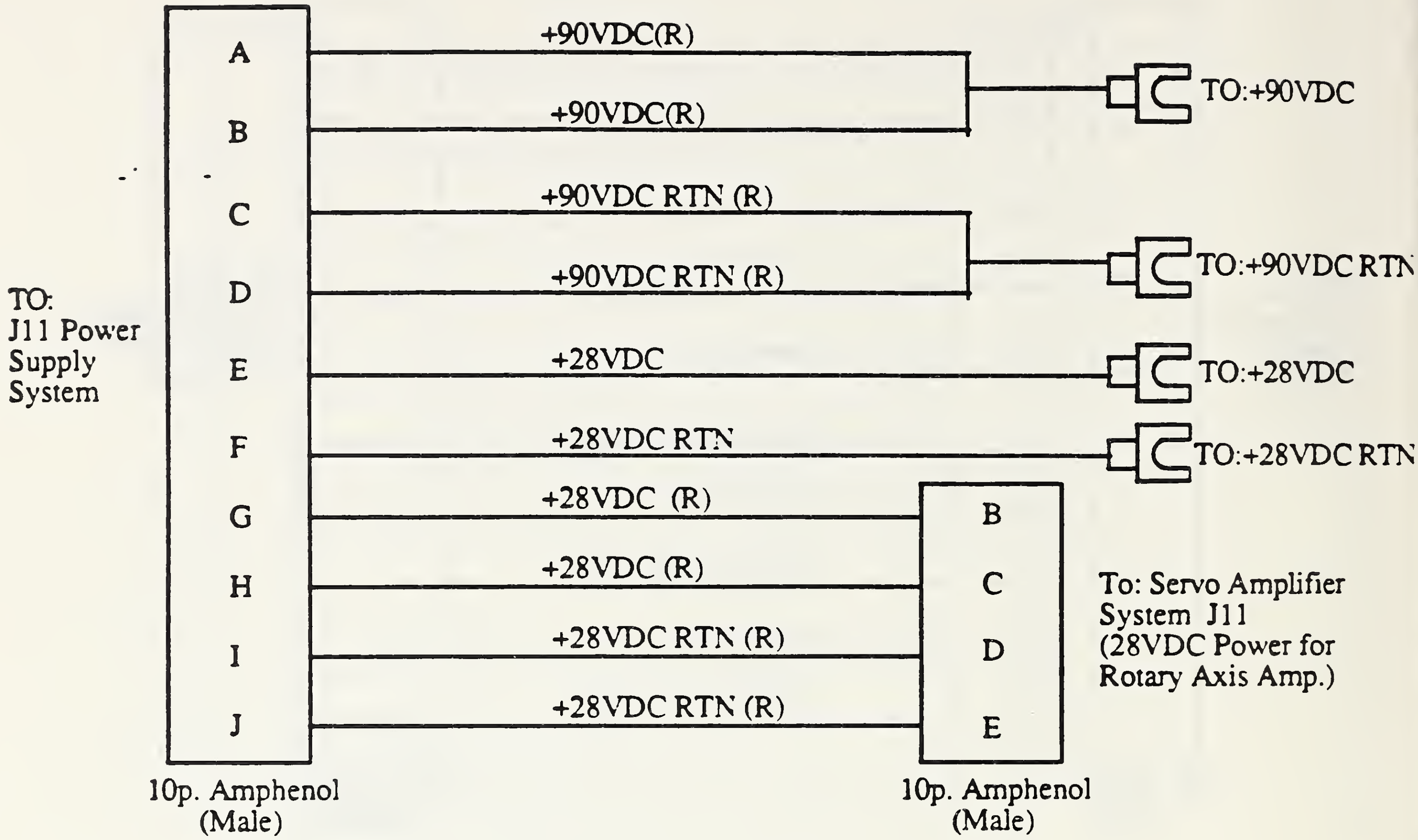


Notes:
1. Cable: 12Pair, sheilded Belden
2. Connectors: 56p. ELCO female
3. Keying: Top - 1, Bottom - 5

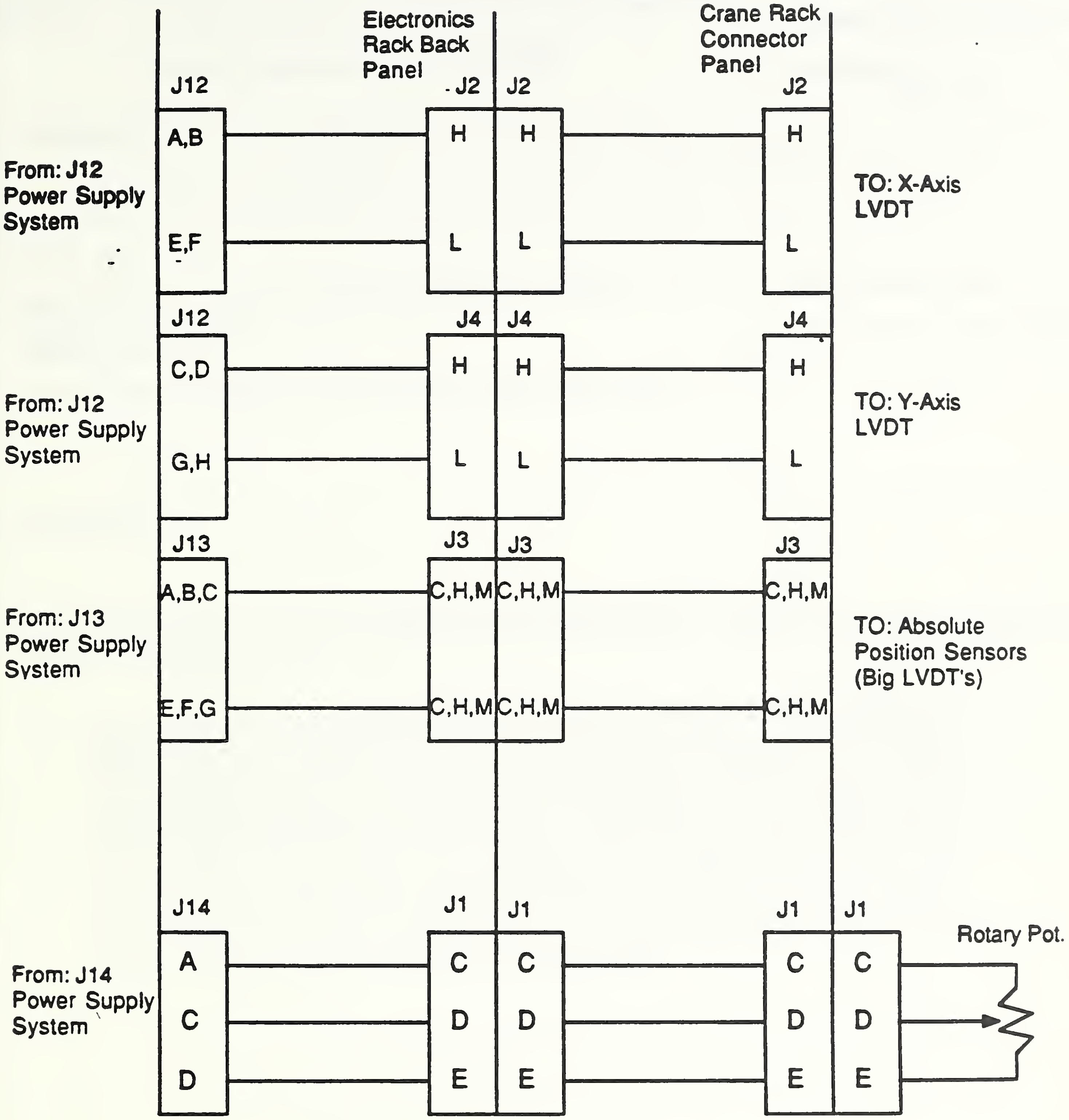
J5 Cable drawing
for: Y - Axis Sensors
(1/8 Scale Crane Model)
Roger Bostelman
August 8, 1988
739.01



J10 Cable
for: Amplifier/Motor Power
(1/8 Scale Crane Model)
Roger Bostelman
October 20, 1988
739.03
(Revised Dec. 3, 1988



J11 Cable
for: Amplifier/Motor Power
(1/8 Scale Crane Model)
Roger Bostelman
December 7, 1988
739.03



J12, J13, J14 Cabling
for: 1/8 Scale Crane Model
Roger Bostelman
December 7, 1988
739 03

NIST-114A
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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This report describes the electronic hardware designed and developed for the Small Scale Model Robot Crane (SSMRC) Project sponsored by the Defense Advanced Research Projects Agency (DARPA). The purpose of this electronic hardware is to provide the necessary servo controls for the three axes of the SSMRC. The report begins with an introduction which explains the overall objectives of the project and describes the SSMRC system configuration. An electronic design section discusses each system component and describes the component from both a hardware and a system point of view. Test procedures and results, which give the troubleshooting methods and data needed for development of the system, are then presented. The report concludes with a brief summary and an appendix which provides electronic design schematics and descriptions of the parts used in the construction of the electronic hardware system.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
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