OPERATING INSTRUCTIONS FOR DYNAMIC PILE FORCE READOUT, MODEL 2174
(An Instrument for Measuring Peak Forces on Piles During Driving)

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Development of Dynamic Peak Force Readout Apparatus for Use in Analysis of Piling Behavior
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ABSTRACT

The Model 2174 Dynamic Force Readout is an instrument developed at Texas Transportation Institute for measuring the peak force on the top of piles during driving. The instrument is intended initially for use with piles which have been instrumented with strain gages and ultimately with a universal transducer which can be placed on the head of the pile during driving. Several design features are incorporated to make the instrument particularly useful as a practical field-worthy measuring tool, such as being self-contained and portable with an internal power supply. It uses a carrier type strain gage amplifier and phase sensitive demodulator to suppress self-generating strain gage responses during driving. A special balance error correction amplifier is incorporated to compensate for bridge balance errors (drift) which will be present in any instrumentation on field test piles.

Key Words: Strain Gage Amplifiers, Piling Instrumentation, Peak Detector, Force Measurements.

SUMMARY

The operating instructions presented in this report are those necessary for operation of the Model 2174 Dynamic Pile Force Readout, an instrument for measuring the peak force on a pile during driving. This instrument was developed at Texas Transportation Institute under research study number 2-5-73-174 after an extensive search was made, without success, to purchase a commercially available instrument which would satisfy the project objective.

This paper lists the tentative specifications for the newly developed readout, gives complete and detailed operating information, describes the theory of operation and presents the complete set of electrical schematic diagrams.

IMPLEMENTATION STATEMENT

Research Report 174-1(F) gives the operating instructions necessary for technical personnel to operate and use the Model 2174 Dynamic Pile Force Readout. It and the operating instructions are now available for use by the Texas Highway Department; however, the instrument is scheduled to undergo an extensive one year field evaluation beginning 1 September 1974 under a currently approved research project sponsored by the Texas Highway Department. At the end of this period, additional user instructions will be furnished to the research sponsor along with the results of the field evaluation in the form of a technical report.

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INTRODUCTION

This manual details the user instructions necessary for operating a Dynamic Pile Force Readout, an electronic instrument which has been developed at the Texas Transportation Institute under Research Project Number 2-5-73-174, entitled "Development of Dynamic Peak-Force Readout Apparatus for Use in Analysis of Piling Behavior." This manual is submitted to fulfill the specific requirements of Task 5, Plan A of the research proposal. The research, sponsored by the Texas Highway Department in cooperation with the Federal Highway Administration, had an objective "to provide an electronic readout unit for displaying the maximum dynamic force on the head of a pile at the time the pile is being driven."

Early in the project an extensive search was made to determine if a device was commercially available which would meet the project objective. Requests to bid on the specifications for the device were sent to over twenty prospective suppliers. No favorable responses were received and in accordance with the project work plan it was decided to design and fabricate the readout device. At the time of this writing the authors feel that the design objective has been met, although this judgement is based solely on laboratory tests. A thorough field evaluation of the readout is to be conducted during the following year under a currently approved research project scheduled to commence on 1 September 1974 .

The authors wish to express their appreciation to Dr. Harry M. Coyle of Texas Transportation Institute and Mr. H. D. Butler of the Texas Highway Department for their detailing of the readout requirements to insure its use as a valuable tool in the overall solution of pile driving problems using the Wave Equation Method of Analysis.

Section 2

TENTATIVE SPECIFICATIONS

I. General Information

The Model 2174 Dynamic Pile Force Readout is a self-contained, field, electronic instrument which provides capabilities to measure the peak value of the compressive impact forces delivered to a pile during driving. This value is displayed directly in Kips on a digital panel meter.

II. Input Transducer

The instrument is intended for use with full bridge strain gage type transducers or piles instrumented with a full bridge having gages ranging in resistance from 120 to 500 ohms.

III. Signal Conditioner

The signal conditioner is of the carrier type intended to suppress self-generating responses of strain gages when used with piles.

A. Carrier Frequency

Approximately 10 KHz, Amplitude stabilized.

B. Excitation Voltage

Approximately 3 VRMS to 4.5 VRMS depending on bridge resistance.

C. Frequency Response

DC to 1 KHz pass-band. Pass-band flatness = ±0.2 db. Down 3 db at 2.55 KHz.

D. Range

Minimum of 50 Kips for direct reading. Full scale of 1,000

Kips for direct reading.

E. Noise

0.1% RMS of full scale.

F. Carrier Suppression

Approximately 50 db.

G. Output Signals Available From Front Panel

1. BNC Oscilloscope output for driving high impedence instruments having input impedence of 1 meg ohm or higher. Approximately +2 V F.S.

2. Binding Post Galvonometer or current output for driving low impendence instruments of approximately 27 ohms. 25 milliamperes F.S.

H. Balance

Resistance Balance with range of approximately 3,000 μ strain. Capacitive Balance with range of approximately 0.0005 Mfd. During operation balance is not critical due to inclusion of a balance error correction amplifier.

IV. Accuracy of the Readout

1% of F.S.

V. Display

3½ digit digital panel meter

VI. Calibration

A front panel push-button switch is provided to insert one of 10 preselected shunt calibration resistors to simulate an impact force. Front panel fine and coarse gain adjustment are provided to scale the display to read directly in Kips.

VII. Power Requirements

The instrument can be operated from 117 VAC line, 12 VDC external battery or from an internal battery provided, selectable from the front panel. The internal battery is of the completely sealed, lead-acid type having a 5 amp-hour rating. It can operate the readout for approximately 3 continuous hours. An integral battery charger is provided which charges the battery automatically when the unit is plugged into a source of 117 VAC. Charging time is approximately 16 hours minimum. The condition of the internal battery can be monitored by depressing a push-button.

VIII. Sampling Rate

A Thumb Wheel Switch having a range of 0 to 99 selects the number of hammer blows between samples whose peak value is detected and displayed on the digital panel meter. A reset button is provided to restart the count to zero if desired.

IX. Warm-up Time

5 seconds.

X. Case

Sealed type, 10" x 16" x 12" high.

XI. Weight

Approximately 26 pounds.

XII. Operating Temperature Range

0°C to 70°C.

Section 3

OPERATING INFORMATION

I. General Description

Research has been conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department in the area of bearing capacity of axially loaded piles. Specifically, the research has centered about the prediction of pile bearing capacity by a method widely known as the Wave Equation Method of Analysis. One of the problems associated with this method is that an accurate model of the pile hammer and driving accessories is difficult to achieve for all driving conditions. This problem can be alleviated to a large degree if the maximum dynamic force which is delivered to the top of the pile by the hammer and cushion assembly can be accurately determined.

The Model 2174 Dynamic Peak Force Readout is designed and intended to make these necessary measurements for use as input data to the computer simulation and solution of these problems by the Wave Equation Method of Analysis.

This unit is currently intended for use with piles instrumented with a full bridge of strain gages to measure the peak compressive force delivered by a typical hammer blow. The readout ultimately is intended for use with a universal strain gage transducer which will greatly simplify calibration and operation of the readout. These operating instructions, however, will detail its operation only with instrumented piles. See Figure 1.

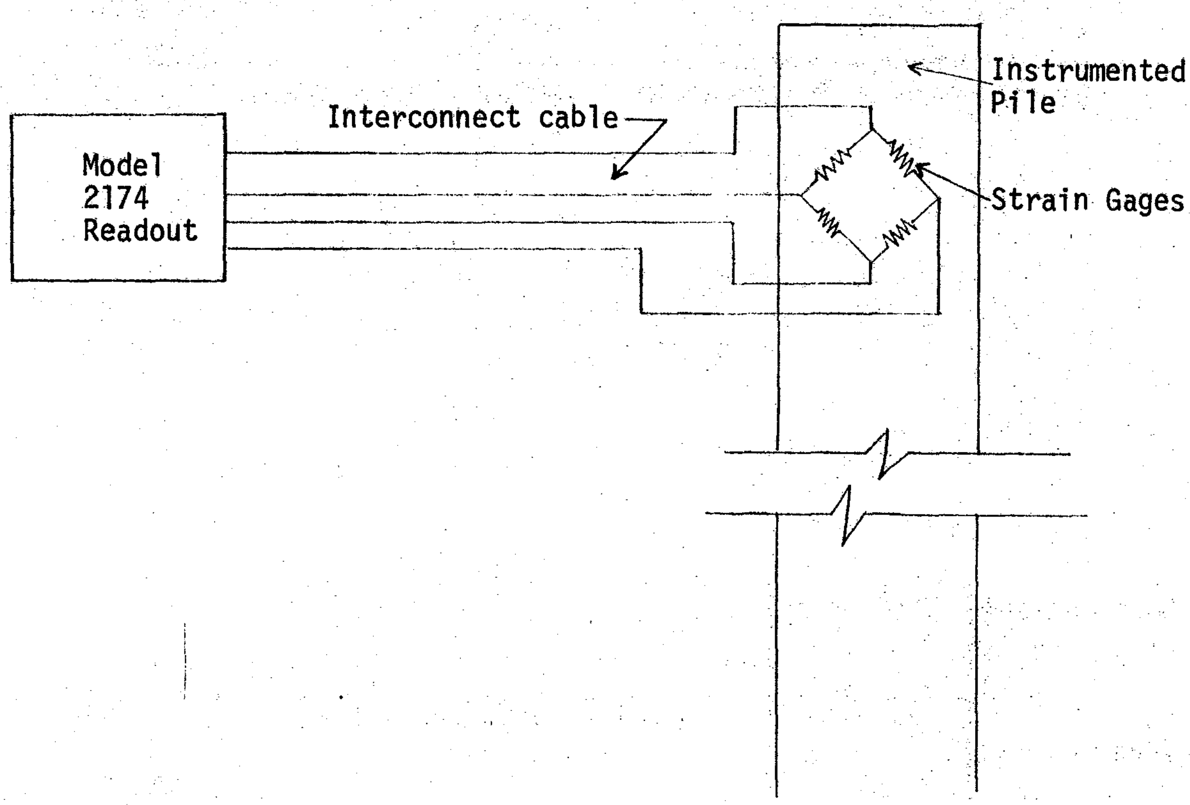


Figure 1. Simplified Block Diagram Showing the Readout Used With Instrumented Piles.

II. Instrumenting the Piles

Piles to be used with the readout by the Texas Highway Department will be either concrete or steel metal shell. Normally the concrete piles are 16" square and the metal shell are 16 inch diameter x ¼ inch wall. Great care should be taken that this instrumentation be installed properly and adequately protected from the environment. A brief discussion of pertinent details for this instrumentation are included below.

A. Concrete Piles

For all concrete piles PML-100S embedment strain gages having a gage resistance of 300 ohms are recommended. They are manufactured by Tokyo Sokki Kenkyujo Co., LTD, of Japan. These gages must be secured with reinforcing steel tie wire to the pre-stressing steel, wired into a full bridge and a cable exited prior to casting of the concrete. "Field Instrumentation For Piles" by Hirsch, et. al., details the installation of these gages. The gages should be located at least 3 feet from the head of the pile so that they are located away from the non-uniform strain field present near the very top of the pile. There are two techniques for installing the full bridge. The first consists of 4 active gages, 2 of which are positioned longitudinally 180° apart and the other 2 positioned horizontally 180° apart. See Figures 2 and 3.

These gages are then wired into a full wheatstone bridge as shown in Figure 4.

The other technique for instrumenting concrete piles is to install 2 longitudinal active gages and 2 "dummy" gages.

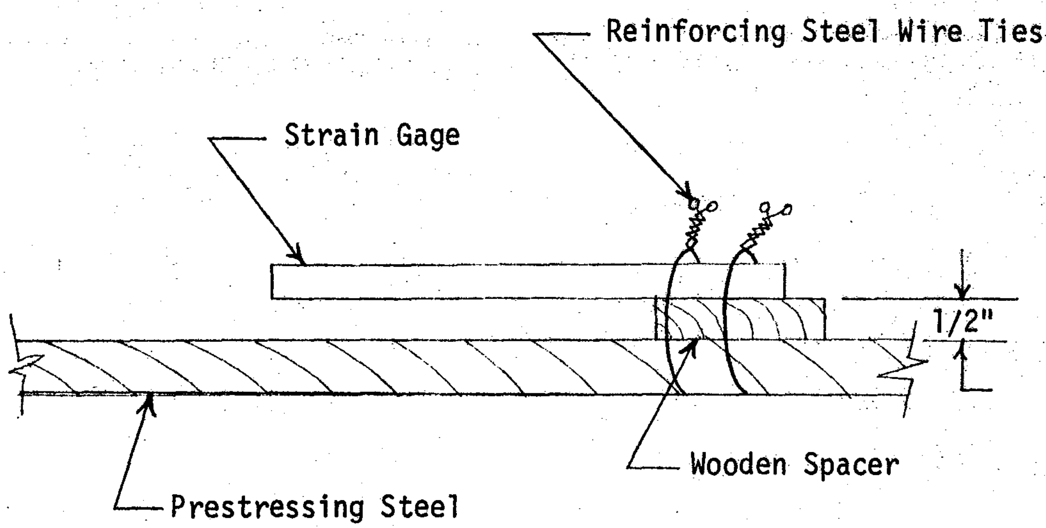
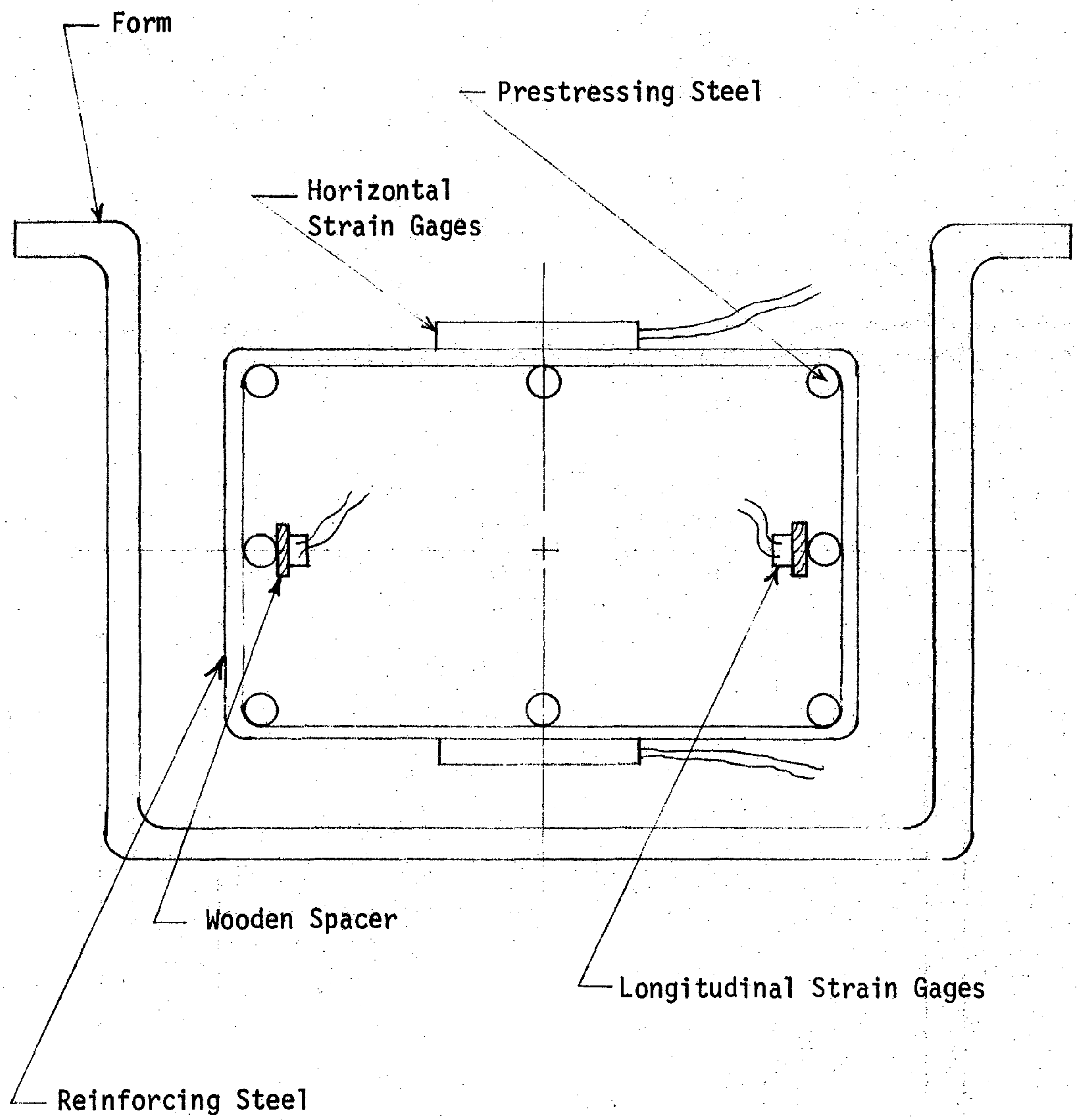


Figure 2. Detail of a single concrete embedment gage tied to the prestressing steel. Note the wooden spacer which allows concrete to completely surround the active portion of the embedment gage.



Note that the pairs of horizontal and longitudinal gages are 180° apart and equally spaced about the center line of the pile.

Figure 3. End view of reinforcing steel and pile form showing placement of concrete embedment gages. Note 2 gages are placed longitudinally and 2 are placed horizontally.

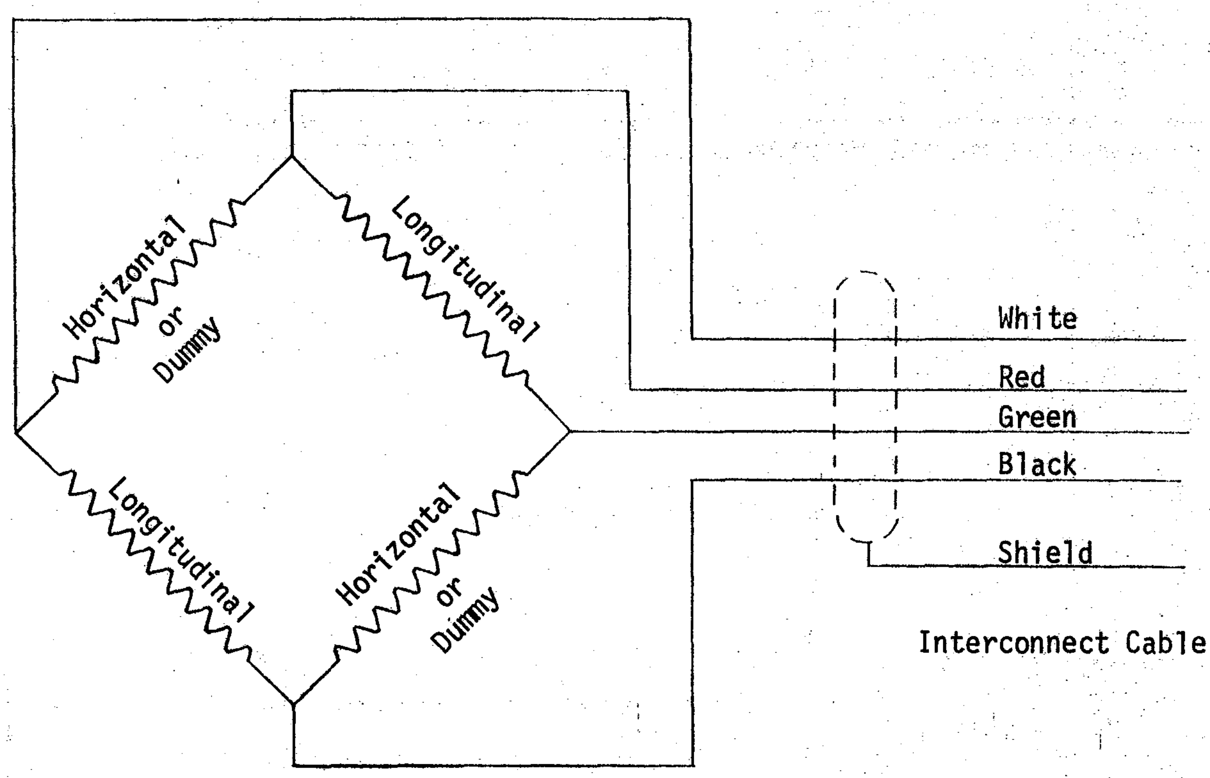


Figure 4. Wiring diagram for the 4 gages installed in a Concrete Pile.

The "dummy" gage is made by taking the same PML embedment strain gage, encapsulating it so that it is insensitive to strains in the concrete but still acts as a temperature sensor to provide approximate temperature compensation for the bridge. Figures 5a and b show details of the construction of the "dummy" gage.

Two pieces of 16 gauge steel (½" x 6" long) is clamped and glued with W. T. Bean RTV epoxy to each face of the embedment gage. These steel strips have a thermal expansion co-efficient close to that of concrete. They thereby provide temperature compensation for the completed bridge. Next, 2 pieces of raw rubber tape approximately 1" x 6" x 1/8" thick are placed on each exposed face of the steel strips. This assembly is then placed into a piece of 1" inside diameter x 7" long x 16 or 18 gauge aluminum tubing. The tubing is squeezed flat in a vise until it holds the gage firmly in place between the rubber "pillow". The gage should not be allowed to move freely inside the aluminum tube. The ends of the aluminum tube are then potted with RTV silastic rubber to complete the waterproofing. The wire is exited through the silastic at one end.

Two of these "dummy" gages along with 2 active gages are tied to the reinforcing steel as shown in Figure 3. In this case the "dummy" gages are placed in the horizontal position and wired into the bridge as shown in Figure 4.

The advantage of this technique is that Poisson's ratio (difficult to determine) for the concrete does not have to be taken into account in the readout calibration.

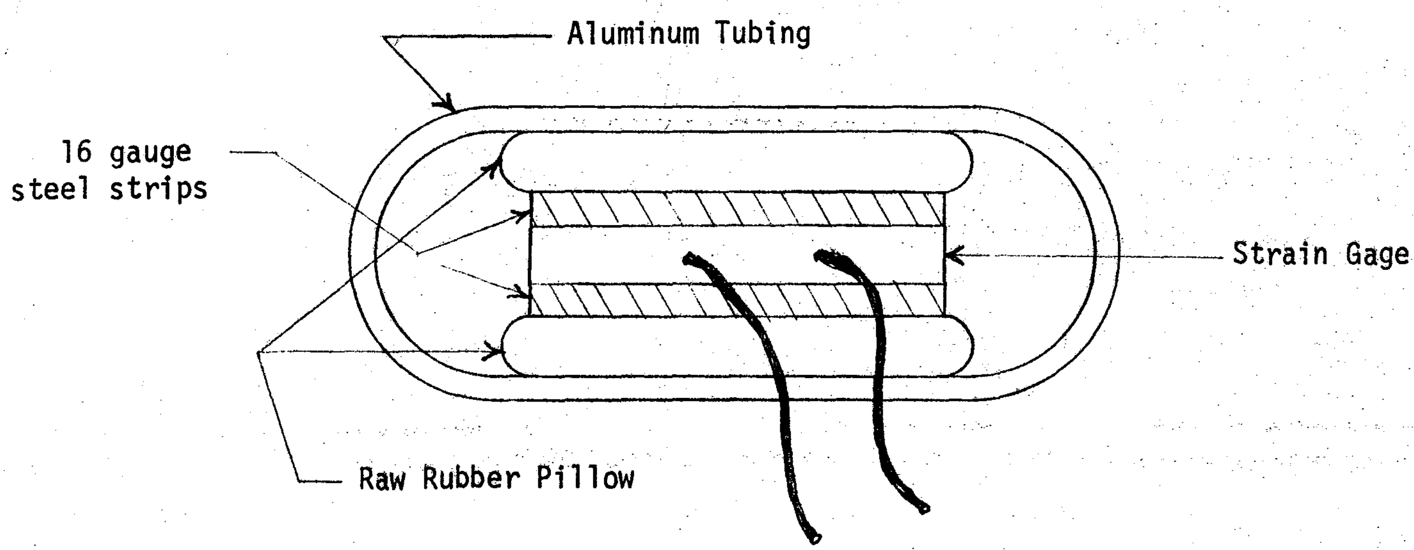


Figure 5a. Shows a cross section of the construction of a "dummy" gage for concrete piles.

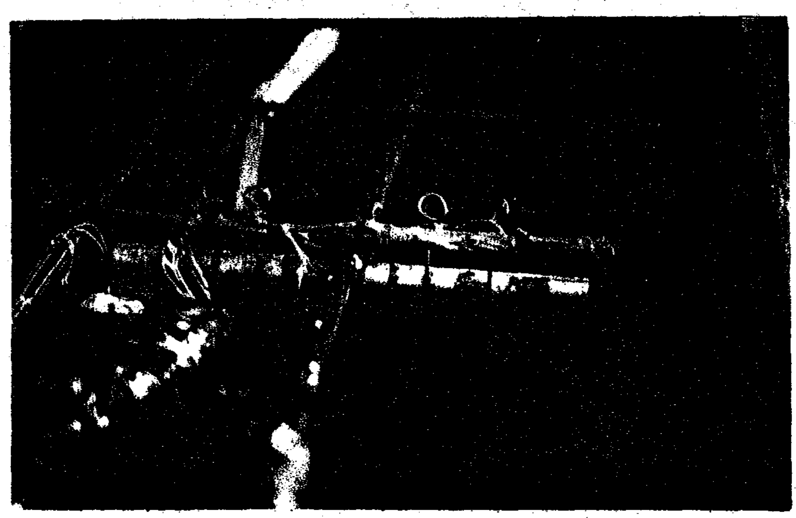


Figure 5b. Shows an outside photograph of the completed gage.

When placing the gages, great care should be taken in securely fastening the gages so that they are not moved during placement of the concrete. Additionally, all wire connections should be coated with a liberal amount of Gage-Cote 1, then a piece of heat shrink tubing is to be shrunk over the connection so that the Gage-Cote is squeezed out of the joint.

B. Metal Shell Steel Pipe Piles

Altech (formerly Microdot, Inc.) No. SG189-120 weldable strain gages available from Technical Products, Inc., Dallas, Texas, are recommended for use on metal shell piles. These gages may be easily and quickly spot welded to the exterior or the interior surface of the pile with minimum surface preparation. For these piles, a full bridge consisting of 8 active gages (4 horizontal and 4 longitudinal) are recommended to be attached at 4 locations spaced 90° apart around the surface of the pile. See Figure 6. The installation should be at least 2 pile diameters from the head of the pile. Adequate installation information for these gages is available from the supplier. Wiring of the eight gages into a full wheatstone bridge is shown in Figure 7. The gage installations should be coated with Bean Gage-Cote 5 and wiring joints should be carefully soldered and protected as outlined for concrete gages.

III. Interconnecting Cable

The readout is provided with a 100 foot piece of Belden 8723 cable which should be connected to the pile bridges as shown in Figures 4 and 7, to maintain proper signal polarity. A compressive stress will then

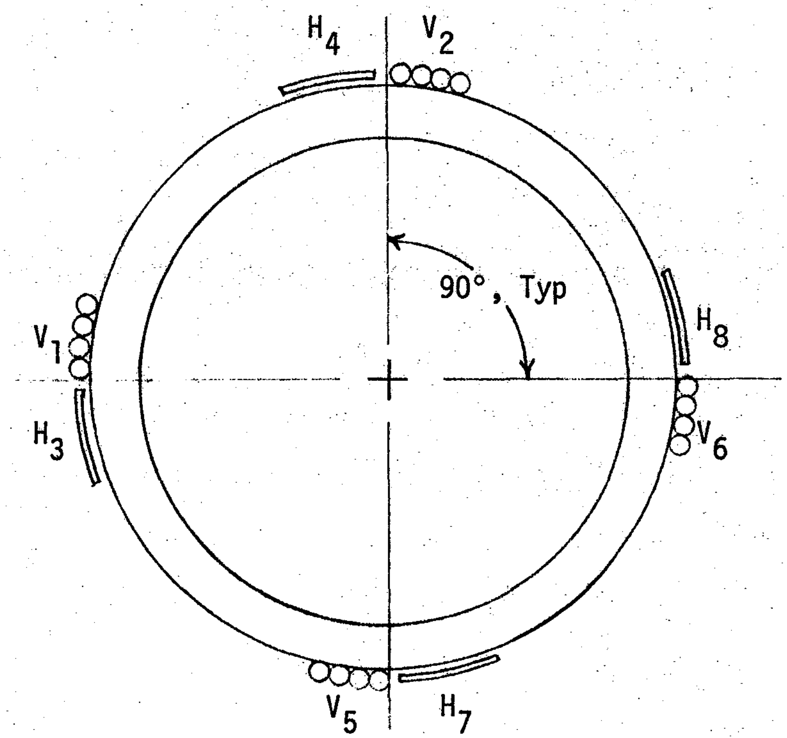


Figure 6. Top View of metal shell pipe pile showing the location of 8 weldable strain gages on the outer surface.

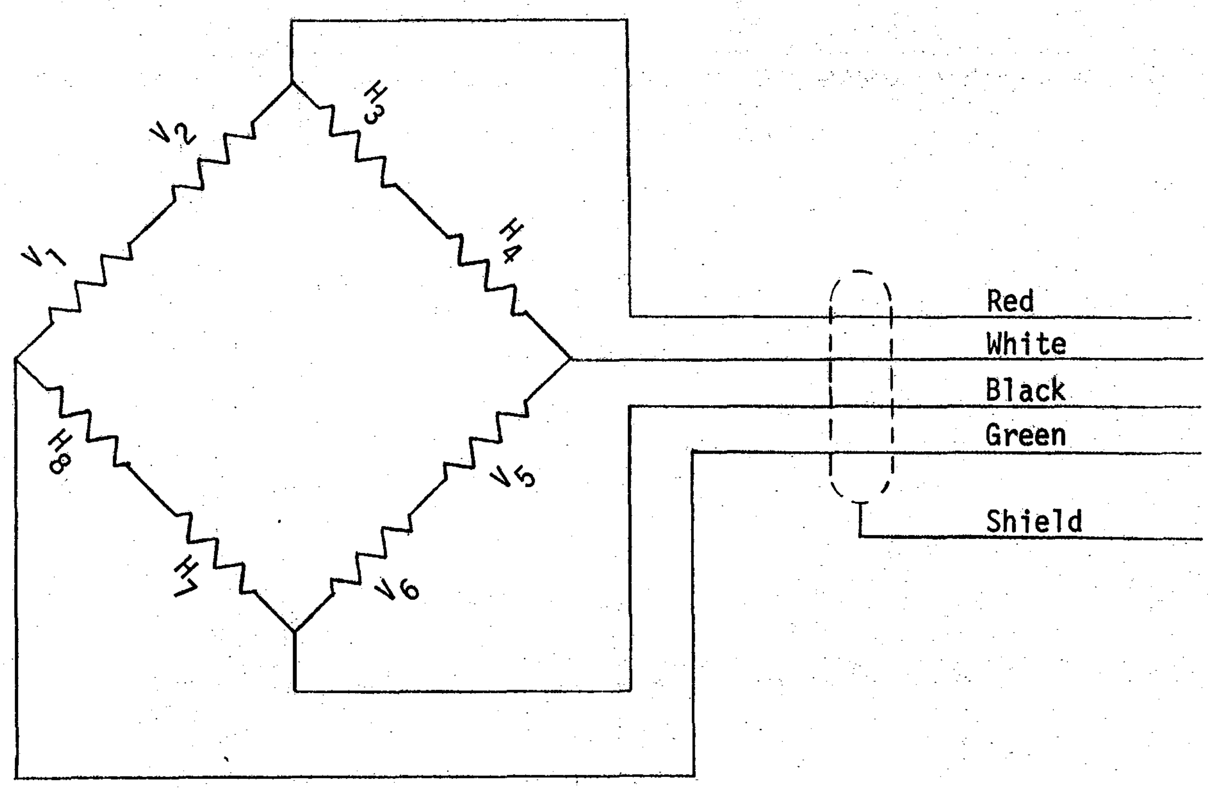


Figure 7. Wiring diagram for the eight weldable strain gages installed on metal shell pipe piles.

yield a positive voltage inside the readout. If a longer cable is needed, additional length of the same type wire can be either spliced onto or connected to the 100 foot piece with a suitable good quality connector. Like colors should be connected together when adding cable.

IV. Function of Front Panel Controls

Refer to Figure 8.

A. 117 VAC input receptacle - located in the upper right hand corner is the input for external AC power used to power the unit and/or charge the internal battery. A mating cable is provided. When this receptacle is connected to an appropriate power source the battery is automatically under charge regardless of the position of other controls.

B. 12 VDC Binding Posts - located in the upper right hand corner of the front panel is the input for external 12 VDC power such as an automobile battery. When using these binding posts it is important that proper polarity be maintained as indicated on the panel. Reverse polarity will not damage the readout, however, it will not operate. <u>A power source greater than 15 VDC under no circumstances must be connected to these terminals</u>.

C. Power Selector Switch - selects one of three alternate power source to operate the readout.

1. Position off: in this position none of the readout electronics is operating. Note that if the readout is connected to 117 VAC the battery is under charge even if this switch is in the off position (Refer to section on battery charging). The readout should be returned to this position when it is not

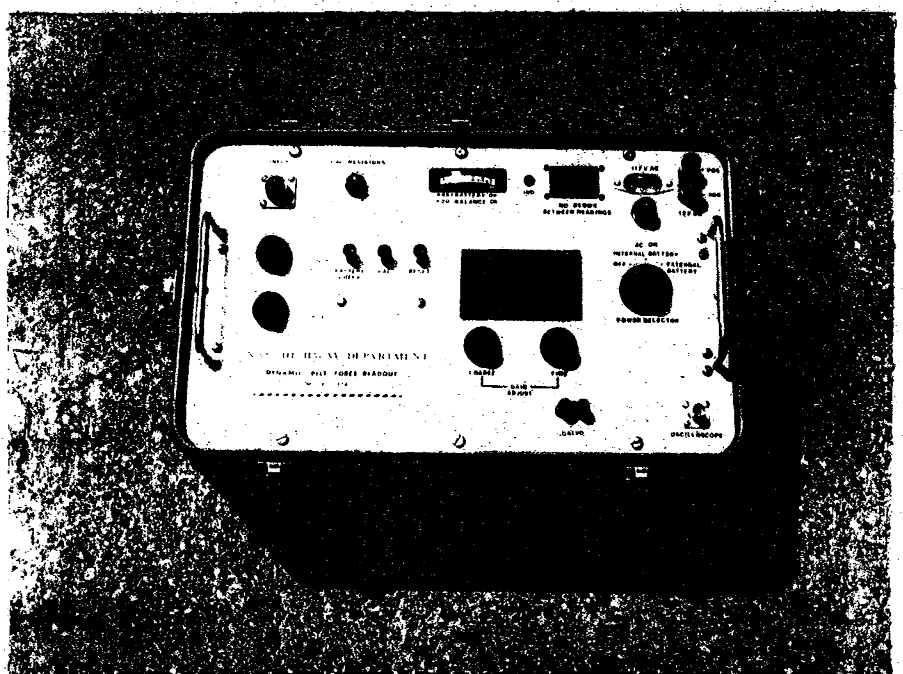


Figure 8. Photograph Showing Front Panel Controls

in use.

2. AC or internal battery position - In this position the internal battery is powering the readout if AC power is not connected. If AC power is connected, it is powering the unit and automatically charging or maintaining charge on the internal battery. When AC power is available it should be used to operate the readout.

3. External battery position: In this position, external 12 VDC power is operating the readout through the 12 VDC Binding Posts. No provision is made for charging an external battery from the readout.

D. Input Receptacle - The instrumented pile or force transducer connects to this receptacle via the interconnecting cable which is provided.

E. R Balance Knob - provides for balancing resistive unbalance in the strain gage bridge and interconnecting cable. There is a standard locking feature located below the knob, which should be engaged after balancing.

F. C Balance Knob - provides for balancing capacitive unbalance in the strain gage bridge and interconnecting cable. There is a standard locking feature located below the knob, which should be engaged after balancing.

G. Calibrate Resistors - This switch selects one of 10 precision resistors to be used in calibrating the readout. The values for these resistors is shown in the following table.

Switch Position	Resistor Value
1	15 K ohms
2	20 K ohms
3	49.9 K ohms
4	60.0 K ohms
5	68.1 K ohms
6	102 K ohms
7	232 K ohms
8	332 K ohms
9	499 K ohms
10	1 megohm

H. Calibrate Push-button - When this button is depressed, the pre-selected calibration resistor is shunted across an appropriate arm of the bridge so as to simulate a positive force of known value.

I. Battery Check Push-button - When this button is depressed, the edgewise panel meter indicates the condition of either the internal battery, the internal AC power supply, or the external battery, depending on the position of the Power Selector Switch. A reading of 45 or greater indicates a satisfactory condition. The internal battery should always be checked when under normal load, i.e.: the AC power cord disconnected and the Power Selector Switch in the AC or internal Battery position.

J. Edge-wise Panel Meter - located in the upper center of the panel, accomplishes two functions. It continuously monitors the degree and adequacy of bridge balance. When the battery check push-button is depressed it indicates power conditions as discussed in paragraph I. above.

K. Reset Button - This button, when depressed, resets all the internal digital logic to zero prior to operation.

L. Thumb Wheel Switch - located above the digital panel meter has a capability for setting in any whole number from 0 to 99. This setting shows the number of hammer blows between sampled blows whose peak value is displayed on the digital panel meter. For example: if the number 3 is set in and the reset button momentarily depressed, the readout will sample the fourth blow, ignore the following 3 blows, then sample the 8th blow, ignore 3 more blows, then sample blow number 12, etc. At any time the reset button may be depressed to restart the count indicated on the Thumb Wheel switches.

M. Gain Control Knobs - provide fine and coarse adjustments for scaling the digital panel meter so that it reads out directly in Kips. Details of setting system gain are given in the section on calibration. Each knob has a standard locking feature which should be engaged when adjustments have been completed.

N. Digital Panel Meter - is a 3½ digit unit wired to indicate force directly in Kips when the readout is properly calibrated. During operation and calibration the decimal point in the tenths position will periodically light, indicating that the next blow will be sampled. This light goes out after sampling occurs. The sampled reading is held until the next blow to be sampled occurs.

O. Indicator Light - (Ind.) is a visual indicator to show that the readout is detecting individual hammer blows. As a blow occurs it will momentarily illuminate for approximately 0.1 seconds as each blow occurs regardless of whether or not that is the blow to be sampled and displayed on the digital panel meter. Its momentary lighting as blows occur is an indication of proper readout operation.

P. Galvonometer Binding Posts - are available as a current output suitable for driving galvonometers and other low impedence devices. Approximately twenty-five (25) milli-amperes are available for full scale or 1,000 Kips for a galvonometer having an impedence of 27 ohms. A Honeywell galvonometer no. M1650 is recommended for use on this output.

Q. Oscilloscope BNC Connector - is available as a voltage output for driving oscilloscopes or other instruments having an input impedence of 1 megohm or higher. Low impedence devices or short circuits should never be connected across this output.

V. Operating Instructions and Calibration

1. Connect Transducer: Connect the instrumented pile or force transducer to the readout input connector using the interconnect cable provided. Insure that proper polarity has been maintained by making the connection between the pile and the interconnect cable in accordance with Figures 3 and 4 or 6 and 7.

2. Select Power Mode. With the Power Selector Switch, select one of 3 modes of power to operate the readout. (1) Internal Battery, (2) AC, or (3) Ext. 12 VDC. If external AC or 12 VDC is to be used the appropriate connections must be made to the source of power. Return the selector switch to the off poistion when not in use.

3. Check Battery. Depress the battery check push-button and insure a reading of 45 or greater on the edgewise panel meter. A periodic check can be made at any time during operation.

4. Balance the Bridge. By turning the R Balance Knob seek a null (minimum reading) on the edgewise panel meter. With the C Balance Knob again seek a null on the meter. Go back to the R Balance; seek a null and again go to the C Balance; again seek a null. Repeat this procedure until turning of the knobs does not result in a smaller reading. Usually a minimum reading of 4 or 5 indicates a good balance. The bridge may be rebalanced at any time during operation; however, as long as the edgewise panel meter indicates twenty or less, rebalancing need not be accomplished.

5. Connect External Instruments. Connect any external instruments, if they are to be used,to the appropriate galvonometer or oscilloscope outputs.

6. Calibrate the Readout. This is the most important step in operating the readout to insure that accurate readings are obtained. If a standard load cell were available, this procedure would be relatively simple and could be quickly accomplished. Until that time certain calculations and engineering judgements must be made in order to decide (A) which calibration resistor to select, and (B) what the value of force in Kips that that resistor represents so that the readout gain can be adjusted. These two numbers can be found by following the procedure outlined in Appendix A. The specific calibrate procedure is as follows:

A. Set the Thumb Wheel Switches to read zero.

B. Momentarily depress the reset button.

C. Set the Cal Resistors Switch to the desired position (as determined from the procedure in Appendix A).

D. Depress the cal push-button. Note that the Ind. light should be flashing at a rate of approximately once per second.

E. While holding the cal button depressed, adjust first the coarse and then the fine gain until the value of the cal resistor in Kips (determined from Appendix A) appears on the digital panel meter within ±1 digit. Note that there will be approximately a two second delay between gain adjustments and a resultant increase or decrease on the digital panel meter.

F. Release the cal push-button. The readout is now calibrated. Note that calibration can <u>not</u> be accomplished while the hammer is hitting the pile.

7. Set Thumb Wheel Switch. Set the switch to the number of hammer blows that are desired between sampled blows. This setting may be changed during operation, but the reset button should then be momentarily depressed to insure an accurate initial count.

8. Momentarily depress reset button.

9. Collect Data. The readout is now calibrated and ready for operation.

Section 4

THEORY OF OPERATION

I. General

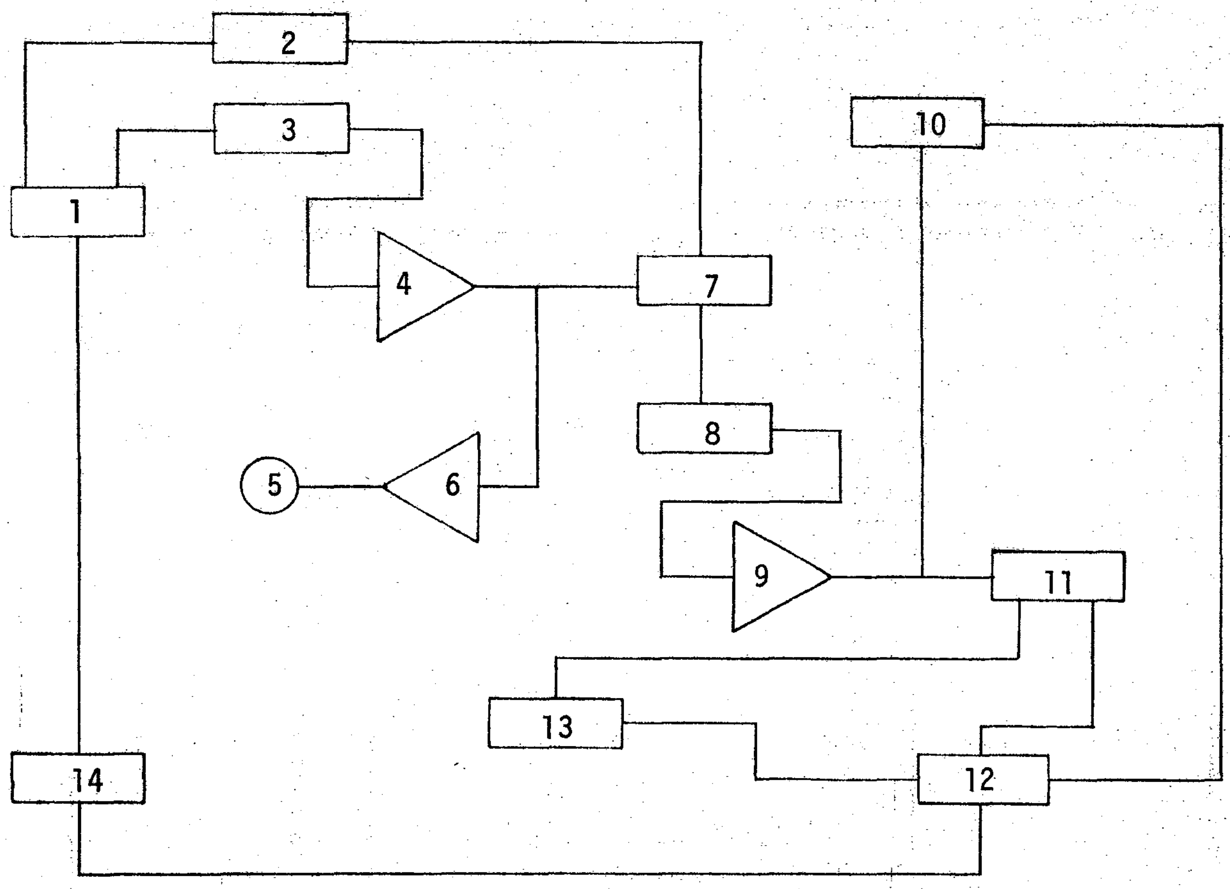
The major components for the Model 2174 Readout are shown in Figure 9, a simplified block diagram. The following discussion should be used in conjunction with that diagram.

II. Power

Power for operating the device is obtained from an internal sealed 12 VDC lead-acid storage battery having a capacity of 5 ampere hours. A front panel switch is provided for selecting either an external 12 VDC battery or conventional 117 VAC, 60 Hz power. Twelve volt power is then converted to ±15 VDC for operating all the signal conditioning and analog circuitry and to +5 VDC for operating the digital logic circuitry and the digital panel meter. Both these power converters are of the high frequency, high efficiency type. The internal battery charger and power supply automatically starts the battery to charging when the unit is plugged into a source of AC power. The battery is charged at approximately 1½ amperes initially and tapers down to approximately 3/4 ampere near full charge. As the battery voltage reaches 14.6 volts, the charger automatically switches to the trickle charge mode and maintains the battery at 13.8 volts.

III. Signal Conditioning

The unit is designed for operation with full bridge resistive strain gage type transducers. The signal conditioning is of the carrier



1. Strain Gage Bridge (modulator)
2. Stable Amplitude Oscillator
3. Balancing Circuitry
4. High Gain Preamp
5. Battery Check and Balance Meter
6. Balance Meter Amplifier
7. Demodulator
8. Low Pass Filter
9. Balance Error Correction Amplifier
10. Schmidt Trigger
11. Peak Detect and Hold
12. Digital Logic
13. Digital Panel Readout
14. Calibration Resistors

Figure 9. Simplified Block Diagram

type having AC voltage for bridge excitation operating at approximately 10 KHz, which inherently rejects or greatly suppresses the self-generating response signals of the strain gage bridge and makes the output signal proportional only to resistive changes of the individual gages. Amplifiers having conventional DC bridge excitation do not make these rejections. For example, Figure 10 shows a simplified electrical schematic of a strain gage bridge connected to a high gain preamplifier which has the bridge excitation disconnected. It is apparent that this amplifier can have no output due to stretching the individual gages since they are a near short circuit across the amplifier inputs. If the bridge (B), however, is moved very rapidly through a magnetic field, a current (I) will flow in the input circuitry and develop a voltage (V) across the amplifier input terminals which will be greatly amplified and appear as an output voltage. This self-generating response will be added to any voltage which is present due to the gages being stretched when the excitation is reconnected. Such a self-generating response is believed to be a major source of error in dynamic strain gage data obtained on piles using DC bridge excitation amplifiers. Certainly there is an area enclosed by the wires connecting the gages, rapid motion is present during driving and magnetic fields are present. Thus the reason for a carrier type amplifier in the Model 2174.

IV. Oscillator

Bridge excitation voltage is generated by the constant amplitude oscillator which consists of an overdamped oscillator stage which is "kicked" at the zero crossing point by an amplifier which has a pair of back to back temperature compensated zeners as a feedback loop, thus,

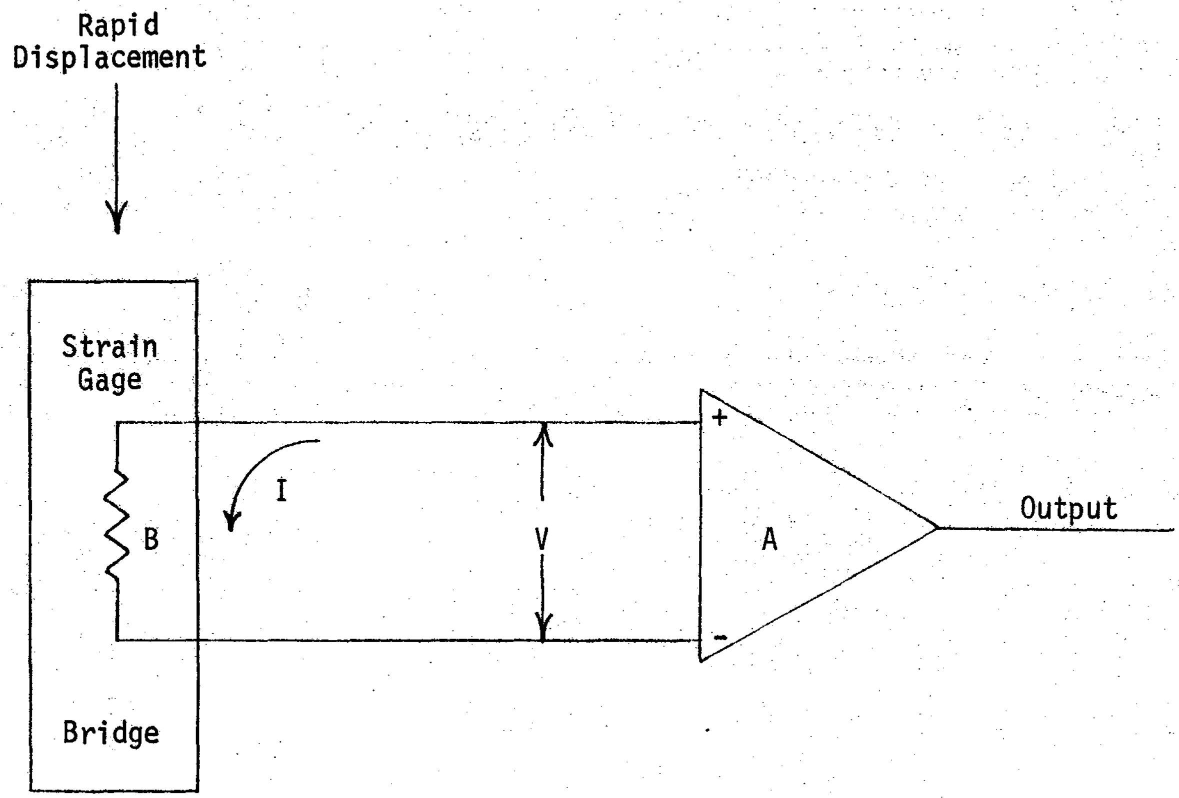


Figure 10. Simplified electrical schematic of a strain gage bridge and high gain amplifier.

maintaining a constant amplitude oscillation. At this point the wave is a slightly distorted sine wave. An output power booster stage along with filtering produces a nearly pure sine wave of sufficient current to drive the bridge. Only amplitude of the excitation voltage is important in maintaining calibration. Small changes in frequency of oscillation and distortions in the wave have no effect on calibration. The 100 ohm resistor in series with the bridge provides short circuit protection for the booster stage.

V. Preamplifier

In operation, the bridge circuit modulates the 10 KHz carrier in accordance with the bridge unbalance produced by the bridge. Under no-signal conditions the bridge is balanced and the carrier is suppressed. The amplitude of the output signal from the bridge is determined by the amount of unbalance. The bridge thus produces suppressed carrier amplitude modulation. The bridge output then contains the modulation sidebands along with any self-generated responses. This signal is AC coupled via an input transformer in the High Gain Preamp which amplifies only the AC portion of the signal around 10 KHz and greatly suppresses the unwanted signals which are substantially lower in frequency than 10 KHz. Its gain is fixed at about 600.

VI. Demodulator

The amplified signal then feeds a potentiometer and a variable resistor which serve as a coarse and fine gain adjust to set the overall signal conditioner gain. The output of this divider network along with the voltage from the oscillator now feeds inputs of the phase sensitive demodulator which, when properly mixed, produces a fluctuating AC output, either plus or minus, which is proportional to the magnitude of the bridge unbalance and whose polarity is indicative of the direction of the bridge unbalance. The demodulator discriminates between the signals that have modulated the carrier and all other signals that have been added to the carrier. The latter is almost totally rejected. The μA796 demodulator integrated circuit used in the readout has excellent carrier suppression qualities along with excellent stability vs temperature.

VII. Filter

The output of the demodulator is fed to a high quality slightly underdamped multi-pole passive filter which has a response approximately like that shown in Figure 11. The response is extremely smooth in the range of DC to 1 KHz, the data pass band of greatest interest. Phase shifts are also small in this band. An additional .05 mfd. capacitor is inserted across the filter output when the calibrate resistor shunts the bridge to prevent any overshoot which would induce errors that would be detected by the peak detector further in the circuitry. This capacitor is automatically disconnected during operation.

VIII. Balance Error Correction Amplifier (BECA)

This amplifier is unique in that it accepts the filtered analog signal and references it to ground (0 volts). It ignores those slowly occurring offset errors due to bridge unbalance, and faithfully passes the dynamic positive going force induced signals in the following manner: Amplifier one is a negative peak detector biased to have a range of approximately +5 V to -10 volts. The 330 K ohm resistor in

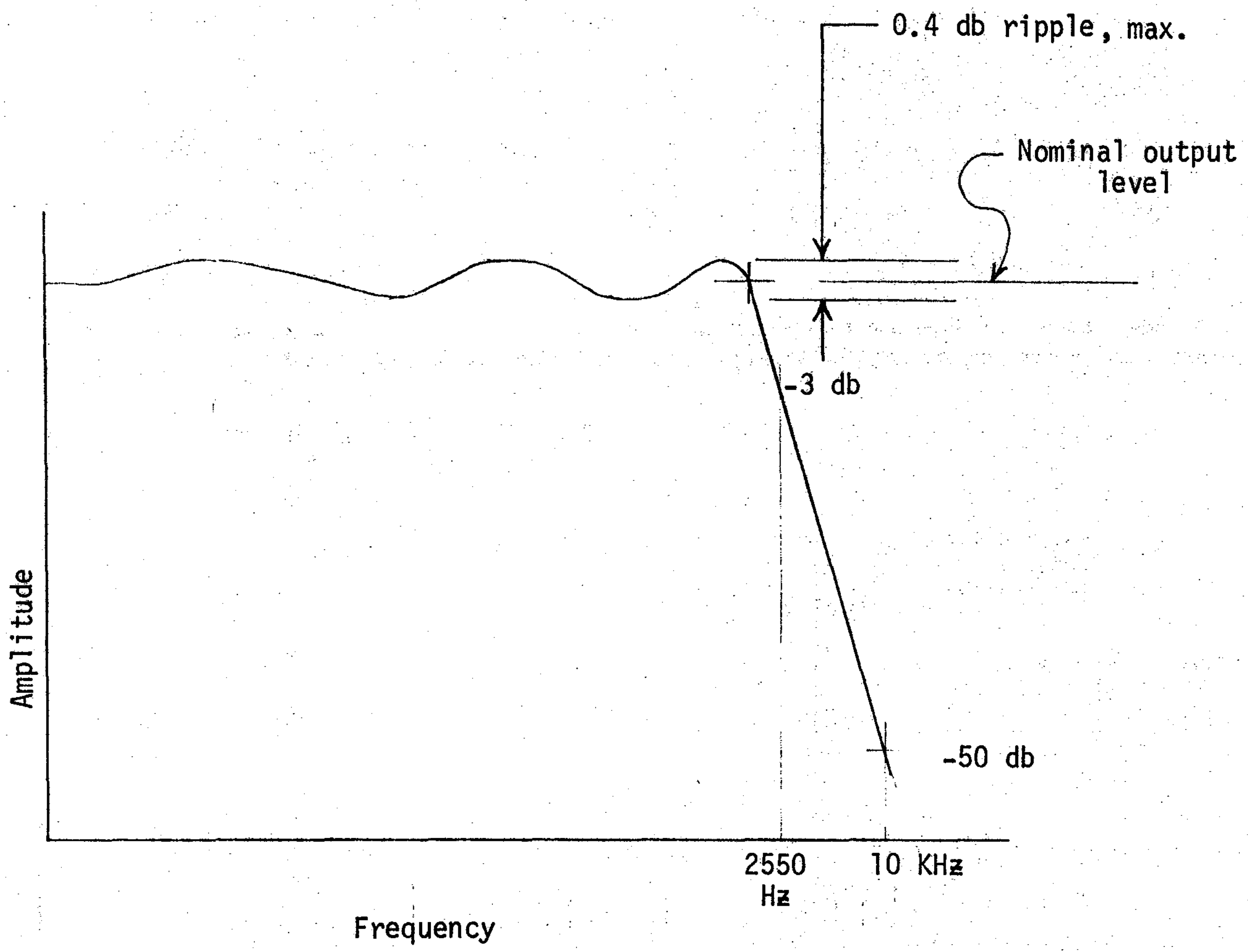


Figure 11. Filter output characteristics.

series with its output prevents the peak detector from following rapidly occurring negative voltages. The negative peak value is stored on the 0.25 mfd. mylar capacitor. Amplifier two is a follower whose input is coupled to the capacitor through a FET switch which is toggled open by the digital logic to further prevent the negative peak detector from erroneously following rapidly occurring negative peaks. Amplifier three subtracts the smoothed most negative going value from the total input signal, thus producing a signal identical to the input signal except that its value when no blow is occurring is biased precisely to ground. Since this is the case, very precise positive going dynamic peak values can be measured from ground potential even in the presence of rather large offset errors due to bridge unbalance.

IX. Schmidt Trigger

Output of the BECA is fed to the Schmidt Trigger whose output toggles positively and tells the digital logic circuitry whenever the input signal reaches a preset positive level, thus identifying the beginning of a blow.

X. Peak Detect and Hold

This circuit detects, upon command from the digital logic, the positive going value of an input signal from the BECA. Two gates are present: the read gate opens the input when high; the reset gate, when high, resets the previously stored peak value. Output of this circuit drives the digital panel meter via an appropriate resistor divider.

XI. Digital Logic Circuitry

The digital logic circuitry serves the function of controlling the timing and sequence of operation of the digital panel meter and certain analog circuits. This is done by sensing the leading edge of a hammer blow from the Schmidt Trigger and activating the analog peak detect and hold module for 0.1 seconds. At the end of this time interval the peak value acquired by the peak detect and hold module during the 0.1 second period begins to be digitized by the panel meter. See Figure 12. At the end of digitization a signal from the Digital Panel Meter commands the peak reader to reset to zero for the next measurement. Also at this time the Digital Panel Meter is switched to a hold condition so that the indicated value will not change until the next cycle is initiated, thus giving the operator maximum time to observe and record the reading.

The digital circuitry also incorporates a two decade counter that will increment one count for every hammer blow. By using the binary output of these counters and the binary output of the two decade panel switches a comparison can be made. This comparison is used to activate the sampling circuitry each time these binary numbers are equal. Upon detection of equality, the decade counters are reset to zero automatically or they can be reset by the reset push-button on the front panel.

XII. Calibration

Calibration is accomplished by shunting one of the strain gage arms with a precision resistor of known value, thus inducing a bridge unbalance of known magnitude. Appendices A & B detail the theory of this technique. When the calibrate button is depressed, a free-running multi-vibrator timer is energized that switches in the calibration resistor approximately once each second for a time of 30 milli-seconds. The resulting bridge unbalance is a pulse input to all circuitry thus

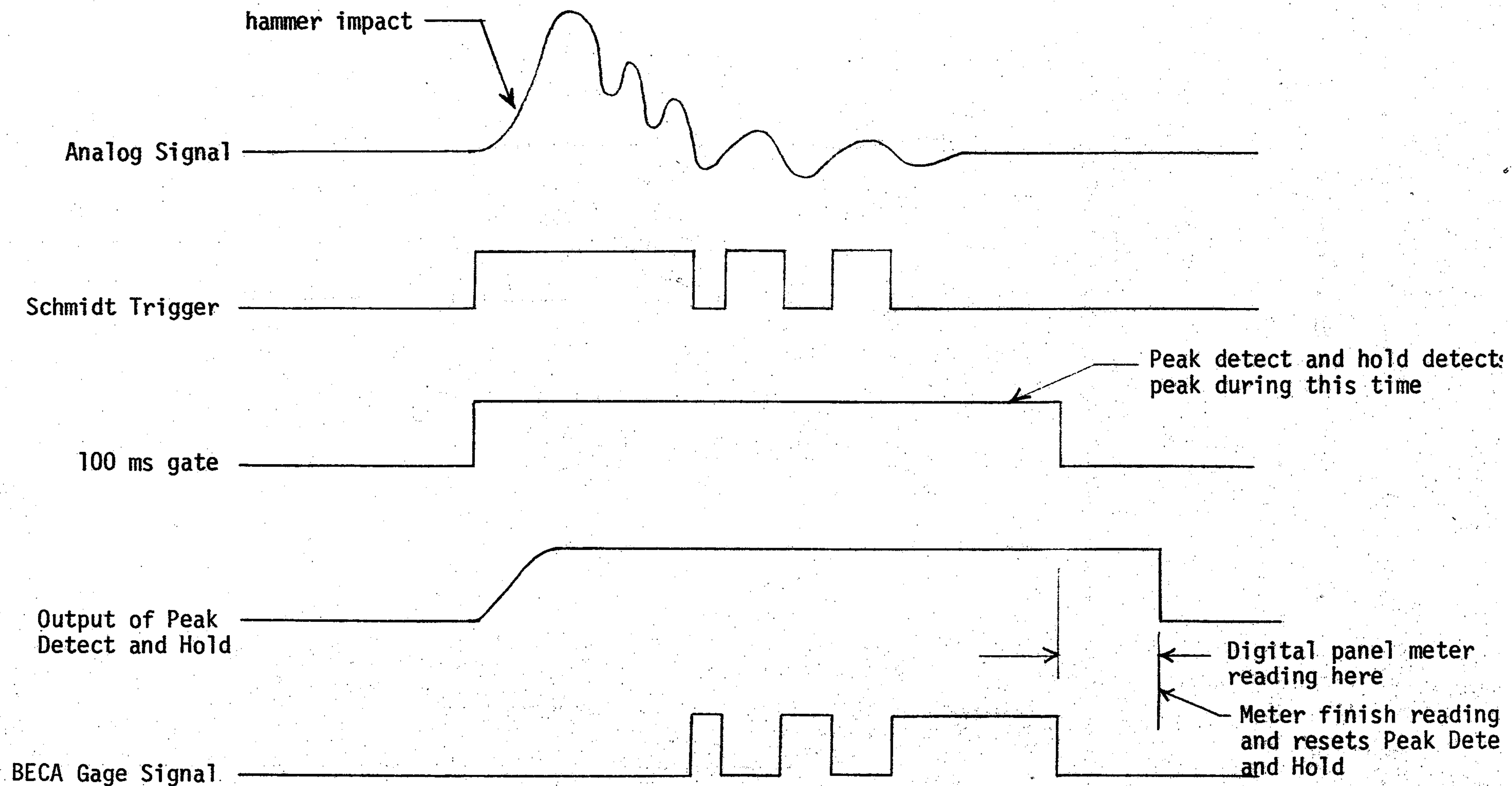


Figure 12. Sequence of signals generated within the readout.

simulating a hammer blow. The system gain is then adjusted to make the digital panel meter correspond to the magnitude of the simulated force. Depressing the calibrate button also inserts a .05 mfd. capacitor across the output of the filter which prevents any overshoot during calibration. The peak detect and hold module thus reads the correct magnitude.

Section 5

BATTERY CHARGING AND MAINTENANCE

I. Battery Charging

The internal battery is charged by a self-contained battery charger housed in the readout. The battery is completely sealed, requiring no additional water or maintenance. Charging time for the completely discharged battery is 16 hours. To charge the battery connect the readout to a source of 117 VAC power. The charger goes into a trickle charge mode near completion of the charge cycle and the battery can be left on charge for long periods of time without damage; however, it is good practice to disconnect the 117 VAC power after 1 or 2 days maximum.

II. Routine Maintenance

Routine maintenance of the readout includes those normal steps which are taken to care for any piece of electronic test equipment. No internal adjustments need be made as routine care and the details for making these adjustments are covered in Section 6. The operator need concern himself only with the adjustment of front panel switches and controls. All the critical circuits which would be affected by dust and moisture have been encapsulated with a potting compound.

III. Details for Operator Maintenance

A. Prevent crimping, sharp bending and stretching of the interconnect cable.

B. Disconnect the readout from 117 VAC power when battery has been charged. Make sure power selector switch is in the off position when the readout is not in use.

C. Store the readout in a dry room at normal room temperature for extended periods of storage.

D. Close the lid and latches when not in use.

E. When storing manuals and cables in the lid, take care not to crush the face of the digital panel meter.

F. Should the readout become extremely wet during use, remove the front panel from the case and allow the inside to dry prior to reassembly and storage.

Section 6

INTERNAL ADJUSTMENTS AND TROUBLESHOOTING

There are only 7 internal adjustments available to be made, 4 are on the battery charger, 1 on the Schmidt Trigger and 2 are located on the peak detect and hold module. All these adjustments are to be considered one time adjustments and should be adjusted only in the rarest of circumstances, i.e., when defective components are replaced.

I. <u>Adjusting Battery Charger</u>

A. High Charge Voltage Adjust

For these adjustments, refer to Figure 13 and the Power Supply and Battery Charger electrical schematic.

1. Remove the front panel from the case and disconnect the 12 VDC internal battery from the barrier strip located near the battery in the bottom of the case.

2. Plug readout into 117 VAC power and place mode selector in the AC or internal battery position.

3. With a high impedence voltmeter connected to the barrier strip set adjustment 1 to read +14.8 VDC.

B. Trigger Level Adjustment

This adjustment sets the voltage level at which the battery charger switches from the high charge range to the trickle charge range. Make this adjustment after the above adjustment is made.

1. Place a variable power rheostat (25 to 0 ohms) on the

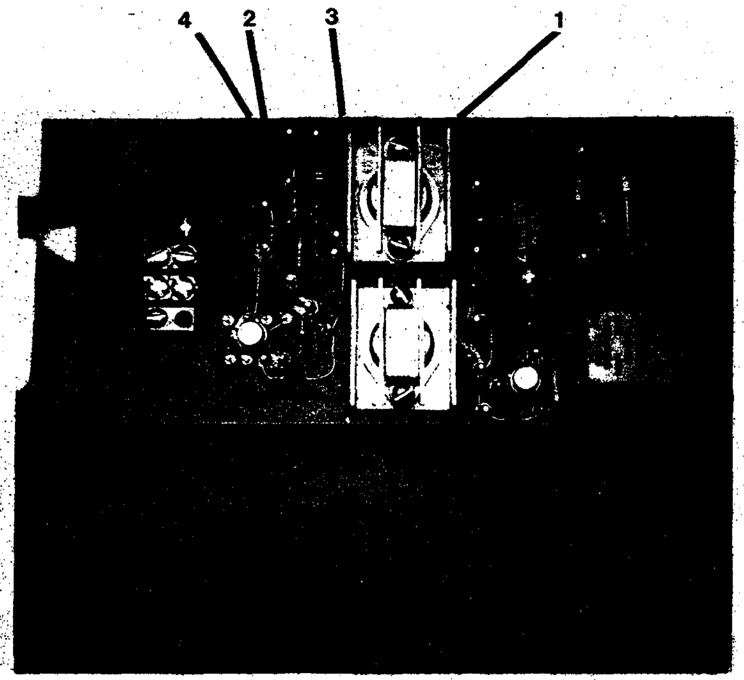


Figure 13. Layout of Power Supply and Battery Charger Board, showing internal adjustments.

battery Terminal Barrier strip along with a voltmeter to monitor the voltage across the rheostat.

2. Starting at about 25 ohms, adjust the rheostat to draw more and more current until the voltage becomes +13.8 VDC.

3. Place another voltmeter to monitor pin 6 of the μA741 amplifier.

4. Set adjustment 3 so that the pin 6 voltage switches low (about +2 V) when the voltage across the rheostat is brought down through +13.8 VDC.

C. Low Charge Voltage Adjust

This adjustment sets the voltage to be maintained on the fully charged battery (trickle charge mode).

1. Reconnect a fully charged internal battery to the barrier strip.

2. Connect the readout to a source of 117 VAC power and set the power selector to AC or Internal Battery.

3. Monitor pin 6 of the μA741 amplifier and insure that it is switched to the low mode (approximately +2 VDC) indicating that the battery is near full-charge and that the charger is in the trickle charge mode.

4. Place a voltmeter across the internal battery at the barrier strip.

5. Set adjustment 2 so that the battery voltage reads +13.8 VDC.

D. Hysteresis Adjust

Adjustment 4 should always remain maximum at 10 K ohms.

II. Adjusting Schmidt Trigger

The one adjustment on the Schmidt Trigger sets the level of the input signal which causes the trigger to toggle, thus indicating a blow. Figure 14 shows the front panel removed and ready for making internal adjustments. Figure 15 shows a lay-out of the components on the analog board.

1. Connect a "dummy" full bridge gage to the input of the readout and set up the readout as outlined in Section 2 down to the step of calibration.

2. Switch the Cal. Resistors switch to position 8.

3. Connect a dual beam oscilloscope to test points 8 and 9.

4. Hold the calibrate push-button depressed.

5. Adjust the coarse gain on the readout until the square wave at test point 8 goes positive by 0.05 volts.

6. Adjust the screwdriver adjustment on the Schmidt Trigger so that it just begins to toggle through zero from approximately -10 VDC to +10 VDC as the input signal reaches +0.05 volts.

III. Adjusting Peak Detect and Hold Module

There is a provision for two adjustments on this module. Do not adjust the screwdriver adjustment furtherest from the output of the module. To adjust the screwdriver adjustment nearest the module output, first complete steps 1 through 5 under Adjusting Schmidt above, then:

1. Increase the coarse gain by approximately 1 turn clockwise.

2. Connect an oscilloscope to the output of the peak detect and hold module.

3. Adjust the screwdriver adjustment nearest the module output

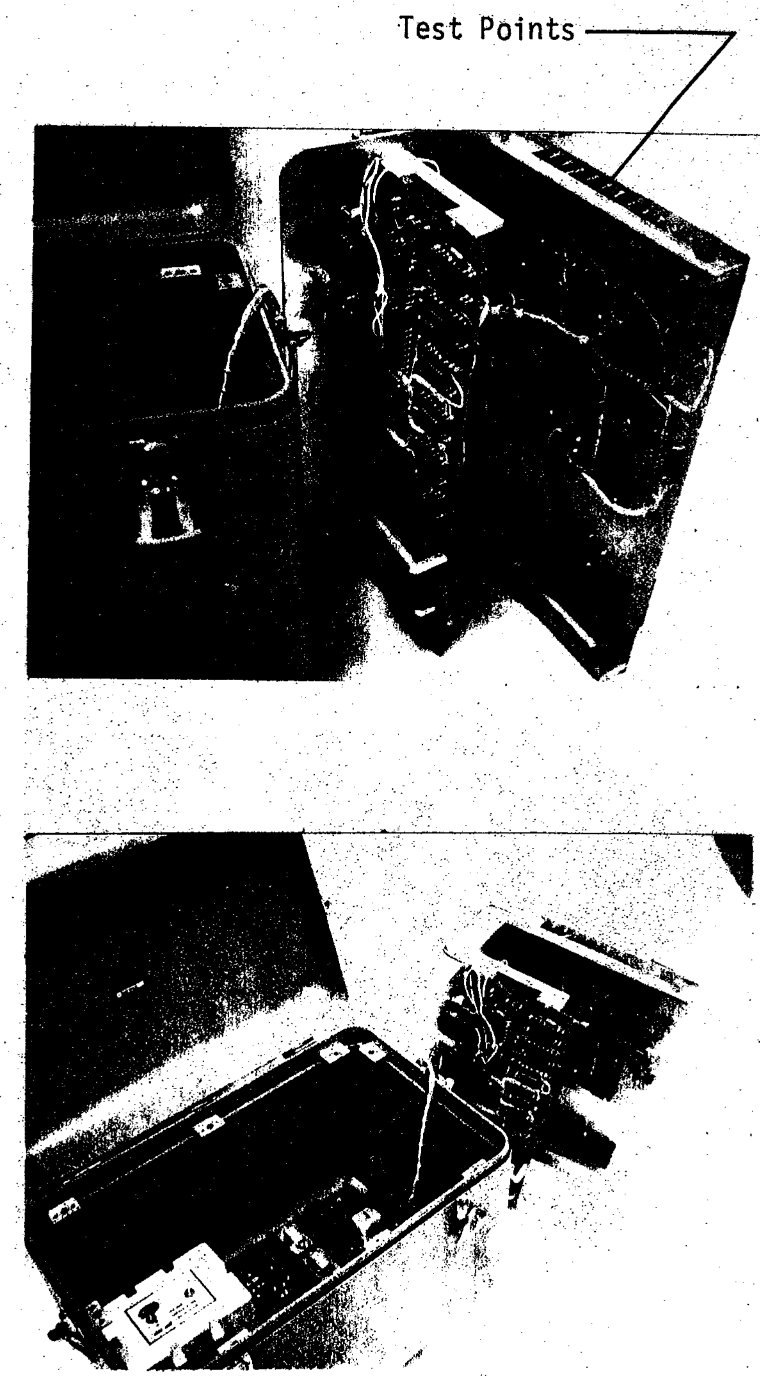


Figure 14. Photo showing the front panel of the readout removed and ready for making internal adjustments.

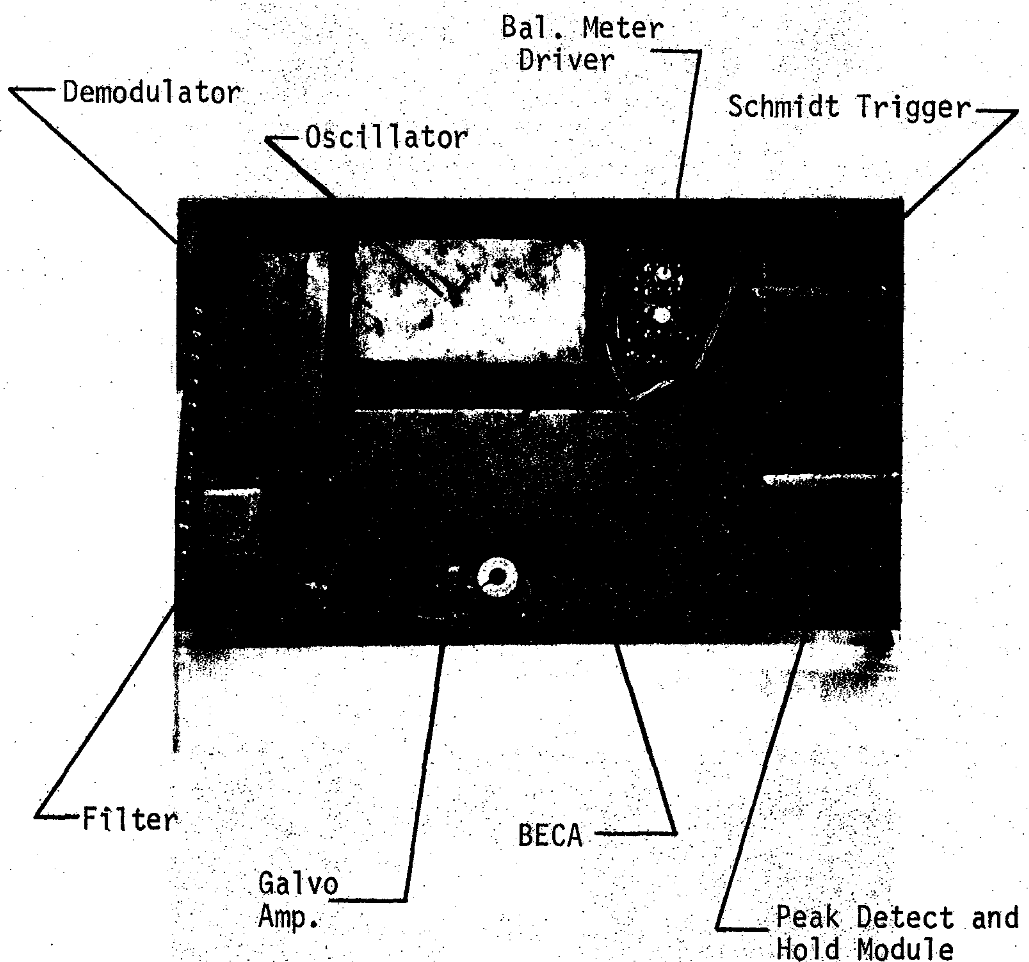


Figure 15. Layout of components on the analog board.

so that the lower part of the square wave is set precisely to ground (0 volts) ±2 milli-volts.

IV. Troubleshooting

There is a row of test points located along one end of the analog board. Test point 1 is nearest the panel, 2 next, 3 next, etc. Set up the readout as follows for monitoring the test points.

1. Connect a 350 ohm full bridge to the input.

2. Follow instructions of Section 3, V, down to calibration.

3. Set Cal. Resistors switch to position 8.

4. Adjust coarse gain to approximately ½ of the range (5 turns from either end).

5. Hold calibrate button depressed while monitoring the test points with respect to analog ground which is test point 2.

   Test point 1 --- should read -15 VDC ± .05 V

   Test point 3 --- should read +15 VDC ± .05 V

6. The following photographs indicate the proper signal that should be observed on test points 4 through 9.

7. Figure 16 can be used along with the schematic for the digital logic to troubleshoot any problem with the logic circuitry.

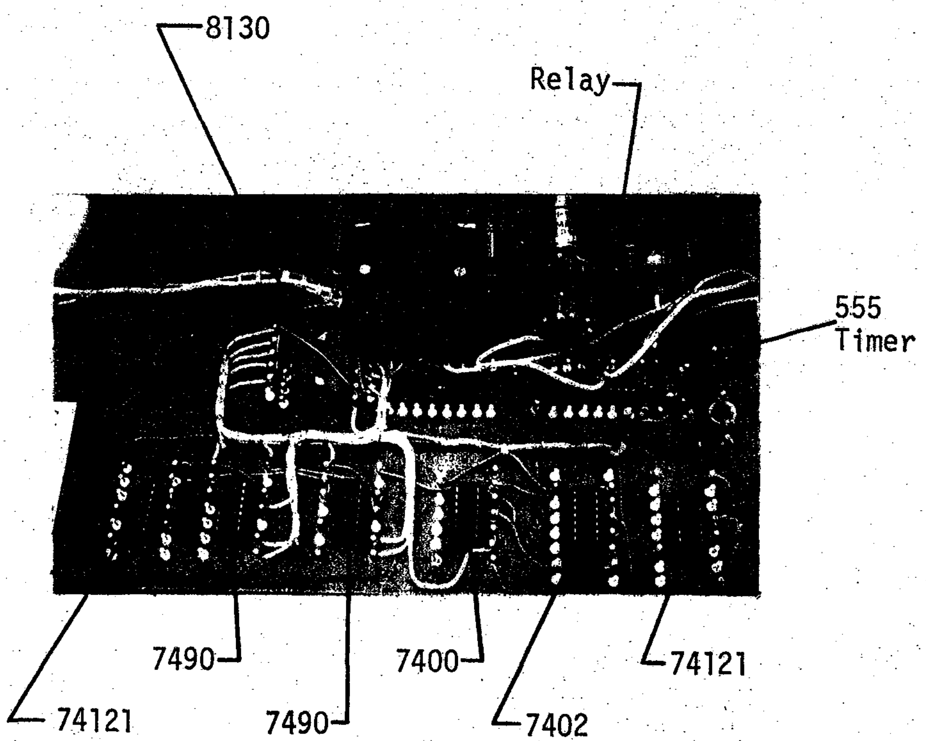
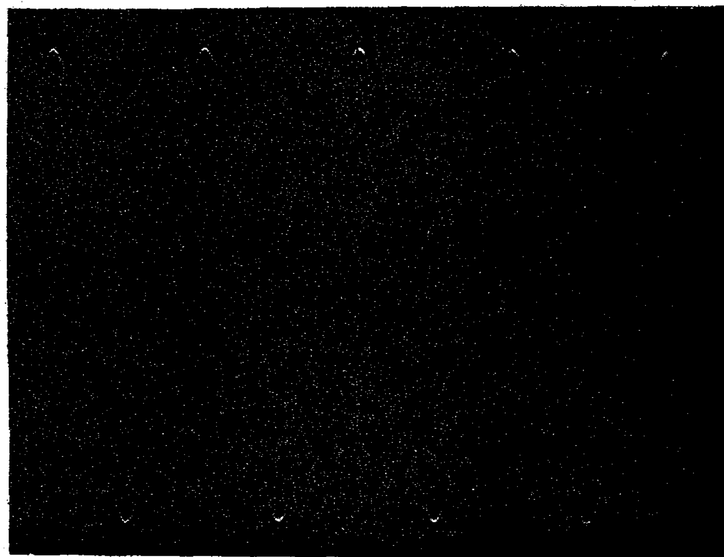
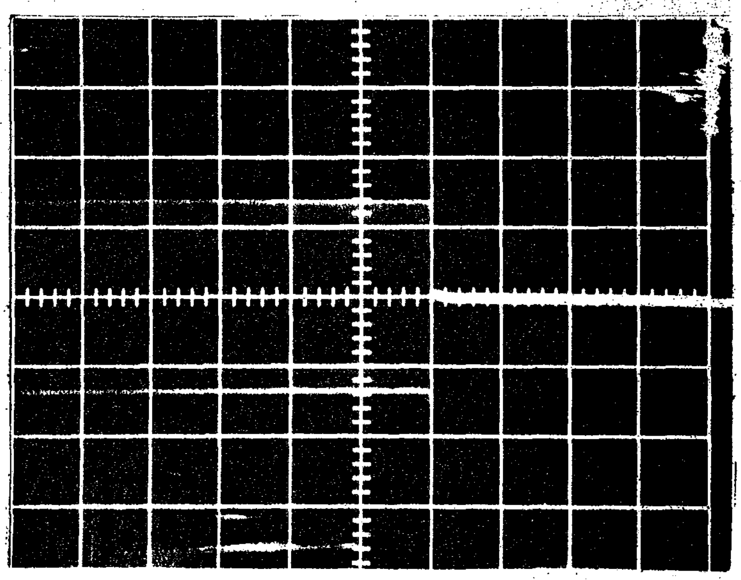


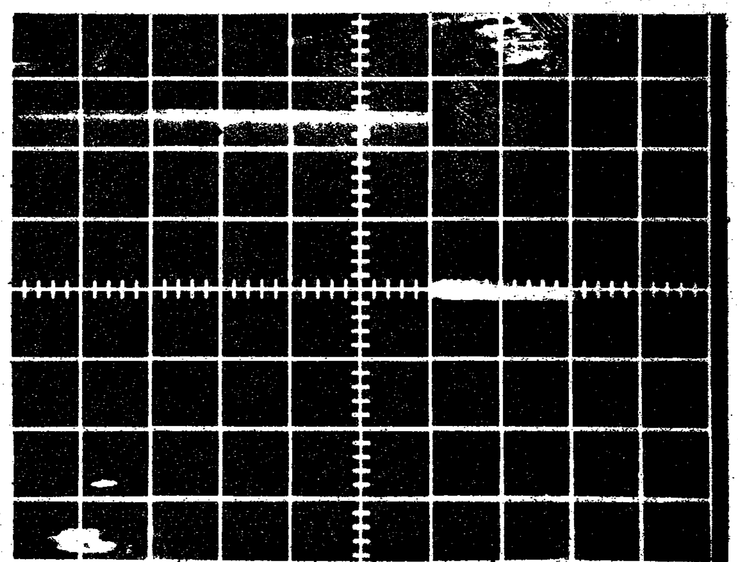
Figure 16. Layout of the Digital Circuit Board.



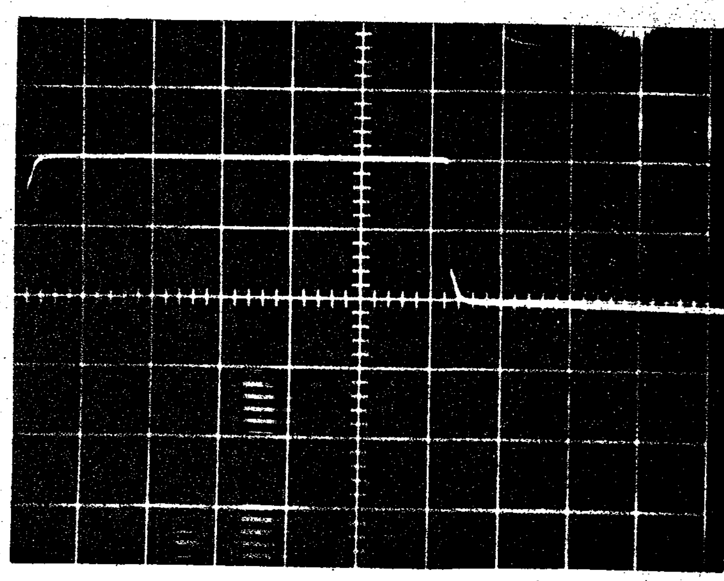
Test Point 4, Oscillator Output
Vertical = 2V/Div.
Horizontal = 50 micro-sec./Div.



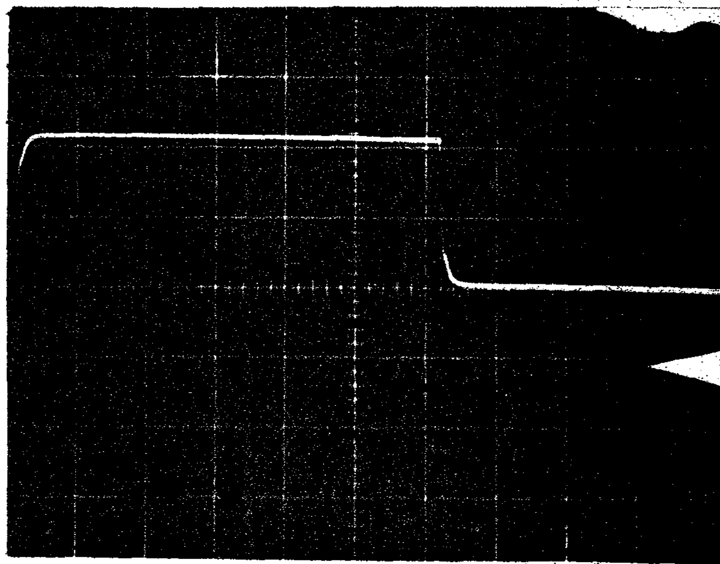
Test Point 5, Preamplifier
Vertical = 0.2V/Div.
Horizontal = 5ms/Div.



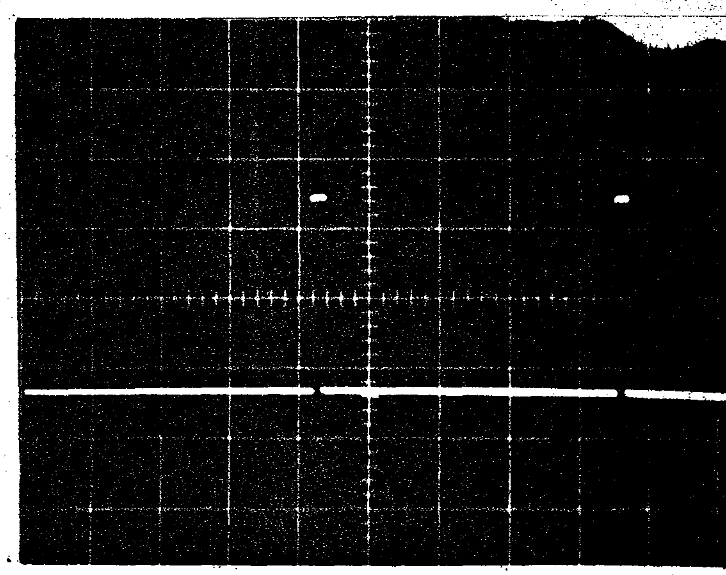
Test Point 6, Demodulator
Vertical = 2V/Div.
Horizontal = 5ms/Div.



Test Point 7, Filter output (During Calib)
Vertical = 1V/Div.
Horizontal = 5ms/Div.



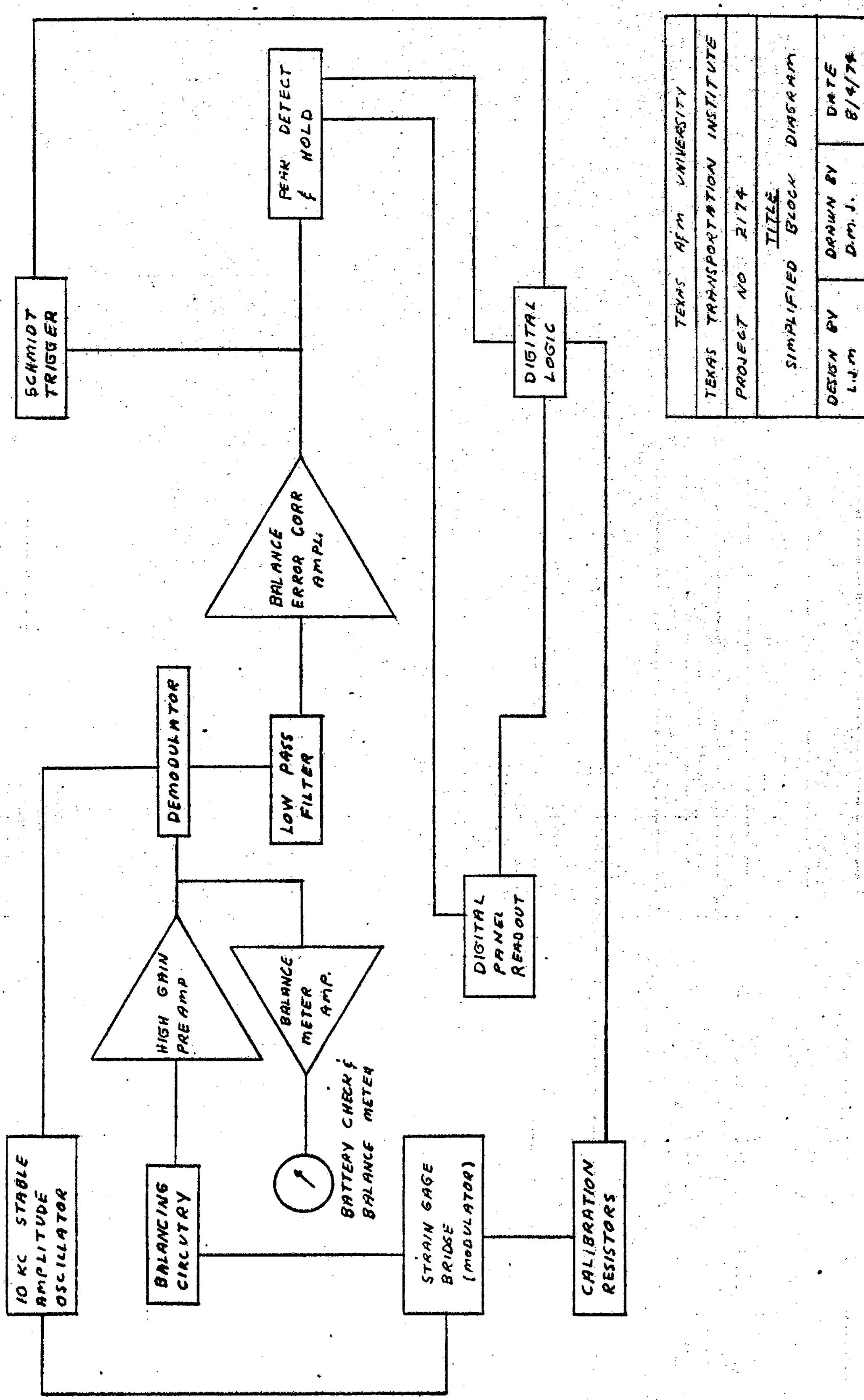
Test Point 8, BECA output
Vertical = 1V/Div.
Horizontal = 5 ms/Div.

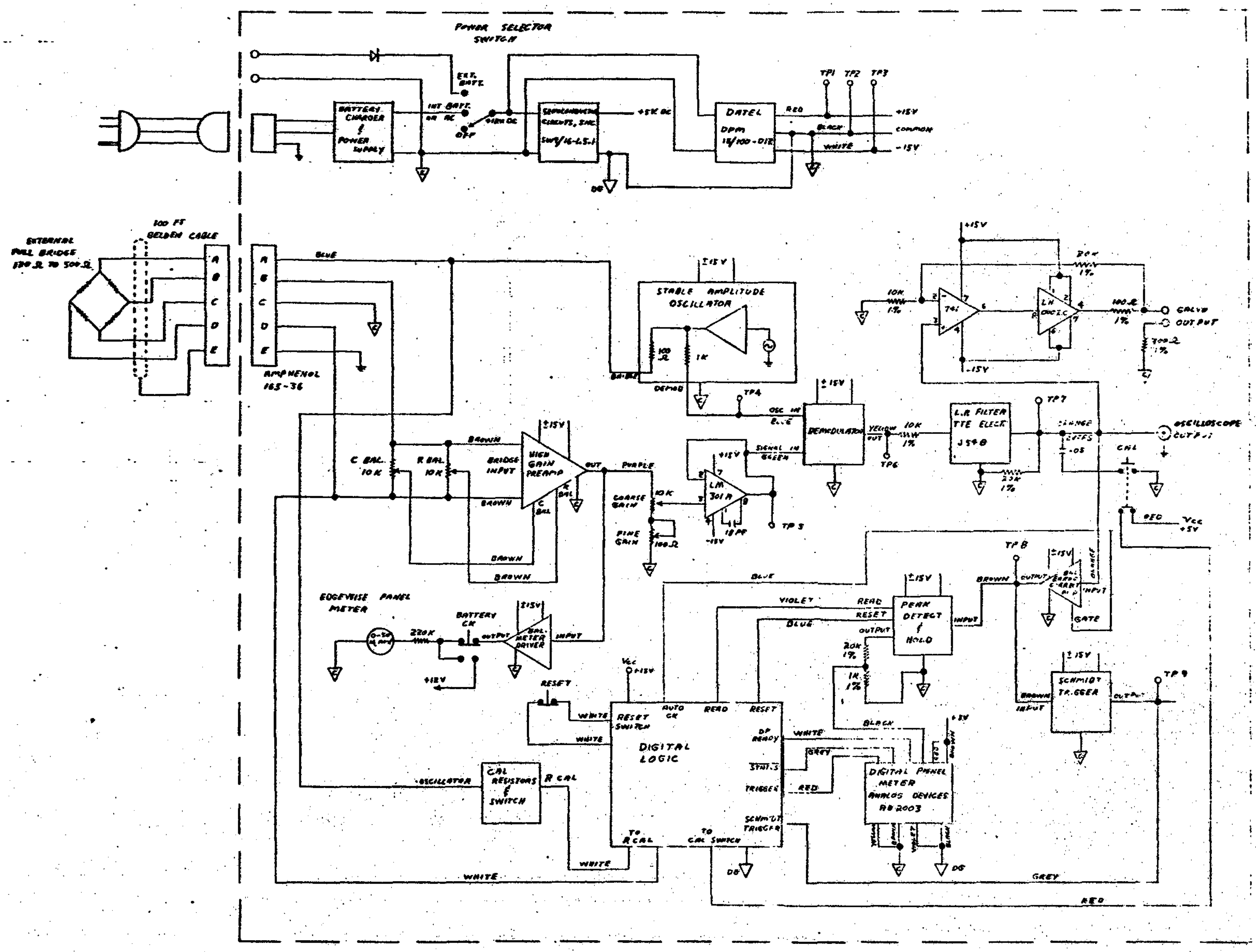


Test Point 9, Schmidt Trigger
Vertical = 10V/Div.
Horizontal = 200ms/Div.

Section 7

ELECTRICAL SCHEMATICS


SCHMIDT TRIGGER
PEAK DETECT & HOLD
BALANCE ERROR CORR AMPL.
DEMODULATOR
LOW PASS FILTER
DIGITAL LOGIC
DIGITAL PANEL READOUT
HIGH GAIN PRE AMP
BALANCE METER AMP.
BATTERY CHECK & BALANCE METER
10 KC STABLE AMPLITUDE OSCILLATOR
BALANCING CIRCUTRY
STRAIN GAGE BRIDGE (MODULATOR)
CALIBRATION RESISTORS
TEXAS A&M UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO 2174
TITLE
SIMPLIFIED BLOCK DIAGRAM
DESIGN BY L.J.M.
DRAWN BY D.M.J.
DATE 8/4/74



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TEXAS TRANSPORTATION INSTITUTE
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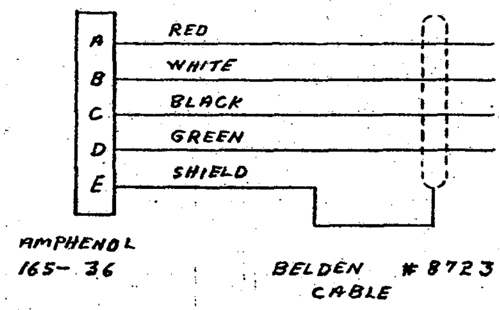
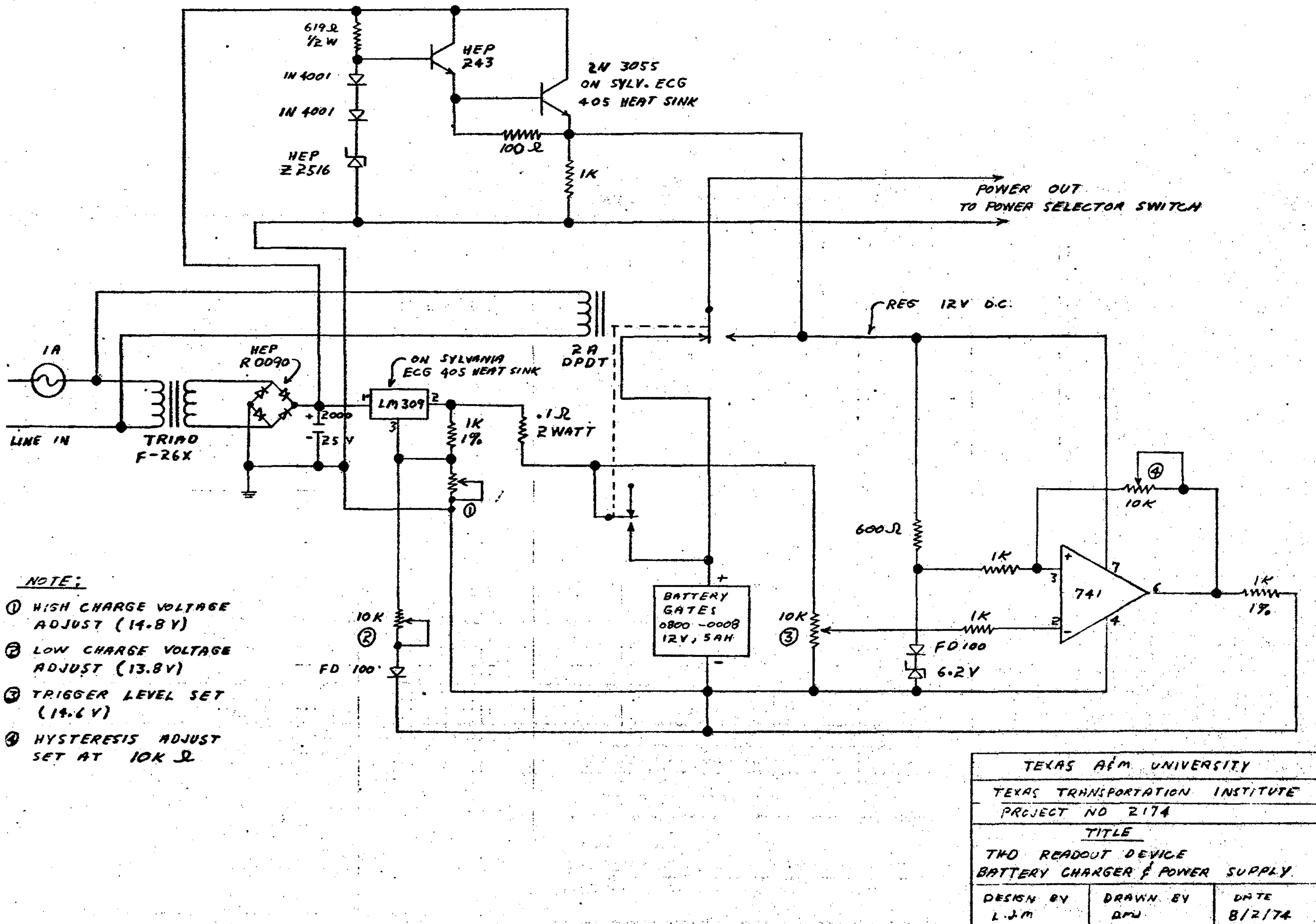
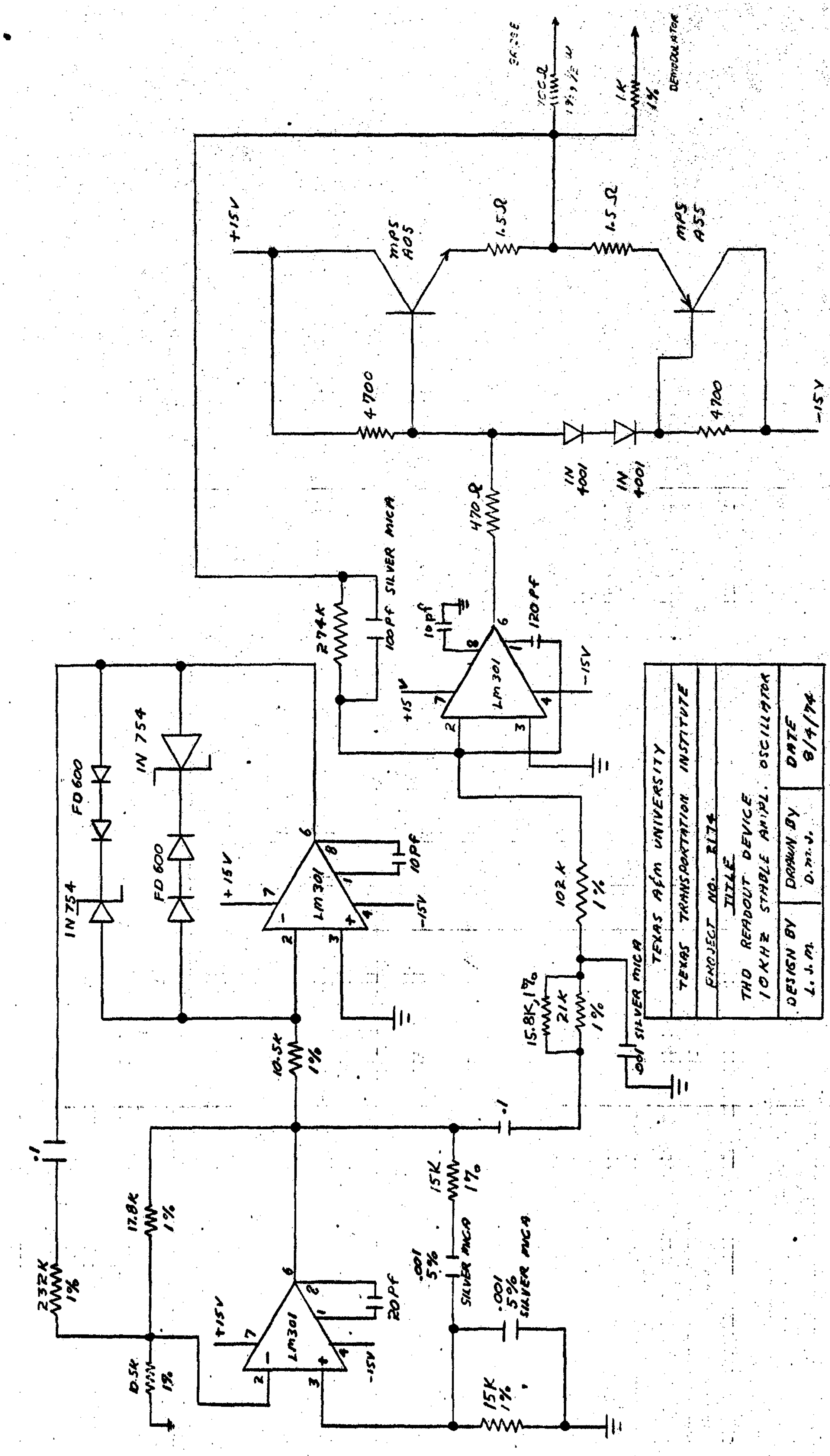
WIRING DIAGRAM
DATE 8/5/74



TEXAS A&M UNIVERSITY		
TEXAS TRANSPORTATION INSTITUTE		
PROJECT NO 2174		
TITLE INTERCONNECT CABLE		
DESIGN BY L.J.M.	DRAWN BY D.M.J.	DATE 8/5/74



619Ω
½ W
IN 4001
IN 4001
HEP
Z 2516
HEP
243
2N 3055
ON SYLV. ECG
405 HEAT SINK
100 Ω
1K
POWER OUT
TO POWER SELECTOR SWITCH
REG 12V D.C.
1A
LINE IN
TRIAD
F-26X
HEP
R 0090
2000
25 V
ON SYLVANIA
ECG 405 HEAT SINK
LM 309
1K
1%
.1 Ω
2 WATT
2A
DPDT
①
10K
②
FD 100
BATTERY
GATES
0800 -0008
12V, 5AH
10K
③
600 Ω
1K
1K
741
FD 100
6.2V
④
10K
1K
1%
NOTE;
① HIGH CHARGE VOLTAGE ADJUST (14.8 V)
② LOW CHARGE VOLTAGE ADJUST (13.8 V)
③ TRIGGER LEVEL SET (14.6 V)
④ HYSTERESIS ADJUST SET AT 10K Ω
TEXAS A&M UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO 2174
TITLE
TKO READOUT DEVICE
BATTERY CHARGER & POWER SUPPLY
DESIGN BY
L.J.M
DRAWN BY
DMJ
DATE
8/2/74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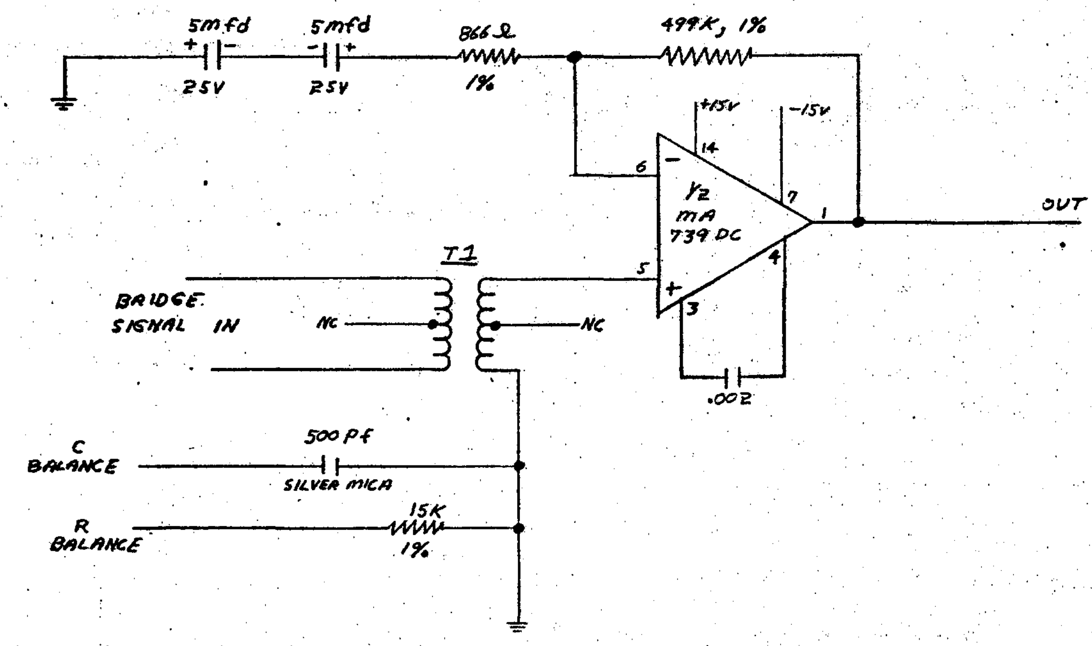
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO. 2174
TITLE
THD READOUT DEVICE
10KHZ STABLE AMPL. OSCILLATOR
DESIGN BY L.J.M.
DRAWN BY D.M.J.
DATE 8/4/74
LM301
LM301
LM301
MPS A05
MPS A55
1N 4001
1N 4001
1N754
1N754
FD600
FD600
+15V
-15V
4700
4700
1.5Ω
1.5Ω
470Ω
274K
100PF SILVER MICA
120PF
10pf
102K 1%
15.8K 1%
21K 1%
.001 SILVER MICA
10.5K 1%
232K 1%
17.8K 1%
15K 1%
.001 5% SILVER MICA
20PF
10PF
1K 1%
DEMODULATOR

T1

TRIAD # SP-67 IN
TRIAD # SP-310 SHIELD

NOTE!
COMPLETE AMP. CONTAINED IN Mu METAL CASE



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TEXAS TRANSPORTATION INSTITUTE		
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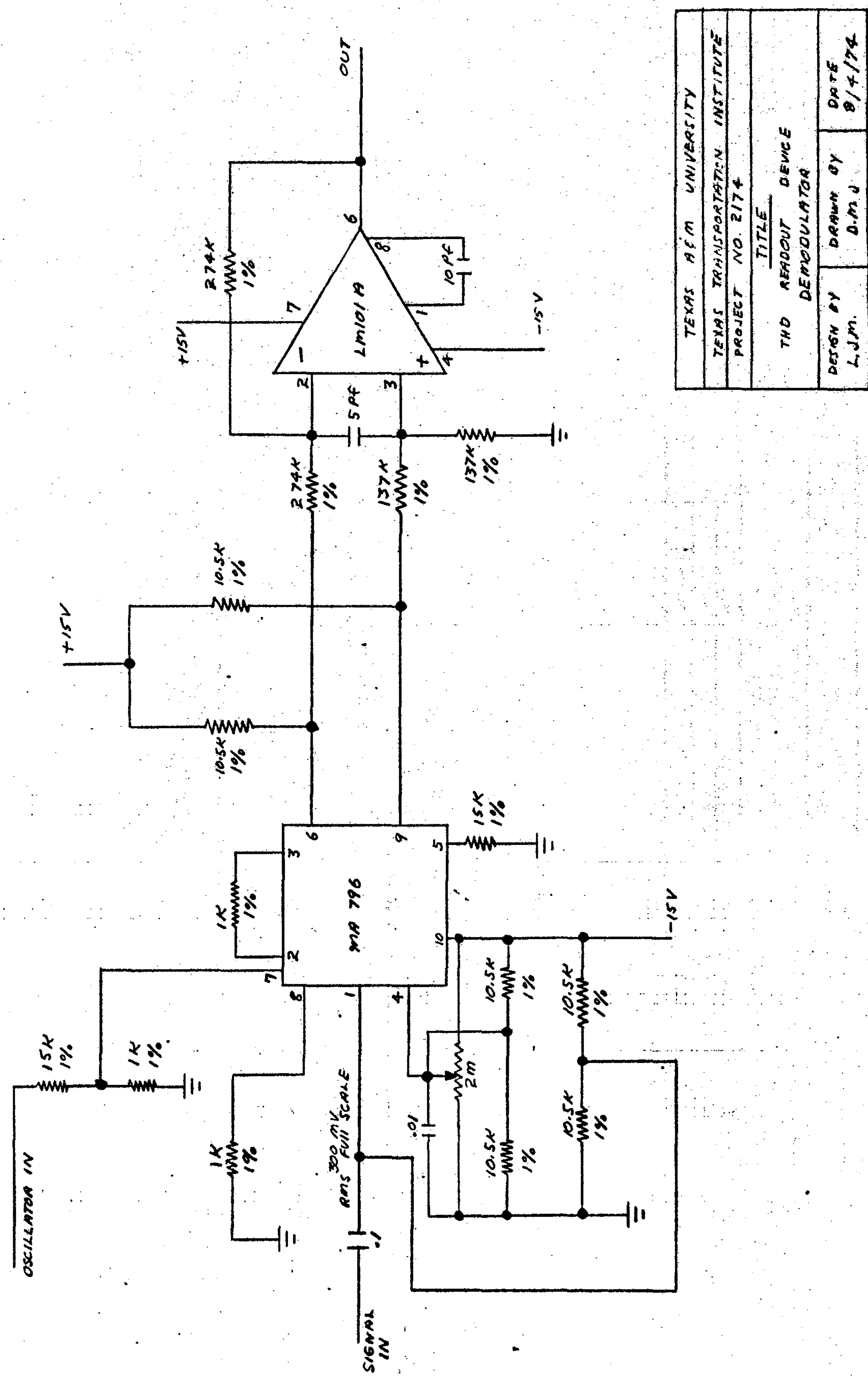
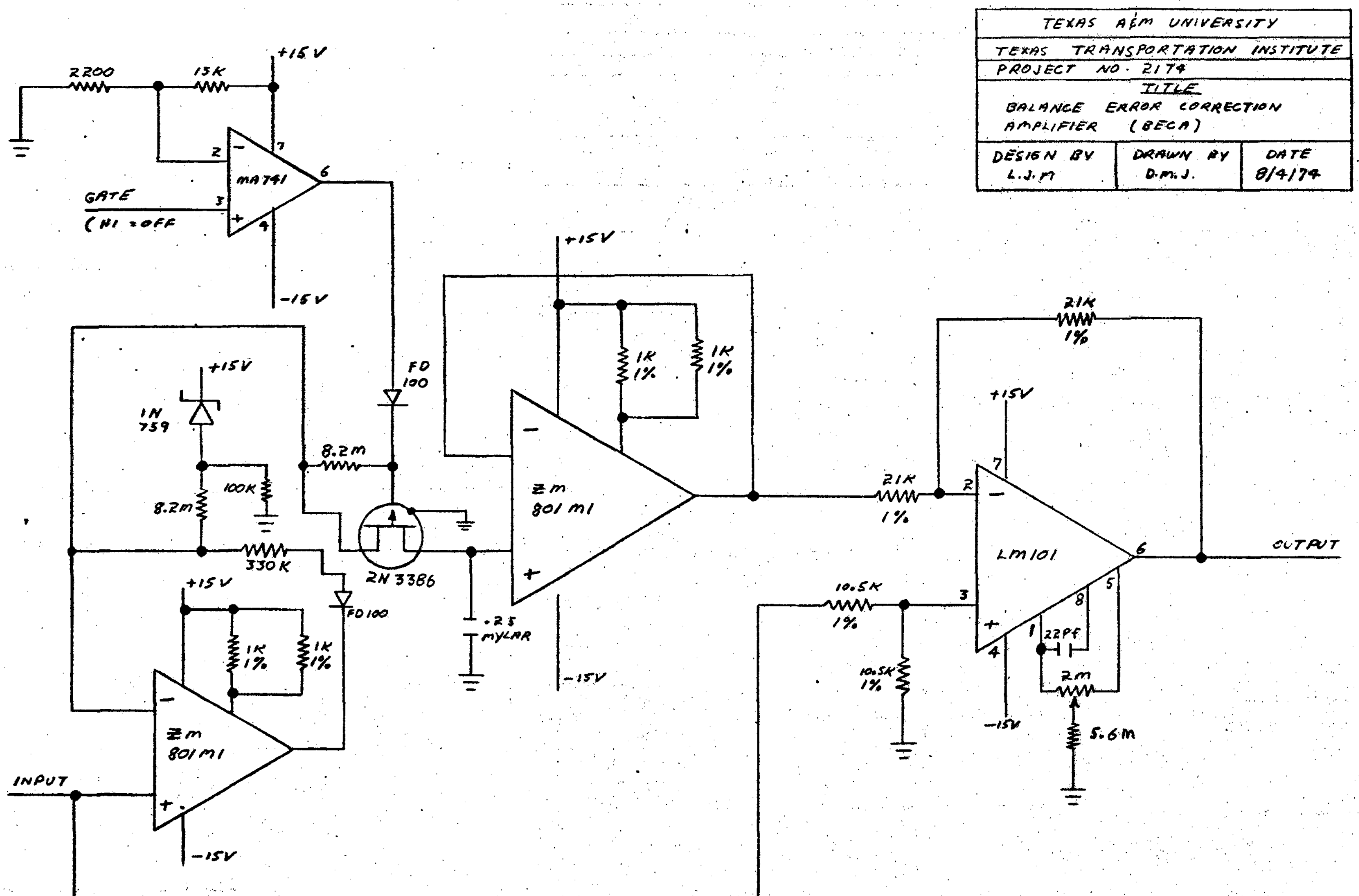
DESIGN BY L.J.M.	DRAWN BY D.M.J.	DATE 8/4/72


TEXAS A&M UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO. 2174
TITLE
THD READOUT DEVICE DEMODULATOR
DESIGN BY L.J.M.
DRAWN BY D.M.J
DATE 8/4/74
OUT
LM101A
+15V
-15V
10pF
5pF
274K 1%
137K 1%
10.5K 1%
MA 796
15K 1%
1K 1%
2M
.01
.1
RMS 300 mV FULL SCALE
OSCILLATOR IN
SIGNAL IN



TEXAS A&M UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO. 2174
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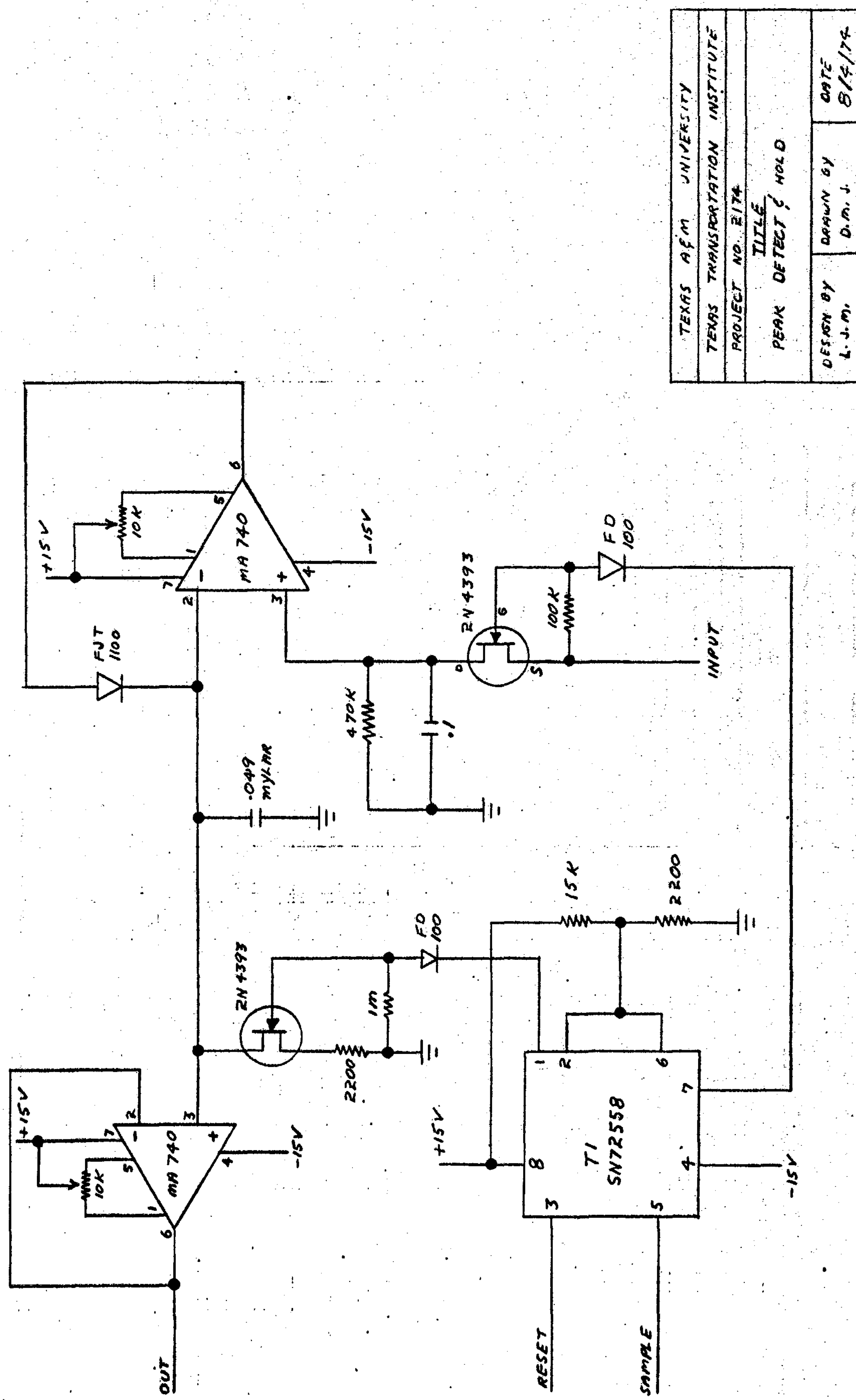
BALANCE ERROR CORRECTION AMPLIFIER (BECA)
DESIGN BY L.J.M
DRAWN BY D.M.J.
DATE 8/4/74
+15V
2200
15K
MA741
GATE
(HI = OFF
-15V
FD 100
1N 759
8.2m
100K
330K
2N 3386
FD100
1K 1%
ZM 801 M1
.23 MYLAR
21K 1%
LM101
10.5K 1%
22PF
2M
5.6M
OUTPUT
INPUT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TEXAS TRANSPORTATION INSTITUTE
PROJECT NO. 2174
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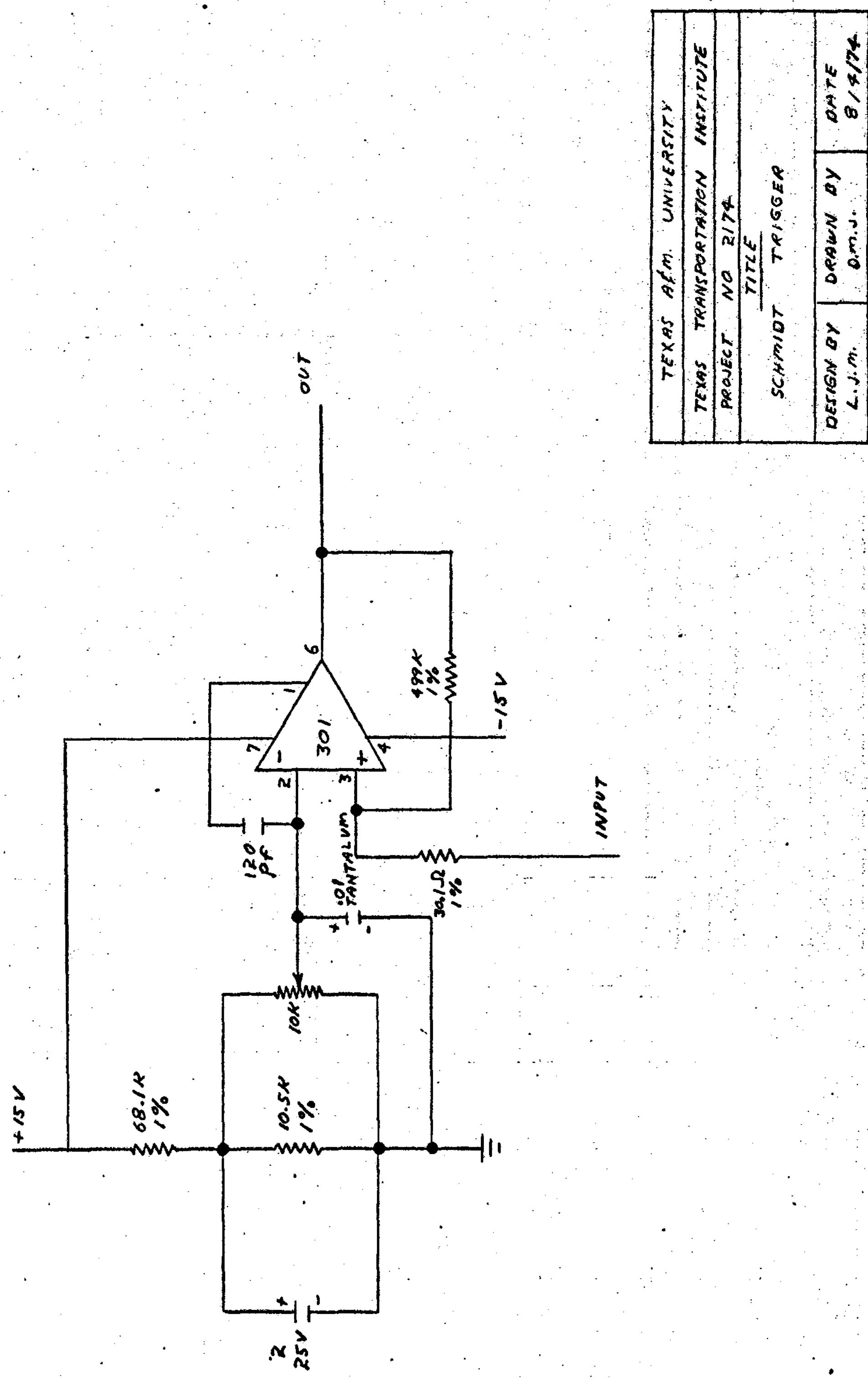
PEAK DETECT & HOLD
DESIGN BY L.J.M.
DRAWN BY D.M.J.
DATE 8/4/74
+15V
-15V
10K
MA 740
FJT 1100
2N4393
100K
FD 100
INPUT
470K
.1
.049 MYLAR
15K
2200
1M
TI SN72558
OUT
RESET
SAMPLE



TEXAS A&M. UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO 2174
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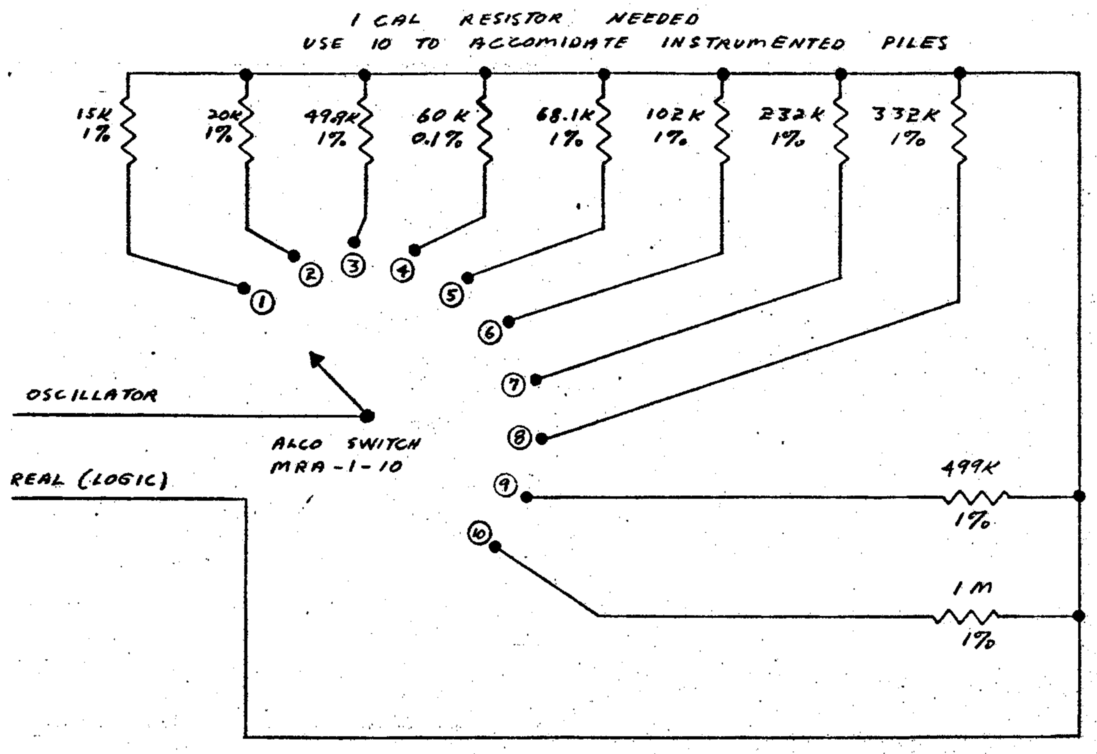
SCHMIDT TRIGGER
DESIGN BY L.J.M.
DRAWN BY D.M.J.
DATE 8/9/74
OUT
INPUT
+15V
-15V
301
499K 1%
120 pF
.01 TANTALUM
30.1Ω 1%
10K
68.1K 1%
10.5K 1%
2 25V



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TEXAS TRANSPORTATION INSTITUTE		
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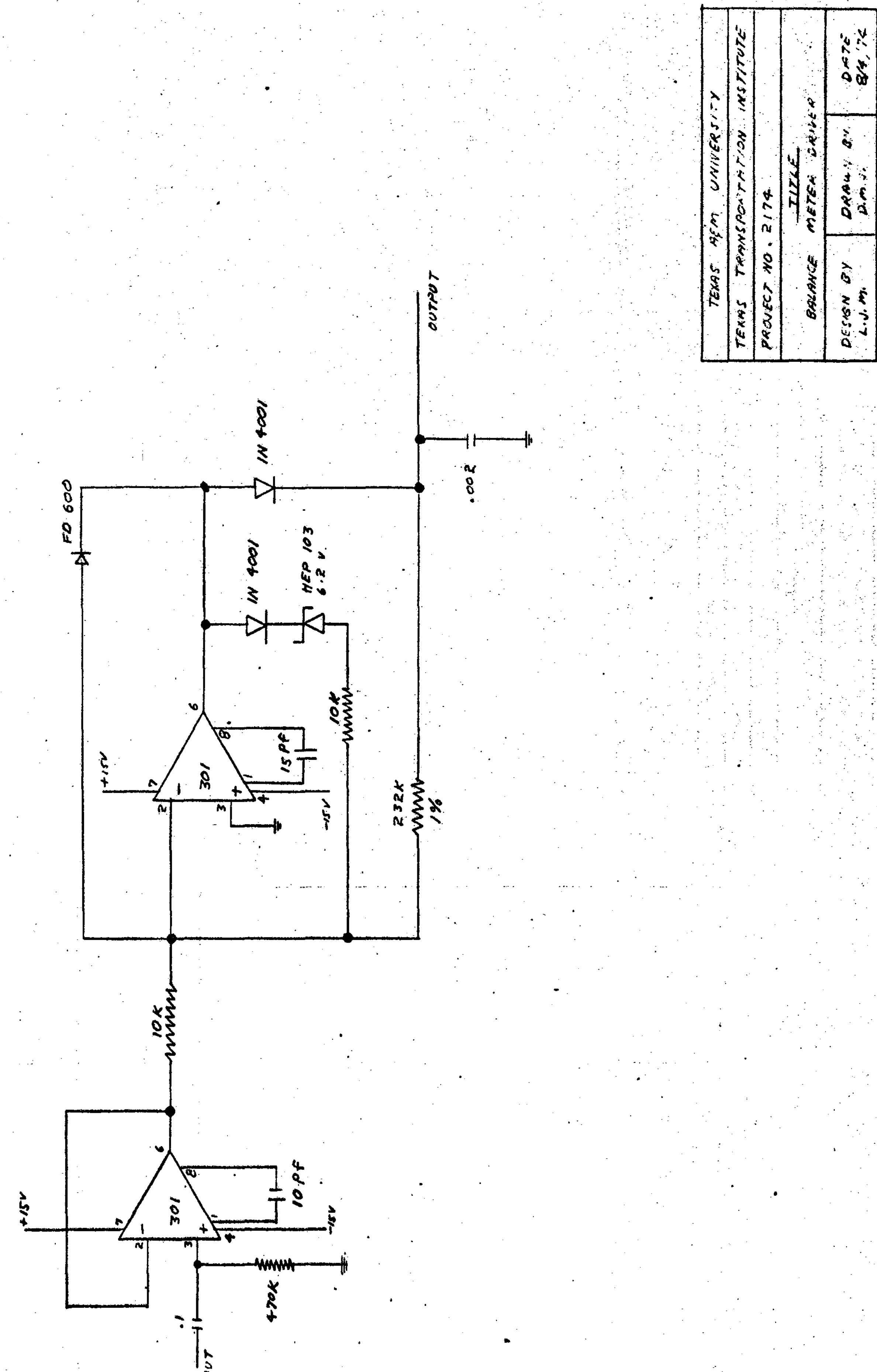
TITLE CALIBRATION RESISTORS & SWITCH		
DESIGN BY L.J.M.	DRAWN BY D.M.J.	DATE 8/4/74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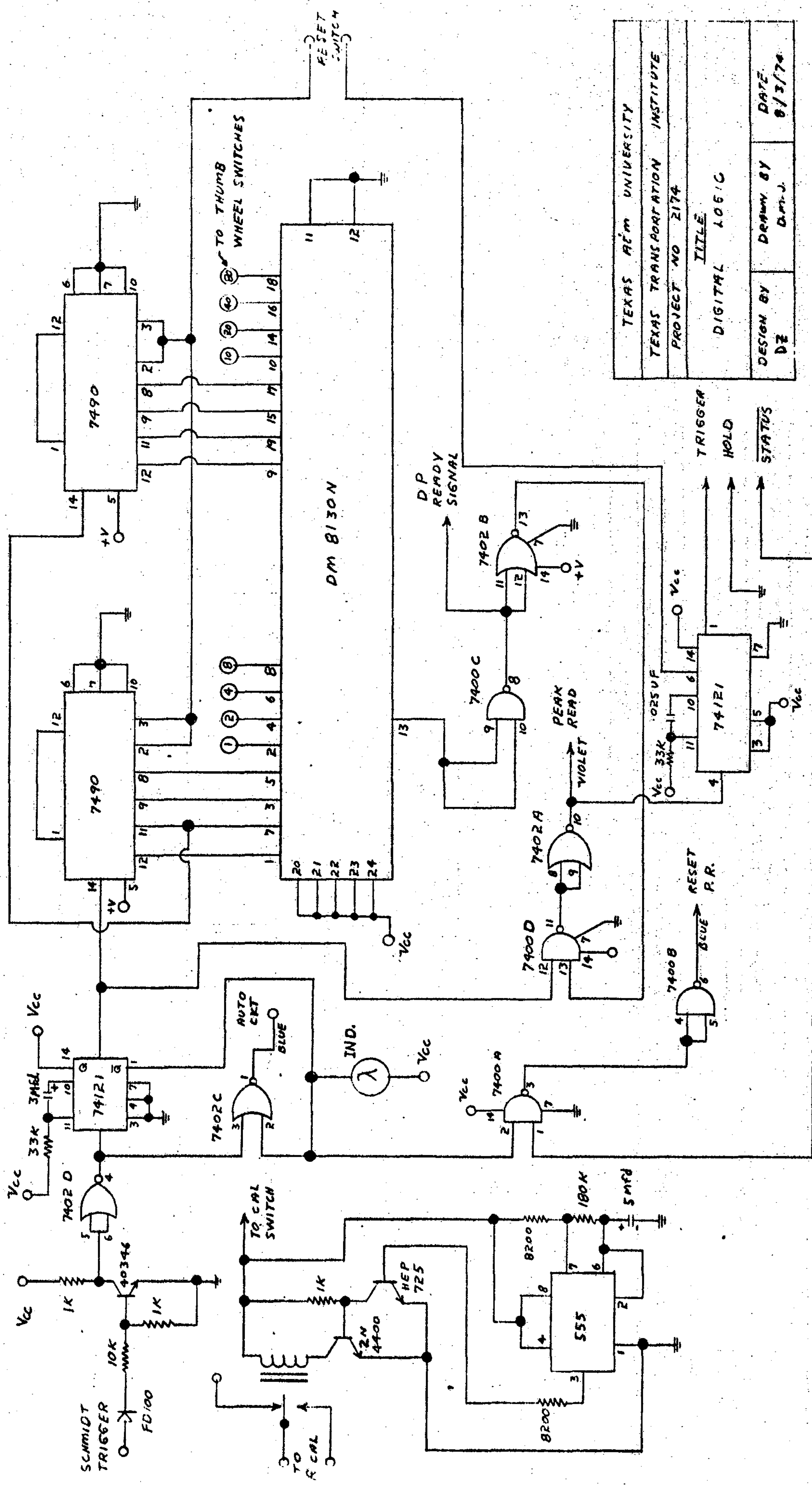
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO. 2174
TITLE
BALANCE METER DRIVER
DESIGN BY
L.J.M.
DRAWN BY
DATE
INPUT
.1
470K
+15V
-15V
301
10PF
10K
FD 600
IN 4001
HEP 103
6.2 V.
15PF
232K
1%
.002
OUTPUT


TEXAS A&M UNIVERSITY
TEXAS TRANSPORTATION INSTITUTE
PROJECT NO 2174
TITLE
DIGITAL LOGIC
DESIGN BY DZ
DRAWN BY D.M.J.
DATE 8/3/74
RESET SWITCH
TO THUMB WHEEL SWITCHES
7490
7490
DM 8130N
74121
74121
555
DP READY SIGNAL
PEAK READ
VIOLET
TRIGGER
HOLD
STATUS
RESET P.R.
BLUE
AUTO CKT
IND.
SCHMIDT TRIGGER
FD100
TO CAL SWITCH
HEP 725
2N 4400
TO R CAL

APPENDIX A

Determining Cal. Resistor Switch Position
and Value in Kips Force of the Cal. Resistor When
Using Readout With Instrumented Piles

The first step is to estimate the peak longitudinal or axial pile strain which is expected during the test as follows:

From the equation:

$$e = \frac{P}{AE} \qquad \text{Equation 1}$$

where:

e = axial strain in in./in.

P = Force in lbs.

A = Cross-sectional area of the pile in inches square.

E = Elastic modulus of the pile material in psi.

Make a judgement for the value of P. The accuracy of this judgement is not important except that it should be an upper value.

Next make an accurate estimate of the value of E and measure A for the particular pile being used. These values will also be used later. Alternatively, estimate P/A in psi. The accuracy of the readout determination is ultimately directly proportional to the accuracy of E and A values estimated and measured. The following values are given and may be used in the absence of more accurate values for a particular pile.

TABLE 1

	Concrete Pile	Steel Pile
$\frac{P}{A}$	2500 psi	30,000 psi
A	256 in.sq. for 16"x16" pile	12.370 $in.^2$ for 16" OD x ¼" wall pile
E	5×10^6 psi	30×10^6 psi
e	0.0005 inch/inch	0.001 inch/inch

Determine the effective number of active longitudinal gages which are being used on the instrumented pile by the following formula:

$$N_{eff} = N_L + \mu N_H \qquad \text{Equation 2}$$

where:

N_{eff} = the number of effective longitudinal gages.

N_L = the number of <u>active</u> longitudinal gages in the wheatstone bridge.

N_H = the number of <u>active</u> horizontal gages in the wheatstone bridge.

μ = Poisson's ratio for the pile materials i.e., concrete or steel.

In the absence of more accurate data on the particular pile material being used a μ of 0.303 for steel and a μ of 0.25 for concrete may be used. If the recommended procedure for instrumenting the piles is followed as outlined in paragraph II of Section 3, N_{eff} will be 2.606 for steel, 2.50 for concrete using 4 active gages and 2.0 for concrete using 2 active and 2 "dummy" gages. Note that it is difficult, if not impossible, to know μ for concrete; thus, as mentioned earlier, the reason for recommending "dummy" horizontal gages in concrete piles.

When the bridges are wired in either of the recommended manners, strains due to bending stress are cancelled and the strains due to axial stress seen by <u>each</u> of the <u>active</u> gages are added within the bridge. Therefore, the equivalent strain output of the bridge is given by:

$$S_o = exN_{eff} \qquad \text{Equation 3}$$

where:

S_o = equivalent strain gage bridge output in inches/inches.

Now, select a shunt calibration resistor (10 are provided in the readout and selectable by the Cal. Resistors switch) which will, when shunted across one of the arms of the wheatstone bridge, closely simulate the value of S_o found above. See Figure A-1.

The well known equation whose derivation is detailed in Appendix B is:

$$S_R = \frac{GR}{GF\ (cal\ R)} \qquad \text{Equation 4}$$

where:

S_R = represented strain in inches/inches.

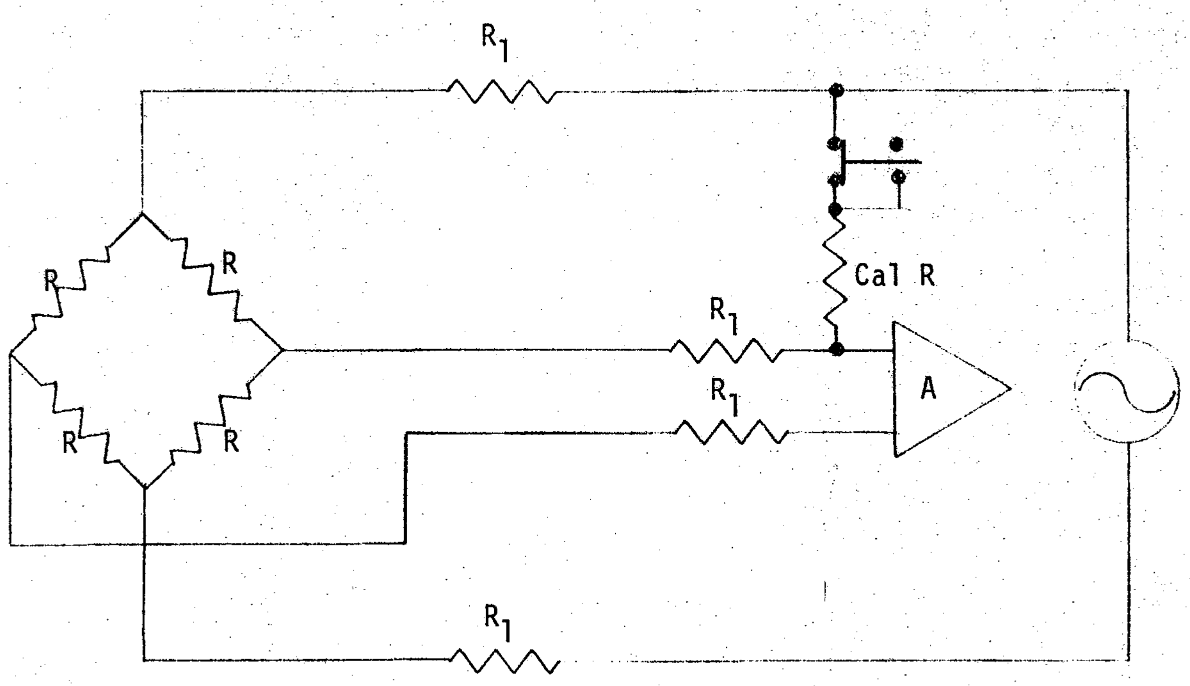
GR = Gage resistance in ohms of the gage which is shunted.

GF = Gage Factor (sensitivity factor) of the strain gages (unit-less)

cal R = Value of the cal resistor in ohms.

When solved for cal R, becomes:

$$cal\ R = \frac{GR}{S_R\ (GF)} \qquad \text{Equation 5}$$



R = Gage Resistance

R_1 = Resistance of a single conductor of the interconnect cable = 1.5 ohms for the cable provided

Figure A-1. Simplified schematic diagram showing a cal resistor shunting a balanced wheatstone bridge to simulate a strain.

Since the value of S_o (equation 3 above) is the strain that is to be simulated, S_o can be substituted for S_R as follows:

$$\text{cal R} = \frac{GR}{S_o\,(GF)} \qquad \text{Equation 6}$$

Now, substituting for S_o from equation 3, equation 6 becomes:

$$\text{cal R} = \frac{GR}{\lfloor e x N_{eff} \rfloor\, GF} \qquad \text{Equation 7}$$

Further substituting for e from equation 1,

$$\text{cal R} = \frac{GR}{[\frac{P}{AE}]\, N_{eff}\,(GF)}$$

Simplifying, equation 7 becomes:

$$\text{cal R} = \frac{(GR)\;E}{(P/A)\;N_{eff}\;(GF)} \qquad \text{Equation 8}$$

Substitute the appropriate values estimated earlier and solve equation 8 for cal R. The result is in ohms. Now find the position corresponding to the next higher value of resistance found in the table in paragraph IV, G, of Section 3, and report this as the <u>Cal. Resistor</u> position that the technician operating the readout is to use for calibrating the readout.

The next step is to calculate the force on the head of the particular instrumented pile which is represented by the cal resistor selected above. This calculation is made be re-arranging equation 8 and solving it for P in pounds.

$$P = \frac{(GR)\;EA}{\text{cal R}\;(N_{eff})\;GF} \qquad \text{Equation 9}$$

Since the results must be in Kips equation 9 becomes

$$P = \frac{(GR)\ EA \times 10^{-3}}{cal\ R\ (N_{eff})\ GF} \qquad \text{Equation 10}$$

When long lead wires connect the bridge to the readout, the effects of this resistance must be taken into account. From Figure A-1 it is apparent that the cal resistor is shunting the gage resistance plus 2 lengths of lead wire conductors so that the effective gage resistance to be used in equation 10 now becomes:

$$GR = R + 2R_1 \qquad \text{Equation 11}$$

where:

R = gage resistance in ohms.

R_1 = resistance of a single conductor of interconnect cable in ohms.

Note: R_1 for Belden 8723 cable is 1.5 ohms/100 ft.

Substituting for GR, equation 10 becomes:

$$P = \frac{[R + 2R_1]\ EA \times 10^{-3}}{cal\ R\ (N_{eff})\ GF}$$

The results is in Kips and this number should be reported (along with Cal. Resistors position) to the technician operating the readout so that he can properly adjust the gain of the readout.

APPENDIX B

Derivation of the Common Equation Used to Compute the Strain Represented by the Shunt Calibration Technique in Strain Gage Circuits

The common equation is:

$$S_R = \frac{R}{GF\ (\text{cal } R)} \qquad \text{Equation 1}$$

where:

S_R = Represented strain in inches/inch.

R = Gage resistance in ohms.

GF = Gage factor (sensitivity factor) for the strain gage (unit-less).

cal R = Value of the shunt calibration resistor in ohms.

Gage factor or the sensitivity of strain gages is defined as:

$$GF = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} \qquad \text{Equation 2}$$

where:

ΔR = Change in gage resistance in ohms.

R = Resistance of the gage in ohms.

ΔL = Change in length due to strain in inches.

L = Original length in inches.

Solving for ΔR we get:

$$GF\left(\frac{\Delta L}{L}\right) = \frac{\Delta R}{R}$$

$$GF\left(\frac{\Delta L}{L}\right) R = \Delta R$$

By letting $\frac{\Delta L}{L}$ equal a strain called S_R we have

$$GF\,(S_R)\,R = \Delta R \qquad \text{Equation 3}$$

Now by inserting a shunt calibration resistor in the circuit of Figure B-1 we can compute the total resistance (R_t) of the circuit with the switch closed as follows:

$$\frac{1}{R_t} = \frac{1}{R} + \frac{1}{\text{cal } R} \qquad \text{Equation 4}$$

Solving for R_t:

$$\frac{1}{R_t} = \frac{\text{cal } R + R}{R(\text{cal } R)}$$

$$R(\text{cal } R) = R_t(\text{cal } R + R)$$

$$\frac{R(\text{cal } R)}{\text{cal } R + R} = R_t \qquad \text{Equation 5}$$

Now we can solve for the change in resistance (ΔR) due to closing the switch by:

$$\Delta R = R - R_t \qquad \text{Equation 6}$$

substituting for R_t the value of R_t in equation 5 we get:

$$\Delta R = R - \left[\frac{R(\text{cal } R)}{\text{cal } R + R}\right]$$

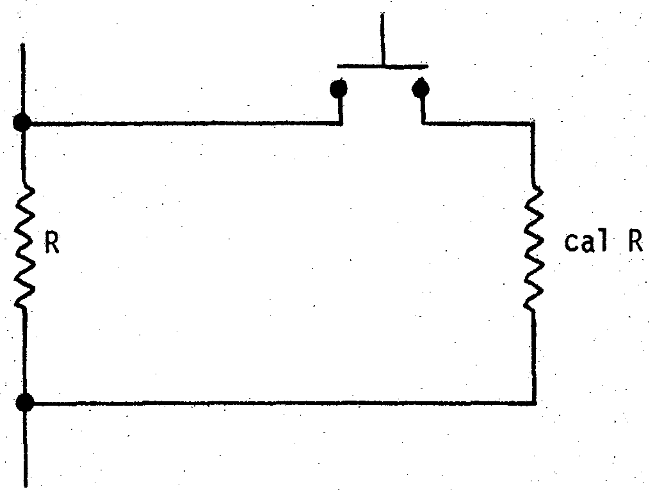


Figure B-1. Cal. Resistor shunting a strain gage.

Simplifying:

$$\Delta R = \frac{R(\text{cal } R + R) - R(\text{cal } R)}{\text{cal } R + R}$$

$$\Delta R = \frac{(R \times \text{cal } R) + R^2 - (R \times \text{cal } R)}{\text{cal } R + R}$$

$$\Delta R = \frac{R^2}{\text{cal } R + R} \qquad \text{Equation 7}$$

Now, setting appropriate portions of equations 3 and 7 equal to each other we get:

$$GF\ (S_R)\ R = \frac{R^2}{\text{cal } R + R}$$

solving for S_R we get:

$$GF\ (S_R)\ R\ [\text{cal } R + R] = R^2$$

$$S_R = \frac{R^2}{GF\ (R)\ [\text{cal } R + R]}$$

$$S_R = \frac{R}{GF\ [\text{cal } R + R]}$$

In practical strain gage circuits, using the shunt calibration technique, the value of cal R will be very large compared to the value of R. Since this is the case, we can simplify this equation as follows at the expense of only very small errors.

$$S_R = \frac{R}{GF(\text{cal } R)}$$

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