AFFDL TM 75-95-FXN

DEVELOPMENT OF A 100 CHANNEL MULTIPLEXER FOR ACQUIRING MODEL DATA FROM THE RENT FACILITY

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December 1975

Approved for public release; distribution unlimited.

T E C H N I C A L M E M O R A N D U M A F F D L - T M - 7 5 - 9 5 - F X N

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NOTICE

This Technical Memorandum has been reviewed and is approved for publication.

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FORWORD

This report was prepared by the Experimental Engineering Branch, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Essentially all the conceptual design work was an in-house effort of the Experimental Engineering Branch under Work Unit 14260302, "Develop a 100 Channel Multiplexer for Acquiring Model Data from the RENT Facility to Test Missile Nose Tip Shapes". This Work Unit is an element of Task 142603 and Project 1426. Mr. John H. Bieber of the Electronics Group was the principal investigator.

Mr. Bieber died prior to the completion of this report. Therefore, Mr. Ballard has been assigned as associate investigator responsible for completion of the Task.

Mr. Ronald E. Land is hereby gratefully acknowledged for developing a miniature thermocouple reference junction suitable for use in this system. No commercial vendor could be found to supply a thermocouple reference junction small enough in physical size for this purpose. Mr. Land designed, and had built under separate contract, five 20-channel universal thermocouple reference junctions.

Bay Laboratories, Incorporated, Cleveland, Ohio, have converted the paper specifications into a very practical piece of hardware. Their custom fabricated system meets or exceeds the system expectations.

This report covers work conducted during the period from January 1972 thru June 1974. The equipment was delivered by the contractor and accepted in December 1973. The multiplexer was installed in the facility but the thermocouple reference junction could not be installed on the model carriage at that time. The high priority nature of testing in the RENT facility has not permitted the required facility downtime to make the necessary model carriage modifications.

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I INTRODUCTION

A need for multiplexing thermocouple signals was recognized in 1972 by the RENT Facility Managers. Initial funding was provided for in FY 73.

The problem was assigned to AFFDL/FXN, Electronics Group. Mr. Bieber, Technical Manager of the Electronics Group, assumed the role of Principal Investigator. He began a study to incorporate this multiplexer in the overall separation of instrumentation for the RENT operations and the HTL operation.

This study revealed the long term need for twenty channels for each of the RENT's five model positions. Further, it was found that each cahnnel must service any type of electrical signal normally found in wind tunnel model instrumentation.

The responsible managers met, studied, and decided upon a multiplexing system concept which would be in harmony with the longer range instrumentation separation problem.

This report expands upon the conversion of this concept into operational hardware.

II MULTIPLEXER SPECIFICATIONS, DESIGN AND DESCRIPTION

A. Facility Requirements and Design Background

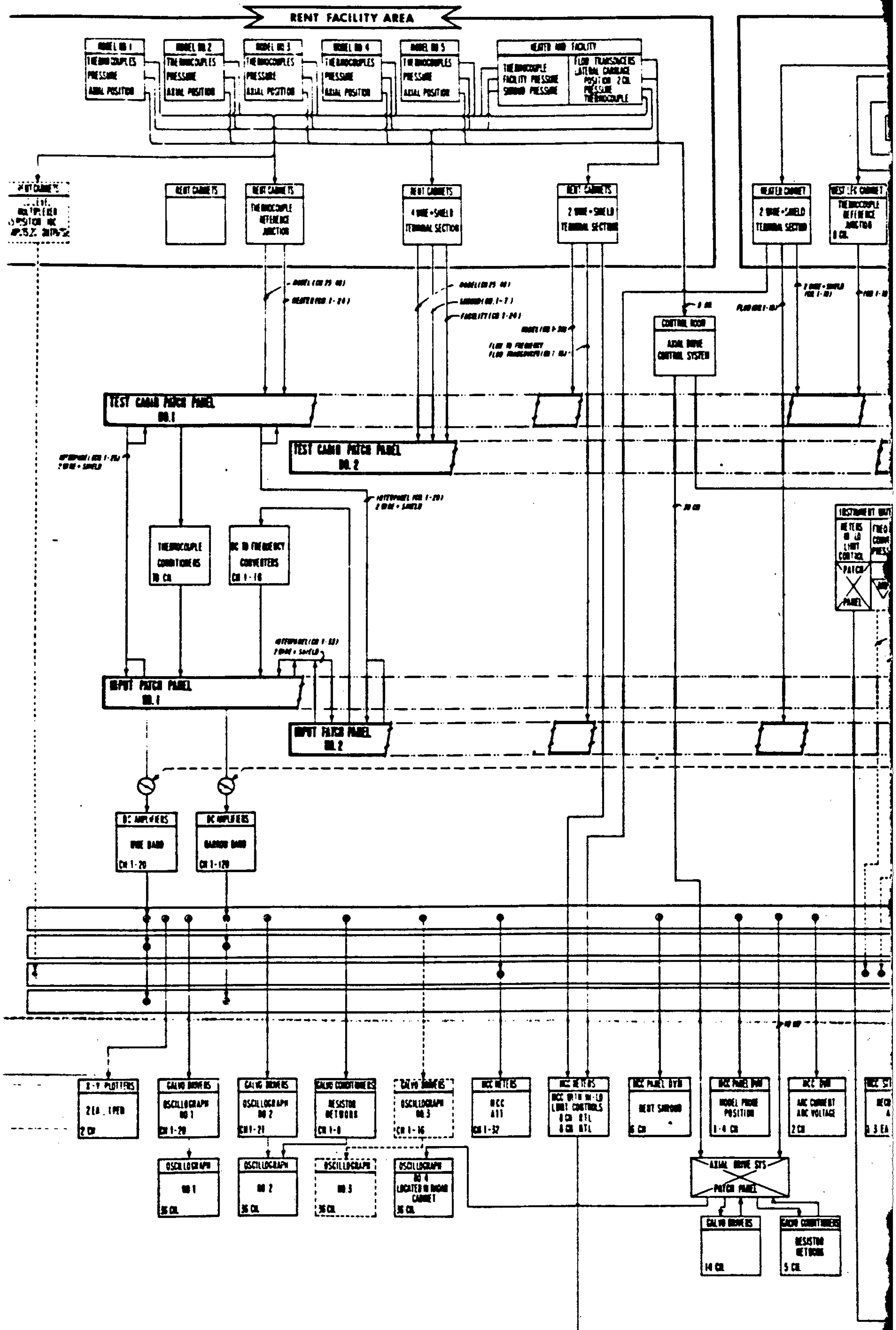
The 50 Megawatt Electrogasdynamics Facility complex was built on a military construction program. It served as a hypersonic wind tunnel using the technique of heating high pressure air with an electric arc.

Soon a request came to use this facility for testing nose tips under simulated space reentry (RENT) conditions. The necessary arc heater, model support, mechanical and electrical systems were designed and purchased. The facility was modified, systems installed and the RENT Test Leg became operational. The original test facility was then designated the HTL Facility (Hypersonic Test Leg).

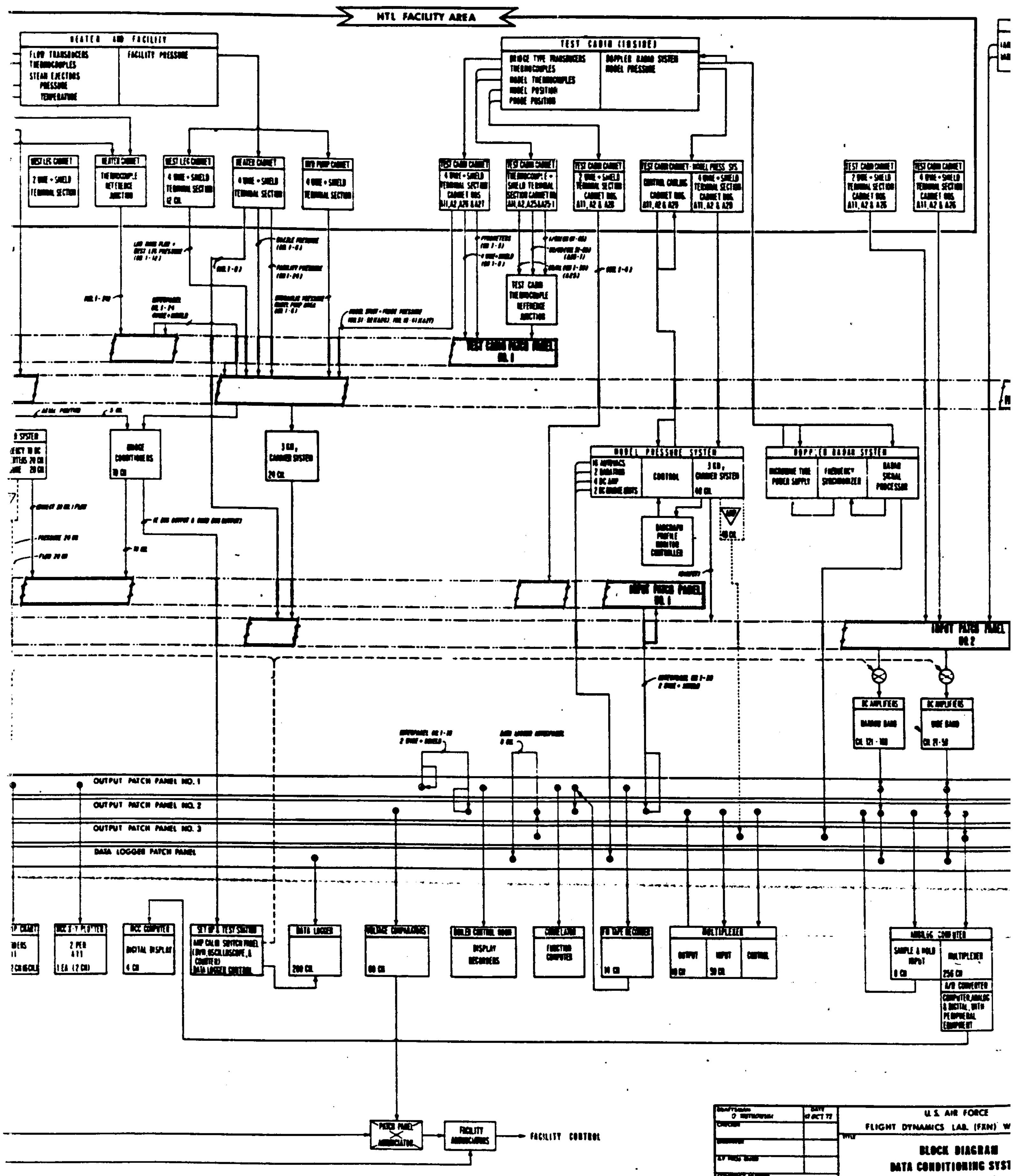
Both facilities shared the electronic instrumentation which is comprised of more than 200 D.C. amplifiers, signal conditioners of all types, oscillographs, tape recorders, and a myriad of other devices including a hybrid analog-digital facility computer.

As test requirements grew, it soom became apparent that separation of the two instrumentation demands must be made. Switching from one facility to another was imposing an unacceptable time element.

The complete facility instrumentation was block diagramed, as shown in Figure 1. Both existing equipment and planned equipment was incorporated in this block diagram. The purpose was to develop and implement a long-term plan to provide this needed separation.



NOTE ITEMS INDICATED THUS [dashed box] ARE PROPOSED FOR FUTURE INSTALLATION



NTL FACILITY AREA
HEATER AND FACILITY
FLOW TRANSDUCERS
THERMOCOUPLES
STEAM EJECTORS
PRESSURE
TEMPERATURE
FACILITY PRESSURE
TEST CABIN (INSIDE)
BRIDGE TYPE TRANSDUCERS
THERMOCOUPLES
MODEL THERMOCOUPLES
MODEL POSITION
PROBE POSITION
DOPPLER RADAR SYSTEM
MODEL PRESSURE
TEST CABIN THERMOCOUPLE REFERENCE JUNCTION
TEST CABIN PATCH PANEL NO. 1
MODEL PRESSURE SYSTEM
CONTROL
DOPPLER RADAR SYSTEM
INPUT PATCH PANEL NO. 1
INPUT PATCH PANEL NO. 2
DC AMPLIFIERS
OUTPUT PATCH PANEL NO. 1
OUTPUT PATCH PANEL NO. 2
OUTPUT PATCH PANEL NO. 3
DATA LOGGER PATCH PANEL
DIGITAL DISPLAY
DATA LOGGER
DISPLAY RECORDERS
FUNCTION COMPUTER
MULTIPLEXER
OUTPUT
INPUT
CONTROL
FACILITY ANNUNCIATORS
FACILITY CONTROL
U.S. AIR FORCE
FLIGHT DYNAMICS LAB. (FXN)
BLOCK DIAGRAM
DATA CONDITIONING SYST
50 MW HTL and ETL
X72F2919

Figure 1.

When this subject multiplexer was identified and funded, the study revealed the need to quickly change up to five models with up to 20 channels of data per model. Three changes per running shift (eight hours) were required; for a total of up to 15 models.

Based on this knowledge, the multiplexer was specified such that 98% of all gain requirements could be selected for each channel by a simple push button switch arrangement. Transducers having a unique output characteristic are type K, S and W thermocouples. Gain for these was fixed at an odd value that would result in a nominal 8 volts output for expected temperature excursions. For the transducers having no unique output characteristics, the standard fixed gains of 1, 10, 100 and 1000 are also push button switch selectable with ± full scale zero offset capability. Where none of the above gains would suffice, a variable gain adjustment with ± full scale zero offset has been provided. A self-contained calibration arrangement has been provided whereby any of the 100 channels can be quickly calibrated or checked.

Each channel has been provided with a selectable filter. The study revealed that, in practice, filtering was often used. Amplifiers with selectable filters had been purchased in large quantities. This function was extensively used and was a viable need.

Automatic control has been provided where the multiplexer position is remotely controlled by the model carriage position indicator. The 20 outputs are available to the facility computer. The multiplexer also senses the model position from the same source as the computer; therefore, the two are synchronized.

The total cost is very much less than we are accustomed to paying for an amplifier per channel arrangement. The overall system utility is gratifying.

B. Description

This multiplexer contains 20 parallel channels switched in five sequential model position steps, making a total of 100 channels, as shown in Figure 2. A complete mix of input signals is possible from channel to channel and model to model. This multiplexer contains five 20 channel universal temperature reference junctions, one calibration voltage source, 20 each five channel input signal conditioning and amplifying sub-units, one control sub-unit, and one digital voltmeter. Specific accumulated accuracy of the completed system is no worse than 0.15% of full scale.

C. Universal Reference Junction

Five each universal reference junctions are used. These are custom built units designed and built by the Government for this particular application. The input arrangement is shown in Figure 3. Amphenol type NS24266 R 24 T 61 PN plugs are used; one for each reference junction. Pin arrangement is shown in Figure 9. Junction temperature is maintained at 150°F ± 1°F.

D. Calibration Voltage Source

This source provides the means to calibrate the multiplexer and is shown in Figure 4. The unit performance characteristics are shown below:

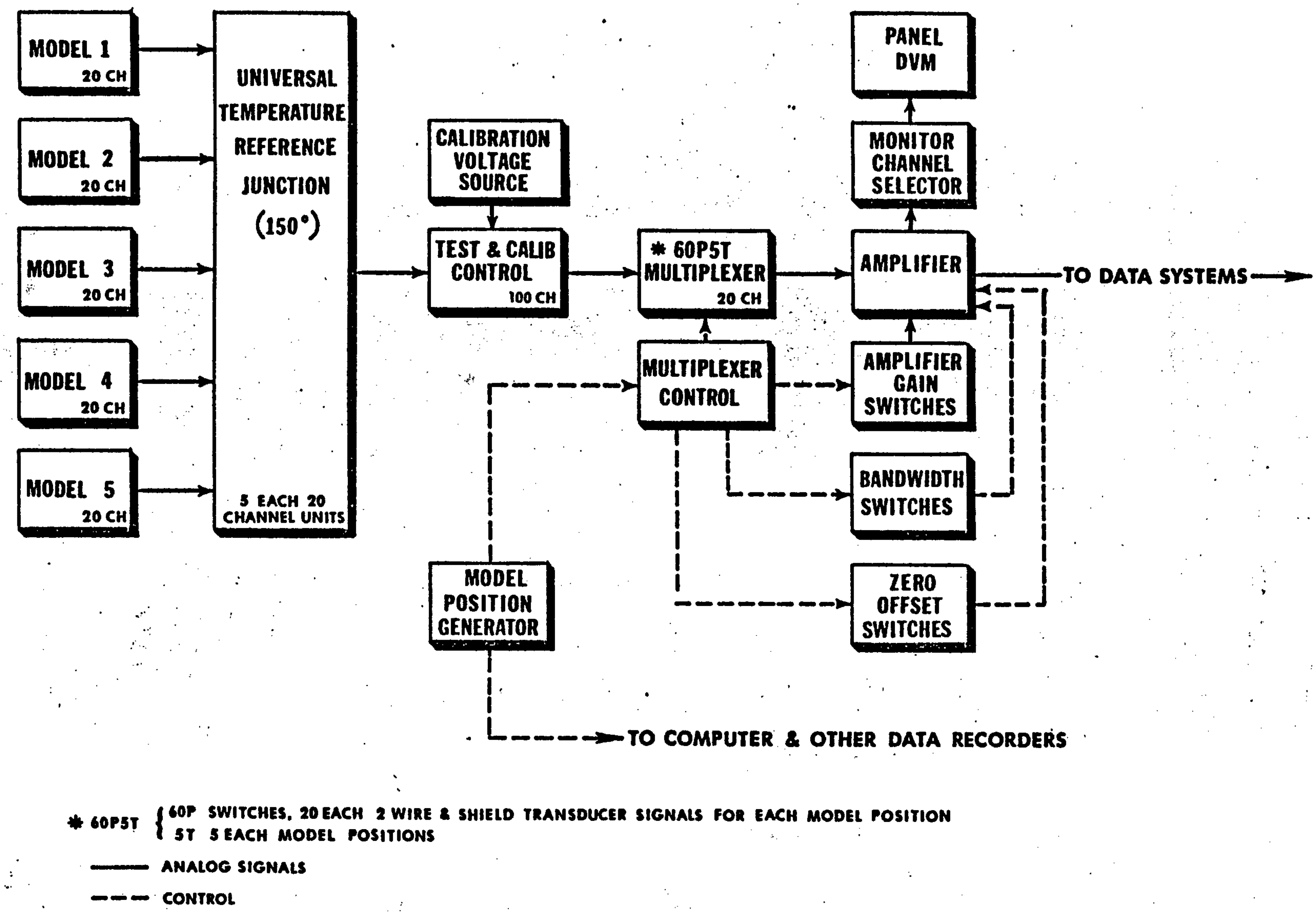


Figure 2. BLOCK DIAGRAM, RENT MULTIPLEXER

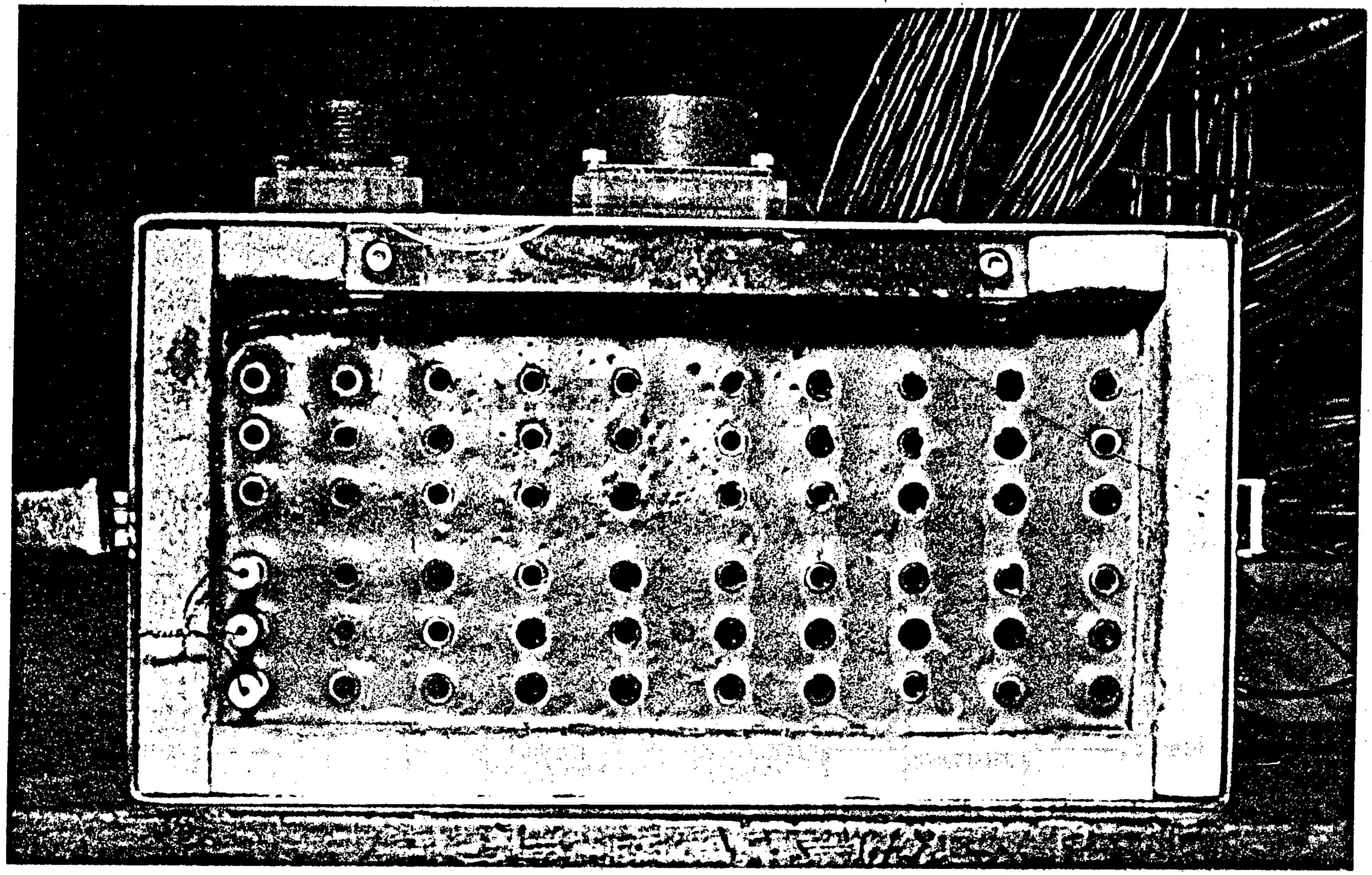


Figure 3. UNIVERSAL REFERENCE JUNCTION

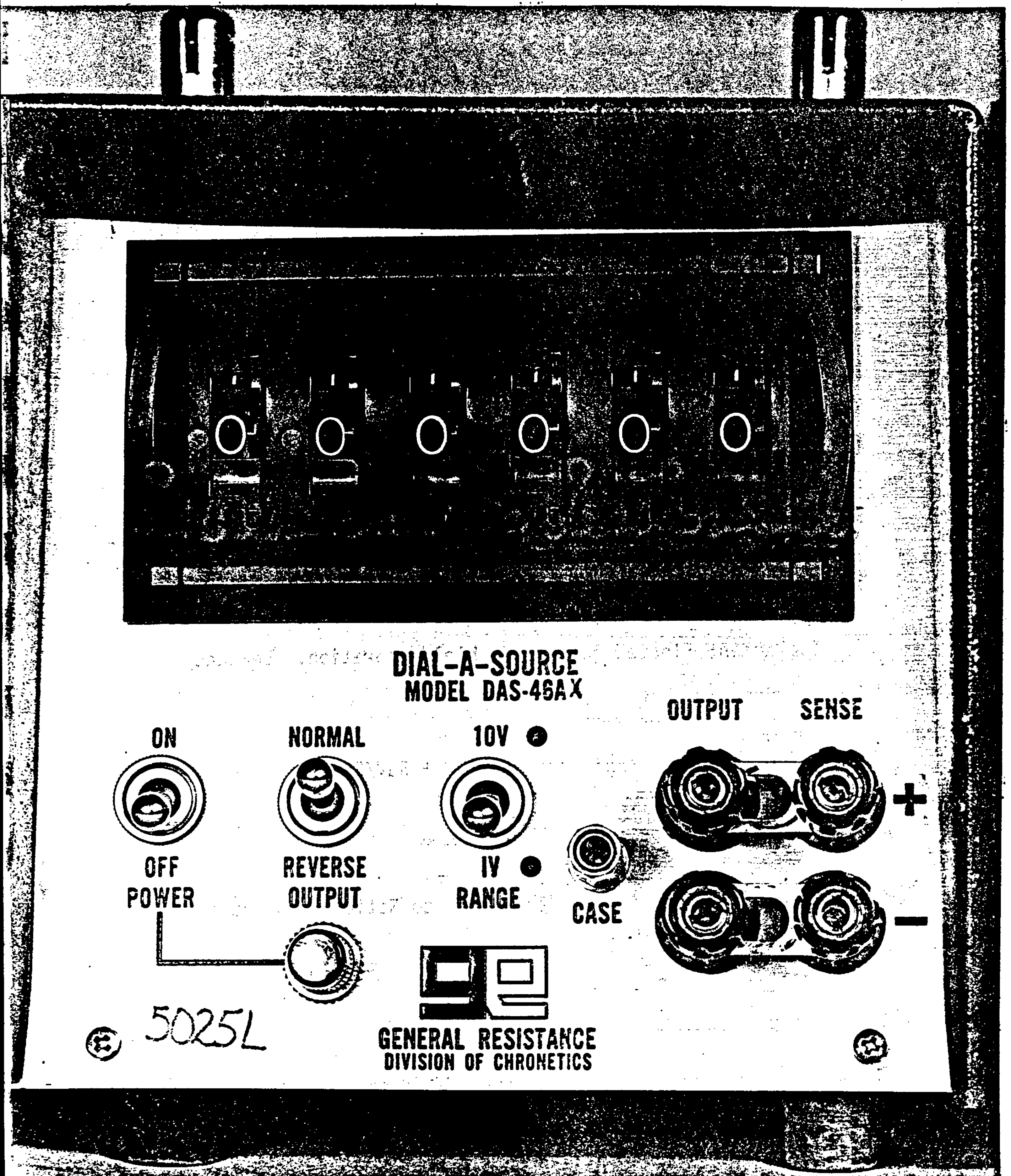


Figure 4. CALIBRATION VOLTAGE SOURCE

1. Ranges

   (a) Range No. 1: 0 to 1 V DC in steps of 1.0μV.

   (b) Range No. 2: 0 to 10 V DC in steps of 10μV.

2. Accuracy of Voltage setting; ±0.0025%.

3. Output Current; 20 mA @ Full Scale Voltage Output.

4. Temperature Coefficient; ±2PPM/°C.

5. Noise and Ripple; 20μV P-P.

6. Combined Line - Load Regulation; ±0.001%.

7. Isolation; Floated for guard shield operation. Leakage nominally 1 Giga ohms and 20pF.

8. Output Voltage Stability; ±10 PPM + 5μV/24 hours.

9. Number of decades; 6.

10. Calibration Certificate, traceable to National Bureau of Standards, was furnished.

E. Signal Conditioning Sub-Unit

Refer to Figure 5. The purposes are to accept 20 channels of two wire and shield inputs from each of five model positions, provide independent gain, bandwidth and zero offset for each of the 100 channels, provide

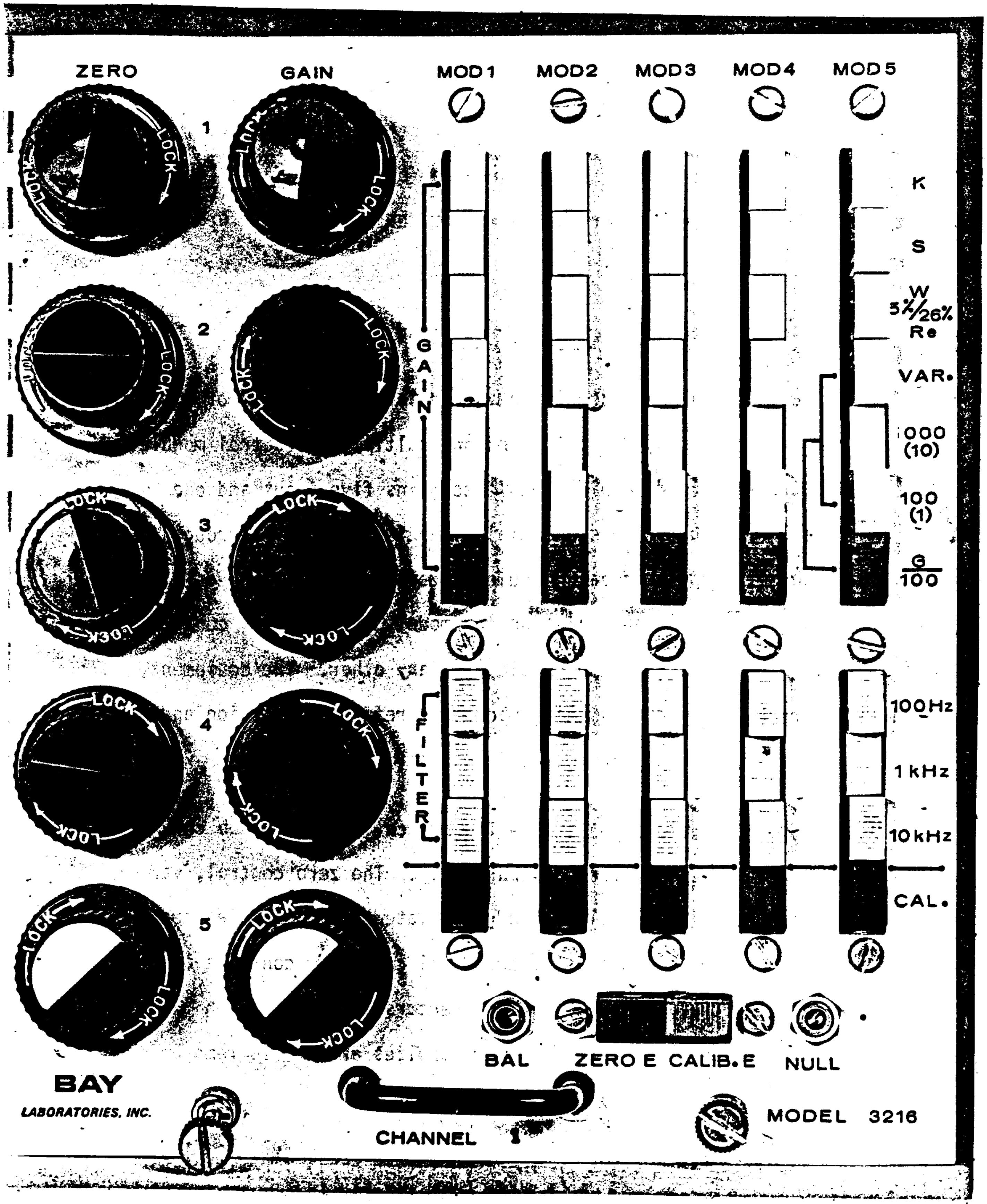


Figure 5. SIGNAL CONTROL AND CONDITIONING MODULE

quick and accurate means of calibration and test set-up at the system, and provide a high degree of reliability and ease of maintenance. Input connectors mate with the connector specified for the universal reference junction.

1. Construction - Refer to Figures 6 and 7.

(a) General - Construction is modular and consists of 20 signal control and conditioning modules and one multiplexer control module. Each signal control and conditioning module contains five input and one output channel. The modules are sequentially labeled Channel 1 through Channel 20. The five inputs of each module are sequentially labeled MOD 1 through MOD 5. MOD is the abbreviation for model. Each signal control and conditioning module is interchangeable with any other. The equipment, mounted in the rack and excluding the temperature reference junction and calibration voltage source, is 49 inches in height.

(b) Type of Construction - The switch group for each channel is mounted on a printed circuit board subassembly. The zero control, variable gain control, amplifier, filter, and associated power supplies are assembled on a single printed circuit board. All connector contacts are low level gold plated type. Input-Output connectors are silk screen labeled. All amplifiers, filters, and power supplies are easily removed for maintenance purposes.

2. Amplifier - Contains an instrumentation amplifier with specifications stated below. Total accumulated error does not exceed

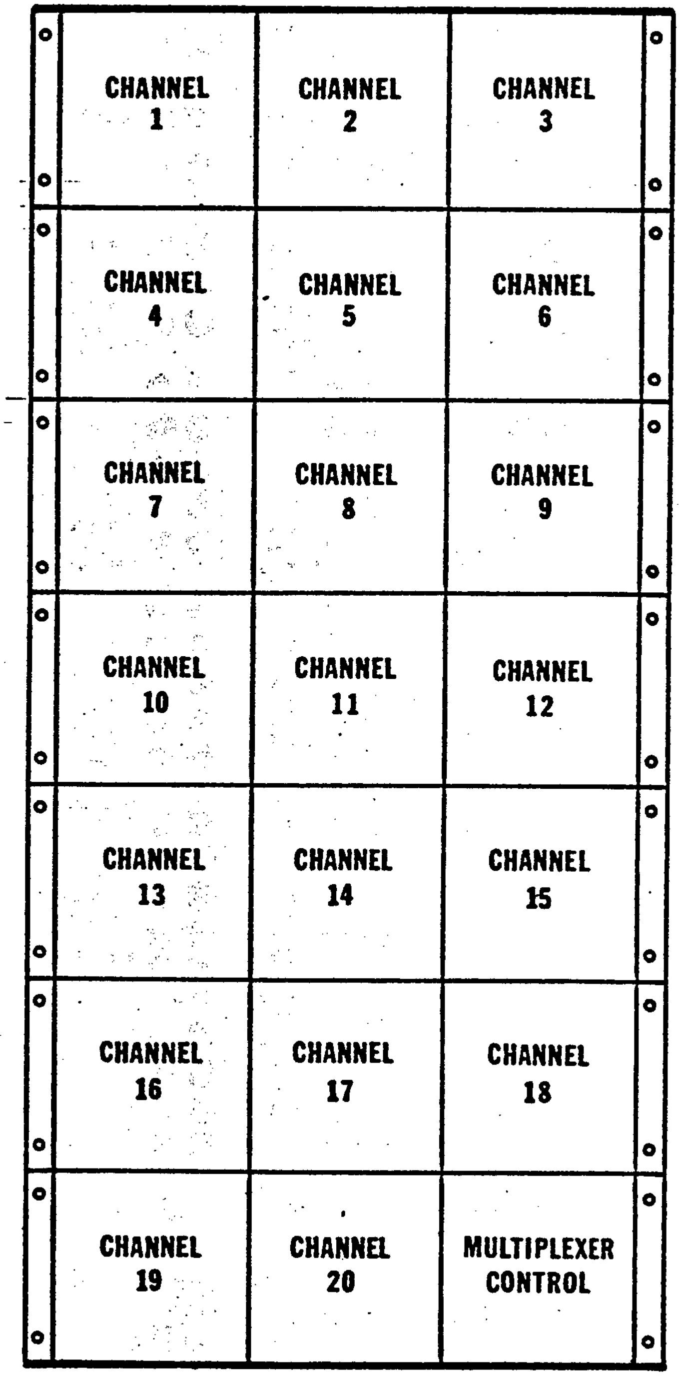


Figure 6. MULTIPLEXER LAYOUT

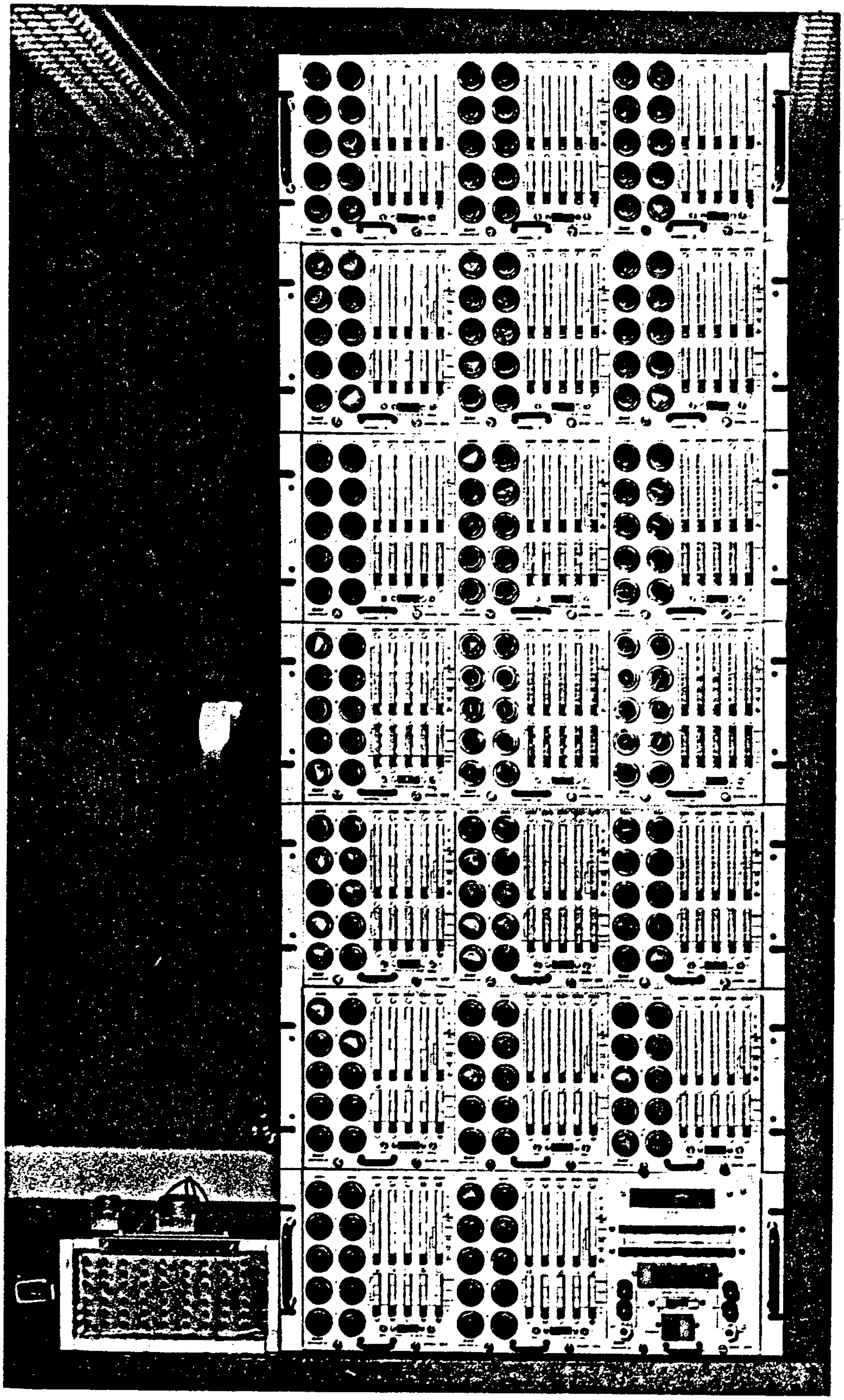


Figure 7. MULTIPLEXER OVERALL VIEW

0.15% FS with ambient temperature varying between 55°F and 90°F.

(a) Input Impedance - 100 megohms differential.

(b) Common Mode Rejection - 60 db + gain in db or 120 db at gain equal 1000 with balanced input.

(c) Gain Nonlinearity - 0.02% at gain equal 100.

(d) Gain Temperature Coefficient - 0.001%/°C.

(e) Gain Range - As specified below. Bailing action on positions 1 through 6 of the switch is provided.

(1) Position No. 1 - Type K thermocouple. 2666°F = 8.000 Volts output. 0°F = 0.000 Volts output.

(2) Position No. 2 - Type S thermocouple. 3200°F = 8.000 Volts output. 0°F = 0.000 Volts output.

(3) Position No. 3 - Tungsten - 5% Rhenium/Tungsten - 26% Rhenium Thermocouple. 4000°F = 8.000 Volts output. 0°F =0.000 Volts output.

(4) Position No. 4 - Variable Gain - 0 to 1000 with ± full scale variable zero control.

(5) Position No. 5 - Fixed gain of 1000 with ± full scale variable zero control.

(6) Position No. 6 - Fixed gain of 100 with ± full scale variable zero control.

(7) Position No. 7 - When depressed, this switch changes the gain ranges of position numbers 4, 5 and 6 to:

a. No. 4 - Variable gain from 0 to 100.

b. No. 5 - Fixed gain = 10.

c. No. 6 - Fixed gain = 1.

Zero control on position numbers 4,5 and 6 are ± full scale output.

(f) Isolation

(1) Input - Output; 100 megohms between signal and amplifier common.

(2) Power Supplies; each of the amplifiers use separate ± 15 V DC electrostatically shielded power supplies.

(3) Channel Separation; each channel is totally separated from all others.

(4) Floating; all channels are floating above ground.

(5) Groundings; input signals can be grounded or floated at transducer. Outputs are grounded at recorder. Total isolation of input-output is provided. Total system error, including noise induced by having different input ground level than output ground level, does not exceed 0.1% of full scale.

(g) Output offset at gain of 1000 is no worse than the following for the conditions specified.

(1) Temperature - ±3mV/°C.

(2) Supply - ±50mV/V.

(3) Time - ±10mV/mo.

(h) Input Noise - No worse than 5μV RMS DC to 10KHz.

(i) Bandwidth - A low pass four pole Butterworth characteristic filter is provided for each amplifier. Each filter has a minimum of three selectable bandwidths with bailing switch action. The attenuation rate is 80 db/decade. Cutoff frequencies are as follows:

(1) Position 1 - 100 Hz.

(2) Position 2 - 1,000 Hz.

(3) Position 3 - 10,000 Hz.

(4) With no bandwidths selected the amplifier output full bandwidth of 50 KHz is provided.

(j) Calibration Switch - Each of the 100 data input channels is provided with a calibration momentary operation type switch. When depressed, the input of that channel is switched from its signal to the Zero-Calib Voltage switch. The output of the amplifier-filter arrangement is switched to the AMP Cal position of the digital voltmeter (DVM) assignment switch assembly. By this method, the calibration source and output monitor are simultaneously selected.

(k) Zero-Calib Voltage Switch - Each of the 20 channel modules is provided with a switch that selects a short circuit or voltage standard for the individual amplifier inputs for calibration purposes. These two positions have bailing operation.

(1) Zero-Control - This control is a 10 turn 0.25% linearity 7/8 inch diameter potentiometer with locking knob. Full scale operation of $\pm$10V is provided at all gain settings. Amplifier output resolution of this control is one millivolt.

(m) Gain Control - This control is a 10 turn 0.25% linearity 7/8 inch diameter type potentiometer with locking knobs. This results in a hyperbolic gain characteristic.

(n) Multiplexer Relays - High reliability type relays are used. Contact resistance is nominally 0.1 ohm. Switching speed is 2 millisecond. Each relay is individually electromagnetic and electrostatic shielded. Full load life, switching of 750 milliamps, is nominally 20 X 10^6 operations. All relays have DC coils.

(1) Amplifier Protection - One relay for each of 20 amplifiers is provided for shorting the input of the amplifiers when relay power is turned off. These relay contacts are form 1B (normally closed).

(2) Signal Switching - One relay for each of 100 signal channels is provided for switching the signals into the amplifier as selected by the control module. These relays are form 3A (normally open).

F. Multiplexer Control Module

Refer to Figure 8. The system control module provides simple manual test set up and check out convenience and operates in slave to facility controllers during test (automatic test mode). This unit distributes all system power.

1. Manual Test and Set-up Mode.

(a) Amplifier Output Channel Selector - This is a bailing type push button switch assembly. The output of this switch assembly is wired to the AMP Mon position of the DVM assignment switch assembly. The switch is wired so that no two switches can short two amplifier outputs. The switch assembly selects any one of the 20 amplifier outputs.

(b) Model Selector - This is a momentary lighted push button. This switch assembly operates the automatic model select logic. This control is inhibited in any model position except neutral where it is activated. This switch assembly has five positions, one position for each model. When a model position is selected all 20 associated signal input relays are energized - signal pair and shield are switched.

(c) DVM Assignment - This is a bailing type push button switch. The output of the switch assembly is wired to the DVM input.

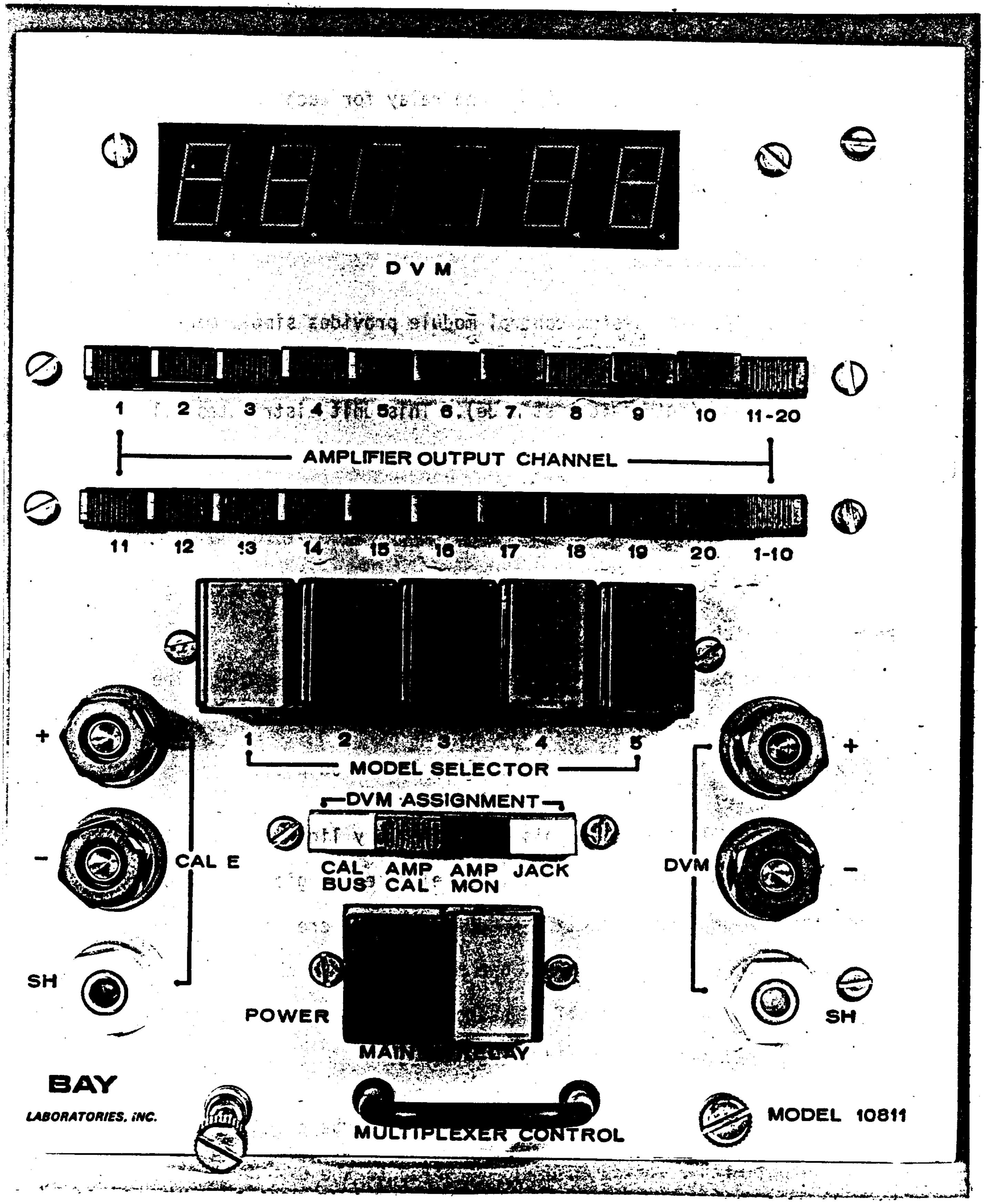


Figure 8. MULTIPLEXER CONTROL MODULE

Signal pair and shield are switched. The following positions are provided.

(1) Cal Bus - wired to the output of the calibration voltage source.

(2) Amp Cal - wired to the DVM input bus.

(3) Amp Mon - wired to the amplifier output channel selector.

(4) DVM Jack - wired to the DVM jack.

(d) DVM Jack - This is a miniature banana binding post type. One each of (+) signal, (-) signal and shield are provided and appropriately color coded. This jack provides an input to the system DVM.

(e) CAL E Jack - This is a miniature banana binding post type. One each for (+) signal, (-) signal and shield are provided and appropriately color coded. This jack provides an output for the calibration voltage source for external uses.

(f) Power On-Off - Two lighted push button power switches are provided. One is for main power and the other for relay power. The main power switch is push-push. The relay power switch turns relay power on and off in the neutral model position. In the automatic operational mode, the relay power automatically turns on with any model position and remains on until neutral position is reached. Upon reaching model neutral position, the relay power is removed until again manually or automatically turned on. The main power switch controls all power in the system. The relay power switch is momentary and alternately turns the relay power on and off when depressed. The switch indicator displays the state of the relay power. The relay power supply remains on continuously, under control of the main power switch, with its output being switched on and off.

2. Automatic Test Mode - Five control signals from GFE facility model position generator operate this multiplexer in automatic mode. Each of the five models independantly generates its own signal when in model test position. These signal levels are +10 V DC $^{+4}_{-2}$ V DC at 1 milliamp. All noise or signal voltages below +8 V DC are inhibited from operating the multiplexer control circuits. Should two signals be received simultaneously, then the number representing the highest model number dominates. Only one group of 20 multiplexer relays are energized at one time under either manual or automatic control. Manual control is operative in model neutral position. With no signal present from any of the five model positions the condition is decoded as model neutral position.

3. Logic - Electromagnetic and electrostatic shielding is provided to minimize electrical noise in all logic circuitry. Power supply transformers are electrostatic shielded. All necessary logic is provided for complete operation of this multiplexer as described herein.

G. Digital Voltmeter

1. Range - ± 19.999 V DC in one range.

2. Resolution - 1 mV.

3. Accuracy - 0.01% of reading ±0.01% of full scale.

4. Polarity - automatic and indicated.

5. Reading Rate - adjustable 0 to 30/seconds.

6. Input - differential with guard shield and 10 megohm input impedance.

H. Installation and Checkout

The multiplexer was installed on site by Government personnel using standard 19 inch GFE equipment enclosures. Checkout of the system was accomplished by Government personnel.

I. System Power - 115 V, 60 Hz.

III OPERATING PROCEDURE

A. Signal Connections

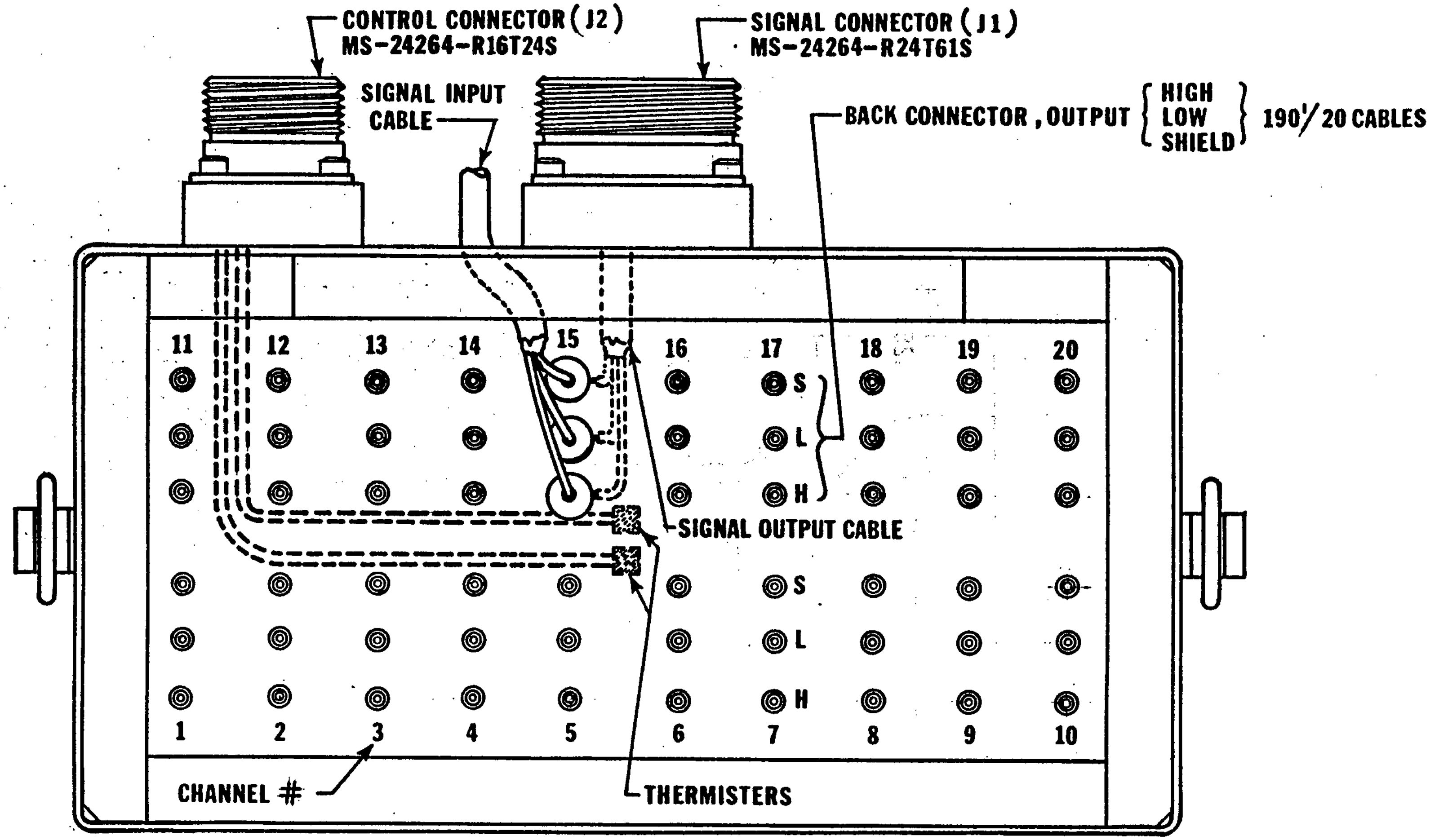
Signal connections are made from the transducer output into the thermocouple reference junction, Figure 9. Signal wires are threaded through the center of the taper plugs and bent upward, Figures 10 and 11. This taper plug is then inserted into the appropriate copper slug of the reference junction. Two sizes of taper plugs allows use of AWG wire size No 22 -28. The material type of the signal joins the copper thus forming the electrical junction. These copper slugs are maintained at a constant 150°F ± 1°F, Figure 12. Any electrical conducting wire material type can be used for making a truly universal thermocouple reference junction. These copper slugs are wired through shielded twisted pair copper signal cables to their assigned multiplexer channel. The signal may be floating or grounded. The signal shield should be attached to transducer case or Lo signal as close to the transducer as possible.

B. Multiplexer Programming

The multiplexer is maintained in an operational state of readiness according to periodic checks and adjustments as prescribed in the equipments operation and maintenance manuals.

The test conductor provides the technicians with a tabulation of signal types and/or gains, bandwidth,and zero settings for each channel to be used. The technician selects the specified gain, bandwidth and zeros. A check of each channel is made after all transducers are connected to assure terminations and polarity are correct, and then a

PIN CONNECTIONS			
RED	BLK	GND	CH#
A	B	C	20
D	E	F	10
G	H	J	6
K	L	M	14
N	P	R	4
S	T	U	3
V	W	X	12
Y	Z	a	18
b	c	d	8
e	f	g	19
h	i	j	5
k	m	n	15
p	q	r	13
s	t	u	11
v	w	x	9
y	z	AA	17
BB	CC	DD	16
EE	FF	GG	1
HH	JJ	KK	7
LL	MM	NN	2
J1			



HEATER	A & B
THERMISTER # 1	C & D
THERMISTER # 2	E & F
BOX GROUND	G
J2	

Figure 9. REFERENCE JUNCTION BOX

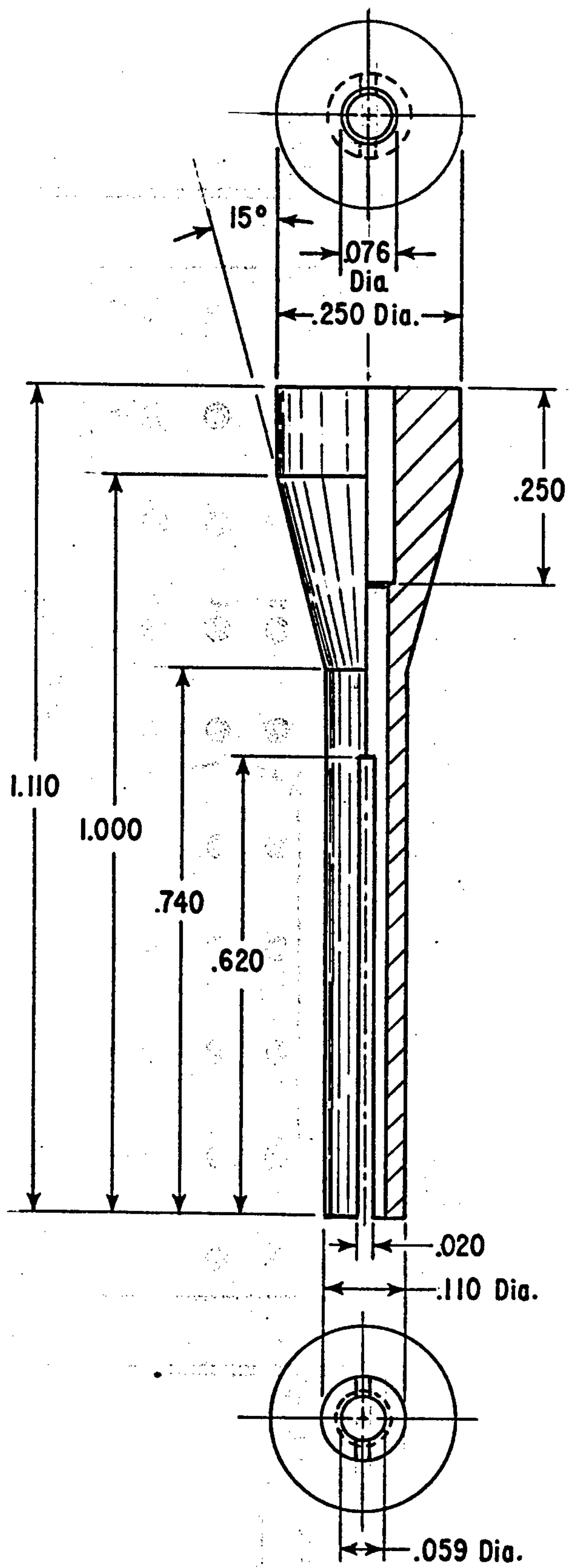


Figure 10. NYLON CONNECTOR PLUG FOR # 22 - 24 AWG

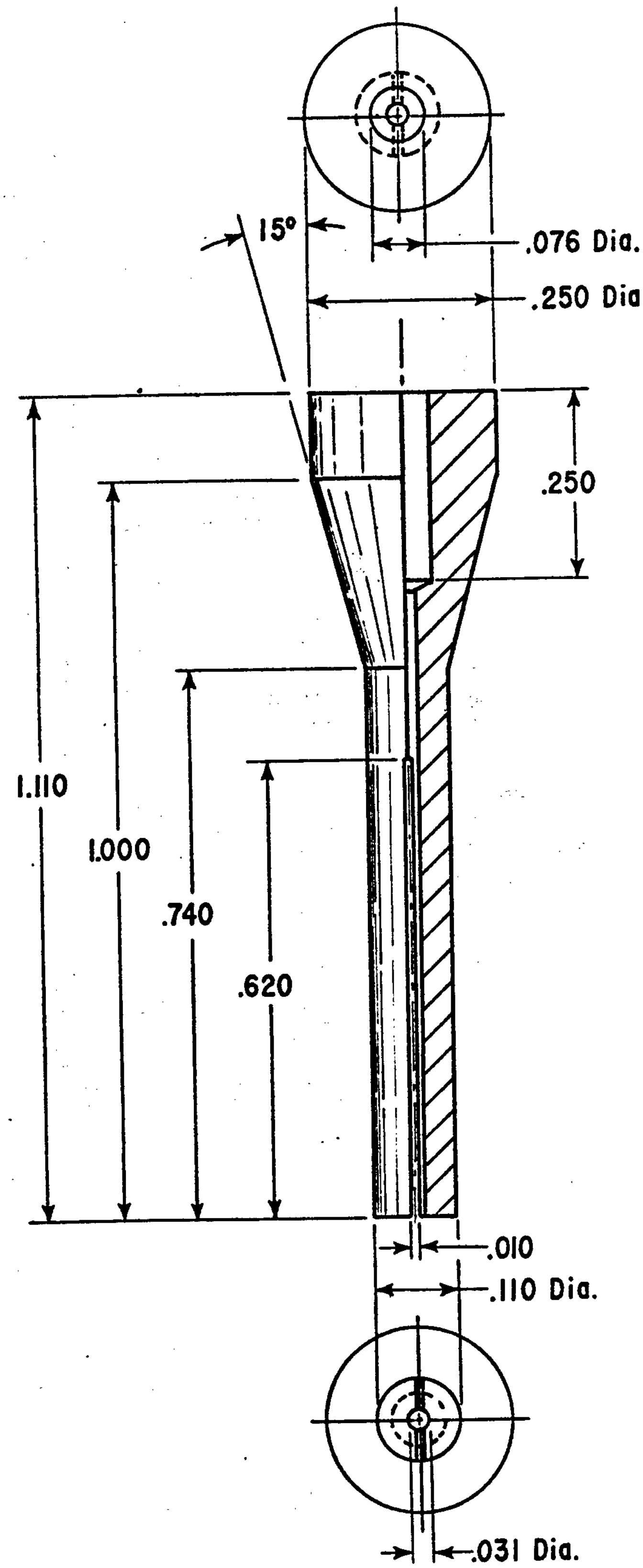


Figure 11. NYLON CONNECTOR PLUG FOR #2

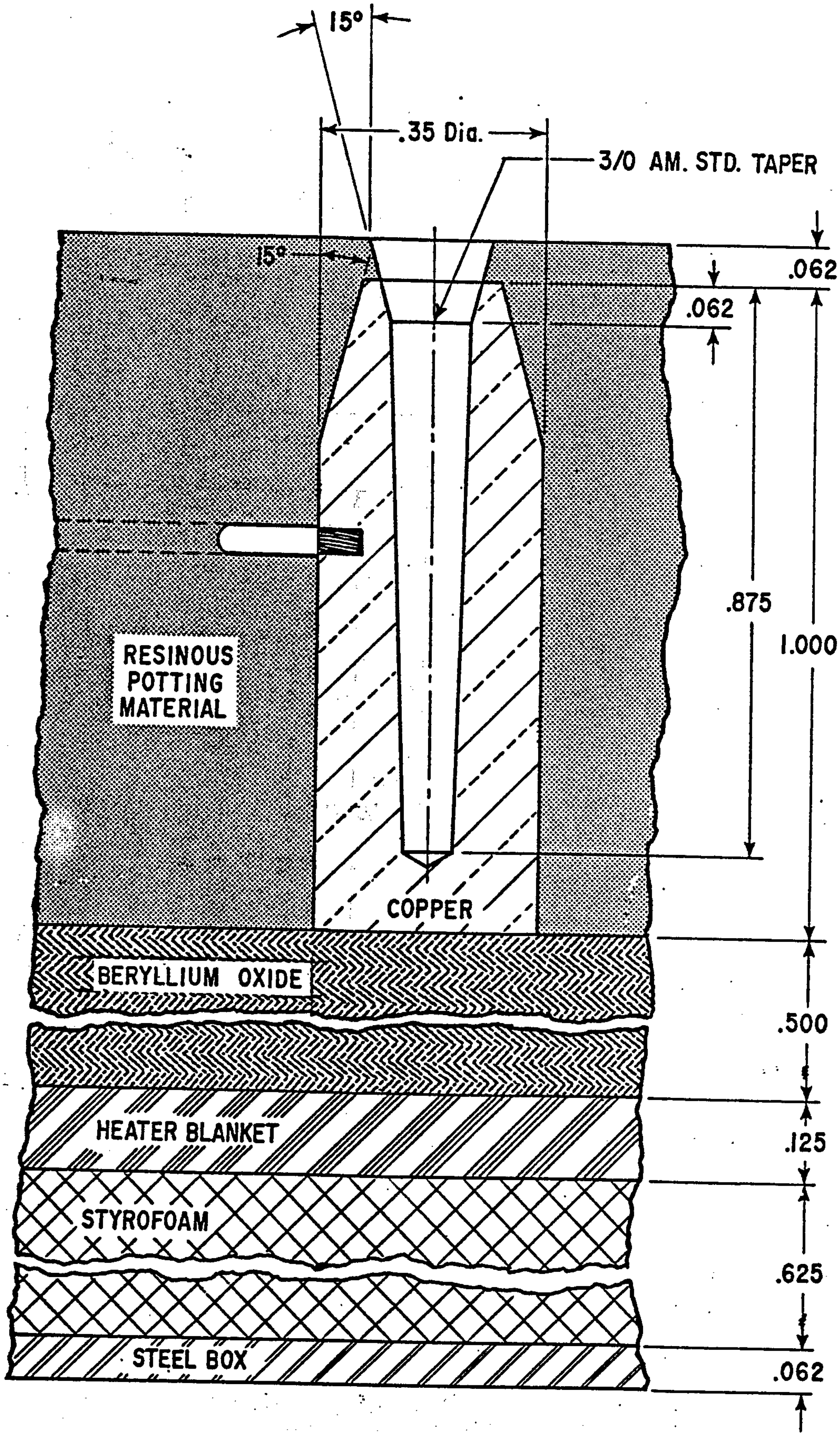


Figure 12. COPPER SLUG TEMPERATURE BATH

quick one point calibration can be made.

Upon completion of these tests, the computer operator is notified. He runs a test through his computer to assure that all is ready for running.

C. Data Run

The manual channel select switch may be left in any position. The channel so selected will automatically release when the first model is positioned in test position. When the carriage returns to neutral position, all channels are disengaged and a short circuit is applied across the amplifiers inputs. This is accomplished automatically by removing the relay power. Relay power is manually engaged for set-up purposes and should be disengaged when not in use.

Post run zeros (hot zeros) can be taken as the model returns to neutral position. Each model transducer set will be multiplexed in the reverse carriage direction. Adequate time will be available for the computer to record these zeros without stopping the carriage. The models are usually destroyed during the test so some of the data channels will be inoperative at this point.

D. Model Preparation

The multiplexer has been located near the model carriage. This arrangement enhances the correct model installation since the multiplexer can be used as an on-site trouble shooting device on a channel by channel basis. The installation, checkout and recording of as many as 300 separate data channels in an eight hour period is no small task. In this case, two technicians are required. The model must be prepared by proper labeling and stripping the signal lead wires prior to test installation time. The full interval of time between tests will not be available for model installation and checkout.

The 0.15% system accuracy is very adequate for this type of test. For the majority of transducers types, this allows for some "slop" in the system accuracy; 1% error for thermocouples usually is acceptable. Provisions exist for those data that require a greater than 0.1% accuracy but on a limited basis. In these exceptional cases, this multiplexer will not be used.

E. Multiplexer Calibration

Table I lists the full scale input voltage for each gain range.

Table II shows a sample form used in recording error in the system. One form should be used for each channel. These records should be kept for a period of time sufficient to predict problems. A schedule of two five-channel modules per week is recommended. This will assure a three month calibration interval.

As a quick check guide, use the input voltage from Table I that corresponds to the transducer type to be used. The output should read 10.000 ± 0.015V. The zero is fixed for gain range K, S and W. Note the zero offset and subtract it from full scale voltage to check true span. For all other gains, the ± full scale zero offset is operative. The zero shall be adjusted near zero so that when the output is full scale,

GAIN RANGE	GAIN =	V INPUT	V OUTPUT ± 0.015mV	COMMENT
K.	136.230	0.073405	10	Chromel-Alumel
S	427.715	0.023380	10	Platimum/Platimum-10% Rhodium
W	219.861	0.045493	10	Tungsten - 5% Rhenium Tungsten - 26% Rhenium
1000	1000	0.010	10	
100	100	0.100	10	
10	10	1.0	10	
1	1	10.0	10	
Var 1000	1.25 (min.)	8.0	10	
	1000 (max.)	0.010	10	
Var 100	1.25 (min.)	8.0	10	
	100 (max.)	0.10	10	

TABLE I. GAIN SCALING CHART

Δ MOD = READINGS (–) ZERO (–) SHOULD READ VALUE ENTER ERROR UNDER APPROPRIATE Δ MOD, MAX ±.015			CALIB.		REF. JUNC. IN	
			SIG. IN		NOISE	
			CHANNEL NO.			

	mV INPUT	SHOULD READ	Δ MOD 1	Δ MOD 2	Δ MOD 3	Δ MOD 4	Δ MOD 5
(K) RANGE	0	0					
	10	1.362					
	20	2.724					
	30	4.087					
	40	5.449					
	50	6.812					
	60	8.174					
	73.405	10.000					
(S) RANGE	0	0					
	10	4.277					
	20	8.554					
	23.380	10.000					
(W) RANGE	0	0					
	10	2.198					
	20	4.397					
	30	6.596					
	40	8.794					
	45.493	10.002					
(1000) RANGE	0	0					
	2	2.000					
	4	4.000					
	6	6.000					
	8	8.000					
	10	10.000					
(100) RANGE	0	0					
	20	2.000					
	40	4.000					
	60	6.000					
	80	8.000					
	100	10.000					
(10) RANGE	0	0					
	200	2.000					
	400	4.000					
	600	6.000					
	800	8.000					
	1000	10.000					
(1) RANGE	0V	0					
	2V	2.000					
	4V	4.000					
	6V	6.000					
	8V	8.000					
	10V	10.000					
MIN	100 mV	10.000					
MAX	10 mV	10.000					
VAR (1000)							
MIN	1 V	10.000					
MAX	100 mV	10.000					
VAR (100)							

Table II. SAMPLE CALIBRATION RECORD CHART the amplifier will not be in saturation. Subtract the zero from the output reading to check true span.

When using variable gain, care should be taken in adjusting span. The lower gains are easily adjusted. The higher the gain, the more sensitive the adjustment. Since the amplifiers have a hyperbolic gain characteristic, gains greater than 100 are extremely difficult to adjust. If a higher variable gain must be used, then a shunting resistor could be placed in parallel with the gain potentiometer. This is not a recommended practice, but the potentiometer can be desensitized by this method. A rough resistor value can be obtained using $R = \frac{40K}{G}$, where gain is between 100 and 1000.

A 100K ohm resistor in series with the gain potentiometer will allow variable gain adjustments to approach 1 from 1.25.

F. Filter Selection

The position of the filter does not affect the DC calibration or zero of the channel. Table III shows the filter characteristics.

FILTER SWITCH POSITION	CUT OFF	RESPONSE
100 Hz	100 Hz	80 db/decade 4 pole Butterworth
1K Hz	1000 HZ	80 db/decade 4 pole Butterworth
10K Hz	10,000 Hz	80 db/decade Butterworth
None	50,000 Hz	3 db/decade

TABLE III. FILTER CHARACTERISTICS

Care should be taken in specifying the bandwidth required. The filter should pass a signal frequency above the maximum signal slewing rate expected. This is usually a function of the burning rate of the model material, heat transfer characteristics of the material and the distance to the model tip. Experience has shown that most models require the 1000 Hz position, some less. Very few require greater than 1000 Hz. If greater than 1000 Hz is required, then recording by oscillograph, tape recording, oscilloscope or other methods must be used since bandwidth will be out of range of the facility computer.

IV TEST RESULTS

A. Operation and Maintenance Manuals

Recommendations for connecting different input configurations are outlined in a manual supplied with the equipment. Directions for calibrating and testing of the system are included therein. The system may be used in the following signal input configurations.

1. Floating Input - Grounded Output
2. Floating Input - Floating Output
3. Grounded Input - Grounded Output
4. Grounded Input - Floating Output

The highest common mode rejection is achieved when the input guard shield is connected to the highest common mode potential with respect to the output common.

All the facility recording devices are floated above building grounds and are all terminated separately to one common instrumentation ground. This is a large isolated copper block whose common is carried to neutral earth grounding point.

Paragraph A-1 and A-3 above are the normal methods of input signal termination.

B. Calibration Demonstration

Table IV shows a typical calibration of module No. 1 which contains channel No. 1 of all five models. This calibration shows the calibration

Δ MOD = READINGS (−) ZERO (−) SHOULD READ VALUE ENTER ERROR UNDER APPROPRIATE Δ MOD, MAX ±.015	CALIB.	REF. JUNC. IN
	SIG. IN	NOISE
	CHANNEL NO.	

	mV INPUT	SHOULD READ	Δ MOD 1	Δ MOD 2	Δ MOD 3	Δ MOD 4	Δ MOD 5
(K) RANGE	0	0	0.000	0.002	0.000	0.002	0.002
	10	1.362	1.363	1.365	1.363	1.364	1.364
	20	2.724	2.727	2.728	2.727	2.727	2.727
	30	4.087	4.090	4.091	4.089	4.090	4.090
	40	5.449	5.453	5.455	5.453	5.454	5.453
	50	6.812	6.816	6.817	6.816	6.817	6.816
	60	8.174	8.179	8.181	8.178	8.180	8.179
	73.405	10.000	10.005	10.007	10.005	10.007	10.006
(S) RANGE	0	0	0.004	0.009	0.006	0.007	0.006
	10	4.277	4.285	4.290	4.285	4.288	4.285
	20	8.554	8.568	8.572	8.566	8.570	8.563
	23.380	10.000	10.013	10.018	10.013	10.018	10.011
(W) RANGE	0	0	0.000	0.003	0.000	0.000	0.000
	10	2.198	2.200	2.202	2.199	2.201	2.200
	20	4.397	4.400	4.402	4.400	4.401	4.399
	30	6.596	6.600	6.602	6.599	6.602	6.599
	40	8.794	8.800	8.802	8.800	8.802	8.798
	45.493	10.002	10.008	10.011	10.008	10.010	10.006
(1000) RANGE	0	0	0.004	0.007	0.008	0.009	0.014
	2	2.000	2.007	2.009	2.011	2.013	2.013
	4	4.000	4.010	4.010	4.014	4.018	4.014
	6	6.000	6.013	6.014	6.016	6.021	6.012
	8	8.000	8.016	8.019	8.020	8.025	8.013
	10	10.000	10.017	10.018	10.020	10.025	10.009
(100) RANGE	0	0	-0.003	-0.009	0.003	0.000	0.004
	20	2.000	1.997	1.991	2.004	2.000	2.004
	40	4.000	3.992	3.992	4.005	4.001	4.004
	60	6.000	6.000	5.994	6.007	6.007	6.006
	80	8.000	8.002	7.995	8.008	8.005	8.007
	100	10.000	10.004	9.997	10.010	10.006	10.009
(10) RANGE	0	0	-0.002	-0.010	0.003	0.000	0.003
	200	2.000	1.997	1.990	2.004	2.000	2.004
	400	4.000	4.000	3.992	4.007	4.002	4.006
	600	6.000	6.002	5.995	6.009	6.004	6.009
	800	8.000	8.003	7.996	8.011	8.006	8.011
	1000	10.000	10.006	9.799	10.013	10.008	10.013
(1) RANGE	0V	0	-0.002	-0.010	0.003	0.000	0.003
	2V	2.000	1.998	1.990	2.004	1.999	2.004
	4V	4.000	4.000	3.992	4.007	4.002	4.003
	6V	6.000	6.002	5.995	6.010	6.005	6.010
	8V	8.000	8.006	8.001	8.016	8.012	8.016
	10V	10.000	10.007	9.999	10.013	10.008	10.012
MIN	100 mV	10.000	10.196	10.191	10.203	10.199	10.202
MAX	10 mV	10.000	10.602	10.609	10.612	10.616	10.599
VAR (1000)							
MIN	1 V	10.000	2.895	2.887	2.902	2.897	2.902
MAX	100 mV	10.000	9.995	9.990	10.003	10.000	10.003
VAR (100)							

Table IV. TYPICAL MODULE CALIBRATION

accuracies of each model. The same amplifier is used. The computer can be used to subtract out the zeros. This will result in a system accuracy equal to or greater than 0.15%.

C. Effectiveness

The cost was about one third of the amplifier per channel arrangement using the 0.01% accuracy type instrumentation amplifiers that have switchable gain and filters.

The time to set-up a test is usually the time required to terminate the model transducers to the reference junction when using two technicians. To do this, the multiplexer must be maintained in an operational ready condition. This can be assured by maintaining a calibration schedule of two five-channel modules per week.

Each module is interchangeable, one with any other. If any channel goes bad, then an unused channel may be moved into that slot. On site repair is recommended to assure a minimum of downtime. This is a one-of-a-kind multiplexer; therfore, a using technician should become knowledgeable in this multiplexer so as to effect repair in a minimum of time.